

# MIDDLE ORDOVICIAN LITHISTID SPONGES FROM THE BACHU-KALPIN AREA, XINJIANG, NORTHWESTERN CHINA

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**ABSTRACT**—Moderately diverse Middle Ordovician sponge faunas of Darriwilian (late Arenig to early Llanvirn) age have been discovered in outcrops in the Bachu-Kalpin area of the Tarim platform of Xinjiang, China. These are the first reported occurrences of early Paleozoic sponges from Xinjiang, China. These sponges occur in the Yijianfang and Dawangou Formations, which are of nearly the same age, but crop out in different areas of the platform margin. Fossil sponges discovered to date are the anthaspidellid lithistid sponges *Archaeoscyphia manganensis* (Billings, 1859); *Hudsonospongia cyclostoma* Raymond and Okulitch, 1940; *Calycocoelia profunda sichuanensis* Deng, 1990; *Calycocoelia* sp.; *Pseudopalmatohindia* sp.; *Aulocopium* sp.; *Annulospongia tarimensis* n. gen. and sp.; *Rhopalocoelia kalpinensis* n. sp.; *Rhopalocoelia bachuensis* n. sp.; and *Zittelella xinjiangensis* n. sp. They are preserved in reefal limestones and are associated with *Calathium*, cyanobacteria, and bryozoans, like in many North American assemblages.

## INTRODUCTION

The Ordovician System is widely exposed around the northern margin of the Tarim platform, and is well exposed at several localities in the Bachu and Kalpin areas, in Xinjiang, China. The sponges described here were collected from two localities situated northeast and east of Bachu, approximately 60 km from the town, and from a third locality near Kalpin County, 8 km north of the town (Fig. 1).

Studies on the stratigraphy, paleontology, and sedimentology of the stratigraphic sequence in the area were carried out largely in the 1970s and 1990s. Zhou et al. (1990) established the Yijianfang Formation and pointed out that the formation belongs to a carbonate platform margin facies and contains carbonate buildups. They reported “*Receptaculites* reefs” from the area for the first time. Zhou et al. (1991) proposed the Dawangou Formation. Wang et al. (1996) published a detailed description of Ordovician lithostratigraphic units in the Kalpin-Bachu area. Subdivision and correlation of chronostratigraphic units of the region were carried out as part of their study. Zhou et al. (1998) discussed facies changes between the two main sections of sponge-bearing beds treated here and observed that the Dawangou Formation of the Kalpin area comprises shelf-slope facies limestone and that it grades southwestward (upslope?) into the Yijianfang Formation of the Bachu area that is of platform-margin facies and includes some reefs, from which some of the sponges described here were collected. Chen et al. (1995, 2001) made correlations of Chinese Ordovician stages with global standard stages, established the geological age of the Yijianfang Formation in the Bachu area as lower Darriwilian and noted that it correlates with the Dawangou Formation of Zhou et al. (1990) in the Kalpin area.

The upper Middle Ordovician rocks are carbonate platform deposits and include numerous patch reefs or bioherms. Fossil sponges were collected by the authors from those reefs or reef-bearing strata during June–August, 1998. The collections described here include ten taxa, some of which are new. They all belong to the Anthaspidellidae and include *Archaeoscyphia*, *Hudsonospongia*, *Calycocoelia*, *Rhopalocoelia*, *Zittelella*, *Aulocopium*, *Pseudopalmatohindia*, and the new genus *Annulospongia*. These are the first reported early Paleozoic sponges from the Tarim platform of northwestern China. They are largely silicified replacements of the once opaline skeletons, but details of their spicular and skeletal relationships are moderately well preserved. Those from the Lower member of the Yijianfang Formation and from the Dawangou Formation in the Kalpin area are somewhat more strongly silicified than those from Middle and Upper members of the Yijianfang Formation from the Bachu area.

Reef-bearing units in which the sponges occur are the Yijianfang and Dawangou Formations, which are approximately of the same Darriwilian age, but occur in different areas. The Yijianfang Formation is exposed in the Bachu area (Figs. 1, 2), where it is 86.8 m thick in the Yijianfang area, and there includes three members. The Lower Member is 20.6 m thick, and is composed of siliceous “zebra” or concretionary limestone, calcarenite, bioclastic limestone, and siliceous “zebra”-bearing calcirudite. This member contains the sponge *Calycocoelia profunda sichuanensis* Deng, 1990, associated with the trilobite *Iliaenus* sp., and the cephalopods *Protocycloceras* sp., *Michelinoceras* sp., and *Cochlioceras* sp.

The Middle Member is 57.3 m thick (Fig. 2) and is mainly composed of gravel-bearing calcarenite, bioclastic limestone, bioclastic micrite, and reef limestone. Various types of reefs are developed in this member. One isolated, sponge-bearing, mound-like reef is approximately 7–8 m high, but some similar reefs are more than 10 m high and they extend horizontally tens of meters to more than 100 m. Sponges collected from this member include: *Calycocoelia profunda sichuanensis* Deng, 1990; *Calycocoelia* sp.; *Rhopalocoelia bachuensis* n. sp.; *Annulospongia tarimensis* n. gen. and sp.; and *Zittelella xinjiangensis* n. sp. Associated fossils mainly include numerous examples of *Calathium* sp., the cephalopods *Chisiloceras*, *Dideroceras*, *Aphetoceras*, *Sactoceras*, *Cycloceras*, and *Protocycloceras*; the trilobites *Iliaenus* and *Nileus*; the brachiopods *Dalmanella*, *Paurorthis*; and the conodont *Baltoniodus* sp.

The Upper Member is 8.9 m thick and is composed of thin-bedded micritic calcarenite and lime mudstone. It contains the conodonts *Panderodus gracilis* (Branson and Mehl, 1933), *Microzarkodina* sp., and *Protopanderodus varicostatus* (Sweet and Bergström, 1962), and the cephalopod *Dideroceras* sp. No sponges were collected from this member.

The Dawangou Formation is exposed in the Kalpin area, where it is 25.2 m thick (Fig. 2), and is mainly composed of nodular bioclastic micrite and calcisiltite in the upper part, and siliceous “zebra” limestone and bioclastic calcarenite in the lower part. Small patch reefs occur in the lower part of the formation and they contain a rich assemblage of sponges and *Calathium*. The sponges include *Archaeoscyphia manganensis* (Billings, 1859); *Hudsonospongia cyclostoma* Raymond and Okulitch, 1940; *Rhopalocoelia kalpinensis* n. sp.; *Pseudopalmatohindia* sp.; and *Aulocopium* sp. Associated conodonts include *Eoplacognathus suecicus* Bergström, 1971; *E. foliaceus* (Fähræus, 1966); *Periodon aculeatus* Hadding, 1913; *Pygodus serrus* (Hadding, 1913); *Protopanderodus varicostatus* (Sweet and Bergström, 1962); *Scolopodus rex* Lindstrom, 1955; and *Dapsilodus mutatus* (Branson and

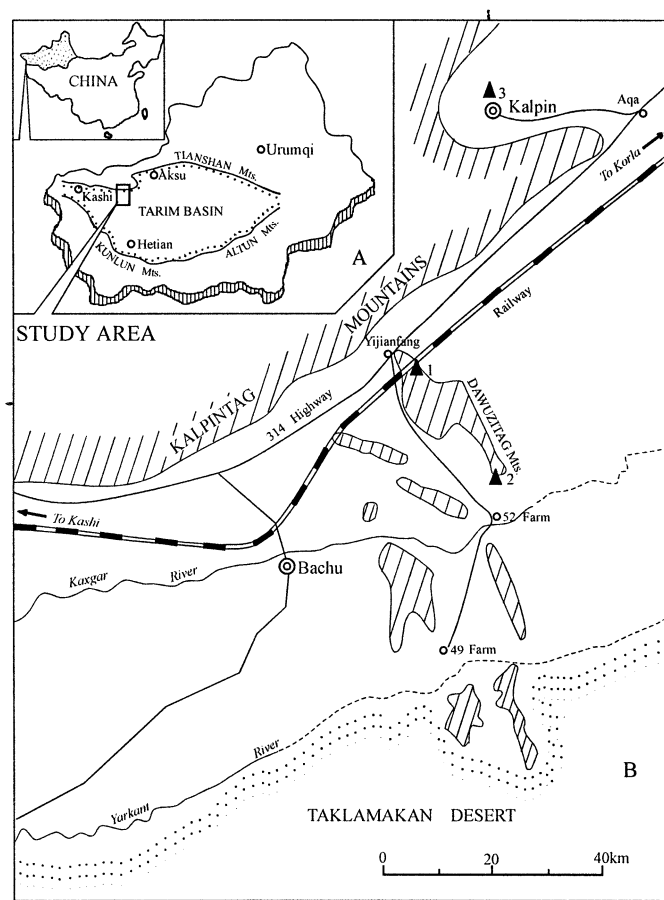


FIGURE 1—Index map to Ordovician sponge localities in the Bachu-Kalpin area along the northern margin of the Tarim platform in Xinjiang, northwestern China. A, Outline map of China showing location of Xinjiang Province; and location of the study area in the northwestern part of the province. B, Locality map showing positions of the principal sponge localities. ▲1, Bachu Yijianfang; ▲2, Bachu Tangwangcheng, and ▲3, Kalpin. Oblique lines indicate mountains or hills.

Mehl, 1933). The fauna of associated fossils, especially the nautiloid cephalopods and conodonts, date the Yijianfang and Dawangou Formations as of Darriwilian age.

The Yijianfang and Dawangou Formations accumulated in open marine platform environments and reef facies during the Darriwilian. Because the small reefs are not as well developed in the northern Kalpin area, the sea there was probably deeper than in the Bachu area to the south. Zhou et al. (1990) concluded that the Kalpin area became a carbonate platform frontal marginal slope (Nileid facies) during the Middle Ordovician, whereas the Bachu area was situated in a platform marginal uplift (Illaenid-Cheirurid facies).

The similarity of these sponge faunas with those of North America suggests that there was an effective seaway connection between the two areas during the Middle Ordovician. These areas have several genera, such as *Hudsonospongia*, *Calycocoelia*, and *Aulocopium*, in common with Baltica (Rhebergen et al., 2001), which may have occupied an intermediate geographic position in the Ordovician.

#### SYSTEMATIC PALEONTOLOGY

**Repository.**—Type and figured specimens are deposited in collections of the Geology Department, Jiangnan Petroleum Institute,

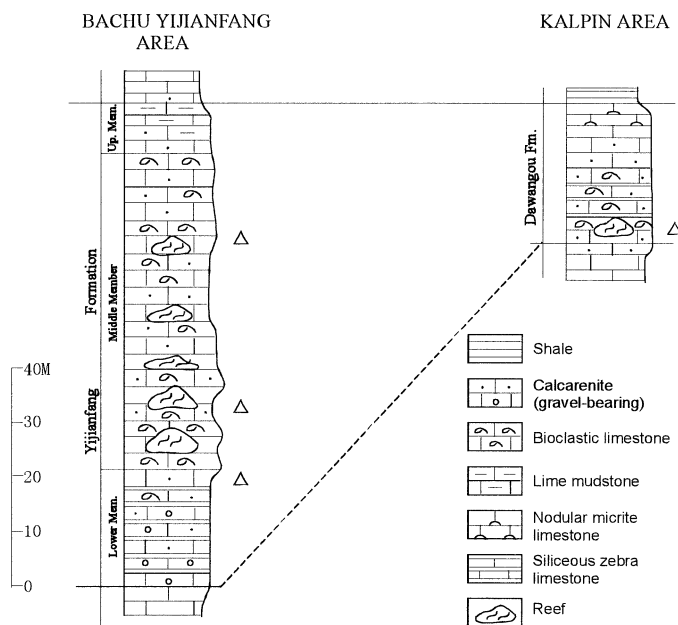


FIGURE 2—Stratigraphic sections of the reef-bearing Middle Ordovician, Darriwilian, Yijianfang Formation in the Bachu Yijianfang area, and the Dawangou Formation in the Kalpin area. Units where fossil sponges were collected from the sections are indicated by the open triangles.

Jiangling, Hubei, China. The specimens are labeled by locality (BD, Bachu, Dawuztag area; BT, Bachu, Tangwangcheng area; and KS, Kalpin area); the formation from which they were collected (Y, Yijianfang Formation; and D, Dawangou Formation); and specimen number, *h*<sub>1</sub>, etc.

Class DEMOSPONGEA Sollas, 1875

Order LITHISTIDA Schmidt, 1870

Suborder ORCHOCALADINA Rauff, 1895

Family ANTHASPIDELLIDAE Miller, 1889

Genus ZITTELELLA Ulrich and Everett, 1890

*Type species.*—*Zittellella typicalis* ULRICH AND EVERETT, 1890.

ZITTELELLA XINJIANGENSIS new species

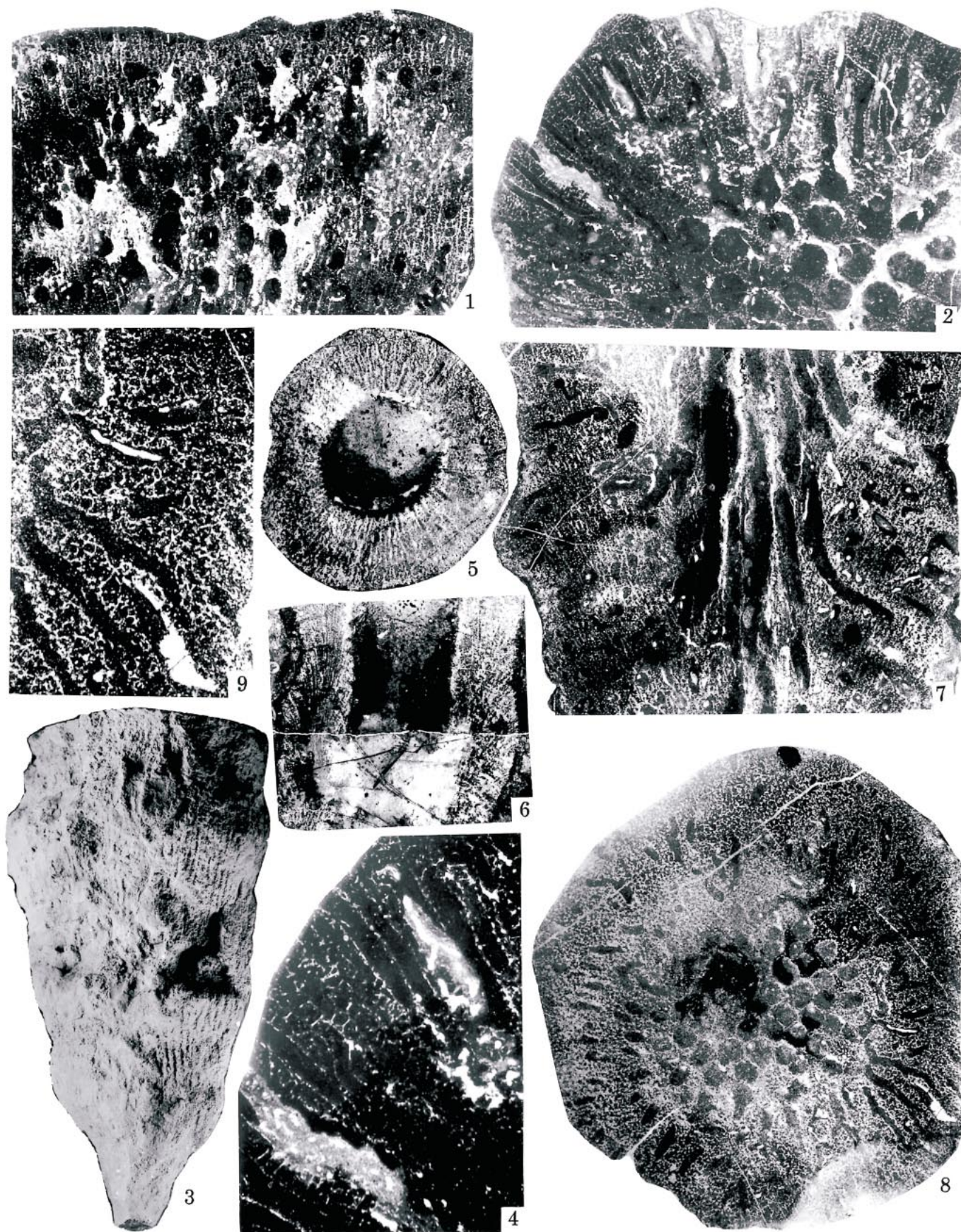
Figure 3.1–3.4

**Diagnosis.**—Sponges large, obconical to conical-cylindrical, with dermal surface marked by irregular, horizontal, annulations or nodes and closely spaced, thin, longitudinal ridges. Shallow spongocoel on upper end, into which opens cluster of coarse, circular, vertical exhalant canals, each approximately 3.5–3.8 mm in diameter. Inhalant canal system principally of regularly stacked, vertical rows of horizontal canals converge to vertical exhalant cluster. Skeletal net anthaspidellid, with trabs 0.1–0.2 mm in diameter that include 2–3 coring spicules; trabs rise steeply or essentially normal to surface of pinnation near gastral margin of wall. Dendroclones I- or Y-shaped, with shafts 0.3–0.5 mm long and about 0.05 in diameter.

**Description.**—Holotype nearly complete, large, obconical sponge, 143 mm high, with maximum diameter of 65 mm near upper end. Exterior marked by irregular horizontal, annulations or nodes and closely spaced, narrow longitudinal ridges and grooves that occur 8–9 per centimeter in dermal view. Prosopores densely stacked in these vertical grooves.

Upper end of specimen with shallow oscular depression, or spongocoel, approximately 15 mm deep and with rounded base, into which opens axial cluster of vertical exhalant canals. Axial region with round cross-section ranges 12–32 mm in diameter







from lower to upper parts of sponge and filled with numerous vertical exhalant canals. Such canals rounded to subrounded tubes, 3.5–3.8 mm in diameter, and separated by 0.6–0.8 mm of skeletal material. These vertical axial canals rise upward in sweeping curves from inner ends of horizontal coarse inhalant canals.

Two series of horizontal canals occur in outer wall; are very regularly radially arranged and stacked in vertical series. Coarse canals exhalant, 1.8–2.2 mm in diameter and 0.4–0.7 mm apart, separated by double row of vertical trabs. Some of these canals curve upward near axial region to join vertical axial exhalant canals. Second set thinner inhalant canals, 0.8–1.2 mm in diameter and 4–6 mm long; occur in outer part of wall and commonly separated by one row of trabs. They extend inward from dermal prosopores and connect to exhalant series. Canals that parallel trabs not observed.

Body wall of sponge 15–18 mm thick and of three-dimensional anthaspidellid skeletal network. Trabs rise steeply or essentially normally to upper surface from ill-defined surface of pinnation that appears to be near gastral margin. These trabs 0.1–0.2 mm in diameter, include 2–3 coring spicules, and formed by union of zygomeres of dendroclones. Latter principally Y- or I-shaped, with smooth shafts 0.2–0.5 mm long and 0.02–0.03 mm in diameter. Some Y-shaped spicules with clads commonly 0.2–0.3 mm long and 0.02 mm in diameter. Trabs in upper part rise parallel to meet dermal surface at sharp angles. They form ladder-like skeletal structures regularly 0.2–0.5 mm apart.

*Etymology*.—Xinjiang, an autonomous region of China, from which the specimen was collected.

*Type*.—Holotype, BT-Y-h<sub>1</sub>.

*Occurrence*.—The holotype and paratype were collected from Locality 2, Tangwangcheng, Bachu County, Xinjiang; from the middle part of the Yijianfang Formation of Darriwilian age.

*Discussion*.—This new species is similar to *Hudsonospongia cyclostoma* Raymond and Okulitch, 1940, as described by Rigby and Webby (1988), in general skeletal structure but has a different shape, dermal appearance, and inhalant canal system. The new species has inhalant ostia stacked in very regular vertical rows. The intervening trabs are arranged in radial rows that are so regular that the structure appears almost septate and coral-like in dermal view and from above. Because of these features, it is placed in *Zittlella* rather than *Hudsonospongia*. The new species has a surface of pinnation near the gastral margin, however, like that exhibited by species of *Hudsonospongia*.

*Zittlella xinjiangensis* n. sp. is characterized by its larger obconical body size and its dermal features, by the cluster of coarse axial exhalant canals and its coarse horizontal canals, both of which are larger than 2.0 mm in diameter.

Genus HUDSONOSPONGIA Raymond and Okulitch, 1940

*Type species*.—*Hudsonospongia cyclostoma* RAYMOND AND OKULITCH, 1940.

HUDSONOSPONGIA CYCLOSTOMA Raymond and Okulitch, 1940  
Figure 3.7–3.9

*Hudsonospongia cyclostoma* RAYMOND AND OKULITCH, 1940, p. 204, pl. 3, figs. 1–4; SHIMER AND SHROCK, 1940, p. 53, pl. 15, figs. 10–12; DE LAUBENFELS, 1955, p. E53; VAN KEMPEN AND TEN KATE, 1980, p. 437–453, figs. 2–6; EGGINK, 1991, p. 31–32; BERESI AND RIGBY, 1993, p. 30–35, pl. 2, figs. 1, 4; pl. 7, fig. 5; pl. 9, figs. 3–5.

*Hudsonospongia* cf. *H. cyclostoma* RAYMOND AND OKULITCH, 1940; RIGBY AND WEBBY, 1988, p. 35–37, pl. 10, figs. 6–8; pl. 11, figs. 1–9, text-fig. 10.

*Hudsonospongia cyclostomata* RAYMOND AND OKULITCH, 1940, LANGE AND BARTHOLOMÄUS, 1991, p. 107–110, pl. 1, figs. 1–4, text-fig. 12.

*Emended diagnosis*.—Cylindrical to obconical sponges of moderate to large size; dermal surface smooth or with some nodular projections. Upper end with shallow spongocoel or central depression, into which empties vertical axial cluster of numerous coarse exhalant canals, each 2–3 mm in diameter. Convergent horizontal inhalant canals stacked vertically, curved and branched, and 1.5–2.0 mm in diameter. Skeletal structure anthaspidellid, with trabs 0.1–0.2 mm in diameter. Trabs rise steeply upward and curve outward to meet dermal surface at sharp angles, but essentially vertical at gastral margin, so surface of pinnation not clearly defined. Dendroclones Y- or X-shaped and arranged in ladder-like series.

*Description*.—Figured, incomplete, obconical sponge 58 mm high, with broken base and with maximum diameter of 48 mm approximately 15 mm below upper end, and 25 mm in diameter at broken base. Dermal surface smooth, but with some node-like projections. Upper end with shallow spongocoel, approximately 10 mm deep and 27–28 mm in diameter, with rounded base into which empty numerous vertical exhalant canals of axial cluster. Four canal series present in sponge. Largest canals 2.3–2.6 mm in diameter, in vertical exhalant cluster where canals round to somewhat polygonal in cross section and spaced side by side, where separated by thin walls of skeletal material. Axial cluster extends upward from near base of sponge and includes upward curved inner ends of higher coarse horizontal canals. Thus number of vertical canals in cluster increases gradually upward.

Second canal series includes radial horizontal exhalant canals that commonly rise upward and inward toward axial cluster, and stacked in vertical series. Canals with rounded to subrounded cross-sections, 1.5–2.0 mm in diameter, whose outer ends formed of two or three convergent thinner branches that range 0.5–1.2 mm in diameter. These branches inner ends of inhalant canals that

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FIGURE 3—*Zittlella*, *Hudsonospongia*, and *Calycocoelia*. 1–4, *Zittlella xinjiangensis* n. sp., holotype, BT-Y-h<sub>1</sub>, from Locality 2; 1, vertical tangential section through the wall near the spongocoel in uppermost part of the sponge shows the stacked canal series and ladder-like series of approximately vertical trabs,  $\times 2$ ; 2, transverse section of upper part of sponge shows the regularly arranged radial lines of trabs, the convergent canal system, and the numerous exhalant canals of the axial cluster,  $\times 2$ ; 3, side view shows the obconical shape of the sponge, weak annulations, and prominent longitudinal ridges made by lines of trabs and stacked ostia of inhalant canals,  $\times 1$ . 5, 6, *Calycocoelia profunda sichuanensis* Deng, 1990, BD-Y-h<sub>5</sub>, from Locality 1; 5, transverse section shows regularly arranged lines of trabs and horizontal canal series,  $\times 2$ ; 6, longitudinal section through the spongocoel shows the moderate thickness of the sponge wall with slightly upward-arched canals and upward divergent trabs from a surface of pinnation at midwall,  $\times 2$ . 7–9, *Hudsonospongia cyclostoma* Raymond and Okulitch, 1940, KS-D-h<sub>6</sub>, from Locality 3; 7, vertical longitudinal section through the axial region showing the central vertical exhalant canal cluster, upward convergent horizontal exhalant canals of the inner wall and somewhat smaller inhalant canals of the outer wall, and the upward divergent trabs from an indistinct surface of pinnation near the gastral surface,  $\times 2$ ; 8, transverse section showing the horizontal smaller inhalant curved canals in the outer wall, and the axial cluster of rounded to prismatic exhalant canals,  $\times 2$ ; 9, enlarged part of section shown in figure 8 showing the skeletal structure of trabs connected by dendroclones and interrupted by curved horizontal inhalant radial canals,  $\times 5$ .

extend inward from dermal ostia and merge to form exhalant horizontal canals at one-half to one-third thickness of wall in from dermal surface.

Canals of third series approximately parallel to trabs, but only a few evident in most thin sections. They have round cross-section, 0.6–0.8 mm in diameter, and penetrate upward within wall and link horizontal canals. Fourth series of canals extend normal to trabs through sponge wall, have small diameters of 0.5–0.7 mm, and probably inhalant. Angular skeletal pores parallel to trabs and approximately 0.2–0.4 mm across.

Trabs mostly 0.2–0.3 mm in diameter, with 2–3 coring spicules, and linked by dendroclones to produce well-defined, parallel, ladder-like skeletal series. Approximately 13–14 trabs occur per 5 mm in radial series in body wall, and rise steeply to meet dermal surface at high angles. Trabs essentially vertical near axial canal cluster. Surface of pinnation near gastral margin, but not well developed.

Dendroclones form rung-like elements between trabs and connected to each other by clads that produce three-dimensional skeletal network. Dendroclones mostly X- and Y-shaped, with smooth shafts, 0.3–0.5 mm long and 0.08–0.15 mm in diameter, and with complex double cladome rays and less expanded brachyome terminations, where finger-like zygomeres developed. Cladomes with double rays about 0.1–0.15 mm long and 0.05 mm in diameter.

**Occurrence.**—The figured specimen, KS-D-h<sub>6</sub>, was collected from Locality 3, Kalpin County, Xinjiang, from the lower Dawangou Formation, of Darriwilian age. Two additional specimens were collected from the upper part of the Middle Member of the Yijianfang Formation at Locality 1, Yijianfang, Bachu County, Xinjiang.

**Discussion.**—The present specimen is similar to *Hudsonospongia* cf. *H. cyclostoma* described by Rigby and Webby (1988), from Australia, and *H. cyclostoma* described by Beresi and Rigby (1993) from Argentina, in outline, shape and skeletal structure. But the Chinese specimen is larger than either of those sponges and has a greater number of axial exhalant canals. In addition, the curved and divergent horizontal canals are better developed, but not enough to characterize a different species. It is also somewhat similar to *Zittebella xinjiangensis* n. sp., in shape and general skeletal structure, but it has an irregular arrangement of horizontal canals, in contrast to the uniform canal pattern in *Zittebella*.

#### Genus CALYCOCOELIA Bassler, 1927

*Type species.*—*Calycocoelia typicalis* BASSLER, 1927.

CALYCOCOELIA PROFUNDA SICHUANENSIS Deng, 1990  
Figure 3.5, 3.6

**Emended diagnosis.**—Cylindrical-obconical, moderate-size sponges with deep and broad circular spongocoel; gastral surface generally smooth. Canals and skeleton arranged regularly in radial rows. Horizontal canals 0.2–0.4 mm in diameter, arch slightly and vertically stacked in regular layers. Anthaspidellid skeleton with surface of pinnation approximately at midwall, from which trabs rise upward and outward, or inward, to meet dermal and gastral

surfaces at acute angles. Trabs about 0.1 mm in diameter. I-shaped dendroclones with smooth shafts 0.1–0.15 mm long and about 0.08 in diameter.

**Description.**—Five specimens in collection irregularly secondarily silicified, with broken bases, and with cylindrical-obconical shape to 40 mm tall. Upper parts to 25 mm in diameter, and lower parts to 19.5 mm in diameter, walls 5.5–7.0 mm thick. Dermal surface smooth but locally with projecting spicules.

Spongocoel deep and broad, 11 mm in diameter in upper end, 8 mm in diameter in lower part, gastral surface smooth. Circular exhalant ostia open on gastral surface and regularly arranged in vertical and horizontal rows.

Horizontal canals 0.2–0.4 mm in diameter, regularly arranged in radial rows and stacked layers, where uparched slightly at midwall and 0.9–1.2 mm apart. They penetrate through wall, with ostia on both dermal and gastral surfaces where both prosopores and exopores expand to 0.5–0.8 mm in diameter and funnel-like, although exopores commonly larger.

Trabs prominent in anthaspidellid skeletal net, with surface of pinnation at about midwall, 2.5–3.5 mm in from dermal surface. Trabs generally 0.1–0.2 mm in diameter and 0.08–0.14 mm apart, and rise upward, like fibers of broom, to meet both gastral and dermal surfaces at acute angles.

Dendroclones mainly I- or Y-shaped, with shafts approximately 0.2 mm long and 0.06–0.08 mm in diameter, but details not evident in silicified preservation.

**Occurrence.**—Five specimens, including the figured specimen BD-Y-h<sub>5</sub>, were collected from Locality 1, Yijianfang, Bachu County, Xinjiang, from the upper part of the lower member of the Darriwilian Yijianfang Formation.

**Discussion.**—*Calycocoelia profunda* (Ivanovsky, 1963) was discussed by Deng (1990), who erected *C. profunda sichuanensis*, which is similar to our specimen in general shape and skeletal structure. Our specimen is also similar to *C. perforata* Beresi and Rigby, 1993, from Argentina, but our specimen is smaller and lacks the numerous, large, irregular ostia like those seen on the dermal surface of that species.

#### CALYCOCOELIA sp.

Figure 4.1, 4.2

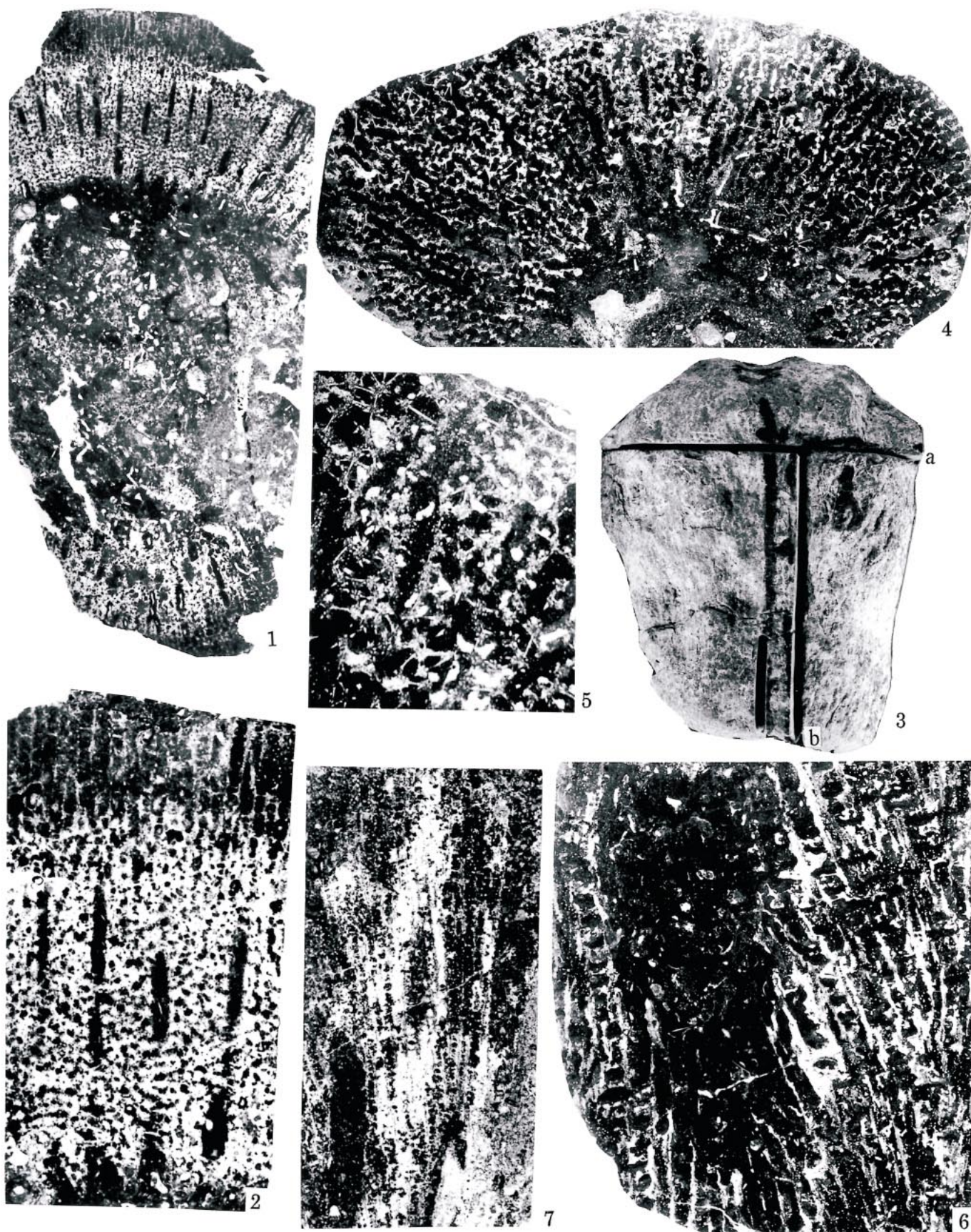
**Description.**—Broken sponge whose complete shape unknown but 32 mm tall, as preserved, with upper end 60 mm and lower end 40 mm in diameter. Body wall 17 mm thick around broad, deep, spongocoel 31 mm in diameter at osculum and 23 mm in diameter at lower end; gastral surface smooth but penetrated by numerous prosopores of radial horizontal canals that regularly arranged in vertical and horizontal rows.

Horizontal canals uparched slightly at midwall, and vertically stacked. Canals round, mainly 0.4–0.6 mm in diameter, and separated 1.4–2.0 mm, and with weakly expanded openings at gastral surface.

Skeleton anthaspidellid with trabs 0.2–0.4 mm in diameter that may include several oxaeas as coring spicules. These spicules 0.03–0.04 mm in diameter, and overgrown or bound together by

FIGURE 4—*Calycocoelia*, *Rhopalocoelia* and *Pseudopalmatohindia*. 1, 2, *Calycocoelia* sp., BD-Y-h<sub>5</sub>, from Locality 1; 1, transverse section showing lines of trabs and canals arranged in regular radial structure around a broad, matrix-filled spongocoel,  $\times 2$ ; 2, enlarged part of wall shown in upper middle part of 1, where trabs are steep or nearly normal to the section for the inner two-thirds of the wall, where the horizontal canals are evident, but curve to become subparallel in the outer dermal part,  $\times 5$ . 3–6, *Rhopalocoelia bachuensis* n. sp., holotype, BT-Y-h<sub>6</sub>, from Locality 2; 3, side view of incomplete specimen in which sawed surfaces are marked a and b,  $\times 1$ ; 4, part of transverse section showing the skeletal structure with relatively coarse trabs and dendroclones and distribution of horizontal canals,  $\times 2$ ; 5, enlarged cross section, part of 4, showing the coring spicules of the trabs as small circular sections and the long- and short-shafted dendroclones,  $\times 5$ ; 6, oblique longitudinal section through the spongocoel shows ladder-like skeletal structure of coarse trabs and spicules, with surface of pinnation near right margin,  $\times 2$ . 7, *Pseudopalmatohindia* sp., KS-D-h<sub>3</sub>, from Locality 3; partial longitudinal section shows parallel exhalant canals and the ladder-like skeletal structure,  $\times 4$ .







cladomes of dendroclones. Surface of pinnation at approximately one-third wall thickness in from dermal surface. Trabs in inner part rise steeply and curve inward to meet gastral surface at sharp angles, but those in outer part rise and curve abruptly outward to meet dermal surface essentially at right angles.

Dendroclones mainly I- and Y-shaped, with smooth long shafts that generally range 0.2–0.3 mm long, but with maximum lengths up to 0.5–0.6 mm, and 0.06–0.08 mm in diameter. Well preserved spicules with binary divergent clads generally 0.08–0.14 mm long, but range up to 0.2 mm long, and with complex zygomies.

**Occurrence.**—Figured specimen BD-Y-h<sub>3</sub>, was collected from Locality 1, from lower beds of the Middle Member of the Yijianfang Formation, at Yijianfang, Bachu County, Xinjiang, from the lower part of the Darriwilian.

**Discussion.**—In comparison with other species of *Calycocoelia* the present specimen is distinctive in that trabs in the outer part of the wall curve strongly outward and upward from the surface of pinnation to meet the dermal surface almost at right angles. This feature differs from that present in other species of the genus and suggests that the specimen probably belongs to a new species. However, because it is so incomplete and many features are not well preserved, even though the ladder-like skeletal structure and trabs are well preserved in the outer one-third to one-fourth of the wall, it is difficult to establish a new species, so we retain it in open nomenclature only as *Calycocoelia* sp.

Genus RHOPALOCOELIA Raymond and Okulitch, 1940

**Type species.**—*Rhopalocoelia clarkii* RAYMOND AND OKULITCH, 1940.

RHOPALOCOELIA KALPINENSIS new species  
Figure 5.3–5.6

**Diagnosis.**—Cylindrical to conical-cylindrical or club-shaped sponges with deep and broad spongocoel extending nearly to base. Dermal surface smooth or undulating. Skeletal canals slightly curved and 0.8–1.1 mm in diameter, in regularly spaced radial rows but irregularly spaced vertically. Skeleton anthaspidellid with prominent relatively loosely packed trabs that diverge upward and outward from surface of pinnation approximately at midwall. Trabs commonly 0.2–0.25 mm in diameter and include several coring spicules. Dendroclones mainly Y-shaped, but X- and I-shaped spicules also present.

**Description.**—Sponge cylindrical to conical-cylindrical, even though upper part commonly missing, range to 90 mm tall, with upper end 49 mm in diameter and basal end probably bluntly obconical; dermal surface irregularly undulating. Body wall 14–16 mm thick, in round to sub-elliptical cross section. Deep and broad spongocoel extends nearly to base, with gastral surface smooth to undulating.

Skeletal structure anthaspidellid, with trabs loosely packed, 0.2–0.25 mm in diameter, including several coring spicules about 0.05 mm in diameter. Surface of pinnation located approximately at midwall, but locally near gastral margin, from where rising trabs diverge outward to meet dermal surface at about 15 degrees and inward at less than 10 degrees or parallel to gastral surface.

Trabs regularly arranged in vertical radial tracts separated 0.3–0.4 mm by major horizontal canals. Each of these tracts formed by two radial rows of trabs separated 0.1–0.2 mm by skeletal pores.

Dendroclones mainly Y-shaped, but X- or I-shaped spicules also present. Y-shaped spicules commonly with smooth shaft about 0.2 mm long and 0.08 mm in diameter, and bifid divergent rays approximately 0.1 mm long.

Two series of horizontal canals occur in sponge wall where both regularly arranged in radial and stacked vertical series. Major long canals elliptical to rectangular in cross section; range 2.1–2.6 mm high and 1.1–1.3 mm wide, with roughly 3.5–4 canals per centimeter in vertical rows. They penetrate wall from dermal surface to gastral surface, with elliptical prosopores regularly arranged in longitudinal rows on dermal surface. Second series contains smaller canals that pass through double row of trabs between major canals and also extend from dermal to gastral surfaces, are round to elliptical in cross section and 0.2–0.3 mm across. Skeletal pores between trabs and dendroclones 0.1–0.3 mm in diameter.

**Etymology.**—Kalpin, a county of Xinjiang, where the specimen was collected.

**Type.**—Holotype, KS-D-h<sub>4</sub>.

**Occurrence.**—The holotype and a paratype were collected from Locality 3, Kalpin County, Xinjiang, from the lower part of the Dawangou Formation of Darriwilian age.

**Discussion.**—The distinctive features of this new species include its larger conico-cylindrical form, the quite regularly arranged skeleton and canal series, and its elliptical to rectangular canal openings between coarse trabs that have several coring oxaeas. These features distinguish the species from other known species of *Rhopalocoelia*. The new species is similar to species of *Calycocoelia* in skeletal structure, but because the cylindrical new species has trabs that rise upward steeply to meet the dermal surface at less than 20 degrees, and the sponge is relatively thin-walled, it is here included in *Rhopalocoelia*.

RHOPALOCOELIA BACHUENSIS new species  
Figure 4.3–4.6

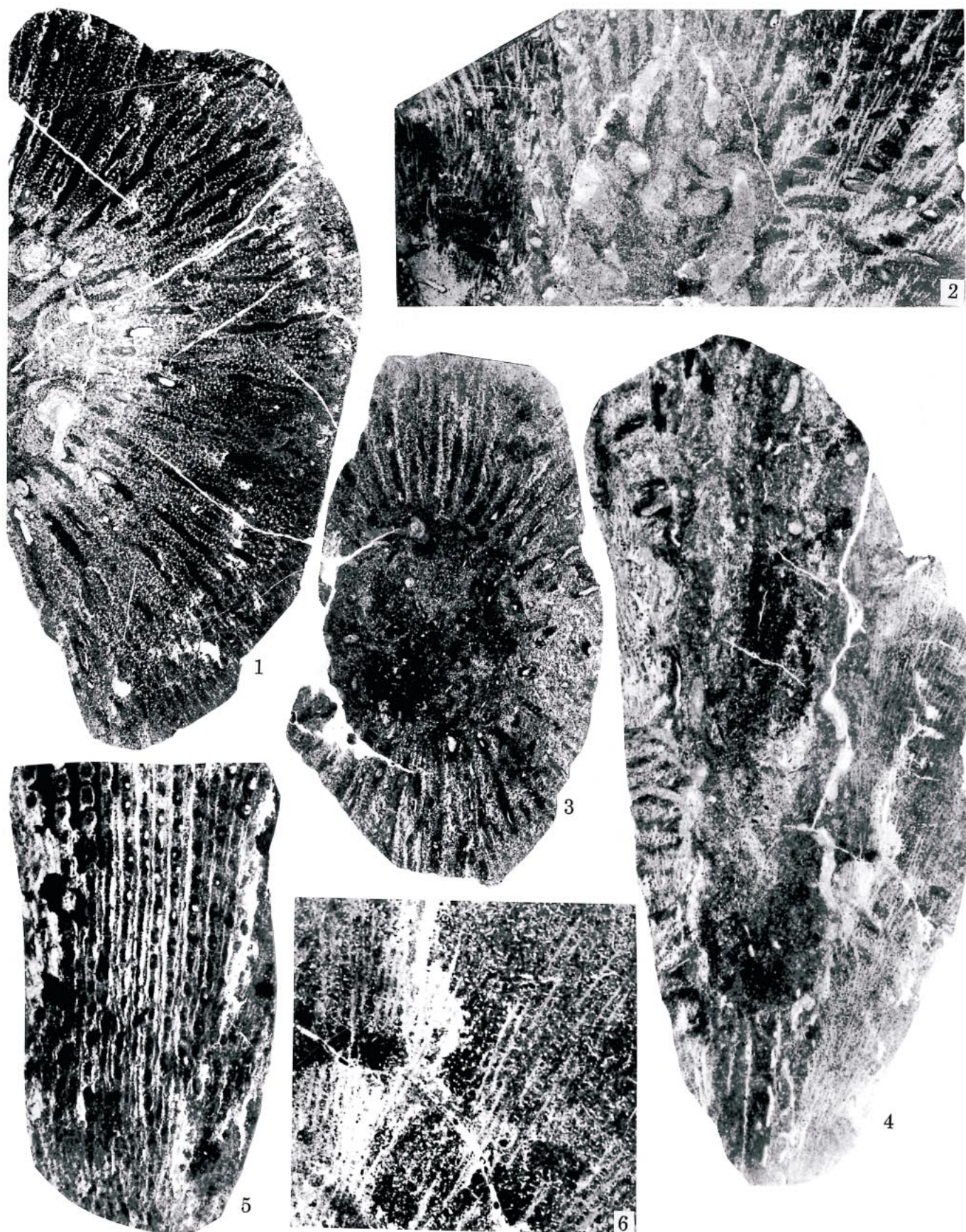
**Diagnosis.**—Relatively large, broadly obconical sponges with generally smooth dermal surface marked by closely spaced, thin, longitudinal ridges. Horizontal canals radially and vertically stacked, 1.2–2.0 mm apart, and 0.8–1.2 mm in diameter. Skeleton anthaspidellid, with relatively coarse trabs, mostly 0.3–0.5 mm in diameter, that include several coring spicules. Surface of pinnation approximately at midwall, from which outer trabs rise nearly vertically, but inner ones curve to meet gastral surface at 20–30 degrees. Dendroclones mainly I-shaped, with smooth shafts 0.8–1.4 mm long and 0.1–0.2 mm in diameter. Spicules connect trabs and form ladder-like series in skeletal network.

**Description.**—Holotype upper part of large, broad, conico-cylindrical sponge whose base and parts of walls broken away. Preserved part 75 mm tall, 67 mm across at upper end and 45 mm across at lower end. Dermal surface generally smooth but marked by closely-spaced, thin longitudinal ridges formed by trabs spaced approximately 10–11 per centimeter. Sponge wall 26–28 mm

FIGURE 5—*Aulocopium?* and *Rhopalocoelia*. 1, 2, *Aulocopium?* sp., KS-D-h<sub>7</sub>, from Locality 3; 1, transverse section of partial specimen showing double lines of trabs between convergent horizontal canals,  $\times 2$ ; 2, vertical section through wall and part of spongocoel showing gently divergent ladder-like skeletal structure of trabs and interconnecting spicules, and horizontal canals,  $\times 2$ . 3–6, *Rhopalocoelia kalpinensis* n. sp., holotype, KS-D-h<sub>4</sub>, from Locality 3; 3, transverse section of upper end shows horizontal canals in wall, separated by double rows of trabs, and matrix-filled spongocoel,  $\times 2$ ; 4, oblique longitudinal section through the matrix-filled spongocoel and the wall showing the ladder-like skeletal structure with a surface of pinnation at about midwall and the stacked, though curved, horizontal canals,  $\times 2$ ; 5, vertical tangential section near the dermal surface in the lower part of the sponge shows the lines of double rows of trabs and the regularly stacked sections of the horizontal canals,  $\times 2$ ; 6, enlarged section of wall in right middle part of 4 shows ladder-like skeletal structure and divergence from surface of pinnation,  $\times 5$ .

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thick, around deep broad spongocoel 32 mm in diameter in upper part and 23 mm in diameter in lower part.

Skeleton characterized by relatively coarse trabs and dendroclones. Trabs mainly 0.3–0.5 mm in diameter, but may range to 0.7–0.8 mm thick in polygonal cross-sections that include 4–6 or more coring oxeas that 0.08–0.1 mm in diameter. Surface of pinnation approximately at midwall, and outer trabs diverge upward, almost vertically, but inner ones rise to meet gastral surface at angles of 20–30 degrees.

Trabs combine with dendroclones to produce typical ladder-like series, and spaced 1.6–3.0 mm apart, but mostly 1.8–2.5 mm apart. Dendroclones mainly I-shaped, and Y-shaped ones relatively rare. Common spicules with smooth shafts 0.6–1.4 mm long and 0.1–0.2 mm in diameter, with complex zygomies that articulate to help produce trabs. Y-shaped dendroclones with double ray clads to 0.2 mm long, and with complex articulating tips.

Horizontal canals radial and vertically stacked, 0.8–1.2 mm in diameter, and spaced 1.2–2.0 mm apart, transversely and vertically, as porous tubes limited by trabs and dendroclones. Horizontal canals extend through wall from dermal to gastral surfaces and are horizontal or slope slightly downward and inward. Skeletal pores parallel to or normal to trabs and have diameters or widths of 1.2–1.5 mm.

*Etymology*.—Bachu, a small county of Xinjiang, where the type specimen was collected.

*Type*.—Holotype, BT-Y-h<sub>8</sub>.

*Occurrence*.—The holotype was collected from Locality 2, Tangwangcheng, Bachu County, Xinjiang, from the middle part of the Yijianfang Formation, of Darriwilian, or late Middle Ordovician age.

*Discussion*.—In comparison to known species of the genus, *Rhopalocoelia bachuensis* n. sp., is a relatively larger and broader obconical sponge. The most distinctive features of the sponge, however, are its relatively coarse trabs and dendroclones, and skeletal pores. These features produce an open, but sturdy, skeletal network suggesting the species may have been adapted to marine environments with stronger currents.

#### Genus ANNULOSPONGIA new genus

*Type species*.—*Annulospongia tarimensis* n. sp.

*Diagnosis*.—Ring-like or tire-like large sponge 25–30 mm high, with diameter up to 140 mm. Spongocoel broad and deep, extending upward from near base. Skeleton anthaspidellid, with vertical trabs nearly parallel to each other, from base to upper oscular margin, so surface of pinnation not developed or present only near base. Horizontal canals radial, straight to curved slightly, and vertically stacked.

*Etymology*.—Annulus (L), ring, to express the general shape of the sponge.

#### ANNULOSPONGIA TARIMENSIS new species

Figure 6.4–6.7

*Diagnosis*.—As for genus.

*Description*.—Single known specimen, holotype, large ring-like or tire-like sponge, with body 25–30 mm high and 140 mm in diameter. Body wall 40–43 mm thick around broad spongocoel approximately 60 mm in diameter from base to oscular margin of sponge. Oscular margin flat and smooth, but outer edge of wall curved down to meet base at angles of 60–75 degrees.

Skeleton anthaspidellid, with trabs mainly 0.2–0.3 mm in diameter, a few of which are hollow, as preserved, but coring spicules may or may not have been present. Trabs vertical and nearly parallel to each other, rise from base to meet uppermost oscular margin almost at right angles. Consequently, surface of pinnation not developed in upper wall. Trabs arranged in regular, double, radial rows around spongocoel. In each double row, trabs close together, 0.2–0.3 mm apart, but between double rows separated by horizontal canals 0.8–1.1 mm wide.

Two main types of dendroclones connect trabs. Ones with short shafts mainly I-shaped, with shafts 0.2–0.3 mm long and 0.06–0.08 mm in diameter and with brachyome or rhabdome terminations, are commonly arranged in double rows. Long-shafted dendroclones X- or Y-shaped, with shafts 0.8–1.1 mm long and 0.1–0.2 mm in diameter, bridge canals between double rows and form window lattice-like structures. Latter dendroclones relatively complex with bifid cladome rays and finger-like zygomies. Locally, short smaller dendroclones vertically cross-connect larger spicules.

Horizontal radial canals 0.8–1.1 mm in diameter and vertically stacked. Such canals straight or curve slightly between double rows of trabs and separated 1.2–1.3 mm, horizontally.

*Etymology*.—Tarim, for the Ordovician Tarim platform, now folded along the margin of the Tertiary basin, from which the type specimen was collected.

*Type*.—Holotype, BT-Y-h<sub>6</sub>.

*Occurrence*.—The holotype was collected from Locality 2, Tangwangcheng, Bachu County, Xinjiang, from the middle part of the Yijianfang Formation, of Darriwilian or late Middle Ordovician age.

*Discussion*.—The most distinctive features of the new genus and species are its ring-like or tire-like shape and its skeletal structure where parallel trabs rise vertically and a surface of pinnation is not developed, at least in the upper part of the sponge. This form may have been adapted to life in strong marine bottom currents, because of its short and rounded body.

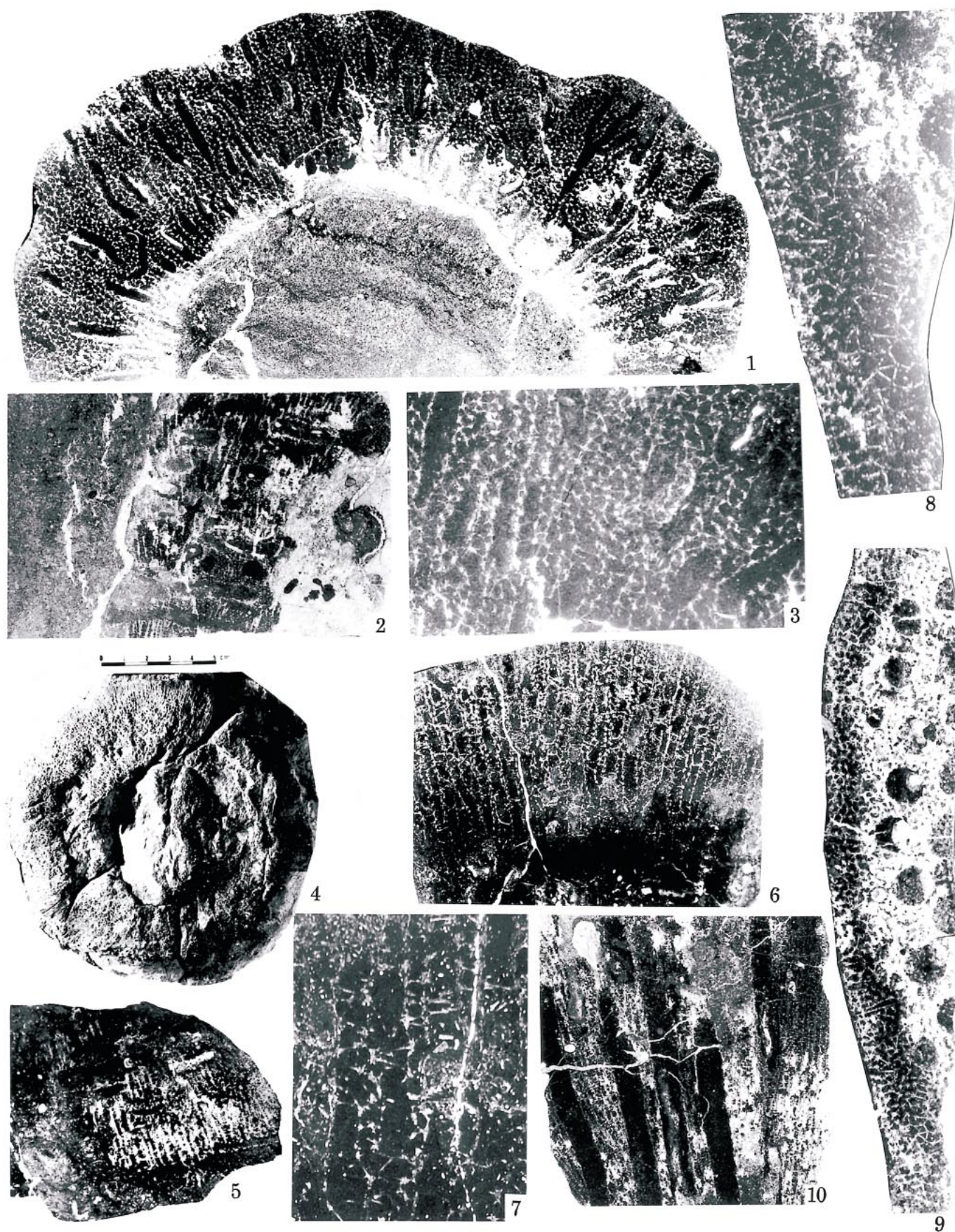
#### PSEUDOPALMATOHINDIA Rigby and Webby, 1988

*Type species*.—*Pseudopalmatohindia digitata* RIGBY AND WEBBY, 1988.

FIGURE 6—*Archaeoscyphia*, *Annulospongia* n. gen., and *Pseudopalmatohindia*. 1–3, *Archaeoscyphia minganensis* (Billings, 1859), KS-D-h<sub>1</sub>, from Locality 3; 1, transverse section of half of specimen showing radial horizontal canals that are irregularly curved and repeatedly branched,  $\times 2$ ; 2, vertical longitudinal section of right part of sponge shows annulate dermal and gastral surfaces, gently uparched horizontal canals, and surface of pinnation near the gastral margin,  $\times 2$ ; 3, enlarged part of transverse section shown in the upper middle part of 1, showing general skeletal structure and canal distribution,  $\times 5$ . 4–7, *Annulospongia tarimensis* n. gen., n. sp., holotype, BT-Y-h<sub>6</sub>, from Locality 2; 4, tire-like nearly complete holotype seen from above, approximately  $\times 0.4$ ; 5, vertical section through wall shows the parallel ladder-like trab series and stacked horizontal canals,  $\times 2$ ; 6, transverse section shows the double rows of trabs and the lattice-like structure of the dendroclone series,  $\times 2$ ; 7, enlarged cross section shows characteristic dendroclones in ladder-like series,  $\times 5$ . 8–10, *Pseudopalmatohindia* sp., BT-Y-h<sub>3</sub>, from Locality 2; 8, transverse section showing skeletal structure of the dermal layer as a triangular network of dendroclones and hollow trabs,  $\times 6$ ; 9, transverse section of whole incomplete specimen with numerous round exhalant canals and a thick dermal layer,  $\times 3$ ; 10, vertical longitudinal section through canals and skeleton showing parallel exhalant system and ladder-like skeletal structure,  $\times 2$ .

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## PSEUDOPALMATOHINDIA sp.

Figures 4.7, 6.8–6.10

**Description.**—Figured specimen of sponge a broken block approximately  $45 \times 25 \times 11$  mm in size, so complete shape of sponge unknown, but appears as part of thick, blade-like or plate-like sponge. Series of parallel, straight, cylindrical excurrent canals developed at midwall. These canals range 1.2–2.4 mm in diameter, but mostly 1.8–2.2 mm in diameter, and spaced 1.0–2.5 mm apart. Thinner canals rare and spread irregularly near dermal layer. Walls of canals porous dense layer with smooth surfaces.

Sponge body with distinct dermal layer, 2.5–3.2 mm thick, characterized by distinct skeletal structure and numerous incurrent ostia and canals 0.7–1.2 mm in diameter and perpendicular to dermal surface.

Skeleton composed by tripod-shaped spicules in anthaspidellid network, with trabs 0.1–0.2 mm in diameter. However many trabs hollow and lack coring spicules. Trabs rise upward parallel to or slightly oblique to excurrent canals and form regular ladder-like structure. Dendroclones I-shaped, with smooth shafts 0.1–0.15 mm in diameter and 0.4–0.5 mm long. Outer rays thickened moderately and with simple brachyome or cladome tips. Tips of three to four dendroclones interconnect in circular fashion to produce hollow trab. These skeletal features readily evident in outer part, but in inner part, where numerous excurrent canals occur, structure obscured by recrystallization.

**Occurrence.**—Figured specimen KS-D-h<sub>3</sub>, and an additional specimen, were collected from Locality 3, Kalpin County, Xinjiang, from the lower part of the Darriwilian Dawangou Formation. A specimen of the genus was also collected from Locality 1, Yijiangfang, Bachu County, Xinjiang, from the upper part of the Middle Member of the Yijiangfang Formation.

**Discussion.**—Relationships of *Pseudopalmatohindia* and *Palmatohindia* were discussed by Rigby and Webby (1988, p. 46–47). The figured specimen, in particular, has a distinct thickened exterior layer and partially hollow trabs. These features suggest that the Chinese sponge is probably a new species of *Pseudopalmatohindia*. However, overall shape and skeletal details remain unknown.

## Genus AULOCOPIUM Oswald, 1847

**Type species.**—*Aulocopium aurantium* OSWALD, 1847.

## AULOCOPIUM? sp.

Figure 5.1, 5.2

**Description.**—Figured specimen large, broadly obconical sponge with broken base and subhemispherical uppermost oscular margin. Sponge 50 mm tall, 70 mm in upper diameter and 50 mm in lower diameter. Sponge wall 23–27 mm thick and with smooth dermal surface marked by faint longitudinal stripes. Spongocoel deep and broad, 28 mm in diameter at upper end and 20 mm in diameter in lower part.

Skeleton anthaspidellid with radial trabs that extend upward and outward and repeatedly diverge, with poorly defined surface of pinnation near gastral margin. Trabs 0.2–0.4 mm in diameter and include long coring oxaeas 0.02–0.03 mm in diameter. Dendroclones mostly Y- or X-shaped, with smooth shafts that range 0.4–0.8 mm, although mainly 0.5–0.6 mm long and about 0.02 mm in diameter. Some spicules I-shaped with long shafts. Terminations of clad rays indistinct because of recrystallization.

Two series of main canals radiate in anastomosing fashion in wall. First series generally horizontal radial canals that penetrate from dermal surface to spongocoel, arch up slightly and curved to branched, in vertically stacked series. These canals 1.2–1.4 mm in diameter and spaced 1.3–1.7 mm apart, horizontally, and 1.6–2.5 mm apart, vertically. Second series also radial canals but

which curve upward from spongocoel margin to uppermost oscular margin and approximately parallel trabs. This series mainly 0.8–1.2 mm in diameter and cross horizontal canals.

**Occurrence.**—Figured specimen KS-D-h<sub>7</sub>, and an additional sponge, of the species were collected from Locality 3, Kalpin County, Xinjiang, from the lower part of the Darriwilian Dawangou Formation.

**Discussion.**—Identification of the sponge is difficult because it is incompletely preserved, but it is tentatively included in *Aulocopium*. The skeletal structure and canal pattern are similar or close to *Aulocopium aurantium* Oswald, 1847 (Rigby and Webby, 1988, p. 31–32, pl. 8, figs. 7, 8; pl. 9, fig. 105), but the present specimen is larger.

## Genus ARCHAEOSCYPHIA Hinde, 1889

**Type species.**—*Archaeoscyphia minganensis* (BILLINGS, 1859).

## ARCHAEOSCYPHIA MINGANENSIS (Billings, 1859)

Figure 6.1–6.3

*Petraia minganensis* BILLINGS, 1859, p. 3.

*Archaeocyathus minganensis* BILLINGS, 1865, p. 354.

*Ethmophyllum minganensis* WALCOTT, 1886, p. 77.

*Archaeoscyphia minganensis* HINDE, 1889, p. 143.

For complete synonymy see RIGBY AND WEBBY (1988, p. 29) and DE FREITAS (1989, p. 1874).

**Description.**—Large incomplete broadly obconical sponge, preserved fragment height 39 mm, upper diameter 72–76 mm, lower diameter approximately 62 mm. Body wall thickness 17–25 mm, exterior marked by annulations projecting 8–10 mm from dermal surface. Rounded ridges or annulations irregularly undulating horizontally, and separated by rounded depressions spaced 10–12 mm apart, with some irregularity.

Spongocoel deep and broad, 37 mm across in upper part and 32 mm across in lower part, with weakly annulate gastral surface whose expansions and contractions correspond to exterior variations.

Skeleton typically anthaspidellid, with trabs 0.1–0.2 mm thick, with triangular or polygonal cross sections, and spaced 0.3–0.5 mm apart. Coring spicules not evident. Trabs rise steeply or sub-vertically from surface of pinnation, which is approximately 1/3–1/4 of wall thickness from gastral margin. Ladder-like series of dendroclones mainly I- and Y-shaped, with smooth shafts 0.3–0.5 mm long and about 0.05 mm in diameter. Spicules with both brachyome or cladome rays and complex articulating zygomeres.

Horizontal canals radial and vertically stacked, spaced 2.4–3.2 mm apart, vertically, and separated horizontally by two lines of trabs. Canals 1.1–1.3 mm in diameter, slightly curved, and branched in outer half of wall. These canals completely pierce walls from dermal surface to spongocoel, arch up slightly at mid-wall, and with expanded exopores on gastral surface. Sponge appears to lack major vertical canals but skeletal pores that parallel trabs well developed and about 0.5 mm in diameter.

**Occurrence.**—Specimen KS-D-h<sub>1</sub>, and three additional specimens of the species, were collected from Locality 3, Kalpin County, Xinjiang, from the lower part of the Darriwilian Dawangou Formation. An additional specimen of the species was collected from Locality 1, Yijiangfang, Bachu County, Xinjiang, from the upper part of the Middle Member of the Yijiangfang Formation, of Darriwilian age.

**Discussion.**—As in other examples of *Archaeoscyphia minganensis* (Billings, 1859), these Chinese specimens have a cylindrical-obconical shape with distinct outer annulations, and the skeletal structure and canal system basically like that of the type material. However, the figured specimen has some minor differences, such as the canals are relatively irregularly curved, have more



branches in the outer half of the wall, and are more closely packed horizontally, but these differences are considered as of minor taxonomic importance.

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