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Carboniferous Tabulate Corals from the Sardar Formation in the Ozbak-kuh Mountains, East-Central Iran

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Abstract Five species of tabulate corals are described from the Serpukhovian–Bashkirian (late early–early late Carboniferous) part of the Sardar Formation in the Ozbak-kuh Mountains, East-Central Iran. They are *Michelinia flugeli* sp. nov., late Bashkirian, *Michelinia* sp. indet., late Bashkirian, *Donetzites mariae* Flügel, 1975, late Serpukhovian, *Syringopora iranica* sp. nov., late Serpukhovian, and *Multithecopora* sp. cf. *M. huanglungensis* Lee and Chu *in* Lee *et al.*, 1930, late Serpukhovian to late Bashkirian. The Sardar tabulate coral fauna occurs from limestones that formed in Peri-Gondwana at the low latitudes of the southern hemisphere and faced the Paleo-Tethys Ocean. Except for a cosmopolitan species, closely related to comparable species with the fauna are reported from the Akiyoshi seamount chain, the South China Continent, and the Australian eastern Gondwana.
Key words: Serpukhovian–Bashkirian, late early–early late Carboniferous, Favositida, Auloporida, Peri-Gondwana

Introduction

The Ozbak-kuh Mountains are a fault topography in the Kashmar-Kerman Tectonic Zone (Stöcklin and Nabavi, 1973) and extend over 40 km with NNE-SSW direction in East-Central Iran. According to Ruttner *et al.* (1970) and Leven and Gorgij (2006, 2011), the Carboniferous rocks in the mountains are divided into the Shishtu, Sardar, and Zaladu formations in ascending order. The purpose of this paper is to describe tabulate corals from the Sardar Formation to add new knowledges to previous investigations concerning its coral fauna, including Flügel (1975, 1995), Badpa (2009, 2015), Badpa *et al.* (2009, 2011a, b, 2014a, b, 2015a, b, 2016), Fernández-Martínez *et al.* (2018) and Wang *et al.* (2019).

Geologic setting and material

The Sardar Formation was proposed by Stöcklin *et al.* (1965) for the Visean (middle lower Carboniferous) to lowest Permian lithostratigraphic unit. Subsequently, Leven and Taheri (2003) and Leven *et al.* (2006) separated its upper part from the formation as the Zaladu Formation that is correlative with the Gzhelian (late late Carboniferous) to Asselian (early early Permian). In the Ozbak-kuh Mountains, the Sardar Formation (sensu stricto) is divided into the lower sandstone part (30 m thick), the middle limestone dominant part (200 m thick) and the upper part (50 m thick) consisting of alternating beds of sandstone and limestone (Badpa *et al.*, 2016). Sohrabi (2005) defined five conodont zones in this middle part of the formation, namely *Declinognathus noduliferus*, *Idiognathodus corrugatus – I. sulcatus*, *Idiognathodus sinuatus – I. primulus*, *Idiognathodus sulcatus parvus*, and *Idiognathodus delicatus* zones. The present tabulate corals were recovered from two stratigraphic horizons: bioclastic wackestone in *Declinognathus noduliferus* zone (late Serpukhovian; late early Carboniferous) at loc. 3 in the Zaladu II Section and loc. 5 in the Cheshmeh Shir Section, and bioclastic wackestone-packstone partly containing boundstone in *Idiognathodus sulcatus parvus* zone (late Bashkirian; early late Carboniferous) at loc. 1 in the Zaladu Section, loc. 2 in the Abrah-e Zaladu Section, loc. 4 in the Tangal-e-zireh Section, and loc. 6 in the Cheshmeh Shir Section (Figs. 1, 2).

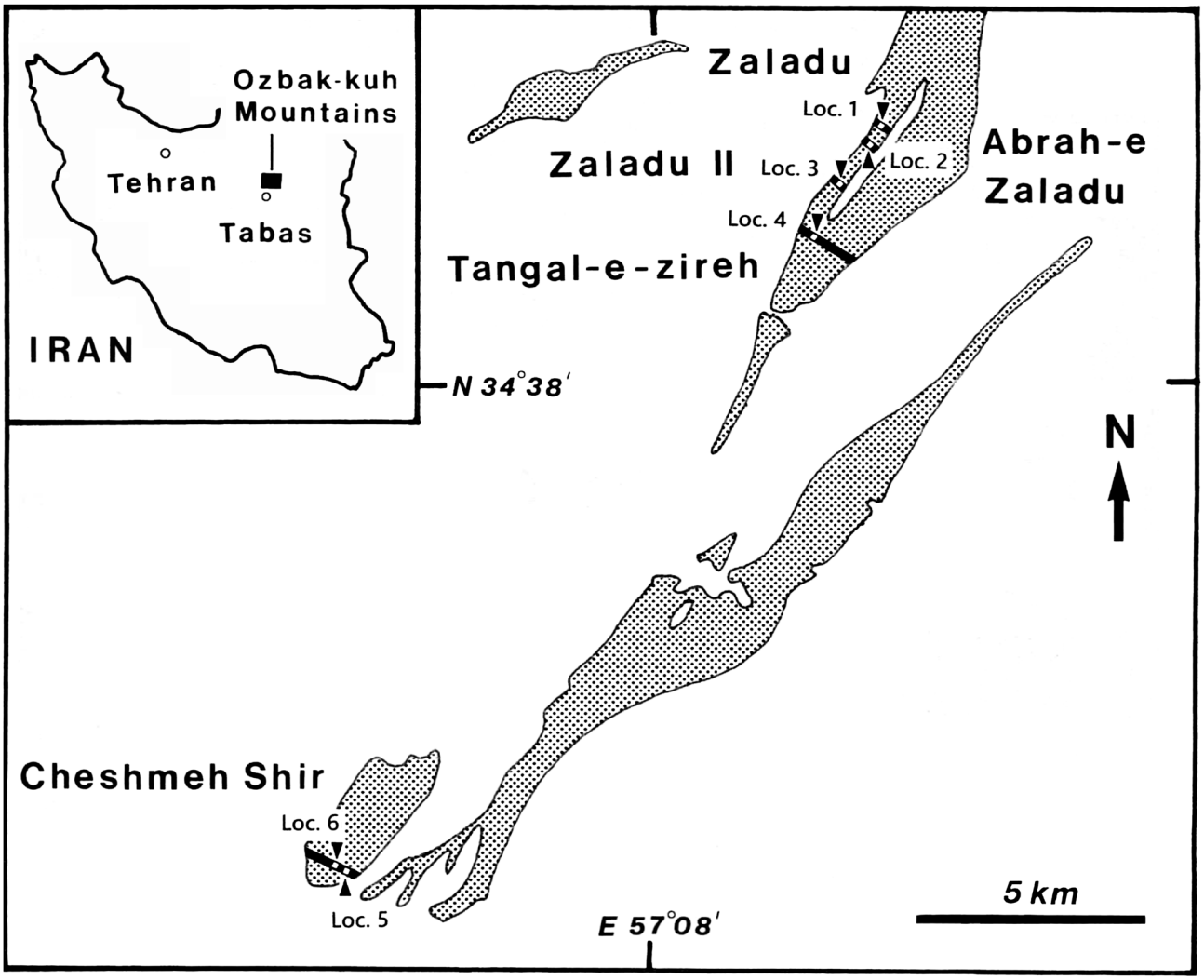


Fig. 1. Map showing distributions of the Sardar Formation in the Ozbak-kuh Mountains, East-Central Iran, with positions of the examined five stratigraphic sections and localities of the tabulate corals.

Iran and the neighboring area consist of multiple continental blocks (namely, Alborz, Central Iran, Farah, Helmand, North West Iran and Sanandaj-Sirjan) separated from each other by tectonic lines within the Cenozoic Alpine-Himalayan orogenic system (Gansser, 1981; Torsvik and Cocks, 2004). Of those, the Sardar Formation belongs to the Central Iranian Block that was situated in the northwestern margin of Gondwana (Peri-Gondwana) at the low latitudes of the southern hemisphere and faced the Paleo-Tethys Ocean during Serpukhovian to Moscovian (middle late Carboniferous) times (e.g., Stampfli, 2000; Arefifard, 2017).

Repositories: Except for the holotype of *Syringopora iranica* sp. nov. that is housed in the National Museum of Nature and Science, Tokyo, Japan, all examined specimens are housed in the paleontological collections at Ferdowsi University of Mashhad, Mashhad, Iran.

Systematic Paleontology

Subclass Tabulata Milne-Edwards and Haime, 1850

Order Favositida Wedekind, 1937

Suborder Favositina Wedekind, 1937

Superfamily Favositoidea Dana, 1846

Family Micheliniidae Waagen and Wentzel, 1886

Subfamily Micheliniinae Waagen and Wentzel, 1886

Genus ***Michelinia*** de Koninck, 1841

Type species: *Calamopora tenuiseptata* Phillips, 1836.

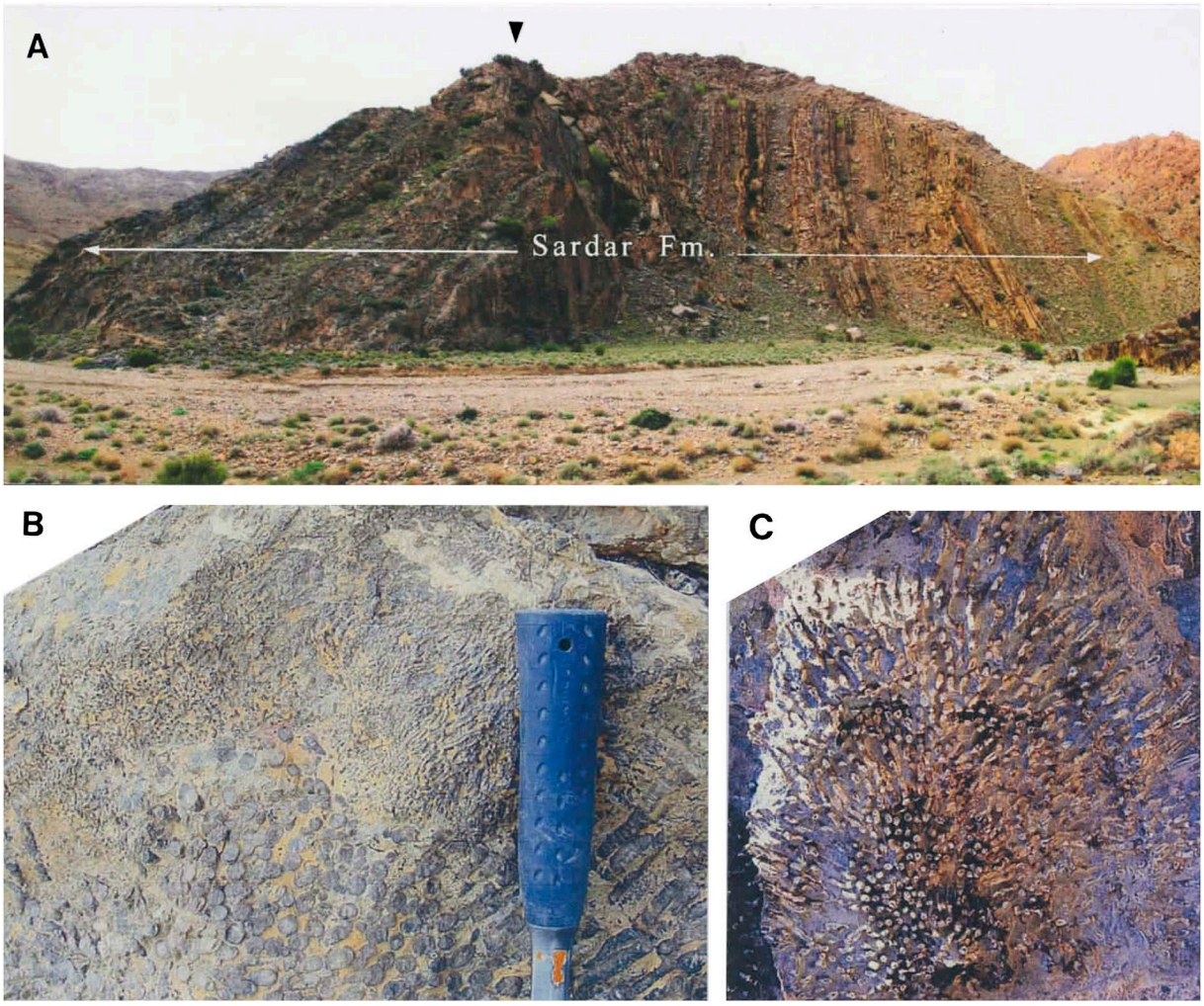


Fig. 2. Field photographs showing exposures of the Sardar Formation. **A**, the Abrah-e Zaladu Section at a hillside facing south, where the formation strikes N 30°E, dips nearly vertical, and becomes younger toward left. In this area, the formation is underlaid by the lower Visean shale belonging to the Shishtu Formation with the unconformable relationship and its upper end is in fault contact with the Devonian sandstone of the Padeha Formation (e.g., Stöcklin *et al.*, 1965). Arrow indicates horizon of the Bashkirian boundstone (loc. 2), from which tabulate coral material was taken. **B**, close-up picture of boundstone at loc. 3 in the Zaladu II Section. The present portion consists mainly of the rugose (*Fomichevella* and *Heintzella*; lower part) and tabulate (*Multithecopora*; upper one) corals. **C**, colony of *Multithecopora* sp. cf. *M. huanglungensis*. Diameter of this colony is approximately 110 mm.

Michelinia flugeli sp. nov.

(Figs. 3-A–H)

Michelinia sp., Badpa *et al.*, 2011b, p. 14.
Michelinia escobari Wilson, 1990; Badpa *et al.*, 2015a, p. 105.
Michelinia sp. 2, Badpa, 2015, pl. 43, figs. 1a, b, 2a, b, 3, pl. 44, figs. 1, 3a, b, 4a, b, 5a, b (not figs. 2a, b).

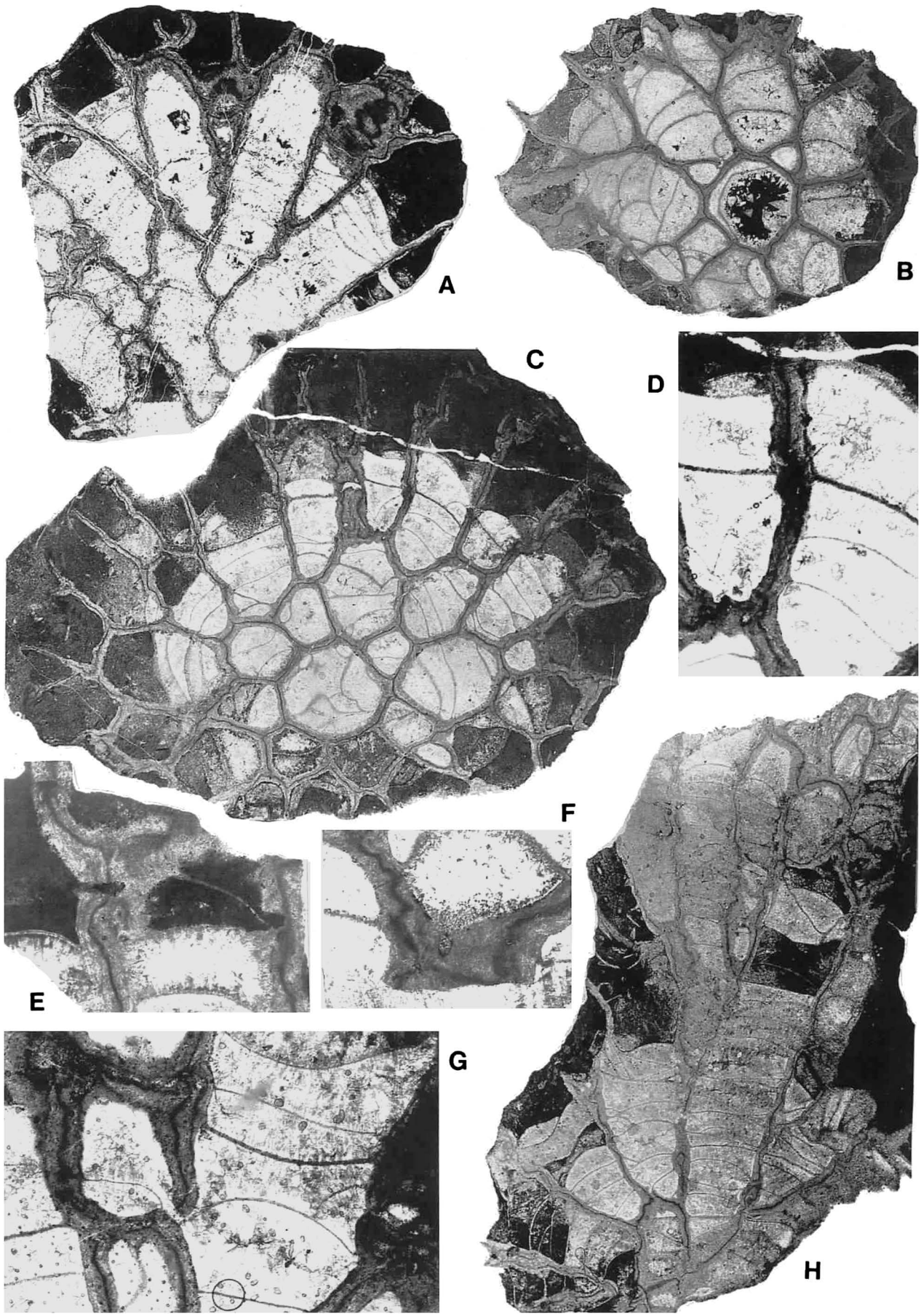
Material examined: Holotype, SDO11, from which two thin sections were prepared. Nine thin sections were studied from the five paratypes, SDO14, SDO15, SDO18, SDO19 and SDO20. In addition, a single corallum, C11, was also examined.

Occurrence: Localities 1 (C11) and 4 (SDO11, SDO14, SDO15, SDO18, SDO19, SDO20).

Age: Late Bashkirian.

Diagnosis: Species of *Michelinia* with small coralla indicating subspherical to longitudinally prolonged domical or columnar in growth form; diameter of coralla 12–25 mm; corallite small in diameter, 2.7 mm mean; intercorallite walls thin, usually 0.23–0.46 mm; septal spines sporadic; mural pores uncommon, occur angles and faces; most common tabulae complete and weakly up-arched.

Description: Coralla cerioid, small for the genus, somewhat variable in growth form, mostly subspherical to longitudinally prolonged domical, but


A
B
C
D
E
F
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H

columnar corallum also recognized; diameters of coralla are 12–25 mm; no holotheca preserved. Corallites prismatic with 3 to indistinct 10 sides in transverse section and divergently arranged; corallite diameters small for the genus, range from 0.6 to 4.0 mm; mean diameter in the holotype is 2.7 mm; increase of new corallite is rare, possibly intermural; tabularia wide, subpolygonal in transverse section; depths of calical pits are variable, ranging shallow to moderately deep. Intercorallite walls are thin for the genus, usually 0.23–0.46 mm and structurally differentiated into weakly sinuated median dark line and stereoplasm; microstructure of stereoplasm is lamellar; mural pores uncommon, circular in profile, occur at corners as corner pores and on faces of corallites as mid-wall pores; corner pores developed between immature and mature corallites; diameters of mural pores are somewhat variable, ranging from 0.10 to 0.17 mm; septal spines sporadic, low conical having 0.04–0.06 mm in length of their protruded portions into tabularium; tabulae well-developed; complete and weakly up-arched tabulae are most common, but incomplete ones indicating vesicular forms are not rare; there are 5–12 tabulae in 5 mm of corallite length; some tabulae faintly thickened.

Etymology: The specific name honors the late Dr. H. W. Flügel, in recognition of his contributions to the study of the Iranian coral faunas.

Discussion: In its gross corallum shape and corallite diameter, *Michelinia flugeli* sp. nov. is most similar to *M. japonica* Niko (2002, pp. 26, 30, figs. 1–4, 5; 2-1–3; 3-1–6), which is reported from the Serpukhovian to Bashkirian rocks in the allochthonous limestone bodies of southwest Japan, including the Hina Limestone (type locality; Niko, 2002), the Akiyoshi Limestone (Niko and Haikawa, 2009), and the Omi Limestone (Niko *et al.*, 2011). These limestones were formed as the Akiyoshi seamount chain in the equatorial region of the Panthalassic Ocean (e.g., Kanmera *et al.*, 1988; Ross and Ross, 1990). The principal difference between the two species is corallite wall thickness, i.e., intercorallite walls of *M. flugeli* are thin, usually 0.23–0.46 mm, whereas *M. japonica* has thickened walls reaching 1.09 mm in thickness. In addition, a smaller number of spins of *M. flugeli* than those of *M. japonica* also serves differentiate these two species. The new species somewhat resembles *M. crassapina* Webb (1990, pp. 115, 116, figs. 67-A–E) from the upper Visean carbonate intervals of the Rockhampton Group in Queensland, Australia, eastern Gondwana and *M. salebrosa* Chu (1933, p. 6, pl. 1, figs. 6–8) from the lower Carboniferous Kinling Limestone, South China, but coralla of the former species give rise to branches and the latter one has approximate corallite diameters of 5–6 mm and very prominent septal spines.

We reject the previous assignment of the present material by Badpa *et al.* (2015a) to *Michelinia escobari* Wilson (1990, pp. 72, 74, figs. 10.7, 11.1–11.3) from the Lower Permian of Bolivia. The natures of corallite walls and tabulae of the Permian species suggest that it should be removed from *Michelinia* and placed instead in *Protomichelinia* Yabe and Hayasaka, 1915.

Michelinia sp. indet.

(Figs. 4-A–C)

Michelinia sp. 2, Badpa, 2015, pl. 44, figs. 2a, b (not pl. 43, figs. 1a, b, 2a, b, 3, pl. 44, figs. 1, 3a, b, 4a, b, 5a, b).

Material examined: CH3.

Occurrence: Locality 6.

Age: Late Bashkirian.

Description: A small fragment of cerioidal corallum is available for study. Corallites are prismatic, large at least approximately 9 mm in diameter. Intercorallite walls are approximately 0.4–1.1 mm in thickness; corner and mid-wall pores commonly occur; diameters of mural pores are 0.01–0.38 mm; septal spines common, conical, 0.06–0.15 mm in length of protrude portions into tabularium; tabulae well-developed, incomplete; some tabulae thick-

Fig. 3. *Michelinia flugeli* sp. nov., thin sections. **A**, paratype, SDO19, longitudinal section of corallum, ×5. **B**, paratype, SDO15, transverse section of corallum, ×5. **C**, **D**, **G**, holotype, SDO11. **C**, transverse section of corallum, ×5. **D**, partial enlargement to show details of intercorallite wall structure and septal spines, ×14. **G**, oblique sections of corallites, note corner pore, ×14. **E**, **F**, paratype, SDO14. **E**, longitudinal sections of corallites, note mid-wall pores, ×14. **F**, oblique sections of corallites, note mid-wall pore, ×14. **H**, paratype, SDO20, longitudinal section of corallum, ×5.

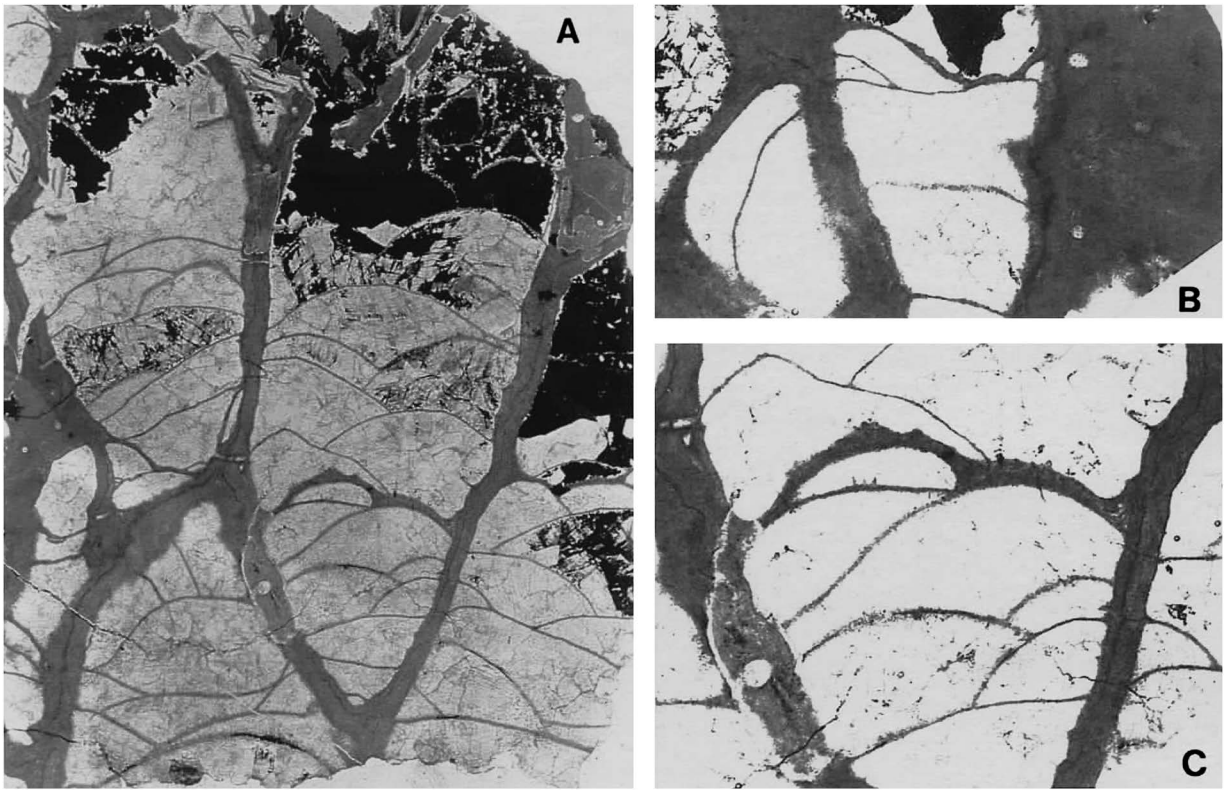

Fig. 4. *Michelinia* sp. indet., CH3, thin sections. **A**, oblique sections of corallites, ×5. **B**, partial enlargement to show details of tabulae and mural pores, ×10. **C**, partial enlargement to show details of intercorallite wall structure, tabulae, septal spines, and spine-like saliences on tabulae, ×10.

ened, where spine-like saliences developed on their upper surface.

Discussion: Large corallite diameters and the lacking of complete tabulae of this species easily distinguish it from a co-occurring species, *Michelinia flugeli* sp. nov. (this report). Fragmentary nature of the present material precludes confident comparisons with the previously known Carboniferous species of *Michelinia*.

Family Cleistoporidae Easton, 1944

Genus ***Donetzites*** Dampel, 1940

Type species: *Donetzites milleporoides* Dampel, 1940.

Donetzites mariae Flügel, 1975

(Figs. 5-A–D)

Donetzites mariae Flügel, 1975, pp. 47–49, pl. 1, figs. 1, 2; 1995, p. 38; Badpa, 2015, pl. 50, figs. a–e.

Material: ACH1.

Occurrence: Locality 5. The holotype of *Donetzites mariae* was recovered from the upper Serpukhovian limestone at the same section (Flügel, 1995).

Age: Late Serpukhovian.

Description: Corallum cerioid, massive, 30 mm in maximum observable diameter and 22 mm in maximum observable height. Corallites subprismatic with 3–6 sided to subcircular transverse sections and divergently arranged; diameters of corallites defined by postulated intermediate plane of walls are large for the genus, 1.6–4.6 mm with 4.0 mm mean; tabularia circular to subpolygonal in transverse section; no calice preserved. Intercorallite walls highly variable in thickness, ranging from 0.08 to 1.83 mm; wall structure not preserved; thickened portions of walls pierced by numerous vermiform tunnels and exhibit spongy appearance; diameters of tunnels are 0.13–0.46 mm; septal spine probably absent; tabulae sparse, complete; there are 1–3 tabulae (tabula) in corallite length of 5 mm.

Discussion: The present specimen differs in no significant respects from the holotype of *Donetzites mariae* Flügel, 1975. Furthermore, its large corallite diameters are very distinct from most of the *Donetz-*

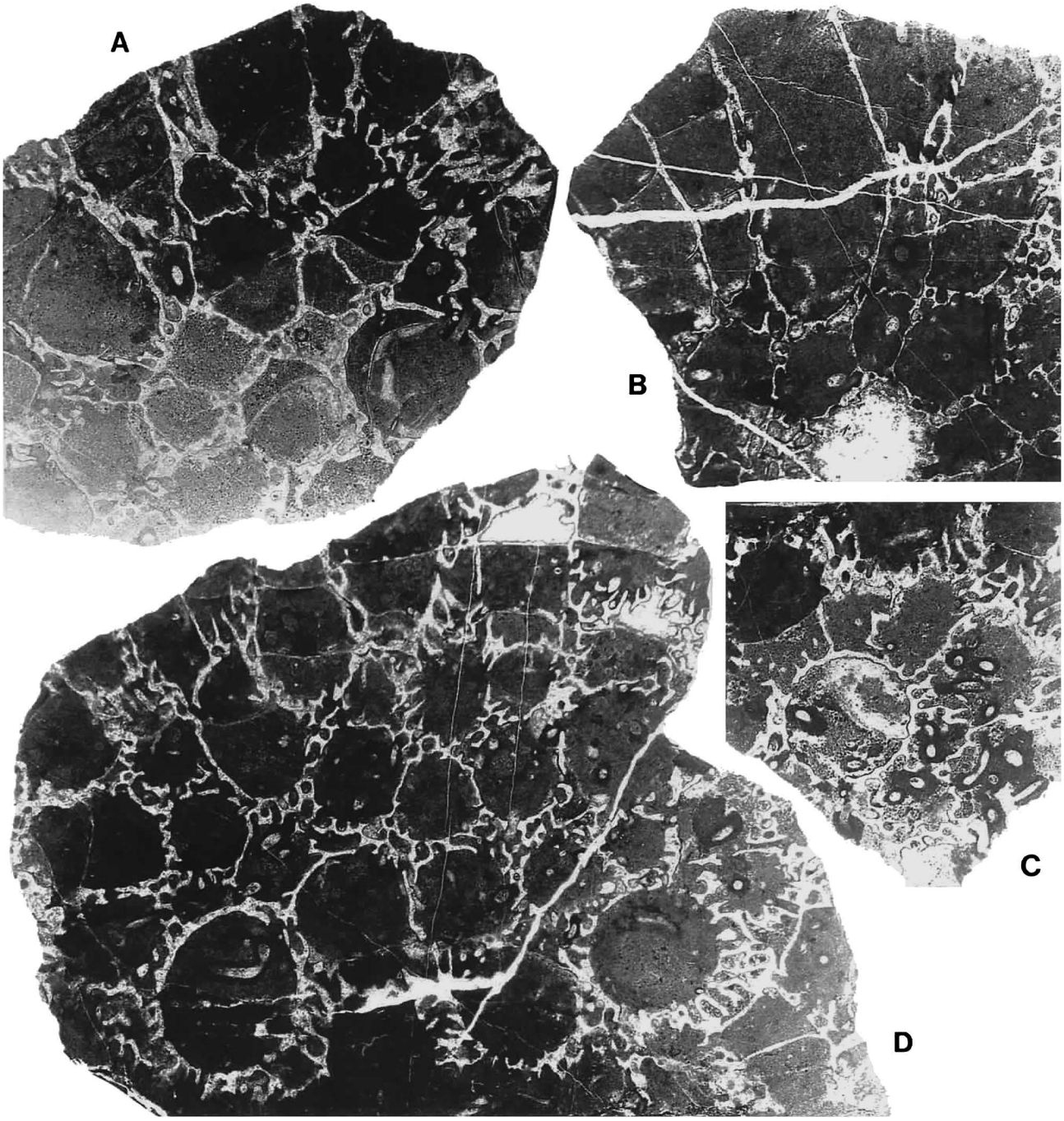

Fig. 5. *Donetzites mariae* Flügel, 1975, ACH1, thin sections. **A**–**D**, transverse to oblique sections to corallum, ×5.

ites species. Only *D. vermiculatus* Niko (1999, pp. 35, 37, figs. 5-1–4) from the upper Visean to lower Bashkirian part of the Hina Limestone has corallite sizes similar to those of *D. mariae*. This Japanese species, however, exhibits closer spacing of tabulae, i.e. 6–8 tabulae in corallite length 5 mm.

Order Auloporida Sokolov, 1947

Superfamily Syringoporoidea de Fromentel, 1861

Family Syringoporidae de Fromentel, 1861

Genus ***Syringopora*** Goldfuss, 1826

Type species: *Syringopora ramulosa* Goldfuss, 1826.

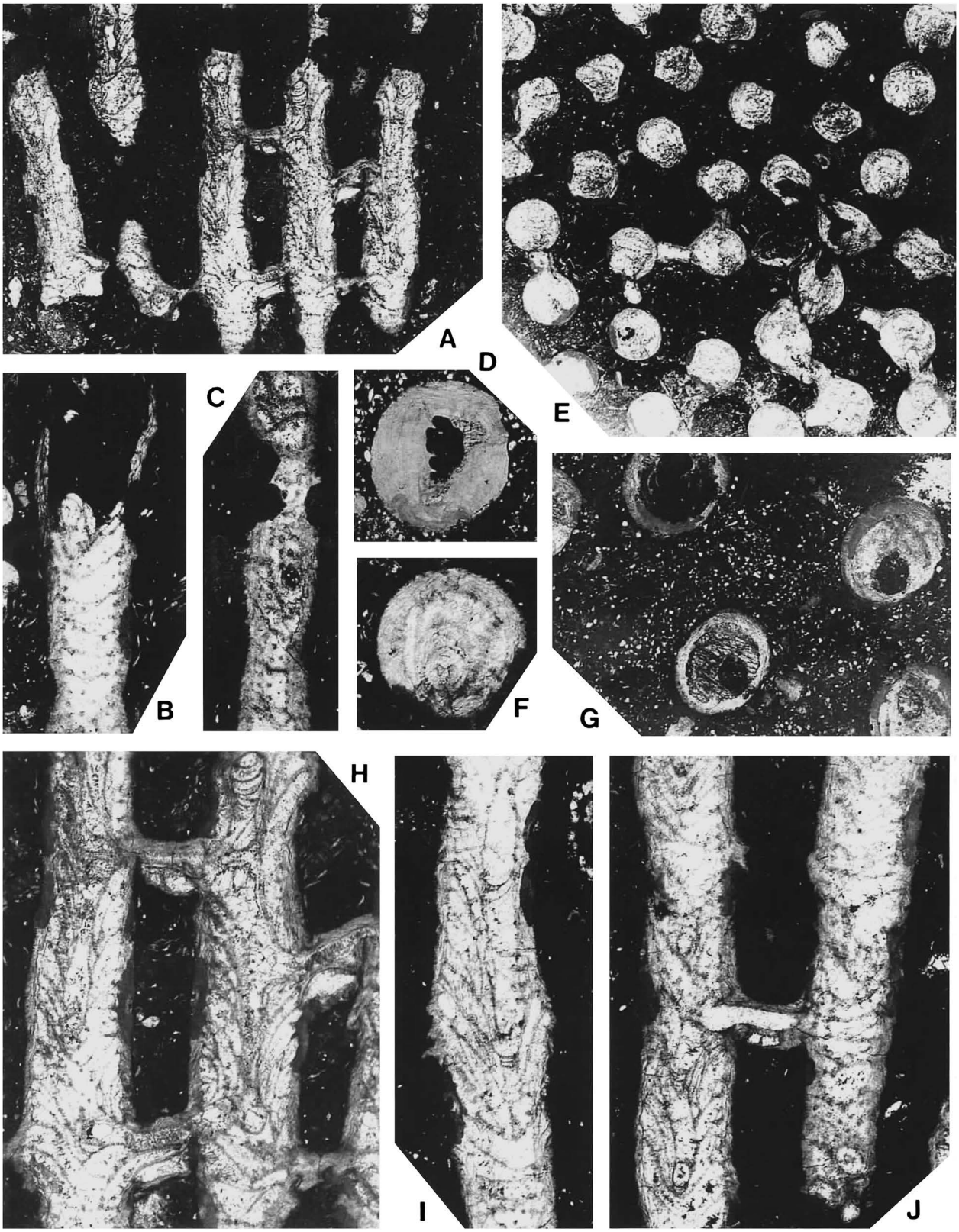

Fig. 6. *Syringopora iranica* sp. nov., holotype, NMNS PA19901, thin sections. **A**, longitudinal sections of corallites, ×5. **B**, longitudinal section of corallite, showing details of calice, ×10. **C**, longitudinal section of corallite, note rows of septal spines, ×10. **D**, transverse section of corallite near calice, note spine-like saliences on tabulae. **E**, transverse sections of corallites, ×14. **F**, transverse section of corallite, ×14. **G**, transverse sections of corallites, ×10. **H**, longitudinal sections of corallites, note lower bulge-like inflations of connecting tubuli and septal spines, ×10. **I**, longitudinal section of corallite, note scaly epitheca and axial tabulae, ×10. **J**, longitudinal sections of corallites, note lower bulge-like inflation of connecting tubule, ×10.

Syringopora iranica sp. nov.

(Figs. 6-A–J)

Material examined: Holotype, NMNS PA19901, from which 11 thin sections were prepared.

Occurrence: Locality 3.

Age: Late Serpukhovian.

Diagnosis: A species of *Syringopora* with approximately 0.8 mm in corallite diameter; usually 2.2–3.6 mm in corallite distance (center-to-center) and well-developed connecting tubuli that tend to occur at same level; some tubuli become enlarged by lower bulge-like inflation; septal spines numerous; granular to spine-like saliences developed on tabulae; axial syrinxes relatively large, 0.4–0.8 mm in diameter.

Description: A single phaceloid corallum is available for study; it has domical growth form with 158 mm in maximum observed diameter and 70 mm in maximum observed height. Corallites cylindrical, 1.4–2.0 mm with 1.8 mm mean in diameter; spacing of corallites is relatively close, usually 2.2–3.6 mm in distance (center-to-center) between corallites; scaly epitheca partly preserved; increase of new corallite rare, probably lateral; connecting tubuli well-developed, have a tendency to occur at same level, and 0.7–1.5 mm in length; most common diameters of connecting tubuli are 0.5–0.9 mm, but some tubuli become enlarged by lower bulge-like inflation, where their diameters attain 1.6 mm; tabularia wide, circular in cross section; calices faintly inflated; calical pits relatively shallow. Corallite walls 0.31–0.42 mm in thickness, and differentiated into epitheca and stereoplasm, the latter of which indicates micro-lamellar stricture; septal spines numerous, long rod-like to relatively long conical or rarely short conical, 0.06–0.28 mm in length of protruded portion into tabularium; tabulae numerous, incomplete, exhibit infundibuliform or uparched dissepiment-like forms; there are 16–21 tabulae of 5 mm of corallite length; granular to spine-like saliences frequently developed on tabulae; crowded tabulae form relatively large axial syrinxes at central to rarely marginal position of corallites; transverse sections of syrinxes are subcircular, elliptical to subtrapezoidal; diameters of syrinxes are 0.4–0.8 mm; ratios of syrinx diameter per corresponding corallite diameter are approximately 0.4; sagging axial tabulae in syrinx well-developed; diaphragms in connecting tubule rarely recognized.

Etymology: The specific name derives from Iran.

Discussion: *Syringopora iranica* sp. nov. is well differentiated from other species assigned to the genus by its lower bulge-like inflation on some tubuli. Except for the character, the diagnosis of the new species is similar to those of such lower Carboniferous species as *S. ramulosa* Goldfuss (1826, p. 76. pl. 25, figs. 7a, b) with wide distribution including Germany (Goldfuss, 1826), southern Grate Britain (Milne-Edwards and Haime, 1852), the Moscow Basin, Russia (Sokolov, 1955), Poland (Nowiński, 1976) and Anhui, Guangxi, Guizhou, Hunan, Jiangsu and Yunnan in South China (Chi, 1933) and *S. weiningensis* King (1974, pp. 237, 238, pl. 152, figs. 2a, b, 3a, b) from Yunnan, South China.

Family Multithecoporidae Sokolov, 1950

Genus ***Multithecopora*** Yoh, 1927

Type species: *Multithecopora penchiensis* Yoh, 1927.

Multithecopora sp. cf. ***M. huanglungensis*** Lee and Chu *in* Lee *et al.*, 1930

(Figs. 2-C, 7-A–G)

Multithecopora sp., Badpa *et al.*, 2009, pl. 1, figs. 7a, b; 2011b, p. 14; 2015a; p. 105.

Multithecopora hypatiae Wilson, 1963; Badpa *et al.*, 2015a, p. 105.

Multithecopora sp. 1, Badpa, 2015, pl. 45, figs. 1–3,

Compare with:

Multithecopora huanglungensis Lee and Chu *in* Lee *et al.*, 1930, pp. 140, 141, pl. 15, figs. 1–3.

Material examined: ACH2, ACH3, ACH4, ACH5, SAH6, SAH7, SAH29, SAH30, SAH31, SDO9, SDO10, SDO12, SZA21, SZB4.

Occurrence: Localities 2 (SAH6, SAH7, SAH29, SAH30, SAH31), 3 (SZA21, SZB4), 4 (SDO9, SDO10, SDO12), and 5 (ACH2, ACH3, ACH4, ACH5).

Age: Late Serpukhovian to late Bashkirian.

Description: Coralla subglobose in growth form, mostly phaceloid, attaining 124 mm in maximum observed diameter and 54 mm in in maximum observed height. Corallites cylindrical to rarely subcylindrical with hemi-circular transverse sections by

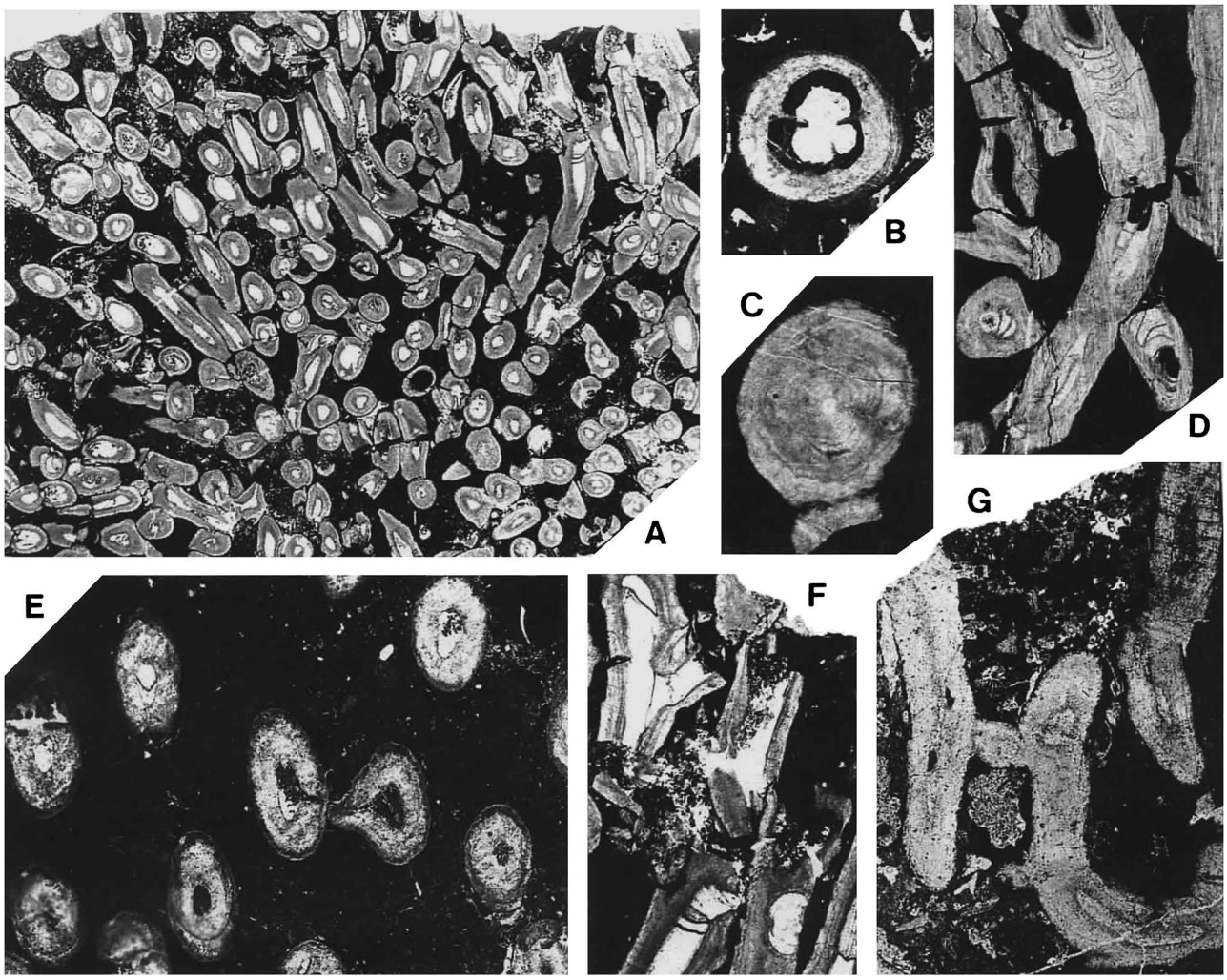

Fig. 7. *Multithecopora* sp. cf. *M. huanglungensis* Lee and Chu *in* Lee *et al.*, 1930, thin sections. **A**, **F**, SAH7. **A**, oblique section of corallum, ×2. **F**, partial enlargement to show details of longitudinal sections of corallites, bifurcate branching, and tabulae, ×5. **B**, ACH3, transverse section of corallite, note septal spines, ×10. **C**, SAH29, transverse section of corallite, note almost closed tabularium (lumen), ×10. **D**, SAH6, longitudinal, oblique and transverse sections of corallites, note compete and incomplete tabulae, ×5. **E**, SDO9, oblique sections of corallites, note connecting tubule, ×5. **G**, ACH4, longitudinal sections of corallites, note connecting tubule, ×5.

partial adhesion; diameters of corallites are 1.4–2.7 mm with 2.1 mm mean; spacing of corallites is variable, close to relatively wide; usually 1.3–5.0 mm in distance (center-to-center) between corallites; increase of new corallite rare, lateral; connecting tubuli rare, have 0.7–1.3 mm in diameter and 0.5–1.7 mm in length; calices cylindrical, deep. Corallite walls thickened to strongly thickened, ranging from 0.27 to 0.86 mm, thus tabularia (lumina) narrowed to almost closed; constituents of walls are epitheca and stereoplasm; structure of stereoplasm differentiated into inner layer consisting of rectradiate fivers and outer micro-lamellar one; septal spine mostly absent, but long needle-like spines are recognized as exceptional cases; lengths of protrude parts of spines are 0.23–0.38 mm; spacing of tabulae variable ranging from nearly absent to crowded; complete and sagging tabulae are most common, but incomplete ones are not rare; incomplete tabulae indicate vesicular-like or infundibuliform; there are 0–6 tabulae (tabula) in corallite length of 2 mm.

Discussion: The most diagnostic characters of the Iranian species are identical with those of *Multithecopora huanglungensis* Lee and Chu *in* Lee *et al.*, 1930, from the middle Carboniferous Huanglung Limestone developed on the South China Continent. The strict specific identification is pending here because the present specimens have slightly larger corallite diameter, 1.4–2.7 mm with 2.1 mm mean, than 1.5–2.0 mm in the holotype of *M. huanglungensis*. In addition, the present specimens bear some long needle-like spines, whereas no spines are rec-

ognized in the latter. Although its morphology was not described, *Multithecopora* sp. listed in Flügel (1995, p. 38) from the Sardar Formation may be the same species with the present *Multithecopora* sp. cf. *M. huanglungensis*.

We reject the previous assignment of the present material to *Multithecopora hypatiae* Wilson (1963, pp. 158–160, pl. 21, figs. 1–5, 7–9, pl. 22, figs. 1–7), from the Middle Pennsylvanian (upper Carboniferous) of Nevada, North America, by Badpa *et al.* (2015a). The most diagnostic feature of the species is the possession of well-developed reptant corallites in their early growth stages, which is not recognized in the Iranian material.

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