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Middle Devonian favositine corals from the Naidaijin Formation, Kumamoto Prefecture, Southwest Japan

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Abstract As the first fascicle in a serial paper concerning tabulate coral assemblage of the Naidaijin Formation in Kumamoto Prefecture, Kyushu Island, Southwest Japan, the present study describes favositines including three favositoids, *Klaamannipora densitabulata* sp. nov., *Pseudofavosites asoensis* sp. nov. and *Sparsisolenia*? sp. indet., and five pachyporoids, *Gracilopora delicata* sp. nov., *Hillaepora* sp. indet., *Parastriatopora* sp. indet., *Thamnopora miyamotoi* sp. nov. and *Thamnoptychia tanimotoi* sp. nov. Judging from a close relationship between *T. miyamotoi* and an index coral, *T. nicholsoni*, the fauna is Givetian (late Middle Devonian) in age. This is the first full description of the Devonian tabulate corals from the Kurosegawa Belt.

Key words: Givetian, Kurosegawa Belt, Favositoidea, Pachyporoidea, Tabulata

Introduction

Previous studies concerning the Middle Paleozoic tabulate corals from the Kurosegawa Belt in Southwest Japan were restricted exclusively to Silurian taxa (e.g., Kobayashi and Iwaya, 1940; Sugiyama, 1944; Hamada, 1956, 1958; Noda, 1960; Nakai, 1981), because the Devonian is mostly represented by clastic rocks and barren of coral fossils, whereas the Silurian reef limestones are dominant throughout the belt. Thus, the discovery of the diversified Devonian fauna containing corals, stromatoporoids and trilobites from the Naidaijin Formation in the Mt. Tenshu-zan area of Yamato-cho, Kumamoto Prefecture, Kyushu Island by Murata *et al.* (1997) was surprising to note. Since this discovery the following tabulate corals have been recorded from the formation: *Favosites* sp. and *Heliolites* sp. (Murata, *et al.*, 1997), *Halysites* sp. (debatable; possibly error of *Heliolites*) and *Favosites* sp. (Tomooka *et al.*, 2005), and *Heliolites* spp., *Favosites* sp., Pachyporidae [Pachypolidae; sic] gen. et sp. indet. and *Alveolites* sp. (Kido, 2008; Kido *et al.*, 2008a, b); however, they were neither illustrated nor described until now. The present study focuses on favositines in a serial paper that plans to reveal the entire specific composition of the highly diversified (including alveolitines, heliolitids and auloporids except for the suborder) and well-preserved Naidaijin tabulate coral assemblage. This is the first full description of the Devonian tabulate corals from the Kurosegawa Belt.

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Geologic setting, Occurrence and Age

The Naidaijin Formation, 170–300 m in thickness, crops out as an east-west trending narrow zone (ca. 8 km length, 0.6 km width) in an area ranging from the southwestern region of Yamato-cho to southeastern region of Misato-machi. It is composed mainly of mudstone with interbedded sandstone, conglomerate and lenticular limestone (Tanimoto and Miyamoto, 1986; Miyamoto and Tanimoto, 1993; Kuwazuru *et al.*, 2004; Saito *et al.*, 2005; Tomooka *et al.*, 2005). Kimura *et al.* (1986) first showed that the upper member of the formation can be assigned to the Upper Devonian based on the occurrence of terrestrial plants, such as *Cyclostigma* sp., *Leptophloeum rhombicum*, and *Aphyllopteris*? sp. A similar result was reported by Yanagida *et al.* (1987), who examined an associated brachiopod *Cyrtospirifer* with these plant fossils. In contrast, the lower member could not be dated until Murata *et al.* (1997) noted the above. They concluded in the

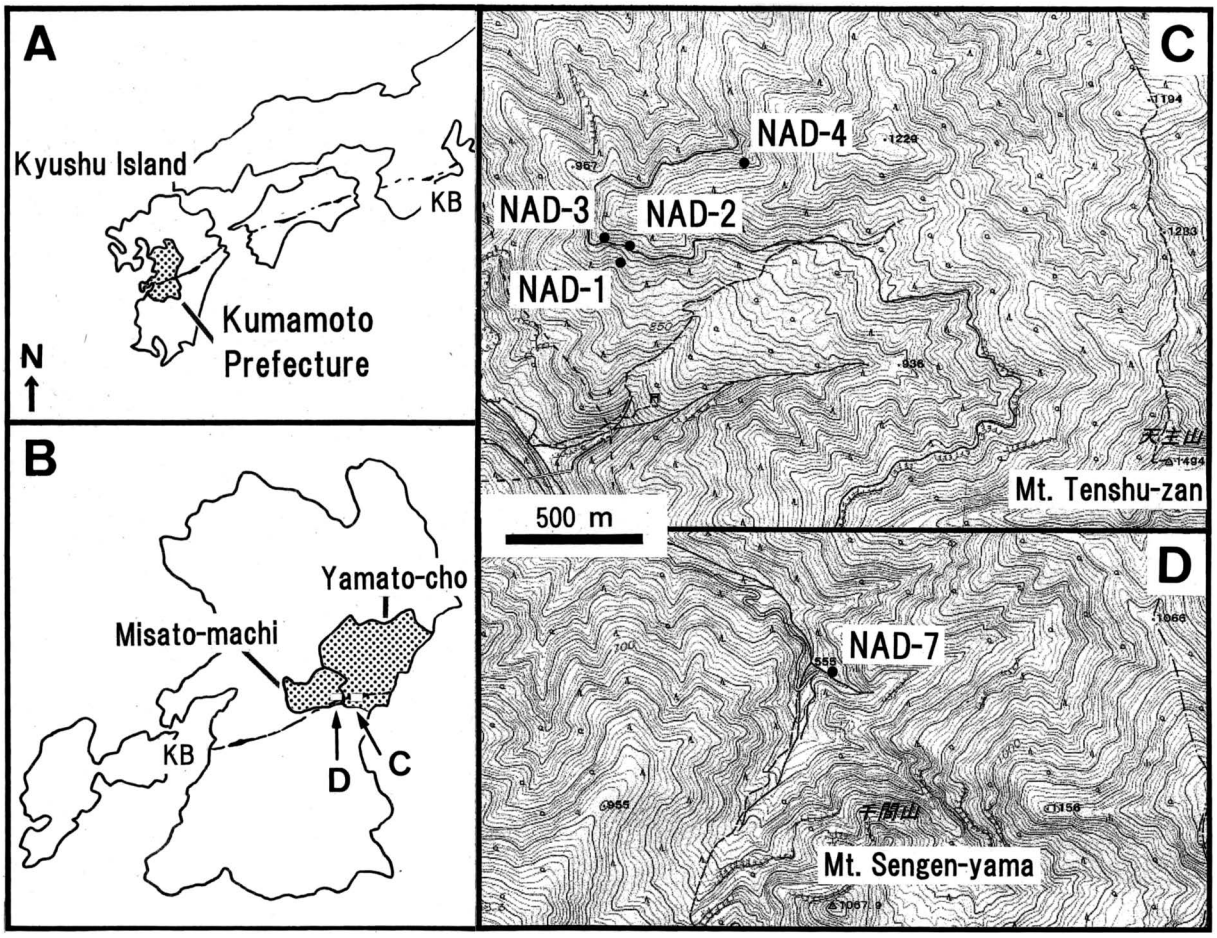

Fig. 1. Maps showing locations of Kyushu Island, Kumamoto Prefecture and the Kurosegawa Belt (BT) in Southwest Japan (**A**), Yamato-cho, Misato-machi, the Kurosegawa Belt, the Mt. Tenshu-zan area (C) and the Mt. Sengen-yama area (D) in Kumamoto Prefecture (**B**), fossil localities (NAD-1–4) in the Tenshu-zan area (**C**), and fossil locality (NAD-7) in the Sengen-yama area (**D**). Used base map is "Digital Japan Basic Map" published by Geospatial Information Authority of Japan.

preliminary report that the trilobite assemblage, including *Taxophacops nonakai* and *Kobayashipeltis paucispinosa*, ranges down to the Emsian (upper Lower Devonian). An alternative approach using rugose corals by Kido (2008) suggests the member contains a part correlative with the Givetian (upper Middle Devonian) because of the presence of *Tabulophyllum*. Recently, Stocker *et al.* (2018) described a newly discovered trilobite and found detrital zircons yielding an age of 383 ± 4.4 Ma, and concluded that "this radiometric age would indicate a likely Givetian age, but given the 4.4 million-year uncertainty, this could also be as young as earliest Frasnian and therefore Late Devonian". Stratigraphically, the zircon-bearing horizon is 2 m above their trilobite locality.

The present tabulate corals occur from limestones and calcareous mudstones at five localities (Fig. 1) belonging to the lower member of the Naidaijin Formation, namely NAD-1 (32° 36′ 22.0″ N, 131° 0′ 29.6″ E; = "lower lenticular limestone" in Murata *et al.*, 1997; loc. 1 in Tomooka *et al.*, 2005), NAD-2 (32° 36′ 23.1″ N, 131° 0′ 29.3″ E; = "upper lenticular limestone" in Murata *et al.*, 1997; loc. 2 in Tomooka *et al.*, 2005; loc. 1, occurring a rugose coral *Tabulophyllum*, in Kido, 2008; trilobite locality in Stocker *et al.*, 2018), NAD-3 (32° 36′ 23.5″ N, 131° 0′ 27.3″ E), and NAD-4 (32° 36′ 23.5″ N, 131° 0′ 27.3″ E; = loc. 3 in Tomooka *et al.*, 2005; loc. 5 in Kido, 2008) in the Mt. Tenshu-zan area of Yamato-cho, while NAD-7 (32° 36′ 26.7″ N, 130° 57′ 7.9″ E; = locality of coral fossils in Saito *et al.*, 2005) in the Mt. Sengen-yama area of Misato-machi. The stratigraphic horizons of localities NAD-2 and NAD-3 are approximately 25 m and 30 m above that of locality NAD-1, respectively. Direct relationships between these contiguous horizons and locality NAD-4 are uncertain. Limestone

intercalated with thin calcareous mudstone beds of locality NAD-7 conformably overlies felsic tuff of the Gionyama Formation and represents the basal portion of the formation. Accurate stratigraphic distance of localities NAD-1 and NAD-7 is unknown, but their horizons are most likely in close proximity judging from the presence of common species (see below) between the both localities.

Identified species herein are as follows: *Klaamannipora densitabulata* sp. nov. (locality NAD-4), *Pseudofavosites asoensis* sp. nov. (locality NAD-2), *Sparsisolenia*? sp. indet. (locality NAD-2), *Gracilopora delicata* sp. nov. (locality NAD-1), *Hillaepora* sp. indet. (locality NAD-1), *Thamnopora miyamotoi* sp. nov. (localities NAD-1, NAD-3, NAD-4 and NAD-7), *Thamnoptychia tanimotoi* sp. nov. (localities NAD-1 and NAD-4) and, *Parastriatopora* sp. indet. (locality NAD-4). Among them, *Thamnopora miyamotoi* is the most effective for the determination of precise age. Its closely related species, *T. nicholsoni* (Frech, 1885), is a typical index tabulate coral and exclusively limited to the Givetian in the previously known occurrences, as indicated in the following discussion of the new species. The present discoveries of *T. miyamotoi* from localities NAD-1, NAD-3, NAD-4 and NAD-7 indicate that a part of the lower member including the base is correlative with the Givetian. This result is not inconsistent with those based on rugose coral (Kido, 2008) and detrital zircons (Stocker *et al.*, 2018), however there exists an inconsistency with the age given by Murata *et al.* (1997) using trilobites.

Systematic paleontology

Order Favositida Wedekind, 1937
Suborder Favositina Wedekind, 1937
Superfamily Favositoidea Dana, 1846
Family Favositidae Dana, 1846
Subfamily Favositinae Dana, 1846
Genus ***Klaamannipora*** Mironova, 1974

Type species: *Favosites coreaniformis* Sokolov, 1952.

Discussion: Mōtus and Hints (2007) reassigned the type species of the genus to *Parastriatopora* Sokolov, 1949. However, the lack of the peripheral stereozone consisting of contiguous septal spines clearly excludes the species from *Parastriatopora*.

Klaamannipora densitabulata sp. nov.

Figs. 2-A–F

Material examined: Holotype, NMNS PA20404, from which nine thin sections were prepared.

Occurrence: Gray limestone at locality NAD-4.

Diagnosis: Species of *Klaamannipora* with large corallite diameters at peripheral zone of corallum, 3.5 mm in mean; thickness of intercorallite walls 0.04–0.33 mm; both mid-wall and angle pores developed; septal spines rare, short; spacing of tabulae very close at distal part of peripheral zone.

Description: An imperfect corallum is available for study; it is subcylindrical, 128 mm in preserved length, 71 mm in maximum preserved diameter, and cerioid. Corallites prismatic, 4–9 sided and run parallel with corallum axis in axial zone of corallum, then they bent outwardly to form peripheral zone; diameters of corallites are mostly large for the genus, 0.7–3.8 mm (rarely attaining 4.5 mm) with 3.5 mm mean in peripheral zone; ratios of diameter of axial zone per corallum diameter are approximately 0.3–0.4; calices open at nearly right angles for corallum surface; calical pits shallow; transverse sections of lumina are polygonal; lateral increases of new corallites rarely occur in axial zone and proximal part of peripheral zone. Intercorallite walls thin, 0.04–0.23 mm in axial zone and slightly thickened in peripheral zone reaching 0.33 mm; wall structure usually not preserved, but in well-preserved part it probably differentiated into median dark line and stereoplasm; microstructure of stereoplasm unknown; mural pores developed on corallite faces as mid-wall pores and at corallite angles as angle pores; mid-wall pores most common; diameters of pores are variable ranging from small to relatively large, indicating 0.09 to 0.35 mm; septal spines rare, short conical with 0.13–0.21 mm in length; tabulae mostly complete, roughly perpendicular to walls in their directions; spacing of tabulae is moderate in axial zone and proximal part of peripheral zone, where there are 3–5 tabulae in corallite length of 5 mm, then it becomes very close in distal part of peripheral zone; numbers of tabulae in 5 mm of corallite length attain 12.

Etymology: The specific name is derived from the

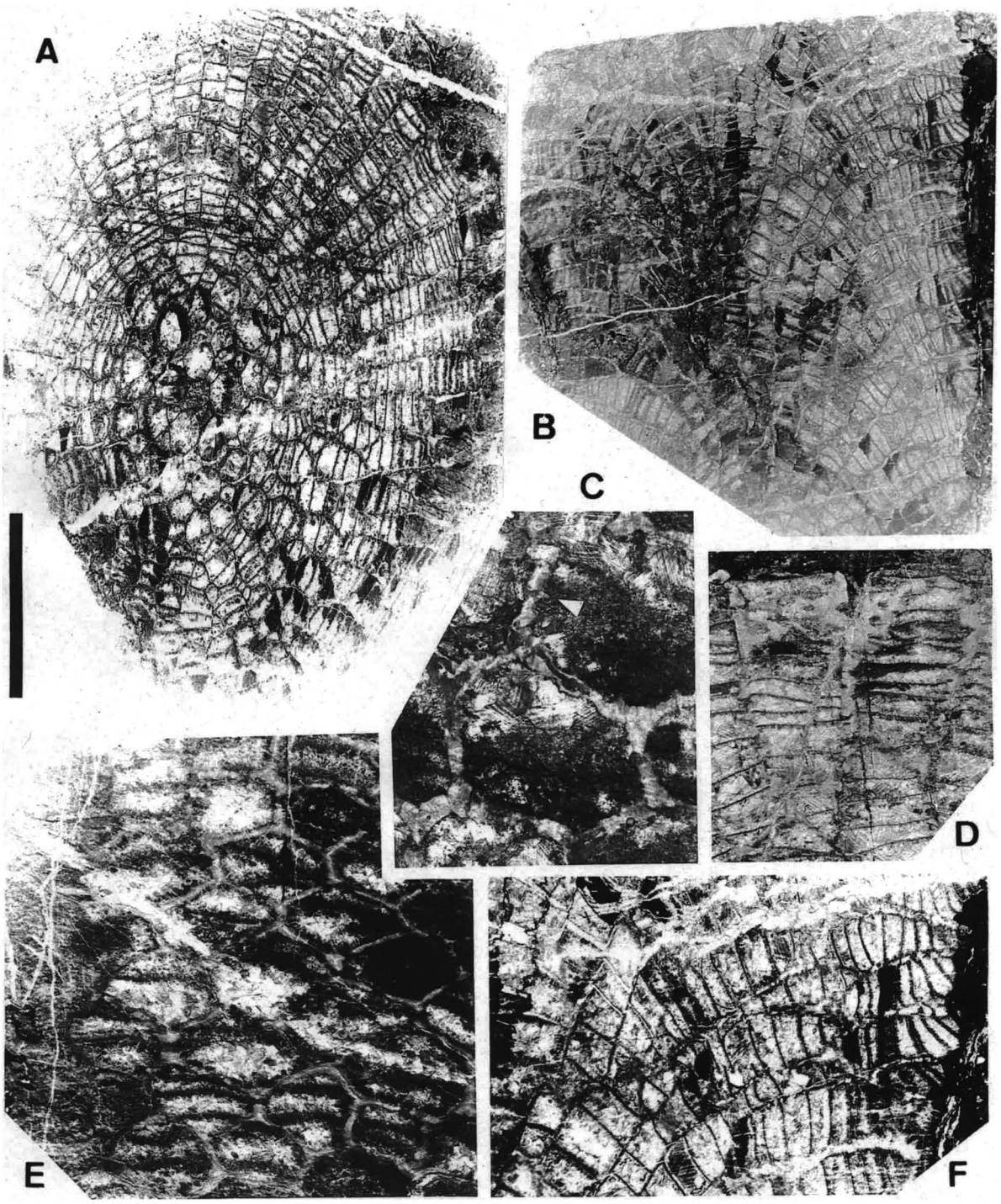

Fig. 2. *Klaamannipora densitabulata* sp. nov., holotype, NMNS PA20404, thin sections. **A**, transverse section of corallum, B, longitudinal section of corallum, **C**, transverse sections of distal corallites, arrow indicates septal spine, **D**, longitudinal sections of distal corallites, **E**, transverse sections of distal corallites, **F**, partial enlargement of B to show longitudinal sections of corallites. Scale bar: 15 mm in A, B; 2.5 mm in C; 6 mm in D, E, F.

Latin *densus*, meaning crowded, and *tabula*, in reference to its close spacing of tabula in its distal part of the peripheral zone.

Discussion: *Klaamannipora densitabulata* sp. nov. is easily distinguished from the typical Silurian species of the genus, such as the type species *K. coreaniformis* (Sokolov, 1952, p. 53, 54, pl. 20, figs. 3–6) from Saaremaa of Estonia, and *K. persiaensis* Niko, Kakuwa, Watanabe and Matsumoto (2000, p. 88, 90, 91, figs. 1,1, 1.2, 2.1–2.3) from the Kerman are, Iran, by its much larger corallite diameter, 3.5 mm in mean, whereas diameters of corallites of *K. coreaniformis* are 0.5–1.3 mm and those of *K. persiaensis* are 0.23–1.46 mm, and closer spacing of tabulae in

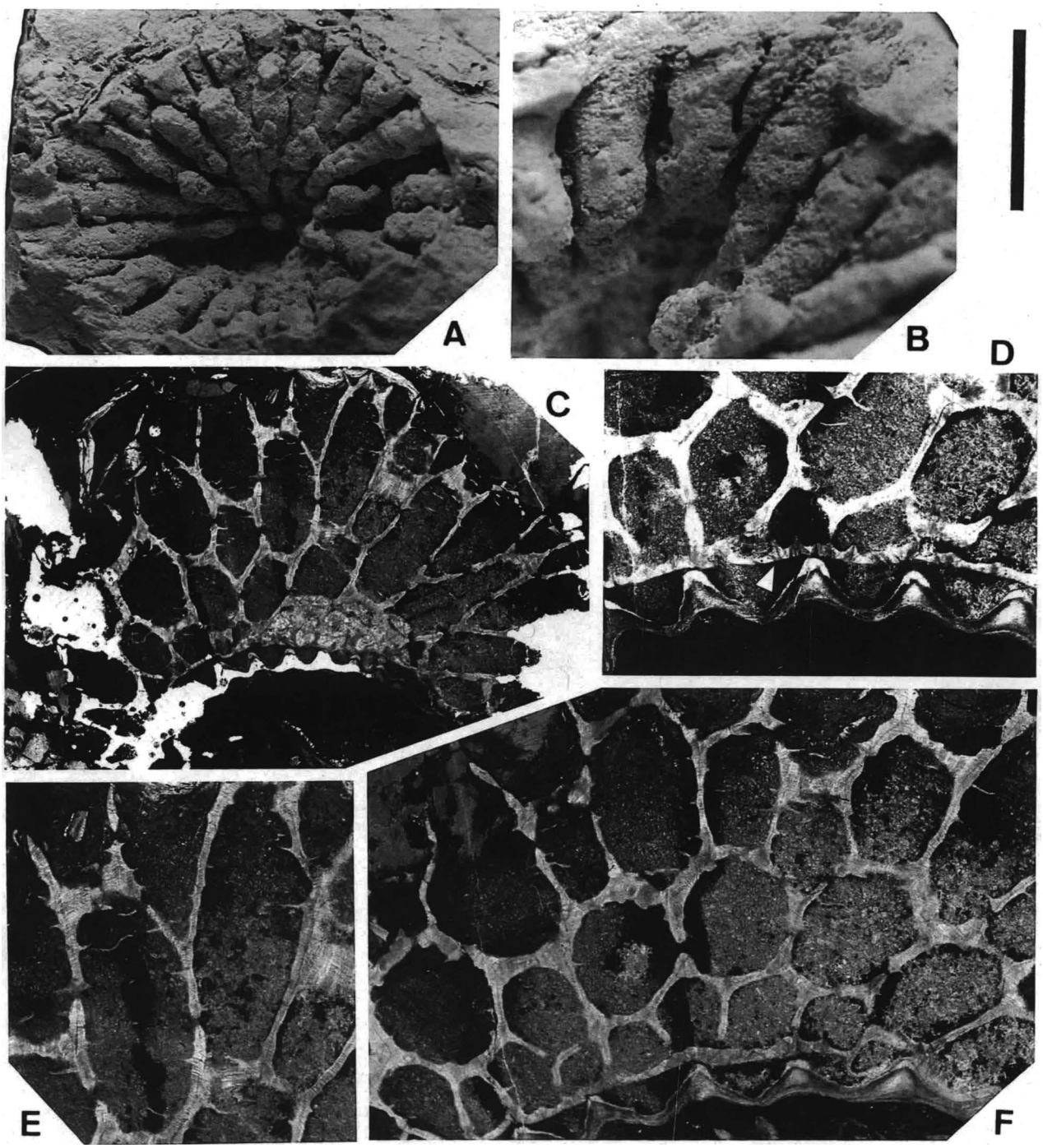

Fig. 3. *Pseudofavosites asoensis* sp. nov. **A**, **B**, paratype, NMNS PA20406, weathered surface; A, upper view of corallum, B, side views of corallites. **C**–**F**, holotype, NMNS PA20405, thin sections; C, longitudinal (slightly oblique) section of corallum, D, proximal part of corallum, arrow indicates base, E, partial enlargement of C to show longitudinal to oblique sections of distal corallites, F, transverse to oblique sections of proximal corallites. Scale bar: 6 mm in A, C; 3 mm in B, E, F; 2.5 mm in D.

the peripheral zone than the Silurian species.

Dubatolov (1969, p. 65–67, pl. 35, figs. 1a, b, v, g, 2, 3) redescribed an Early Devonian favositid, *Favosites* (*Eufavosites*) *forbesi oblonga* Rukhin (1938, p. 49, 50, pl. 9, figs. 5–7) from the upstream region of the Kolyma River, northeastern Siberia, as *F. oblongus*. In recent taxonomic knowledge, its subcylindrical corallum form with large corallum diameter (attaining 60 mm), perpendicularly oriented peripheral corallites for the corallum surface and thin intercorallite walls clearly correspond to the generic diagnosis of *Klaamannipora*. This species resembles *K. densitabulata* especially in the closely spaced tabulae in the peripheral zone. Corallite diameters, however, are much smaller (1.3–1.7 mm) in comparing with *K. densitabulata. Klaa-*

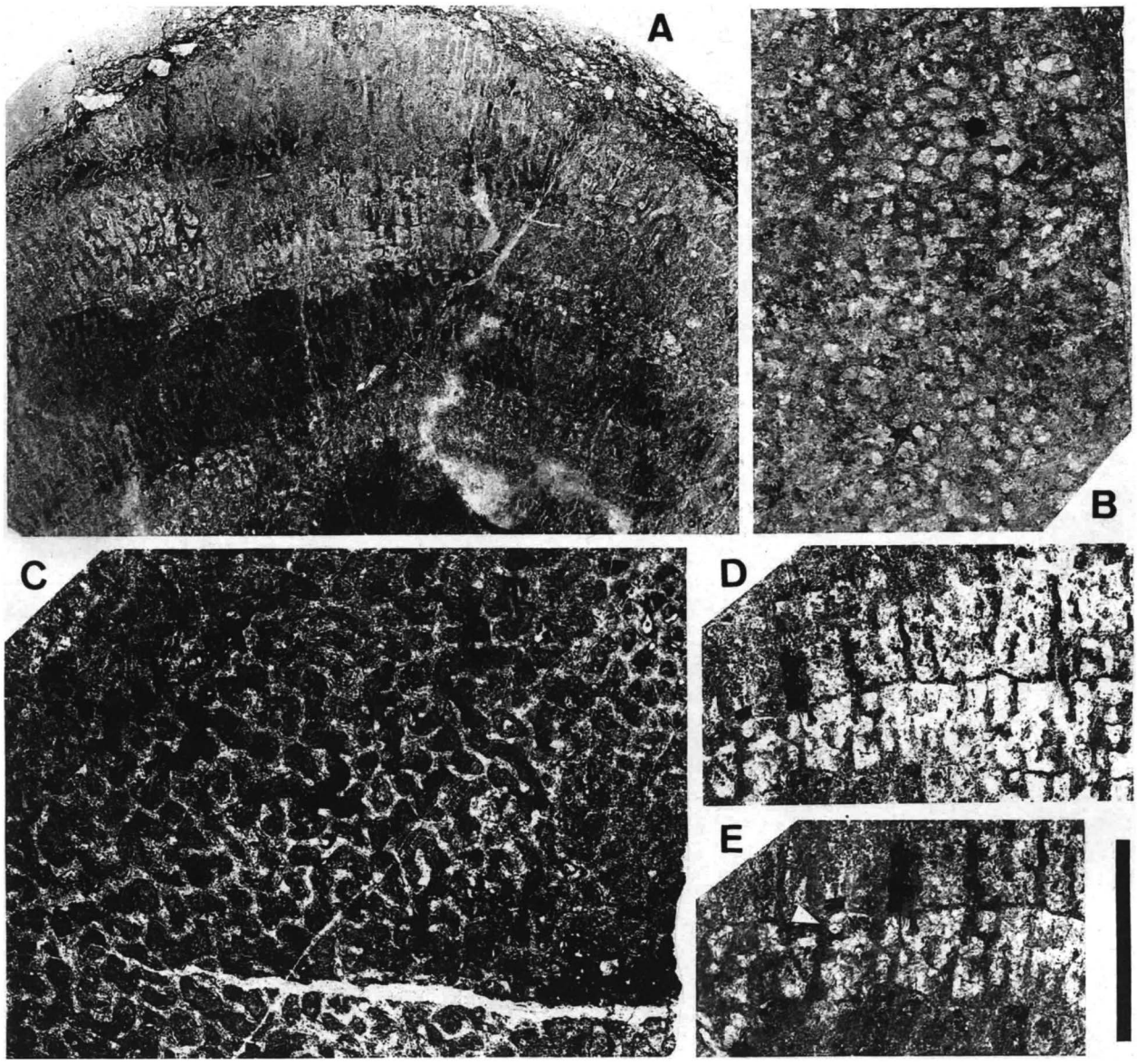

Fig. 4. *Sparsisolenia*? sp. indet., NMNS PA20408, thin sections. **A**, longitudinal section of corallum, **B**, **C**, transverse sections of corallites, **D**, **E**, longitudinal sections of corallites, arrow in E indicates pore protuberance. Scale bar: 7.5 mm in A; 3 mm in B–D; 2.5 mm in E.

mannipora devonica Tchi and Wang (1989, p. 48, 49, pl. 2, figs. 3a, b) from the Lower Devonian of Guangxi, South China is also separated from *K. densitabulata* by its small corallite diameters (0.6–1.5 mm).

Family Pseudofavositidae Sokolov, 1950

Genus ***Pseudofavosites*** Gerth, 1921

Type species: *Pseudofavosites stylifer* Gerth, 1921.

Pseudofavosites asoensis sp. nov.

Figs. 3-A–F

Material examined: Holotype, NMNS PA20405, from which three thin sections were prepared. A weathered surface and two polished sections were studied from a paratype, NMNS PA20406. In addition, a single immature specimen of corallum, UMNS PA20407, was assigned to this species.

Occurrence: Black calcareous mudstones at locality NAD-2.

Diagnosis: Species of *Pseudofavosites* with corallite diameters of approximately 2.1 mm near calical rim; transverse sections of lumina mostly circular to rounded polygonal; thickness of intercorallite walls 0.10–0.38 mm; both mid-wall and angle pores developed; squamulae short, 0.31–0.42 mm; complete tabulae very rarely developed in the most proximal corallites.

Description: Coralla domical to subspherical, attached on substrata (brachiopod shell, holotype;

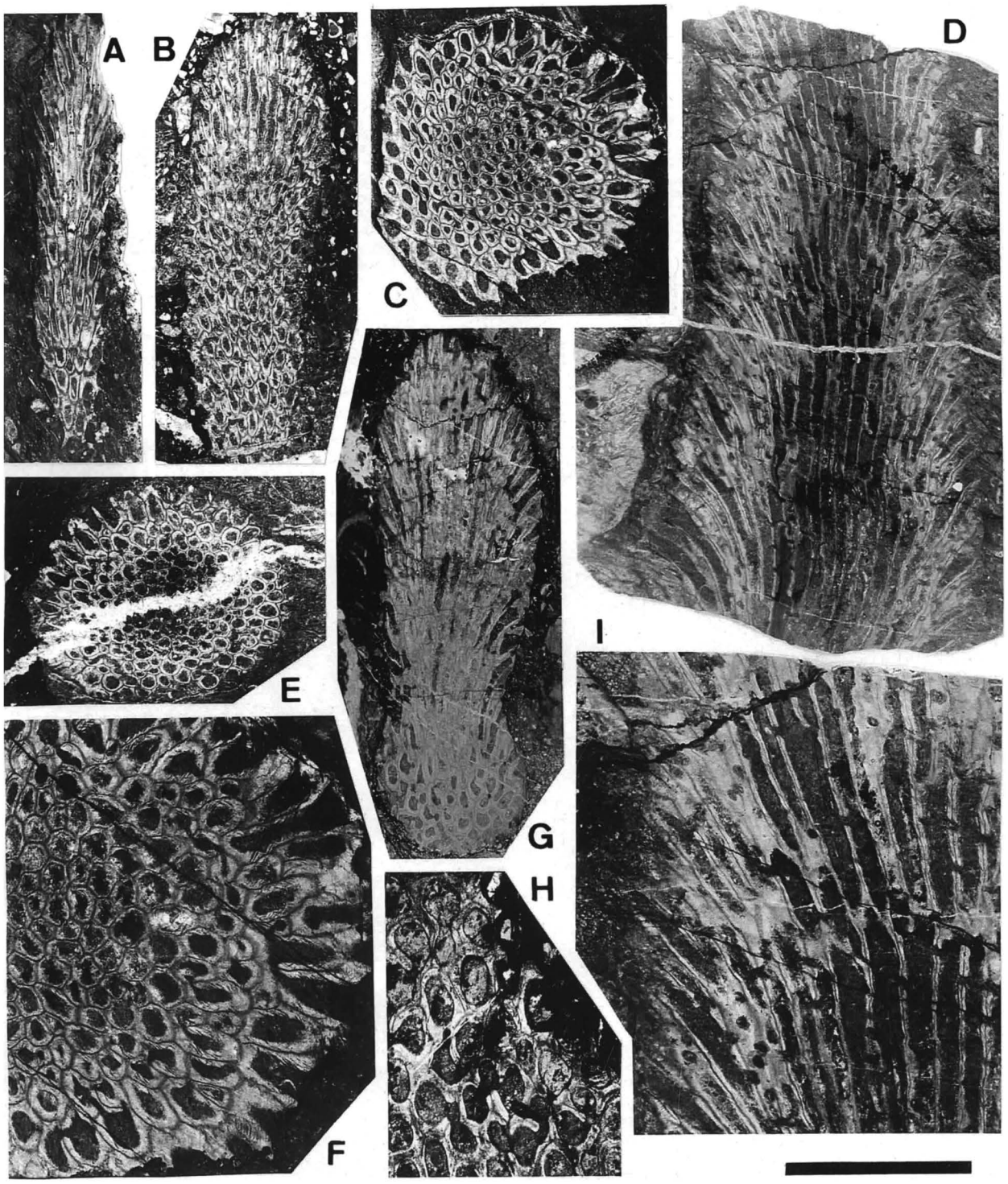

Fig. 5. *Gracilopora delicata* sp. nov., thin sections. **A**, paratype, NMNS PA20417, longitudinal section of immature branch. **B**, paratype, NMNS PA20420, longitudinal to oblique section of branch. **C**, **F**, paratype, NMNS PA20413; C, transverse section of gerontic branch, F, partial enlargement of C to show transverse to oblique sections of axial and longitudinal to oblique sections of peripheral corallites. **D**, **E**, **I**, holotype, NMNS PA20415; D, longitudinal section of gerontic branch, E, transverse section of gerontic branch, I, partial enlargement of D to show longitudinal sections of corallites. **G**, paratype, NMNS PA20416, longitudinal to oblique section of branch. **H**, paratype, NMNS PA20421, transverse sections of peripheral corallites. Scale bar: 6 mm in A–E, G; 3 mm in F, I; 2.5 mm in H.

coral fragment, paratype), and cerioid; the largest corallum (holotype) has 18 mm mm in diameter and 14 mm in height. Except for adhered portions to substrata that indicate hemispherical or subtrapezoidal transverse sections, corallites prismatic to rounded subprismatic with 4 to indistinct 8 sides and radially arranged; diameters of corallites are moderate for the genus, 0.4–2.3 mm with 2.1 mm

mean near calical rim of the holotype; calical pits very deep; transverse sections of lumina are rounded subpolygonal to circular; lateral increases of new corallites uncommonly observable. Intercorallite walls uniformly thickened, 0.10–0.38 mm, and differentiated into median dark line and stereoplasm; microstructure of stereoplasm unknown; mural pores frequently occur on corallite faces as mid-wall pores and at corallite angles as angle pores; diameters are 0.10–0.17 mm in mid-wall and 0.16–0.21 mm in angle pores; squamulae commonly to sporadically occur, short for the genus, 0.31–0.42 mm, and weakly concave proximally, nearly flat or undulate in rare cases; ratios of squamula length per lumen diameter are approximately 0.2; thickness of squamulae is very thin, up to 0.08 mm; no septal spine developed; tabulae very rare, restricted to the most proximal adhered corallites, and complete.

Etymology: The specific name derives from Mt. Aso, that is a famous active volcano in Kumamoto Prefecture.

Discussion: Occurrences of *Pseudofavosites* are dominant in the Upper Permian (Hill, 1981) and relatively rare in the Carboniferous (e.g., Lin, 1984; Niko, 2007). Whereas, previous Devonian record of the genus was exclusively represented by Wang (1983) who documented six species from the Lower Devonian of Xinjiang, Northwest China. Among them, *P. barkolensis* Wang (1983, p. 704, pl. 1, figs. 1a, b) and *P. longispinus* Wang (1983, p. 703, pl. 2, figs. 3a, b) are comparable to *P. asoensis* sp. nov. in their corallite diameters and intercorallite wall thicknesses. However, this new species is characterized by short squamulae for the genus, having 0.31–0.42 mm, on the other hand squamula lengths of the Chinese species leach 1.0 mm or above.

Family Multisoleniidae Fritz, 1950
Genus ***Sparsisolenia*** Stasinska, 1967

Type species: *Sparsisolenia kiaeri* Stasinska, 1967.

Sparsisolenia? sp. indet.
Figs. 4-A–E

Material examined: NMNS PA20408, 20409.

Occurrence: Black (to brownish in weathered part) mudstones at locality NAD-2.

Description: Coralla subglobose with 91 mm in diameter of the largest specimen (NMNS PA20409) and cerioid to partly pseudomeandroid. Corallites subprismatic indicating 4–6 sided polygonal to subcircular transverse sections, straight and very gradually inflated; dimeters of corallites are small, 0.3–0.4 mm. Intercorallite walls thin, 0.08–0.19 mm; pore protuberances developed at pseudomeandroid parts; diameters of pore protuberances are large in comparing with corallite diameter and 0.08–0.21 mm, whose values are nearly equal with corallite face width; septal spines rare, high conical and approximately 0.10 mm in length; tabulae widely spaced, complete and occur at same level in contiguous corallites.

Discussion: This specimen possesses the diagnostic characters for *Sparsisolenia*, such as the coexistence of cerioidal and pseudomeandroidal parts in the same corallum, small corallite diameters, and widely spaced tabulae. However, the material is not well-preserved to enough for a confident identification.

Superfamily Pachyporoidea Gerth, 1921
Family Pachyporidae Gerth, 1921
Genus ***Gracilopora*** Chudinova, 1964

Type species: *Gracilopora acuta* Chudinova, 1964.

Gracilopora delicata sp. nov.
Figs. 5-A–I

Material examined: Holotype, NMNS PA20415, from which four thin sections were prepared. Eleven thin sections were studied from the six paratypes, NMNS PA20411, 20413, 20416, 20417, 20420, 20421. In addition, six specimens, NMNS PA20412, 20414, 20418, 20419, 20422, 20423, were assigned to this species.

Occurrence: Black calcareous mudstones at locality NAD-1.

Diagnosis: Species of *Gracilopora* with usual branch diameters of 3–11 mm; corallite diameters moderate, approximately 0.6 mm; calices oblique; intercorallite walls weakly thickened, 0.17–0.31 mm in peripheral stereozone; both mid-wall and angle pores developed; tabulae sparse, 0–5 tabulae in 2.5 mm.

Description: Coralla ramose with cylindrical branches, cerioid; branching rare, probably bifur-

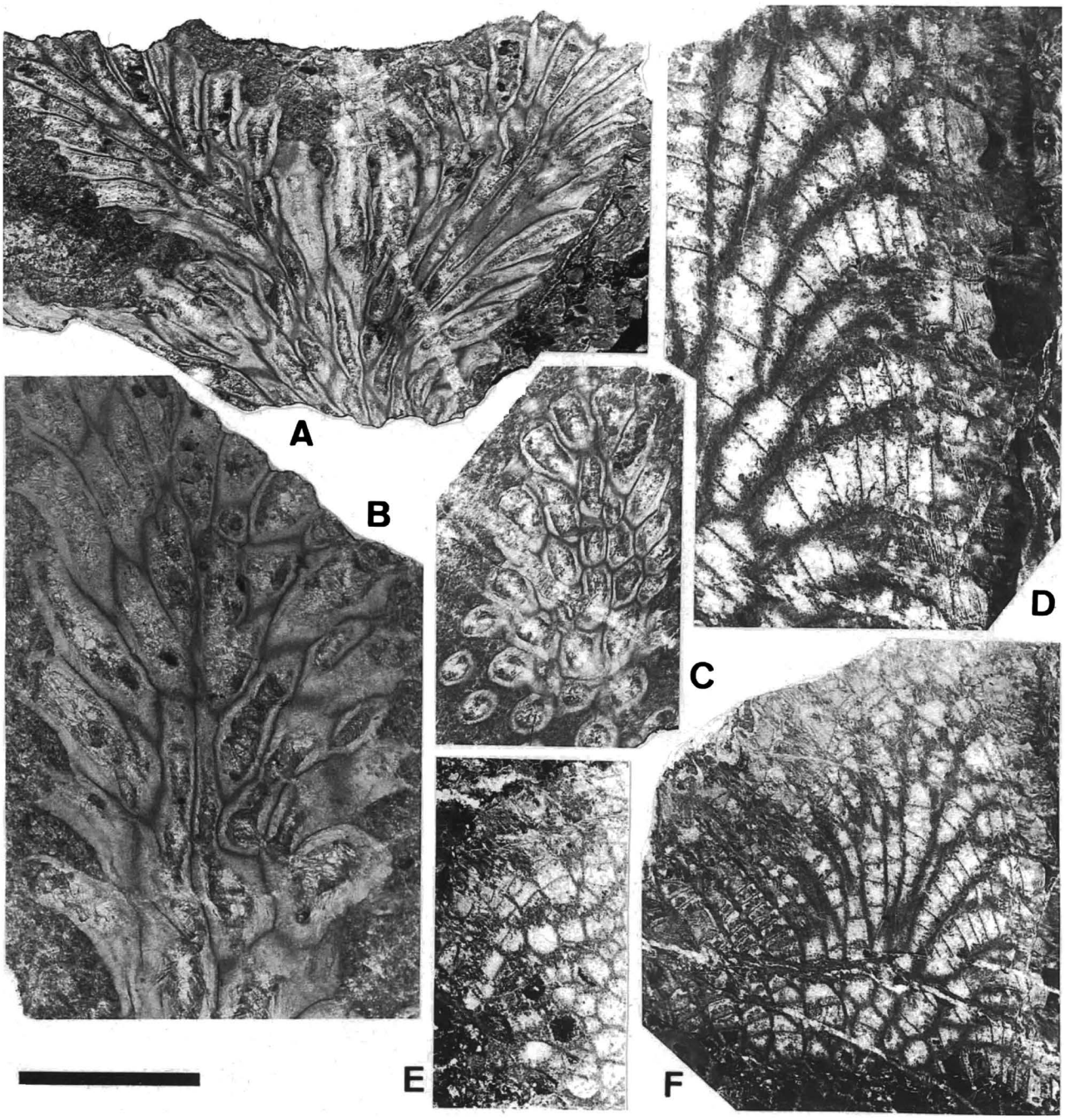

Fig. 6. **A–C**, *Hillaepora* sp. indet., NMNS PA20424, thin sections; A, longitudinal sections of branches, B, longitudinal section of branch, C, oblique section of branch. **D–F**, *Parastriatopora* sp. indet., NMNS PA20410, thin sections; D, longitudinal sections of peripheral corallites, E, transverse section of branch, F, longitudinal section of branch. Scale bar: 6 mm in A, C, E, F; 3 mm in B, D.

cate; usual diameters of branches are fairly variable, ranging from 3 mm to 11 mm; corallum diameter and growth form are unknown owing to fragile nature. Corallites prismatic to subprismatic, slender and gradually expanded; in transverse section of gerontic branch, there are more than 230 corallites; transverse sections of corallites are polygonal with 4–7 sides to rounded subpolygonal; in axial zone of branch, corallites run parallel with branch axis, then they gradually bend outwardly to form peripheral zone; ratios of axial zone diameter per corresponding branch diameter are approximately 0.4 in the holotype; directions of calices are upwardly oblique with 30–75° for branch surface; diameters of corallites are moderate for the genus, 0.3–0.7 mm with 0.6 mm mean; calical pits very deep; transverse sections of lumina are subpolygonal in axial and subcircular in peripheral zones; lateral increases frequently occur near boundary proximal and distal portions. Intercorallite walls usually thin, 0.05–

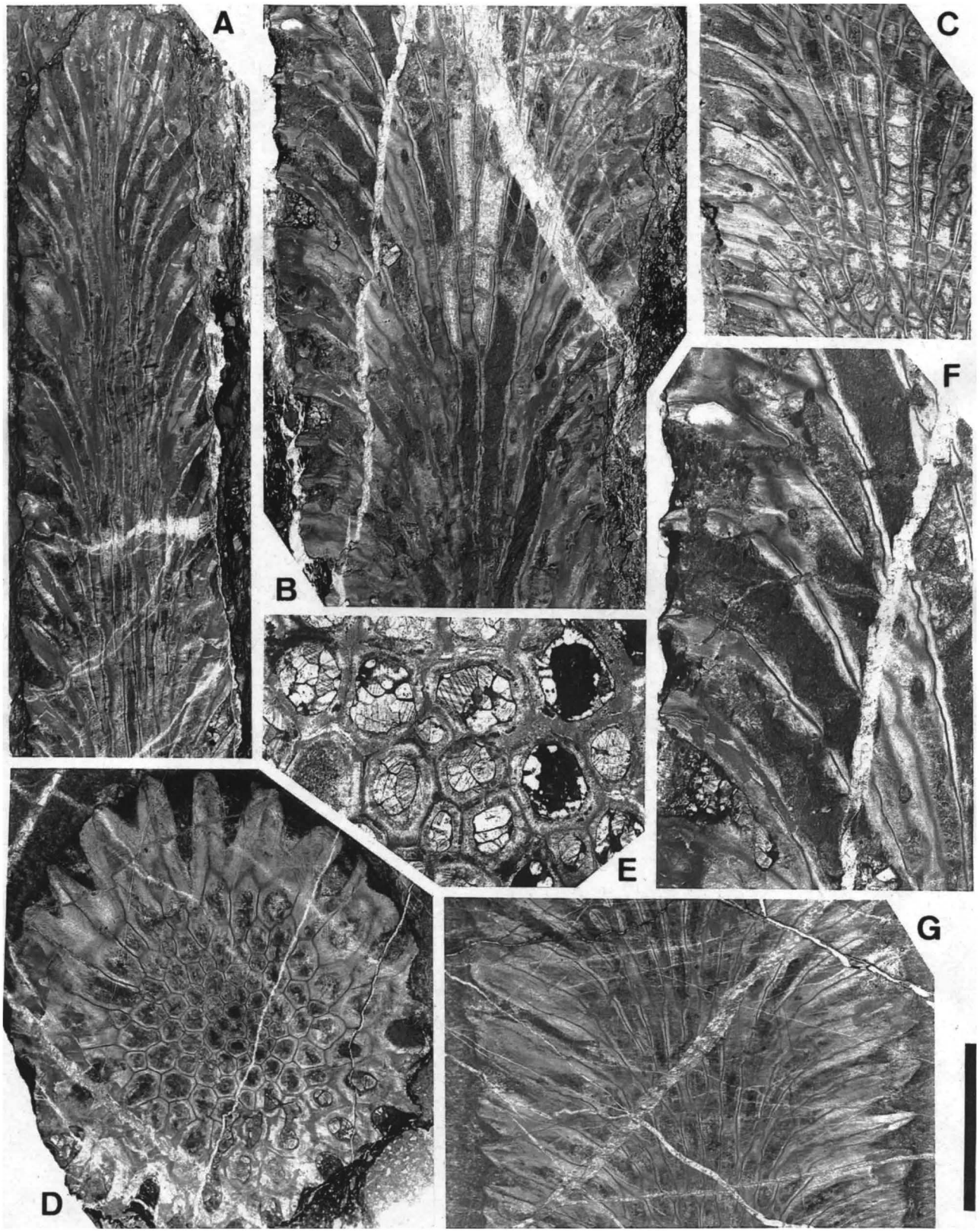

Fig. 7. *Thamnopora miyamotoi* sp. nov. thin sections. **A**, paratype, NMNS PA20450, longitudinal section of branch. **B**, **F**, holotype, NMNS PA20462; B, longitudinal section of branch, F, partial enlargement of B to show longitudinal sections of peripheral corallites. **C**, paratype, NMNS PA20444, longitudinal sections of corallites. **D**, **G**, paratype, NMNS PA20458; D, transverse section of gerontic branch, G, longitudinal section (slightly off branch axis) of gerontic branch. **E**, paratype, NMNS PA20449, transverse sections of peripheral corallites. Scale bar: 6 mm in A–D, G; 2.5 mm in E; 3 mm in F.

0.21 mm, but distal corallites in peripheral zone of gerontic branches indicate weak thickening, 0.17–0.31 mm, and form stereozone; structurally walls differentiated into median dark line and stereoplasm, microstructure in which the latter layer is lamellar; mural pores abundant on corallite faces as mid-wall pores and at corallite corners as angle pores; mid-wall pores have longitudinally elongated elliptical to circular in profile and 0.13 × 0.19, 0.15 × 0.25, 0.15 mm in diameter of typical pores; angle pores have longitudinally elongated elliptical and 0.11 × 0.23, 0.15 × 0.21 mm in diameter of ditto; no distinct septal spine observable; tabulae sparse, complete and nearly horizontal or weakly uparched; there are 0–5 tabulae in corallite length of 2.5 mm.

Etymology: The specific names is derived from the Latin *delicatus*, meaning delicate, in reference of its corallite nature.

Discussion: *Gracilopora delicata* sp. nov. is somewhat similar to *G. nana* (Dubatolov, 1959, p. 79, 80, pl. 21, figs, 6a, b, v; 1969, p. 112, 113, pl. 63, figs. 1a, b, v, 2a, b, 3a, b, v) from the upper Lower and lower Middle Devonian of the Kuznetsk Basin in southwestern and the upper reaches of the Yana River in northeastern Siberia, *G. spina* Deng (1979, p. 156, pl. 1, figs. 5a–c, pl. 2, figs. 2a–c) from the Eifelian (lower Middle Devonian) of Guizhou, Southwest China, and *G. tenera* Koksharskaya (1967, p. 11, pl. 1, figs. 5a, b) from the Lower Devonian of the Sette-Daban Range in northeastern Siberia. However, the morphologic combination of the new species, including its large gerontic branch diameters (leaching 11 mm versus 5 mm in *G. nana* and *G. spina*), moderate corallite diameter for the genus (approximately 0.6 mm versus relatively large, 0.8–1.0 mm, in *G. tenera*), and sparse tabulae (0–5 tabulae in 2.5 mm versus 4–8 tabulae in *G. nana*), serves differentiate. Niko (2019, p. 13, 14, figs. 3-A, B) discovered a fragmentally pachyporid from the Middle Devonian (probably Givetian) Kamiarisu Formation in Iwate Prefecture, Northeast Japan, and described it as *Gracilopora*? sp. indet. The perpendicularly oriented calices to the branch surface of the Kamiarisu species clearly exclude it from *G. delicata*.

Genus ***Hillaepora*** Mironova, 1960

Type species: *Hillaepora spica* Mironova, 1960.

Hillaepora sp. indet.

Figs. 6-A–C

Material examined: NMNS PA20424.

Occurrence: Gray limestone at locality NAD-1.

Description: A fragment of branched corallum is available for study; it is cerioid in main portion and phaceloid near periphery; branch slender with usual diameters of 6–7 mm. Corallites prismatic in cerioid and cylindrical in phaceloid portions; they gradually diverge to form oblique and deep to relatively shallow calices; diameters of corallites are 0.6–1.5 mm. Intercorallite walls thickened, 0.15–0.31 mm in axial zone of branch, then their thickness increases distally and attain 0.60 mm; mural pores common on corallite faces and nearly circular in profile; diameters of pores are 0.17–0.19 mm; no distinct septal spine developed; tabulae mostly rare, but crowded in part, complete or incomplete in are cases.

Discussion: The presence of phaceloidal portion in this branched specimen warrants for its generic assignment to *Hillaepora*. It probably represents a new species, because the thickened intercorallite walls distinguish the species from other ones of the genus. However, the insufficient material precludes to make transverse thin section of the branches. Its specific identification must wait for discovery of additional specimens.

Genus ***Thamnopora*** Steininger, 1831

Type species: *Thamnopora madreporacea* Steininger, 1831.

Thamnopora miyamotoi sp. nov.

Figs. 7-A–G

Material examined: Holotype, NMNS PA20462, from which three thin sections were prepared. Thirty-five thin sections were studied from the 12 paratypes, NMNS PA20435, 20440, 20441, 20444, 20447, 20449–20451, 20458–20460, 20468. In addition, 40 specimens, NMNS PA20425–20434, 20436–20439, 20442, 20443, 20445, 20446, 20448, 20452–20457, 20461, 20463–20467, 20469–20477, were assigned to this species.

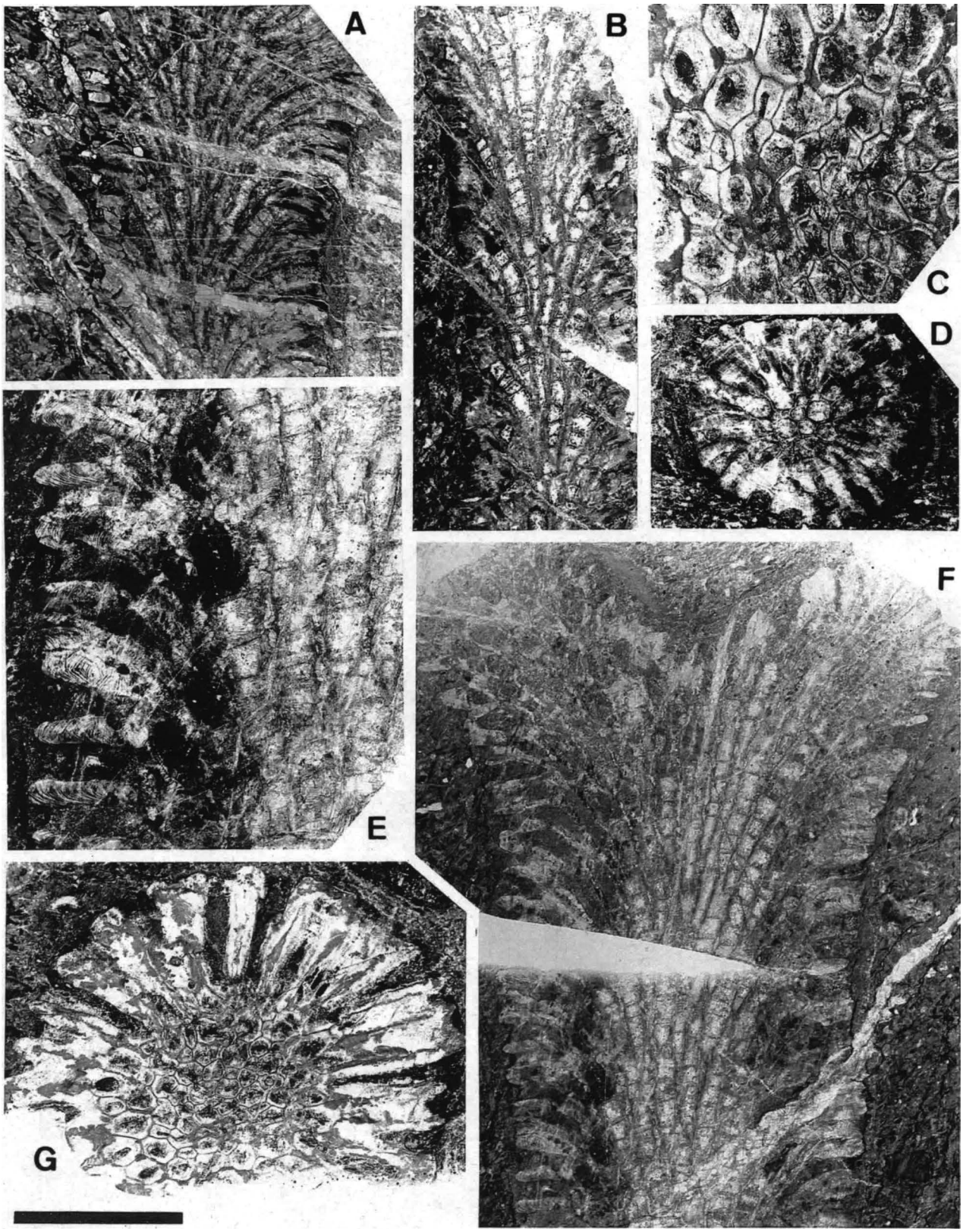

Fig. 8. *Thamnoptychia tanimotoi* sp. nov., thin sections. **A**, paratype, NMNS PA20485, longitudinal section of branch. **B**, paratype, NMNS PA20480, longitudinal section of immature branch. **C**, **E**, **F**, **G**, holotype, NMNS PA20490; C, partial enlargement of G to show transverse sections of axial corallites, E, partial enlargement of F to show longitudinal sections of corallites, F, longitudinal sections of gerontic branches G, transverse section of gerontic branch. **D**, paratype, NMNS PA20483, transverse section of branch. Scale bar: 6 mm in A, B, D, F, G; 3 mm in C, E.

Occurrence: Dark gray impure limestones at localities NAD-1 (NMNS PA20425–20431, 20433, 20435, 20438, 20439), NAD-3 (NMNS PA20471–20477) and NAD-4 (NMNS PA20440, 20441, 20445, 20446, 20448, 20450–20461, 20463); black (to brownish in weathered part) calcareous mudstones at localities NAD-1 (NMNS PA20432, 20434, 20436, 20437), NAD-4 (NMNS PA20442–20444, 20447, 20449, 20462) and NAD-7 (NMNS PA20464–20470).

Diagnosis: Species of *Thamnopora* with moderate branch diameter, usually 6–19 mm, and relatively small corallite diameters, 0.5–2.0 mm; intercorallite walls gradually thickened and attain 1.08 mm in peripheral zone; mural pores well developed, elliptical in profile; septal spines rare; tabulae complete or incomplete, variable in distribution ranging from almost absent to somewhat crowded.

Description: Coralla fasciculate, consisting of cylindrical branches, cerioid; branching rare, probably bifurcate; anastomoses of branches are not observable; diameters of branches moderate for the genus, usually 6–19 mm; corallum diameter and growth form are unknown owing to fragile nature. Corallites prismatic, 4–7 sided; there are approximately 125 corallites in transverse section of gerontic branch; in axial zone of branch, corallites run parallel with branch axis, then they gradually bend outwardly and form peripheral zone; calices open upward, oblique, indicating with 40°–70° for branch surface; ratios of axial zone diameter per corresponding branch diameter are 0.3–0.4; inflation of corallite is gradual in axial zone and relatively rapid in peripheral one; diameters of corallites are relatively small for the genus, 0.5–2.0 mm, with 1.7 mm mean near calical rim; calical pits very deep to deep; transverse sections of lumina are subcircular; increases of new corallites are lateral and frequently occur in axial zone. Intercorallite walls thickened, 0.48–0.58 mm even in axial zone; their thicknesses increase gradually up to 1.08 mm in peripheral zone; structurally, walls differentiated into median dark line and stereoplasm; microstructure of stereoplasm is rect-radiate fibers; mural pores well developed, form a single row on corallite face; profiles of pores are longitudinally elongated elliptical; typical pores have 0.19 × 0.26, 0.21 × 0.43, 0.23 × 0.52 mm in diameter; septal spines rare, conical to needle-like in rare cases, and 0.19–0.31 mm in length; tabulae mostly complete, but incomplete and dissepiment-like tabulae are not rare; complete tabulae somewhat variable in longitudinal section, such as roundly to triangularly concave, nearly flat and strongly oblique; distribution of tabulae also variable, ranging from almost absent to somewhat crowded; there are 0–8 tabulae in corallite length of 5 mm.

Etymology: The specific name honors Dr. T. Miyamoto, in recognition of his contributions to geology of the Kurosegawa Belt in Kyushu, especially in Miyamoto and Tanimoto (1993).

Discussion: *Thamnopora miyamotoi* sp. nov. indicates the close phylogenetic relationships with *T. nicholsoni* (Frech, 1885, p. 104, 105; Dubatolov, 1972, p. 74, 75, pl. 14, figs. 1a, b, 2a, b, v, 3a, b, v, pl. 15, figs. 1a, b) from the Givetian of Germany, Novaya Zemlya, Ukraine, Morocco, Altai, South China, and the Kamianama Formation, central Japan (see Niko and Senzai, 2011, for their references) by its general corallite shape and characters of mural pores, septal spines and tabulae. However, *T. miyamotoi* lacks abrupt inflations of intercorallite walls at the calical rims, that are the diagnostic character of *T. nicholsoni*. The new species also resembles *T. siavis* Dubatolov in Dubatolov *et al.* (1959, p. 22, 23, pl. 7, figs. 2a–e) from the Middle Devonian of Inner Mongolia, but the corallite diameters of the latter species are smaller, up to 0.4 mm, than those of the new species. Other known Middle Devonian species of the genus from Japan, namely *T. itoae* Niko, Ibaraki and Tazawa (2014, p. 61, 63, figs. 2-1–3, 4-1–6) from limestone pebbles in the Jurassic Kuruma Group of Niigata Prefecture and *T. sumitaensis* Niko (2019, p. 16, figs. 3-C–K) from the lowest part (probably Givetian) of the Kamiarisu Formation, Iwate Prefecture, differ from the new species by their smaller branch diameters (attaining 19 mm versus 6.6–10.8 mm in *T. itoae*, 5–12 mm in *T. sumitaensis*). *Thamnopora miyamotoi* is one of the most abundant coral in the Naidaijin Formation and appears to be an index for the Givetian.

Genus ***Thamnoptychia*** Hall, 1876

Type species: *Madrepora limbata* Eaton, 1832.

Thamnoptychia tanimotoi sp. nov.
Figs. 8-A–G

Material examined: Holotype, NMNS PA20490, from which 12 thin sections were prepared. Ten thin sections were studied from the nine paratypes, NMNS PA20478, 20480, 20481, 20483–20485, 20491–20493. In addition, six specimens, NMNS PA20479, 20482, 20486–20489, were assigned to this species.

Occurrence: Dark gray impure limestones at localities NAD-1 (NMNS PA20478–20486) and NAD-4 (NMNS PA20490, 20491, 20493); black calcareous mudstones at locality NAD-4 (NMNS PA20487–20489, 20492).

Diagnosis: Species of *Thamnoptychia* with 5–15 mm in usual branch diameter; corallite diameters approximately 2.1 mm near calical rim; peripheral zone (= peripheral stereozone) relatively narrow; ratios of axial zone diameter per branch diameter 0.3–0.5; intercorallite walls attain approximately 1.2 mm in thickness; mural tunnels rare to common; tabulae well developed.

Description: Coralla ramose, consisting of cylindrical branches, cerioid; branching uncommon, bifurcate; diameters of branches are moderate for the genus, usually 5–15 mm; corallum diameter and growth form are unknown owing to fragile nature. Corallites prismatic, 4–8 sided; there are more than 100 corallites in transverse section of gerontic branch; in axial zone of branch, corallites curve gently away from branch axis, then they abruptly bend and form relatively narrow peripheral zone; calices open nearly right angles for branch surface; ratios of axial zone diameter per corresponding gerontic branch diameter are 0.3–0.5; inflation of corallite is gradual; diameters of corallites are 0.3–1.1 mm in axial zone, then they attain 2.5 mm in peripheral zone; mean corallite diameter near calical rim is 2.1 mm; calical pits deep; lumina narrow to relatively narrow, with subcircular transverse sections; increases of new corallites are lateral and commonly occur in axial zone. Intercorallite walls thick even in axial zone, 0.21–0.69 mm, then their thicknesses increase in peripheral zone, attaining approximately 1.2 mm, to form peripheral stereozone; structurally, walls differentiated into median dark line and stereoplasm, microstructure in which the latter layer is rect-radiate fibers; mural pores occur on corallite face, relatively rare in axial zone, and common in peripheral zone; profiles of pores are nearly circular, with diameters of 0.13–0.25 mm; apparent septal spine is not observable; tabulae complete, flat or oblique in rare cases, well developed; there are 6–9 tabulae in corallite length of 5 mm.

Etymology: The specific name honors Mr. Y. Tanimoto, in recognition of his contributions to geology of the Mt. Tenshu-zan area, especially in Tanimoto and Miyamoto (1986).

Discussion: In its relatively narrow peripheral zone and well-developed tabulae, *Thamnoptychia tanimotoi* sp. nov. is somewhat similar to *T. mana* Niko and Senzai (2010, p. 50, 52, figs. 10-1–8) that was collected from the Lower Devonian of the Kamianama Formation, Fukui Prefecture, central Japan. However, *T. mana* has smaller branch diameters (usually 7–8 mm), much smaller corallite diameters at the calical rim (1.1–1.3 mm in center to center distances of neighboring calical pits) and thinner intercorallite walls (up to 0.71 mm) than those of *T. tanimotoi*.

Family Parastriatoporidae Chudinova, 1959
Genus ***Parastriatopora*** Sokolov, 1949

Type species: *Parastriatopora rhizoides* Sokolov, 1949.

Parastriatopora sp. indet.
Figs. 6-D–F

Material examined: NMNS PA20410.

Occurrence: Gray limestone at locality NAD-4.

Description: A fragmentary branch is available for study; it is cerioid and 14 mm (imperfect) in diameter. Corallites prismatic having 4–8 sides in transverse section and run parallel with corallum axis in axial zone of corallum, then they bent outwardly to form peripheral zone; diameters of corallites are 0.6–1.6 mm; calices open at nearly right angles for branch surface; calical pits very shallow. Intercorallite walls relatively thin in axial zone, 0.08–0.17 mm, then they gradually thickened in proximal part of peripheral zone, where wall thickness is up to 0.27 mm; in distal part of peripheral zone, they abruptly thickened by contiguous septal spines and septal ridges, attaining approximately

0.5 mm, and form peripheral stereozone; mural pores rarely occur on corallite faces and have elliptical profiles; diameters of typical pores are 0.13 × 0.23, 0.17 × 0.25 mm; tabulae well-developed, complete; there are 3–7 tabulae in corallite length of 2.5 mm; the most distal some tabulae thickened by stereoplasmic layer, especially the last tabula in each corallite indicates high value, attaining 0.83 mm in thickness, and gives mound-like calical base.

Discussion: This specimen undoubtedly belongs to *Parastriatopora* by the possessions of the peripheral stereozone formed by contiguous septal elements and the thickened distal tabulae. Furthermore, there is a possibility that it represents a new species. The poor preservation, however, leaves its confident specific comparison.

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