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Additional Material of Favositid Tabulate Corals from the Devonian Kamianama Formation, Fukui Prefecture, Japan

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Abstract The Kamianama Formation in the Kuzuryu Lake–Ise River area, Fukui Prefecture, Central Japan consists of the Lochkovian (early Early Devonian) to Emsian (late Early Devonian) Oisedani Member and the Emsian to probably Eifelian (early Middle Devonian) Hakubado Member. Five species of tabulate corals of the order Favositida add to the Kamianama fauna. They are *Pachyfavosites hidensiformis* (Mironova, 1961), *Parastriatopora fukuiensis* sp. nov., and *Planocoenites ozakii* Niko, 2003 from the Oisedani Member, *Parastriatoporella arashimaensis* sp. nov. from the uppermost part of the Hakubado Member and a Givetian (upper Middle Devonian) species of *Thamnopora nicholsoni* (Frech, 1885) from a float block of tuffaceous shale. There is a possibility that the tuffaceous shale block containing *T. nicholsoni* was derived from the missing part of the formation. The new occurrence of *P. arashimaensis* represents the oldest and first Devonian records of *Parastriatoporella*, in addition the geographic range of the genus is increased to now include Japan.

Key words: Early to Middle Devonian, tabulate corals, Favositida, Kamianama Formation, Oisedani Member, Hakubado Member, Fukui

Introduction

This paper describes five additional species of favositids to the tabulate coral fauna of the Devonian Kamianama Formation in the Kuzuryu Lake–Ise River area, Fukui Prefecture, Central Japan. See our previous papers (Niko and Senzai, 2006, 2010; Senzai and Niko, 2007) for information of geographic and geologic settings of the formation. Used abbreviations indicating fossil repositories are HMM (Hikaru Memorial Museum) and NSM (National Science Museum).

Systematic Paleontology

Order Favositida Wedekind, 1937

Suborder Favositina Wedekind, 1937

Superfamily Favositoidea Dana, 1846

Family Favositidae Dana, 1846

Subfamily Pachyfavositinae Mironova, 1965

Genus ***Pachyfavosites*** Sokolov, 1952

Type species: *Calamopora polymorpha* var. *tuberosa* Goldfuss, 1826.

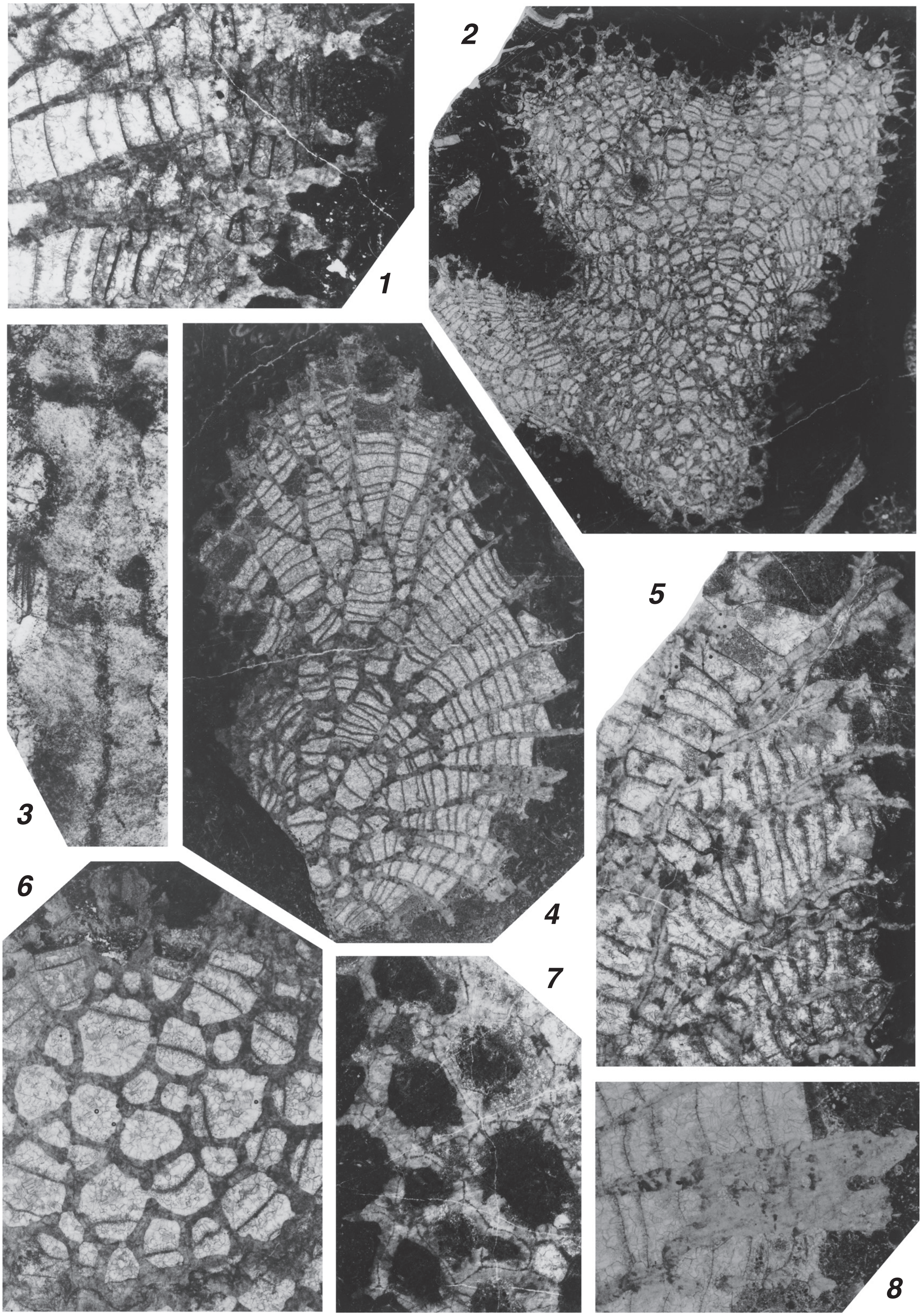
Pachyfavosites hidensiformis (Mironova, 1961)

(Figs. 1-1–8)

Favosites? *hidensiformis* Mironova, 1961, p. 149, 150, pl. 5, figs. 1a, b, v, g.
Pachyfavosites hidensiformis (Mironova); Dubatolov, *et al*., 1968, p. 60, 61, pl. 21, figs. 1, 2a, b, 3a, b, 4, 5, pl. 23, figs. 1a, b; Dubatolov, 1969, p. 79, pl. 45, figs. 3a, b, v, g, d; Mironova, 1974, p. 64, pl. 9, figs. 1a, b, 2a, b.

Material examined: Ten coralla, HMM03542, NSM PA16471–16477, 16713, 16714.

Description: Coralla indicate variable growth forms with lobated, massive to high bul-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bous, columnar, or ramose outlines, cerioid; frequent reticulations developed in ramose corallum; the largest specimen (HMM03542) at least has 112 mm in diameter and 175 mm in height. Corallites prismatic, straight with radiate in arrangement in bulbous, or gently curved with divergent in arrangement in columnar portions; transverse sections of immature corallites are 3–6 sides, then ontogenetically they shift indistinct 6–10 sides; corallite diameters range from 0.5 to 1.9 mm, with approximately 1.6 mm mean in adult corallites; calices shallow to moderately deep, perpendicularly oriented to corallum surface; tabularia (lumina) exhibit rounded polygonal profiles; increase of new corallite is lateral, common. Intercorallite walls differentiated into median dark line and stereoplasm, the latter of which has rect-radiate microstructure, thickened even in proximal portions of coralla; usual thickness of intercorallite walls is 0.10–0.23 mm, furthermore it increases to 0.42 mm in peripheral zone of corallum; mural pores common to well-developed, occur on corallite faces as mid-wall pores that have longitudinally elongated profiles; usual mural pores closed by pore plates; diameter of typical mural pore is 0.19×0.28 mm; septal spines well developed in peripheral zone, low to high conical with 0.06–0.17 mm in length of protrude portion; tabulae mostly complete having nearly flat to rarely oblique profiles; lobe-like depression in complete tabula is recognized only a single instance; there are 5–16 tabulae in 5 mm of corallite length.

Occurrence: Calcareous shale (NSM PA16713) at locality KU-1. Float blocks of calcareous shale (HMM03542, NSM PA16714) and argillaceous limestone (NSM PA16471, 16472) in the Kamaharadani Valley. Float blocks of calcareous shale (NSM PA16477) and argillaceous limestone (NSM PA16473–16476) in the Tanobora Valley. These specimens are derived from the Oisedani Member.

Discussion: Compared to average specimens of *Pachyfavosites hidensiformis* (Mironova, 1961), those from the Lower Devonian (Lochkovian) of Salair, southwestern Siberia have the fewer septal spines in the peripheral zone of the coralla than the Kamianama specimens. However, the specimens agree in other essential features with the types including the overall corallum shape and morphologies of the corallite. *Pachyfavosites hidensiformis* is also recorded from the Lower Devonian strata in the Altai of southwestern Siberia (Dubatolov *et al*., 1968) and the basin of the River Yana of eastern Siberia (Dubatolov, 1969).

Superfamily Pachyporoidea Gerth, 1921

Family Pachyporidae Gerth, 1921

Genus ***Thamnopora*** Steininger, 1831

Type species: *Thamnopora madreporacea* Steininger, 1831.

Thamnopora nicholsoni (Frech, 1885)

(Figs. 2-1–8)

Pachypora cervicornis (de Blainville); Nicholson, 1879, p. 82–87, pl. 4, figs. 3, 3a–d.

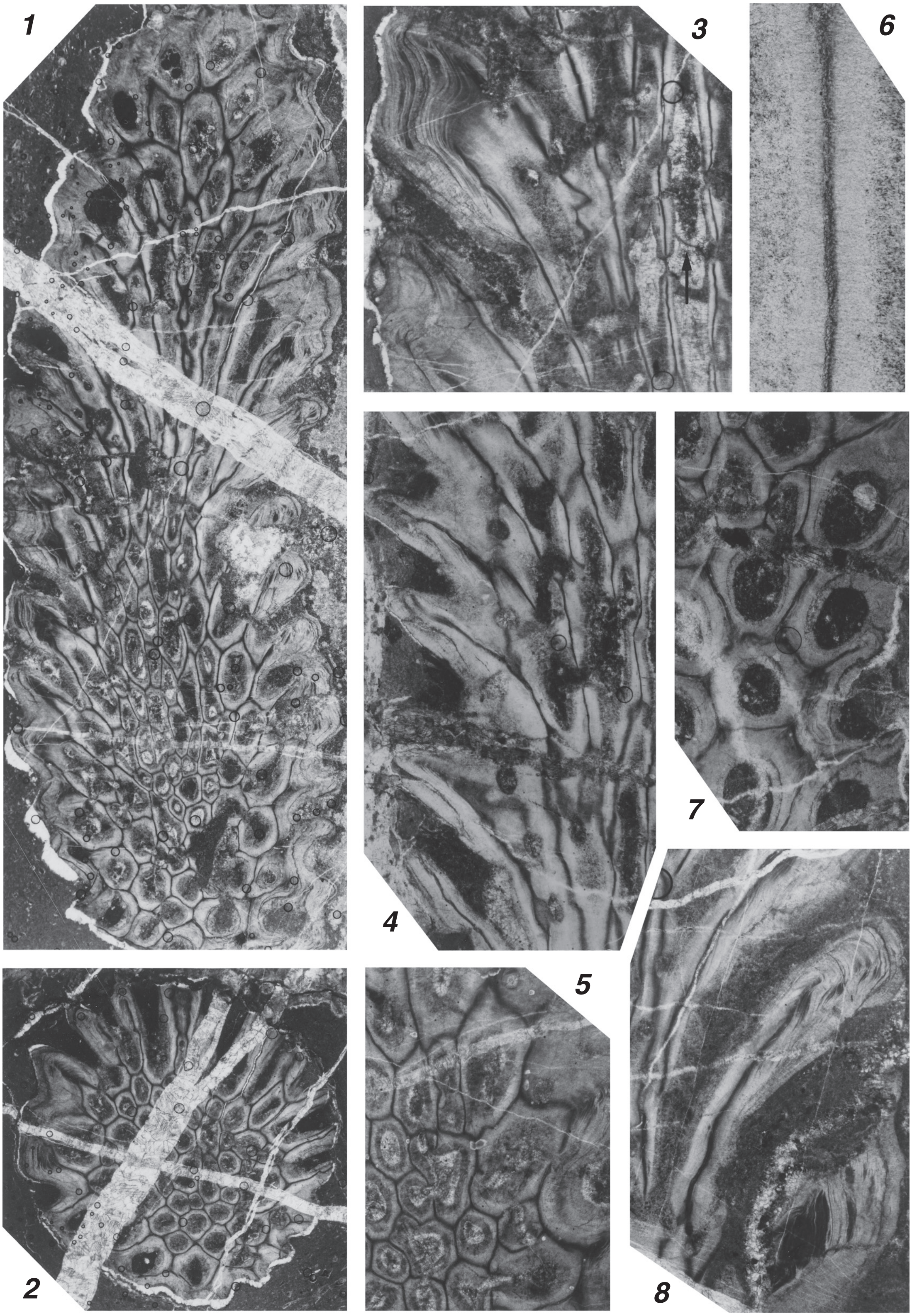
Favosites nicholsoni Frech, 1885, p. 104, 105.

Pachypora nicholsoni (Frech); Chernyshev, 1937, p. 88, 89, pl. 8, figs. 4a, b; Kelus, 1939, p. 48, text-figs. 40, 41, pl. 3, fig. 25.

Thamnopora nicholsoni (Frech); Termier and Termier, 1950, p. 77; Dubatolov, 1959, p. 108, 109, pl. 33, figs. 3a, b, v; Dubatolov, 1972, p. 74, 75, pl. 14, figs. 1a, b, 2a, b, v, 3a, b, v, pl. 15, figs. 1a, b; Tchi, 1975, p. 106, 107, pl. 2, figs. 2a, b.

Material examined: A single corallum, NSM

Fig. 1. *Pachyfavosites hidensiformis* (Mironova, 1961), thin sections. **1**, **6**, NSM PA16477. **1**, longitudinal sections of distal corallites, ×10. **6**, transverse section of columnar corallum, showing transverse sections of proximal corallites and oblique sections of distal ones, ×10. **2**, **3**, **5**, **7**, NSM PA16474. **2**, oblique section of corallum, ×2.5. **3**, partial enlargement to show intercorallite wall structure, longitudinal section, ×75. **5**, longitudinal sections of distal corallites, ×10. **7**, transverse sections of distal corallites, × 10. **4**, **8**, NSM PA16476. **4**, longitudinal section of corallum,×5. **8**, longitudinal sections of distal corallites, ×14.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PA16643.

Description: Coralla ramose with cylindrical branches, cerioid; branching rare, probably bifurcate; diameters of branches 5.1–11.0 mm; total corallum diameter and growth form unknown owing to its fragile nature. Corallites prismatic, 4–8 sided; depressed corallite face commonly occurs; there are 47–73 corallites in transverse section of branch; each corallite consists of narrowly divergent proximal portion and outwardly curved distal one; proximal and distal portions of corallites respectively form axial and peripheral zones of branches; ratios of axial zone width per branch diameter are approximately 0.4; diameters of corallites range from 0.3 to 2.2 mm, with 1.9 mm mean in distal corallite; tabularia (lumina) have subcircular transverse sections, and shift to very deep calical pits; calices open obliquely upward with 53°–70° in angle to branch axis; lateral increase of new corallite frequently occurs in axial zone. Intercorallite walls uniformly thickened in axial zone, 0.17–0.40 mm; their thickness gradually increases attaining 0.82 mm in peripheral zone; constituents of intercorallite walls are median dark line and stereoplasm, the latter of which may have rect-radiate microstructure; lamellar structure of stereoplasm well-developed in peripheral stereozone; mural pores abundant forming a single row on each corallite face, relatively large with longitudinally elongated elliptical to circular profiles; diameters of typical mural pores are 0.29×0.42, 0.33 mm; some mural pores in axial zone are closed by pore plates; apparent septal spine is not detected in the present material; tabulae very rare, complete, weakly concave proximally, restrict in axial zone.

Occurrence: Float block of greenish gray tuffaceous shale co-occurring with *Thamnoptychia mana* Niko and Senzai, 2010 and *Alveolites* sp. cf. *A. maillieuxi* Lecompte, 1933 in the Oboradani Valley. Because reddish matrix partly remains in the block, the fossil bearing shale cropped out as a boulder in the Mesozoic Otani Conglomerate.

Discussion: Although direct comparisons of the Kamianama specimens with the types of *Thamnopora nicholsoni*, described and illustrated in the nineteenth century by Nicholson (1879) and designated by Frech (1885), are difficult, their important respects including gross corallite shape and characters of the intercorallite walls, mural pores and tabulae are almost identical to those of the specific diagnosis shown by Dubatolov (1972). *Thamnopora nicholsoni* has been recorded from the Givetian (late Middle Devonian) deposits in Eifel of Germany (Nicolson, 1879), Novaya Zemlya (Chernyshev, 1937), Ukraine (Kelus, 1939), Morocco (Termier and Termier, 1950), the Kuznetsk Basin (Dubatolov, 1959) and Altai (Dubatolov, 1972) of southwestern Siberia, and Guangxi of South China (Tchi, 1975). The Kamianama Formation is divided into the Lochkovian (early Early Devonian) to Emsian (late Early Devonian) Oisedani Member and the Emsian to probably Eifelian (early Middle Devonian) Hakubado Member in ascending order. Based on lithologic similarities, Niko and Senzai (2010, p. 36) suggested that the tuffaceous shale block, yielding *Thamnoptychia mana* Niko and Senzai, 2010, *Alveolites* sp. cf. *A. maillieuxi* Lecompte, 1933 and the present specimen of *T. nicholsoni*, was probably derived from the upper part of the Oisedani Member. However, it is difficult to extend downward the stratigraphic range of *T. nicholsoni* to the Emsian. Tabulate corals from the uppermost part of the Hakubado Member probably denote the Eifelian. In consideration of these facts, this discovery of *T. nicholsoni* in-

Fig. 2. *Thamnopora nicholsoni* (Frech, 1885), NSM PA16643, thin sections. **1**, longitudinal to oblique section of branch, ×5. **2**, transverse section of branch, ×5. **3**, partial enlargement of Fig. 2-1, showing longitudinal sections of corallites, arrow indicates tabula, ×10. **4**, longitudinal sections of corallites, ×10. **5**, transverse section of branch, showing transverse sections of proximal corallites and oblique sections of distal ones, ×10. **6**, partial enlargement to show intercorallite wall structure of proximal corallites, longitudinal section, ×75. **7**, transverse sections of distal corallites, ×10. **8**, longitudinal sections of distal corallites, ×10.

dicates a possibility that the block was originated from the missing Givetian part of the Kamianama Formation.

Thamnopora hayasakai Niko (2005, p. 22–26, figs. 6-1–9; Niko and Senzai, 2010, p. 49, 50, figs. 8-3, 4) from the Takaharagawa Member of the Fukuji Formation and the Oisedani Member of the Kamianama Formation clearly differs from *T. nicholsoni* by having somewhat narrower branch diameter, fewer number of the corallites in transverse section of the branches, the thinner intercorallite walls, much smaller corallite diameter in the distal corallites, smaller diameter of the mural pores, and the common septal spines.

Family Parastriatoporidae Chudinova, 1959

Genus ***Parastriatopora*** Sokolov, 1949

Type species: *Parastriatopora rhizoides* Sokolov, 1949.

Parastriatopora fukuiensis sp. nov.

(Figs. 3-1–7)

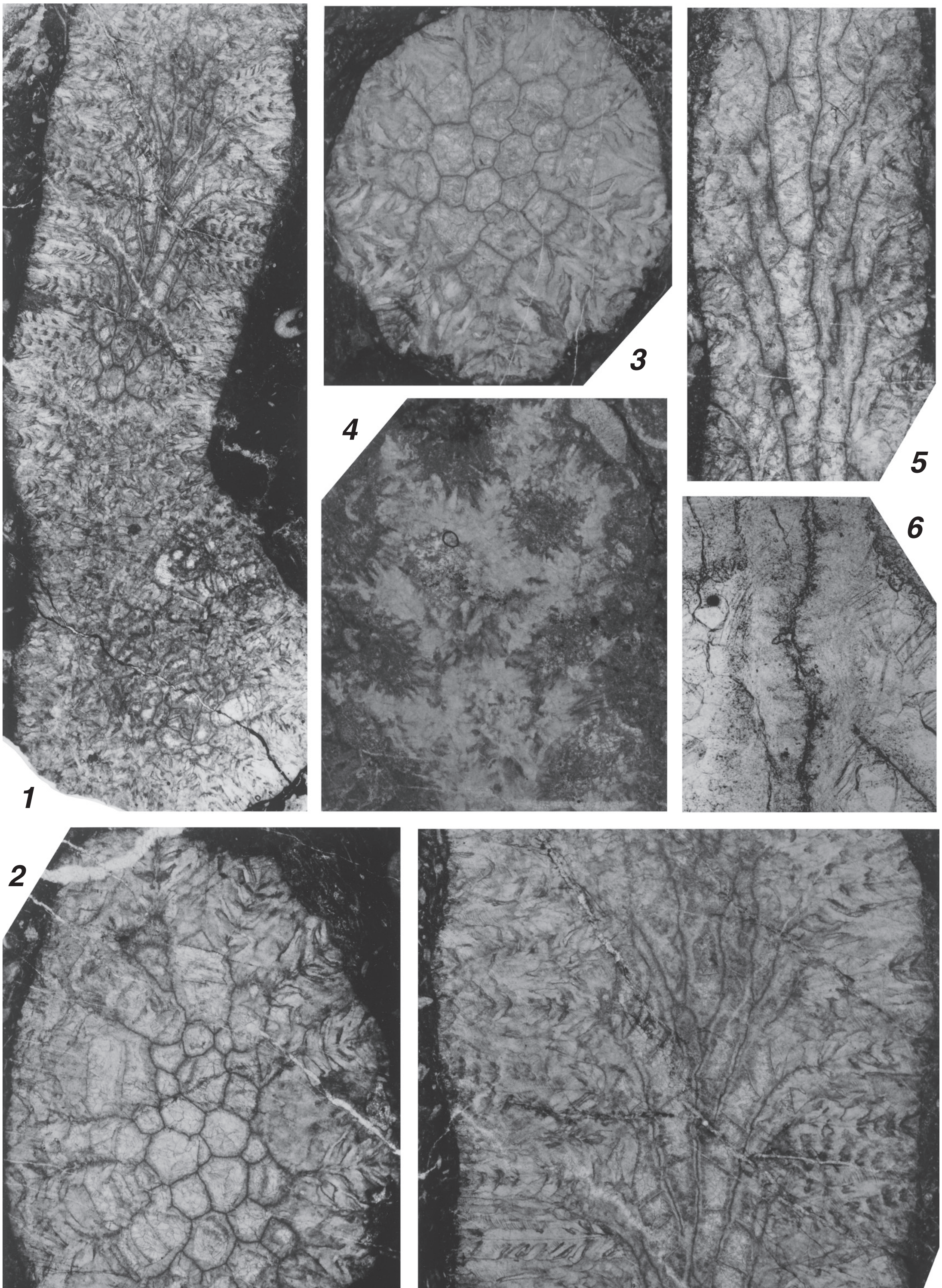
Holotype: NSM PA16666, from which 16 thin sections were made.

Other specimens: Twelve thin sections were studied from the five paratypes, NSM PA16665, 16667, 16673–16675. In addition, nine fragmentary specimens, NSM PA16661–16664, 16668–16672, were assigned to this new species.

Diagnosis: Species of *Parastriatopora* with usual branch diameters of 5–8 mm, number of corallites in transverse section of branch is 26–52; distal corallites have approximately 1.4 mm in diameter; intercorallite walls in axial zone relatively thin, 0.08–0.27 mm, then attaining 1.09 mm in peripheral zone (=peripheral stereozone); increases of new corallites common; calical opening perpendicular; mural pores well-developed in axial zone, shift to numerous tunnels in peripheral zone forming 2 rows; septal spines numerous, restricted in peripheral zone; tabulae well-developed, complete.

Description: Coralla ramose with cylindrical to subcylindrical branches, cerioid; branching rare, probably bifurcate; diameters of branches range from 3.6 to 10.3 mm, usually 5–8 mm in mature portions; total corallum diameter and growth form unknown owing to its fragile nature. Corallites prismatic in proximal portion with 4–10 sides, but outlines of corallites became obscure in distal portion; depressed corallite face and corner frequently occur; there are 26–52 corallites in transverse section of branch; each corallite consists of narrowly divergent proximal portion and distal nearly straight portion; turning from proximal to distal portions of corallite denotes sharp outwardly bend; proximal and distal portions respectively form axial and peripheral zones of branches; ratios of axial zone width per branch diameter are approximately 0.3–0.4; corallite diameters range from 0.3 to 1.7 mm, with 1.4 mm mean in distal portion; tabularia (lumina) have polygonal transverse sections in axial zone, then they almost closed by thickened intercorallite walls in peripheral zone; calices very shallow, perpendicularly oriented for branch surface; increase of new corallite lateral, commonly occurs at axial zone. Intercorallite walls in axial zone are relatively thin with 0.08–0.27 mm, composed of thin median dark line and stereoplasm, then walls abruptly thickened by addition of contiguous septa and stereoplasm, attaining 1.09 mm and forming peripheral stereozone; microstructure of stereoplasm probably rect-radiate fibers; median dark line disappears in peripheral stereozone; mural pores well-developed in axial zone, occur on corallite faces as mid-wall pores, longitudinally elongated elliptical with 0.12×0.19 mm

Fig. 3. *Parastriatopora fukuiensis* sp. nov., thin sections. **1–3**, **5–7**, holotype, NSM PA16666. **1**, longitudinal to transverse section of branch, ×5. **2**, **3**, transverse sections of branches, ×5. **5**, longitudinal section of immature branch, ×10. **6**, partial enlargement to show intercorallite wall structure, longitudinal section, ×75. **7**, partial enlargement of Fig. 3-1, showing longitudinal sections of corallites, ×10. **4**, paratype, NSM PA16674, transverse to oblique sections of distal corallites, ×10.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in diameter in typical one, forming a single row; walls in peripheral zone (=peripheral stereozone) are pierced by numerous mural tunnels that are circular to subcircular transverse sections, narrow with approximately 0.07 mm in diameter, and form two rows on each corallite face; septal spines restrict in peripheral zone, numerous, long attaining 0.44 mm, however their basal portions are anastomosed with adjoining septa, thus only short edges are recognizable in tabularium and calical pit; tabulae well-developed, complete with profiles of nearly flat or concave proximally; there are 3–6 tabulae in 2.5 mm of corallite length; most distal tabulae weakly thickened.

Etymology: The specific name is derived from prefectural name, Fukui, of the type locality.

Occurrence: Float block of argillaceous limestone at the Kamaharadani Valley (NSM PA16661). Float blocks of argillaceous limestone (NSM PA16662) and black limestone (bioclastic wackestone; NSM PA16663) at the Oboradani Valley. Float blocks of argillaceous limestone (NSM PA16664–16673) at the Tanobora Valley. Float blocks of argillaceous limestone (NSM PA16675) and black limestone (bioclastic wackestone; NSM PA16674) at the Oisedani Valley. These specimens are derived from the Oisedani Member.

Discussion: *Parastriatopora fukuiensis* sp. nov. is most similar to *P. fallacis* Yanet (and *P. f.* forma *delicata* Yanet) *in* Dubatolov *et al*. (1968, p. 82, 83, pl. 30, figs. 3a, b, pl. 34, figs. 1a, b, 2a, b, 3a, b, v) from the Lower Devonian of the Urals. Although measurements of the Russian species are not always sufficient, the new species differs from it by some respects, including the thinner intercorallite walls at the axial zone of the branches and the more numerous mural tunnels in the peripheral zone. The new species is also comparable with a Wenlock (late Early Silurian) species, *P. hyugaensis* Niko (1999, p. 116, 117, 119, figs. 3-2, 3; 4-1–6) from the G2 Member of the Gionyama Formation in Miyazaki Prefecture, however it apparently differs by having somewhat larger diameters of the branches (usually 5–8 mm versus approximately 5 mm in *P. hyugaensis*), the fewer corallites in transverse section of the branches (26–52 versus 84–104 in ditto) with less frequent increases of the new corallites, and much larger approximate diameters of the distal corallites (1.4 mm versus 0.74 mm in ditto). *Parastriatopora fukuiensis* can be easily distinguished from *P. innae* Dubatolov (1963, p. 64–66, pl. 24, figs. 1a, b, 2a, b, v, g; Niko, 2005, p. 26, 28, figs. 7-1–6; 8-1–6; Niko and Senzai, 2010, p. 52, figs. 8-6, 9), that is associated with the new species in the Oisedani Member, by having much smaller diameters of the branch and distal corallites, whose dimensions of the latter species are 16.3 mm and 2.40 mm, respectively.

Genus ***Parastriatoporella*** Chudinova, 1959

Type species: *Striatopora immota* Moore and Jeffords, 1945.

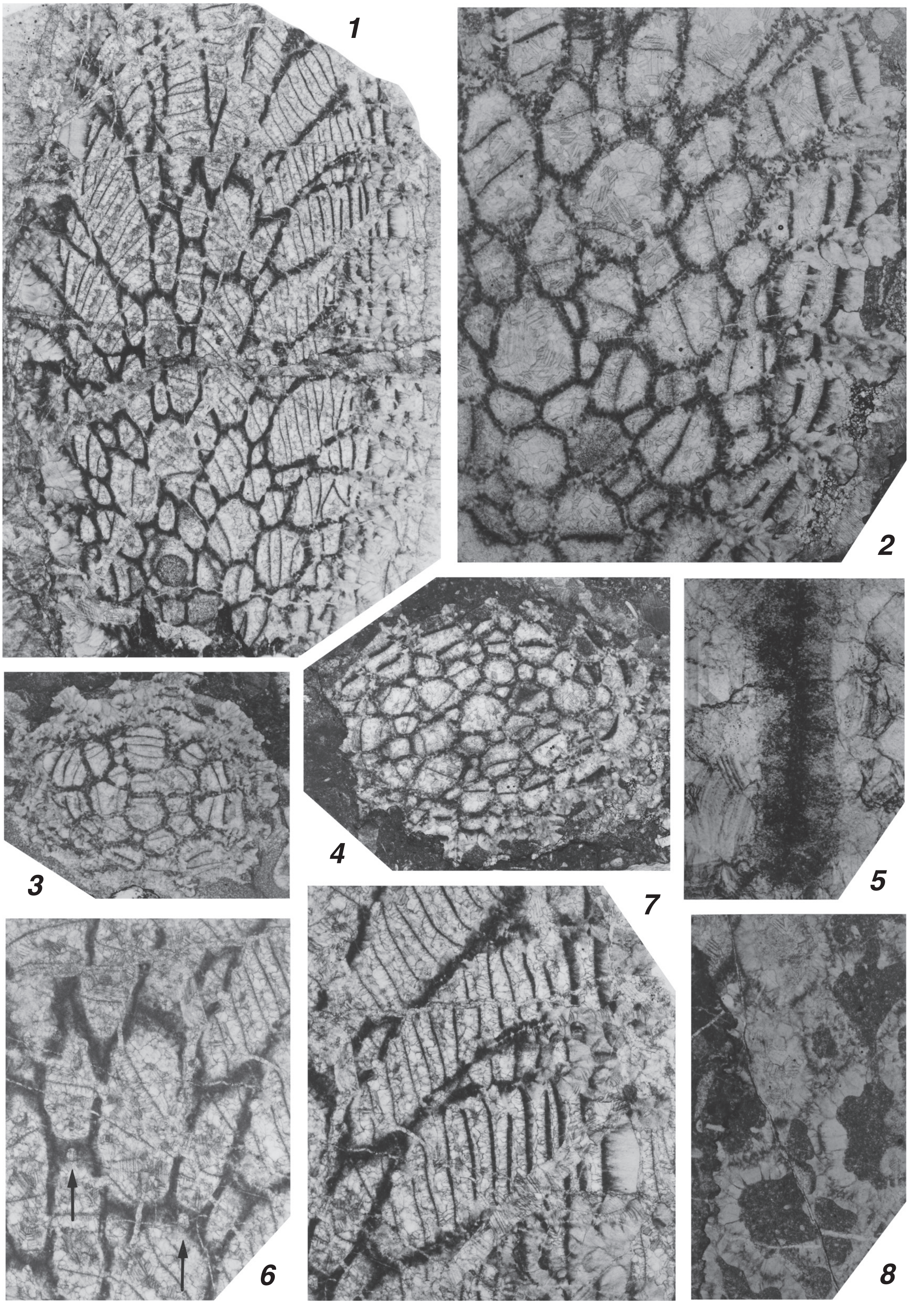
Remarks: Chudinova (1959) and Lin *et al*., (1988) believed *Parastriatoporella* to be closely related to *Parastriatopora*. Tentatively, we follow their view, and assign the genus to the family Parastriatoporidae.

Parastriatoporella arashimaensis sp. nov.

(Figs. 4-1–8)

Holotype: NSM PA16492, from which six thin sections were made.

Fig. 4. *Parastriatoporella arashimaensis* sp. nov., thin sections. **1**, **5**–**7**, holotype, NSM PA16492. **1**, oblique section of branch, ×5. **5**, partial enlargement to show intercorallite wall structure, longitudinal section, ×75. **6**, oblique sections of proximal corallites, arrows indicate mural pores, ×10. **7**, longitudinal sections of distal corallites, ×10. **2**, **4**, paratype, NSM PA16494. **2**, transverse section of branch, showing transverse sections of proximal corallites and oblique sections of distal ones, ×10. **4**, transverse section of branch, ×5. **3**, paratype, NSM PA16687, transverse section of branch, ×5. **8**, paratype, NSM PA16694, transverse sections of distal corallites, ×10.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Other specimens: Twenty-three thin sections were studied from the five paratypes, NSM PA16490, 16493, 16494, 16687, 16689. In addition, 10 specimens, NSM PA16489, 16491, 16686, 16688, 16690–16694, 16715, were also examined.

Diagnosis: Species of *Parastriatoporella* with 7–14 mm in usual branch diameter and high ratios (approximately 0.4–0.5) of axial zone width per branch diameter; full-grown corallite diameters approximately 2.0 mm; intercorallite walls thickened attaining 0.59 mm, form narrow peripheral stereozone; mid-wall pores most common, but angle pores not rare; septal spines rare in axial and well-developed in peripheral zones; tabulae well-developed, include both complete and incomplete forms; most distal tabulae thickened.

Description: Coralla ramose with cylindrical branches, cerioid; branching rare, probably bifurcate; diameters of branches rarely exceed 20 mm near branching point, but they are usually 7–14 mm; total corallum diameter and growth form unknown owing to its fragile nature. Corallites prismatic, of which profiles are 3–5 sided in most proximal and 5–10 sided (somewhat indistinct) in more distal portions; there are 38–84 corallites in transverse section of branch; each corallite consists of proximal portion with low divergent angle to central axis and outwardly curved distal one; proximal and distal portions respectively form axial and peripheral zones of branches; ratios of axial zone width per branch diameter are high for the genus, approximately 0.4–0.5; diameters of corallites are variable even in peripheral zone, ranging from 0.5 to 2.2 mm, with 2.0 mm mean in full-grown corallite; tabularia (lumina) have polygonal to subpolygonal transverse sections; calices very shallow, perpendicularly oriented to branch surface; increase of new corallite frequently occurs in axial zone. Intercorallite walls consist of median dark line and stereoplasm, relatively thin in axial to inner peripheral zone, 0.10–0.20 mm, and abruptly thickened by addition of stereoplasm and partly contiguous septa, attaining 0.59 mm in outer peripheral zone; microstructure of stereoplasm rect-radiate fibers; distal ends of thickened intercorallite walls form narrow peripheral stereozone, thus calical pits are narrowed with substellate to somewhat irregular in transverse sections; mural pores well-developed to abundant, longitudinally elongated in profiles, 0.18×0.21 mm in diameter in typical one; mid-wall pores on corallite faces are most common, but angle pores at corallite corners are not rare; arrangement of mid-wall pores is a single row in axial zone and two rows in peripheral zone; in peripheral stereozone, mural pores shift to narrow tunnels with subcircular profiles, having 0.04–0.08 mm in diameter; some mural pores closed by pore plates; septal spines rare in axial to inner peripheral zones, well-developed in outer peripheral zone (=peripheral stereozone), high conical or rod-like in rare cases; usual length of septal spines 0.12–0.25 mm; tabulae well-developed, usually complete, but incomplete and vesicular tabulae frequently recognized in peripheral zone, where their spacing becomes closer than that in axial zone; profiles of complete tabulae are nearly flat; most distal 2–6 tabulae thickened and attain to approximately 0.6 mm; there are 1–9 tabulae in 2.5 mm of corallite length.

Etymology: The specific name is taken from a famous mountain, named Mt. Arashima-dake, near the type locality.

Occurrence: Light gray limestone (bioclastic wackestone) at locality KU-4 (NSM PA16690, 16691). Float blocks of light gray to light brownish gray limestone (bioclastic wackestone) near locality KU-4 (NSM PA16490–16494, 16686–16689, 16692–16694, 16715). Float block of light gray limestone (bioclastic wackestone) in the Oboradani Valley (NSM PA16489). These specimens are derived from the uppermost part of the Hakubado Member.

Discussion: The distinctive features of *Parastriatoporella arashimaensis* sp. nov. include its wide axial zone in comparing branch diameter and narrow peripheral stereozone. These features distinguish it from other known species of *Parastriatoporella*. Previous records of the genus were

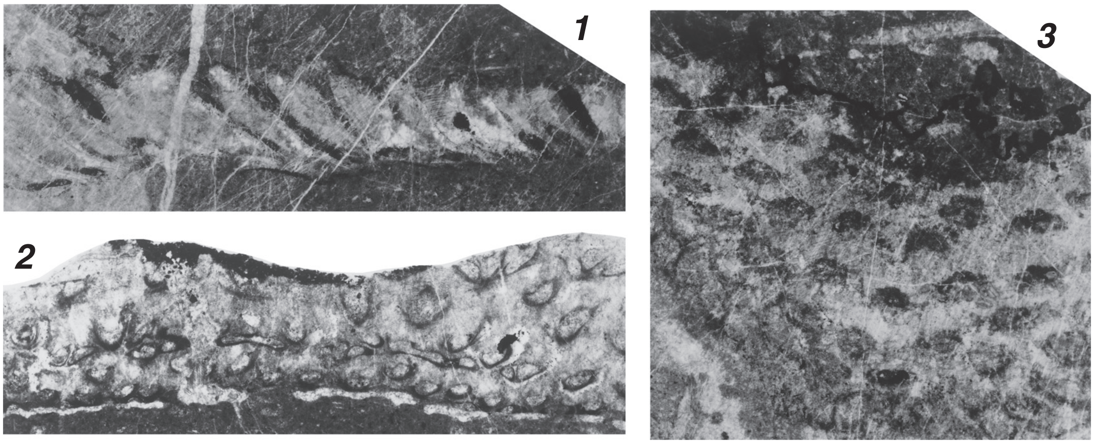

Fig. 5. *Planocoenites ozakii* Niko, 2003, NSM PA16696, thin sections. **1**, longitudinal section of corallum, showing longitudinal sections of corallites, ×10. **2**, longitudinal section of corallum, showing transverse sections of corallites, ×10. **3**, transverse section of corallum, showing transverse sections of distal corallites, ×14.

restricted in the Carboniferous of North America, thus the new occurrence in the uppermost part (probably Eifelian) of the Hakubado Member, Kamianama Formation, Central Japan extends its geographic and stratigraphic ranges.

Hitoeganella hidensis Niko (2004, p. 32, 34, figs. 6-1–6; 7-1–7; the type and only known species of the genus), from the Upper Silurian (probably late Ludlow) Hitoegane Formation of the Gifu Prefecture, is somewhat similar to *Parastriatoporella arashimaensis*, but differs in having the exceptionally thickened and anastomosed distal tabulae that are major constituent of the peripheral stereozone, and the fewer septal spines in the peripheral zone of the branches.

Suborder Alveolitina Sokolov, 1950

Family Coenitidae Sardeson, 1896

Genus ***Planocoenites*** Sokolov, 1952

Type species: *Coenites orientalis* Eichwald, 1861.

Planocoenites ozakii Niko, 2003

(Figs. 5-1–3)

Planocoenites ozakii Niko, 2003, p. 21, 23, 24, figs. 2-5; 3-1–4; Hirata, 2006, p. 24, pl. 6, figs. 19-1, 2.

Material examined: Two coralla, NSM PA16696, 16697.

Occurrence: Float blocks of argillaceous limestone (NSM PA16696) in the Kamaharadani Valley and black limestone (bioclastic wackestone; NSM PA16697) in the Oisedani Valley. These specimens are derived from the Oisedani Member.

Remarks: On the basis of the specimens from the lower part of the Takaharagawa Member in the Fukuji area, *Planocoenites ozakii* has been adequately described by Niko (2003), thus the diagnostic features are not repeated here.

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