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Late Silurian orthocerid cephalopods from the Suberidani Group, Tokushima Prefecture, Southwest Japan

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Abstract: Orthocerid cephalopods are described for the first time from the Ludlow (early late Silurian) limestone of the Suberidani Group in the Kurosegawa Belt. The examined specimens occur from float brocks collected in the Katuura area, Tokushima Prefecture, Southwest Japan. Four species, *Michelinoceras* (*Michelinoceras*) *alticameratum* Kobayashi, 1984, *Kopaninoceras kobayashii* Niko, Hamada and Yasui, 1989, *Orthocycloceras* sp., and *Arionoceras tokushimaense* sp. nov., are identified. The Suberidani assemblage belongs to the *Kopaninoceras* Fauna developed in the northern margin of Gondwana. This discovery is new evidence suggesting a Gondwana origin of the Kurosegawa Belt.

Introduction

The Silurian to Devonian Suberidani Group (Hirayama et al., 1956) is an unmetamorphosed constituent of the Kurosegawa Belt that crops out in the Katuura area of Tokushima Prefecture, Southwest Japan (Figures 1.A, 1.B). It is divided into the lowest limestone dominant unit (10−19 m thick) and the main clastic unit (more than 475 m thick), which consists mostly of sandstone with intercalations of volcanic and volcaniclastic rocks (Hamada, 1959; Hamada, 1965; Wakamatsu et al., 1990). Although limestone of the lowest unit yields diverse marine fauna, they have been undocumented with the exception of some tabulate corals including halysitids (Yamashita, 1946), aulocystids (Niko, 2001), and pachyporids (Niko, 2003). Among the unestablished taxa, the present paper focuses on cephalopods for the first time and discusses their paleobiogeographic significance. The examined fossil specimens herein occur in float brocks of limestone collected from the river-bed of the Miyaga-dani Valley (Loc. 1) and an abandoned quarry in the Chouzuga-dani Valley (Loc. 2). Detailed geographic positions of the both localities are given in Figure 1.C. Coral data indicate that the limestone dominant unit can be correlative with the Ludlow (lower upper Silurian) G3 Member of the Gionyama Formation (Yamashita, 1946; Niko, 2001, 2003).

Except for preliminary reports, such as Hamada (1961; *Geisonocerina*? sp. from the Gionyama Formation) and Hirata (1965; *Orthoceras* sp. from the Yokokurayama Group), the first reliable study about Silurian cephalopods in Japan was conducted by Kobayashi (1983), in which the presence of six Ludlow species of orthocerids from the Yokokurayama Group was revealed. The specific composition of the assemblage subsequently compensated by Kobayashi (1894) and Niko et al. (1989, 2017) is as follows: *Michelinoceras* (*Michelinoceras*) *alticameratum* Kobayashi, 1984 (? = *M. mizobuchii* Kobayashi, 1984), *Kopaninoceras kobayashii* Niko, Hamada and Yasui, 1989, *Orthocycloceras gomiense* Kobayashi, 1983, *O.* aff. *gomiense*, *Leurocycloceras*? sp. indet., *Arionoceras densiseptum* Kobayashi, 1983, *Protokionoceras fessicancellatum* Kobayashi, 1984, and geisonoceratid gen. et sp. indet. These strata, as with the Suberidani Group, belong to the Kurosegawa Belt. Additionally, the other structural belts, South Kitakami and Hida-Gaien, containing Middle Paleozoic rocks, also yield Silurian cephalopods. Of those, Niko (2016) described only a single species, *Bandoceras gifuense* Niko, 2016, from the Ludlow Hitoegane Formation belonging to the Hida-Gaien Belt. It can be said that our knowledge on Japanese Silurian cephalopods is still insufficient; therefore, the present new discovery from the Ludlow unit of the Suberidani Group is noteworthy.

Repository.—All specimens are stored in the Tohoku University Museum (Institution abbreviation: IGPS = Institute of Geology and Paleontology, Faculty of Science, Tohoku University, Sendai).

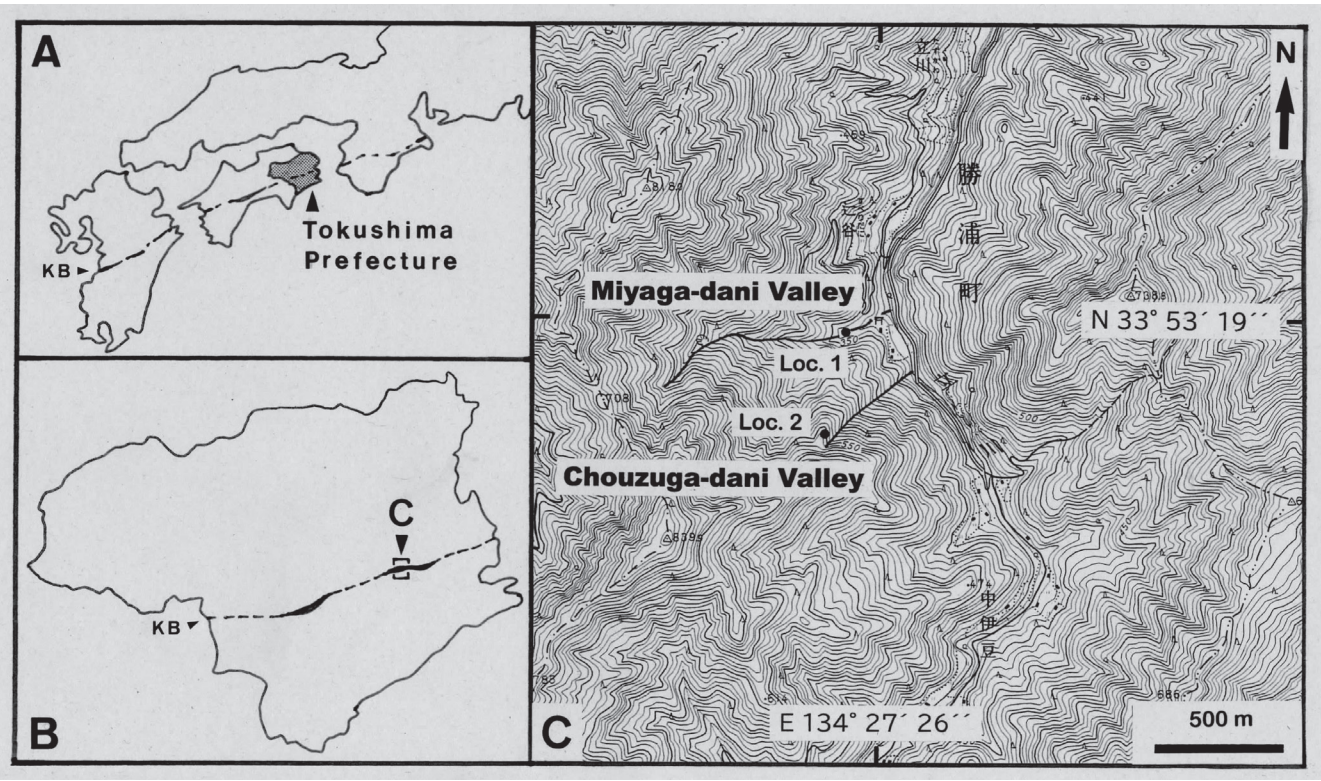


Figure 1. Maps showing distribution of the Kurosegawa Belt (KB) and location of Tokushima Prefecture in Southwest Japan (**A**), distribution of the Kurosegawa Belt and location of studied area in Tokushima Prefecture (**B**), detailed locations of collecting sites of cephalopods in the Katuura area (**C**). Used topographic map is "Ai" scale 1:25,000 published by the Geospatial Information Authority of Japan.

Systematic Paleontology

Order Orthocerida Kuhn, 1940
Superfamily Orthoceratoidea M'Coy, 1844
Family Orthoceratidae M'Coy, 1844
Subfamily Michelinoceratinae Flower, 1945
Genus ***Michelinoceras*** Foerste, 1932
Type species.—*Orthoceras michelini* Barrande, 1866.
Subgenus ***Michelinoceras*** Foerste, 1932, emend. Kiselev and Gnoli, 1992

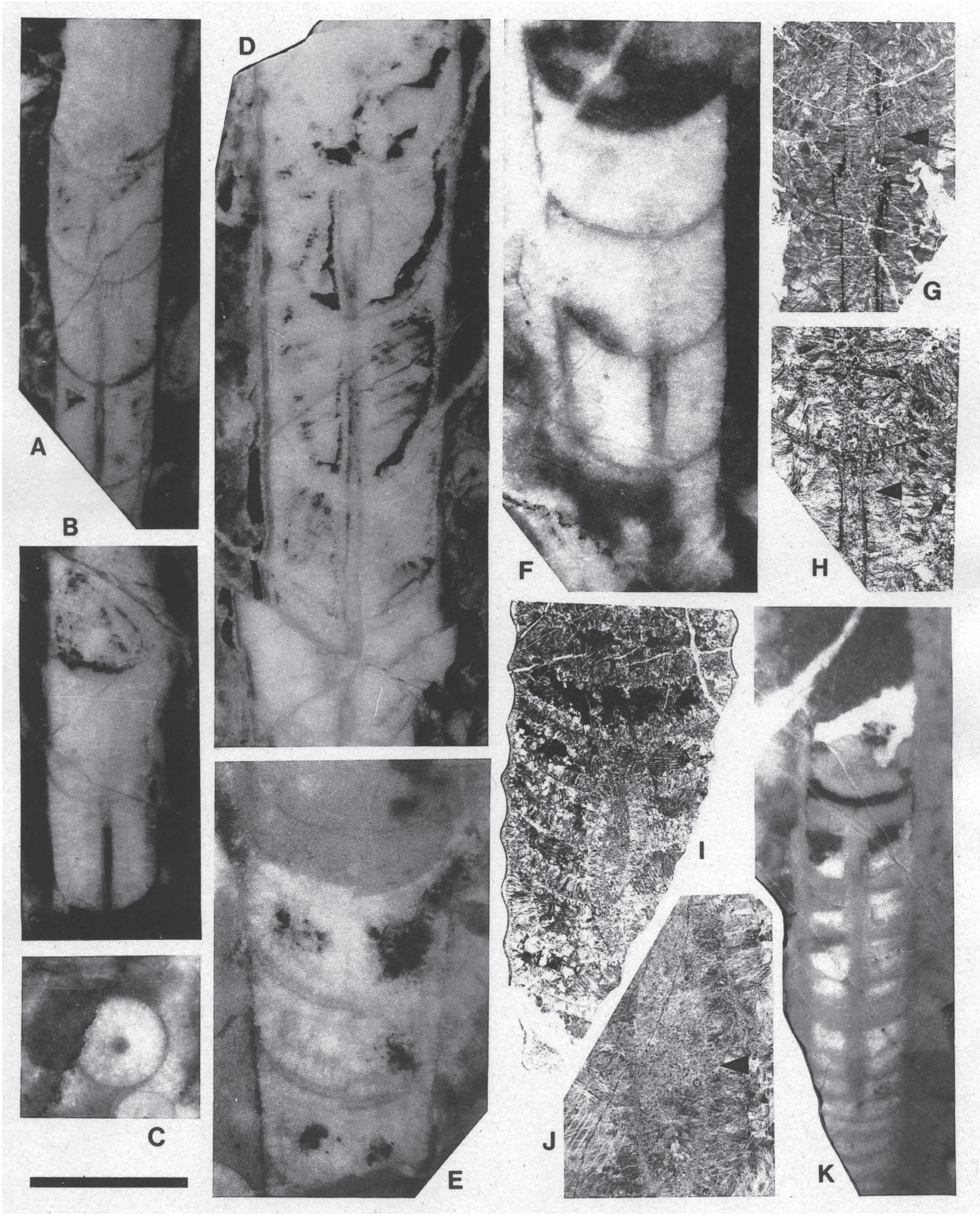
Michelinoceras* (*Michelinoceras*) *alticameratum
Kobayashi, 1984
Figures 2.A−2.D, 2.G

Michelinoceras sp. α, sp. nov., Kobayashi, 1983, p. 293, fig. 1.
Michelinoceras alticameratum Kobayashi, 1984, p. 245, pl. 3, fig. 1; 1988, p. 1.

Description.—Longiconic large orthocones with circular cross section; conch expansion is gradual, approximately 4° in angle; the largest specimen (IGPS coll. cat. no. 112448)

→

Figure 2. A−D, G. *Michelinoceras* (*Michelinoceras*) *alticameratum* Kobayashi, 1984. A, IGPS coll. cat. no. 112446, longitudinal polished section: B, IGPS coll. cat. no. 112447, longitudinal (dorsoventral) polished section, venter on right: C, IGPS coll. cat. no. 112449, transverse polished section, venter down: D, G, IGPS coll. cat. no. 112448; D, longitudinal polished section; G, longitudinal thin section, showing siphuncular structure, arrow indicates septal neck. **E, F, H.** *Kopaninoceras kobayashii* Niko, Hamada and Yasui, 1989. E, IGPS coll. cat. no. 112455, longitudinal (slightly off conch center) polished section: F, H, IGPS coll. cat. no. 112452; F, longitudinal (dorsoventral) polished section, venter on right; H, longitudinal thin section, arrow indicates septal neck. **I−K.** *Orthocycloceras* sp., IGPS coll. cat. no. 112456. I, longitudinal thin section: J, partial enlargement of I, arrow indicates septal neck: K, longitudinal polished section. Scale bar is 15 mm in A, B, D, K; 6 mm in C, E−G, I; 3 mm in H, J.


A
B
C
D
E
F
G
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I
J
K

attains 20 mm in conch diameter; shell surface probably smooth; apex and body chamber are not preserved. Camerae long to relatively long with form ratios (maximum width/length) of 1.0−1.4; septa deep; sutures directly transverse; siphuncle narrow and slightly subcentral in position; siphuncular wall consists of orthochoanitic septal necks and cylindrical connecting rings; length of septal neck is very long, attaining 2.5 mm at approximate conch diameter of 13 mm. Cameral deposits episeptal-mural.

Material examined.—IGPS coll. cat. nos. 112443−112450.

Occurrence.—Locs. 1 (IGPS coll. cat. nos. 112443−112449) and 2 (IGPS coll. cat. no. 112450).

Discussion.—The present material including large specimens from the Suberidani Group is assigned to *Michelinoceras* (*Michelinoceras*) *alticameratum* from the Yokokurayama Group in the Yokokurayama area, Southwest Japan, based on angles of conch expansion and slightly subcentral siphuncular position. Because *M.* (*M.*) *alticameratum* was represented by an only known holotype whose adoral end has 9 mm in diameter, the new specimens indicate more adoral shell characters.

Genus ***Kopaninoceras*** Kiselev, 1969

Type species.—*Orthoceras jucundum* Barrande, 1870.

Kopaninoceras kobayashii Niko, Hamada and Yasui, 1989

Figures 2.E, 2.F, 2.H

Kopaninoceras kobayashii Niko, Hamada and Yasui, 1989, p. 61, 63, figs. 2.A, 2.B.

Description.—Longiconic orthocones with circular cross section; conch expansion is relatively rapid, approximately 9° in angle; the largest specimen (IGPS coll. cat. no. 112455) attains 8 mm in conch diameter; shell surface probably smooth; apex and body chamber are not preserved. Cameral length varies from short to relatively long with form ratios (maximum width/length) of 1.4−3.5; septa relatively deep; sutures slightly oblique; siphuncle narrow and subcentral in position; siphuncular wall consists of orthochoanitic septal necks and cylindrical connecting rings; length of septal neck is long, 1.2 mm at conch diameter of 5 mm; septal necks converge faintly adapically and indicate narrow funnel-shape, where siphuncle shallowly constricted. Camera filled with calcite that may be recrystallized cameral deposits.

Material examined.—IGPS coll. cat. nos. 112451−112455.

Occurrence.—Locs. 1 (IGPS coll. cat. nos. 112451−112453) and 2 (IGPS coll. cat. nos. 112454, 112455).

Discussion.—The author cannot detect differences in most of the important taxonomic criteria, including general conch shape, cameral length, siphuncular position and nature of siphuncular wall, between the Suberidani specimens and the type series of *Kopaninoceras kobayashii*, that was collected from the Yokokurayama Group (Niko et al., 1989).

Subfamily Leurocycloceratinae Sweet, 1964

Genus ***Orthocycloceras*** Barskov, 1972

Type species.—*Orthocycloceras alayense* Barskov, 1972.

Orthocycloceras sp.

Figures 2.I−2.K

Description.—A single longiconic specimen of annulated orthocone was available for study, whose cross section is circular and adoral part represents body chamber; conch expansion is gradual, approximately 3° in angle; conch diameter attains 10 mm; there are 4−5 annuli in length of corresponding conch diameter; apex and peristome are not preserved. Camerae short to very short with approximate form ratios (maximum width/length) of 3−6 in usual camerae and attaining 15 in the last camera; sutures slightly oblique; siphuncle relatively large for the family and central in position; siphuncular wall consists of orthochoanitic septal necks and weakly inflated connecting rings; length of septal neck is short, 0.4 mm at conch diameter of 8 mm. Cameral deposits episeptal-mural.

Material examined.—IGPS coll. cat. no. 112456.

Occurrence.—Loc. 2.

Discussion.—This poorly preserved specimen shows close similarities to *Orthocycloceras gomiense* Kobayashi, 1983, from the Yokokurayama Group, but differs by its shorter camerae and weakly inflated connecting rings. Because of insufficient material, it is left in open nomenclature.

Family Arionoceratidae Dzik, 1984

Genus ***Arionoceras*** Barskov, 1966

Type species.—*Orthoceras arion* Barrande, 1866.

Arionoceras tokushimaense sp. nov.

Figures 3.A−3.I

Diagnosis.—Species of *Arionoceras* with depressed conch cross sections; camerae short; cameral form ratios ranges from 3.0 to 4.9; sutures slightly incline toward dorsum; siphuncle nearly central in apical and subcentral in more adoral shells, thus its position ratios decrease to 0.4; septal necks orthochoanitic and very short, 0.19−0.63 mm.

Description.—Conchs longiconic orthocones with moderate to relatively rapid expansion, whose angle ranges from 8° to 10°; cross sections of conch are dorsoventrally depressed oval with approximate form ratio (lateral diameter/dorsoventral diameter) of 1.3; the largest specimen of fragmentary phragmocone (holotype) has 15

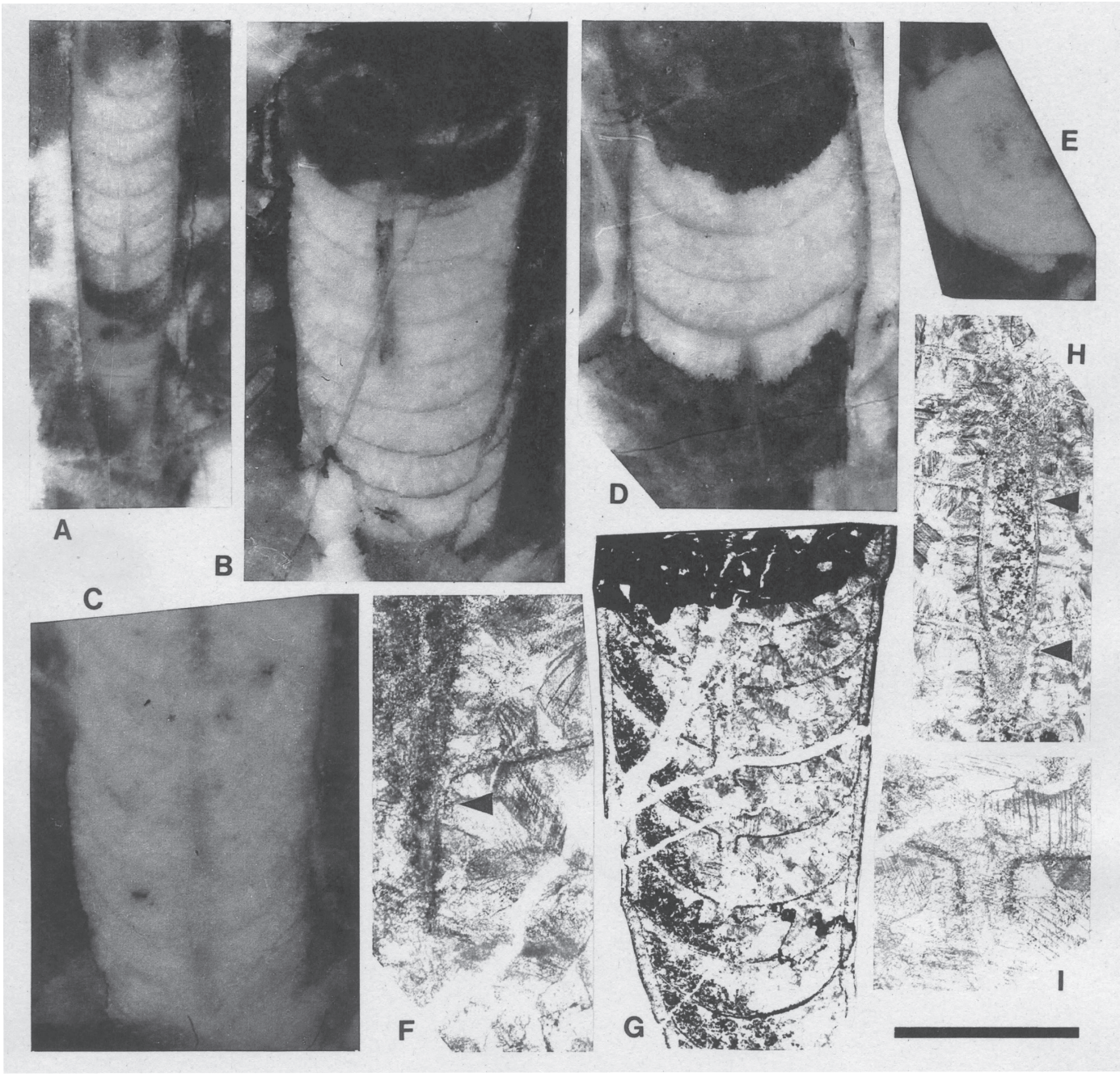

Figure 3. *Arionoceras tokushimaense* sp. nov. **A.** Paratype, IGPS coll. cat. no. 112458, longitudinal (slightly oblique) polished section; venter on right. **B, F.** Holotype, IGPS coll. cat. no. 112461: B, longitudinal (dorsoventral) polished section, venter on left: F, longitudinal (dorsoventral) thin section, showing ventral siphuncular wall, arrow indicates septal neck. **C, E.** Paratype, IGPS coll. cat. no. 112463: C, longitudinal (slightly off conch center) polished section: E, transverse polished section, venter down. **D, H.** Paratype, IGPS coll. cat. no. 112462: D, longitudinal (slightly oblique) polished section: H, longitudinal (slightly oblique) thin section, arrows indicate septal necks. **G, I.** Paratype, IGPS coll. cat. no. 112457: G, longitudinal (dorsoventral) thin section: I, partial enlargement of G to show details of septal neck. Scale bar is 6 mm in A−E; 0.6 mm in F, I; 2.1 mm in G, H.

mm in length and 8 mm in adoral dorsoventral diameter; shell surface probably smooth; apex and body chamber are not preserved. Camerae short with form ratios (maximum dorsoventral width/length) of 3.0−3.9 in a paratype (IGPS coll. cat. no. 112457, approximately 3 mm in dorsoventral diameter) representing apical shell and 4.1−4.9 in the holotype; sutures straight and slightly incline toward dorsum; siphuncle narrow; diameters of siphuncle are 0.21 mm in apical shell and 0.73 mm in the holotype; siphuncular position nearly central in apical shell, then it becomes subcentral with 0.4 in position ratios (distance between central axis of siphuncle and surface of ventral shell surface/ corresponding dorsoventral conch diameter) at more adoral shells; siphuncular wall consists of orthochoanitic septal necks and cylindrical connecting rings; length of septal neck is very short, 0.19 mm in apical shell and 0.63 mm in the holotype; connecting rings thin, undifferentiated. Cameral deposits episeptal-mural; no endosiphuncular deposits developed.

Material examined.—Holotype, IGPS coll. cat. no. 112461. Paratypes, IGPS coll. cat. nos. 112457, 112458, 112462, 112463. In addition, four poorly preserved specimens, IGPS coll. cat. nos. 112459, 112460, 112464, 112465, were also examined.

Occurrence.—Locs. 1 (IGPS coll. cat. nos. 112457−112463) and 2 (IGPS coll. cat. nos. 112464, 112465).

Etymology. —The specific name is derived from Tokushima Prefecture.

Discussion.—*Arionoceras tokushimaense* sp. nov. is somewhat similar to *A. densiseptum* Kobayashi, 1983, but the new species has shorter camerae and more eccentric siphuncular position in the adoral shells than those of the previously known species from the Yokokurayama Group. The type species of the genus, *A. arion* from the Prague Basin in Bohemia, differs from the new species by its circular cross sections of the conch and nearly central siphuncular position even in the adoral shells. *Arionoceras mahsuri* Niko, Sone and Leman, 2017, from the Langkawi Islands, Malaysia, clearly differs from the new species by its much longer camerae.

Significance

The orthocerid cephalopod assemblage of the Suberidani Group described here is composed of *Michelinoceras* (*Michelinoceras*) *alticameratum*, *Kopaninoceras kobayashii*, *Orthocycloceras* sp., and *Arionoceras tokushimaense* sp. nov. It has greater affinity with that of the Yokokurayama Group. *Michelinoceras* (*M.*) *alticameratum* and *K. kobayashii* are common to both assemblages. In addition, there are related species in the Yokokurayama assemblage for a species of *Orthocycloceras* left in open nomenclature and *A. tokushimaense*, i.e., *O. gomiense* and *A. densiseptum*. Niko et al (2017) posted the *Kopaninoceras* Fauna and indicated that it includes a local cephalopod assemblage from the Yokokurayama Group. Consequently, the Suberidani assemblage also belongs to the *Kopaninoceras* Fauna. Because the main territory of the *Kopaninoceras* Fauna was the northern margin of Gondwana including North Africa, Variscan Europe, southern Afghanistan, western Tibet, and Malaysia (Niko et al., 2017), this new discovery provides additional paleontological evidence supporting Hada and Yoshikura's (1999) theory that the Kusosegawa Belt has a Gondwana origin.

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