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Cover image: Body design of Final Jomon Pottery drawn by the technigue of “erased-over cord impressions”. Original photograph by Miki Kikuchi.

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Virgilian (Late Pennsylvanian) coiled nautiloids from the Finis Shale Member of the Graham Formation in Texas, southern Midcontinent North America

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Abstract: Nine species of Virgilian (Late Pennsylvanian) coiled nautiloids are described from the Finis Shale Member of the Graham Formation in north-central Texas, southern Midcontinent of North America. They include *Tainoceras monilifer* Miller, Dunbar and Condra, *Metacoceras quadratum* sp. nov., *Endolobus sturgeoni* sp. nov., *Domatoceras tuckeri* sp. nov., *Titanoceras* sp., *Solenochilus jackense* sp. nov., *Liroceras liratum* (Girty), *Peripetoceras bridgeportense* Tucker and Mapes, and *Ephippioceras ferratum* (Cox). The habitat of the nautiloid assemblage was the low latitudes in the Marginal Sea of the Panthalassic Ocean. Strong biotic linkage between the Marginal Sea and the southern Late Pennsylvanian Midcontinent Sea is confirmed.

Introduction

The Finis Shale Member, introduced by Plummer and Moore (1922), is an early Virgilian (Late Pennsylvanian = latest Carboniferous) unit in the Graham Formation, Cisco Group. It varies between 15−60 m in thickness and consists mainly of shale characterized by the abundant presence of ironstone concretions; it also contains sandstone and limestone in its basal part (Plummer and Hornberger, 1936). This member outcrops in north-central Texas near the Oklahoma border and west of Dallas on the southern Midcontinent of North America (McGowen *et al*., 1972; Barnes *et al*., 1987). A diverse marine fauna, including foraminifers, sponges, cnidarians and mollusks, is recorded from the member, and exceptionally well-preserved cephalopod specimens provide material for taxonomic (Miller *et al*., 1933; Plummer and Scott, 1937; Miller and Downs, 1950; Furnish *et al*., 1962; Hansman, 1965; Mapes, 1979; McKinzie and McLeod, 2003; Doguzhaeva *et al*., 1999, 2006; Niko and Mapes, 2010, 2011; Mutvei *et al*., 2012; Mutvei and Mapes, 2018), biostratigraphic (Boardman *et al*., 1994), and bionomic (Mapes, 1987; Mapes *et al*., 1995; Mapes and Chaffin, 2003; Wani *et al*., 2012) studies. Adding to these, the present paper analyzes coiled nautiloids as the third fascicle in our recent studies describing non-ammonoid cephalopods of the member and discusses their faunal significance.

Fossil material used in this serial project was recovered from dark gray (to brownish-yellowish in weathered parts) shales near Jacksboro, north-central Texas at 16 localities. These comprise exposures (Figure 1) at pond dams (TXV-34, 84), on hill sides (TXV-36, 78), at barren glades with grooves, gullies to ravines (TXV-40, 54, 55, 56, 61, 120), at road sites (TXV-60, 62), on the east slope of Lost Creek (TXV-63), at the Old Lake Jacksboro Dam and spillway (TXV-69), near an abandoned oil well pad excavation (TXV-92), and at the excavation that serves as emergency spillway for Lost Creek Lake (Lake Jacksboro; TXV-200).

Repository.—The specimens examined in the present paper are reposited in the paleontological collections of the American Museum of Natural History in New York City (prefixed AMNH) and the Tohoku University Museum in Sendai (prefixed IGPS).

Systematic Paleontology

Subclass Nautiloidea Agassiz, 1847
Order Nautilida Agassiz, 1847
Superfamily Tainoceratoidea Hyatt, 1883
Family Tainoceratidae Hyatt, 1883
Genus ***Tainoceras*** Hyatt, 1883
Type species.—*Nautilus quadrangulus* McChesney, 1859.

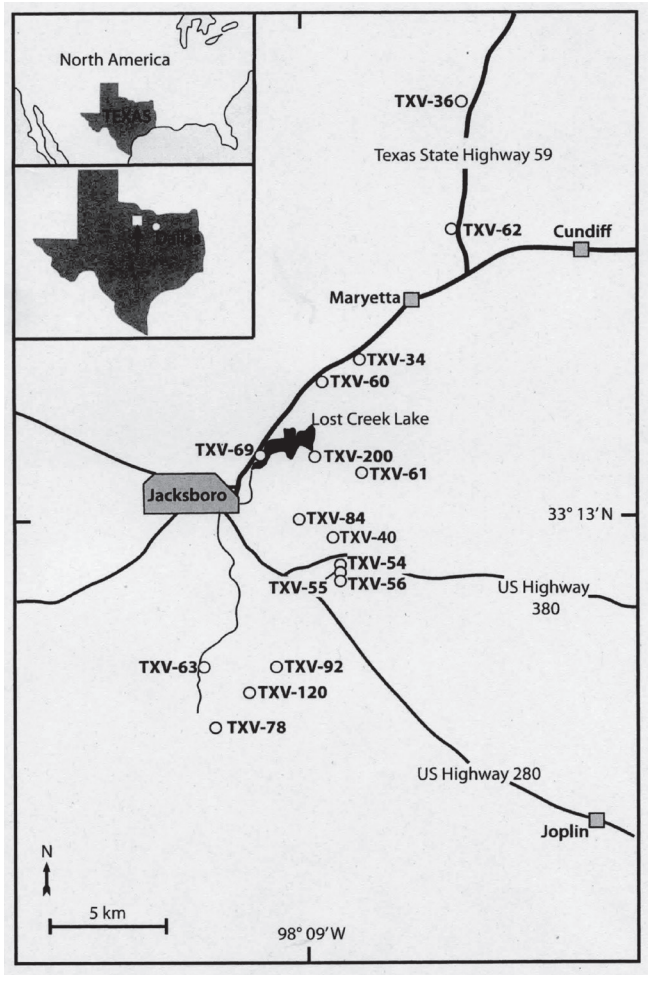

Figure 1. Map showing the geographic positions of non-ammonoid cephalopod localities in the Finis Shale Member near Jacksboro, north-central Texas.

Tainoceras monilifer Miller, Dunbar and Condra, 1933
Figure 2

Tainoceras monilifer Miller, Dunbar and Condra, 1933, p. 148–151, pl. 10, figs. 1–5, text-fig. 23; Unklesbay, 1962, p. 31–33, pl. 2, fig. 10; Tucker, 1976, p. 59, pl. 1, fig. 7, text-figs. 1a, b.

[not] *Tainoceras monilifer*; Miller and Unklesbay, 1942a, p. 142, 143, pl. 4, figs. 1–3 [figs. 1, 2 = *T. sexlineatum* Tucker, 1976; fig. 3 = *T*. sp. nov.]; 1947, p. 322, 323.

Tainoceras sp., Mapes and Chaffin, 2003, figs. 4A, 4D, 4F; McKinzie and McLeod, 2003, p. 88, fig. 4-32 top.

Description.—Conchs moderate in size, having 140 mm in reconstructed diameter, discoidal and evolute with gradual whorl expansion; umbilicus perforated; except for embryonic to juvenile shell indicating subcircular whorl sections, more adoral shells have dorsoventrally depressed and subquadrate whorl sections with width/height ratios of 1.3–2.1; profiles of adoral whorls consist of weakly inflated venter with a median groove, straight flanks, straight umbilical zone obtusely converging to dorsum and shallowly rounded impressed area; apex corn-shaped. Shell surface ornamented by oblique lirae in embryonic to juvenile shell, then these lirae become subdued and nodes are added on venter and at ventrolateral and umbilical angles; ventral nodes closely spaced, laterally elongated, forming two rows due to separation by a median groove; nodes at ventrolateral angles are strongly protruded. Septa shallow forming sutures with sub-triangular to broadly rounded ventral lobes, weak ventrolateral saddles, and relatively deep lateral lobes; siphuncle central to faintly subcentral in position.

Material examined.—AMNH 5998–6014, 6016–6080, 6474–6483.

Occurrence.—The holotype of *Tainoceras monilifer* was collected from the Finis Shale Member near Jacksboro, Texas (Miller *et al*., 1933). Specimens of this species are also known from the Upper Pennsylvanian of the Iatan Limestone in Nebraska (Miller *et al*., 1933), the Lawrence Shale, the Kereford and Burlingame Limestones in Kansas, and the Vamoosa Formation in Oklahoma (Unklesbay, 1962).

Localities of each examined specimen in this study are as follows; TXV-34 (AMNH 5998–6010, 6474–6483), TXV-55 (AMNH 6011), TXV-56 (AMNH 6012–6014, 6016–6022), TXV-120 (AMNH 6023–6025), TXV-200 (AMNH 6026–6080).

Discussion.—Miller and Unklesbay (1942a) assigned three specimens, Carnegie Museum cat. nos. 149, 10.434, and 22.299, from the Upper Pennsylvanian Conemaugh Formation of Pennsylvania to *Tainoceras monilifer*. Tucker (1976) reexamined them and concluded that 1) the former one is undoubtedly assignable to *T. monilifer* and 2) the latter two need to be separated from the species and designated as the types of a new species, *T. sexlineatum* Tucker, 1976. Although his second opinion is reasonable, we cannot agree with his first decision because the ventral nodes of specimen no. 149 vanish in the adoral shell; this diagnosis is not known from any previously named species of *Tainoceras*. Thus, this specimen (Carnegie Museum cat. no. 149) probably represents a new species. In addition, Tucker (1976) synonymized *T. murrayi* Miller and Unklesbay, 1942b, with *T. monilifer*. This taxonomic treatment is also unacceptable. *Tainoceras murrayi* is well differentiated from *T. monilifer* by the absence of nodes at umbilical angles.

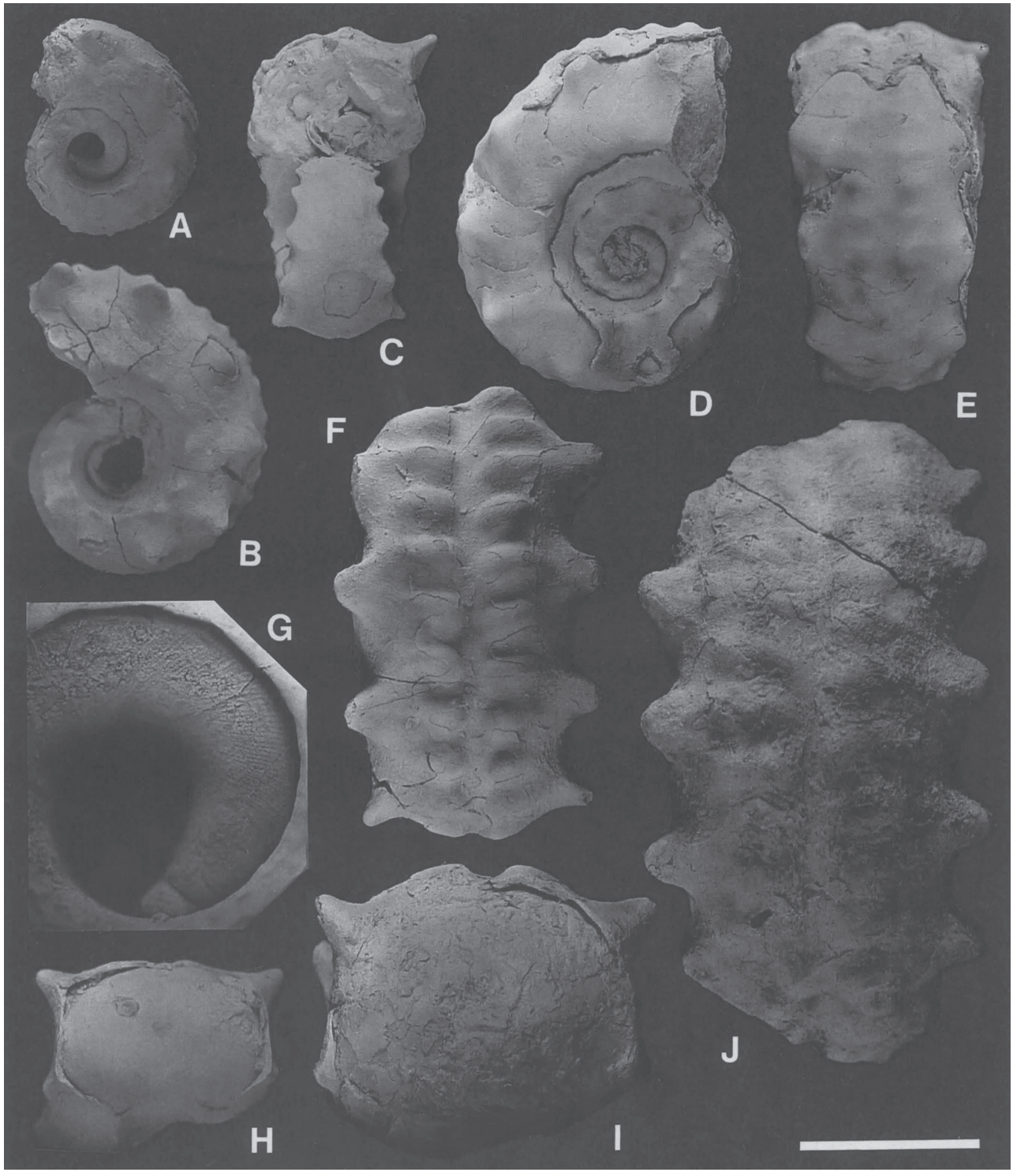

Figure 2. *Tainoceras monilifer* Miller, Dunbar and Condra, 1933. **A, G.** AMNH 6023: A, lateral view; G, partial enlargement of A to show embryonic to early juvenile shell morphologies. **B, C.** AMNH 6038: B, lateral view; C, ventral-apertural view. **D, E.** AMNH 6068, shell wall mostly exfoliated: D, lateral view; E, ventral view. **F, I.** AMNH 6007: F, ventral view; I, septal view, venter up. **H.** AMNH 6060, septal view, venter up. **J.** AMNH 6077, ventral view. Scale bar is 30 mm in A–F, J; 6 mm in G; 20 mm in H, I.

Genus ***Metacoceras*** Hyatt, 1883

Type species.—*Nautilus* (*Discus*) *sangamonensis* Meek and Worthen, 1860.

Metacoceras quadratum sp. nov.
Figure 3

Metacoceras sp., Mapes and Chaffin, 2003, fig. 4E; McKinzie and McLeod, 2003, p. 88, fig. 4-31.

Diagnosis.—Small species of *Metacoceras* with whorl sections of depressed subtrapezoidal in adoral phragmocones and depressed subquadrate shape in body chamber; width/height ratios of whorls usually 1.4–1.9; concavities of impressed area shallow to very shallow; nodes strongly protruded, possess weak bulla-like extension.

Description.—Conchs small, discoidal and evolute with gradual whorl expansion; umbilicus perforated; the holotype (largest specimen) represents an imperfect body chamber with the last septum and is 40 mm in length, 24 mm in maximum whorl width and 16 mm in maximum whorl height; reconstructed conch diameter from the holotype is approximately 60 mm; apex and peristome are not preserved; whorl sections in juvenile shells facing umbilical perforation are subcircular with a very shallow median groove at venter, then their profiles shift towards depressed subtrapezoidal shape with weakly inflated venter, rounded ventrolateral shoulders, nearly straight flanks that acutely converse to dorsum, nearly straight umbilical zones that obtusely converse to dorsum, and shallowly rounded impressed area; furthermore, shapes of whorl sections in body chamber shift to depressed subquadrate, where venter becomes nearly flat, flanks weakly inflated, and concavity of impressed area becomes very shallow; umbilical angles rounded; median ventral groove disappears in adoral phragmocone and body chamber; width/height ratios of whorls are 1.4–1.9 in adoral phragmocone and 1.4–1.5 in body chamber. Juvenile shell surface ornamented by distinct lirae that form V-shaped sinueses at venter, carinae at ventrolateral shoulders and rounded sinueses at dorsum; in more adoral shells, lirae become accentuated growth lines and strongly protruded and spine-like nodes develope on the position of ventrolateral shoulders; nodes possess weak bulla-like extension on their dorsal side; peristome shape can be reconstructed by growth lines as lingulate ventral (hyponomic) and shallow lateral (ocular) sinuses. Septa very shallow; sutures composed by broadly rounded ventral lobes, rounded ventrolateral saddles, shallow lateral lobes, and subtriangular dorsal lobes; siphuncle situates near halfway between conch center and ventral margin in juvenile, and subcentral position in more adoral shells; ratios of distance between ventral shell surface and central axis of siphuncle per whorl height at dorsoventral plane are 0.31–0.44.

Material examined.—Holotype, AMNH 6159. Paratypes, AMNH 6102, 6108–6111, 6118, 6130, 6134, 6147–6149, 6472. In addition, 61 specimens (AMNH 6091–6101, 6103–6107, 6112, 6115–6117, 6119–6129, 6131–6133, 6135–6146, 6150–6158, 6160–6163, 6473) are assigned to *Metacoceras quadratum* sp. nov.

Occurrence.—TXV-34 (AMNH 6092–6099), TXV-56 (AMNH 6091, 6100–6112, 6473), TXV-120 (AMNH 6115), TXV-200 (AMNH 6116–6163, 6472). All previous records of the new species as *Metacoceras* sp. by Mapes and Chaffin (2003) and McKinzie and McLeod (2003) are from the Finis Shale Member in Texas.

Etymology.—The specific name is derived from the Latin, *quadratus* (= quadrangular), referring to its whorl section shapes in the body chamber.

Discussion.—In its gross conch form of the adoral shells and ornament, *Metacoceras quadratum* sp. nov. is most similar to *M. cornutum* Girty (1911, p. 145, 146; 1915, p. 240–242, pl. 29, figs. 4, 4a, 4b, 5, 5a, 5b), which was described from the Desmoinesian (Middle Pennsylvanian) of Oklahoma. However, the impressed area of this new species is shallower than that of *M. cornutum* and the subtrapezoidal profiles developed in the phragmocones are not recognized in *M. cornutum*. A Virgilian species, *Metacoceras copei* Tucker (1976, p. 61, 62, pl. 1, fig. 6, pl. 3, figs. 1, 2, pl. 4. fig. 3) from the Mattoon Formation of Illinois, also resembles *M. quadratum*, but it possesses a median ventral groove in the adoral shells and the knob-like distal ends of nodes exclude it from *M. quadratum. Metacoceras clinocostatum* Sturgeon, Windle, Mapes and Hoare (1982, p. 1455, 1457, 1458, pl. 1, figs. 4, 8; 1997, p. 34, 35, pl. 1-8, figs. 4–9), from the Desmoinesian Allegheny Group and the Missourian (Late Pennsylvanian) part of the Conemaugh Group of Ohio, differs from *M. quadratum* by having strongly elongated nodes attaining the umbilical angles.

Family Koninckioceratidae Hyatt *in* Zittle, 1900

Genus ***Endolobus*** Meek and Worthen, 1865

Type species.—*Nautilus spectabilis* Meek and Worthen, 1860.

Endolobus sturgeoni sp. nov.
Figure 4

Diagnosis.—Species of *Endolobus* with 1.4–2.0 in width/height ratios of adoral whorls; flanks narrowly rounded; impressed area deeply concaved; nodes low and dorsoventrally elongated.

Description.—Conchs thick discoidal, evolute; whorl expansion rapid in phragmocone, but it becomes gradual in

Figure 3. *Metacoceras quadratum* sp. nov. **A, B, E–G.** paratype, AMNH 6118: A, lateral view of juvenile shell; B, septal view of juvenile shell, venter up; E, ventral view; F, lateral view; G, septal view, venter up. **C, D.** paratype, AMNH 6472, juvenile shell: C, ventral view; D, lateral view. **H.** paratype, AMNH 6130, septal view, venter up. **I.** paratype, AMNH 6134, dorsal view. **J.** paratype, AMNH 6102, lateral view. **K.** paratype, AMNH 6147, septal view, venter up. **L, M, P, Q.** holotype, AMNH 6159: L, lateral view; M, cross sectional view, venter up; P, ventral view; Q, dorsal view. **N.** paratype, AMNH 6110, ventral view, showing details of surface ornamentation. **O.** paratype, AMNH 6111, lateral view. Scale bar is 6 mm in A–D; 12 mm in E–H, J, N; 15 mm in I, K–M, O–Q.

Figure 4. *Endolobus sturgeoni* sp. nov. **A–C.** paratype, AMNH 6081, shell wall mostly exfoliated: A, lateral view; B, cross sectional view, venter up; C, partial enlargement of A to show details of juvenile shell. **D.** paratype, AMNH 6082, septal view, venter up. **E, F, L.** paratype, AMNH 6085: E, lateral view; F, dorsal view; L, ventral view. **G.** paratype, AMNH 6087, shell wall mostly exfoliated, lateral view. **H, J, M, N.** holotype, AMNH 6086: H, lateral view; J, cross sectional view, venter up; M, ventral view; N, dorsal view. **I, K.** paratype, AMNH 6084, shell wall mostly exfoliated: I, lateral view; K, cross sectional view, venter up. Scale bar is 15 mm in A, B; 6 mm in C; 20 mm in D–N.

body chamber; umbilicus perforated; the holotype represents an imperfect body chamber with the last septum and is 47 mm in length, 34 mm in maximum whorl width, and 18 mm in maximum whorl height; the largest specimen (paratype, AMNH 6089) has 41 mm in whorl width and 21 mm (imperfect) in whorl height; reconstructed conch diameter of the holotype is approximately 60 mm; apex not preserved; whorl sections are circular in juvenile shells facing umbilical perforation, then they shift towards depressed subelliptical shapes, whose profiles consist of broadly rounded venter to ventrolateral shoulders, narrowly rounded flanks (= umbilical angles), weakly inflated umbilical zones and rounded impressed area; width/height ratios of whorls are 1.4–1.6 in adoral phragmocone, these ratios increase to 2.0 in body chamber. Shell surface marked by dorsoventrally elongated low nodes on flanks; except for nodes, surface ornamentation absent; no peristome is preserved, but presence of deep lingulate ventral (hyponomic) and very shallow lateral (ocular) sinuses can be reconstructed by growth line shapes. Septal curvature moderate; sutures roughly straight, but some sutures have shallow lateral lobes, directly transverse in juvenile shell and strongly incline towards venter in adoral shell; siphuncle supracentral with weak to moderate dorsum wards shifting; ratios of distance between ventral shell surface and central axis of siphuncle per whorl height at dorsoventral plane are 0.54–0.72.

Material examined.—Holotype, AMNH 6086. Paratypes, AMNH 6081–6085, 6087–6089.

Occurrence.—TXV-34 (AMNH 6081–6086), TXV-200 (AMNH 6087–6089).

Etymology.—The specific name is in honor of the late Myron T. Sturgeon in recognition of his contributions to paleontological studies of Pennsylvanian nautiloids and conodonts.

Discussion.—*Endolobus schucherti* Miller (1932, p. 64–66, pl. 12, figs. 12, 13) from the Upper Pennsylvanian sandstone of New Mexico has similar node shapes as *E. sturgeoni* sp. nov., but it differs in its shallower impressed area. In addition, a median longitudinal ridge on the venter of *E. schucherti* is not developed in the new species.

Superfamily Trigonoceratoidea Hyatt, 1884
Family Grypoceratidae Hyatt *in* Zittle, 1900
Genus ***Domatoceras*** Hyatt, 1891
Type species.—*Domatoceras umbilicatum* Hyatt, 1891.

Domatoceras tuckeri sp. nov.
Figure 5

Domatoceras sp., Mapes and Chaffin, 2003, figs. 4C, 4G, 4I; McKinzie and McLeod, 2003, p. 88, fig. 4-29.

Diagnosis.—Species of *Domatoceras* having whorl sections of compressed subtrapezoidal with concave venter in adoral phragmocone and compressed subrectangular in body chamber; width/height ratios of whorls 0.8–1.1; weakly waved carinae developed at ventral angles.

Description.—Conchs moderate in size, lenticular and evolute with relatively rapid whorl expansion; umbilicus perforated; the holotype of fragmentary phragmocone consisting of three volutions is 67 mm in maximum length, 37 mm in maximum whorl width, and 41 mm in maximum whorl height; the largest specimen (paratype, AMNH 6227) of imperfect body chamber attains 42 mm in whorl width (reconstructed from half width), 51 mm in whorl height and approximately 160 mm in reconstructed conch diameter; apex and peristome are not preserved; whorl sections are subcircular in juvenile shell facing umbilical perforation, subtrapezoidal to compressed subtrapezoidal in more adoral phragmocone, and compressed subrectangular in body chamber; profiles of whorl sections in adoral phragmocones consist of shallowly concave venter as ventral groove, nearly straight ventrolateral shoulders that acutely converge to venter, straight flanks that very acutely converge to venter, straight umbilical zones that obtusely converge to dorsum, and quadrate impressed area; in body chamber, venter becomes flat, shoulders and flanks integrate; umbilical angles bluntly pointed; width/height ratios of whorls are 0.9–1.1 in adoral phragmocone and 0.8–0.9 in body chamber. Surface of juvenile shell marked by sinuous lirae that persist in body chamber at ventral side, but are replaced by growth lines in other parts of more adoral shells; strong carina having weakly waved margin and frill-like appearance developed at ventral angle with bilateral symmetry in adoral shells; lirae and growth lines suggest peristome shape with V-shaped ventral (hyponomic) and shallow lateral (ocular) sinuses. Septal curvatures are relatively weak; sutures indicate shallow ventral and broadly rounded lateral lobes. Siphuncle is subcentral in position; ratios of distance between ventral shell surface and central axis of siphuncle per whorl height at dorsoventral plane are 0.48–0.52.

Material examined.—Holotype, AMNH 6278. Paratypes, AMNH 6181, 6186, 6208, 6209, 6227–6230, 6255, 6256, 6279–6281. In addition, 95 specimens (AMNH 6173–6180, 6182–6185, 6187–6207, 6210–6226, 6231–6254, 6257–6277) are assigned to *Domatoceras tuckeri* sp. nov.

Occurrence.—TXV-34 (AMNH 6173–6185), TXV-55 (AMNH 6186), TXV-56 (AMNH 6187–6227), TXV-200 (AMNH 6228–6281). All previous records of the new species as *Domatoceras* sp. by Mapes and Chaffin (2003) and McKinzie and McLeod (2003) are from the Finis Shale Member in Texas.

Etymology.—The specific name is to honor the late John K. Tucker in recognition of his contributions to paleontological

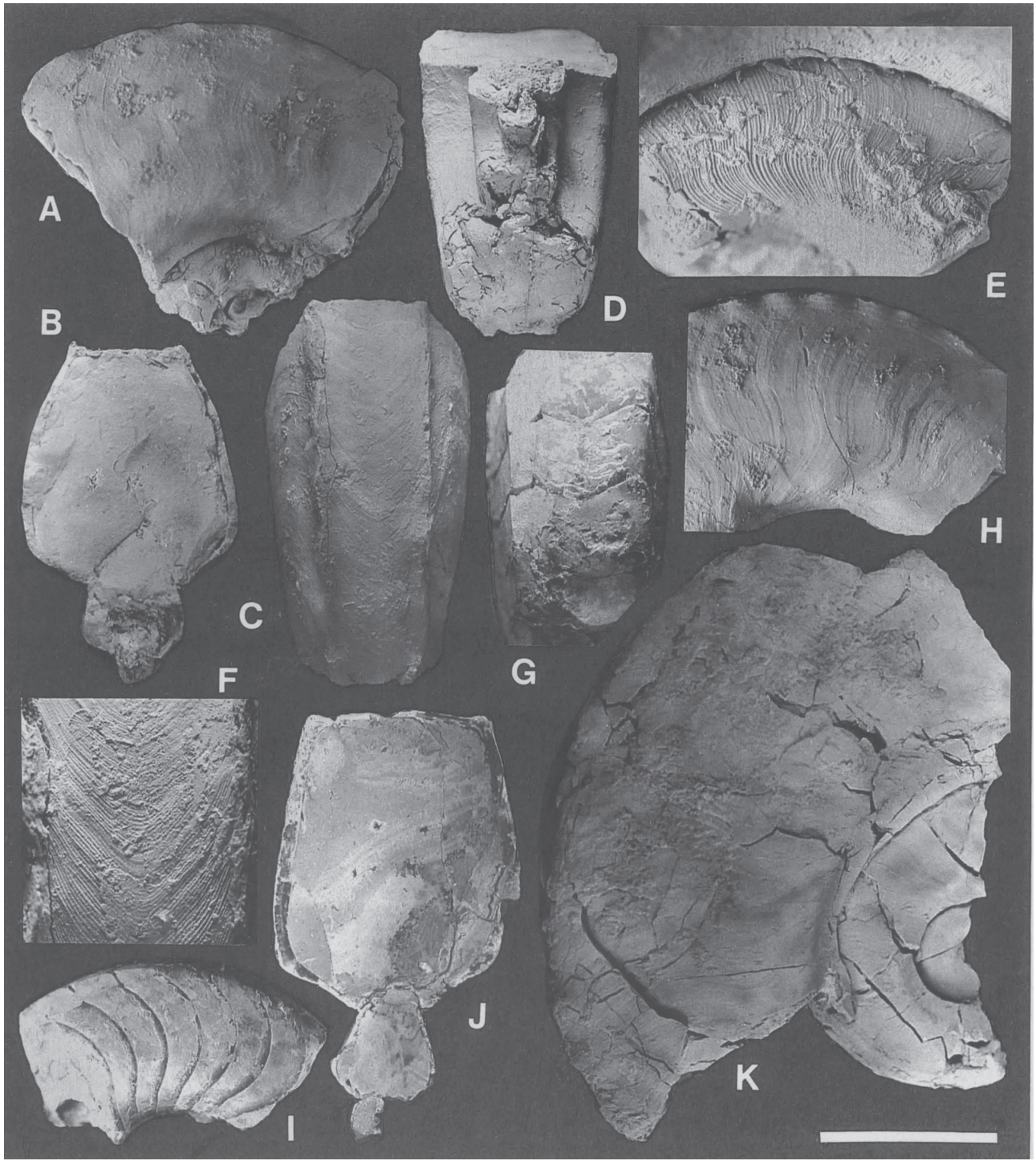

Figure 5. *Domatoceras tuckeri* sp. nov. **A–F.** holotype, AMNH 6278: A, lateral view; B, cross sectional view, venter up; C, ventral view; D, dorsal view; E, lateral view of juvenile shell; F, partial enlargement of C to shew details of surface ornamentation. **H.** paratype, AMNH 6281, lateral view. **G, I.** paratype, AMNH 6208, shell wall exfoliated: G, ventral view; I, lateral view. **J, K.** paratype, AMNH 6227: J, cross sectional view, venter up; K, lateral view. Scale bar is 30 mm in A–D, I–K; 6 mm in E; 10 mm in F; 20 mm in G; 37.5 mm in H.

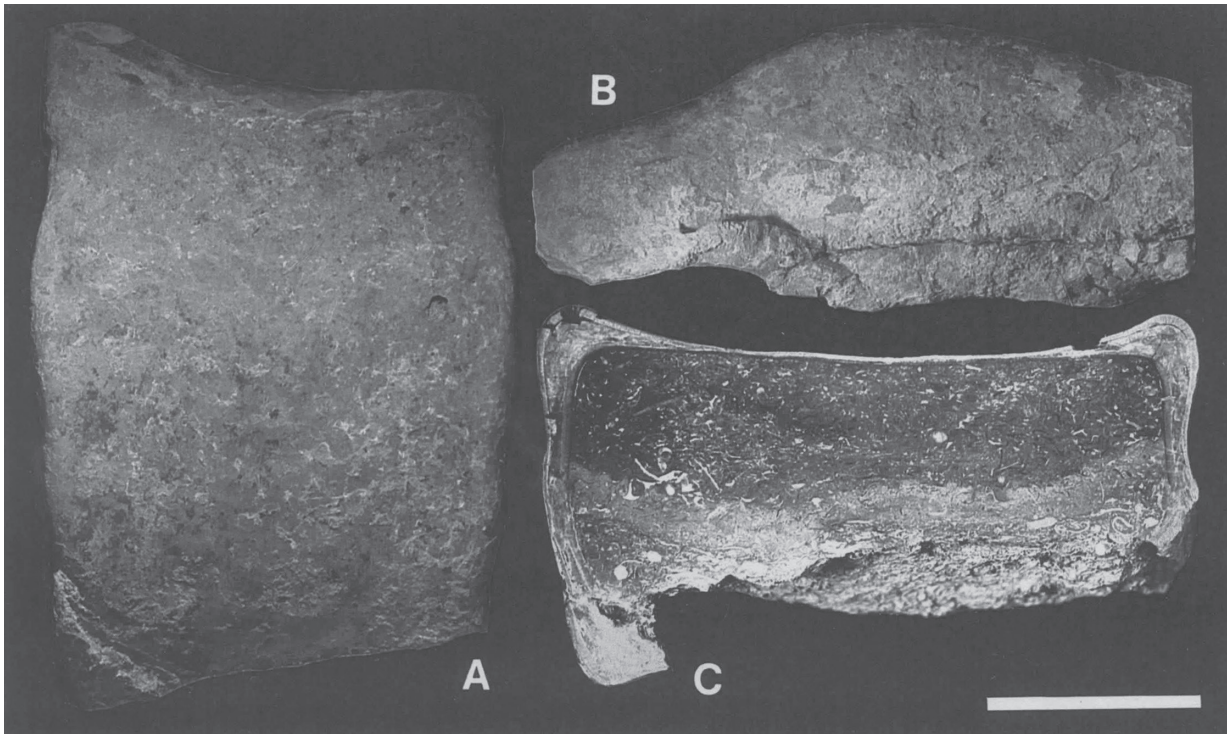

Figure 6. *Titanoceras* sp., IGPS coll. cat. no. 112545. **A.** ventral view. **B.** lateral view. **C.** cross sectional view, venter up. Scale bar is 100 mm in A, B; 75 mm in C.

studies of Pennsylvanian nautiloids.

Discussion.—This new species most closely resembles *Domatoceras oreskovichi* Sturgeon, Windle, Mapes and Hoare (1982, p. 1468, 1469, pl. 2, figs. 6, 7, 9, pl. 3, fig. 2; 1997, p. 60, 61, pl. 1-23, figs. 6, 7, pl. 1-24, figs. 2, 3, pl. 1-26, figs. 1, 2, pl. 1-27, figs. 1–6, text-fig. 1-8A), from the Desmoinesian Allegheny Group of Ohio, by having compressed subquadrate whorl sections with a concaved venter. However, larger amplitude of the waved carinae distinguishes it from *Domatoceras tuckeri* sp. nov. A concaved venter is also developed in *D. texanum* Tucker and Mapes (1978, p. 597, pl. 2, figs. 4, 5, pl. 3, fig. 6) from the Missourian Wolf Mountain Shale of Texas. The differences between *D. texanum* and *D. tuckeri* are its subtrapezoidal whorl sections remain in the body chambers and morphological shifting from carinae to nodes as shell grows.

Genus ***Titanoceras*** Hyatt**,** 1884

Type species.—*Nautilus ponderosus* Meek, 1872.

Titanoceras sp.

Figure 6

Titanoceras sp., McKinzie and McLeod, 2003, p. 91, fig. 4-33.

Description.—A single very large specimen of fragmentary body chamber is available for study; it is 352 mm in length, 225–232 mm in whorl width and 137 mm in whorl height; whorl sections are strongly depressed, subquadrate with width/height ratios of approximately 1.6 and consists of broadly concave venter and weakly inflated flanks; most of umbilical zone is missing, but preserved part indicates shallow concavity. Shell surface smooth; ventrolateral and umbilical angles are carinated; longitudinally elongated nodes occur on carina at ventrolateral angles.

Material examined.—IGPS coll. cat. no. 112545.

Occurrence.—TXV-200. Previous record of the species by McKinzie and McLeod (2003) is from the Finis Shale Member in Texas.

Discussion.—Its depressed subquadrate whorl sections with a broadly concaved venter suggest the generic assignment of this specimen to *Titanoceras* rather than *Latitemnocheilus* Sturgeon, Windle, Mapes and Hoare (1982; type species, *Nautilus* (*Temnocheilus*) *latus* Meek and Worthen, 1870) and *Temnocheilus* M'Coy (1844; type species, *Nautilus* (*Temnocheilus*) *coronatus* M'Coy, 1844).

General shape of the venter of *Latitemnocheilus* is weakly convex and the whorl section of *Temnocheilus* indicates subtrapezoidal profile.

The present *Titanoceras* sp. is well differentiated from other species assigned to the genus by having a larger width/height ratio of the whorl. However, erection of new species is not possible due to lacking information about the phragmocone.

Superfamily Aipoceratoidea Hyatt, 1883
Family Solenochilidae Hyatt, 1893
Genus ***Solenochilus*** Meek and Worthen, 1870

Type species.—*Nautilus* (*Cryptoceras*) *springeri* White and St. John, 1868.

Solenochilus jackense sp. nov.
Figure 7

Diagnosis.—Species of *Solenochilus* with subelliptical whorl sections, whose width/height ratios are 1.4–1.5; venter broadly rounded; ventrolateral shoulders rounded; flanks weakly inflated to straight; umbilical angles carinated; umbilical zones weakly concaved; impressed area moderately concaved; camerae relatively long; except for relatively deep ventral sinus, sutures roughly transverse.

Description.—Conchs large, subglobose with rapid whorl expansion; inner whorls are narrowly evolute with narrow umbilical area, then coiling becomes loose in more adoral phragmocone; apex not observable; the holotype (largest specimen) is fragmentary whorl of mature phragmocone having 58 mm in whorl length, 52 mm in maximum whorl width (reconstructed from half width, exfoliated lateral shall wall), and 36 mm in maximum whorl height (exfoliated ventral shall wall); a paratype (AMNH 6167) representing immature phragmocone is 45 mm in diameter, 40 mm in maximum whorl width (reconstructed from half width), 27 mm in maximum whorl height, and 0.2 in approximate ratio of umbilical diameter per conch diameter; whorl sections are depressed and subelliptical; profiles of whorl sections in immature phragmocone consist of broadly rounded venter, rounded ventrolateral shoulders, weakly inflated flanks, weakly concaved umbilical zones and shallowly rounded impressed area; in mature phragmocone, flanks become straight and acutely converge to venter; umbilical angles carinated; width/height ratios of whorls are 1.4–1.5; no body chamber preserved. Shell surface is mostly smooth except for umbilical carinae that are marked by longitudinal lirae; umbilical spine not preserved. Septa are shallowly concaved; sutures are roughly transverse with narrow but relatively deep ventral sinus, weak ventrolateral saddles, and nearly straight at lateral to dorsolateral portions; cameral lengths are relatively long for the genus, 17–20 mm at ventral margin in the holotype. Siphuncle is at the ventral margin; septal necks are suborthochoanitic in immature and orthochanitic in mature phragmocones.

Material examined.—Holotype, AMNH 6168. Paratypes, AMNH 6166, 6167. In addition, two specimens (AMNH 6164, 6165) are assigned to *Solenochilus jackense* sp. nov.

Occurrence.—TXV-34 (AMNH 6164), TXV-200 (AMNH 6165–6168).

Etymology.—The specific name is derived from Jack County, from which all examined specimens including the type series were collected.

Discussion.—*Solenochilus missouriensis* Miller, Lane and Unklesbay (1947, p. 10, pl. 4, figs. 3, 4), from the Middle Pennsylvanian Winterset Limestone of Missouri, most closely resembles the new species, by its subelliptical whorl sections with a width/height ratio of approximately 1.5 and relatively long camerae. However, this species has more strongly fluted sutures especially at the lateral to dorsolateral portions than those of *S. jackense* sp. nov. *Solenochilus greenensis* Sturgeon (1946, p. 33–35, pl. 8, fig. 6, pl. 9, fig. 3, text-fig. 3A; Sturgeon *et al*., 1997, p. 71, 72, pl. 1-31, figs. 1, 2, pl. 1-32, fig. 2, pl. 1-33, fig. 3, pl. 1-34, figs. 1–3, text-fig. 1-11B), described from the Desmoinesian Hamden Limestone, Ohio also resembles *S. jackense*, but its dorsal part of the flanks is strongly concave. *Solenochilus mcfarlandi* Sturgeon, Windle, Mapes and Hoare (1982, p. 1469, 1471, 1472, pl. 5, figs. 3, 4; 1997, p. 73, 74, pl. 1-35, fig. 2, pl. 1-37, figs. 2, 3, text-fig. 1-12A) from the Missourian part of the Conemaugh Group of Ohio differs from *S. jackense* in having more depressed whorl sections exceeding 1.8 in a width/height ratio and shorter camerae. Other comparable species, including *S. brammeri* Miller, Dunbar and Condra (1933, p. 234–236, pl. 22, figs. 6, 7, pl. 23, fig. 1, pl. 24. fig. 1) from the Missourian Argentine Limestone of Nebraska and *S. springeri* (White and St. John, 1868, p. 124, 125, fig. 10; Kummel, 1964, figs. 319, 320,1, 321; Mikesh and Glenister, 1966, p. 273–277, figs. 1A, 1B) from the Middle Pennsylvanian of Iowa and Arkansas, are well differentiated from *S. jackense* by the presence of a mid-ventral groove in their mature phragmocones.

Superfamily Clydonautiloidea Hyatt *in* Zittel, 1900
Family Liroceratidae Miller and Youngquist, 1949
Genus ***Liroceras*** Teichert, 1940

Type species.—*Coloceras liratum* Girty, 1911.

Liroceras liratum (Girty, 1911)
Figure 8

Coloceras liratum Girty, 1911, p. 144, 145; 1915, p. 237, 238, pl. 28, figs. 2, 2a, b, 3, 3a, b, 4, 4a, 5, 6, 6a; Miller *et al*., 1933, p. 132–134, pl. 6, figs. 1–8.

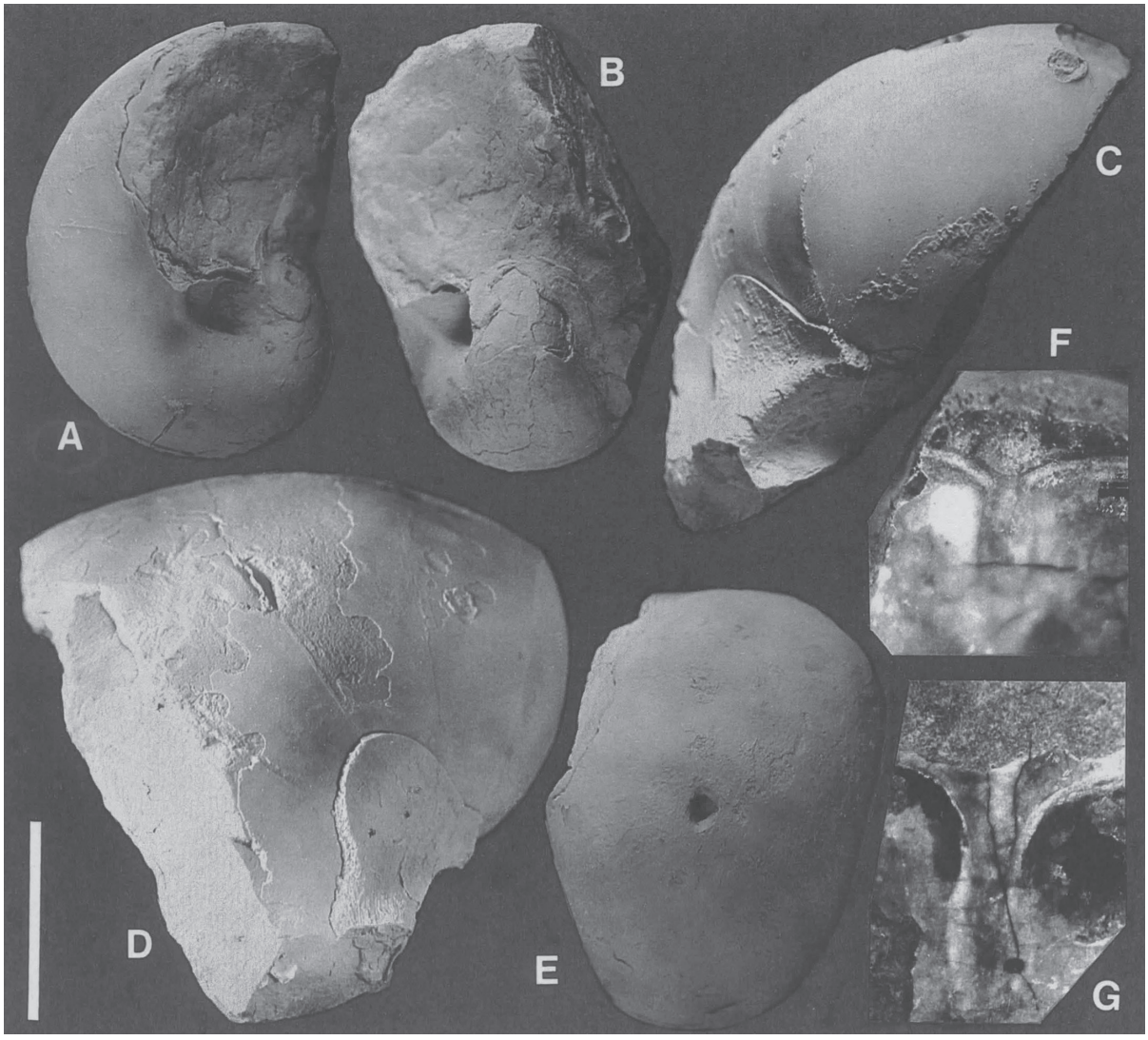

Figure 7. *Solenochilus jackense* sp. nov. **A, B, E, F.** paratype, AMNH 6167: A lateral view; B, ventral-apertural view; E, ventral view; F, ventral view, showing details of siphuncle. **C, D, G.** holotype, AMNH 6168, shell wall mostly exfoliated: C, septal view, venter up; D, lateral view; G, ventral view, showing details of siphuncle. Scale bar is 20 mm in A–E; 6 mm in F, G.

Coloceras liratum obsoletum Girty, 1911, p. 145; 1915, p. 238, 239, pl. 29, figs. 1, 1a, b, 2, 2a, 3, 3a.

Coloceras obsoletum Girty. Miller *et al*., 1933, p. 134–136, pl. 7, figs. 4–7.

Coloceras liratum? Girty. Miller and Cline, 1934, p. 173–175, pl. 28, figs. 24–26.

Liroceras liratum (Girty). Teichert, 1940, p. 590; Young, 1942, p. 122; Sturgeon, 1946, p. 19–21, pl. 4, figs. 6–9; Miller and Youngquist, 1949, pl. 53, figs. 3–6; Unklesbay and Palmer, 1958, p. 1073, pl. 138, figs. 1–3; Unklesbay, 1962, p. 45–47, pl. 5, figs. 6–8, pl. 6, figs. 5, 6, text-fig. 1; Kummel, 1964, figs. 324,3a, b; Murphy, 1970, p. 203, 204, pl. 36, fig. 9; Tucker, 1976, p. 67, 68, pl. 3, fig. 4; Sturgeon *et al*., 1997, p. 78, 79, pl. 1-44, figs. 1, 3–12; Seuß *et al*, 2009, p. 627.

Liroceras cf. *liratum* (Girty). Young, 1942, p. 122.

Liroceras sp., Miller and Unklesbay, 1942a, p. 137, 138, pl. 1, fig. 13, text-fig. 1A; Sturgeon and Miller, 1948, p. 76, 77; Mapes and Chaffin, 2003, fig. 4B; McKinzie and McLeod, 2003, p. 88, fig. 4-30.

Description.—Conchs small, having 70 mm in reconstructed diameter, subglobose, involute with moderate whorl expansion; whorl sections are depressed and reniform

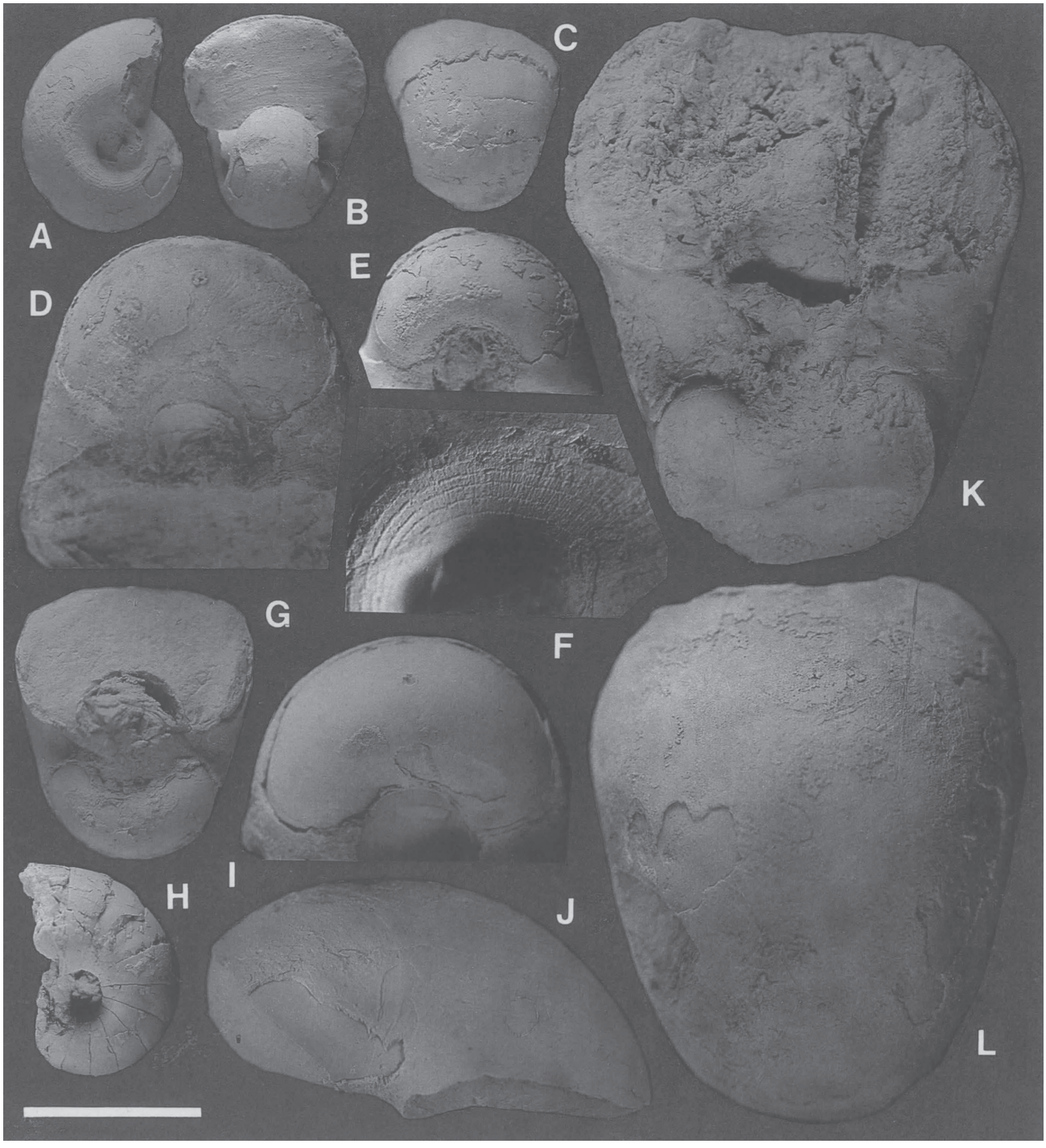

Figure 8. *Liroceras liratum* (Girty, 1911). **A, B, F.** AMNH 6305: A, lateral view; B, ventral-apertural view; F, lateral view, showing details of surface ornamentation. **C.** AMNH 6348, shell wall mostly exfoliated, ventral view. **D.** AMNH 6310, septal view, venter up. **E.** AMNH 6354, septal view, venter up. **G.** AMNH 6352, dorsal view. **H.** AMNH 6345, shell wall exfoliated, lateral view. **I.** AMNH 6360, septal view, venter up. **J.** AMNH 6355, lateral view. **K, L.** AMNH 6357: K, dorsal view; L, ventral view. Scale bar is 20 mm in A–E, G–L; 6 mm in F.

consisting of rounded venter, ventrolateral shoulders to flanks, broadly rounded umbilical zones and rounded impressed area; umbilical angles narrowly rounded; width/height ratios of whorls are 1.2–1.7. Shell surface is smooth, except for portion of umbilical angles to umbilical zones in inner volutions, where reticulate ornamentation is developed; growth lines exhibit shallow ventral (hyponomic) and lateral (ocular) sinuses. Septa relatively deep; sutures are directly transverse. Siphuncle is subcentral.

Material examined.—AMNH 6298–6471.

Occurrence.—The syntypes were collected from the Desmoinesian Wewoka Formation of Oklahoma (Girty, 1911). Except for the type stratum, specimens of this species are widely known from the Middle to Upper Pennsylvanian of the North American Midcontinent including the Allegheny and Conemaugh Formations in Pennsylvania (Miller and Unklesbay, 1942a), the Pottsville, Allegheny and Conemaugh Formations in Ohio (Sturgeon, 1946), the Mattoon Formation in Illinois (Tucker, 1976), the Burgner Formation in Missouri (Unklesbay and Palmer, 1958), the Weston Shale in Kansas (Miller *et al*., 1933), the Atoka, Pumpkin Creek, Boggy, Stuart, Senora, Wetumka, Holdenville, Nellie Bly, Wann, Vamoosa and Kanwaka Formations in Oklahoma (Miller *et al*., 1933), the Jacksboro Limestone and the Finis Shale Member in Texas (Miller *et al*., 1933), and the Magdalena Group in New Mexico (Young, 1942).

Localities of each examined specimen in this study are as follows; TXV-34 (AMNH 6298–6302), TXV-36 (AMNH 6303), TXV-54, (AMNH 6304), TXV-56 (AMNH 6305–6341), TXV-120 (AMNH 6342–6347), TXV-200 (AMNH 6348–6471).

Discussion.—Unklesbay (1962) considered that differences between *Liroceras liratum* and *L. obsoletum*, especially in their surface ornamentations are intraspecific variations and synonymized them. We agree with his proposal. *Liroceras liratum* is the most abundant nautiloid species in the Finis Shale Member.

Genus ***Peripetoceras*** Hyatt, 1894

Type species.—*Nautilus freieslebeni* Geinitz, 1843.

Peripetoceras bridgeportense Tucker and Mapes, 1978
Figure 9

Peripetoceras bridgeportense Tucker and Mapes, 1978, p. 598, 600, 603, pl. 1, figs. 1–3, pl. 2, figs. 1, 2, pl. 3, fig. 7.
Peripetoceras sp., Wani *et al*., 2012, fig. 3D.

Description.—Conchs small, having 50 mm in reconstructed diameter, subglobose, involute with rapid whorl expansion; whorl sections depressed, reniform in apical and subtrapezoidal in adoral shells; profiles of apical whorls consist of rounded venter, ventrolateral shoulders to flanks, narrowly rounded umbilical zones and rounded impressed zone; in adoral whorls, subquadrate ventral angles appear and following profiles indicate nearly flat venter, nearly flat ventrolateral shoulders to flanks converging acutely to venter, narrowly rounded umbilical zones, and deeply rounded and wide impressed zone; umbilical angles broadly rounded throughout; width/height rations of whorls range from 1.5 to1.7. Shell surface is smooth; growth lines exhibit narrowly rounded ventral (=hyponomic) sinus, broadly rounded ventrolateral lobes, very shallow lateral (= ocular) sinus; sutures are transverse and roughly straight; siphuncle is supracentral in position and slightly off to dorsum.

Material examined.—AMNH 6282–6297.

Occurrence.—The holotype and all paratypes of *Peripetoceras bridgeportense* were collected from the Missourian (early Late Pennsylvanian) Wolf Mountain Shale, Texas (Tucker and Mapes, 1978).

Localities of each examined specimen in this study are as follows; TXV-34 (AMNH 6282–6287), TXV-54 (AMNH 6288), TXV-56 (AMNH 6289–6292), TXV-200 (AMNH 6293–6297). Previous record of the species by Wani *et al*. (2012) is from the Finis Shale Member in Texas.

Discussion.—We assign the present specimens to *Peripetoceras bridgeportense* on the basis of similarities with the holotype in their whorl section shapes, ratios of conch expansion, and siphuncular position. It is possible that an unfigured species, *Peripetoceras* sp., recorded from the Finis Shale Member by McKinzie and McLeod (2003) also is conspecific with *P. bridgeportense*.

Family Ephippioceratidae Miller and Youngquist, 1949

Genus ***Ephippioceras*** Hyatt, 1884

Type species.—*Nautilus ferratus* Cox, 1858.

Ephippioceras ferratum (Cox, 1858)
Figure 10

Nautilus ferratus Cox, 1858, p. 574, 575, pl. 10, figs. 2, 2a.
Ephippioceras ferratum (Cox). Hyatt, 1884, p. 290; 1894, p. 539, pl. 10, figs. 23–26; Miller *et al*., 1933, p. 114–118, pl. 3, figs. 14–17; Miller and Owen, 1934, p. 209–211, pl. 12, figs. 3, 4, text-figs. 1A, B; Smith, 1938, p. 10, 11, pl. 1, fig. 17; Miller and Unklesbay, 1942a, p. 136, pl. 1, figs. 14, 15; Sturgeon, 1946, p. 18, 19, pl. 4, figs. 2–4; Miller and Unklesbay, 1947, p. 320, pl. 1, figs. 7, 8; Miller *et al*., 1947, p. 6, pl. 2, figs. 7–10; Miller and Youngquist, 1949, p. 129, pl. 53, figs. 7, 8; Unklesbay, 1962, p. 50–52, pl. 4, fig. 3; Kummel, 1963, p. 357, pl. 15, figs. 4–7; 1964, fig. 326, 2; Sturgeon *et al*., 1997, p. 81, 82, pl. 1-46, figs. 1–5, 7, 9.
Ephippioceras (*Nautilus*) *ferratum* (Cox). Hyatt, 1891, p. 352.
[not] *Ephippioceras ferratum* (Cox). Gordon, 1964, p. 162,

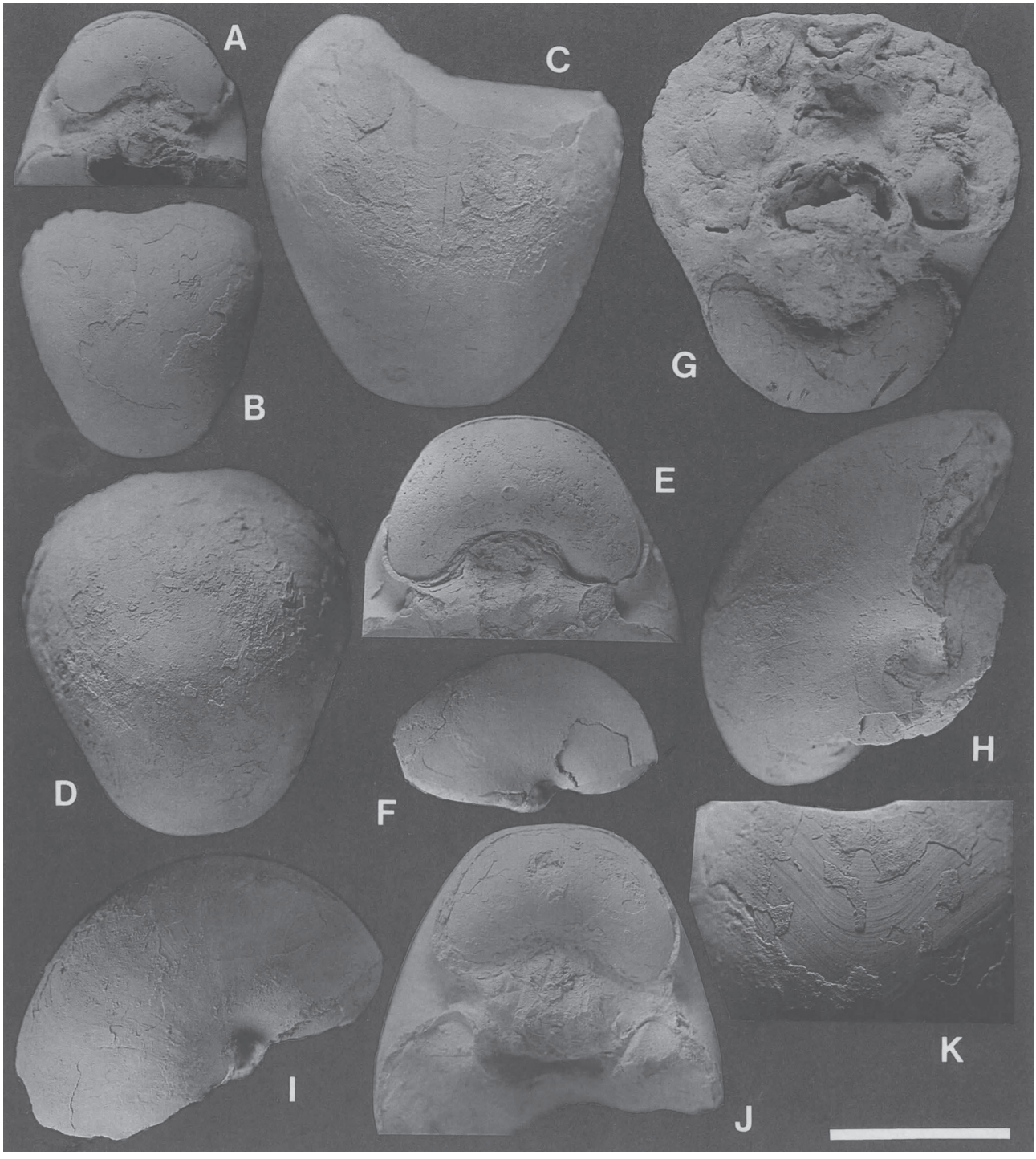

Figure 9. *Peripetoceras bridgeportense* Tucker and Mapes, 1978. **A, B, F, K.** AMNH 6289: A, septal view, venter up; B, ventral view; F, lateral view; K, partial enlargement of B to show details of surface ornamentation. **C, I, J.** AMNH 6283: C, ventral view; I, lateral view; J, septal view, venter up. **D, G.** AMNH 6292: D, ventral view; G, dorsal view. **E.** AMNH 6295, septal view, venter up. **H.** AMNH 6297, lateral view. Scale bar is 20 mm in A–J; 12 mm in K.

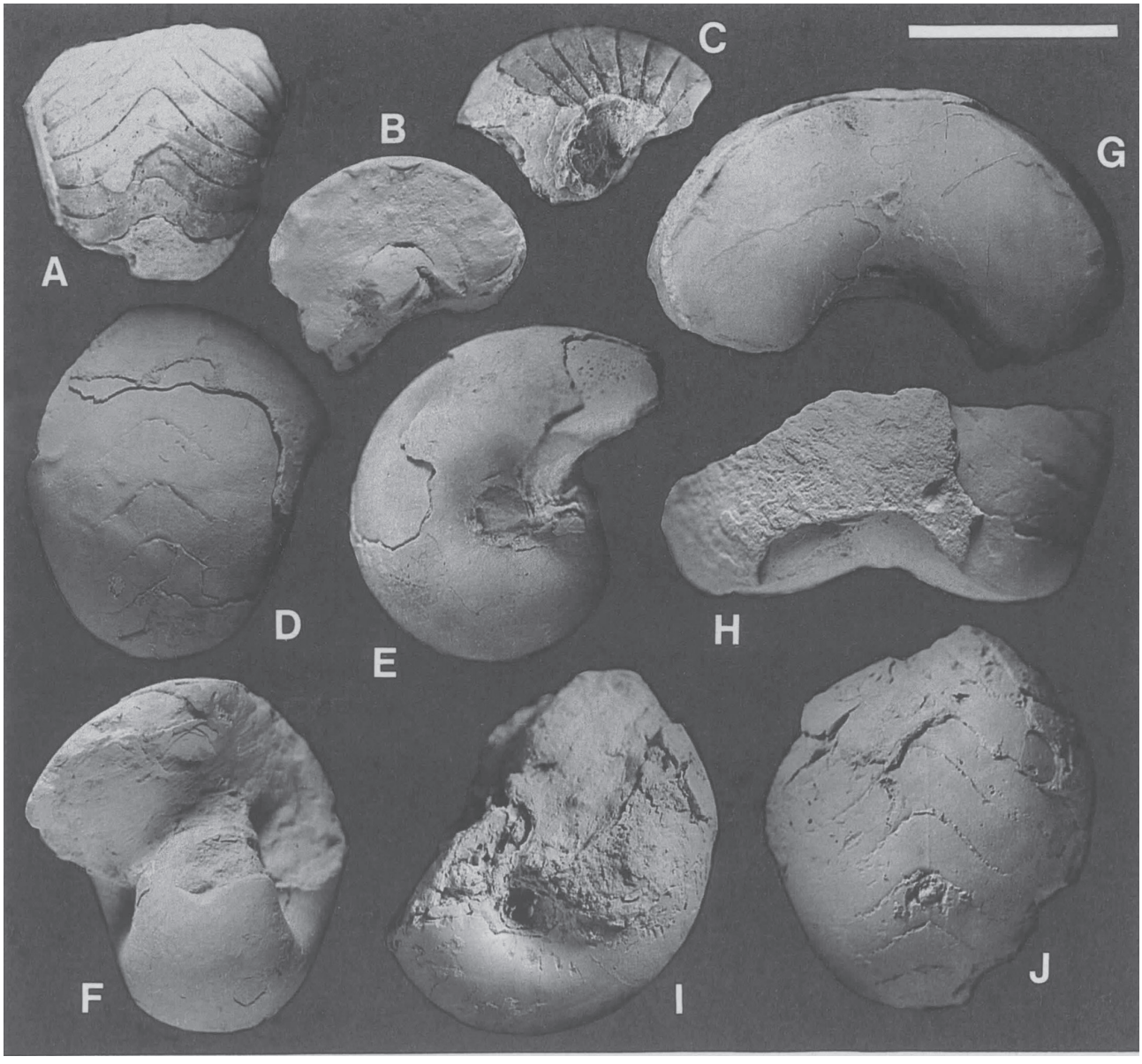

Figure 10. *Ephippioceras ferratum* (Cox, 1858). **A–C.** AMNH 6169, shell wall mostly exfoliated: A, ventral view; B, cross sectional view, venter up; C, lateral view. **D–F.** AMNH 6170, shell wall mostly exfoliated: D, ventral view; E, lateral view; F, ventral-apertural view. **G, H.** AMNH 6171: G, septal view, venter up; H, ventral view. **I, J.** AMNH 6172, shell wall mostly exfoliated: I, lateral view; J, ventral view. Scale bar is 15 mm.

163, pl. 16, figs. 1–3, text-fig. 31 [= *E*. sp. nov.].

Eohippioceras [sic.] *ferratum* (Cox). Seuß *et al*, 2009, p. 627.

Description.—Conchs small, subglobose and involute with relatively rapid whorl expansion; a well-preserved specimen (AMNH 6172) has 29 mm in conch diameter; whorl sections are strongly depressed, reniform consisting of rounded venter, ventrolateral shoulders to franks, weakly inflated umbilical zones and deeply rounded impressed area; umbilical angles bluntly pointed; width/height ratios of whorls are 1.6–1.8; mid-ventral conchal furrow developed. Shell surface smooth. Cameral length short; sutures exhibit distinct flutings indicating V-shaped and very prominent

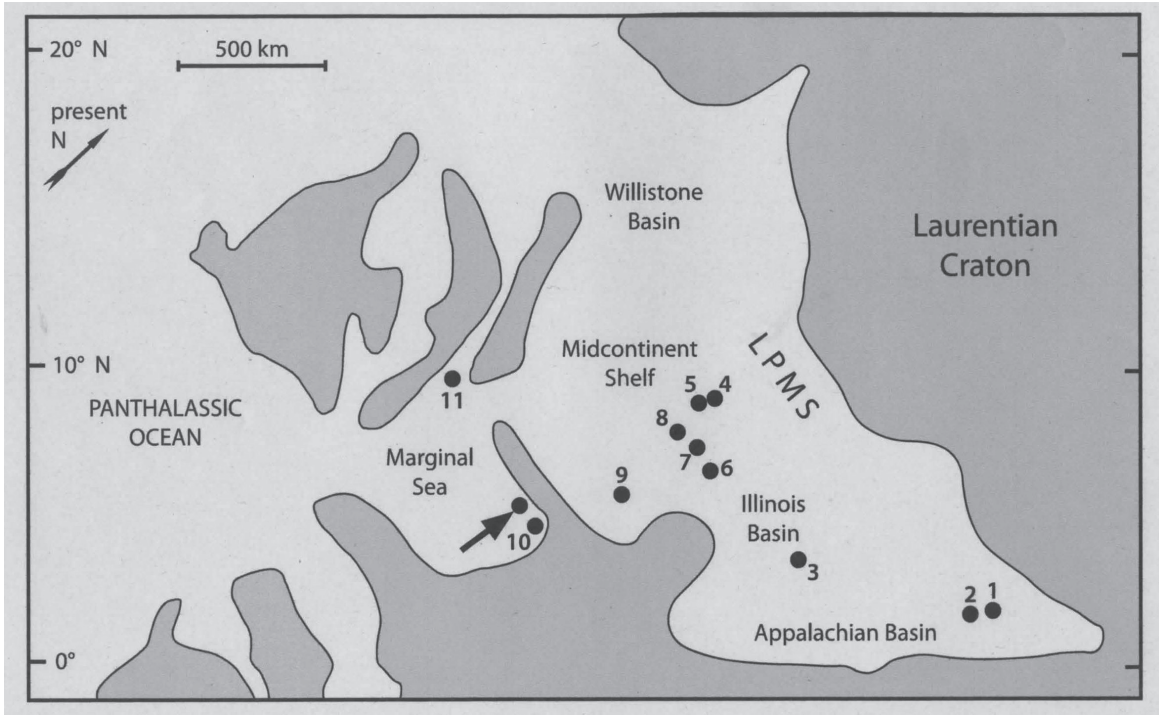

Figure 11. Paleogeographic reconstruction of the distribution of common Late Pennsylvanian coiled nautiloid species with the Finis Shale assemblage (arrow). Map based on and modified from Algeo and Heckel (2008). 1, *Liroceras liratum* and *Ephippioceras ferratum* in the Conemaugh Formation, Pennsylvania; 2, *L. liratum* and *E. ferratum* in the Conemaugh Formation, Ohio; 3, *L. liratum* in the Mattoon Formation, Illinois; 4, *E. ferratum* in the South Bend Formation, Nebraska; 5, *Tainoceras monilifer* in the Iatan Limestone, Nebraska; 6, *E. ferratum* in the Dennis and Westerville limestones, Missouri; 7, *L. liratum* in the Weston Shale, Kansas;8, *T. monilifer* in the Lawrence Shale and Kereford and Burlingame Limestones, Kansas; 9, *T. monilifer* in the Vamoosa Formation and *L. liratum* in the Nellie Bly, Wann, Vamoosa and Kanwaka Formations, Oklahoma; 10, *Peripetoceras bridgeportense* in the Wolf Mountain Shale, Texas; 11, *L. liratum* in the Magdalena Group, New Mexico.

ventral saddle, broadly rounded lateral lobes and low umbilical saddle. Siphuncle central to slightly supracentral in position.

Material examined.—AMNH 6169–6172.

Occurrence.—The holotype of *Ephippioceras ferratum* was collected from the Pennsylvanian (specific stratigraphic setting unknown) of Kentucky (Cox, 1858). Specimens of this species are also known from the Middle to Upper Pennsylvanian of the Conemaugh Formation in Pennsylvania (Miller and Unklesbay, 1942a), the Pottsville, Allegheny and Conemaugh Formations in Ohio (Sturgeon, 1946), the Cherokee Formation and the Dennis and Westerville Limestones in Missouri (Miller *et al*., 1933), the South Bend Formation in Nebraska (Miller *et al*., 1933), and the Boggy Formation in Oklahoma (Smith, 1938).

Localities of each examined specimen in this study are as follows; TXV-34 (AMNH 6169–6171), TXV-56 (AMNH 6172).

Discussion.—Gordon (1964) assigned a single Morrowan (Early Pennsylvanian) specimen from the Hale Formation, Arkansas to *Ephippioceras ferratum* and stated that it is the earliest record of this species. However, we cannot agree with his point of view because the ventral saddle in the suture of this Morrowan specimen is much lower than that of the typical ones of *E. ferratum*. We think that this specimen probably represents a new species and the chronological range of *E. ferratum* is, therefore, constrained exclusively in Middle to Late Pennsylvanian time.

Coiled Nautiloid Assemblage

The Late Pennsylvanian coiled nautiloid assemblage from the Finis Shale Member is composed by *Tainoceras monilifer* Miller, Dunbar and Condra, *Metacoceras quadratum* sp. nov., *Endolobus sturgeoni* sp. nov., *Domatoceras tuckeri* sp. nov., *Titanoceras* sp., *Solenochilus jackense* sp. nov., *Liroceras liratum* (Girty), *Peripetoceras bridgeportense* Tucker and Mapes, and *Ephippioceras ferratum* (Cox). In our previous studies concerning fossil cephalopods

in the Midcontinent of North America, Niko *et al*. (2018) examined the Middle Pennsylvanian orthoconic cephalopod assemblage in the Buckhorn Asphalt Quarry, located ca. 150 km northeast of Jacksboro, and concluded that it demonstrates provincialism. In contrast to this assemblage, the Finis Shale assemblage indicates cosmopolitanism and is characterized by the absence of endemic genera and presence of common, widely occurring species to high degree. Most of the area of Midcontinent North America, situated in the low latitudes at this time, was flooded due to the rise of the sea level forced by melting Gondwanan ice sheets and submergence in the shelf sea (i.e., the Late Pennsylvanian Midcontinent Sea (LPMS); Heckel, 1994). The LPMS included the Appalachian Basin, the Illinois Basin, the Midcontinent Shelf and the Willistone Basin, and was connected to the Panthalassic Ocean through the Marginal Sea (Algeo and Heckel, 2008; Algeo *et al*., 2008; Algeo and Herrmann, 2017).

As obvious from the proceeding systematic part, Late Pennsylvanian occurrences of the previously known four species from outside the Finis Shale Member are as follows: *T. monilifer* (Nebraska, Kansas, Oklahoma), *L. liratum* (Pennsylvania, Ohio, Illinois, Oklahoma, New Mexico), *P. bridgeportense* (Texas), and *E. ferratum* (Pennsylvania, Ohio, Missouri, Nebraska, Oklahoma). Among these, all localities in Texas (including the Finis Shale) and New Mexico belong to the Marginal Sea while others are in the LPMS; more particularly they belong to the Appalachian Basin (Pennsylvania, Ohio), the Illinois Basin (Illinois) and the Midcontinent Shelf (Missouri, Nebraska, Kansas, Oklahoma), whose areas represent the southern part of the sea (Figure 11). Niko *et al*. (2018) suggested that the Buckhorn Asphalt was deposited in the restricted epeiric sea during a cool episode. Differences of above-mentioned composition between these two assemblages can be referred to sea level change triggered by forming and melting of ice sheets. We can conclude that the coiled nautiloid assemblage from the Finis Shale inhabited the Marginal Sea that was open to the Panthalassic Ocean at that time and thus, had strong biotic linkage with the southern LPMS including the Appalachian Basin, the Illinois Basin, and the Midcontinent Shelf.

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Middle Permian cephalopods of the Takakurayama Formation in the Yaguki area, the southwestern margin of the South Kitakami Belt, Northeast Japan

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Abstract: Middle Permian coiled nautiloids and ammonoids are described from two horizons belonging to the upper part of the Takakurayama Formation distributed in the Yaguki area, Northeast Japan. The nautiloids consist of nine species belonging to four genera, and include one new species: *Tainoceras* cf. *abukumaense* Hayasaka, *Tainoceras* sp., *Pleuronautilus chisatoi* sp. nov., *Pleuronautilus* cf. *gregarius* (Miller), *Pleuronautilus* sp., *Pleuronautilus*? sp., *Endolobus*? sp. and *Domatoceras* sp. The ammonoid fauna is composed of eight species belonging to eight genera and an indeterminable Kufengoceratinae: *Agathicera*s sp., *Stacheoceras* sp., Kufengoceratinae gen. and sp. indet., *Waagenoceras* sp., *Jilingites* cf. *bidentus* Liang, *Roadoceras* cf. *roadense* (Böse), *Neopopanoceras* cf. *scrobiculatum* (Gemmellaro), *Propinacoceras* sp., *Propinacoceras*? sp. and *Paraceltites* cf. *elegans* Girty. Reexaminations of some existing ammonoid species are also given. Including the known ones, the ammonoid fauna of the formation clearly indicates that the Takakurayama Formation is Wordian in age.

Introduction

The Permian mudstone-dominated strata, the Takakurayama Formation, is narrowly distributed in the Yaguki area, Iwaki City, in the southeastern margin of the Abukuma Massif, Northeast Japan. It belongs to the South Kitakami Belt and situated at the southwestern margin of the belt. Rather rich cephalopod fossils have been known from its upper part (Hayasaka, 1965; Yanagisawa, 1967; Tazawa et al., 2005; Ehiro, 2008; Fujikawa and Suzuki, 2011). Based on the ammonoid fauna, Hayasaka (1965) correlated the Takakurayama Formation with the Middle Permian Sosio Stage. Yanagisawa (1967) considered that the Takakurayama Formation ranges in age from Early to Middle Permian. Tazawa et al. (2005) dated the ammonoid fauna as Middle Permian Wordian in age, but regarded them as reworked fossils, without showing any sedimentological evidences. Ehiro (2008) described some ammonoids from the formation. He also reviewed the taxonomy of the previously reported ammonoids and the mode of occurrence of fossils from the formation, and concluded that the Takakurayama Formation is correlated with the Wordian. On the other hand, Fujikawa and Suzuki (2011) reported some Early Permian ammonoids, including *Artinskia*, in addition to the Wordian ones.

Recently, many cephalopod samples from the Takakurayama Formation, collected mainly in the 1960's to the early 1970's by Chisato Suzuki, were donated to the Tohoku University Museum. They are important for dating the Takakurayama Formation. This paper describes them and discuss on the age of the formation.

Stratigraphy of the Takakurayama Formation and fossil horizons

The Takakurayama Formation is distributed in a narrow area, elongated from north to south, east of Mt. Takakurayama in the Yaguki area, the southeastern margin of the Abukuma Massif (Fig. 1). It was originally named as the Takakurayama Series (Iwao and Matsui, 1961) or Takakurayama Group (Yanagisawa and Nemoto, 1961), and subdivided into the Iriishikura, Motomura and Kashiwadaira formations, in ascending order (Yanagisawa, 1967). Later, Onuki (1966) treated the group as a formation rank and the formations as members (Fig. 2). The Iriishikura Member is more than 100 m thick and consists mostly of laminated mudstone. The Motomura Member is 60 to 7 m in thickness, thinning to the south, and is mainly composed of sandstone and alternating beds of sandstone and mudstone. In the northern area, it includes conglomeratic sandstone with limestone pebbles-boulders and lenses. The Kashiwadaira Member is rather thick (more than 250 m) and consists of

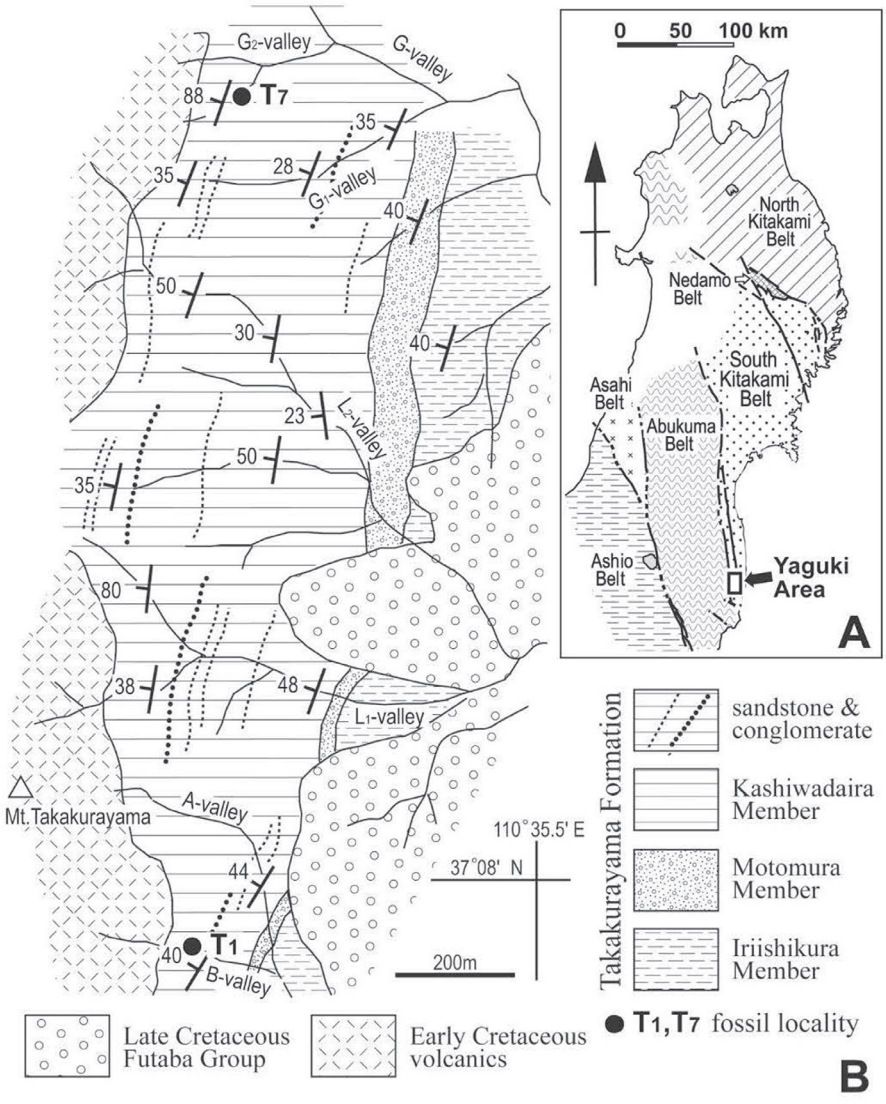

Figure 1. Geotectonic division map of Northeast Japan showing the study area (Yaguki Area) in the South Kitakami Belt (A) and geologic map of the Yaguki Area (B). Longitude and latitude are from the International Terrestrial Reference Frame.

laminated mudstone intercalated with thin sandstones and lenticular pebbly mudstones. Thickness of these sandstones and pebbly mudstones are occasionally reaches 2 m, very rarely 4 m, but usually less than 1 m. These strata trend north-northeast and dip moderately to steeply west. Based on the sedimentary structures such as cross beddings and graded beddings in sandstone beds and laminas, no overturned part exists.

Yanagisawa (1967) named small valleys in this area as A-valley, B-valley, G_2-valley, etc. for convenience (Figure 1). He recognized eight fossil localities in the Takakurayama Group (Formation) and named them as T_1 to T_8, and situated T_1 Locality (B-valley) in the upper part of the Iriishikura Formation, T_3 (L_2-valley), T_4 (D_3-valley) and T_5 (F-valley) in the Motomura Formation, and T_2?, T_6 (G_1-valley), T_7 (G_2-valley) and T_8 (H-valley) in the Kashiwadaira Formation. Tazawa et al. (2005), Tazawa (2008) and Fujikawa and Suzuki (2011) used these Yanagisawa's locality numbers (T_1, T_7 and T_8), and also positioned T_1 in the Iriishikura Member and T_7 and T_8 in the Kashiwadaira Member, but they did not show any geologic map.

There is a large difference about the geologic map around A-, B- and L_1-valleys between Yanagisawa (1967), and Ueno (1992) and Ehiro (2008). In the geologic map of Yanagisawa (1967), the southern extension of the Motomura Member (Motomura Formation) is in the upper reaches of the L_1- and A-valleys, whereas Ueno (1992) and Ehiro (2008) extended it to the middle reaches of the L_1- and A-valleys. According to my field survey, there is no thick sandstone-dominated beds, correspond to the southern extension of

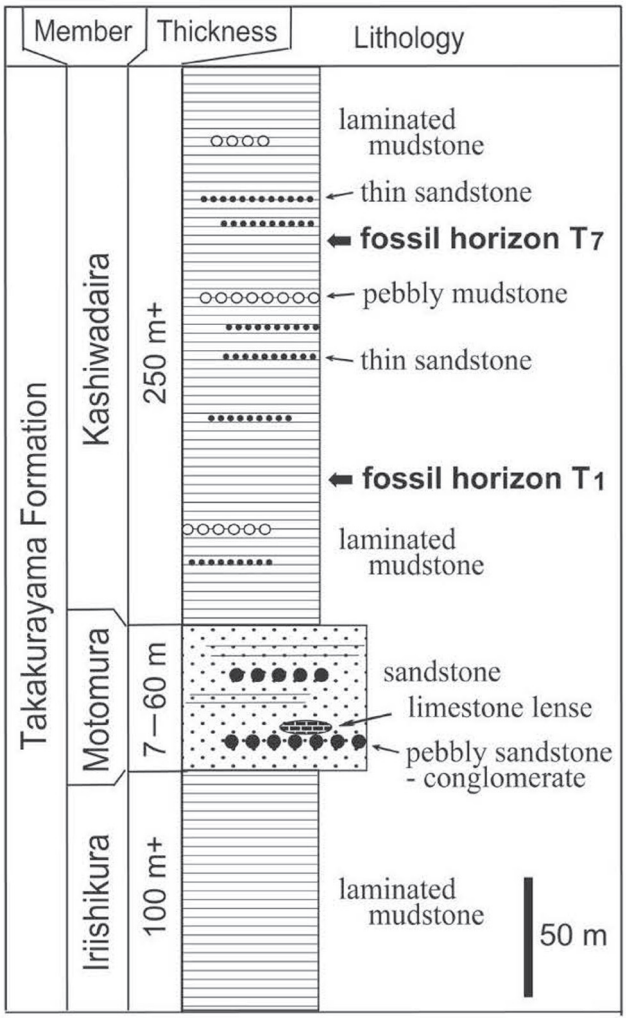

Figure 2. Generalized columnar section of the Takakurayama Formation, showing the fossil horizons.

the Motomura Member, in the upper reaches of the L_1- and A-valleys. Instead, thick sandstone-dominated beds (ca. 10 m in L_1-valley and ca. 7 m in A-valley) expose in their middle reaches, situated in the extended direction of the member distributed in L_2-valley, as shown in geological maps of Ueno (1992) and Ehiro (2008). Although Yanagisawa (1967), Tazawa et al. (2005), Tazawa (2008) and Fujikawa and Suzuki (2011) positioned the fossil locality T_1 in the upper part of the Iriishikura Member, according to Ueno (1992) and Ehiro (2008), it is reasonable to consider that its stratigraphic position is in the lower part of the Kashiwadaira Member.

The cephalopod specimens of the Takakurayama Formation have been reported from three localities: T_1, T_7 and T_8. As shown above, the first horizon is situated in the lower part of the Kashiwadaira Member, and the latter two are in the middle part of the member. The exact stratigraphic relationship between the last two is not clear, because two areas including these two localities are separated by the metamorphic rocks and not continuous (Yanagisawa, 1967). The present ammonoid specimens were collected from the T_1 and T_7 localities (Fig. 2).

Systematic description

Specimens described in this paper are housed in the Tohoku University Museum (Institution abbreviation: IGPS = Institute of Geology and Paleontology, Tohoku University, Sendai). Morphological terminology basically follows Arkell et al. (1957) and the classification of taxonomic ranks higher than genus follows Teichert et al. (1964) for the order Nautilida, Furnish et al. (2009) for the orders Goniatitida and Prolecanitida, and Arkell et al. (1957) for the order Ceratitida. The following abbreviations are used in the descriptions: *D* = diameter of whorl, *H* = height of whorl, *W* = width of whorl, *UD* = diameter of umbilicus.

Subclass Nautiloidea Agasizz, 1847
Order Nautilida Agasizz, 1847
Superfamily Tainoceratoidea Hyatt, 1883
Family Tainoceratidae Hyatt, 1883
Genus ***Tainoceras*** Hyatt, 1883
Type species.—*Nautilus quadrangulus* McChesney, 1860

Tainoceras cf. ***abukumaense*** Hayasaka
Fig. 3.1

cf. *Tainoceras abukumaense* Hayasaka, 1957, p. 24, pl. 8, figs. 1–3; Hayasaka, 1965, p. 13.
Tainoceras abukumense Hayasaka. Hayasaka, 1962, p. 137, pl. 11, figs. 1–3, text-fig. 1; Hayasaka, 1967, p. 1, text-figs. A, B; Koizumi, 1975, p. 32, pl. 5, figs. 1–2.

Material examined.—One specimen, IGPS coll. cat. no. 112470.

Description.—An outer mold of left side is examined. The sub-evolute shell attains more than 75 mm in diameter and the ratio of *UD*/*D* is about 0.3. The flank is inclined to the umbilicus. The umbilical wall is moderately inclined. The ventral shoulder is nearly perpendicular, although the venter is not fully preserved. The shell surface is ornamented with sinuous growth lines. There are two rows of nodes on the flank, one along the ventral shoulder and the other along the umbilical shoulder. Both numbered 18–19 (partly estimated) per volution. The former nodes are large and high, the cross section of which is circular to laterally elongated, and sometimes associated with short ribs diminishing their height toward the umbilicus. The latter nodes are considerably

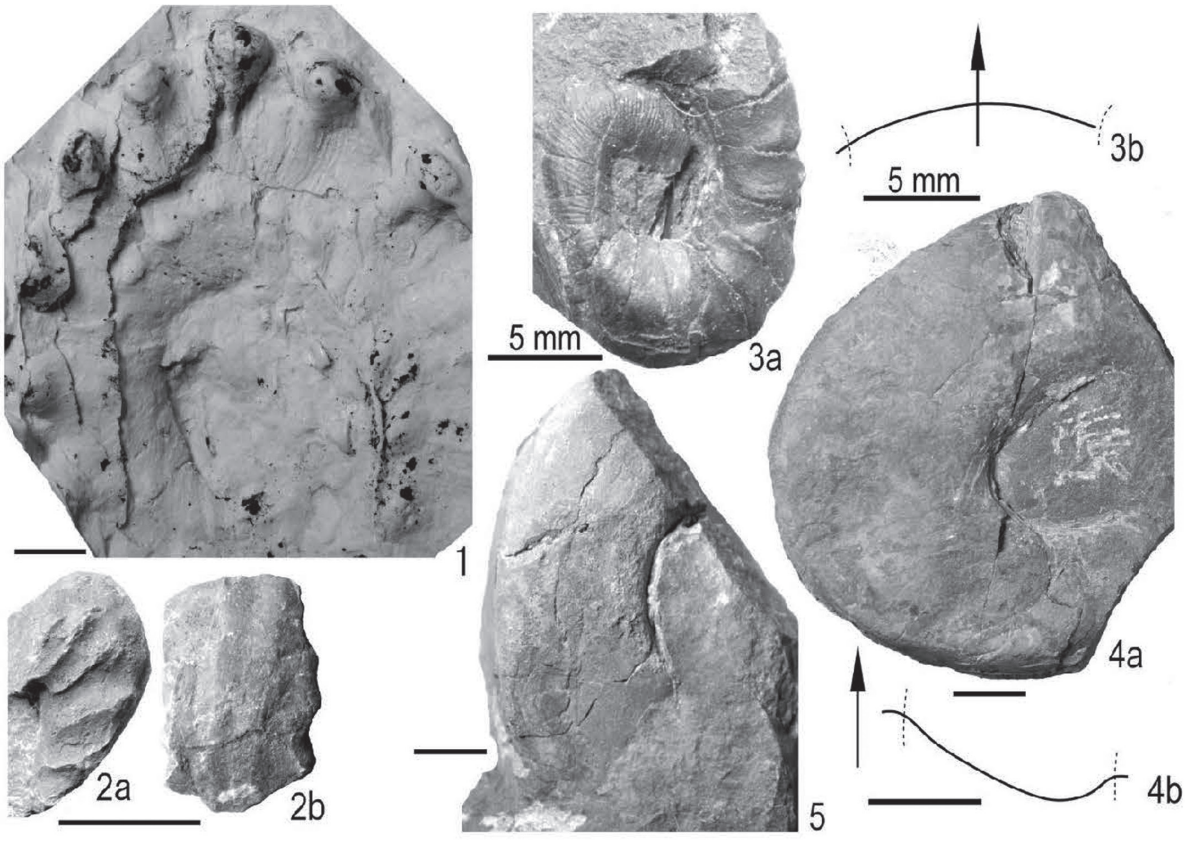

Figure 3. Nautiloids (*Tainoceras*, *Endolobus*? and *Domatoceras*) from the Takakurayama Formation.
1, *Tainoceras* cf. *abukumaense* Hayasaka, IGPS coll. cat. no. 112470, lateral view; **2**, *Tainoceras* sp., IGPS coll. cat. no. 112471, lateral (2a) and ventral (2b) views; **3**, *Endolobus*? sp., IGPS coll. cat. no. 112480, lateral view (3a) and suture line (3b); **4** and **5**, *Domatoceras* sp.; 4, IGPS coll. cat. no. 112481, lateral view (4a) and suture line (4b); 5, IGPS coll. cat. no. 12482, lateral view. Scale bars are 1 cm, unless otherwise stated.

smaller than the former ones. The suture is not preserved.

Comparison.—The shape of the flank and its ornamentation, especially the shape of two rows of nodes of the present specimen is similar to the holotype of *Tainoceras abukumaense* Hayasaka collected from the Takakurayama Formation, but I refrain from identifying it at the specific level because its shell cross section and suture lines are unknown.

Occurrence.—From the middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Tainoceras sp.
Figs. 3.2a–b

Material examined.—One specimen, IGPS coll. cat. no. 112471.

Descriptive remarks.—A fragmental inner mold, obliquely deformed, are examined. The evolute shell attains more than 24 mm in shell diameter. At the preserved end, the height is ca. 14 mm and the width is ca. 16 mm. The flanks are flat and the venter is broadly rounded. There are sharp radial ribs, run from the umbilical shoulder and end at the ventral shoulder forming small nodes. Two fine ridges run on the venter forming the shallow central groove. The suture is not preserved.

Based on the general shell morphology, it is highly probable that the present specimen belongs to the genus *Tainoceras* Hyatt, 1883, but the specific identification is difficult due to the poor state of preservation.

Occurrence.—From the middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Genus ***Pleuronautilus*** Mojsisovics, 1882
Type species.—*Pleuronautilus trinodosus* Mojsisovics, 1902

Pleuronautilus chisatoi sp. nov.
Figs. 4.1a–f

Etymology.—The species name is to honor Mr. Chisato Suzuki, who collected the holotype and making it available for study.

Material examined.—One specimen, IGPS coll. cat. no. 112472 (holotype).

Diagnosis.—A species of *Pleuronautilus* with thickly discoidal and sub-evolute shell. The shell surface is ornamented with prorsiradiate ribs on the flanks and longitudinal lirae on both the flanks and venter.

Description.—The shell attains about 48 mm in maximum diameter along the longest axis of the elliptically deformed specimen, and the corresponding height and umbilical diameter are 20.9 (*H*/*D* = 0.44) and 18.6 mm (*UD*/*D* = 0.39), respectively. The shell width is apparently ca. 9.0 mm, but this value is under tectonically flattened state and its exact value is unknown. The flanks are slightly convex, with the maximum shell width near the umbilical shoulder to umbilical one-thirds of the flanks, and gently converge to the venter. The umbilical wall is steep with acutely rounded umbilical shoulder. The venter, with rounded ventrolateral shoulders, is nearly flat but its median part is slightly concave.

There are prominent lateral ribs on the flanks, numbered 24–25 per volution. The ribs are prorsiradiate and run from the umbilical shoulder, slightly strengthened ventrally, and end at the ventrolateral shoulder forming small nodes. Near the umbilical shoulder, the ribs incline forward. In addition, both the lateral and ventral shell surfaces are ornamented with fine longitudinal lirae.

The external suture consists of very shallow? ventral lobe, low ventrolateral saddle, and wide and shallow lateral lobe. The dorsal suture seems to be nearly straight.

Comparison.—*Pleuronautilus chisatoi* sp. nov. is clearly distinguished from all other species of *Pleuronautilus* in having longitudinal lirae on the shell surface.

Occurrence.—Lower part of the Kashiwadaira Member of the Takakurayama Formation at B-valley (T_1 Locality), eastern slope of Mt. Takakurayama, Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Pleuronautilus cf. ***gregarius*** (Miller)
Figs. 4.2–4.3

cf. *Metacoceras gregarium* Miller, 1945, p. 283, pl. 45, figs. 5–8.

Foordiceras gregarium (Miller). Miller and Youngquist, 1949, p. 98, pl. 36, fig. 5, pl. 38, figs. 5–8, pl. 39, figs. 1, 2, 6–9, pl. 40, figs. 1–4, pl. 41, figs. 5–9.

Pleuronautilus (*P.*) *gregarium* (Miller). Kummel, 1953, p. 36.

Pleuronautilus gregarius (Miller). Shimanskiy, 1967, p. 93.

Material examined.—Two specimens, IGPS coll. cat. no. 112473 and 112474.

Description.—The specimens are obliquely deformed. One specimen (no. 112473), consisting of phragmocone and a part of the body chamber, attains 55.7 mm in maximum diameter along the elliptically deformed specimen, and the corresponding height and umbilical diameter are 26.1 (*H*/*D* = 0.47) and 16.9 mm (*UD*/*D* = 0.30), respectively. The shell width is apparently ca. 15 mm, but this value is under tectonically flattened state and its exact value is unknown. Another one (no. 112474) is a phragmocone. It attains 64.0 mm in maximum diameter along the longest axis of the elliptically deformed specimen, and the corresponding height and umbilical diameter are 26.0 (*H*/*D* = 0.41) and 22.2 mm (*UD*/*D* = 0.35), respectively.

The flanks of the specimens are nearly flat. The venter, with rounded ventrolateral shoulders, is nearly flat, but there is a shallow groove? on the median part of no. 112473. There are slightly prorsiradiate lateral ribs on the flanks, running from the umbilical shoulder to the ventrolateral shoulder. They curve slightly backward and become wide ventrally. The specimen no. 112473 have 19-20 ribs per volution, adoral ones of which are slightly depressed at the middle part. The ribs of another specimen (no. 112474) numbers 11-12 per half volution, but they are indistinct near the adoral end.

The external suture consists of shallow ventral lobe, low ventrolateral saddle, and wide and shallow lateral lobe. The dorsal lobe is very shallow to nearly straight.

Comparison.—The present specimens from the Takakurayama Formation are similar to *Pleuronautilus gregarius* (Miller) from the Wordian strata of USA, but the precise identification is difficult because of their poor state of preservation. *Foordiceras gregarium* (Miller) described by Yanagisawa (1967) from the Takakurayama Formation (Loc. T_7: G_2-valley) is very poorly preserved and fragmental, and hence difficult to identify not only at the species level but also at the genus level.

Occurrence.—Lower part of the Kashiwadaira Member of the Takakurayama Formation at B-valley (T_1 Locality), eastern slope of Mt. Takakurayama (no. 112473) and middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality) (no. 112474), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Pleuronautilus sp.
Fig. 4.4

Material examined.—One specimen, IGPS coll. cat.

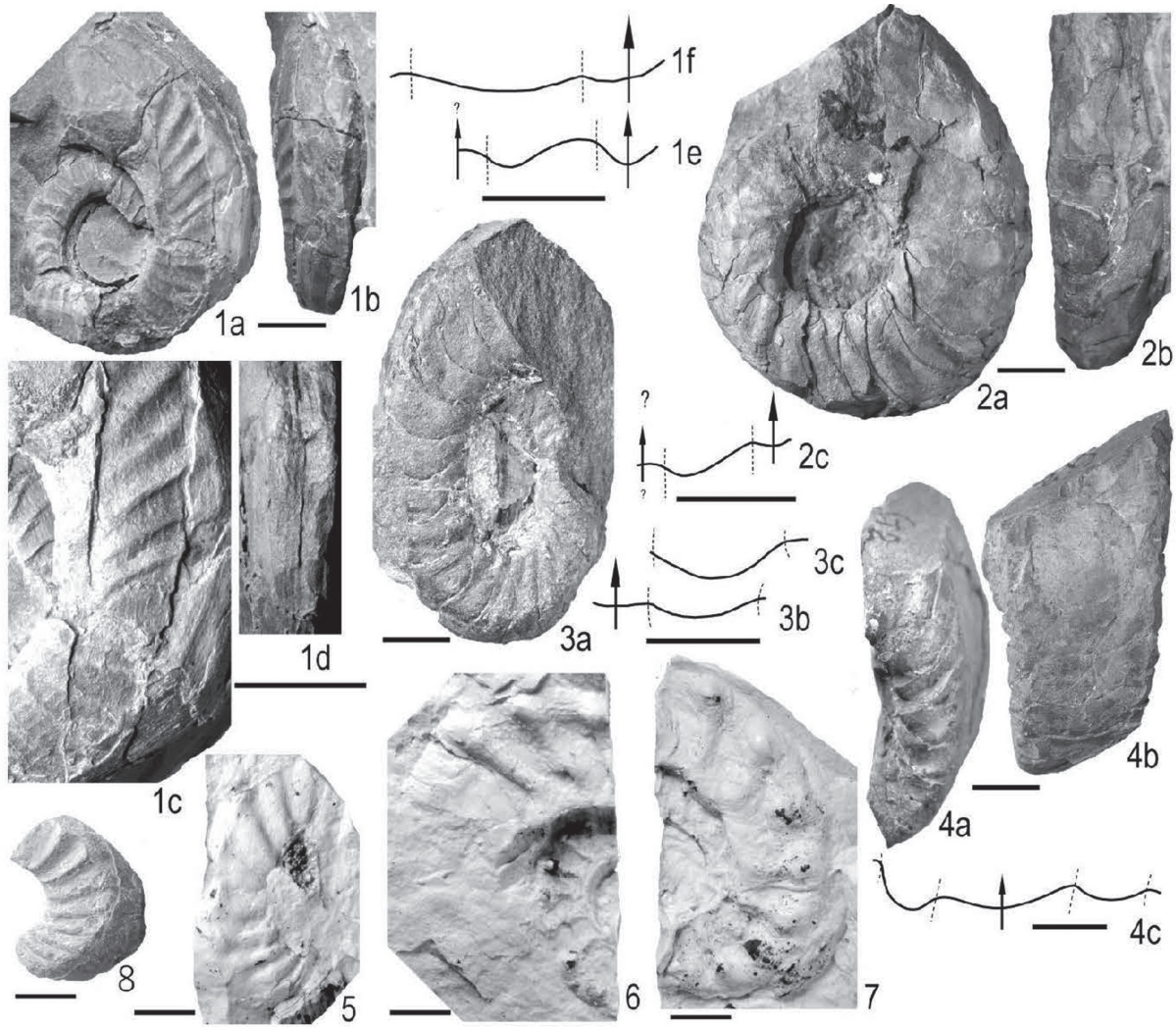

Figure 4. Nautiloids (*Pleuronautilus* and *Pleuronautilus*?) from the Takakurayama Formation.
1, *Pleuronautilus chisatoi* sp. nov., IGPS coll. cat. no. 112472 (holotype); 1a and 1b, lateral (1a) and ventral (1b) views; 1c and 1d, partial enlargements of lateral (1c) and ventral (1d) views showing longitudinal lirae; 1e and 1f, suture lines at H = 10 mm (1e) and 17 mm (1f); **2** and **3**, *Pleuronautilus* cf. *gregarius* (Miller); 2, IGPS coll. cat. no. 112473, lateral view (2a), ventral view (2b) and suture line (2c); 3, IGPS coll. cat. no. 112474; 3a, lateral view; 3b and 3c, suture lines at H = 15 mm (3b) and 22 mm (3c); **4**, *Pleuronautilus* sp., IGPS coll. cat. no.112475, lateral view (4a), ventral view (4b) and suture line (4c); **5**–**8,** *Pleuronautilus*? sp., all lateral views; 5, IGPS coll. cat. no. 112476; 6, IGPS coll. cat. no. 112477; 7, IGPS coll. cat. no. 112478; 8, IGPS coll. cat. no. 112479. Scale bars are 1 cm, unless otherwise stated.

no.112475.

Descriptive remarks.—A fragmental inner mold, tectonically compressed dorso-ventrally, is at hand. The shell is evolute and attains more than 55 mm in diameter. At the preserved adoral end, the height and width are ca. 14 and 32 mm, respectively. The flat to slightly concave flanks, with acutely rounded umbilical and ventral shoulders, converge toward the venter. The umbilical wall is nearly perpendicular. The wide venter is flat to slightly concave. There are radial ribs, curved backward, on the flanks. The venter is smooth. The suture consists of a wide and shallow ventral lobe, small and low ventrolateral saddle and a moderately deep lateral love. The dorsal suture is not well preserved.

Based on the shell outline, surface ornamentation and the shape of the external suture, the present specimen is considered to belong to the genus *Pleuronautilus*, but the specific identification is difficult because of its poor state of preservation.

Occurrence.—Middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

***Pleuronautilus*? sp.**
Figs. 4.5–4.8

Material examined.—Four specimens, IGPS coll. cat. no. 112476–112479.

Descriptive remarks.—Four fragmental outer molds, obliquely deformed, are examined. They are evolute and the flanks are nearly flat. The largest specimen (no. 112478) attains more than 55 mm in diameter. The maximum shell diameter of the second one is about 55 mm and its corresponding umbilical diameter is ca. 23 mm (*UD*/*D* = 0.42). The third one is 43 mm in maximum diameter with the ratio of *UD*/*D* = ca. 0.35. The smallest specimen attains a diameter of 29 mm. There are prominent prorsiradiate lateral ribs on the flanks. The ribs run from the umbilical shoulder, slightly strengthened ventrally, and end at the ventrolateral shoulder forming longitudinal nodes. Near the umbilical shoulder, the ribs incline forward.

The shell outline and surface ornamentation of the present specimens resemble those of the species of the genus *Pleuronautilus*, such as *P*. *gregarius* (Miller). But there remains some doubt on the generic position of them, because they are fragmental and their shell cross sections are unknown.

Occurrence.—All specimens are from the middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Family Koninckioceratidae Hyatt in Zittel, 1900
Genus ***Endolobus*** Meek and Worthen, 1865
Type species.—*Nautilus spectabilis* Meek and Worthen, 1860

***Endolobus*? sp.**
Figs. 3.3a–3b

Material examined.—One specimen, IGPS coll. cat. no. 112480.

Descriptive remarks.—The small specimen is tectonically deformed obliquely, and precise original shell shape is not known. It consists of inner mold and probable natural cast of the outer mold, and shows semi-evolute and probably thickly discoidal shell outline. The maximum shell diameter attains about 18 mm along the elliptically deformed longest axis, and the corresponding height and umbilical diameter are both about 7 mm (*H*/*D* and *UD*/*D* = 0.39), respectively. The shell width exceeds 5 mm. The flanks converge to the umbilicus. The venter is estimated to be broadly rounded with angular ventrolateral shoulders. The adapical part of shell surface is ornamented with fine radial striae or growth lines. There are also rows of small nodes along the ventrolateral shoulders. The external suture consists of very shallow (nearly straight) ventral and lateral lobes with indistinct ventrolateral saddle.

Based on the estimated shell outline, presence of ventrolateral nodes and the shape of the external suture line, the present specimen is considered to belong to the genus *Endolobus*, but some doubt remains on the generic identification because of its severe tectonic deformation.

Occurrence.—Middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Superfamily Trigonoceratoidea Hyatt, 1884
Family Grypoceratidae Hyatt in Zittel, 1900
Genus ***Domatoceras*** Hyatt, 1891
Type species.—*Domatoceras umbilicatum* Miller, Dunber and Condra, 1933

***Domatoceras* sp.**
Figs. 3.4–3.5

Material examined.—Two specimens, IGPS coll. cat. no. 112481 and112482.

Description.—Two fragmental specimens, both preserved only one side, are examined. They are laterally compressed, sub-evolute and flattened, and shell cross section is sub-rectangular. One specimen (no. 112481) attains about 64 mm in diameter, and its corresponding height and umbilical diameter are ca. 25 (*H*/*D* = 0.39) and ca. 19 mm (*UD*/*D* = 0.30), respectively. The width exceeds 10 mm, but the precise value is not known because of its ill preservation. The flanks are nearly flat to very broadly convex, and parallel to very slightly converge to the venter. The umbilical shoulder is rounded and the umbilical wall is steeply dipping. The ventrolateral shoulder is acutely rounded. The shell surface is almost smooth, but the specimen 112481 has some laterally elongated nodes with short radial ribs on the ventral shoulder of the phragmocone to the beginning of the body chamber. Only the lateral suture, which consists of a large love, is preserved in the specimen 112481.

Comparison.—The present specimen 112481 is characterized by having small elongated nodes of the ventral shoulder. *Domatoceras* sp. from the Wordian of Mexico (Miller and Youngquist, 1949, p. 47, pl. 45, fig. 8) somewhat resembles in shell outline and having ventrolateral nodes. *Domatoceras sculptile* (Girty) (*Metacoceras sculptile* Girty, 1911, p. 148; Girty, 1915, p. 245, pl. 31, figs. 1-2a; *Pseudometacoceras sculptile*, Miller et al., 1933, p. 226, pl. 6, figs. 9-12; *Domatoceras sculptile*, Miller and Youngquist,

1949, p. 41, text-fig. 5) from the Upper Carboniferous of Oklahoma, *Domatoceras williami* Miller and Owen (Miller and Owen, 1934, p. 246, pl. 16, fig. 4, pl. 17, figs. 1-4, pl. 18, fig. 1, text-fig. 6) from the Upper Carboniferous of the Mid-Continent region, *Domatoceras hayi* (Hyatt) (*Metacoceras Hayi* Hyatt, 1891, p. 339, text-figs. 38-39; Hay, 1893, p. 38, text-figs. 8-9; Miller et al., 1933, p. 173, text-fig. 25) from the Lower Permian (Carboniferous?) of the Mid-Continent region also have ventrolateral nodes. It is, however, difficult to identify the present specimens at the specific level, because they are fragmental and poorly preserved.

Occurrence.—Both specimens are from the middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Subclass Ammonoidea Zittel, 1884
Order Goniatitida Hyatt, 1884
Suborder Goniatitina Hyatt, 1884
Superfamily Agathiceratoidea Arthaber, 1911
Family Agathiceratidae Arthaber, 1911
Genus ***Agathiceras*** Gemmellaro, 1887
Type species.—*Agathiceras suessi* Gemmellaro, 1887

Agathiceras sp.
Figs. 5.1–5.5

Material.—IGPS coll. cat. no. 112483–112496.

Descriptive remarks.—Fourteen specimens, elliptically and obliquely deformed, are examined. Specimens are small, the diameter of which ranges from 17 to 23 mm along the elliptically deformed longest axis. The umbilicus is very small and almost closed. The sides are convex with broadly rounded umbilical and ventral shoulders. The venter is rounded. The shell surface is ornamented by many fine spiral lirae. The suture is poorly preserved in some specimens, and five saddles and four lobes are present on the lateral side. The crests of the saddles are rounded. The bases of the lobes are also rounded, but slightly pointed at the center.

Based on the general shell shape, surface ornamentation and the outline of the suture line, the present specimens are considered to belong to the genus *Agathiceras*, but the strong tectonic deformation makes it difficult to identify them at the species level.

Occurrence.—Specimens no. 112483–112485 are from the lower part of the Kashiwadaira Member of the Takakurayama Formation at B-valley (T_1 Locality), eastern slope of Mt. Takakurayama, and no. 112486–112496 are from the middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Superfamily Cycloloboidea Zittel, 1895
Family Vidrioceratidae Plummer and Scott, 1937
Genus ***Stacheocera***s Gemmellaro, 1887
Type species.—*Stacheoceras mediterraneum* Gemmellaro, 1887

Stacheoceras sp.
Figs. 5.6–5.7

Material.—IGPS coll. cat. no. 112497 and 112498.

Descriptive remarks.—Two fragmental specimens are examined. One specimen (no. 112497) consists of an outer mold with a small fragmental inner mold. The shell diameter attains more than 30 mm. It is involute with closed umbilicus. The conch has convex sides and acutely rounded to carinate venter with a lenticular cross section, although the lenticular shape may be due to the tectonic flattening. The shell surface seems to be smooth. The external suture is partly preserved. The ventral lobe is wide and deep, but its basal part is not preserved. On the side, at least four set of lateral saddles and lobes are recognized, all diminishing in size toward the umbilicus. The crests of all saddles are rounded. The first lateral lobe is bifid at the base. The second to fourth are bi- or trifid at the base. Another one (no. 112498) is a tectonically flattened, fragmental phragmocone. The apparent cross section is lenticular. The shell surface seems to be smooth. A part of the lateral suture, consisting at least four saddles and lobes are preserved on the side. They gradually diminish in size toward the venter. All saddles have rounded crest. The lateral lobes are trifid, the central branches of them are deepest.

Based on the general shell shape and suture line, the present specimens are considered to belong to the genus *Stacheoceras*, but the specific identification is difficult because of its poor state of preservation.

Occurrence.—The middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Family Cyclolobidae Zittel,1895
Subfamily Kufengoceratinae Zhao,1980

Kufengoceratinae gen. and sp. indet.
Figs. 5.8a–b

Material.—IGPS coll. cat. no. 112499.

Descriptive remarks.—A small, elliptically deformed and flattened specimen is examined. It is involute to sub-involute and apparently discoidal. The diameter of the shell attains 30.2 mm along the longest axis of the elliptically deformed specimen, and the corresponding height and umbilical diameter are ca. 14.0 (*H*/*D* = 0.46) and 4.4 mm (*UD*/*D*

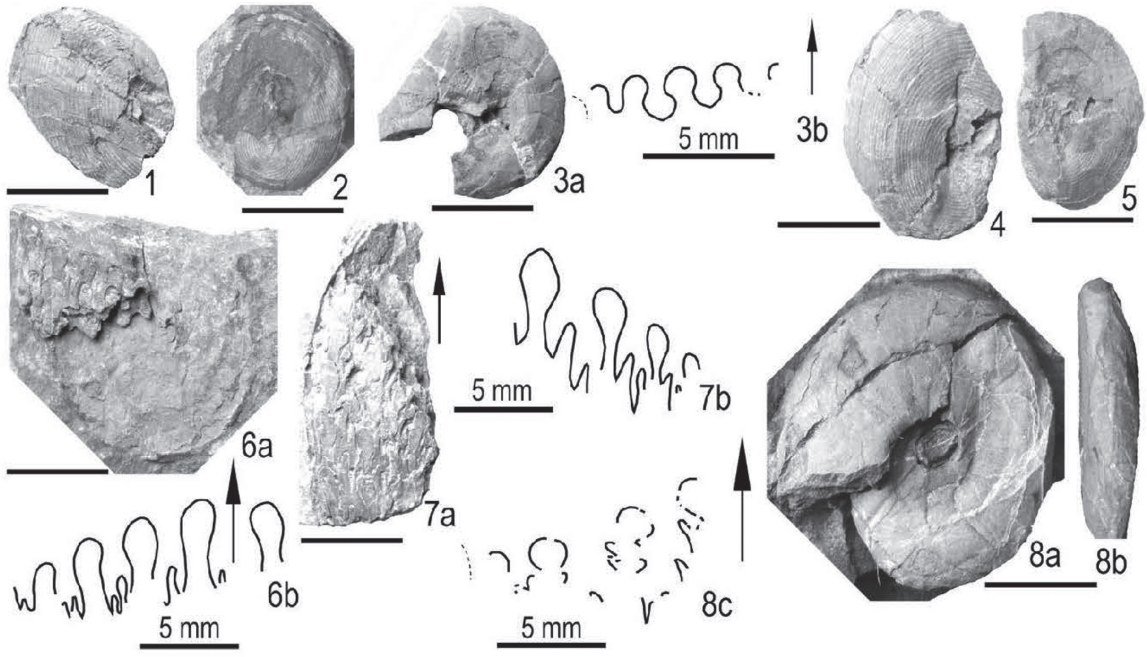

Figure 5. Ammonoids (*Agathiceras*, *Stacheoceras* and Kufengoceratinae gen. and sp. indet.) from the Takakurayama Formation.
1–**5**, *Agathiceras* sp.; 1, IGPS coll. cat. no. 112483, ventro-lateral view; 2, IGPS coll. cat. no. 112484, lateral view; 3, IGPS coll. cat. no. 112486, lateral view (3a) and suture line (3b); 4, IGPS coll. cat. no. 112487, lateral view; 5, IGPS coll. cat. no. 112488, lateral view; **6** and **7**, *Stacheoceras* sp.; 6, IGPS coll. cat. no. 112497, lateral view of the outer mold and a part of the inner mold (6a) and suture line (6b); 7, IGPS coll. cat. no. 112498, lateral views of fragmental inner mold of the ventro-lateral part (7a) and suture line (7b); **8**, Kufengoceratinae gen. and sp. indet., IGPS coll. cat. no. 112499, lateral view (8a), ventral view (8b) and suture line (8c). Scale bars are 1 cm, unless otherwise stated.

= 0.15), respectively. The sides of the shell are broadly rounded. The umbilical wall is steep with sharply rounded umbilical shoulder. The venter is acutely rounded with broadly rounded ventral shoulders. There are faint, rather widely spaced, slightly prorsiradiate ribs or striations on the shell surface. There are some variations in the thickness, height and interspaces of the ribs. The fragmental lateral suture consists of four saddles and three to four lobes. The crests of saddles are all rounded. The lobes are rather strongly serrated up to the upper part of the sides. The base of the first lateral lobe has deep serrations, but bases of the other lobes are not well preserved.

Based on the general shape of the suture line, the present specimen is considered to belong to the subfamily Kufengoceratinae, probably a species of the genus *Guiyangoceras* Zhou, 1985, *Liuzhouceras* Zhao, 1980 or *Paratongluceras* Zhao and Zheng, 1977. The present specimen has a discoidal conch shape and differs from those of these kufengoceratids, which have pachyconic to globular conch. This is, however, due to the tectonic deformation. It is difficult to identify it at the generic level because of its poor state of preservation, especially ill preserved suture line.

Occurrence.—From the middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Subfamily Cyclolobinae Zittel,1895
Genus ***Waagenoceras*** Gemmellaro, 1887
Type species.—*Waagenoceras mojsisovicsi* Gemmellaro, 1887

Waagenoceras sp.
Figs. 6.1–6.4

Material.—IGPS coll. cat. no. 112500–112503.

Descriptive remarks.—Four specimens, elliptically deformed, are examined. They are fragmental, except for the largest specimen (no. 112500). The last specimen attains a shell diameter about 120 mm in the obliquely deformed state, and its corresponding height, width and umbilical diameter are ca. 80, ca. 40 and ca. 15? mm, respectively.

The shell flanks are broadly rounded with rounded umbilical and ventral shoulders. The venter is also rounded. The shell surface looks like smooth. The suture is partly preserved in all specimens. It is typical *Waagenoceras*-type as shown in Figure 6.1b, 6.2b, 6.3b and 6.4b.

Based on the general shell shape and the suture line, the present specimens undoubtedly belong to the genus *Waagenoceras*, but the species level identification is difficult because of its poor and severely deformed preservation.

Occurrence.—All specimens are from the middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Superfamily Marathonitoidea Ruzhentsev, 1938
Family Marathonitidae Ruzhentsev, 1938
Genus ***Jilingites*** Liang, 1982
Type species.—*Jilingites bidentus* Liang, 1982,

Jilingites cf. ***bidentus*** Liang
Figs. 6.5–6.8

cf. *Jilingites bidentus* Liang, 1982, p. 651, pl. 1, figs. 10–13, text-fig. 6.

Material.—IGPS coll. cat. no. 112504–112510.

Description.—Seven elliptically deformed specimens are examined. The shell is small and its maximum diameter ranges from 20 to 45 mm, but the largest specimen attains at least 60 mm. Six specimens are consists of phragmocone. The living chamber, occupying more than three quarters of the last whorl, is only preserved in one specimen (no, 112507). The conch has convex sides with a rounded venter and a very small to closed, shallow? umbilicus. The ventral and umbilical shoulders are broadly rounded. Although the original shell shape is not precisely known due to the tectonic deformation, its cross-section is presumably thickly discoidal and the maximum shell width is near the umbilical two-thirds. The ornamentation of the shell surface is not known, but the surfaces of inner molds are smooth. The suture lines are partly preserved. The broad ventral lobe is divided into two bifid prongs by rather high median saddle, which is about four-fifth of the ventrolateral saddle. On the lateral sides, there are four to five bifid lateral lobes and rounded saddles, but the suture near the umbilicus is not preserved. The lateral lobes are all similar shape and diminish in size towards the umbilicus.

Comparison.—Two species of *Jilingites* have been reported: *Jilingites bidentus* Liang, 1982 from the Wordian of Jiling, North China and *J. kesennumensis* Ehiro and Araki, 1997 from the Capitanian of South Kitakami Belt, Northeast Japan. One questionable specimen of *Jilingites* was also reported from the Takakurayama Formation (Ehiro, 2008). The present species is similar to the type species *Jilingites bidentus* in the shell shape and smooth shell surface, but the specimens are rather poorly preserved and deformed, and some doubt remains in the specific identification.

Occurrence.—Specimens no. 112504 and 112505 are from the lower part of the Kashiwadaira Member of the Takakurayama Formation at B-valley (T_1 Locality), eastern slope of Mt. Takakurayama, and specimens no. 112506–112510 are from the middle part of the Kashiwadaira Member at G_2-valley (T_7 Locality), Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Superfamily Neoicoceratoidea Hyatt in Zittel, 1900
Family Paragastrioceratidae Ruzhentsev, 1951
Subfamily Pseudogastrioceratinae Furnish, 1966
Genus ***Roadoceras*** Zhou, 1985
Type species.—*Gastrioceras roadense* Böse, 1919

Roadoceras cf. ***roadense*** (Böse)
Fig. 6.9

cf. *Gastrioceras roadense* Böse, 1919, p. 85, pl. 2 figs. 28–47.
Paragastrioceras roadense (Böse). Plummer and Scott, 1937, p. 227, pl. 22, figs.15–17; Hayasaka, 1947, p. 27, pl. 1, fig. 4, pl. 2, fig. 3, text-fig. 4.
Pseudogastrioceras globulosissmum Plummer and Scott, 1937 (parts), p. 279, pl. 18 fig. 10.
Pseudogastrioceras roadense (Böse). Miller and Furnish, 1940, p. 89, pl. 16, figs.1–7, pl. 17, fig. 5, pl. 18 fig. 10, 11, pl. 28 figs. 1–3; Miller in King et al., 1944, p. 89, fig. 8, pl. 24, figs. 2, 3, pl. 25, figs. 1–6; Miller, 1945, p. 16, pl. 6, figs. 3–5, pl. 7, figs. 1–3; Clifton, 1946, p. 558, pl. 85, figs. 1, 2; González-Arreola et al., 1994, p. 215, pl.1, figs. i–k.
Altudoceras roadense (Böse). Ruzhentsev, 1960, fig. 34a; Liang, 1982, p. 649, pl. 2, figs. 3–4, pl. 3, figs. 3–6, text-figs. 4a, 4b.
Roadoceras roadense (Böse). Zhou, 1985, p. 196; Zhou, 1987, p. 327; Glenister et al. in Furnish et al., 2009, p. 172, text-figs. 106.6a–6c.
Pseudogastrioceras zittelli Gemmellaro. Tokai Fossil Society, 1995, p. 50.

Material.—IGPS coll. cat. no. 112511.

Description.—The shell is discoidal with rounded venter. The sides are broadly convex, with acutely rounded umbilical shoulder and broadly rounded ventral shoulder. The maximum shell width is about the center of the flank. The umbilicus is small with steep umbilical wall. The shell attains about 30 mm in diameter with a ratio of *UD*/*D* = ca. 0.24. The shell surface is ornamented with fine spiral ribs. In

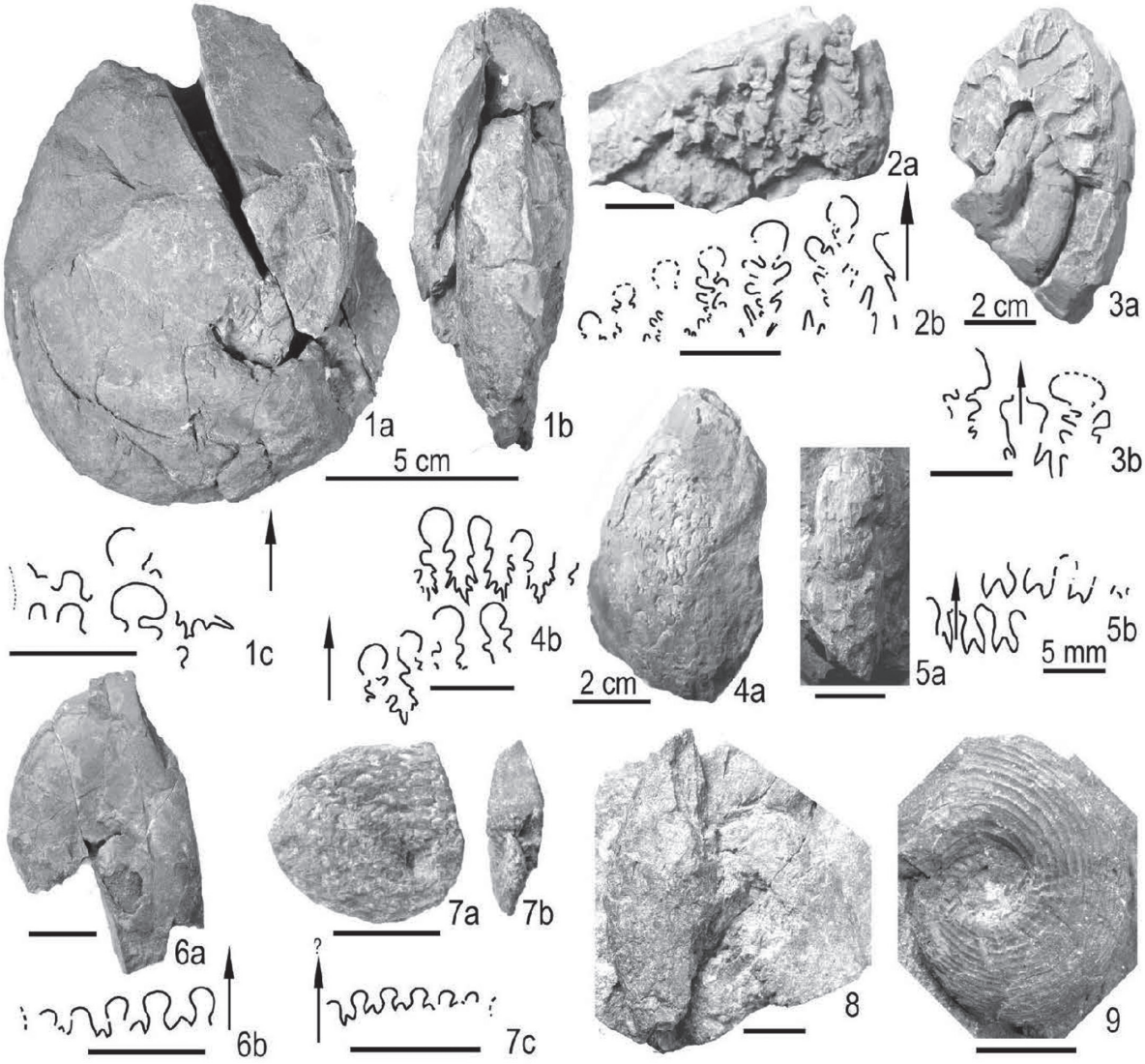

Figure 6. Ammonoids (*Waagenoceras*, *Jilingites* and *Roadoceras*) from the Takakurayama Formation.
1–**4**, *Waagenoceras* sp.; 1, IGPS coll. cat. no. 112500, lateral view (1a), ventral view (1b) and part of the suture line (1c); 2, IGPS coll. cat. no. 112503, lateral view of the fragmental inner mold (2a) and suture line (2b); 3, IGPS coll. cat. no. 112501, cross section (3a) and ventral lobe (3b); 4, IGPS coll. cat. no. 112502, lateral view (4a) and suture line (4b); **5**–**8**, *Jilingites* cf. *bidentus* Liang; 5, IGPS coll. cat. no. 112505, ventral view (5a) and ventro-lateral suture line (5b); 6, IGPS coll. cat. no. 112507, lateral view (6a) and suture line (6b); 7, IGPS coll. cat. no. 112508, lateral view (7a), ventral view (7b) and suture line (7c); 8, IGPS coll. cat. no. 112504, lateral view of the outer mold and a part of the inner mold; **9**, *Roadoceras* cf. *roadense* (Böse), IGPS coll. cat. no. 112511, lateral view. Scale bars are 1 cm, unless otherwise stated.

addition, there are 16-17, fine and short, radial ribs per half volution, along the umbilical shoulder. They are prorsiradiate and extend to the inner one-thirds of the flank, but become indistinct forward. The suture line is not preserved.

Discussion.—This specimen is probably the same specimen reported as *Pseudogastrioceras zittelli* Gemmellaro, 1887 by Tokai Fossil Society (1995, p. 50). Based on the general shell shape and ornamentation, the present specimen is considered to belong to the genus *Roadoceras* Zhou, 1985, and comparable with the type species *Roadoceras roadense* (Böse, 1919). However, I refrain from identifying it at the specific level precisely

because of its ill state of preservation and lacking the suture line.

Occurrence.—Lower part of the Kashiwadaira Member of the Takakurayama Formation at B-valley (T_1 Locality), eastern slope of Mt. Takakurayama, Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Genus ***Neopopanoceras*** Schindewolf, 1939
Type species.—*Popanoceras scrobiculatum* Gemmellaro, 1887

Tauroceras Tumanskaia, 1938, non Hope, 1840 (modern insect)

Neopopanoceras Schindewolf, 1939, non Spath, 1951 (Triassic ammonoid); Glenister et al., 2009

See "Nomenclatorial note" by Zhou and Glenister in Furnish et al., 2009, p. 218.

Neopopanoceras cf. ***scrobiculatum*** (Gemmellaro)
Figs. 7.1–7.4

cf. *Popanoceras scrobiculatum* Gemmellaro, 1887, p. 25, pl. 3, figs. 22–26, pl. 8, fig. 26; Gemmellaro, 1888, p. 14, pl. B, figs. 2–4, pl. C, figs. 9, 10; Frech, 1902, pl. 59a, figs. 7a–7e; Ruzhentsev, 1951, text-fig. 56d; Miller et al., 1957, L. 52, text-fig. 2-8; Termier et al., 1972, p. 114, pl. 17, figs. 5–8

Tauroceras scrobiculatum (Gemmellaro). Tumanskaia, 1938, p. 145, text-figs. 1–4; Ruzhentsev, 1960, p. 111, text-fig. 1g; Glenister and Furnish, 1988, p. 45, pl. 3, fig. 8, pl. 4, fig.12–13, text-fig.1; Leonova, 2002, S 95, text-fig. 59; Zhou and Yang, 2005, p. 387, text-figs. 5.1, 5.2, 11.

Neopopanoceras scrobiculatum (Gemmellaro). Glenister et al. in Furnish et al., 2009, p. 181, text-figs. 115.1a–1f.

Material.—IGPS coll. cat. no. 112512–112515.

Description.—Four small specimens, elliptically deformed, are examined. They are mostly outer molds, but some fragmental inner molds are also preserved. The maximum conch diameters range from ca. 12 to 35 mm.

The shell is narrowly discoidal and evolute, with a medium-sized umbilicus (the *UD*/*D* ratios are about one-thirds). The flanks and venter are flattened with abruptly rounded ventrolateral shoulders. Fine and dense radial ribs are prominent on the umbilical wall to the venter, but are rather inconspicuous on the flanks of the inner volution. They are sinuous on the flanks and form a deep U-shaped ventral sinus. At the midpoint of the flanks of the inner volution, there are remarkable pits, which change in outline from circular or longitudinally elongated to become radially elongated as they grow. The suture is not preserved.

Discussion.—From the shell shape and ornamentation, the present specimens undoubtedly belong to the genus *Neopopanoceras* Schindewolf, 1939, and most probably identified as *N. scrobiculatum* (Gemmellaro). But the precise identification at the specific level is difficult since they are poorly preserved and lacking the suture line.

Occurrence.—Middle part of the Kashiwadaira Member of the Takakurayama Formation at G_2-valley (T_7 Locality), eastern slope of Mt. Takakurayama, Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Order Prolecanitida Miller and Furnish, 1954
Superfamily Medlicottitoidea, Karpinsky, 1889
Family Medlicottidae Karpinsky, 1889
Subfamily Propinacoceratinae Plummer and Scott, 1937
Genus ***Propinacoceras*** Gemmellaro, 1887
Type species.—*Propinacoceras Beyrichi* Gemmellaro, 1887

Propinacoceras sp.
Figs. 7.5–7.8

Material.—IGPS coll. cat. no. 112516, 112519–112522.

Descriptive remarks.—Five fragmental specimens are at hand. The conch is thinly discoidal and involute with almost closed umbilicus. The sides are flat and almost parallel to each other, but slightly converge toward the umbilicus. The venter is also flat, but bears two rows of prominent nodes or short ribs, which are separated by a median groove. The umbilical and ventral shoulders are acutely rounded. The suture is only poorly preserved in one specimen (no. 112516). The ventrolateral saddle seems to be low and wide with some serrations, but the precise shape is not known. Lateral lobes are bifid or rounded at the base. All saddles are rounded.

Based on the shell shape, shell ornamentation and general shape of suture line, the present specimens seem to belong to the genus *Propinacoceras* Gemmellaro, 1887. But it is difficult to identify at the specific level, because of their poor state of preservation.

Occurrence.—Lower and middle part of the Kashiwadaira Member of the Takakurayama Formation at B-valley (T_1 Locality: no. 112516) and G_2-valley (T_7 Locality: no. 112519–112522), eastern slope of Mt. Takakurayama, Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Propinacoceras? sp.
Figs. 7.9–7.11

Material.—IGPS coll. cat. no. 112517, 112518, 112523–112536.

Descriptive remarks.—Many fragmental specimens are

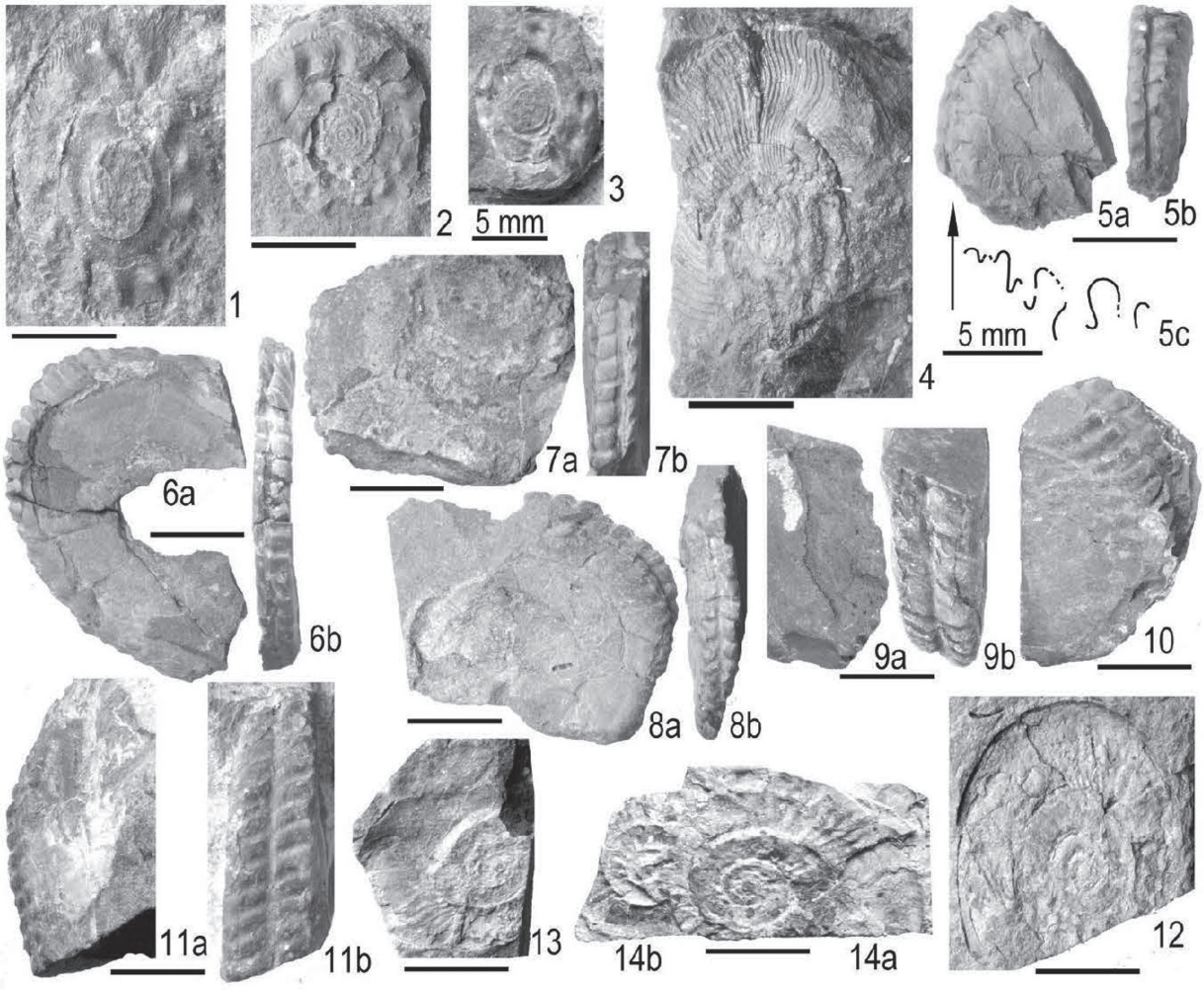

Figure 7. Ammonoids (*Neopopanoceras*, *Propinacoceras*, *Propinacoceras*? and *Paraceltites*) from the Takakurayama Formation.
1–**4**, *Neopopanoceras* cf. *scrobiculatum* (Gemmellaro), all lateral views; 1, IGPS coll. cat. no. 112513; 2, IGPS coll. cat. no. 112512; 3, IGPS coll. cat. no. 112515; 4, IGPS coll. cat. no. 112514; **5**–**8**, *Propinacoceras* sp.; 5, IGPS coll. cat. no. 112516, lateral view (5a), ventral view (5b) and suture line (5c); 6, IGPS coll. cat. no. 112519, lateral (6a) and ventral (6b) views; 7, IGPS coll. cat. no. 112520, lateral (7a) and ventral (7b) views; 8, IGPS coll. cat. no. 112521, lateral (8b) and ventral (8b) views; **9**–**11**, *Propinacoceras*? sp.; 9, IGPS coll. cat. no. 112523, lateral (9a) and ventral (9b) views; 10, IGPS coll. cat. no. 112524, lateral view; 11, IGPS coll. cat. no. 112525, lateral (11a) and ventral (11b) views; **12**–**14**, *Paraceltites* cf. *elegans* Girty, all lateral views; 12, IGPS coll. cat. no. 112537; 13, IGPS coll. cat. no. 112538; 14, IGPS coll. cat. no. 112539 (14a) and 112540 (4b). Scale bars are 1 cm, unless otherwise stated.

at hand. Most specimens are small fragment of the ventral part. The fragmentation is considered to be almost occurred during the sampling process. The conch is thinly discoidal with flat and parallel sides. The venter is also flat, with two rows of prominent nodes or short ribs, which are separated by a median groove. The ventral shoulders are acutely rounded.

The present specimens are likely to belong to the genus *Propinacoceras* Gemmellaro, 1887, because they yielded with *Propinacoceras* specimens and having the same shell shape and shell ornamentation with the genus. There is, however, another possibility that these species belong to any genera of subfamily Propinacoceratinae, such as *Bamyaniceras* Termier and Termier, 1970 and *Difuntites* Glenister and Furnish, 1988 by their shell shape and ornamentation.

Occurrence.—Lower and middle part of the Kashiwadaira Member of the Takakurayama Formation at B-valley (T_1

Locality: no. no. 112517, 112518) and G_2-valley (T_7 Locality: no. 112523–112536), eastern slope of Mt. Takakurayama, Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Order Ceratitida Hyatt, 1884
Superfamily Xenodiscoidea Frech, 1902
Family Paraceltitidae Spath, 1930
Genus ***Paraceltites*** Gemmellaro, 1887
Type species.—*Paraceltites elegans* Girty, 1908

Paraceltites cf. ***elegans*** Girty
Figs. 7.12–7.14

cf. *Paraceltites elegans* Girty, 1908, p. 499, pl. 25, figs. 12–14; Plummer and Scott, 1937, p. 367, pl. 37, figs. 1–8; Miller and Furnish, 1940, p. 67, pl. 22, figs. 1–10, text-fig. 17B; Yanagisawa, 1967, p. 103, pl. 3, fig. 11; Spinosa et al., 1975, p. 249, pl. 1, pl. 2, figs. 1–7, pl. 3, figs. 1–9, text-figs. 3, 4, 5C, 10A, 11, 12; Zhao and Zheng, 1977, p. 248, pl. 5, figs. 11, 12; Liang and Guo, 1982, p. 278, pl. 106, figs. 8, 9; Zheng, 1984, p. 191, pl. 1, figs. 1–7, text-figs. 8a, 8b; Misaki and Ehiro, 2004, p. 136, fig. 8.3; Ehiro and Misaki, 2005, p. 11, figs. 6.8–6.9.

Material.—IGPS coll. cat. no. 112537–112540.

Descriptive remarks.—Four elliptically deformed specimens are examined. They are mostly outer mold and the maximum shell diameter ranges from 14 to 29 mm. The shells are evolute, with the ratios of *UD*/*D* about 0.5, and thinly discoidal with nearly flat to slightly convex sides. The umbilicus is shallow and the umbilical shoulder is acutely rounded. The venter seems to be rounded with rounded ventral shoulders. The shell surface is ornamented by fine sinuous ribs, which fade out near the ventral shoulder. The suture is not preserved.

Based on the shell shape and the surface ornamentation, the present specimens are comparable with *Paraceltites elegans* Girty, 1908. The precise specific identification, however, is difficult, because they are rather poorly preserved and the suture is unknown.

Occurrence.—Middle part of the Kashiwadaira Member of the Takakurayama Formation at G_2-valley (T_7 Locality), eastern slope of Mt. Takakurayama, Yaguki, Iwaki City, Fukushima Prefecture. Middle Permian (Wordian).

Discussion

Faunal composition of cephalopods from the Takakurayama Formation

As discussed in the stratigraphic section, cephalopod fossils of the Takakurayama Formation came from three horizons: the lower part (T_1: B-valley) and middle part (T_7: G_2-valley, and T_8: H-valley) of the Kashiwadaira Member. The T_8 Locality is isolated and its exact stratigraphic relation with T_7 Locality is unknown. In this paper, eight species belonging to four genera of coiled nautiloids, including some questionable ones, and nine species belonging to eight genera of ammonoids and an indeterminable Kufengoceratinae are described from the T_1 and T_7 localities. In the ammonoid fauna, *Propinacoceras* (including questionable ones) is most abundant (more than twenty specimens) and *Agathiceras* is the second (eleven). Others are less than six specimens each. The faunal compositions of the two horizons are as follows:

T_1 Locality:
- Nautiloids: *Pleuronautilus chisatoi* sp. nov., *Pleuronautilus* cf. *gregarius* (Miller)
- Ammonoids: *Agathicera*s sp., *Jilingites* cf. *bidentus* Liang, *Roadoceras* cf. *roadense* (Böse), *Propinacoceras* sp., *Propinacoceras*? sp.

T_7 Locality:
- Nautiloids: *Tainoceras* cf. *abukumaense* Hayasaka, *Tainoceras* sp., *Pleuronautilus* cf. *gregarius* (Miller), *Pleuronautilus* sp., *Pleuronautilus*? sp., *Endolobus*? sp., *Domatoceras* sp.
- Ammonoids: *Agathicera*s sp., *Stacheoceras* sp., Kufengoceratinae gen. and sp. indet., *Waagenoceras* sp., *Jilingites* cf. *bidentus* Liang, *Neopopanoceras* cf. *scrobiculatum* (Gemmellaro), *Propinacoceras* sp., *Propinacoceras*? sp., *Paraceltites* cf. *elegans* Girty

In addition, some coiled nautiloid species have been described from the Takakurayama Formation. Hayasaka (1957, 1965) described *Tainoceras abukumaense* Hayasaka, *T*. aff. *unklesbayi* Miller and Youngquist and *Tylonautilus permicus* Hayasaka. Yanagisawa (1967) reported *Foordiceras gregarium* (Miller) (= *Pleuronautilus gregarius*). The last specimen is, however, very poorly preserved, and fragmental, so its specific identification seems to be difficult. These species are collected from the T_7 Locality.

Ehiro (2008) described five genera of ammonoids from the T_7 Locality: *Agathiceras*, *Jilingites*?, *Waagenoceras*, *Popanoceras* and *Tauroceras* (= *Neopopanoceras*). He also reviewed and arranged the ammonoid fauna previously reported from the Takakurayama Formation by Hayasaka (1965), Yanagisawa (1967), Koizumi (1975), Tokai Fossil Society (1995) and Tazawa et al. (2005), and recognized 17 species belong to 13 genera and a questionable Medlicottidae from the formation. They are:

T_1 Locality: *Roadoceras* sp., *Paraceltites* aff. *elegans* Girty

T_7 Locality: *Agathiceras* cf. *suessi* Gemmellaro,

Agathiceras sp., *Popanoceras* sp., *Tauroceras* sp. (= *Neopopanoceras*), *Stacheoceras* aff. *grunwaldti* Gemmellaro, *Waagenoceras* sp., *Mexicoceras*? sp., *Newellites richardsoni* (Miller and Furnish), *Jilingites*? sp., *Altudoceras* sp., *Propinacoceras* aff. *knighti* Miller and Furnish, *Propinacoceras* sp., *Medlicottia* cf. *costellifera* Miller and Furnish, Medlicottidae? gen. and sp. indet., *Paraceltites* sp.

T_8 Locality: *Paraceltites elegans* Girty

However, some doubt remains on the specific assignments of the genera *Agathiceras*, *Stacheoceras* and *Medlicottia*, because they are ill preserved and severely deformed. And, moreover, the generic assignment of *Medlicottia* by Yanagisawa (1967) is questionable, since it is fragmental, deformed specimens without suture line.

Later, Fujikawa and Suzuki (2011) reported some ammonoids from the T_1 Locality, such as *Thalassoceras*? sp., *Agathiceras* sp., *Paragastrioceras*? sp. and *Artinskia* sp. This generic identification has, however, some problems. The specimens assigned to *Thalassoceras*? sp. and *Paragastrioceras*? sp. are rather ill preserved to identify it at the generic level. Moreover, generic identification of their *Artinskia* specimens is questionable. Because, according to their figures, 1) these specimens have two rows of nodes on the venter to ventral shoulder, and they do not extend to the lateral part. 2) Although it is only partly preserved, the ventrolateral saddle of the external suture is simple and low. These features, especially the shape of the ventrolateral saddle of the suture, completely differ from those of the genus *Artinskia*, and, instead, indicate that these specimens belong to any genera of subfamily Propinacoceratinae, such as *Bamyaniceras* Termier and Termier, 1970, *Difuntites* Glenister and Furnish, 1988 and *Propinacoceras* Gemmellaro, 1887.

Therefore, the generic compositions of each cephalopod locality in the Kashiwadaira Member of the Takakurayama Formation are as follows:

T_1 Locality: *Pleuronautilu*s, *Agathicera*s, *Jilingites*, *Roadoceras*, *Propinacoceras* and *Paraceltites*.

T_7 Locality: *Tainoceras*, *Pleuronautilus*, *Endolobus*?, *Domatoceras*, *Agathicera*s, *Stacheoceras*, Kufengoceratinae, *Waagenoceras*, *Mexicoceras*?, *Newellites*, *Jilingites*, *Popanoceras*, *Neopopanoceras*, *Altudoceras*, *Propinacoceras*, *Medlicottia*? and *Paraceltites*.

T_8 Locality: *Paraceltites*.

Of the cephalopod faunas from the Takakurayama Formation, the fauna of the T_7 Locality is rather diverse, whereas the rest are less variety. Genera of the T_1 and T_8 localities are, except for *Roadoceras*, included in the fauna of the T_7 Locality, and there is no remarkable difference in generic compositions in these faunas.

Age of the cephalopod fauna and Takakurayama Formation

Of the nautiloid genera of the Kashiwadaira Member, including the previously described ones, *Tainoceras*, *Pleuronautilus* and *Domatoceras* are long ranging from Late Carboniferous to Permian or Triassic. *Tylonautilus* is rather rare genus and only known from the Lower Carboniferous and from the Takakurayama Formation. The stratigraphic range of the genus *Endolobus* is generally considered to be restricted in the Kungurian. Occurrences of *Endolobus*, however, have also been reported from the Wuchiapingian of South China (Zhao et al., 1978) and from the Changhsingian of South China and Iran (Korn et al., 2019). They were not described, but their conch parameters were shown in table S1 of Korn et al. (2019).

The present paper confirmed the occurrences of eight genera of ammonoid (*Agathiceras*, *Stacheoceras*, *Waagenoceras*, *Jilingites*, *Neopopanoceras*, *Roadoceras*, *Propinacoceras* and *Paraceltites*) and added Kufengoceratinae gen. and sp. indet. in the ammonoid fauna of the Takakurayama Formation arranged by Ehiro (2008). In addition, five genera have also been known from the formation: *Mexicoceras*?, *Newellites*, *Popanoceras*, *Altudoceras* and *Medlicottia*?

As discussed by Ehiro (2008), the ammonoid fauna from the Takakurayama Formation is Wordian in age. Additional Kufengoceratinae does not conflict with this conclusion, because it ranges from the Roadian to Capitanian (Lopingian?). Fujikawa and Suzuki (2011) reported some ammonoids from the T_1 Locality, including *Artinskia* sp., and concluded that this fauna indicates an Early Permian (Sakmarian–Artinskian) age. As discussed above, however, their generic identification of their *Artinskia* specimens is incorrect, and it belongs to any genera of subfamily Propinacoceratinae, most probably *Propinacoceras*, which ranges up to the middle–upper Permian.

Among the Takakurayama ammonoids, *Jilingites* (ranges from Wordian to Capitanian), *Waagenoceras* (Wordian to Capitanian), *Newellites* (Wordian), *Mexicoceras* (Roadian to Wordian), *Altudoceras* (Roadian to Capitanian), *Roadoceras* (Wordian to Wuchiapingian) and *Neopopanoceras* (Wordian) strongly support the Wordian age of the fauna.

On the other hand, Tazawa et al. (2005, 2015) regarded almost all fossils from the Takakurayama Formation are reworked, except for very few brachiopod specimens which are considered to be Lopingian in age. As discussed by Ehiro (2008), this interpretation has no sedimentological evidence. The Takakurayama Formation includes some pebbly mudstone, but the fossil horizons are composed of massive or sharply laminated mudstone. Almost all fossils, such as trilobites, brachiopods, gastropods, bivalves, nautiloids and ammonoids, except for some fusulinoideans

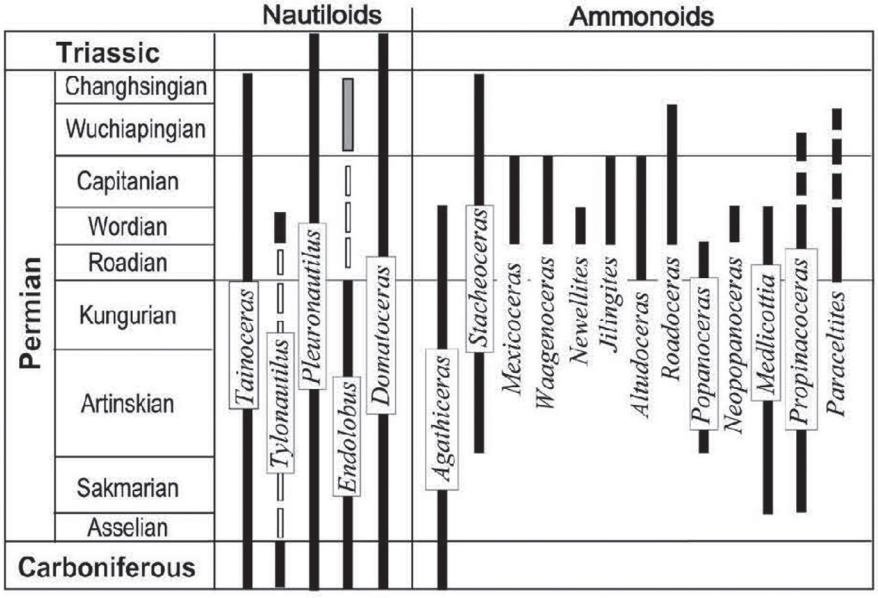

Figure 8. Stratigraphic ranges of the cephalopod genera known from the Takakurayama Formation. Data from Arkell et al. (1957), Furnish et al. (2009), Kummel (1953), Miller et al. (1957) and others.

and corals from the limestone pebbles and boulders in the Motomura Member, have similar state of preservation. They are usually well preserved, although suffered severe tectonic deformation. Some specimens are fragmental, but this is mainly due to the damage during the sampling process. Therefore, the age of the Takakurayama Formation (Kashiwadaira Member) is Wordian as shown by the ammonoid fauna. I think there is a large possibility that these "Lopingian" brachiopods actually range down into the Middle Permian.

The Takakurayama fauna, comprising four genera of nautiloid and fourteen genera of ammonoid, is the most diverse Wordian cephalopod fauna in Japan. It is far more than a next diverse fauna from the uppermost part of the Hosoo Formation, which is composed of six ammonoid genera (Ehiro, 2010) with some nautiloids, distributed in the southern part of the Kitakami Massif, also belongs to the South Kitakami Belt.

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Early Anisian (Aegean) ammonoids from the Fukkoshi Formation (Inai Group) with special reference to the Olenekian/Anisian boundary in the South Kitakami Belt, Northeast Japan

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Abstract: The Triassic Fukkoshi Formation is integral to clarifying the Olenekian/Anisian boundary in the South Kitakami Belt, Northeast Japan, because it overlies conformably the Olenekian Osawa Formation and one hand is covered by the Anisian Isatomae Formation. The middle and upper parts of the Fukkoshi Formation distributed in the Kamiwarizaki area yield abundant ammonoids consisting of over 30 species belonging to 21 genera, including one new genus *Psilokhvalynites* and four new species, *Parapopanoceras involutum*, *Psilokhvalynites takaizumii*, *Paracrochordiceras watanabei* and *Paradanubites ozashiense*. The Fukkoshi ammonoid fauna is dominated in the genera *Leiophyllites* (very abundant), *Paradanubites*, *Danubites* and *Paracrochordiceras*, and, in addition, characterized common occurrences of those belonging to the families Parapopanoceratidae, Japonitidae and Longobarditidae. Although it includes some Olenekian-type genera, such as *Hemilecanites*, *Pseudosageceras* and *Metadagnoceras*, the majority of the fauna are early Anisian (Aegean) genera and species. Therefore, the fauna is early Anisian in age, and the Olenekian/Anisian boundary is considered to locate somewhere in the lower part of the Fukkoshi Formation. The generic composition of the Fukkoshi Aegean ammonoid fauna has similarities with those of some localities located in the low-latitude regions of the Tethys and Panthalassa, especially with that of Qinghai, west China.

Introduction

The Triassic Fukkoshi Formation is the third formation of the Lower–Middle Triassic Inai Group in the South Kitakami Belt, Northeast Japan, which is distributed widely in the southern part of the Kitakami Massif (Figure 1). The group is composed of a continuous, fossiliferous, shallow marine (partly alluvial to nearshore marine) clastic sediments, and therefore, one of the most important reference sequences of the Lower–Middle Triassic of Japan. It consists of the Hiraiso, Osawa, Fukkoshi and Isatomae formations, in ascending order (Onuki and Bando, 1959: Figure 2). The Osawa and Isatomae formations are rich in ammonoids, and many late Olenekian and Anisian–(Ladinian) ammonoids, respectively, have been known. The Fukkoshi Formation locates stratigraphically between them and, therefore, is important to elucidate the stratigraphic position of the Olenekian/Anisian boundary (OAB) in the South Kitakami Belt. The Fukkoshi Formation is, however, almost baren of ammonoid, since it is dominated in sandstone. Very few ammonoids have been described or reported from the Fukkoshi Formation until now, but it still remains doubtful about the stratigraphic position and taxonomy of these specimens, as discussed below.

Recently, new ammonoid localities of the Fukkoshi Formation were found in the Kamiwarizaki area, the border area of the north-side Minamisanriku Town and south-side Kitakami-cho of Ishinomaki City, Miyagi Prefecture. The ammonoid fauna is rather diverse and were collected definitely from some horizons belong to the middle to upper part of the formation. This paper describes these ammonoids and discusses its biostratigraphical and biogeographical significances.

Stratigraphy of the Fukkoshi Formation and its biostratigraphic problems

The Fukkoshi Formation, 200 to 300 meters in total thickness, consists mostly of sandstone and alternating beds of sandstone and mudstone, with minor amount of

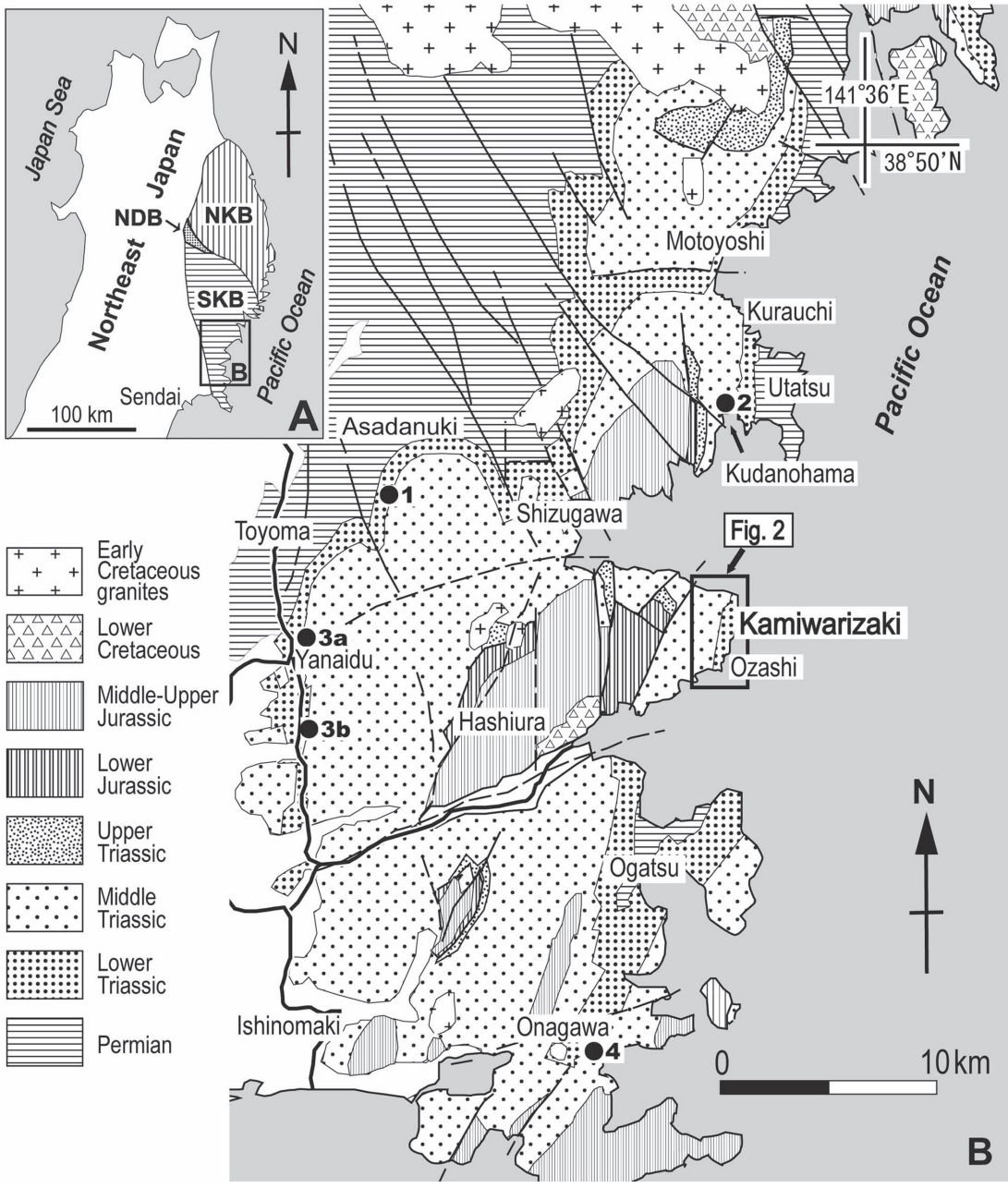

Figure 1. Index map (A) and simplified geologic map of the Southern Kitakami Massif (South Kitakami Belt), Northeast Japan, showing the distribution of the Lower-Middle Triassic Inai Group and study area (Fig. 2) (B). Longitude and latitude are from the International Terrestrial Reference Frame. Thick solid and broken lines are faults. NDB: Nedamo Belt, NKB: North Kitakami Belt, SKB: South Kitakami Belt. Localities 1–4 are related ammonoid localities: see text.

mudstone. It overlies conformably the Osawa Formation, and in turn is covered conformably by the Isatomae Formation.

The Osawa Formation is dominated in laminated mudstone (250 to 350 m thick), and yields rich ammonoids. Twenty-seven ammonoid genera have been described from the formation (e.g. Bando and Shimoyama, 1974; Ehiro et al., 2016; Ehiro, 2022 in press). The lower to middle part of the formation, the *Subcolumbites* Zone of Bando and Shimoyama (1974), yields *Columbites parisianus* Hyatt

and Smith and *Subcolumbites perrinismithi* (Arthaber), associated with such genera as *Hemilecanites*, *Albanites*, *Pseudosageceras*, *Tardicolumbites*, *Yvesgalleticeras*, *Hellenites*, *Metadagnoceras*, *Procarnites*, *Olenekoceras*, *Nordophiceratoides*, etc. The lower part of the upper part, the *Arnautoceltites* Zone of Bando and Shimoyama (1974), contains *Arnautoceltites*, *Nordophiceras*, *Prenkites*, etc. These two zones are correlated with the upper Olenekian (Bando and Shimoyama, 1974; Ehiro et al., 2016). Ehiro (2022 in press) proposed a new ammonoid zone, the *Eodanubites* Zone, in the uppermost part of the formation, based on the section at the south of Asadanuki (Loc. 1 in Figure 1). It consists of Olenekian genera *Eodanubites*, *Pseudosageceras*, *Ceccaisculitoides* and *Procarnites*, associated with *Japonites* and *Procladiscites*. The latter two genera are common in the Anisian, but already appeared in the latest Olenekian strata, and therefore, the *Eodanubites* Zone is correlated with the uppermost Olenekian (Ehiro, 2022 in press).

Recently, Shigeta (2022 in press) re-examined some ammonoid species reported from the lower to middle part (*Subcolumbites* Zone) of the Osawa Formation by Bando and Shimoyama (1974), and concluded that *Columbites parisianus*, *Subcolumbites perrinismithi* and *Eophyllites* cf. *dieneri*, collected from the Motoyoshi area, should be attributed to *Hellenites tchernyschewiensis* Zakharov, *H. inopinatus* Kiparisova, *Neocolumbites grammi* Zakharov, *N. insignis* Zakharov, *Procolumbites ussuriensis* (Zakharov) and *P. subquadratus* Zakharov. Even in such case, this fauna is compared with that of the *N. insignis* Zone of South Primorye, Russian Far East, and correlated to the upper Olenekian (Spathian) as a conventional one.

The Fukkoshi Formation is composed of thick sandstone and alternating beds of sandstone and mudstone, with total thickness of 200–300 m. According to Kamada (1984) these sandstones of the Fukkoshi Formation were deposited as a submarine fan complex. Because of its sandstone dominated facies, the Fukkoshi Formation is almost baren of ammonoids. Only some Anisian species, *Gymnites* cf. *watanabei* (Mojsisovics), *Hollandites* sp. and *Balatonites* cf. *kitakamicus* (Diener), reported by Shimizu (1930), were designated to come from the middle part of the Fukkoshi Formation (Onuki and Bando, 1959). However, there are some doubts about the stratigraphic position and locality of these ammonoids (Ishibashi, 2006) and reexamination is needed. The locality of Shimizu (1930)'s ammonoids was positioned by Onuki and Bando (1959) to the east of Yanaizu (Loc. 3a in Figure 1), where the Fukkoshi Formation is distributed. But, according to the attached label of *Balatonites* cf. *kitakamicus* specimen (IGPS coll. cat. no. 36530) by Shimizu (1930), the locality is "Road side near the southern end of Yanaizu Town". The southern end of Yanaizu Town in 1930 is located about 4 km to the south of Yanaizu (Fig. 1, loc. 3b), not to the east, and therefore exact stratigraphic horizon of these ammonoids is unknown.

On the other hand, ammonoid specimens, *Danubites* aff. *ambica* Diener, *Danubites* sp., *Leiophyllites* cf. *pitamaha* (Diener) and *L.* aff. *pradyumna* (Diener), described from a locality at Konori (Konori-hama), Onagawa Town (Bando, 1970; Loc. 4 in Figure 1), which are considered to come from the Osawa Formation, may actually belong to the Fukkoshi Formation. Bando (1970) stated that these ammonoids were collected from the alternating beds of the uppermost part of the Osawa Formation, but these alternating beds may lithologically belong to the Fukkoshi Formation. In fact, Working Group on the Permian-Triassic Systems (1975, p. 172), the members of which include Y. Bando, regarded the horizon of these ammonoids as the Fukkoshi Formation. The outcrop at Konori, however, was lost when the reconstruction work of "2011 off the Pacific coast of Tohoku Earthquake" was extended, and the effective re-examination is impossible.

Thus, the reliability of the ammonoid stratigraphy, considered to come from the Fukkoshi Formation until now, is insufficient.

The Isatomae Formation is more than 1,000 m thick and consists of sandy laminated mudstone, often with thick sandstones or alternating beds of sandstone and mudstone. Many Anisian ammonoids have been described from the formation by Mojsisovics (1888), Diener (1916a), Shimizu (1930) and others. The fauna comprises such genera as *Hollandites*, *Danubites*, *Gymnites*, *Japonites*, *Sturia*, *Balatonites*, *Ussurites*, *Leiophyllites*, etc. These ammonoids are mostly from the middle part of the formation and those from the lower part are rare. Ishibashi (2006) reported, although not yet described, some species collected from the basal part of the formation at Kudanohama in Utatsu area (Loc. 2 in Figure 1). He set two ammonoid zones in the basal part: the *Grambergia kitakamiensis* Zone below and the *Lenotropites isatomaensis–Leiophyllites* cf. *pseudopradyumna* Zone above. The former zone yields *Grambergia kitakamiensis* Ishibashi (MS), *Grambergia* sp., *Tropigastrites* cf. *lahontanus* Smith and *Ussurites* sp. The latter consists of *Lenotoropites isatomaensis* Ishibashi (MS), *Leiophyllites pseudopradyumna* (Welter) and *Paracrochordicera*s sp. These Kudanohama ammonoid zones probably corresponds to the *Lenotropites–Japonites* Zone (Aegean: lowermost Anisian) of Qinghai, China (He et al., 1986), *Japonites welteri* beds to *Lenotropites caurus* Zone (lower Anisian) of Nevada (Bucher, 1989), *Paracrochordiceras–Japonites* beds (Aegean) of Deşli Caira Hill, Romania (Grădinaru et al., 2007) and Chios (Assereto, 1974; Fantini Sestini, 1981).

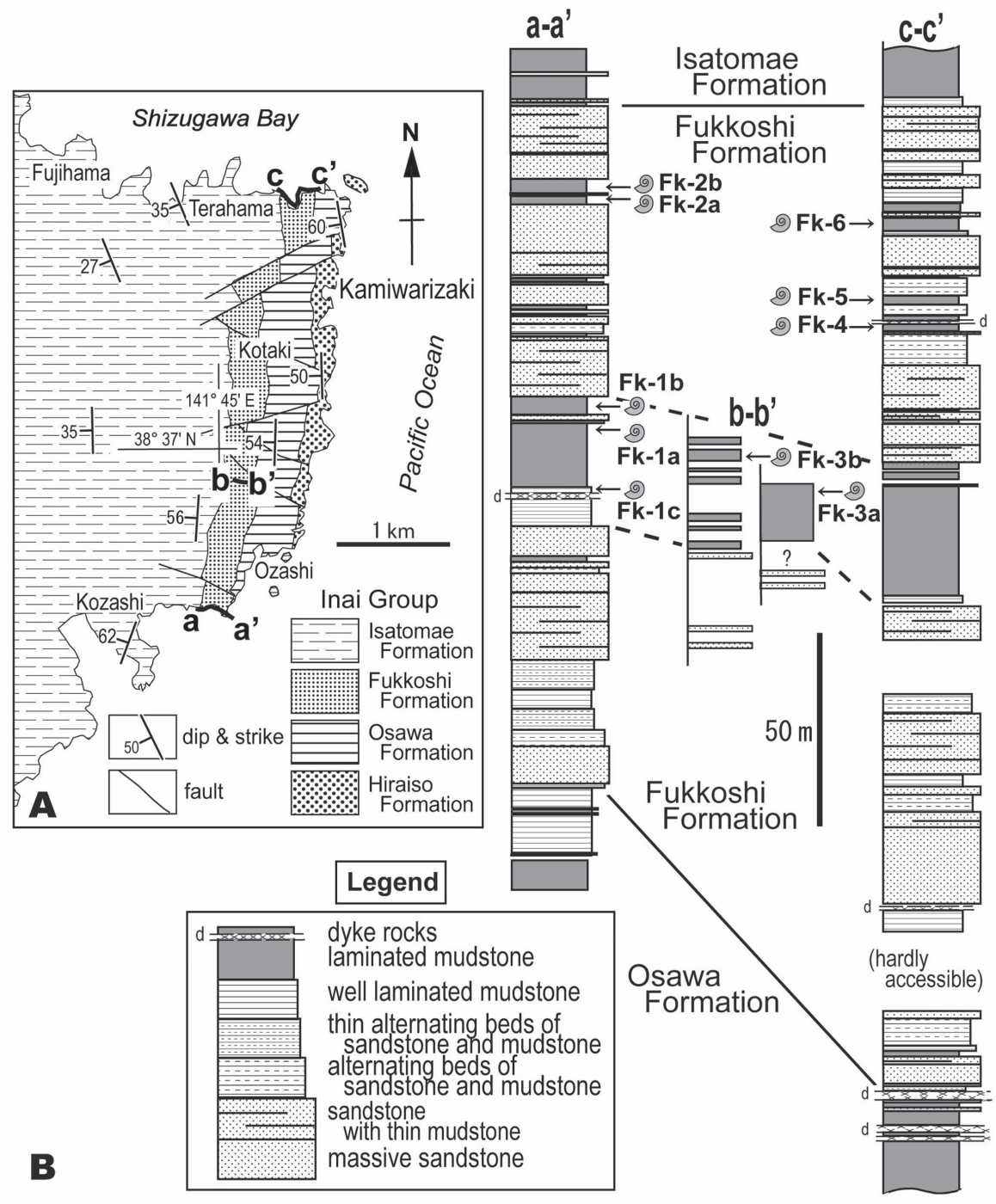

Figure 2. Geologic map of the Kamiwarizaki area (simplified from Kamada and Takizawa, 1992) (A) and columnar sections of the Fukkoshi Formation showing the ammonoid horizons (Fk-1–Fk-6) (B). Routes of the columnar sections (a–a', b–b' and c–c') are shown in figure A.

Materials and the stratigraphy of the new ammonoid localities

Ammonoids specimens described here were collected from the middle to upper part of the Fukkoshi Formation distributed in the Kamiwarizaki area (Figure 1). In this area, strata of the Inai Group, from the middle part of the Hiraiso Formation to the lower part of the Isatomae Formation, distribute parallel to the eastern coast of Kamiwarizaki (Figure 2A), striking nearly N-S and dipping 45˚-70˚ westerly.

Nearly continuous sections of the Fukkoshi Formation crop out along the southern and northern coasts, but the outcrops are rather rare and imperfect in the inland area. Along the southern coast (a-a' section in Figure 2B), the basal part of the Fukkoshi Formation, consisting of the alternating beds of sandstone and mudstone, conformably covers the laminated mudstone of the underlying Osawa Formation. The lower part of the formation (about 65 m thick) is dominated in massive sandstone and sandstone dominated alternating beds of sandstone and mudstone, but intercalating with thin alternating beds or mudstone dominated alternating beds of sandstone and mudstone (about 22 m) in the lower part. The middle part (about 34 m) is composed of laminated or poorly laminated mudstones, intercalating with thin sandstone beds (ca. 1.5 m thick, consisting of alternating beds of sandstone and mudstone, and sandstone) in the uppermost part (from ca. 4.5 m to 3 m below the top). Ammonoid horizons Fk-1a, Fk-1b and Fk-1c are in this mudstone beds (located at 38°36′18″N, 141°30′59″E). Horizon Fk-1c is situated about 7-8 m above the base of the mudstone. Fk-1a and Fk-1b are in the uppermost part of the mudstone beds and separated by the above-mentioned sandstone beds. Fk-1a has an interval (1.5 m thick) from ca. 2 m to 0.5 m below the intercalating sandstones, and Fk-1b has ca. 2 m interval immediately above the sandstone (Figure 2B). The upper part of the formation is about 75 m in thickness and dominated in sandstone. Thin (usually less than 3 m) mudstone beds are often intercalated in the lower part, and about 7 m mudstone dominated part are in the upper part. The last mudstone beds are separated into the lower and upper parts by thin sandstone. The ammonoid horizon Fk-2a and Fk-2b (located at 38°36′19″N, 141°30′56″E) are situated in the lower and upper parts of this mudstone beds, respectively (Figure 2B).

Along the old forest road (b-b' section in Figure 2B) to the northwest of Ozashi, rather thick mudstone beds (20 m+ thick) are sporadically cropped out, dipping steeply to the west. This mudstone beds are situated above the sporadically distributed sandstone beds and are correlated with the mudstone dominated part (middle part) of the a-a' section. From the upper part of this beds, two ammonoids were collected (Horizon Fk-3a and 3b: 38°36′53″N, 141°31′8″E).

Nearly continuous section of the Fukkoshi Formation can also be observed along the northern coast, east of Terahama (c-c' section in Figure 2B). Although some parts are missing or hardly accessible, the total thickness of the formation is estimated to be about 240 m, which is slightly thicker than that along the southern coast. In this section, the lower (about 110 m) and upper (ca. 90 m) parts of the Fukkoshi Formation are composed mainly of sandstone and alternating beds of sandstone and mudstone, with minor amount of mudstone intercalations. The middle part (ca. 35 m thick) consists of laminated mudstone. This mudstone dominated part is stratigraphically correlated with the middle mudstone dominated part along the southern coast, although no ammonoid fossil has been collected here. Some mudstone intercalations in the upper part yield ammonoids: Fk-4 and Fk-5 (38°38′9″N, 141°31′26″E), and Fk-6 (38°38′10″N, 141°31′25″E) (Figure 2B). Fk-4 yields only one poorly preserved, undeterminable specimen, so it will not be covered here.

The precise correlation of thin mudstone intercalations in the upper part of the formation between those distribute along the southern and northern coasts is difficult, because of lateral facies change and thickness change of each bed. But, considering their relative stratigraphic positions, the horizon Fk-2a and Fk-2b seem to be roughly correlated with Fk-6.

Ammonoid specimens studied in this paper were buried in mudstone beds with their plane of symmetry lying mostly parallel to the bedding plane. Many specimens are preserved only their lower half due to probably the synsedimentary erosion. Some specimens having extremely narrow shell, such as ones belong to the genera *Pseudosageceras*, *Psilokhvalynites*, *Arctohungarites* and *Leiophyllites*, sometimes hold both sides of the shell, but it is difficult to measure their exact shell width, because they had suffered from severe tectonic flattening. Thin film-like pyrite crystals are sometimes formed on the outer or inner shell surfaces.

Systematic description

The specimens described here are all kept in the Tohoku University Museum (Institution abbreviation: IGPS = Institute of Geology and Paleontology, Tohoku University, Sendai). Systematic descriptions basically follow the classification established by Tozer (1981, 1994) and terminology of conch shape (umbilical width) follows Korn (2010). The following abbreviations are used in the descriptions: *D* = diameter of whorl, *H* = height of whorl, *W* = width of whorl, *UD* = diameter of umbilicus.

Order Ceratitida Hyatt, 1884
Superfamily Xenodiscoidea Frech, 1902
Family Hemilecanitidae Guex et al., 2010
Genus ***Hemilecanites*** Spath, 1934

Type species.—*Lecanites discus* Arthaber, 1908.

Hemilecanites discus (Arthaber, 1908)
Figures 3.1, 3.2

Lecanites discus Arthaber, 1908, p. 268, pl. 11, figs. 5a–c; Renz and Renz, 1948, p. 55.
Hemilecanites discus (Arthaber), Spath, 1934, p. 135, pl. 13, figs. 7a–7d; Kummel in Arkell et al., 1957, p. L136, fig. 169-3; Chao, 1959, p. 41, pl. 3, figs. 1, 2; Kummel, 1969, p. 374, pl. 25, figs. 9, 10, text-fig. 4-E; Ehiro et al., 2016, p. 93, figs. 2.1–2.3.

Material examined.—Two specimens, IGPS coll. cat. nos. 112546 and 112547.

Descriptive remarks.—The conch is evolute and compressed, with lenticular cross section. They attain more than 23 (no. 112547) and 27 mm (no. 112546) in maximum diameter, but the last volution of each conch is not well preserved. It consists of phragmocone and living chamber, the latter occupies about one volution. In specimen no. 112547, at a diameter of ca. 20 mm, the corresponding height and umbilical diameter are ca. 6.0 and 8.8 mm (*UD*/*D* = 0.44), respectively. In specimen no. 112546, the height and umbilical diameter at *D* = ca. 27 mm are ca. 7.5 and 13.3 mm (*UD*/*D* = 0.49), respectively.

The flanks are broadly convex to nearly flat, with broadly rounded umbilical and ventral shoulders. The maximum width is at about the center of the flank. The venter is not well preserved. The umbilicus is shallow. The shell surface seems to be smooth. The external lateral suture is partly preserved. It is goniatitic and consists of three rounded saddles and three probably rounded lobes. Sides of lobes are nearly parallel. The saddles and lobes diminish in size slightly towards the umbilicus.

Although the sutural trace differs slightly from that of the type specimen of *Hemilecanites discus* (*Lecanites discus* Arthaber, 1908), the general shell shape and dimensions of the present specimens are similar to those of the type specimen from the late Olenekian of Albania (Arthaber, 1908, p. 268, pl. 11, figs. 5a–c). The species of the genus *Hemilecanites* have mostly been known from the late Olenekian strata, but *H*. cf. *paradiscus* Kummel were described from the Lower Anisian *Japonites welteri* beds, NW. Nevada (Bucher, 1989, p. 961, pl.6, figs. 7-8, text fig. 3).

Occurrence.—Both specimens are from the middle part (Fk-1b) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Superfamily Sageceratoidea Hyatt, 1884
Family Sageceratidae Hyatt 1884
Genus ***Parasageceras*** Welter, 1915

Type species.—*Parasageceras discoidale* Welter, 1915.

Parasageceras aff. ***discoidale*** Welter
Figures 3.3, 3.4

aff. *Parasagecers discoidale* Welter, 1915, p. 113, pl. 89, fig. 4; Kutassy, 1932, p. 608; Spath, 1934, p. 62, text-figs. 9a–9c.
Parasagecers aff. *discoidale* Welter, Spath, 1934, p. 62.

Material examined.—Two specimens, IGPS coll. cat. nos. 112548 and 112549.

Description.—The specimen no. 112548 consists largely of a phragmocone with a part of body chamber. The conch diameter attains about 25 mm in the obliquely deformed state. The umbilicus is not well preserved, but very small. Another specimen (no. 112549) is composed of phragmocone and body chamber, the latter of which occupies about three-fourth of the last whorl. It attains a diameter of ca. 21.5 mm, and corresponding height and umbilical diameter are 12.2 and 2.2 mm (*UD*/*D* = 0.10), respectively. The sides of both specimens are nearly flat, with broadly rounded umbilical shoulder and acute ventral shoulder. The venter seems to be flat. Faint, slightly sigmoidal fine ribs, projected and most distinct near the ventral shoulder, are on the sides.

The ventral lobe is shallow and divided into two, simple, pointed prongs by a low, rounded, median saddle. The first lateral lobe is widest and has four irregular denticulations at the base. A denticulation situated on the ventral side is most remarkable. The second to sixth lateral lobes are bifid, and the followings (more than three, probably eight or more) have rounded base. The second lobe has nearly the same width as the first, but slightly small and shallow. The second lateral saddle is as large as the first and highest. The other saddles and lobes diminish in size toward the umbilicus. Almost lateral saddles have rounded crest, except for the sixth, which is slightly wider than the surrounding ones and divided into two parts by a shallow depression.

Comparison.—The shell shape and surface ornamentation of the present species are similar to those of *Parasagecers discoidale* Welter, 1915 from the Anisian of Timor. But the present species differs from the Timor species in having more flexosus ribs, and in having complex first lateral lobe.

Occurrence.—Middle part (Fk-1a: no. 112548 and Fk-

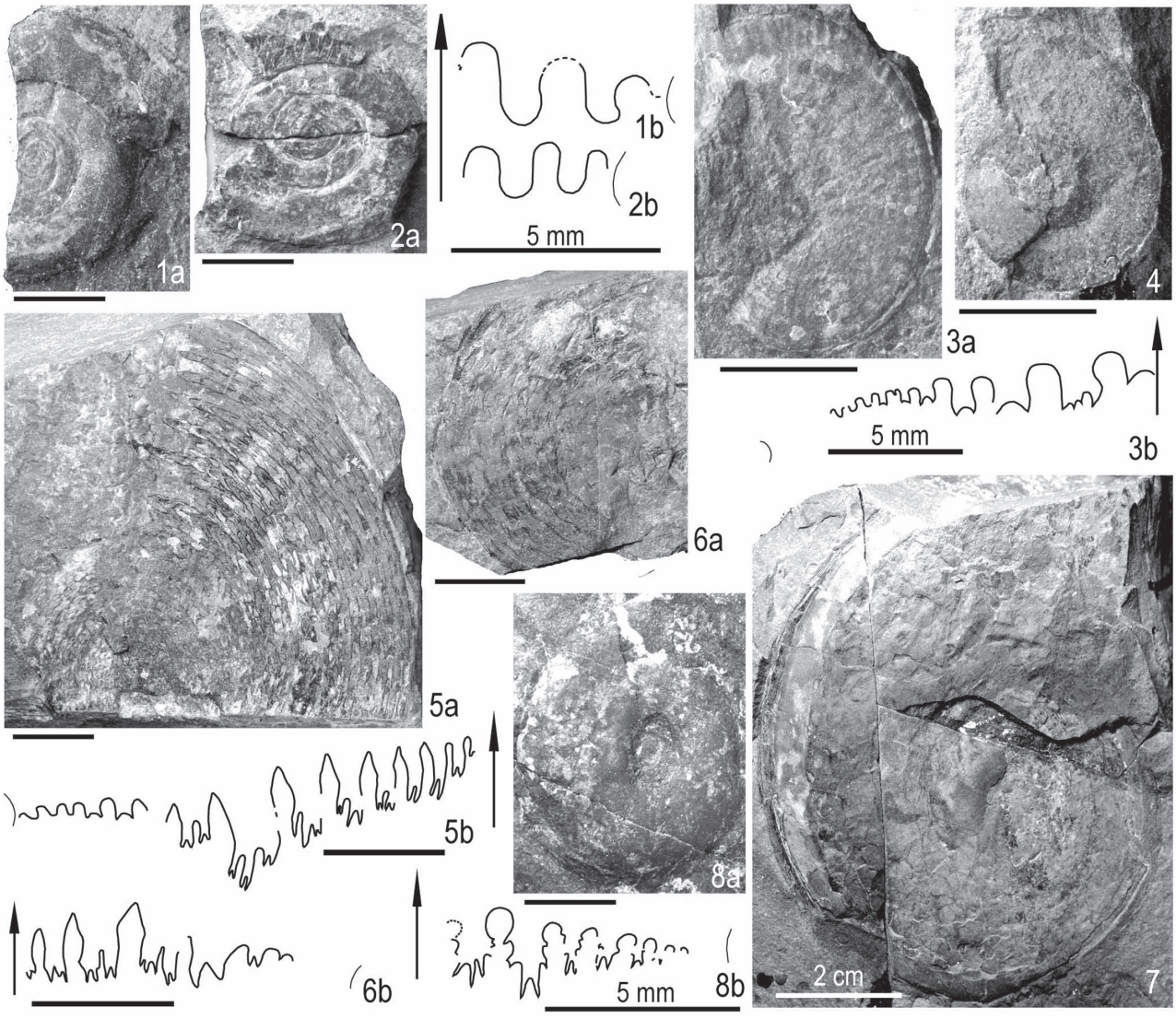

Figure 3. *Hemilecanites*, *Parasageceras*, *Pseudosageceras* and *Megaphyllites* from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1 and **2**, *Hemilecanites discus* (Arthaber); 1, IGPS coll. cat. no. 112546; 1a, lateral view; 1b, suture line; 2, IGPS coll. cat. no. 112547; 2a, lateral view; 2b, suture line; **3** and **4**, *Parasageceras* aff. *discoidale* Welter; 3, IGPS coll. cat. no. 112548; 3a, lateral view; 3b, suture line; 4, IGPS coll. cat. no. 112549, lateral view; **5**–**7**, *Pseudosageceras multilobatum* Noetling; 5, IGPS coll. cat. no. 112550; 5a, lateral view; 5b, suture line; 6, IGPS coll. cat. no. 112551; 6a, lateral view; 6b, suture line; 7, IGPS coll. cat. no. 112552, lateral view; 8, *Megaphyllites* sp., IGPS coll. cat. no. 112664; 8a, lateral view; 8b, suture line. Scale bars are 1 cm unless otherwise stated.

1b: no. 112549) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Family Hedenstroemiidae Waagen, 1895
Genus ***Pseudosageceras*** Diener, 1895a

Type species.— *Pseudosageceras* sp., Diener, 1895a.

Pseudosageceras multilobatum Noetling
Figures 3.5–3.7

Pseudosageceras sp., Diener, 1895 a, p. 28, pl. 1, fig. 8.

Pseudosageceras multilobatum Noetling, 1905a, p. 181, pls. 19–27; Noetling, 1905b, pl. 23, fig. 4, pl. 25, fig. 1, pl. 26, fig. 3; Arthaber, 1908, p. 279, pl. 12, fig. 3; Krafft and Diener, 1909, p. 145, pl. 21, fig. 5; Wanner, 1911, p. 181, pl. 7, fig. 4; Welter, 1922, p. 94, text-fig. 3; Diener, 1925, p. 96, fig. 26 ; Smith, 1932, p. 87, pl. 4, figs. 1–3, pl. 5, figs. 1–6, pl. 25, figs. 7–16, pl. 60, fig. 32, pl. 63, figs. 1–6; Collignon, 1933, p. 56, pl. 11, fig 2; Spath, 1934, p. 54, text-fig. 6a; Kiparisova, 1947, p. 127, pl. 25, figs. 3–4; Chao, 1959, p. 31, 183, pl. 1, figs., 9, 12; Jeannet, 1959, p. 30, pl. 6, fig. 1; Tozer, 1961, p. 44, pl. 13, figs. 8, 9; Chao et al., 1965, p. 135, pl. 35, fig. 5; Kummel, 1966, p. 388, pl. 1, figs. 11, 12; Hada, 1966, pl. 4, fig. 6; Kummel and Erben, 1968, p. 112, pl. 19, fig. 9; Shevyrev, 1968, p. 79, pl. 1, figs. 1, 2; Kummel, 1969, p. 361, pl. 34, fig. 6, text-fig. 2; Collignon, 1973, p. 5, pl. 1, fig. 1; Weitschat and Lehmann, 1978, p. 75, pl. 10, fig. 2; Vu Khuc, 1984, p. 26, pl. 1, fig. 1, text-fig. 1; Pakistani-Japanese Research Group, 1985, pl. 12, figs. 5–7, pl. 14, fig. 3; Vu Khuc, 1991, p. 119, pl. 45, figs. 5, 6, text-fig. 2.2; Tozer, 1994, p. 83, pl. 18, fig. 1, text-fig. 17; Brayard and Bucher, 2008, p. 70, pl. 37, figs. 1–5, text-fig. 61; Shigeta and Zakharov, in Shigeta et al., 2009, p. 140, figs. 129, 130; Brühwiler et al., 2010, p. 429, fig. 16.14; Brühwiler and Bucher in Brühwiler et al., 2012a, p. 47, pl. 26, fig. 4; Brühwiler and Bucher, in Brühwiler et al., 2012b, p. 109, figs. 95A–95N; Brayard et al., 2013, p. 208, figs. 77a–77f; Shigeta and Nguyen, in Shigeta et al., 2014, p. 137, figs. 98, 99; Ehiro, 2016, p. 2, fig. 2.1; Ehiro, 2022 in press, figs. 5.2, 5.3.

Pseudosageceras intermontanum Hyatt and Smith, 1905, p. 99, pl. 4, figs. 1–3, pl. 5, figs. 1–6, pl. 63, figs. 1, 2.; Mathews, 1929, p. 3, pl. 1, figs. 18–22; Renz and Renz, 1948, p. 90, pl. 16, figs. 4, 7.

Pseudosageceras drinense Arthaber, 1911, p. 201, pl. 17, figs. 6, 7; Spath, 1934, p. 55, text-fig. 6c; Renz and Renz, 1948, p. 92, pl. 16, fig. 6.

Pseudosageceras clavisellatum Diener, 1913, p. 28, pl. 4, figs. 5, 6.

Pseudosageceras paomochungenense Tien, 1933, p. 24, pl. 3, fig. 7; Chao et al., 1965, p. 137, pl. 35, figs. 12, 13.

Pseudosageceras cf. *clavisellatum* Diener, Renz and Renz, 1948, p. 90, pl. 16, fig. 3.

Pseudosageceras longilobatum Kiparisova, in Kiparisova and Krishtofovich, 1954, p. 20, pl. 11, fig. 3; Kiparisova, 1961, p. 29, pl. 6, fig. 1, 2, text-fig. 2; Popov, 1961, p. 12, pl. 10, fig. 1, text-fig. 2.

Pseudosageceras cf. *longilobatum* Kiparisova, 1961, p. 30, pl. 5, fig. 3, text-fig. 3.

Pseudosageceras longilobatum var. *kwangsiense* Chao, 1959, p. 32, 186, pl. 1, figs. 5, 6, pl. 8, figs. 10, 11, text-fig. 5c; Chao et al., 1965, p. 136, pl. 35, figs. 14–16.

Pseudosageceras tsotengense Chao, 1959, p. 32, 184, pl. 1, figs. 7, 8, text-fig. 5b; Chao et al., 1965, p. 136, pl. 35, figs. 9–11.

Pseudosageceras schamarense Kiparisova, 1961, p. 31, pl. 7, figs. 3a, 3b.

Material examined.—Three specimens, IGPS coll. cat. nos. 112550–112552.

Description.—Three specimens, strongly compressed and involute with almost closed umbilicus, are at hand. The specimen no. 112552 is about 80 mm in diameter and consists of phragmocone and body chamber, the latter occupies about three-fourth of the last whorl. The diameter of the fragmental specimens nos. 112550 and 112551, both consists of phragmocone, exceed 60 and 40 mm, respectively. The sides are almost flat except for the slightly depressed umbilical margin. The venter is not well preserved, but estimated to be acutely rounded. The shell surface appears to be smooth. The suture is ceratitic with numerous adventitious elements. The lateral lobes are essentially bifid, but some of which are again bifid or, rarely, trifid.

Discussion.—Although the present specimens of *Pseudosageceras* are not so well preserved, their general shell morphologies and especially the shape of the suture lines allow to identify it with *Pseudosageceras multilobatum* Noetling.

Occurrence.—Middle part (Fk-1a: no. 112551; Fk-1b: nos. 112550 and 112552) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Superfamily Megaphyllitoidea Mojsisovics, 1896
Family Parapopanoceratidae Tozer, 1971
Genus ***Parapopanoceras*** Haug, 1894

Type species.— *Popanoceras verneuili* Mojsisovics, 1886.

Remarks.—When Popov (1961) proposed a new genus *Stenopopanoceras*, the fundamental difference between the genera *Parapopanoceras* and *Stenopopanoceras* is in the shell shape. However, Dagys and Ermakova (1981) clarified that the shell shape of the genus *Parapopanoceras* is variable not only between species but also in the steps of ontogeny, and shell shape in some of them is similar to that of *Stenopopanoceras*. They considered, instead, that the distinctive feature of the genus *Parapopanoceras* is in the suture line: the species of the genus *Parapopanoceras* have at least four external lateral lobes, which are serrated not only the bases but also their sides, even in their early ontogenetic stage.

Parapopanoceras involutum sp. nov.

Figures 4.1–4.7

Material examined.—Eight specimens, IGPS coll. cat. nos. 112553 (holotype) and 112554–112560 (paratypes).

Etymology.—The species name is from its involute shell form.

Diagnosis.—*Parapopanoceras* having very small umbilicus (*UD*/*D* < 0.11) even in the large specimen (*D* up to 120 mm). The number of lateral lobes, which are strongly denticulate, is four in all ontogenetic stages (*D* from 20 to 120 mm).

Description.—The specimen no. 112554 is a small fragment of the ventral part of the phragmocone. The width of it reaches at least 20 mm. The venter is broadly rounded, but its broadness may partly be caused by the tectonic flattening. The ventral shoulder is rounded. The specimen no. 112557 is a small fragmental phragmocone, and about a half of a volution is preserved. The shell diameter is ca. 20 mm with a small umbilicus, the ratio of *UD*/*D* is estimated to be 0.21-0.25. The flank is broadly convex and continues smoothly with broadly rounded venter. The umbilical shoulder is rounded. Other specimens, including the holotype (no. 112553), consist of phragmocone and body chamber, the latter of which occupies about two-thirds of a volution. The maximum preserved shell diameter ranges from ca. 48 to 124 mm, and the ratios of *H*/*D* and *UD*/*D* at the last whorls range 0.42-0.54 and 0.07-0.11 (mostly 0.10-0.11), respectively. Although the umbilical edge of the body chamber of the largest specimen (no. 112558) is broken off and precise ratio of *UD*/*D* is unknown, the adoral end of the phragmocone is well preserved and the ratio of *UD*/*D* there (*D* = ca. 120 mm) is ca. 0.10. The side is convex with rounded umbilical and ventral shoulders. The maximum shell width is near the center of the flank. In two specimens (holotype and no. 112559), there are faint, slightly sigmoidal growth lines on the shell surface, but the shell surfaces of the rest seem to be smooth.

The ventral lobe is divided into two prongs by a low and narrow median saddle, and the base to lower one-third of the sides of the prong is denticulate. The median saddle is about a half height to the ventrolateral saddles. The first lateral love has nearly the same width and depth as the ventral lobe. There are four lateral lobes in all specimens. All lobes are strongly denticulate in their base to lower one-third of their sides. The first lobe is the largest and they diminish in size toward the umbilicus. There are some auxiliary lobes, except for the smallest specimen, at the umbilical margin. The crests of lateral saddles are all rounded, and the saddles also gradually diminish in size towards the umbilicus.

Discussion.—Based on the general shell shape, having rounded venter and small umbilicus, and the trace of external suture lines, the present specimens are considered to belong to the genus *Parapopanoceras* Haug, 1894. The present species differs from the known species of the genus in having small ratio of *UD*/*D* (0.10 to 0.11) even in the large specimens (*D* = ca. 50 to 120 mm). Small specimens (*D* < 40 mm) of *P. plicatum* Bytschkov have rather small umbilicus (*UD*/*D* = 0.12–0.16), but larger specimens of the species (*D* > 40 mm) have rather large umbilicus (*UD*/*D* = 0.15–0.34) (Bytschkov in Bytschkov et al., 1976, p. 138, pl. 23, figs. 2–4, text-fig. 13; Dagys and Ermakova, 1981, p. 61, pl. 11, figs. 1–7, text-figs. 38–41).

Occurrence.—Middle part of the Fukkoshi Formation at the south of Ozashi (Fk-1c: nos. 112558, 112560; Fk-1a: nos. 112554, 112557; Fk-1b: nos. 112553, 112556, 112559) and at the northwest of Ozashi (Fk-3b: no. 112555) , Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Family Megaphyllitidae Mojsisovics, 1896
Genus ***Megaphyllites*** Mojsisovics, 1879

Type species.—*Ceratites Jarbas* Münster, 1841.

Megaphyllites sp.
Figures 3.8a, b

Material examined.—One specimen, IGPS coll. cat. no. 112664.

Descriptive remarks.—A small, discoidal and involute to sub-involute specimen is examined. It consists of the phragmocone and body chamber, the latter attains about one-thirds of the preserved last whorl. The shell diameter attains 30.4 mm in the elliptically deformed state, and its corresponding height and umbilical diameter are 7.2 and ca. 5.0 mm (*UD*/*D* = 0.16), respectively. The umbilical margin is somewhat indistinct. The side of the phragmocone is broadly convex and the maximum width is at about the center of the side, whereas the side of the body chamber is nearly flat. The ventral shoulder is rounded. The small umbilicus is rather deep and funnel-shaped. The shell surface is smooth without any ornamentation and constriction. The external suture line is imperfectly preserved, but typical for the genus *Megaphyllites*. There are at least seven saddles and six lobes. The crests of saddles are all rounded. The second saddle is highest and saddles gradually diminish in size towards the umbilicus. The deep first lateral lobe is denticulate not only at the base but also on the sides. The basal denticulations are strong. The second lobe is nearly equal in depth with the first and have the same denticulations, the basal two denticulation of which are very long. The third lobe has nearly the same outline as the second, but the depth is about two-thirds of the second. Following lobes gradually diminish in size towards the

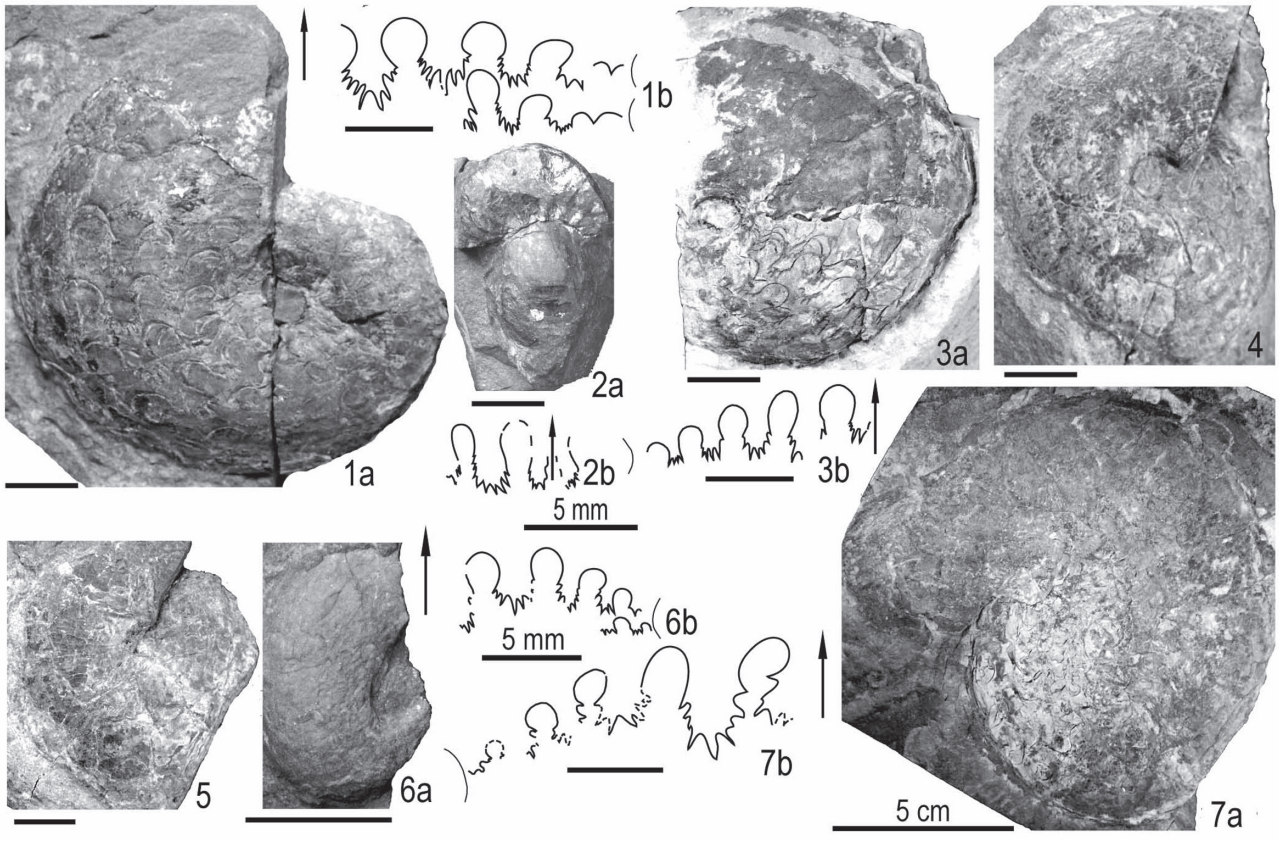

Figure 4. *Parapopanoceras involutum* sp. nov. from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1, IGPS coll. cat. no. 112553 (holotype); 1a, lateral view; 1b, suture line; **2**, IGPS coll. cat. no. 112554; 2a, ventral view; 2b, suture line; **3**, IGPS coll. cat. no. 112555; 3a, lateral view; 3b, suture line; **4**, IGPS coll. cat. no. 112556, lateral view; **5**, IGPS coll. cat. no. 112559, lateral view; **6**, IGPS coll. cat. no. 112557; 6a, lateral view; 6b, suture line; **7**, IGPS coll. cat. no. 112558; 7a, lateral view; 7b, suture line. Scale bars are 1 cm unless otherwise stated.

umbilicus.

The general shell shape of the present specimen, with broadly convex to flat sides and small but distinct umbilicus, is similar to those of *Megaphyllites compressus* Shevyrev from Caucasus (Shevyrev, 1995, p. 123, pl. 22, fig. 4, text-fig. 73), *Megaphyllites evolutus* Welter from Timor (Welter, 1915, p. 114, pl. 7, figs. 2a–2c) and from Qinghai (He et al., 1986, p. 207, pl. 17, figs. 5–7, text-fig. 14c), and *Megaphyllites tenuis* Chen in He et al. from Qinghai (He et al., 1986, p. 207, pl. 17, figs. 14–16, text-fig. 14d). But it is somewhat difficult to identify it at the specific level because of its small size and poor state of preservation.

Occurrence.—Middle part (Fk-1b) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Superfamily Dinaritoidea Mojsisovics, 1882

Family Khvalynitidae Shevyrev, 1968
Genus ***Metadagnoceras*** Tozer, 1965

Type species.—*Metadagnoceras pulchrum* Tozer, 1965.

Metadagnoceras sp. A
Figures 5.2a, b

Material examined.—One specimen, IGPS coll. cat. no. 112561.

Descriptive remarks.—A small specimen is discoidal and involute to sub-involute. The maximum shell diameter may exceed 40 mm, but exact diameter is unclear because its ventral part of the preserved end is missing. The umbilicus is small and the ratio of *UD*/*D* is estimated to be 0. 15 or so. The side is broadly convex to nearly flat with the maximum width at about the center of it. The umbilicus is shallow, but

the umbilical wall is steep with rounded umbilical shoulder. The venter seems to be convex to flat with sharp ventral shoulder. The shell surface looks like smooth, but fine sinuous ribs are preserved near the apertural end. The external suture consists of shallow ventral lobe, narrow first lateral saddle, very large and deep first lateral lobe, large and rounded second lateral saddle and auxiliaries near the umbilical margin. One of the prongs of the ventral lobe is visible and its base has irregular denticulations. The first lateral saddle is rounded, but its crest is incised. The first lateral lobe occupies the center of the side and is denticulate deeply at the base. The denticulations extend up to the ventral side to nearly the top of the first lateral saddle, whereas the umbilical side is almost smooth. The wide rounded second lateral saddle is asymmetric having long ventral side and short umbilical side. The auxiliaries are shallow and pointed.

The present specimen is rather small and not well preserved, so the specific identification is difficult. It somewhat resembles *Metadagnoceras pulchrum* Tozer, 1965 from the upper Olenekian (Spathian) of British Columbia in the general shell shape and outline of the suture, but the shape of the first lateral saddle is different; *M. pulchrum* has a symmetric, equally incised first lateral saddle, whereas the that of the present specimen has irregularly incised ventral side.

Occurrence.—Middle part (Fk-1a) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Metadagnoceras sp. B
Figures 5.1a, b

Material examined.—One specimen, IGPS coll. cat. no. 112562.

Descriptive remarks.—A fragmental phragmocone is at hand. Its height attains more than 30 mm. The venter is not preserved. The side is nearly flat with acutely rounded umbilical shoulder. The umbilicus probably deep with steep wall, but not well preserved. The shell surface seems to be smooth. The external lobe is partly preserved, although the ventral lobe is missing. The probable first lateral saddle is highly denticulate, but may be not well individualized. The large and deep first lateral lobe occupies the central part of the side and strongly denticulate. The denticulations extend up to the ventral side to nearly the top of the first lateral saddle, whereas the umbilical side is almost smooth. The second lateral saddle is large and rounded, and its outline is asymmetrical, having long ventral side and short umbilical side. Near the umbilical edge, there are some pointed auxiliary lobes.

Based on the general shell shape and the outline of the suture, the present specimen is considered to belong to the genus *Metadagnoceras* Tozer, 1965. Its sutural pattern is somewhat similar to that of *M. youngi* Bucher from the lower Anisian of Nevada (Bucher, 1989, p. 963, pl. 1, figs. 2–5, text-fig. 5), but the specific designation is difficult because of the fragmental state of preservation of the present specimen.

Occurrence.—Middle part (Fk-1b) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Genus ***Psilokhvalynites*** gen. nov.

Type species.—*Psilokhvalynites takaizumii* gen. and sp. nov.

Etymology.—The generic name refers to it smooth (Greek, *Psilo*-) shell surface, and a genus name *Khvalynites*, the general shell shape and sutural trace of which resemble those of the present new genus.

Diagnosis.—The shell is involute and extremely discoidal with almost smooth surfaces. The sides are broadly convex and converge slightly to the flat to convex venter. The external suture line is similar to that of the genus *Khvalynites*, consisting a large and deeply denticulate lateral lobe and two rounded lateral saddles. The ventral side of the first lateral saddle is smooth.

Discussion.— *Psilokhvalynites* gen. nov. resembles an Olenekian (Early Triassic) genus *Khvalynites* Shevyrev, 1968 in its general shell shape and sutural traces. However, smooth shell surface of the new genus is the most distinctive character from *Khvalynites*, which has remarkable radial ribs. The smooth ventral side of the first lateral saddle of the new genus is also unique in the family Khvalynitidae. Some species of Anisian genus *Alanites* Shevyrev, 1968, such as *Alanites visendus* Shevyrev 1968 and *A. laevis* Tozer, 1994 have smooth surface, but is easily distinguished from the present new genus in having thickly trapezoidal shell cross section and having serrated saddles.

Psilokhvalynites takaizumii gen. and sp. nov.
Figures 5.3–5.7

Material examined.—Seven specimens, IGPS coll. cat. no. 112563 (holotype) and nos. 112564–112569 (paratypes).

Etymology.—The specific epithet is dedicated to Yukihiro Takaizumi, who donated many ammonoid specimens, including the present new species, from the Fukkoshi Formation.

Diagnosis.—As for the genus.

Description.—The shell is involute and extremely discoidal. The holotype is the largest and its maximum

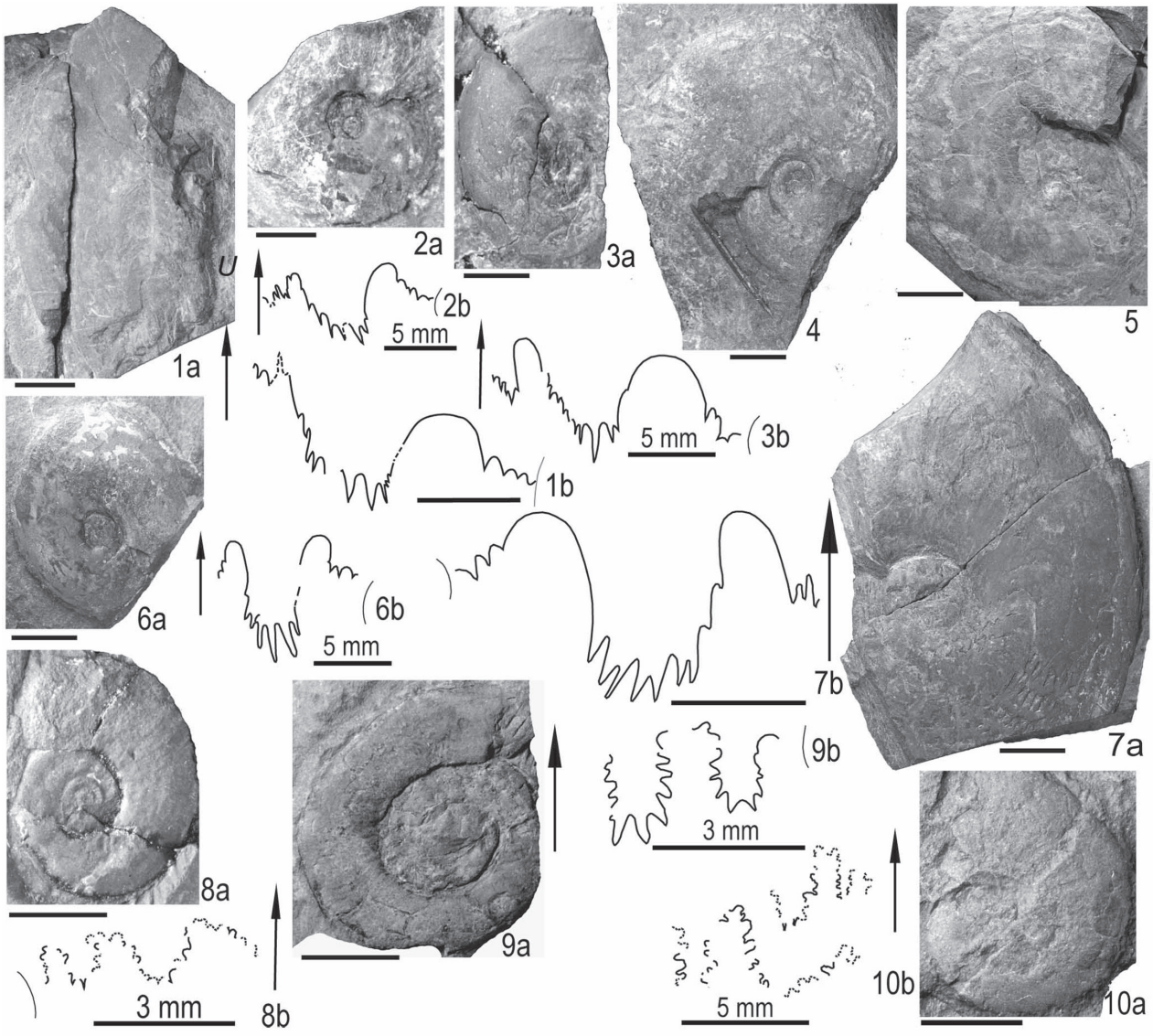

Figure 5. *Metadagnoceras*, *Psilokhvalynites*, *Aegeiceras*?, *Eogymnites* and *Buddhaites*? from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1, *Metadagnoceras* sp. B, IGPS coll. cat. no. 112562; 1a, lateral view (*U*: umbilicus); 1b, suture line; **2**, *Metadagnoceras* sp. A, IGPS coll. cat. no. 112561; 2a, ventral view; 2b, suture line; **3**–**7**, *Psilokhvalynites takaizumii* gen. and sp. nov.; 3, IGPS coll. cat. no. 112565; 3a, lateral view; 3b, suture line; 4, IGPS coll. cat. no. 112564, lateral view; 5, IGPS coll. cat. no. 112569, lateral view; 6, IGPS coll. cat. no. 112566; 6a, lateral view; 6b, suture line; 7, IGPS coll. cat. no. 112563 (holotype); 7a, lateral view; 7b, suture line; **8**, *Aegeiceras*? sp., IGPS coll. cat. no. 112583; 8a, lateral view; 8b, suture line; **9**, *Eogymnites* sp., IGPS coll. cat. no. 112584; 9a, lateral view; 9b, suture line; **10**, *Buddhaites*? sp., IGPS coll. cat. no. 112588; 10a, lateral view; 10b, suture line. Scale bars are 1 cm unless otherwise stated.

diameter may attain to 90 mm, but it lacks part of shell margins. The preserved shell diameters of other specimens range from ca. 30 mm to over 80 mm. The ratio of *UD*/*D* ranges from 0.12 to 0.17, the majority of which is 0.12 to 0.13. The sides are broadly convex to nearly flat with broadly rounded umbilical shoulder. The maximum shell width is at or near the umbilical shoulder and the sides slightly converge to the venter. The venter is not well preserved, but, in the holotype, seems to be nearly flat with acute ventral shoulders. The umbilicus is shallow with low umbilical wall.

The shell surface is almost smooth, except for faint sinuous growth lines.

The general outline of the external suture line is similar to that of the genus *Khvalynites*. The ventral lobe is not well preserved, and only probably a part of its prong is visible. It is shallow and denticulate, with smooth side. A wide and deep, U-shaped lateral lobe occupies the central part of the flank, with two rounded saddles on each side. The base of the lobe is deeply denticulate and some small denticulations are up to the middle part of the ventral side. Crests of two saddles are rounded. The first lateral saddle is symmetrical, whereas the wide second saddle is asymmetrical with short umbilical side, which continue to some pointed small auxiliary lobes on the umbilical shoulder.

Occurrence.—Middle part (Fk-1a: no. 112564; Fk-1b: nos. 112563, 112565–112568) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City and from the upper part (Fk-5: no. 1112569) at the eastern coast of Terahama, Togura, Minamisanriku Town, Miyagi Prefecture.

Superfamily Ceratitoidea Mojsisovics, 1879
Family Acrochordiceratidae Arthaber, 1911
Genus ***Paracrochordiceras*** Spath, 1934

Type species.—*Acrochordiceras anodosum* Welter, 1915.

Paracrochordiceras cf. ***denseplicatum*** Fantini Sestini
Figures 6.1–6.3

cf. *Acrochordiceras* ex aff. *anodosum* Welter, Bender, 1970, p. 439, pl. 2, fig. 9.
Paracrochordiceras denseplicatum Fantini Sestini, 1981, p. 49, pl. 4, figs. 2, 3.

Material examined.—Three specimens, IGPS coll. cat. nos. 112570–112572.

Descriptive remarks.—Specimens are discoidal and sub-evolute. The flanks are nearly flat with acutely rounded umbilical shoulder. The umbilicus is shallow. The venter is not well preserved. Sample no. 112570 attains a maximum diameter of ca. 42.0 mm, and its corresponding height and umbilical diameter are ca.16.0 and 14.0 mm (*UD*/*D* = 0.33), respectively. There are 39–40 ribs on the shell surface. The ribs are rectiradiate and run from the umbilical shoulder to the ventral shoulder, slightly strengthened to the venter, but slightly curve forward at the ventral shoulder. They reach to the venter, but whether they cross the venter or not is unclear because the venter is not well preserved. Very few ribs bifurcate near the ventral shoulder. The maximum shell diameter of sample no. 112571 is 43.5 mm, with corresponding height and umbilical diameter of ca. 13.5 and 15.5 mm (*UD*/*D* = 0.36), respectively. There are 34–35 rectiradiate ribs on the last whorl. The ribs run from the umbilical shoulder, slightly strengthened to the venter and probably cross the venter. About one-thirds of ribs bifurcate or associated with short secondary ribs near the ventral shoulder. No. 112572 is a fragmental and deformed specimen having fine ribs resemble to no. 112571.

The external suture is partly preserved in specimen no. 112570. Three lateral saddles and two lateral lobes are observable, although the first saddle is only preserved on its umbilical side. The saddles are rounded. The lobes are strongly denticulate at the base and small denticulations reach to the middle part of their sides.

The general shell outline and surface ornamentation, especially their flat sides, closely resemble *Paracrochordiceras denseplicatum* Fantini Sestini, 1981, described from the Lower Anisian (Aegean) of Chios Island, Greece. But I refrain from identifying the present specimens definitely at the specific level, because the present specimens are not well preserved and Chios specimen lacks suture line. *Proacrochordiceras kiparisovae* Korchinskaya described from Spitsbergen (Korchinskaya, 1983, p. 110, figs 1a–h, 2a–b) is somewhat similar to the present species in its shell form, surface ornamentation and outline of the suture line. But the former differs from the latter in having umbilical tubercles on the inner whorls and in having coarser ribs.

Occurrence.—Upper part of the Fukkoshi Formation at the southern coast of Ozashi (Fk-2b: no. 112570), Jusanhama, Kitakami-cho, Ishinomaki City, and at the eastern coast of Terahama (Fk-5: nos. 112571, 112572), Togura, Minamisanriku Town, Miyagi Prefecture.

Paracrochordiceras watanabei sp. nov.
Figures 6.4–6.7

Material examined.—Six specimens: IGPS coll. cat. nos. 112573 (holotype) and 112574–112578 (paratypes).

Etymology.—The species name is to honor Yuta Watanabe, who collected important specimens including the holotype, and making them available for this study.

Diagnosis.—*Paracrochordiceras* having coarse radial ribs which are largely rursiradiate. The shell is moderately evolute with oval cross section.

Description.—The shell is discoidal and sub-evolute. It consists of a phragmocone and body chamber, the latter of which occupies about half part of the preserved last volution. The maximum diameter ranges from ca. 30 mm to 52.5 mm. The ratio of *UD*/*D* is in the range of 0.38–0.43 (Table 1). The flanks are nearly flat to broadly convex with acutely rounded umbilical shoulder. The umbilicus is shallow. The venter is not fully preserved, but probably rounded with broadly

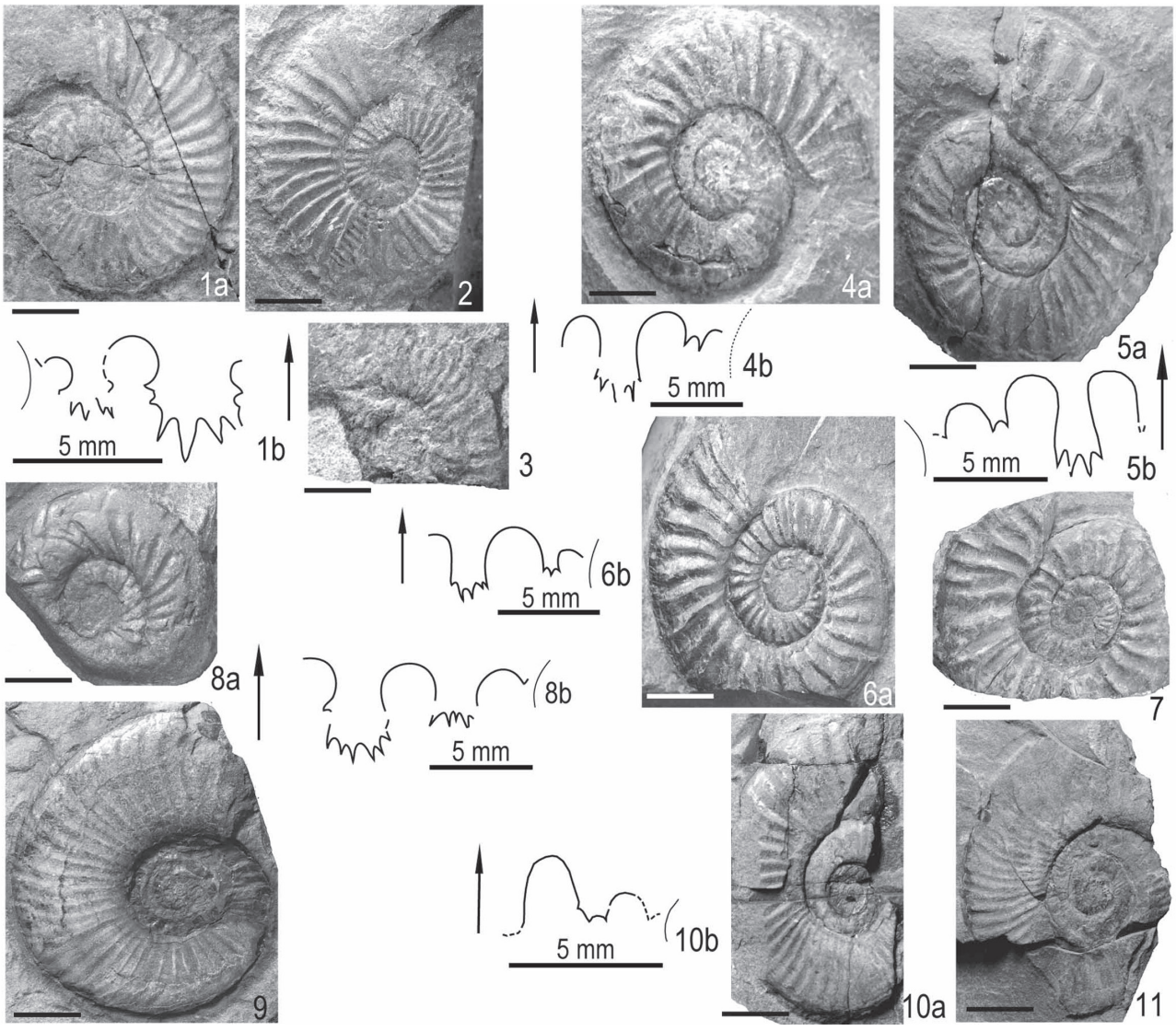

Figure 6. *Paracrochordiceras* from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan. **1**–**3**, *Paracrochordiceras* cf. *denseplicatum* Fantini Sestini; 1, IGPS coll. cat. no. 112570; 1a, lateral view; 1b, suture line; 2, IGPS coll. cat. no. 112571, lateral view; 3, IGPS coll. cat. no. 112572, lateral view; **4**–**7**, *Paracrochordiceras watanabei* sp. nov.; 4, IGPS coll. cat. no. 112574, 4a, lateral view; 4b, suture line; 5, IGPS coll. cat. no. 112573 (holotype); 5a, lateral view; 5b, suture line; 6, IGPS coll. cat. no. 112575; 6a, lateral view; 6b, suture line; 7, IGPS coll. cat. no. 112576, lateral view; **8**, *Paracrochordiceras* sp. A, IGPS coll. cat. no. 112579; 8a, lateral view; 8b, suture line; **9**-**11**, *Paracrochordiceras* sp. B; 9, IGPS coll. cat. no. 112580, lateral view; 10, IGPS coll. cat. no. 112581; 10a, lateral view; 10b, suture line; 11, IGPS coll. cat. no. 112582, lateral view. Scale bars are 1 cm unless otherwise stated.

rounded ventral shoulder, which continued from the rounded margin of the side. The maximum shell width is at the center to ventral two-thirds of the flank, and the flanks slightly converge to the umbilicus. There are rursiradiate ribs on the flanks. They are convex and sometimes slightly sigmoidal. They run from the umbilical wall, slightly strengthened and widened to the venter, and probably cross the venter. They seem to be simple on the inner whorls, but, on the last whorl, sometimes bifurcate near the ventral shoulder or associated by intercalary ribs. There are 28 to 32 (rarely 24) primary ribs on the last whorl.

The external lateral suture consists of three rounded

Table 1. Dimensions (in mm) and ratios of *Paracrochordiceras watanabei* sp. nov. from the Fukkoshi Formation. α: the angular position adapical from the preserved end; *D*: diameter of whorl; *H*, height of whorl; *W*: width of whorl; *UD*: diameter of umbilicus.

IGPS no.	α	*D*	*H* (*H*/*D*)	*W*	*UD* (*UD*/*D*)
112573	0°	52.5	19.5 (0.37)		20.0 (0.38)
(holotype)	0°	39.3	15.1 (0.38)		15.6 (0.40)
	-180°	38.9	12.5 (0.32)		15.8 (0.41)
112574	0°	42.6	ca.13.0 (0.30)		18.3 (0.43)
	-90°	41.7	13.9 (0.33)		17.2 (0.41)
	-180°	30.3	12.4 (0.41)		11.5 (0.38)
112575	0°	42.0	15.1 (0.36)		17.8 (0.42)
112576	0°	37.5	ca.12.5 (0.33)		15.8 (0.42)
	-90°	33.9	11.6 (0.34)		14.2 (0.42)
112577	-90°	29.8	ca.10.0 (0.34)		12.1 (0.41)
112578	0°	31.0	10.4 (0.34)		12.6 (0.41)

saddles and two serrated lobes. The ventral lobe is not preserved. The second saddle is widest and the third is small. The first lateral lobe is deep, with smooth sides which are subparallel each other to slightly widened toward the base. The base has four to five strong denticulations. The small and shallow second lobe bifurcates, rarely trifurcates at the base. The auxiliary robe is simple and pointed.

Discussion.—The general shell outline and surface ornamentation, especially their nearly flat sides, of the present species somewhat resembles *Paracrochordiceras denseplicatum* (Fantini Sestini, 1981, p. 49, pl. 4, figs. 2, 3) described from the Lower Anisian (Aegean) of Chios Island, Greece. The present species, however, clearly distinguished from *P. denseplicatum* and other previously known species of *Paracrochordiceras* in having coarser, rursiradiate ribs.

Occurrence.—Middle part (Fk-1a: nos. 112577, 112578; Fk-1b: nos. 112573–112576) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Paracrochordiceras sp. A
Figures 6.8a, b

Material examined.—One specimen, IGPS coll. cat. no. 112579.

Descriptive remarks.—A specimen collected from a float near the locality Fk-1a and Fk-1b is examined. About two-thirds of the conch is preserved. It is discoidal and sub-evolute. The maximum diameter is about 35 mm, and its corresponding height and umbilical diameter are ca. 12 and 12-13 mm (*UD*/*D* = 0.34-0.37), respectively. The broadly rounded flanks continue to the umbilical wall and venter without well-defined umbilical and ventral shoulders. The maximum shell width is at about the center of the flanks. Exact shell width is not known, but, based on the preserved shell thickness, the width at least reaches 10 mm, and probably larger than the corresponding height. The umbilicus is deep and umbilical wall is steep. The shell surface is ornamented with strong radial ribs, which run from the umbilical shoulder, broadened to the venter and probably cross the venter. They are rursiradiate on the inner whorls, but partly falcoid on the last whorl. Although the large part of the shell surface of the last whorl is worn out and not well preserved, many of the ribs on the preserved last whorl seem to bifurcate at the center of the flank or near the ventral shoulder. There are 15-16 primary ribs per half volution.

The external suture is partly preserved, but the ventral lobe and auxiliary ones near the umbilicus are not preserved. The crests of three saddles are all rounded. The first saddle is highest, but narrow, and the second is wide. The first lateral lobe is wide and deep, showing somewhat circular outline. Its base is strongly denticulate and shallow denticulations are up to the middle part of the ventral side. The small second lateral lobe is also denticulate.

Based on its general shell shape and shape of suture line, the present specimen very likely belongs to the genus *Paracrochordiceras*. Although its coarse ribbing and unique rib pattern suggests that the present species is a new species, I refrain from proposing it because of their poor state of preservation.

Occurrence.—From a float at the middle part (Fk-1) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Paracrochordiceras sp. B
Figures 6.9–6.11

Material examined.—Three specimens, IGPS coll. cat. nos. 112580–112582.

Descriptive remarks.—The specimens are discoidal and sub-involute to sub-evolute. The maximum diameters of them are ca. 45 mm, and the ratios of *UD*/*D* are 0.30 (specimen no. 112580), 0.38 (no. 112581) and 0.44 (no. 112582). The flanks are nearly flat to broadly convex with acutely rounded umbilical and ventral shoulders. The venter is not well preserved, but seems to be rounded. The umbilicus is shallow. The maximum width is near the ventral shoulder to the center of the flank. The shell surface is ornamented with slightly sigmoidal to slightly concave, rectiradiate to slightly rursiradiate, fine radial ribs. They run from the umbilical shoulder, slightly broadened to the venter, and fade out short before the venter or probably

cross the venter. Very fine ribs or growth lines, parallel to the primary ribs, are also present in specimen no. 112580. There are about 50 primary ribs per volution. The suture is only preserved in specimen no. 112581. It is rather simple and consists of deep ventral lobe, high and large, rounded first lateral saddle, moderately deep first lateral lobe, small second rounded saddle and small second lobe. Although all lobes are not well preserved, the lower part of the first lateral lobe is pointed at three or four parts.

The general shell shape and rib pattern, and the outline of the suture line of the present specimen resemble with those of the species of the genus *Paracrochordiceras*. The ribs of the present specimens are remarkably finer than those of the known species. However, I refrain from identifying it at the specific level, because they are in poor state of preservation.

Occurrence.—From the middle part (Fk-1a) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Superfamily Pinacoceratoidea Mojsisovics, 1879
Family Gymnitidae Waagen, 1895
Subfamily Japonitinae Tozer, 1971
Genus ***Aegeiceras*** Fantini Sestini, 1981

Type species.—*Gymnites ugra* Diener, 1895b.

Aegeiceras? sp.
Figures 5.8a, b

Material examined.—One specimen, IGPS coll. cat. no. 112583.

Descriptive remarks.—A small specimen is discoidal and sub-evolute. It consists of phragmocone and body chamber, the latter occupies about a half of the last whorl. The shell attains 24.4 mm in diameter and its corresponding height and umbilical diameter are 10.0 and 8.0 mm (*UD*/*D* = 0.33), respectively. The side is broadly convex with maximum width at the center of it. The apparent width is very small and about 2 mm, but this is partly tectonic flattening. The venter is carinate, without remarkable ventral shoulder. The umbilicus is shallow with rounded umbilical shoulder. The shell cross section is lenticular. The shell surface seems to be smooth on the phragmocone, but on the body chamber, there are faint, fine radial ribs, running from just above the umbilical shoulder to near the venter. They are rectiradiate on the inner side of the whorl, but slightly curve adorally on the outer side. There are also seen three, indistinct spiral ridges on the body chamber: at the ventral one-fourth, center and ventral three-fourth. They slightly expand on the radial ribs.

The external lateral suture line is ammonitic and similar to that of *Aegeiceras*, although the ventral lobe is only partly preserved and its details sometimes in distinct because of its small size and ill preservation. The all saddles and lobes are finely frilled. The ventral lobe is shallow than the first lateral lobe. There are three saddles on the lateral side, the second is highest and the third is low. The first lateral lobe is deepest. The second lobe is slightly shallow than the first. Near the umbilical edge, there are some auxiliaries.

The general shell shape and sutural outline are similar to those of the genus *Aegeiceras* Fantini Sestini, 1981, although the ratio of *UD*/*D* of the present species is little smaller than the known species of *Aegeiceras*. The species of *Aegeiceras* have only one spiral ornament constituted by clavi. The present species has three faint spiral ridges on the body chamber. Some specimens of *Aegeiceras ugra* also have additional spiral ornament, although they are very indistinct ridge (Diener, 1895b, pl. 30, fig 5a; Bender, 1970, pl. 3, fig. 6; Fantini Sestini, 1981, pl. 5, fig. 2). The spiral ornaments of the present species are ridge, instead of clavi, but they expand on the radial ribs as nodes. Thus, the present species is thought to belong to the genus *Aegeiceras*, but there remain some questions about the generic assignment due to its small size and poor state of preservation.

Occurrence.—Middle part (Fk-1a) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Genus ***Eogymnites*** Spath, 1951

Type species.—*Japonites arthaberi* Diener, 1915.

Eogymnites sp.
Figures 5.9a, b

Material examined.—One specimen, IGPS coll. cat. no.112584.

Descriptive remarks.—A small specimen, consisting of phragmocone and body chamber, is at hand. The body chamber occupies more than two-thirds of the preserved last whorl. The shell is extremely discoidal and sub-evolute. It attains 32.8 mm in diameter and its corresponding height and umbilical diameter are ca. 12.0 and 14.5 mm (*UD*/*D* = 0.44), respectively. The apparent width is 1.8 mm, but its discoidal form may be partly due to the synsedimentary compaction and tectonic flattening. The sides are broadly convex with broadly rounded umbilical and ventral shoulders. The umbilicus is shallow and the venter is probably acutely rounded. The maximum shell width is at the center of the flank, and the shell cross section is lenticular. The shell surface is almost smooth, but with faint, slightly sinuous, radial ribs.

The external lateral suture consists of large and deep first lateral lobe, high second lateral saddle, deep second lateral lobe and small third lateral saddle on the umbilical shoulder. Ventral lobe is not seen and the first lateral saddle is only preserved on its umbilical side. At maturity all parts of saddles and lobes are serrated, but on the inner whorls the crests of saddles are rounded. The serration of the base of the lobes are rather deep. Sides of lateral lobes are parallel to each other.

Based on the general shell shape and sutural traces, especially in having parallel lobe sides, the present specimen belongs to the genus *Eogymnites* Spath, 1951. But the precise specific identification is difficult, because it is rather small and ill preserved.

Occurrence.—Middle part (Fk-1a) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Genus ***Japonites*** Mojsisovics, 1893

Type species.—*Ceratites planiplicatus* Mojsisovics, 1888.

Japonites cf. ***meridianus*** Welter
Figures 7.5a, b

cf. *Japonites meridianus* Welter, 1915, p. 122, pl. 93. figs. 2a–2c, text-fig. 21; Wang and He, 1976, p. 414, pl. 42, figs. 3–4, pl. 43, figs. 10–11; He et al., 1986, p. 240, pl. 9, figs. 7–14, text-figs. 33c–33d.

Material examined.—One specimen, IGPS coll. cat. no. 112585.

Descriptive remarks.—A fragmental specimen, about a half volution, is at hand. Inner whorls are missing. It largely consists of body chamber, but a part of the phragmocone is also preserved. The shell attains about 54 mm in diameter, and its corresponding height and umbilical diameter are ca. 15.5 and 23.3 mm, respectively. The ratio of *UD*/*D* is 0.43. The shell is compressed and the side is nearly flat to broadly convex. The ventral and umbilical shoulders are not well preserved, but seem to be acutely rounded. The shell surface bears faint fine ribs, which are rursiradiate and partly slightly sinuous. They run from the umbilical shoulder to near the ventral shoulder. The external suture line is rather well preserved, except for ventral lobe and auxiliaries near the umbilical shoulder. It is typical *Japonites*-type. The ventral lobe is probably bifurcated by the median saddle and the serrated prong is moderately deep. There remains three lateral saddles and two lateral lobes, all are fully serrated. The first and second saddles are nearly the same height and the third is low. The first lateral lobe is deeper than the second.

Based on the general shell shape, shell ornamentation and outline of the suture line, the present specimen closely resembles *Japonites meridianus* Welter, but the exact specific identification is difficult, because the present specimen is fragmental and not well preserved. *J*. cf. *meridianus* collected from the underlying Osawa Formation (Ehiro, 2022 in press) has smaller umbilicus.

Occurrence.—Middle part (Fk-1a) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Japonites raphaelizoyae (Tommasi)
Figures 7.7a, b

Gymnites Raphaelis Zoja Tommasi, 1899, p. 41, pl. 6, figs. 5, 6; Renz, 1910, p. 41, pl. 2, figs. 10, 12 (non 2), text-fig. 4.
Japonites Raphaelis Zojae (Tommasi), Welter, 1915, p. 123, pl. 10, figs. 1–4, text-figs. 22–24.
Japonites raphaelis-zojae (Tommasi), Bender, 1970, p. 448, pl. 4, fig. 1.
Japonites raphaelis zojae (Tommasi), He et al., 1986, p. 240, pl. 9, figs. 15–19, text-fig. 33g.
Japonites raphaelis zojae (Tommasi), Wang et al., 1979, p. 46, pl. 11, figs. 11–14, text-fig. 25b–c.

Material examined.—One specimen, IGPS coll. cat. no. 112586.

Description.—The shell is discoidal and evolute. It consists of phragmocone and body chamber, the latter occupies about three-fourth of the last whorl. The shell diameter at the preserved end is 73.5 mm, with corresponding height and umbilical diameter of 25.0 and 34.3 mm (*UD*/*D* = 0.47), respectively. The sides are broadly rounded connecting to the rounded venter and rounded umbilical slope without distinct shoulders. The maximum shell width is near the center of the flank, and it is more than 10 mm. The shell cross section is approximately elliptical. The umbilicus is shallow. There are strong, slightly sigmoidal radial ribs, 26–27 per volution, on the shell surface. They run from the umbilical wall, widening to the venter, to the ventral shoulder and fade out. Fine ribs or growth lines, parallel to the ribs, are also present.

The external suture is preserved except for the ventral lobe. It consists of high, rather narrow first lateral saddle, deep and wide first lateral lobe, wide second lateral saddle, shallow second lateral lobe, small third lateral saddle and some auxiliary lobes on the umbilical shoulder to umbilical wall. All saddles and lobes are serrated irregularly. The first lateral lobe has nearly parallel sides and its base is strongly serrated. The second lateral lobe narrows toward the base.

Comparison.—The general shell shape, especially in having elliptical shell cross section and rather wide

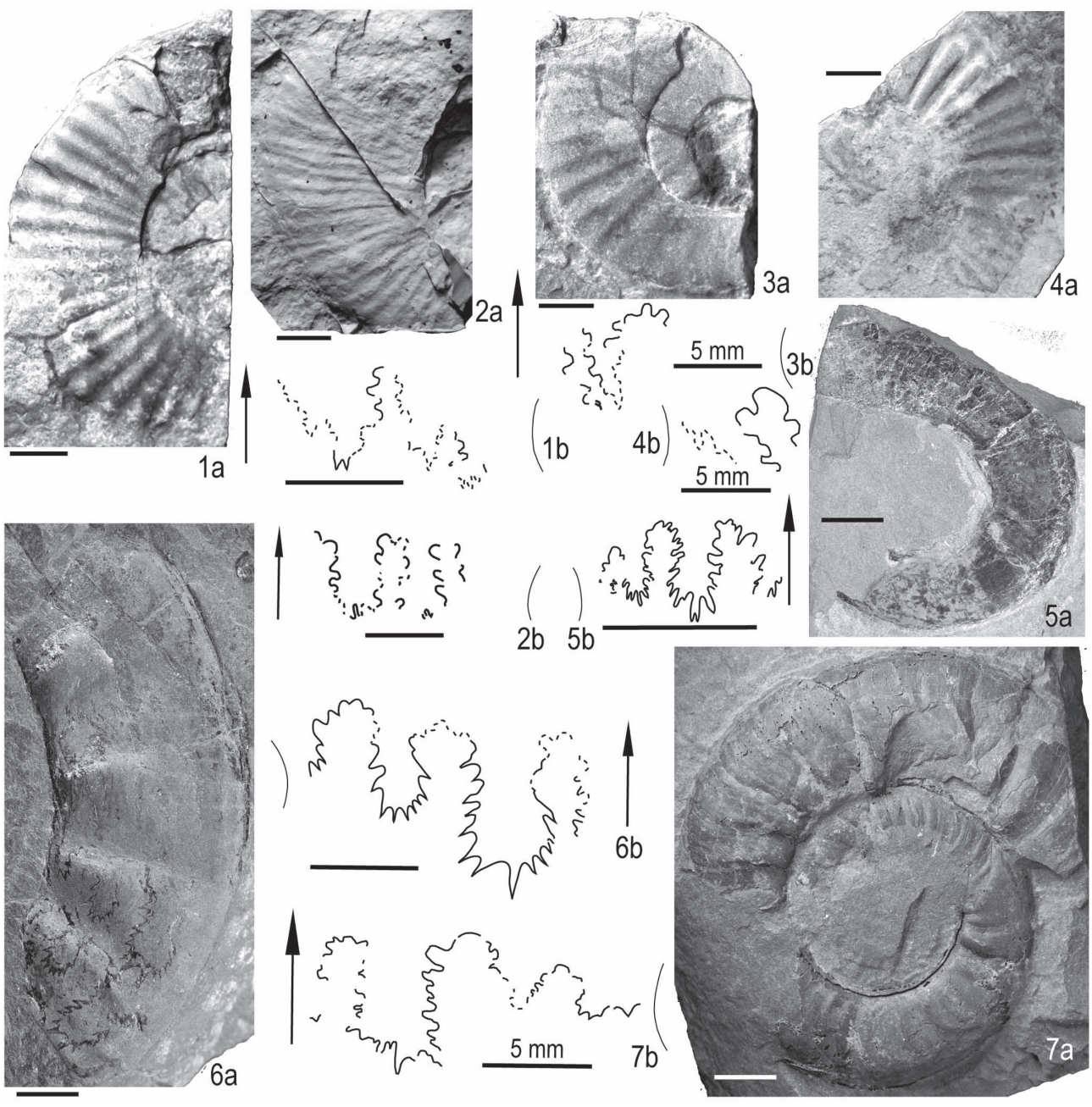

Figure 7. *Japonites* from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1, **3**, **4**, *Japonites* sp. B; 1, IGPS coll. cat. no. 112667; 1a, lateral view; 1b, suture line; 3, IGPS coll. cat. no. 112665; 3a, lateral view; 3b, suture line; 4, IGPS coll. cat. no. 112666; 4a, lateral view; 4b, suture line; **2**, *Japonites* sp. C, IGPS coll. cat. no. 112668; 2a, lateral view (rubber cast); 2b, suture line; **5**, *Japonites* cf. *meridianus* Welter, IGPS coll. cat. no. 112585; 5a, lateral view; 5b, suture line; **6**, *Japonites* sp. A, IGPS coll. cat. no. 112587; 6a, lateral view; 6b, suture line; **7**, *Japonites raphaelizoyae* (Tommasi), IGPS coll. cat. no. 112586; 7a, lateral view; 7b, suture line. Scale bars are 1 cm unless otherwise stated.

umbilicus, the present specimen is identified with *Japonites Raphaelis Zojae* (Tommasi), especially very similar to the specimen *J. Raphaelis Zojae* form 2 described by Welter (1915, p. 123, pl. 10, fig. 2, text-fig. 23) from Timor.

Occurrence.—Upper part (Fk-6) of the Fukkoshi Formation at the eastern coast of Terahama, Togura, Minamisanriku Towny, Miyagi Prefecture.

Japonites sp. A
Figures 7.6a, b

Material examined.—One specimen, IGPS coll. cat. no. 112587.

Descriptive remarks—A fragmental specimen, about a quarter of one-volution, consists of phragmocone and body chamber. It is evolute and discoidal, and its maximum diameter is considered to exceeds 100 mm. The side is broadly convex with rounded umbilical shoulder. The venter is not well preserved. The maximum shell width is near the umbilical shoulder, and sides converge to the venter. The shell surface is ornamented with low, but wide, radial ribs, which run from the umbilical wall, bifurcate at the umbilical shoulder, and run to the ventral shoulder. There are four primary ribs per quarter whorl. The external suture is preserved except for the ventral lobe. Three lateral saddles are all serrated from lower to top. The first and second saddles are nearly the same height. The first is narrow, whereas the second is wide. The height of the third is about a half of the second. The first lateral lobe is large and deep with strong denticulations at the base. The lower part of it is slightly expanded. The depth of the second lobe, which is denticulate as with the first, is about two-thirds of the first. There may be some auxiliary lobes near the umbilical shoulder, but only a part is visible.

Based on the general shell shape and outline of the suture line, the present specimen is considered to belong to the genus *Japonites*. Bifurcate rib pattern of the present specimen is unique for the genus *Japonites*, but it is not well preserved enough to propose a new species.

Occurrence.—Middle part (Fk-1b) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Japonites sp. B
Figures 7.1, 7.3, 7.4

Material examined.—Three specimens, IGPS coll. cat. nos. 112665–112667.

Descriptive remarks—Three fragmental specimens are at hand. They are discoidal and sub-evolute. The maximum shell diameter of the specimen no. 112665 exceeds 60 mm. At the estimated diameter is ca. 65.0 mm, its corresponding height and umbilical diameter are ca. 20, and ca. 28 mm (*UD*/*D* = 0.43), respectively, and at *D* = ca. 50.5 (about 180° adapical from the preserved end) the height and umbilical diameter are 17.2 and 19.3 mm (*UD*/*D* = 0.38), respectively. Another specimen (no. 112666) is a fragment of about one-third of a whorl, the height of which is ca. 22 mm. They have nearly flat to very slightly convex side with acutely rounded umbilical and ventral shoulders. The venter probably rounded, but not well preserved. The umbilicus is shallow. There are low but prominent ribs on the shell surface. They are substantially rectiradiate, but slightly rursiradiate and convex, and run from umbilical shoulder to ventral shoulder, slightly strengthened to the venter. On the outer molds there are also fine striae parallel to the ribs, although they are rather obscure. There are nine to ten ribs per quarter volution (ca. 40 ribs per volution) of the whorl.

Specimen no. 112667 moderately large specimen, about a half of outer volution and a part of inner volution is preserved. It is discoidal and sub-evolute. The maximum shell diameter probably attains about 80 mm, with the corresponding height (estimated) and umbilical diameter are 30 and 31.0 mm (*UD*/*D* = 0.39), respectively. The sides are nearly flat to very broadly convex with acutely rounded umbilical shoulder. The umbilical wall is steep. The venter is probably rounded with broadly rounded shoulder. The maximum shell width is near the ventral shoulder and the sides slightly converge toward the umbilicus. On the shell surface, there are 22–23 rectiradiate ribs per half volution. They run from umbilical wall to the venter, strengthened to the ventral shoulder.

The suture lines are only partly preserved and obscure in all specimens. Preserved parts are the ventral side region of the inner whorl in specimen no. 112665, the umbilical side region in specimen no. 112666 and the ventral two-thirds in specimen no. 112667. They are composed of the fully serrated deep lobes and/or high saddles.

The present specimen is considered to belong to the genus *Japonites*, based on the general shape of the suture lines and discoidal and sub-evolute shell shape. The surface ornamentation is somewhat similar to that of *Japonites meridianus*, but the specific identification is difficult because of their poor state of preservation.

Occurrence.—Two specimens (nos. 112665, 112666) come from the middle part (Fk-1c) and one specimen (no. 112667) from the upper part (Fk-2a) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Japonites sp. C
Figures 7.2a, b

Material examined.—IGPS coll. cat. no. 112668.

Descriptive remarks—A fragmental phragmocone, about one-third to one-fourth of a volution, is at hand. It is discoidal and sub-evolute. The diameter near the preserved end is estimated to be 80–85 mm, and its corresponding height and umbilical diameter are ca. 30 and 28 mm (*UD*/*D* = 0.33–0.35), respectively. The side is nearly flat with broadly rounded ventral shoulder and acutely rounded umbilical shoulder. The venter and umbilicus are not well preserved. The maximum shell width is at the ventral shoulder and the sides slightly converge to the umbilicus. On the flanks there are 13 to 15 fine ribs per quarter. They are rectiradiate and slightly concave, and run from the umbilical shoulder to the ventral shoulder. Few ribs bifurcate at about ventral one-third. Fine striae parallel to the ribs are also seen.

The suture lines are obscure and only parts of narrow and high saddles are visible, although some parts are little unreliable. They are fully serrated.

The present specimen is considered to belong to the genus *Japonites*, based on the general shape of the suture lines and discoidal and sub-evolute shell shape. The specific identification is difficult because of the poor state of preservation. It has finer and closely spaced ribs than the above-described *Japonites* sp. B.

Occurrence.—From the middle part (Fk-1a) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Subfamily Gymnitinae Waagen, 1895
Genus ***Buddhaites*** Diener, 1895b

Type species.—*Gymnites* (*Buddhaites*) *rama* Diener, 1895b.

Buddhaites? sp.
Figures 5.10a, b

Material examined.—One specimen, IGPS coll. cat. no. 112588.

Descriptive remarks.—Specimen attains a maximum diameter of ca. 26.5 mm. It is discoidal and involute. The umbilicus is not well preserved but its diameter is probably less than 2 mm. The side is broadly convex with maximum width at the center of the side. The umbilicus is shallow. The venter, with broadly rounded ventral shoulder is not well preserved but seems to be acutely rounded. The shell surface seems to be smooth. The partly preserved external suture line is ammonitic and resembles that of the family Gymnitidae. The first lateral saddle (ventro-lateral saddle) is wide and asymmetrical. Its ventral side, the enveloping surface of which is gently inclined ventrally, has rather deep secondary lobes.

Based on the shell morphology and the sutural outline, the present specimen is considered to belong to the genus *Buddhaites* Diener, 1895b, but there remains a question about the generic assignment due to the poor state of the preservation of the suture line.

Occurrence.—Middle part (Fk-1a) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Superfamily Danubitoidea Spath, 1951
Family Danubitidae Spath, 1951
Genus ***Danubites*** Mojsisovics, 1893

Type species.—*Ceratites Floriani* Mojsisovics, 1882.

Danubites cf. ***ambika*** Diener
Figures 8.1, 8.2

cf. *Danubites ambika* Diener, 1895b, p. 104, Pl. 29, figs. 2a–2c.
Danubites aff. *ambika* Diener, Bando, 1970, p. 347, pl. 38, fig. 1.

Material examined.—Three specimens, IGPS coll. cat. nos. 112589, 112590, 112669.

Descriptive remarks.—Specimens are discoidal and evolute. Conch is slowly increasing in height and shallowly embracing the preceding whorls. The maximum shell diameter of specimen no. 112589 exceeds 35 mm, and at the diameter of 34.9 mm, the corresponding height and umbilical diameter are 10.7 (*H*/*D* = 0.29) and 16.2 mm (*UD*/*D* = 0.46), respectively. The maximum diameter of the specimen no. 112590 exceeds 45 mm, and at a diameter of 44.9 mm the ratios of *H*/*D* and *UD*/*D* are 0.32 and 0.43, respectively. The maximum diameter of the specimen no. 112669 is 47.8 mm, with the corresponding height and umbilical diameter are 17.2 (*H*/*D* = 0.36) and 18.2 mm (*UD*/*D* = 0.38), respectively. The sides are broadly convex to nearly flat and sometimes slightly concave in the outer part. The umbilical and ventral shoulders are acutely rounded. The venter is not well preserved, but seems to be flat to slightly convex. The umbilicus is shallow. The shell surface is ornamented with strong, rectiradiate ribs, which run from umbilical shoulder to near the ventral shoulder and fade out. They become widened forward. There are 28-29 (specimen no. 112589) or about 34 (no. 112590, 112669) ribs on the last whorl. The suture is only preserved in specimen no. 112669. Three lateral saddles and two lateral lobes are observed. The crests of saddles are all rounded. The second is highest and the third is small. The first lateral lobe is wide and deep, with parallel sides and denticulate base. The second lobe has similar shape as the first, but small in size.

The present specimens resemble *Danubites ambika*

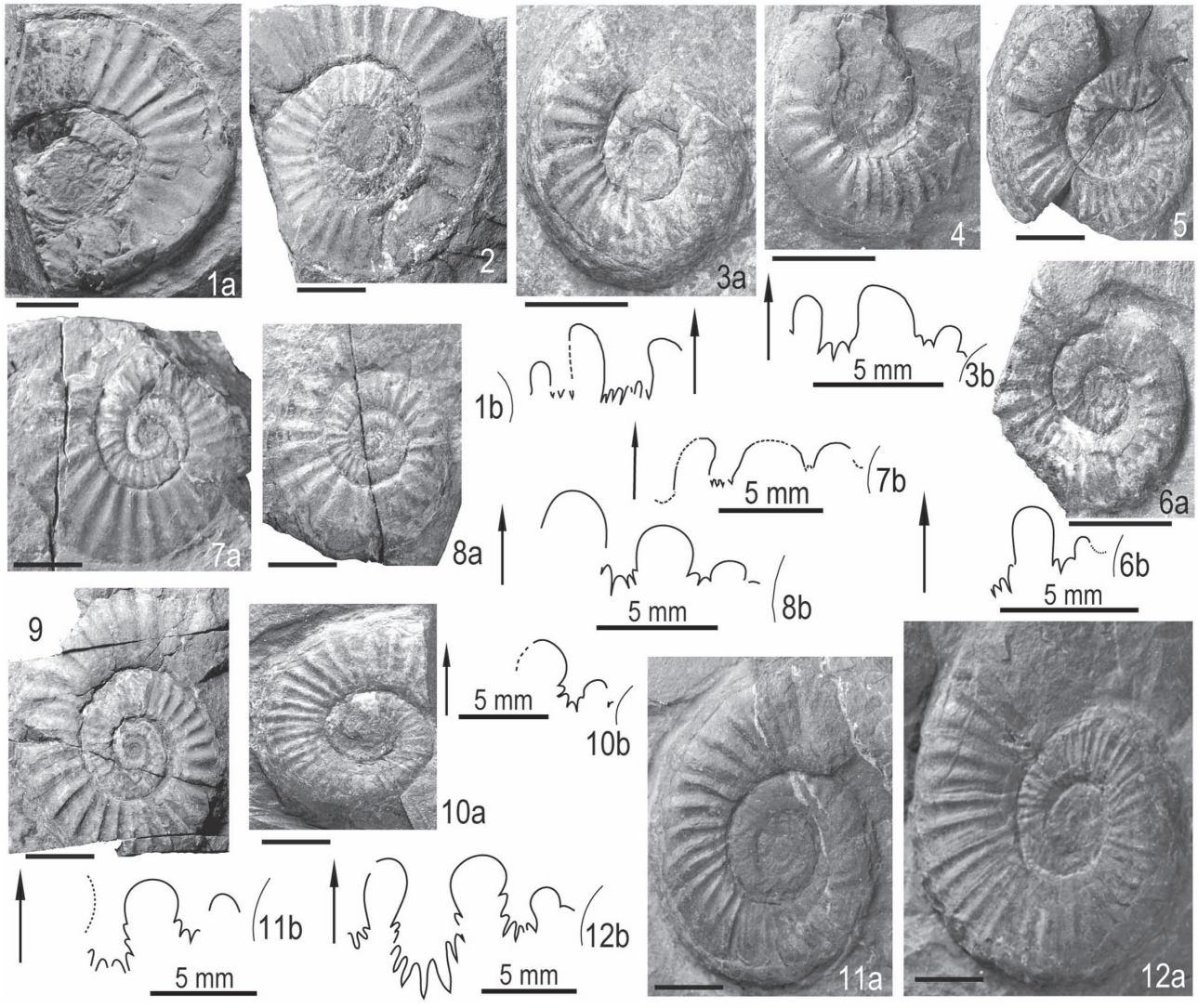

Figure 8. *Danubites* and *Paradanubites* from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1–**2**, *Danubites* cf. *ambika* Diener; 1, IGPS coll. cat. no. 112669 ; 1a, lateral view, 1b, suture line; 2, IGPS coll. cat. no. 112590, lateral view; **3**–**6**, *Danubites floriani* (Mojsisovics); 3, IGPS coll. cat. no. 112591; 3a, lateral view; 3b, suture line; 4, IGPS coll. cat. no. 112592, lateral view; 5, IGPS coll. cat. no. 112593, lateral view; 6, IGPS coll. cat. no. 112594; 6a, lateral view; 6b, suture line; **7**–**9**, *Danubites* cf. *tozeri* Korchinskaya; 7, IGPS coll. cat. no. 112595; 7a, lateral view; 7b, suture line; 8, IGPS coll. cat. no. 112596; 8a, lateral view; 8b, suture line; 9, IGPS coll. cat. no. 112597, lateral view; **10**–**12**, *Paradanubites ozashiense* sp. nov.; 10, IGPS coll. cat. no. 112605; 10a, lateral view; 10b, suture line; 11, IGPS coll. cat. no. 112604; 11a, lateral view; 11b, suture line; 12, IGPS coll. cat. no. 112603 (holotype); 12a, lateral view; 12b, suture line. Scale bars are 1 cm unless otherwise stated.

Diener from the lower Anisian of Himalayas (Diener, 1985b) and *Danubites* aff. *ambika* Diener from the late Olenekian Osawa Formation (Bando, 1970), especially the latter, in having evolute shell with rather flat sides and rather coarse ribbing. But its precise comparison is difficult, because present specimens are poorly preserved. As stated in the preceding chapter, there is some doubt on the stratigraphic position of Bando's specimen. The present author considers that it may come from the Fukkoshi Formation.

Occurrence.—All specimens from the middle part (Fk-1a) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi

Prefecture.

Danubites floriani (Mojsisovics)
Figures 8.3–8.6

Celtites Floriani Mojsisovics, 1882, p. 145, pl. 28, figs. 5–7, pl. 31, fig. 4.
Danubites Floriani Mojsisovics, 1893, p. 398; Spath, 1951, p. 13.
Florianites floriani Hyatt, 1900, p. 553.

Material examined.—Four specimens, IGPS coll. cat. nos. 112591–112594.

Description.—Specimens are slightly deformed obliquely and flattened laterally. The shell is composed of the phragmocone and body chamber, the latter occupies about a half of the last whorl. The specimens are moderately evolute. The maximum shell diameter ranges from 24.5 to 39.0 mm, with the ratios of *H*/*D* and *UD*/*D* are 0.31–0.40 and ca. 0.37, respectively (Table 2). The exact shell width is not known, but, judging by the preserved half part, the maximum width of specimen no. 112591 is ca. 8 mm. The sides and venter are both broadly rounded and the umbilicus is rather deep with steep umbilical wall. Both umbilical and ventral shoulders are gradual. The maximum shell width is at the center of the side, and therefore, the shell cross section is nearly circular, although it is suffered from tectonic flattening. The shell surface is ornamented with simple, rectiradiate to slightly rursiradiate ribs, which are slightly strengthened to the venter and fade out before the venter. On the last whorl there are 26 to 30 ribs

The ventral lobe is not preserved. The large first lateral lobe is deep with nearly parallel sides and the base of it has many denticulations. The second lateral lobe is smaller remarkably than the first and trifurcates at the base, the middle branch of which is the deepest. There are three rounded saddles on the side and the second is the widest.

Comparison.—The present specimens from the Fukkoshi Formation closely resemble *Danubites floriani* (Mojsisovics, 1882) (originally described as *Celtites Floriani*) from the Middle Triassic of Austria in the shell shape, surface ornamentation and sutural trace. The ratio of *UD*/*D* of the Austrian specimens ranges from 0.32 to 0.45, increasing as the diameter increase, and those of the present specimens are in this range. The number of ribs of the former is slightly larger than those of the latter, but almost the same. The lateral suture line of the Mojsisovics (1882)'s specimen (figured in pl. 31, fig. 4 ; at about 39 mm in shell diameter) is almost similar to that of the present specimen. The both specimens have the large and deep first lateral lobe with denticulate base and trifurcated small second lateral lobe. Both second saddles are wider than the first.

Table 2. Dimensions (in mm) and ratios of *Danubites floriani* (Mojsisovics) from the Fukkoshi Formation. Abbreviations see Table 1.

IGPS no.	α	*D*	*H* (*H*/*D*)	*W*	*UD* (*UD*/*D*)
112591	0°	26.4	9.0 (0.34)	8+	9.8 (0.37)
112592	0°	24.5	ca.9.5 (0.39)		ca.9.0 (0.37)
112593	0°	ca.39.0	ca.12.0 (0.31)		14.5 (0.37)
	-90°	ca.30.0	11.2 (0.37)		10.7 (0.37)
112594	0°	ca.29.0	ca.11.5 (0.40)		10.2 (0.35)

Occurrence.—Middle part (Fk-1a: nos. 112591, 112592; Fk-1b: nos. 112593, 112594) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Danubites cf. ***tozeri*** Korchinskaya
Figures 8.7–8.9

cf. *Danubites tozeri* Korchinskaya, 1982, p. 60, pl. 16, figs. 7–9, text-figs. в, г; Vavilov and Arkadiev, 1986, p. 41, pl. 3, fig. 3, text-fig. 3a.

Material examined.—Three specimens, IGPS coll. cat. nos. 112595–112597.

Descriptive remarks—The specimens are compressed and sub-evolute. It consists largely of phragmocone with a part of the living chamber. The shell diameter of the preserved end of no. 112595 is 36.4 mm with the corresponding height and umbilical diameter of 13.2 and 15.0 mm (*UD*/*D* = 0.41), respectively. At the diameter of ca. 32 mm, the height and umbilical diameter are 11.4 and 14.2 mm (*UD*/*D* = 0.44), respectively. The shell diameter of no. 112596 exceeds 35 mm in the deformed state. At the diameter of ca. 28.5 mm, about 60° adapical from the preserved end, the corresponding height and umbilical diameter are ca. 9.0 (*H*/*D* = 0.32) and 12.7 mm (*UD*/*D* = 0.45), respectively. At about 180° adapical from the preserved end (D = ca. 29 mm), height and umbilical diameter are 11.8 and 11.5 mm (*UD*/*D* = 0.40), respectively. No. 112597 exceeds 35 mm in diameter and the ratio of *UD*/*D* is ca. 0.41.

The side are broadly convex and the maximum width is about the center of the side. The steeply dipping umbilical wall is low but distinct with rounded umbilical shoulder. The ventral shoulder is rounded but the venter is not well preserved. The shell surface is ornamented with slightly rursiradiate, straight, coarse ribs, running from the umbilical wall to the ventral shoulder. The ribs are slightly broadened to the ventral shoulder, but seem to not cross the venter. There are 24 to 26 ribs per volution.

The ventral lobe is not preserved. There are three

rounded saddles on the lateral side. The second saddle is widest and the third is small. The first lateral lobe, having subparallel smooth sides, is wide and deep, and the base has four denticulations. The second lobe is small and bi- or tri-furcate. The auxiliary lobe is not seen.

The general shell shape, coarse ribbing and outline of the suture line of the present species resembles to those of *Danubites tozeri* Korchinskaya reported from the lower Anisian of Svalbard (Korchinskaya, 1982) and eastern Taimyr (Vavilov and Arkadiev, 1986). But the present forms differ from the latter two in having oval cross section instead of sub-square to sub-rectangular, and in having slightly rursiradiate ribs.

Occurrence.—Middle part (Fk-1a: no. 112595, 112597; Fk-1b: no. 112596) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Genus ***Paradanubites*** Shevyrev, 1968

Type species.—*Ceratites* (*Danubites*) *kansa* Diener, 1895b.

Paradanubites kansa (Diener)
Figures 9.1–9.3

Ceratites (*Danubites*) *kansa* Diener, 1895b, p. 103, pl. 29, fig. 1.
Ceratites (*Florianites*) *kansa* (Diener), Diener, 1907, p. 70, pl. 5, fig. 5.
Danubites kansa Diener, Diener, 1915, p. 116 ; Arkell et al., 1957 , p. 154, fig. 186.6.
Paradanubites kansa (Diener), Shevyrev, 1968, p. 123 ; He et al., 1986, p. 228, pl. 5, figs. 22–30, text-figs. 26c, 26f.

Material examined.—Three specimens, IGPS coll. cat. nos. 112598–112600.

Description.—The compressed shell of no. 112598 is moderately evolute. It consists of phragmocone and body chamber, and the latter occupies the about 3/4 of the preserved last whorl. The maximum shell diameter is about 77 mm and corresponding height and umbilical diameter are ca. 32.0 (*H*/*D* = 0.42) and 28. 2 mm (*UD*/*D* = 0.37), respectively. The ratios of *UD*/*D* of the inner volutions are slightly small (0.35–0.34). The cross section of the shell is elongated oval with convex sides and acutely rounded venter. The umbilical wall is steep with rounded umbilical shoulder. The ventral shoulders are broadly rounded. The maximum shell width is near the center of the flanks, but at the preserved end it is near the center, but a little to the venter. The shell surface is ornamented with strong radial ribs. They run from the umbilical wall, become thickening slightly, to the ventral shoulder and fade out. There are 34 (inner whorl) to 39 (last whorl) ribs per volution. The venter is smooth.

Other two specimens are fragmental. Specimen no. 112599 is a phragmocone, the diameter of which attains 48.8 mm and the ratio of *UD*/*D* is 0.42. On the last whorl, there are 34-35 radial ribs per volution. Specimen no. 112600 consists probably phragmocone and body chamber and its maximum diameter attains 40 mm, but it is ill preserved. It has 17-18 ribs per half volution.

The external lateral suture of no. 112598 consists of three rounded saddles and serrated lobes. The ventral lobe is not preserved. The first lateral lobe is very large and deep with sides slightly widened toward the base. The base of it is strongly serrated with deep denticulations and the lower half of the sides are also serrated. The second lobe is small and its base tri-furcate remarkably. The small auxiliary lobe has two denticulations. The first lateral saddle is narrow, the second is high and wide and the third is small. The external lateral suture of no. 112599 has deep and denticulate first lateral lobe, narrow second lateral saddle, small second lobe with four denticulations and small auxiliary lobe having two small denticulations.

Comparison.—The general shell shape, surface ornamentation and suture line of the present specimen are all very similar to those of the holotype of *Paradanubites kansa* (Diener).

Occurrence.—Middle part (Fk-1a: nos. 112598, 112599; Fk-1b: no. 112600) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Paradanubites cf. ***kansa*** (Diener)
Figures 9.4, 9.5

Synonym list compared see above.

Material examined.—Two specimens, IGPS coll. cat. nos. 112601, 112602.

Description.—Two large, discoidal and subevolute specimens are at hand. One specimen, no. 112601, consists of about two-thirds of inner volutions and a fragmental outer one. Its maximum diameter probably exceeds 120 mm. The body chamber occupies over one volution. The ratio of *UD*/*D* is estimated to be about 0.40. Sides are nearly flat to broadly convex with maximum width at the center of the side. The umbilical shoulder is broadly rounded and low wall is steeply dipping. The venter is probably acutely rounded, though it is not well preserved, with rounded shoulder. The shell surface is ornamented with radial ribs, which run from the umbilical wall to ventral shoulder. There are 15–16 ribs per half volution on the inner whorl. The ribs rarely bifurcate near the umbilical shoulder.

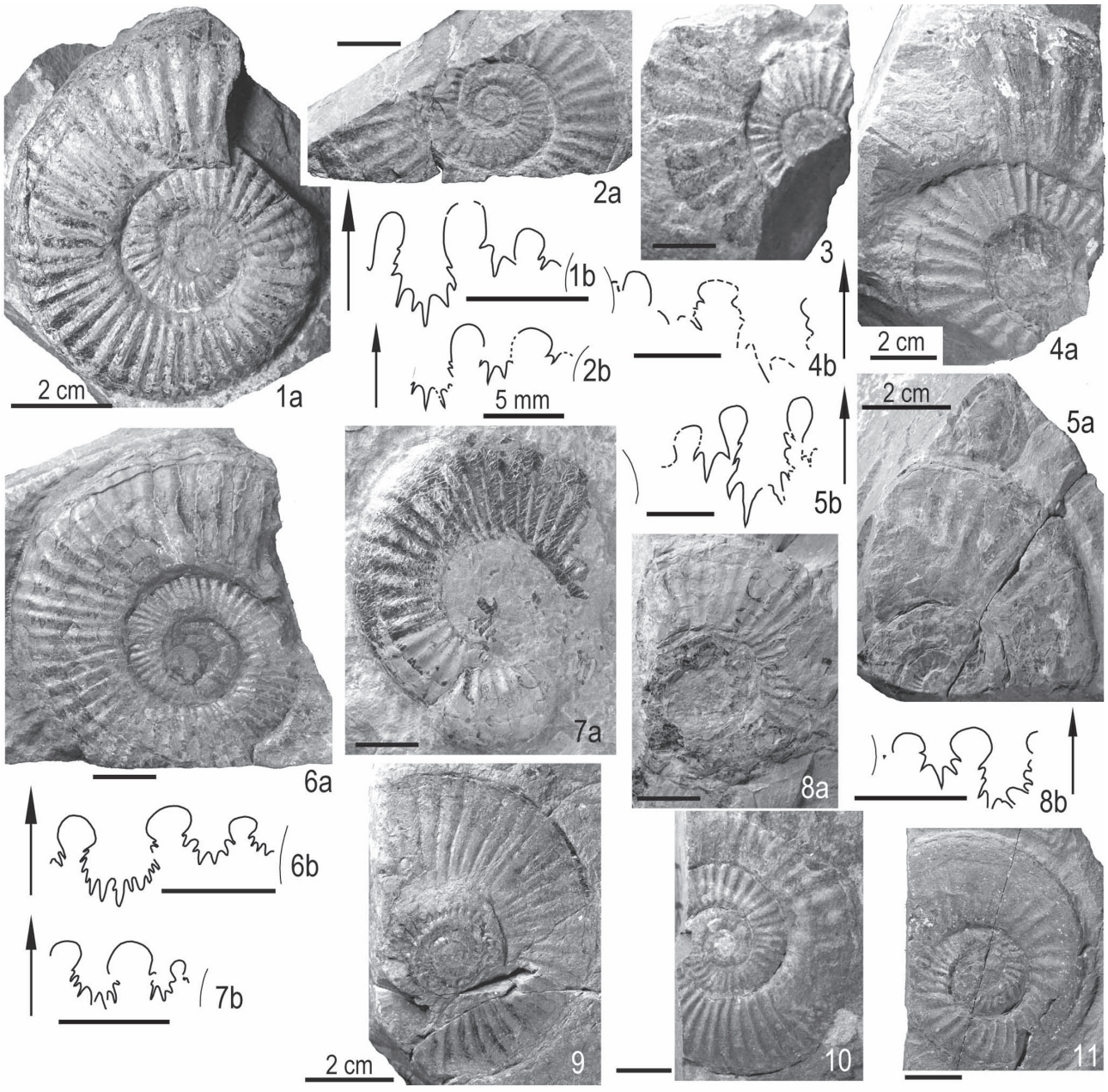

Figure 9. *Paradanubites* from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan. **1**–**3**, *Paradanubites kansa* (Diener); 1, IGPS coll. cat. no. 112598; 1a, lateral view; 1b, suture line; 2, IGPS coll. cat. no. 112599; 2a, lateral view; 2b, suture line; 3, IGPS coll. cat. no. 112600, lateral view; **4** and **5**; *Paradanubites* cf. *kansa* (Diener); 4, IGPS coll. cat. no. 112601; 4a, lateral view; 4b, suture line; 5, IGPS coll. cat. no. 112602; 5a, lateral view; 5b, suture line; **6**–**8**, *Paradanubites phyllus* He; 6, IGPS coll. cat. no. 112606; 6a, lateral view; 6b, suture line; 7, IGPS coll. cat. no. 112607; 7a, lateral view; 7b, suture line; 8, IGPS coll. cat. no. 112608; 8a, lateral view; 8b, suture line; **9**–**11**, *Paradanubites* sp.; 9, IGPS coll. cat. no. 112610, lateral view; 10, IGPS coll. cat. no. 112611, lateral view; 11, IGPS coll. cat. no. 112612, lateral view. Scale bars are 1 cm unless otherwise stated.

Another specimen, no. 112602, is fragmental and a quarter of the shell is preserved. Its diameter probably reaches 80 mm. The side is nearly flat with acutely rounded umbilical and ventral shoulders. The umbilicus is shallow. On the shell surface there are rectiradiate ribs, about 12 per quarter (about 40 per volution) on the outer whorl.

The external suture lines are both partly preserved, although somewhat deformed. They consist of three narrow saddles, having rounded crests, and large and wide first lobe, small and shallow second lobe, and small auxiliaries near the umbilical margin. The base of the first lateral lobe has three deep denticulations and short denticulations extend up to the both sides, gradually diminishing in size. The second lobe also deeply denticulate at the base, but the number of denticulations is rather small: three to five? in no. 112601 and three in no. 112602.

Comparison.—The general shell shape, surface ornamentation and suture line of the present specimen are similar to those of *Paradanubites kansa* (Diener). But their shell sizes are larger than the known specimens of *P. kansa* and the details of the suture line somewhat differ from each other. Then, it is difficult to identify them with *P. kansa* definitely.

Occurrence.—Middle part (Fk-1b) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

***Paradanubites ozashiense* sp. nov.**

Figures 8.10–8.12

Material examined.—Three specimens, IGPS coll. cat. nos. 112603 (holotype), 112604 and 112605 (paratypes).

Etymology.—The species name is from the geographic name “Ozashi” near the fossil locality.

Diagnosis.—*Paranubites* having rursiradiate, convex, coarse ribs, the width and interspaces of them are somewhat irregular. The shell is moderately evolute with oval cross section. The umbilical side of the second lateral lobe is smooth.

Description.—Three specimens, slightly deformed obliquely and flattened laterally, are at hand. They consist of the phragmocone and body chamber, the latter occupies at least a half volution. The specimens are compressed and sub-evolute. The sides are broadly convex with acutely rounded umbilical shoulder and broadly rounded ventral shoulder. The maximum shell width is at about the center of the flank. The venter is probably rounded. The umbilicus is shallow, but with steep wall. The shell cross section is elongated oval. In holotype specimen, the maximum shell diameter attains ca. 51.0 mm, and corresponding height and umbilical diameter are 16.7 (*H*/*D* = 0.35) and 18.5 mm (*UD*/*D* = 0.39), respectively. In specimen no. 112604, the maximum shell diameter is ca. 48 mm, with ratios of *H*/*D* and *UD*/*D* are 0.35 and 0.39, respectively. Specimen no. 112605 attains a diameter of 33.5 mm and ratios of *H*/*D* and *UD*/*D* are 0.37 and 0.31, respectively. The shell surface is ornamented with slightly rursiradiate, convex ribs. They are simple and run from the umbilical wall, slightly strengthening to the venter, and reach to the venter. It is uncertain whether they cross the venter or not, because the venter is not fully preserved. The width of ribs and the width of interspaces are rather irregular and partly associated with very fine ribs. On the last whorl there are 39–40 (no. 112603) or 34–35 (no. 112604, 112605) primary ribs.

The ventral lobe is not fully preserved and only a part of one denticulate prong is visible. The depth is about two-thirds of that of the first lateral lobe. The first lateral lobe is deep with laterally expand sides and the outline of the lobe is ellipse. There are numerous strong denticulations on the base of it and shallow denticulations extend upwards, reducing in size, to two-thirds of the sides. The second lateral lobe is small and asymmetrical. The ventral side is long and serrated from the base to near the top, but the umbilical one is short and smooth. The auxiliary lobe is simple. All saddles have rounded crest. The second is widest and the first is rather elongated vertically.

Comparison.—The present new species is easily distinguished from other species of the genus *Paradanubites* in having small number of ribs, which are rursiradiate and have rather irregular widths and interspaces, and in having asymmetrical second lateral lobe.

Occurrence.—Middle part (Fk-1b) of the Fukkoshi Formation at the southern coast of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

***Paradanubites phyllus* He**

Figures 9.6–9.8

Paradanubites phyllus He in He et al., 1986, p. 231, pl. 6, figs. 22–29, text-figs. 26d, 26e.

Material examined.—Four specimens, IGPS coll. cat. nos. 112606–112609.

Description.—The shell is compressed and sub-evolute. The shell dimeter ranges from 42 to 55 mm, and the ratio of *UD*/*D* ranges 0.37 to 0.42. The flanks are broadly convex with rounded umbilical and ventral shoulders. The cross section of the shell is elongated oval and the maximum shell width is at the center to ventral one-thirds of the flanks. The venter is not well preserved. The umbilicus is shallow. The shell surface is ornamented with sharp ribs, which are rectiradiate and straight, but sometimes slightly concave. They run from the umbilical wall, become thickening slightly, to the ventral shoulder and fade out. There are 40 to 46 ribs

per volution.

The external lateral suture consists of three rounded saddles and serrated lobes. The ventral lobe is not preserved. The first lateral lobe is very large. Its sides expand laterally and the outline of the lobe is sub-circular. The base of it is strongly denticulate and the denticulations extend up to the two-thirds of sides. The outline of the second and probably third lateral lobes are similar to the first, but small and shallow. All lateral saddles have small, sub-circular crest.

Comparison.—The general shell shape, surface ornamentation and suture line, especially the external lateral suture line of the present specimens are very similar to those of *Paradanubites phyllus* He in He et al., 1986.

Occurrence.—Middle part (Fk-1a: of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Paradanubites sp.
Figures 9.9–9.11

Material examined.—Three specimens, IGPS coll. cat. nos. 112610–112612.

Descriptive remarks.—The shell is compressed and sub-evolute. The shell dimeter exceeds 50 mm. The ratio of *UD*/*D* is 0.40-0.42 in specimen no. 112611 at *D* = ca. 40 mm, and ca. 0.32 in specimen no. 112610 at *D* = ca. 70 mm. The flanks are broadly convex with rounded umbilical and ventral shoulders. The maximum shell width is near the center of the flank. The venter is not well preserved. The umbilicus is shallow. The shell surface is ornamented with strong rectiradiate ribs. They run from the umbilical wall, become thickening slightly, to the ventral shoulder and fade out. In specimen no. 112610, faint striae or growth lines also run parallel to the ribs. There are 40 to 45 ribs per volution. The suture is not preserved.

Based on the general shell shape and surface ornamentation, the specimens are considered to belong to the genus *Paradanubites*, and they somewhat resemble *Paradanubites phyllus* He. But I refrain from identifying them at the specific level since no suture line is preserved.

Occurrence.—Middle part (Fk-1a) of the Fukkoshi Formation at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Family Longobarditidae Spath, 1951
Subfamily Groenlanditinae Assereto, 1966
Genus ***Groenlandites*** Kummel, 1953

Type species.—*Groenlandites nielseni* Kummel, 1953.

Groenlandites sp.
Figures 9.1a, b

Material examined.—A specimen, IGPS coll. cat. no. 112613.

Descriptive Remarks.—A fragmental conch, about a half of a volution, is compressed and involute. The maximum shell diameter is ca. 23.0 mm and corresponding height and umbilical diameter are ca. 11.0 (*H*/*D* = 0.48) and ca. 2.0 mm (*UD*/*D* = 0.09), respectively. The maximum shell width is at the umbilical third to the central part of the side. The shell is laterally flattened tectonically and, in the deformed state, the maximum width is estimated larger than 6 mm. The sides are slightly convex with rounded ventral shoulder and the venter is rounded. The shell surface seems to be almost smooth.

The external lateral suture consists of five saddles and lobes. The ventral lobe is not preserved. The first lateral lobe is widest and deepest with strongly denticulate base. The second and third lobes, become narrower and shallower than the first, also have denticulate bases. The bases of the fourth and fifth lobes seem to be smooth. All saddles have rounded crests and become smaller to the umbilicus.

Based on the general shell outline and the shape of the suture, the present specimen is considered to belong to the genus *Groenlandites* Kummel, but the specific identification is difficult due to their poor state of preservation.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1a) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Genus ***Lenotropites*** Popov, 1961

Type species.—*Lenotropites solitarius* Popov, 1961.

Lenotropites spp.
Figures 9.2, 9.3

Material examined.—Two specimens, IGPS coll. cat. nos. 112614, 112615.

Descriptive Remarks.—Two small specimens, the conch of which are compressed and involute to sub-involute, are at hand. The smaller one (no. 112614) consists of phragmocone and body chamber, the latter occupies more than a half volution. It attains a maximum diameter of ca. 18.5 mm (at -60° from the preserved end) in the elliptically deformed state. Its corresponding height and umbilical diameter are ca. 9.0 and ca. 3.5 mm (*UD*/*D* = 0.19), respectively. The sides are broadly convex with the maximum width near the center of the side. The shell cross section is oval with broadly rounded umbilical shoulder and rounded ventral shoulder. The venter may be rounded. The umbilicus is shallow. Shell surface is ornamented with

sigmoidal faint ribs or growth lines.

The other specimen (no. 1126105) is also elliptically deformed and composed of phragmocone and body chamber. The body chamber reaches more than a volution. The maximum shell diameter is 25.8 mm (at -30° from the preserved end), and its corresponding height is 14.9 mm. The umbilicus is almost closed. The sides are broadly convex with rounded umbilical and broadly rounded ventral shoulders. The maximum width is near the umbilical shoulder to a little on the outer part, and the sides converge to the venter. The venter is probably rounded. Shell surface is ornamented with sigmoidal, low, faint ribs and/or growth lines.

In the both specimens the ventral suture are not preserved. In specimen no. 112614 the lateral suture consists probably of five set of saddle and lobe. The rounded saddles diminish in size towards the umbilicus. The first and second lateral lobes are deep with parallel sides and serrated base. The rest are small and shallow, and their bases are probably rounded. The lateral suture of the specimen no. 112615 consists of four saddles and at least three, probably four lobes. The crests of saddles are all rounded. The first one is the highest and the second to fourth are gradually diminish in their size. The first lateral lobe is large and deep with parallel sides. Its base is strongly denticulate. The second has a similar shape to the first but smaller in size. The third is small and simple.

Although two specimens slightly differ from each other in shell morphology and sutural traces, based on their general shell morphology and the shape of the suture line, they are considered to belong to the genus *Lenotropites* Popov, 1961. But it is difficult to identify them at the specific level because of their poor state of preservation.

Occurrence.—Both from the middle part of the Fukkoshi Formation (Fk-1b) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Subfamily Longobarditinae Spath, 1951
Genus ***Grambergia*** Popov 1961

Type species.—*Grambergia taimyrensis* Popov, 1961.

Grambergia cf. ***tetsaensis*** McLearn
Figures 9.4–9.8

cf. *Grambergia tetsaensis* McLearn, 1969, p. 36, p1. 7, figs. 1–5, text-fig. 15; He et al., 1986, p. 210, pl. 11, figs. 23–25, 31–33, text-fig. 15a; Tozer, 1994, p. 101, pl. 43, figs. 3, 4, pl. 44, figs. 3, 4, 10, text-figs. 31c, d.

Material examined.—Five specimens, IGPS coll. cat. nos. 112616–112620.

Description.—The specimens are small, ranging their maximum shell diameters from ca. 21 mm to ca. 32 mm. They are compressed with almost flat sides and very involute with the ratios of *UD*/*D* = 0.08–0.13. The specimen no. 112617 and 112619 have acutely rounded to acute ventral shoulder. In the specimen no. 112618, there is a faint spiral ridge near the venter on the flank, which probably corresponds to the ventral shoulder. The surface of the shell is almost smooth, but in the specimen no. 112618, some faint sigmoidal growth lines are present.

The external suture lines consist of shallow ventral lobe, deep and wide first lateral lobe and following 3–4 lobes and rounded saddles, but they vary in detail among specimens. The ventral lobe of the specimen no. 112616 is shallow and divided into serrated prongs by low, rounded median saddle. The first lateral lobe is widest and deepest with remarkable denticulation at the base. The second to fourth lateral lobes are also denticulate, but become considerably shallower and smaller than the first. The small fifth lobe is V-shaped and there is probably an additional lobe at the umbilical shoulder. All lateral saddles are rounded. The ventral lobes of other specimens are also shallow and divided into two prongs, but their precise shapes are not seen. The second lateral lobes of the specimens no. 112617 and 112618 bear denticulations at the base, whereas that of specimen no.112619 seems to be smooth, and the following lobes have smooth bases.

Discussion.—Based on their general shell shapes, having very compressed, nearly flat, smooth sides, and suture lines with shallow ventral lobe, considerably deep first lateral lobe and following 4–5 lobes, the present specimens are considered to belong to the genus *Grambergia* Popov 1961. They closely resemble *Grambergia tetsaensis* McLearn, 1969 in having deep first lateral lobe and high second saddle, but the precise identification is difficult due to the poor state of preservation and small size.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1a: nos. 112616–112618; Fk-1b: no. 112619; Fk-1c: no. 112620) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Subfamily Czekanowskitinae Tozer, 1994
Genus ***Arctohungarites*** Diener, 1916 b

Type species.—*Hungarites triformis* Mojsisovics, 1886.

Arctohungarites sp.
Figures 11.1–11.3

Material examined.—Three specimens, IGPS coll. cat. nos. 112621–112623.

Descriptive remarks.—Three more or less fragmental, imperfect specimens are at hand. The shell is compressed

and involute. Specimen no. 112621 consists of phragmocone and body chamber, but their boundary is not well known. The shell diameter exceeds 55 mm and estimated ratio of *UD*/*D* is ca 0.16. Specimen no. 112622 is a fragment of a shell having small umbilicus. Specimen no. 112623 attains a maximum diameter of ca. 59.0 mm, and its corresponding height and umbilical diameter are ca. 25.0 and 19.0 mm (*UD*/*D* = 0.32), respectively. The sides of the specimens are broadly convex, the maximum width of which is at about the center of the side. The venter is probably acutely rounded with rounded ventral shoulder. The umbilicus is shallow and its shoulder is acutely rounded. The shell cross section is thin lenticular, although its compressed shell shape is partly due to the tectonic deformation. The shell surface is ornamented with widely spaced, low and slightly sinuous ribs, which run from the umbilical shoulder to near the ventral shoulder. There are 12-13 ribs per half volution.

The poorly preserved external suture line consists of large and rounded first lateral saddle, large and deep first lateral lobe, the base of which is denticulate, second rounded saddle, medium-sized, serrated second lateral lobe, small rounded third saddle, small third lateral lobe and small fourth lateral saddle. The base of the third lobe is not well observed.

Based on the general shell shape, surface ornamentation and outline of external suture line, the present specimens are considered to belong to the genus *Arctohungarites* Diener, 1916b with high probability. But it is difficult to identify them at the specific level because of their poor state of preservation.

Occurrence.—All from the middle part of the Fukkoshi Formation (Fk-1b) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Longobarditidae? gen. and sp. indet.
Figure 9.10

Material examined.—One specimen, IGPS coll. cat. no. 112624.

Descriptive Remarks.—A small specimen is at hand. It is compressed and involute. The conch attains about 14.0 mm in diameter and the corresponding umbilical diameter is 2.8 mm (*UD*/*D* = ca. 0.20). The sides are convex and the venter is probably carinate or acutely rounded without remarkable ventral shoulder. The shell surface has rather strong, sinuous ribs. They run from the umbilical shoulder to the ventral one-fourth, with maximum height at the center of the side, and fade out. There are 25 ribs per volution. The suture is not preserved.

The general shell outline and its rib pattern of the present specimen are somewhat similar to those of *Groenlandites silberlingi* Tozer, 1994. But the present specimen is so small in size, poor state of preservation and lacks suture line. Moreover, some species belong to the longobarditid genera, such as *Lenotropites* Popov, 1961 and *Intornites* Assereto, 1966, have similar shell shape and ornamentation in their early ontogenetic stages.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1b) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Superfamily Arcestoidea Mojsisovics, 1875
Family Cladiscitidae Zittel, 1884
Subfamily Procladiscitinae Gamsjäger, 1982
Procladiscites Mojsisovics, 1882

Type species.—*Procladiscites broncoi* Mojsisovics, 1882.

Procladiscites brancoi Mojsisovics
Figures 11.4–11.6

Procladiscites broncoi Mojsisovics, 1882, p. 114, pl. 48, figs. 1–2 ; Arthaber, 1896, p. 85; 1915, p.175, pl. 5, fig. 8; He et al., 1986, p. 233, pl. 18, figs. 6–16, 20–22, text-figs. 28a–b; Germani, 1997, p. 288, pl. 3, figs. 2a–b, text-fig. 11.
Procladiscites brancoi Mojsisovics var., Salopek, 1911, p. 24, pl. 2, figs. 3a–b.
Procladiscites cf. *yasoda* Diener, Welter, 1915, p. 112, pl. 9, fig. 4.

Material examined.—Three specimens, IGPS coll. cat. nos. 112625–112627.

Description.—Two specimens (specimens no. 112625 and no. 112627) are side of the conch and the rest (no. 112626) is a fragment of the venter. The conch is compressed and involute with almost closed umbilicus. The sides are slightly convex with maximum width at half height of the whorl. The umbilical shoulder is rounded. The venter is not well preserved, but seems to be acutely rounded to rounded. The shell surface is ornamented with numerous spiral striae.

The lateral suture consists of phylloid and terminated lateral saddles and denticulate ptychitid lateral lobes. The ventral lobe, only preserved in the fragmental specimen (no. 112626), is divided into two prongs by a moderately high median saddle. The base of the prong has two deep denticulations. The crests of first three lateral saddles are semi-triangular. The second lateral saddle is the highest and then saddles are become smaller to the umbilicus. There are at least six, probably eight to nine, lateral lobes. The bases of these lobes are deeply denticulate. The second lateral lobe is the largest and deepest, and the third has about a half depth of the second and following ones become smaller to the umbilicus.

Discussion.—Based on the general shell shape and

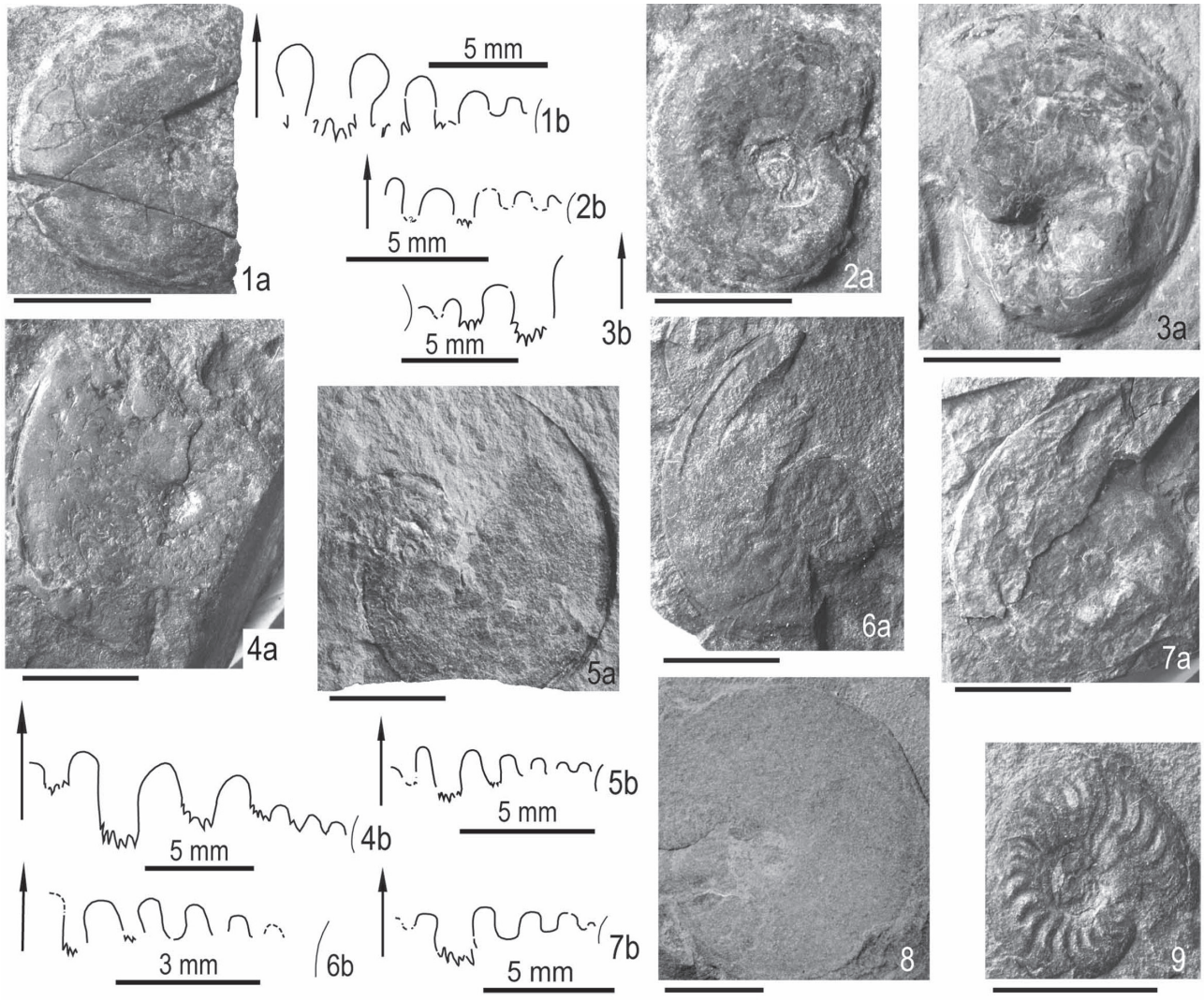

Figure 10. *Groenlandites*, *Lenotropites*, *Grambergia* and Longobarditidae? gen. and sp. indet. from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1, *Groenlandites* sp., IGPS coll. cat. no. 112613; 1a, lateral view; 1b, suture line; **2** and **3**, *Lenotropites* sp.; 2, IGPS coll. cat. no. 112614; 2a, lateral view; 2b, suture line; **3**, IGPS coll. cat. no. 112615; 3a, lateral view; 3b, suture line; **4**–**8**, *Grambergia* cf. *tetsaensis* McLearn; 4, IGPS coll. cat. no. 112616; 4a, lateral view; 4b, suture line; 5, IGPS coll. cat. no. 112617; 5a, lateral view; 5b, suture line; 6, IGPS coll. cat. no. 112618; 6a, lateral view; 6b, suture line; 7, IGPS coll. cat. no. 112619; 7a, lateral view; 7b, suture line; 8, IGPS coll. cat. no. 112620, lateral view; **9**, Longobarditidae? gen. and sp. indet., IGPS coll. cat. no. 112624. Scale bars are 1 cm unless otherwise stated.

surface ornamentation, the present species is well identified with *Procladiscites broncoi* Mojsisovics, 1882. They differ only in details of the median saddle of the ventral lobe: The sides of it is simple in the holotype, but serrated in the Fukkoshi specimen. Welter's (1915) specimen from Timor has similar serrated median saddles. ***P. towaensis*** (Bando and Ehiro) (originally described as *Eosturia towaensis* Bando and Ehiro, 1982) from the uppermostpart of the underlying Osawa Formation is somewhat similar to the present species in the general shape of the suture line, but clearly distingished by having lateral ribs along the ventral margin.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1a: nos. 112625, 112626; Fk-1b: no. 112627) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Procladiscites sp.
Figure 11.7

Material examined.—IGPS coll. cat. no. 112628.

Descriptive remarks.—Two fragments of lateral part and one fragment of ventral part, yield adjoining each other, are at hand. It is unclear whether they are parts of the same individual or not. The largest fragment consists of flat flank with the umbilical margin, which is slightly depressed gently. It attains more than 70 mm in height, and the umbilicus is rather small, probably less than 15 mm. Another small fragment of a part of a flank is also flat and more than 30 mm in height. The ventral fragment has broadly rounded venter and apparent shell width attains more than 27 mm. The shell surface of both the venter and flank are ornamented with numerous spiral striae. The suture is not preserved.

Although the specimens are fragmental, based on the estimated shell shape and surface ornamentation the present species is considered to belong to the genus *Procladiscites*. The specific identification, however, is difficult because of the poor state of preservation.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1b) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Order Phylloceratida Zittel, 1884
Superfamily Ussuritoidea Hyatt, 1900
Family Palaeophyllitidae Popov, in Luppov and Drushchits, 1958
Genus ***Leiophyllites*** Diener, 1915

Type species.—*Monophyllites suessi* Mojsisovics, 1882.

Leiophyllites cf. ***confucii*** (Diener)
Figure 12.1

cf. *Monophyllites Confucii* Diener, 1895b, p. 107, pl. 30, fig. 7, pl. 31, figs. 1, 2; Diener. 1907, p. 107, pl. 13, fig. 10; Arthaber, 1915, p. 151, pl. 13, fig. 6.
Monophyllites cf. *suessi* Toula, 1896, p. 171, pl. 20, fig. 7.
Monophyllites (*Leiophyllites*) *confucii* (Diener), Frech, 1903, p. 17, fig. 4; Diener, 1915, p. 205.
Monophyllites (*Monophyllites*) *confucii* Diener, Diener, 1907, p. 103, pl. 13, fig. 10.
Leiophyllites confucii (Diener), Wang et al., 1979, p. 53, pl. 14, figs, 9, 10, text-fig. 30a.
Leiophyllites visendus Shevyrev, 1968, p. 113, pl. 6, fig. 2, text-fig. 26.
Leiophyllites taramelti (Martelli), 1906, p. 135, pl. 6, figs. 3-4.

Material examined.—One specimen, IGPS coll. cat. no. 112529.

Descriptive remarks.—Small specimen is extremely discoidal and evolute to very evolute, with slowly increasing whorls. Specimen attains a diameter of ca. 17.0 mm, and its corresponding height and umbilical diameter are ca. 4.0 (*H*/*D* = 0.24) and 10.0-10.5 mm (*UD*/*D* = ca. 0.60), respectively. The sides are broadly convex and the maximum shell width is at the center of the flanks. The umbilical and ventral shoulders are rounded. The umbilicus is very shallow. The venter is not well preserved. Suture is not preserved.

Based on in its shell shape, especially having large umbilicus and slowly increasing height, the present species resemble to *Leiophyllites confucii* (Diener) described from Himalayas and eastern Europe. But, the precise identification at the specific level is difficult because it lacks suture line.

Occurrence.—Upper part (Fk-5) of the Fukkoshi Formation at the eastern coast of Terahama, Togura, Minamisanriku Towny, Miyagi Prefecture, Miyagi Prefecture.

Leiophyllites pitamaha (Diener)
Figures 11.2–11.7

Monophyllites pitamaha Diener, 1895b, p. 107, pl. 31, figs. 5, 7, 8.
Xenodiscus middlemissi Diener, 1895b, p. 110, pl. 30, fig. 6.
Monophyllites (*Leiophyllites*) *pitamaha* (Diener), Diener, 1915, p. 205; Kutassy, 1932, p. 595; Mitrova and Nestorovsky, 1960, p. 105, pl. 1, fig. 2.
Xenodiscus indo-australica Welter, 1915, p. 129, pl. 93, fig. 4.
Leiophyllites pitamaha (Diener), Spath, 1934, p. 297; Shevyrev, 1968, p. 112, pl. 6, fig. 3, text-fig. 25; Wang et al., 1979, p. 54, pl. 15, fig.4; Fantini Sestini, 1981, p. 57; He et al., 1986, p. 252, pl. 16, figs. 4–12, 16–22, text-fig. 29.
Leiophyllites? *middlemissi* (Diener). Spath, 1934, p. 308.
Xenaspis laevis Welter. Bender, 1970, p. 429, pl. 2, fig. 8.
Leiophyllites stoecklini Tozer, 1972, p. 37, pl. 5, fig. 5, text-fig. 2B.
Leiophyllites cf. *middlemissi* (Diener). Wang and He, 1976, p. 429, pl. 47, figs. 6–8, text-fig. 73c.
Leiophyllites cf. *pitamaha* (Diener). Wang and He, 1976, p. 430, pl. 47, figs. 14, 15, pl. 48, figs. 8, 9, text-fig. 73e.
Leiophyllites aff. *pitamaha* (Diener). Fantini Sestini, 1988, p. 69, pl.14, fig. 5.

Material examined.—Seven specimens, IGPS coll. cat. nos. 112630–112636.

Description.—The shell is discoidal and evolute. The

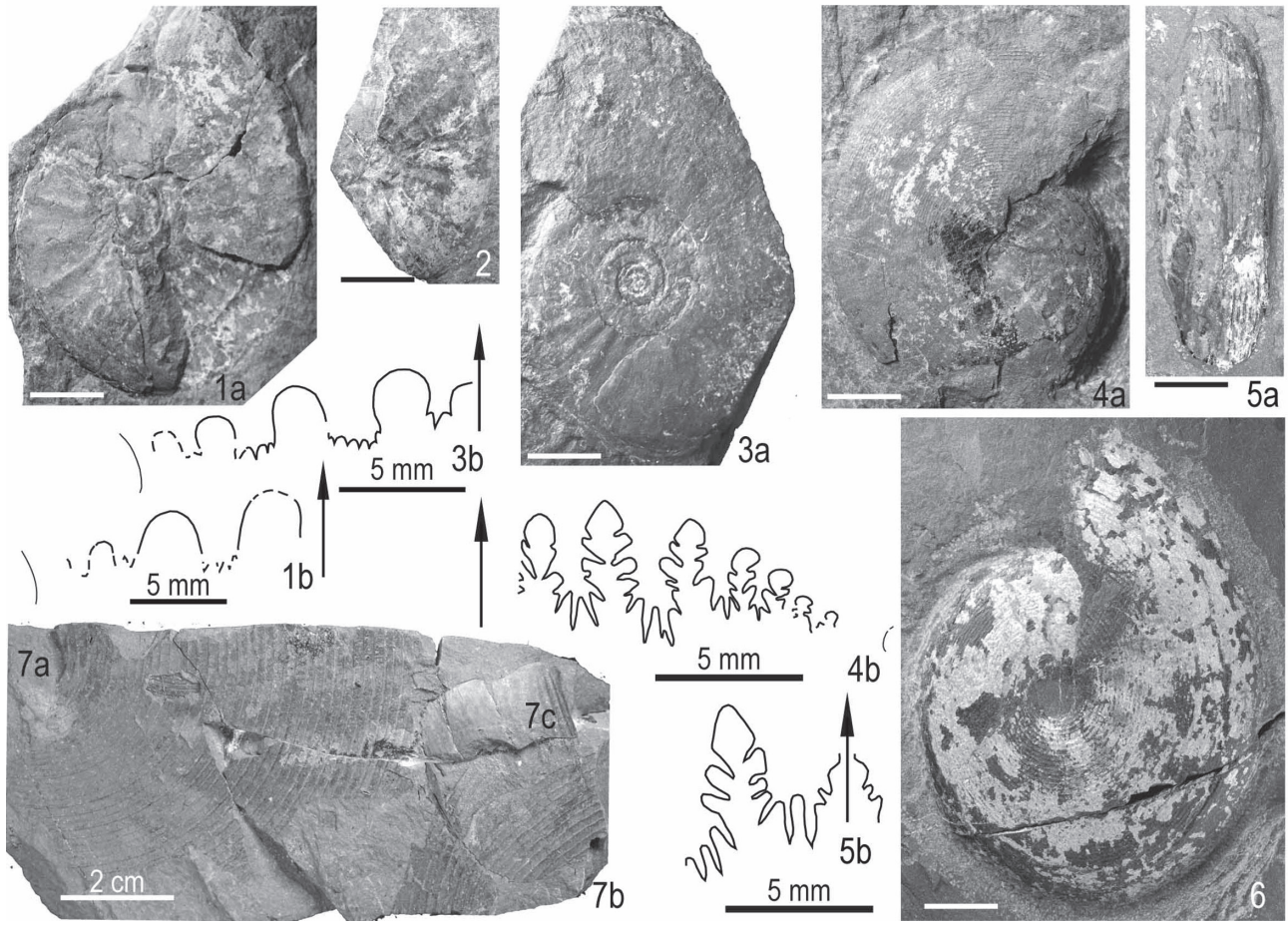

Figure 11. *Arctohungarites* and *Procladiscites* from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1–**3**, *Arctohungarites* sp.; 1, IGPS coll. cat. no. 112621; 1a, lateral view; 1b, suture line; 2, IGPS coll. cat. no. 112622, lateral view; 3, IGPS coll. cat. no. 112623; 3a, lateral view; 3b, suture line; **4**–**6,** *Procladiscites brancoi* Mojsisovics; 4, IGPS coll. cat. no. 112625; 4a, lateral view; 4b, suture line; 5, IGPS coll. cat. no. 112626; 5a, ventral view; 5b, suture line; 6, IGPS coll. cat. no. 112627, lateral view; **7**, *Procladiscites* sp., IGPS coll. cat. no. 112628, lateral (7a and 7b) and ventral (7c) views. Scale bars are 1 cm unless otherwise stated.

maximum diameter ranges from 28 mm to more than 75 mm. The larger specimens (D > 40 mm) are composed of phragmocone and body chamber, the latter occupies over a half volution. The ratio of *H*/*D* ranges from 0.26 to 0.39, but mostly about 0.30. The ratio of *UD*/*D* ranges from 0.44 to 0.53, but mostly 0.48 to 0.53 (Table 3). The sides are nearly flat to slightly convex. The umbilicus is shallow with moderately inclined wall and rounded umbilical shoulder. The venter is acutely rounded with broadly rounded umbilical shoulder which continued to the flanks without clear boundary. The cross section is compressed oval. Inner whorls are sometimes ornamented by faint and low, radial to concave ribs or fold. The surface of outer whorls is almost smooth, but often have faint sigmoidal ribs or growth lines. Constrictions parallel to the ribs or growth lines are rarely visible on the last whorl.

The ventral lobe is not well preserved, but shallow. The first lateral lobe is wide and its base has irregular, strong denticulations, seven to eight in number. The second lobe is small, but it also has four to five strong denticulations. Auxiliary lobe is simple and pointed. There are three saddles on the lateral side. The saddles are all rounded and narrowed toward the base. The second saddle is highest and the third is small.

Discussion.—The present specimens are very similar to *Leiophyllites pitamaha* Diener reported from the Anisian

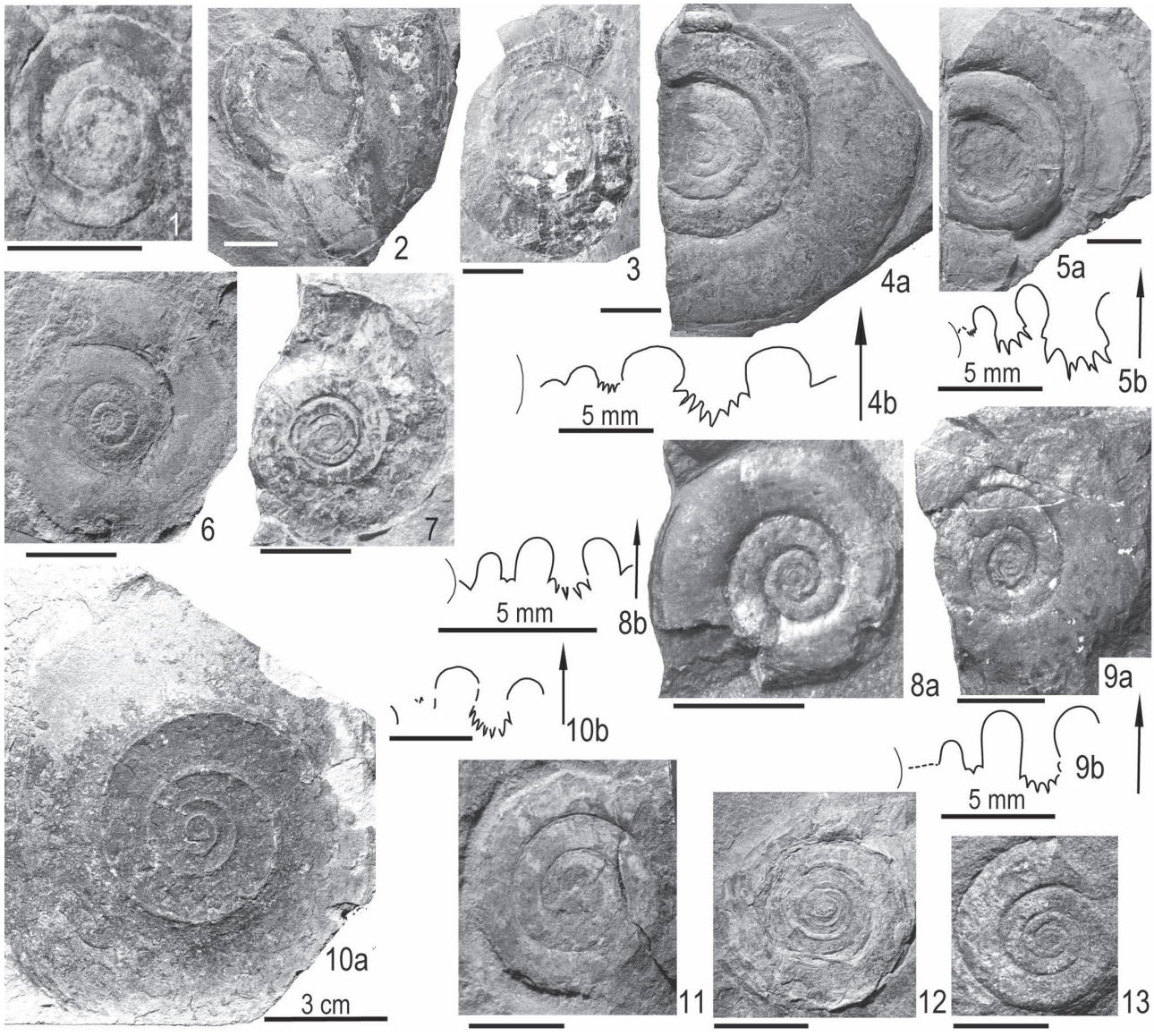

Figure 12. *Leiophyllites* from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan. **1**, *Leiophyllites* cf. *confucii* (Diener), IGPS coll. cat. no. 112629, lateral view; **2**–**7**, *Leiophyllites pitamaha* (Diener); 2, IGPS coll. cat. no. 112632, lateral view; 3, IGPS coll. cat. no. 112633, lateral view; 4, IGPS coll. cat. no. 112630; 4a, lateral view; 4b, suture line; 5, IGPS coll. cat. no. 112631; 5a, lateral view; 5b, suture line; 6, IGPS coll. cat. no. 112635, lateral view; 7, IGPS coll. cat. no. 112636, lateral view; **8** and **9**, *Leiophyllites* cf. *praematurus* Kiparisova; 8, IGPS coll. cat. no. 112637; 8a, lateral view; 8b, suture line; 9, IGPS coll. cat. no. 112638; 9a, lateral view; 9b, suture line; **10**, *Leiophyllites* sp. A; 10a, lateral view; 10b, suture line; **11**–**13**, *Leiophyllites* sp. B; 11, IGPS coll. cat. no. 112657, lateral view; 12, IGPS coll. cat. no. 112658, lateral view;13, IGPS coll. cat. no. 112661, lateral view. Scale bars are 1 cm unless otherwise stated.

strata of Himalayas, Qinghai and east Europe, in the general shell shape, surface ornamentation, although the umbilicus of the present specimens is slightly larger than that of the holotype (*UD*/*D* = 0.44).

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1c: no. 112635; Fk-1a: nos. 112630–112634) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, and upper part (Fk-6: no. 112636) at the eastern coast of Terahama, Togura, Minamisanriku Town, Miyagi Prefecture.

Table 3. Dimensions (in mm) and ratios of *Leiophyllites pitamaha* (Diener) from the Fukkoshi Formation. Abbreviations see Table 1.

IGPS no.	α	*D*	*H* (*H*/*D*)	*W*	*UD* (*UD*/*D*)
112630	-90°	ca.53.0	15.5 (0.29)	4-5	26.5 (0.50)
	-180°	ca.38.0	11.5 (0.30)		20.0 (0.53)
112631	0°	ca.55.0	14.5 (0.26)	?	28.5 (0.52)
	-90°	ca.40.5	12.0 (0.30)		20.0 (0.53)
112632	-90°	47.4	ca.18.5 (0.39)		20.8 (0.44)
112633	0°	ca.55.0	ca.15.0 (0.37)		27.5 (0.50)
112634	0°	56.4	16.4 (0.29)		27.5 (0.49)
112635	0°	ca.34.5	9.6 (0.28)		16.4 (0.48)
112636	0°	29.4	10.5 (0.33)		13.7 (0.46)

Leiophyllites cf. ***praematurus*** Kiparisova, 1958
Figures 11.8, 11.9

cf. *Leiophyllites praematurus* Kiparisova, in Kiparisova and Popov, 1958, p. 32, pl. 7, fig. 13, text-fig. 17б; Kiparisova, 1961, p. 134, pl. 28, figs. 5, 6, text-figs. 101, 102.

Leiophyllites pitamaha Diener. Kummel, 1969, p. 531, text-fig. 49B.

Material examined.—Two specimens, IGPS coll. cat. nos. 112637, 112638.

Descriptive remarks.—Two specimens are both phragmocone, and the shell is discoidal and sub-evolute to evolute. The maximum shell diameter of the small specimen (no. 112636) is 19.6 mm and the corresponding height and umbilical diameter are 5.6 (*H*/*D* = 0.29) and 9.0 mm (*UD*/*D* = 0.46), respectively. The larger specimen (no. 112637) attains a maximum diameter of ca. 25 mm and its corresponding height and umbilical diameter are ca. 9.5 (*H*/*D* = 0.38) and 10.2 mm (*UD*/*D* = 0.41), respectively. The sides are rounded in the smaller specimen and broadly convex in the larger one, with the maximum width near the center of the flank. The venter of the small specimen is rounded with a keel. That of the larger specimen is not well preserved. The umbilicus is shallow. Both the ventral and umbilical shoulder are indistinct and rounded to convex side continue to the venter and umbilical wall. The conch section is compressed oval, and that of the larger one is more compressed. There are short, low but wide ribs, slightly curved backward, on the inner side of the flanks of the smaller specimen. The shell surface of the larger specimen is nearly smooth, but similar short ribs are on the inner whorls.

The ventral lobe is not seen. The external lateral suture consists of three saddles, two lobes and auxiliary ones. All saddles have rounded crests and nearly parallel sides. The first and second saddles have nearly the same height, but the third is considerably small. The first lateral lobe is deep with subparallel sides. The base of it has six strong denticulations and the lower part of the sides are also denticulate, though very weak. The second lobe is shallow and its base has three short or indistinct denticules. The auxiliary lobe is simple and pointed.

Although there are some differences in the ratio of *H*/D and *UD*/*D* and surface ornamentation between the two materials described, their general shell form and sutural shape resemble those of *Leiophyllites praematurus* Kiparisova (1958, 1968). But the present species differs from the latter in having a ventral keel. The present species also somewhat resembles *L. laevis* (Welter) form 1 (originally as *Xenaspis laevis*) from the Anisian of Timor (Welter, 1915, p. 130, pl. 10, figs. 7a–7b). The Timor specimen differs from *L. praematurus* in having larger umbilicus and in having downwardly narrowed saddles.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1a: no. 112637; Fk-1b: 112638) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Leiophyllites suessi (Mojsisovics)
Figures 13.1–13.7

Monophyllites Suessi Mojsisovics, 1882, p. 205, pl. 79, fig.4; Hauer, 1887, p. 33; Patte, 1926, p. 185, pl. 12, figs. 6, 7.

Monophyllites (*Mojsvarites*) *Suessi* Mojsisovics, Kraus, 1916, p. 289.

Monophyllites (*Leiophyllites*) *Suessi* (Mojsisovics), Renz, 1931, p. 57; Kutassy, 1932, p. 595.

Leiophyllites suessi (Mojsisovics), Spath, 1934, p. 303, text-fig. 104b; Wiedmann, 1970, p. 969, pl. 1, figs. 1, 2, text-fig. 3.

Leiophyllites pradyumna (Diener), Zakharov, 1968, p. 124, pl. 23, figs. 2, 3, text-fig. 29h.

Leiophyllites suessi (Mojsisovics), Krystyn and Tatzreiter, 1991, p. 142, pl. 2, fig. 7.

Material examined.—Ten specimens, IGPS coll. cat. nos. 112639–112648.

Description.—The shell is discoidal and sub-evolute to evolute. The maximum diameter ranges from 24 mm to more than 70 mm. They are composed of phragmocone and body chamber, the latter occupies over three-fourth of the last whorl. The ratio of *H*/*D* ranges from 0.29 to 0.35 (mostly 0.31-0.35) and that of *UD*/*D* ranges from 0.41 to 0.53 (mostly 0.45-0.48) (Table 4). The sides are broadly convex to rounded with maximum width near the umbilical shoulder to the center of the flank. The venter is acutely rounded with rounded ventral shoulder. The umbilicus is shallow. There

Table 4. Dimensions (in mm) and ratios of *Leiophyllites suessi* (Mojsisovics) from the Fukkoshi Formation. Abbreviations see Table 1.

IGPS no.	α	*D*	*H* (*H*/*D*)	*W*	*UD* (*UD*/*D*)
112639	-90°	47.1	15.8 (0.34)		21.6 (0.46)
112640	-30°	49.8	14.2 (0.29)		22.6 (0.45)
112641	0°	45.4	14.2 (0.31)		21.3 (0.47)
112642	-30°	ca.70.0	23.8 (0.34)		31.5 (0.45)
112643	-90°	ca.61.0	19.0 (0.31)		29.0 (0.48)
112644	0°	ca.24.0	ca.7.0 (0.29)		11.5 (0.48)
112645	0°	ca.58.0	ca.18.0 (0.31)		27.0 (0.47)
112646	0°	ca.55.0	19.2 (0.35)		23.6 (0.43)
112647	-30°	ca.35.0	11.8 (0.34)		14.5 (0.41)
112648	0°	ca.28.0	9.8 (0.35)		14.7 (0.53)

is no remarkable umbilical shoulder and the sides gradually down into the umbilical seam. The cross section of the conch is elongated oval. The shell surface is almost smooth, but on the last whorl there are faint, slightly convex to falcoid ribs or growth lines. Many strong and wide constrictions, which are also convex to falcoid, are also visible on the outer whorl. They number four to eight, mostly six to seven per volution.

The external suture consists of three saddles, two lobes and auxiliary ones. The ventral lobe is not well preserved and only a part of the prong, having at least three denticulations at the base, is visible. The crests of saddles are all rounded. The saddles are vertically elongated and become narrower downward. The second one is the highest. The first lateral lobe is deep and wide, and expanded base has five to seven (mostly five) strong denticulations. The second lobe has a similar shape to the first, including the denticulation, but smaller in size, The auxiliary one is composed of a small, pointed lobe, and low and wide saddle on the umbilical shoulder.

Discussion.—The present specimens from the Fukkoshi Formation are very similar to *Leiophyllites suessi* (Mojsisovics) reported from the Anisian strata of east Europe in the general shell shape, surface ornamentation and the outline of the suture line. A slight deference between them is a number of constrictions. The Fukkoshi specimens have more constrictions than the European specimens. *Leiophyllites pradyumna* (Diener) resembles to *Leiophyllites suessi* (Mojsisovics) in the general shell shape and shape of the suture. But it differs from the latter in having bulges (ribs) instead of constrictions on the shell surface. *L. pseudopradyumna* Welter, 1915 is also distinguished from the present species in having bulges.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1c: nos. 112645–112648; Fk-1a: nos. 112639–112644) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Leiophyllites wakoi Ehiro, Sasaki and Kano
Figures 14.1–14.6

Leiophyllites wakoi Ehiro, Sasaki and Kano, 2016, p. 99, figs. 4.4a–d.

Material examined.—Seven specimens, IGPS coll. cat. nos. 112649–112655.

Descriptive remarks.—Small- to medium-sized shells are discoidal and evolute. They consist of phragmocone and a part of the body chamber. The shell diameter ranges from ca. 25 to 58 mm. The ratio of *H*/*D* ranges from 0.27 to 0.31 and that of *UD*/*D* varies from 0.47 to 0.53 (mostly around 0.50) (Table 5). The sides are broadly convex to flat at maturity, with broadly rounded umbilical and ventral shoulders. The maximum conch width is near the center of the flank. The cross section is flattened oval. The shell surface of the inner whorls seems to be smooth, whereas fine but distinct, biconcave ribs are on the outer whorl. Some shallow constrictions parallel to the ribs are also present.

The ventral lobe is not well preserved and only a part of its prong is visible, which has denticulate base. The first lateral lobe is large and its rounded base has five to seven, slightly irregular denticulations. The second lobe is about half depth of the first and asymmetrical. It has four to six denticulations. Main deep denticulations are at the base. Small, one or two denticulations are up to the lower part of the ventral side, whereas the umbilical side is smooth. The auxiliary lobe is simple and pointed. There are three rounded saddles on the lateral side. The second is largest and highest, and the third is small.

The general shell shape and especially the biconcave ribs on the last volution of the present specimens are closely similar to those of *Leiophyllites wakoi* described by Ehiro

Table 5. Dimensions (in mm) and ratios of *Leiophyllites wakoi* Ehiro, Sasaki and Kano from the Fukkoshi Formation. Abbreviations see Table 1.

IGPS no.	α	*D*	*H* (*H*/*D*)	*W*	*UD* (*UD*/*D*)
112649	0°	ca.39.5	ca.11.0 (0.28)		20.4 (0.52)
	-180°	28.4	ca.8.0 (0.28)		15.1 (0.53)
112650	-70°	ca.34.0	10.2 (0.30)		17.1 (0.50)
112651	0°	ca.30.5	ca.8.8 (0.29)		15.6 (0.51)
112652	0°	ca.33.0	ca.10.0 (0.30)		16.4 (0.50)
112653	-60°	ca.25.4	ca.8.0 (0.31)		12.4 (0.49)
112654	-90°	ca.58.0	15.7 (0.27)	4-	29.0 (0.50)
112655	0°	ca.31.5	ca.9.5 (0.30)		14.8 (0.47)

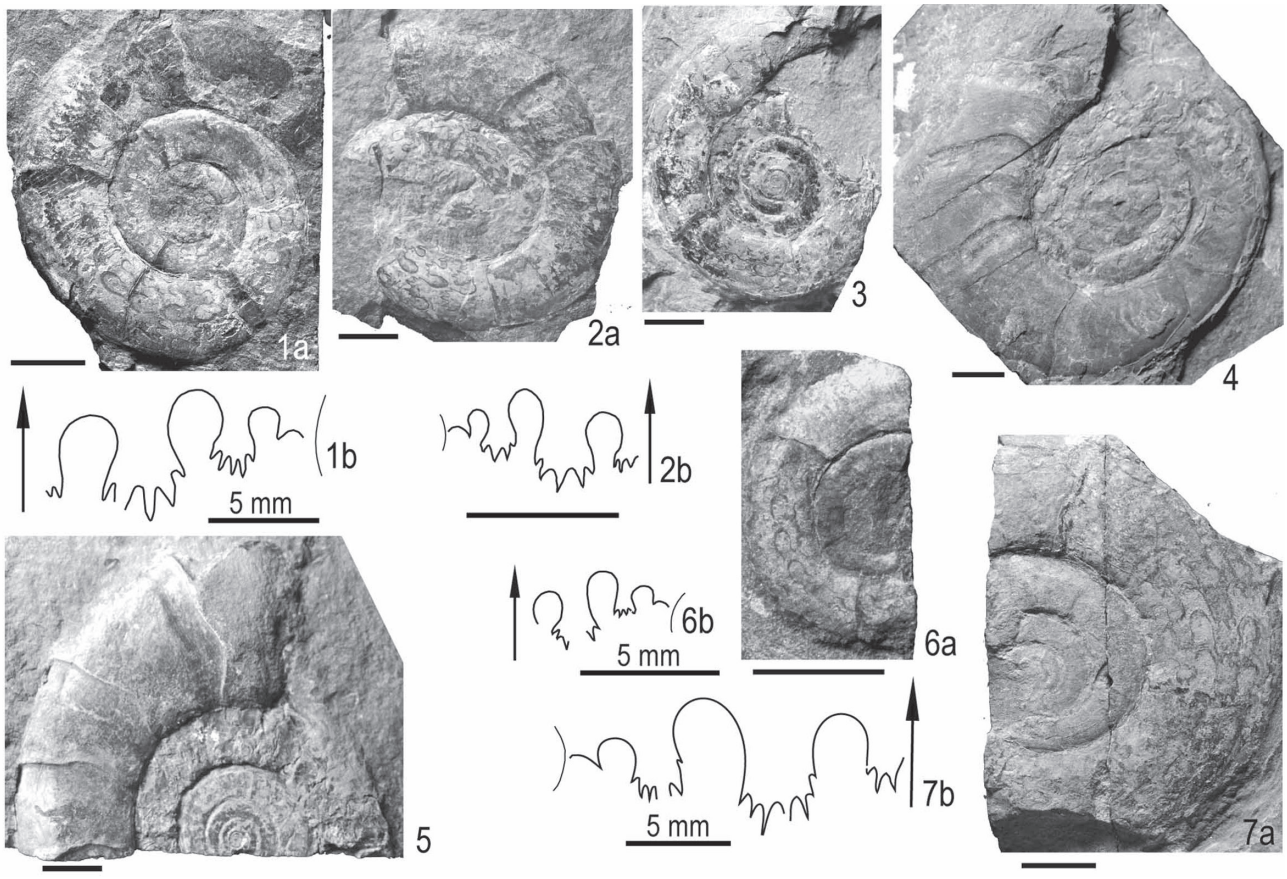

Figure 13. *Leiophyllites suessi* (Mojsisovics) from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1, IGPS coll. cat. no. 112639; 1a, lateral view; 1b, suture line; 2, IGPS coll. cat. no. 112640; 2a, lateral view; 2b, suture line; 3, IGPS coll. cat. no. 112641, lateral view; 4, IGPS coll. cat. no. 112642, lateral view; 5, IGPS coll. cat. no. 112643, lateral view; 6, IGPS coll. cat. no. 112644; 6a, lateral view; 6b, suture line; 7, IGPS coll. cat. no. 112645; 7a, lateral view; 7b, suture line. Scale bars are 1 cm unless otherwise stated.

et al. (2016) from the underlying late Olenekian Osawa Formation. The ratio of *UD*/*D* of the latter is rather small (0.40 at *D* = 65-90 mm), but it is 0.45–0.46 at *D* = 43 mm, and almost the same as the present specimens.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1a: nos. 112649, 112651–112654; Fk-1b: nos. 112650, 112655) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Leiophyllites sp. A
Figure 12.10a, b

Material examined.—One specimen, IGPS coll. cat. no. 112656.

Descriptive remarks.—An outer mold of moderately large specimen with impressions of suture lines are at hand. It consists of phragmocone and body chamber, the latter occupies about a half part of the last volution. The shell is probably extremely discoidal and sub-evolute. The maximum shell dimeter attains more than 97 mm, and at *D* = ca. 81 mm, corresponding height and umbilical diameter are ca. 25.0 and 35. 5 mm (*UD*/*D* = 0.44), respectively. The side is broadly convex with broadly rounded umbilical and ventral shoulders. The maximum shell width is near the umbilical shoulder and the sides slightly converge to the venter. The venter is not well preserved. The shell surface is almost smooth. The external lateral suture, preserved as impressions on the outer mold, consists of the first and second lateral saddles and first and second lateral lobes. The crests of saddles are both rounded and the second lateral saddle is higher than the first. The first lateral lobe is deep and wide, and its base has many denticulations. The

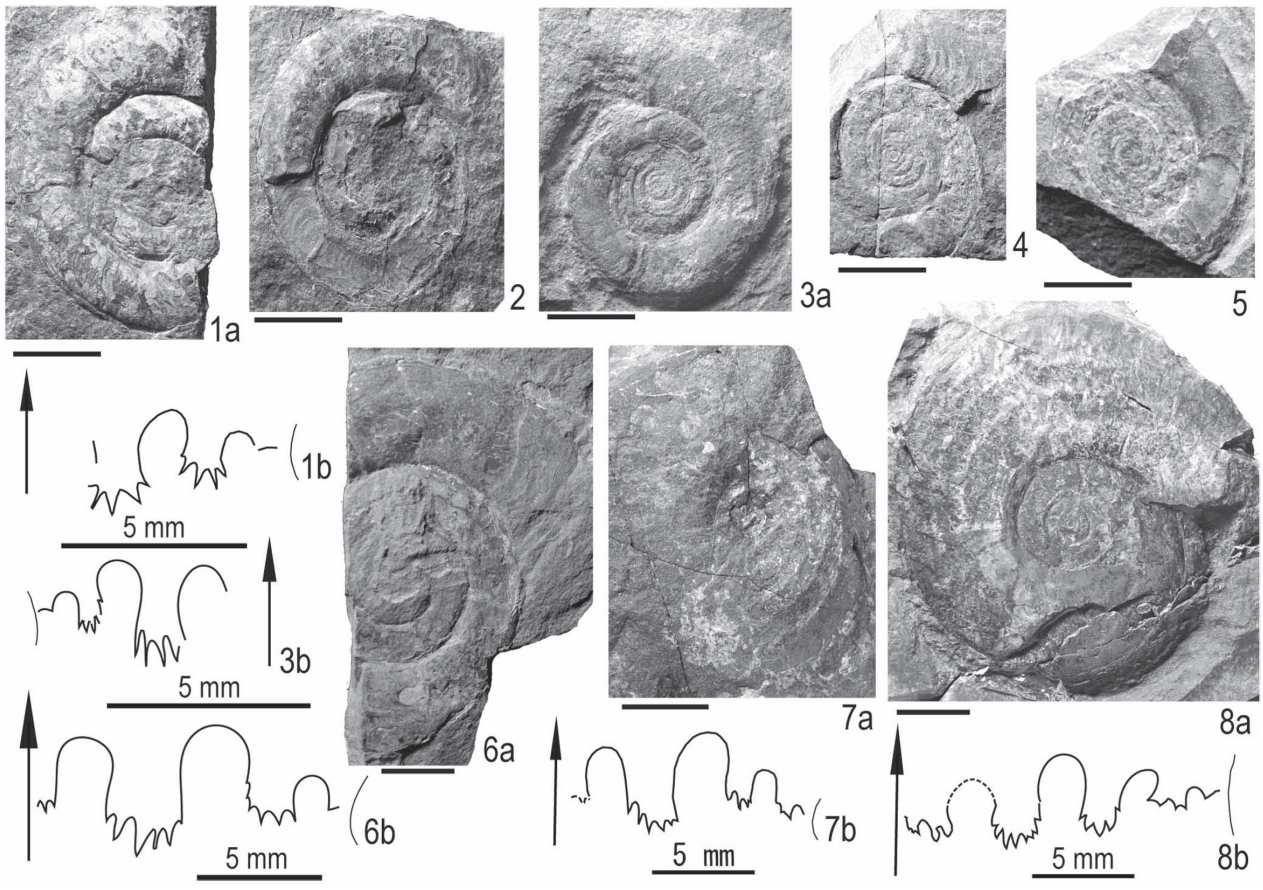

Figure 14. *Leiophyllites wakoi* and *Ussuriphyllites amurensis* from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan.
1–**6**, *Leiophyllites wakoi* Ehiro, Sasaki and Kano; 1, IGPS coll. cat. no. 112649; 1a, lateral view; 1b, suture line; 2, IGPS coll. cat. no. 112650, lateral view; 3, IGPS coll. cat. no. 112651; 3a, lateral view; 3b, suture line; 4, IGPS coll. cat. no. 112652, lateral view; 5, IGPS coll. cat. no. 112653, lateral view; 6, IGPS coll. cat. no. 112654; 6a, lateral view; 6b, suture line; **7** and **8**; *Ussuriphyllites amurensis* (Kiparisova); 7, IGPS coll. cat. no. 112663; 7a, lateral view; 7b, suture line; 8, IGPS coll. cat. no. 112662; 8a, lateral view; 8b, suture line. Scale bars are 1 cm unless otherwise stated.

second lobe is shallow and small, and its base is probably tri-denticulate. The ventral lobe is not preserved and there is some space between the third saddle and the umbilical edge.

Based on the general shell form and suture line, the present specimen is considered to belong certainly the genus *Leiophyllites* Diener, 1915, but the specific identification is difficult because of its poor state of preservation. This specimen is clearly larger than the other *Leiophyllites* species collected from nearly the same horizon at the south of Ozashi (Fk-1a–1c).

Occurrence.—Middle part of the Fukkoshi Formation (Fk-3a) at the west of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Leiophyllites sp. B
Figures 12.11–12.13

Material examined.—Five specimens, IGPS coll. cat. nos. 112657–112661.

Descriptive remarks.—Small shells are discoidal and evolute. The maximum shell diameter ranges from ca. 20 to 40 mm. The ratio of *H*/*D* ranges from 0.20 to 0.32, but mostly around 0.30. The ratio of *UD*/*D* varies from 0.47 to 0.60. They have five to six volutions at *D* = 20 mm. The sides are broadly convex to flat, with broadly rounded umbilical and ventral shoulders. The maximum conch width is near the center of the flank. The umbilicus is very shallow. The cross section is flattened oval. The shell surface is almost smooth.

The suture is not preserved.

Based on the general shell form, the present specimen is considered to belong certainly the genus *Leiophyllites* Diener, 1915 and somewhat similar to the juvenile shell of *L. pitamaha*, but the specific identification is difficult because they lack of suture line and are poor state of preservation.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1c: nos. 112657–112660; Fk-1a: no. 112661) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Genus ***Ussuriphyllites*** Zakharov, 1967

Type species.—*Eophyllites amurensis* Kiparisova, 1961.

Ussuriphyllites amurensis (Kiparisova)
Figures 14.7, 14.8

Eophyllites amurensis Kiparisova, 1961, p. 137, pl. 28, figs. 7, 8, text-fig. 104.

Ussuriphyllites amurensis (Kiparisova), Zakharov, 1967, p. 50, pl. 4, figs. 8–10, text-figs. 1g, 1h, 2; Zakharov, 1968, p. 123, pl. 22, figs. 12, 13, pl. 23, fig. 1; Zakharov et al., 2005a, fig. 3; Zakharov et al., 2005b, fig. 8; Shigeta and Kumagae, 2016, p. 54, figs. 6A, 6B.

Material examined.—Two specimens, IGPS coll. cat. nos. 112662, 112663.

Description.—Two specimens are discoidal and sub-involute, and consists of phragmocone and body chamber, the latter of which occupies about three-fourth of the last whorl. The sides are broadly convex. The maximum width is at about the center of the flank, from where the flank converges to both the venter and umbilicus. The umbilicus is very shallow without distinct umbilical wall. The venter is not well preserved, but seems to be acute or carinated. The shell cross section is lenticular. The maximum shell dimeter of specimen no. 112662 attains more than 60 mm, and at *D* = ca. 58 mm, corresponding height and umbilical diameter are 23.8 and 15.5 mm (*UD*/*D* = 0.28), respectively. Another smaller specimen (no. 112663: max. D > 45 mm) has rather small umbilicus (*UD*/*D* < 0.08). The shell surface is ornamented with faint, slightly sigmoidal, fine radial ribs and fine, sparse, concentric ribs. There are four to five concentric ribs between the umbilical shoulder to the ventral shoulder.

The ventral lobe is partly preserved and its base is serrated. Three lateral saddles have rounded crest. The second is largest and the third is small. The first and second lateral lobes are denticulate at the base and the denticulations are up to the one-third of the sides in the specimen no. 112662. The auxiliary loves are irregular in shape and size.

Discussion.—The shell shape, surface ornamentation and outline of the suture line of the present specimens from the Fukkoshi Formation are identical with those of *Ussuriphyllites amurensis* (Kiparisova) reported from the Triassic strata of South Primorye, Far East Russia, although the umbilicus is rather small in the small specimen.

Occurrence.—Middle part of the Fukkoshi Formation (Fk-1a: no. 112662; Fk-1b: no. 112663) at the south of Ozashi, Jusanhama, Kitakami-cho, Ishinomaki City, Miyagi Prefecture.

Discussion

Ammonoid fauna of the Fukkoshi Formation and its geologic age

Fukkoshi ammonoid fauna comprises 13 families, 21 genera and about 40 species listed below:

Family Hemilecanitidae
- *Hemilecanites discus* (Arthaber)

Family Sageceratidae
- *Parasageceras* aff. *discoidale* Welter

Family Hedenstroemiidae
- *Pseudosageceras multilobatum* Noetling

Family Parapopanoceratidae
- *Parapopanoceras involutum* sp. nov.

Family Megaphyllitidae
- *Megaphyllites* sp.

Family Khvalynitidae
- *Metadagnoceras* spp.
- *Psilokhvalynites takaizumii* gen. and sp. nov.

Family Acrochordiceratidae
- *Paracrochordiceras* cf. *denseplicatum* Fantini Sestini
- *Paracrochordiceras watanabei* sp. nov.
- *Paracrochordiceras* spp.

Family Japonitidae
- *Aegeiceras*? sp.
- *Eogymnites* sp.
- *Japonites* cf. *meridianus* Welter
- *Japonites raphaelizoyae* (Tommasi)
- *Japonites* spp.

Family Gymnitidae
- *Buddhaites*? sp.

Family Danubitidae
- *Danubites* cf. *ambika* Diener
- *Danubites floriani* (Mojsisovics)
- *Danubites* cf. *tozeri* Korchinskaya
- *Paradanubites kansa* (Diener)
- *Paradanubites* cf. *kansa* (Diener)
- *Paradanubites ozashiense* sp. nov.
- *Paradanubites phyllus* He
- *Paradanubites* sp.

Family Longobarditidae

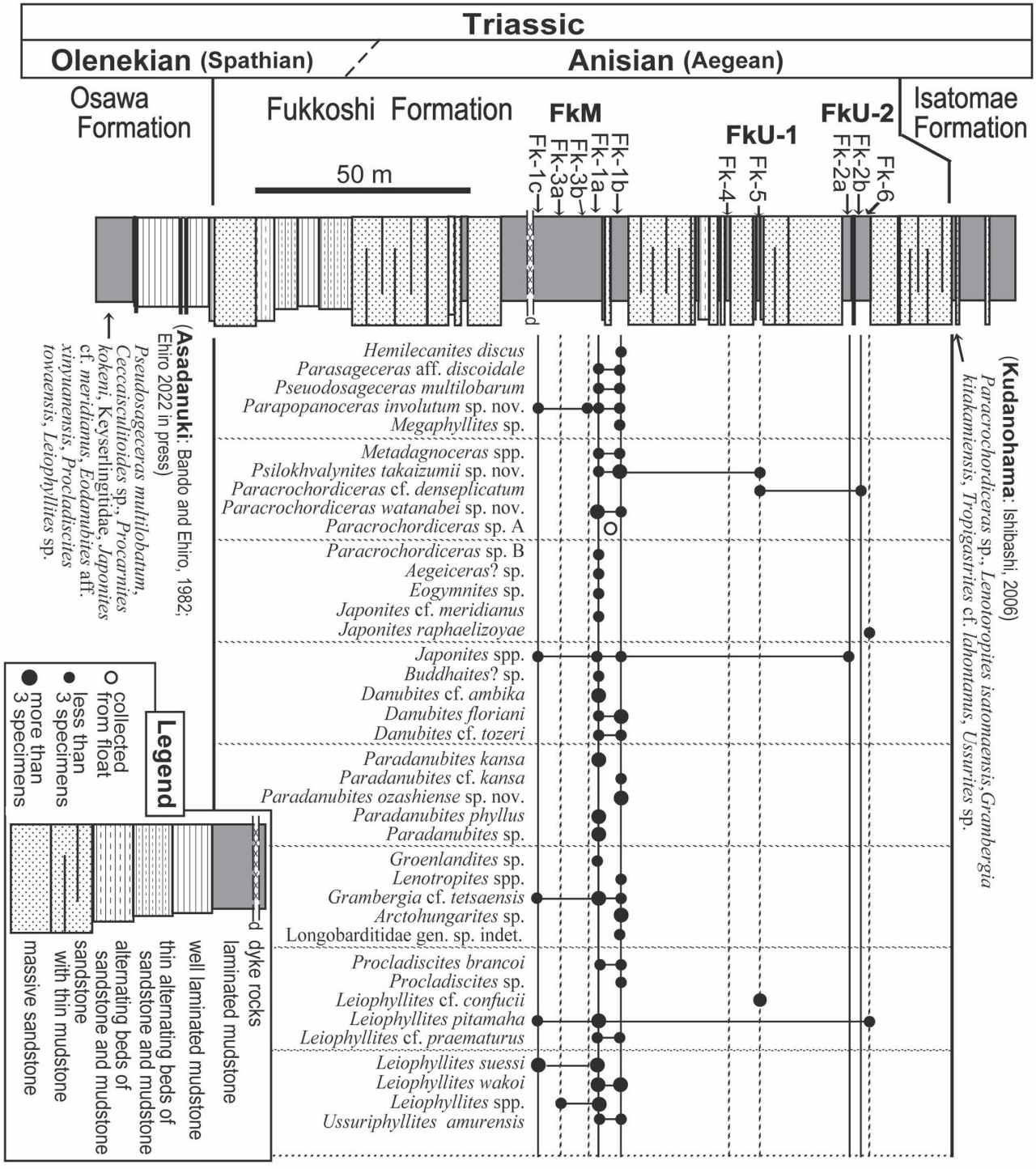

Figure 15. Stratigraphic distribution of ammonoid species from the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan. Ammonoids from the uppermost part of the Osawa Formation at the south of Asadanuki and from the lowermost part of the Isatomae Formation at Kudanohama are also shown.

Groenlandites sp.
Lenotropites spp.
Grambergia cf. *tetsaensis* McLearn
Arctohungarites sp.
Longobarditidae? gen. and sp. indet.
Family Cladiscitidae
Procladiscites brancoi Mojsisovics
Procladiscites sp.
Family Palaeophyllitidae
Leiophyllites cf. *confucii* (Diener)
Leiophyllites pitamaha (Diener)
Leiophyllites cf. *praematurus* Kiparisova
Leiophyllites suessi (Mojsisovics)
Leiophyllites wakoi Ehiro, Sasaki and Kano
Leiophyllites spp.
Ussuriphyllites amurensis (Kiparisova)

These ammonoids were collected from the nine localities (horizons) belonging to the middle to upper part of the Fukkoshi Formation (Figure 15), but these are largely classified into three horizons: the mudstone dominated middle part (FkM: including the horizons Fk-1c, Fk-3a, Fk-3b, Fk-1a and Fk-1b: about 30 m total stratigraphic interval), mudstone beds of the lower part of the upper part (FkU-1: horizon Fk-5) and upper mudstone dominated beds in the upper part (FkU-2: including the horizons Fk-2a, Fk2b and Fk-6: less than 10 m interval). FkM has rather wide stratigraphic range of ca. 30 m, but there is no remarkable difference between the generic compositions of Fk-1a and Fk-1b, and genera from the Fk-1c, Fk-3a and Fk-3b are also yield from Fk-1a and Fk-1b. The ammonoid specimens are few in number in both FkU-1 and FkU-2 and it makes precise comparison with FkM difficult, but their faunas are poor in number of specimens belong to the family Palaeophyllitidae and Danubitidae, which are predominated in the FkM.

Among the fauna of FkM, specimens belong to the genera *Leiophyllites* are most dominated and hold more than half of the collection, including those ill preserved and undescribed ones. Those belong to the genera *Paradanubites* is the next, and those of *Parapopanoceras*, *Psilokhvalynites*, *Paracrochordiceras* and *Danubites* are also common.

More than half of the genera (13 genera) among the fauna (20 genera: excluding the new genus *Psilokhvalynites*), are known from the Anisian strata (rarely from also Ladinian or late Triassic strata), and mostly restricted in the lower Anisian (Aegean): *Parasageceras*, *Parapopanoceras*, *Megaphyllites*, *Paracrochordiceras*, *Aegeiceras*, *Buddhaites*, *Danubites*, *Paradanubites*, *Groenlandites*, *Lenotropites*, *Grambergia*, *Arctohungarites* and *Ussuriphyllites*. The last genus has been only known from the lower Anisian *Ussuriphyllites amurensis* Zone of South Primorye (Zakharov, 1967, 1968; Zakharov et al., 2005a, 2005b). Shigeta and Kumagae (2016) stressed that the genus *Ussuriphyllites* is late Olenekian (late Spathian) in age, because it is associated with *Keyserlingites* sp. However, *U. amurensis* is accompanied with typical Anisian genera, such as *Parasageceras*, *Megaphyllites*, *Paracrochordiceras*, *Prohungarites*, *Arctohungarites*, *Tropigastrites* and *Ussurites* in the *U. amurensis* Zone of the Atlasov Cape section, South Primorye (Zakharov et al., 2005a, 2005b). Moreover, genus *Keyserlingites* is not restricted in the Olenekian. Many species of *Keyserlingites* (= *Durgaites*) have been reported from the lower Anisian strata in the Tethys region, such as Qinghai (e.g. Wang, 1985; He et al., 1986) and Spiti (Krystin et al., 2004). Therefore, the genus *Ussuriphyllites* is early Anisian in age.

Two genera, *Japonites* and *Procladiscites*, are also typical for the Anisian of Tethys province, although they already appeared in the latest Olenekian as reported from the uppermost part of the underlying Osawa Formation (Ehiro, 2022 in press). The genus *Leiophyllites* ranges from Olenekian to Anisian.

Few exceptions are the genera *Hemilecanites*, *Pseudosageceras*, *Metadagnoceras* and *Eogymnites*. They are typical Olenekian or Induan to Olenekian genera. However, the first three have been also described from the lower Anisian strata, although very few in number. Bucher (1989) described *Hemilecanites* cf. *paradiscus* Kummel, *Metadagnoceras youngi* Bucher and *Metadagnoceras* sp. from the Lower Anisian of Nevada. *Pseudosageceras*? sp. described from the Anisian strata of Primorye, Far East Russia (Kiparisova, 1961) is ill preserved, but it has involute conch with multi-lobed suture line and its generic assignment is highly probable. The present discovery of these three genera from the Fukkoshi Formation in association with many Anisian genera clarified that they range up to the lower Anisian, although these genera are generally thought to be restricted in pre-Anisian strata. The species of the genus *Eogymnites* have been reported from the upper Olenekian, but *Eogymnites* is closely related with *Japonites* and some authors consider that it is synonymous with the genus *Japonites*.

Among the Fukkoshi ammonoid fauna from FkM, two genera, *Parapopanoceras* and *Buddhaites*, are generally considered to be middle Anisian (to late Anisian) genera, but the majority of the genera of the fauna are stratigraphically restricted to or range down into the lower Anisian. Therefore, the ammonoid fauna from FkM is definitely early Anisian (Aegean) in age.

Fauna from FkU-1 and FkU-2 are not diverse, and comprise only *Psilokhvalynites* (gen. nov.), *Paracrochordiceras*, *Japonites* and *Leiophyllites*. They are also considered to be early Anisian in age, because of the occurrence of *Paracrochordiceras*. The early Anisian genera, such as *Grambergia*, *Lenotropites*, *Tropigastrites*

and *Ussurites*, are also known from the lowermost part of the overlying Isatomae Formation (Ishibashi, 2006).

Olenekian/Anisian boundary in the South Kitakami Belt, Northeast Japan

Although some candidate sections have been proposed as the global boundary stratotype section and point (GSSP) for the base of the Anisian, it is yet to be ratified. There are two dominant biostratigraphic markers for the base of the Anisian: ammonoid and conodont. When Grădinaru et al. (2007) proposed the base of ammonoid *Paracrochordiceras–Japonites* Beds in the Deşli Caira Hill, Dobrogea, Romania as the GSSP, this level was considered to coincide also with the FAD of conodont *Chiosella timorensis* (Orchard et al., 2007). Goudemand et al. (2012), however, clarified that this conodont FAD datum is actually in the underlying *Deslicairites* Beds, which characterized by Olenekian ammonoids.

Gaetani et al. (1992) had proposed that the base of the *Aegeiceras–Japonites* beds, that is correlated with the *Paracrochordiceras–Japonites* Beds of Dobrogea, at the Marathovouno section in Chios Island, Greece as the base of the Anisian. It coincides with the base of the Aegean Substage proposed by Assereto (1974). Also in Chios, the FAD of *C. timorensis* is slightly below the base of the *Aegeiceras–Japonites* beds and located in the late Spathian bed with *Procarnites* and *Hellenites* (Assereto et al., 1980; Gaetani et al., 1992). The same stratigraphic relationship between the ammonoids and conodonts are also known from Nevada, North America. The occurrence of *C. timorensis* from the upper part of the Olenekian *Neopopanoceras haugi* Zone was reported by Goudemand et al. (2012).

Based mainly on the FAD of *C. timorensis*, some OAB boundary sections in the Nanpanjiang Basin, Guangxi, South China have been introduced for the candidate GSSP for the base of the Anisian (e.g. Ovtcharova et al., 2006; Galfetti et al., 2007, 2008; Chen et al*.,* 2020). In these sections, unfortunately, the ammonoid fossils are very poor.

Recently, Golding (2021) proposed a new criterion of conodont-based definition for the base of the Anisian. He suggests that *Neogondolella curva* and associated species is suitable for the index of the base of the Anisian. The FADs of these species are slightly above that of *C. timorensis* and nearly the same as those of Anisian ammonoids, that characterize the *Paracrochordiceras–Japonites* Beds or its correlatives. Grădinaru (2022) investigated the biostratigraphy of some OAB boundary sections and the stratigraphic position of FAD of *C. timorensis* with problems on its taxonomy and definition, and stressed that *C. timorensis* is ineligible for the stratigraphic index for the OAB and the OAB boundary should be defined basically on ammonoids.

By adopting the ammonoid-based (traditional) criteria or Golding's (2021) proposal, the base of the Anisian in the South Kitakami Belt is considered to be located below the middle part of the Fukkoshi Formation, because it yields rich early Anisian (Aegean) ammonoids, which correlate with *Paracrochordiceras–Japonites* Beds and its correlatives. Since the uppermost part of the underlying Osawa Formation is characterized by the Olenekian ammonoids (Ehiro, 2022 in press), the Olenekian/Anisian boundary is considered to locate somewhere in the lower part of the Fukkoshi Formation.

Comparison with the early Anisian ammonoid faunas in the Tethys and Panthalassa regions

The ammonoid fauna of the Fukkoshi Formation is very diverse (consisting of 21 genera and 38 species) among the early Anisian (Aegean) ammonoid fauna, being equal to those of Qinghai, China (He et al., 1986) and Nevada, North America (Bucher, 1989). It is most dominated in the genera of the Family Palaeophyllitidae, mostly of *Leiophyllites*, and characterized common occurrences of the families Danubitidae (*Danubites* and *Paradanubites*), Acrochordiceratidae (*Paracrochordiceras*) and Longobarditidae (*Groenlandites*, *Lenotropites*, *Grambergia* and *Arctohungarites*). The fauna also includes quite a few specimens belong to the families Parapopanoceratidae (*Parapopanoceras*) and Khvalynitidae (*Metadagnoceras*, *Psilokhvalynites*). The Fukkoshi ammonoid fauna has some resemblance in the generic and species compositions to those known from southern Tethys (Himalayas: Diener, 1895b; Timor: Welter, 1915), western and central Tethys (Chios: Fantini Sestini, 1981 and Gaetani et al., 1992; Caucasus: Shevyrev, 1968, 1995; Qinghai, western China: He et al., 1986), western Panthalassa (South Primorye: Zakharov et al., 2005a, 2005b) and eastern Panthalassa provinces (Nevada: Bucher, 1989).

Qinghai, west China: The ammonoid fauna reported from Qinghai, west China (He et al., 1986) is one of the most diverse Aegean faunas, which comprises 47 species belonging to 18 genera of ammonoids. According to He et al. (1986), the majority of this fauna are specimens belonging to the genera *Groenlandites*, *Pearylandites*, *Lenotropites*, *Grambergia* and *Arctohungarites* (family Longobarditidae) and those of the genera *Keyserlingites*, *Japonites*, *Procladiscites*, *Leiophyllites*, *Ussurites*, *Paradanubites* and *Megaphyllites* are also common. Among the genera known from Qinghai, ten genera are also known in the Fukkoshi fauna, and dominant and common genera in the Qinghai fauna are also included in the Fukkoshi fauna, except for the genus *Ussurites*. The main difference between these two faunas is the absence of the genera of family Acrochordiceratidae in the Qinghai fauna.

Nevada, USA: Lower Anisian beds in the northern Humboldt Range, Nevada, USA are classified into the *Japonites welteri* beds, *Pseudokeyserlingites guexi* beds, *Mulleri* Zone and *Caurus* Zone, in ascending order (Bucher, 1989). The lower Anisian ammonoid fauna of Nevada is another diverse one and comprises 28 species of 17 genera. Ten genera are common in both Nevada and Fukkoshi faunas. It is worthy of attention that both faunas include two "relict" genera *Hemilecanites* and *Metadagnoceras*. However, there are some faunal differences between them: *Silberlingites* and *Caucasites*, both common elements in the Nevada fauna are absent in the Fukkoshi fauna and, on the other hand, the genera of the family Danubitidae and Palaeophyllitidae, dominated or common in the latter, are rare in the former.

Timor: From the Anisian limestone (2 m in thickness) in Nifoekoko, Timor, Welter (1915) described 12 genera (23 species) of ammonoids. Based on the re-examination of these genera by Shevyrev (1968, 1995), Spath (1954), Fantini Sestini (1981), etc., this fauna is considered to be composed of 13 genera (22 species). Among these, eight genera are common to the Fukkoshi fauna. Genera of the family Longobarditidae are missing and those of Acrochordiceratidae are rare in the Timor fauna.

Chitichun, Himalayas: The Chitichun limestone in Himalayas is classical Aegean ammonoid locality. Chitichun ammonoids originally described by Diener (1895b) have been reexamined by Diener (1915), Spath (1934), Shevyrev (1968), Wang and Chen (1979) and Fantini Sestini (1981, 1988), and are now classified into 13 species belonging to eight genera: *Paracrochordiceras pandya* (Diener), *Danubites ambika* Diener, *Paradanubites kansa* (Diener), *Aegeiceras ugra* (Diener), *Psilosturia mongolica* (Diener), *Procladiscites yasoda* Diener, *Leiophyllites confucii* (Diener), *L*.? *middlemissi* (Diener), *L*. *pitamaha* (Diener), *L*. *pradyumna* (Diener), *L*. *pseudopradyumna* (Welter), *Ussurites hara* (Diener) and *U*. *kingi* (Diener). Among these eight genera, six of them are common to the Fukkoshi fauna, and three species (*P*. *kansa*, *L*. *confucii*, *L*. *pitamaha*) from the Fukkoshi Formation are identified or compared to the Chitichun ones. According to Diener (1895b), specimens of *Leiophyllites* have, as with the Fukkoshi fauna, the largest number (35 specimens) among the fauna, followed by those of *Procladiscites* (10 specimens). On the other hand, the Chitichun fauna lacks the genera of the family Longobarditidae.

South Primorye: The Lower Anisian strata of the Atlasov Cape section, South Primorye, Far East Russia yield 15 species belonging to 12 genera of ammonoids (Zakharov et al., 2005a, 2005b). Among them seven genera are common to the Fukkoshi fauna. The fauna dominated in *Ussuriphyllites amurensis* (Kiparisova), which is endemic to South Primorye but now known from the Fukkoshi Formation. The Atlasov Cape fauna, however, differ from the Fukkoshi fauna in lacking the genera belonging to the families Japonitidae and Longobarditidae, and in small number of specimens of family Danubitidae and genus *Leiophyllites*.

Chios Island, Greece: The Marathovouno section in Chios Island, Greece includes the proposed candidate GSSP (the base of the *Aegeiceras–Japonites* beds: the base of the Aegean Substage proposed by Assereto, 1974) for the base of the Anisian (Gaetani et al., 1992). The Aegean ammonoid fauna was studied by Bender (1970), Assereto (1974), Fantini Sestini (1981) and Gaetani et al. (1992). This fauna comprises 17 species in 10 genera, of which seven genera are common to the Fukkoshi fauna. Former fauna differs from the latter in lacking the genera of the family Longobarditidae.

Caucasus: According to Shevyrev (1995), the lower Anisian Malotkhach Formation of Caucasus yields *Stenopopanoceras transiens* Tozer, *Megaphyllites compressus* Shevyrev, *Megaphyllites* sp., *Groenlandites*? *glaber* Shevyrev, *Longobardites caucasius* Shevyrev, *Laboceras gracile* Shevyrev, *Leiophyllites pitamaha* (Diener). Three genera of them are also known in the Fukkoshi fauna, but the Caucasus fauna lacks in the genera belonging to the families Danubitidae and Acrochordiceratidae, which are common in the Fukkoshi fauna.

Conclusions

1. Ammonoid fauna from the middle to upper part of the Fukkoshi Formation in the Kamiwarizaki area, South Kitakami Belt, Northeast Japan is diverse, consisting 21 genera. Among them, the genus *Leiophyllites* is most dominated and specimens belonging to the genera *Paradanubites*, *Parapopanoceras*, *Psilokhvalynites*, *Paracrochordiceras* and *Danubites* are also abundant. The majority of the genera are stratigraphically restricted to or range down into the lower Anisian, and therefore, the ammonoid fauna is considered definitely to be early Anisian (Aegean) in age.

2. Since the uppermost part of the underlying Osawa Formation yields late Olenekian ammonoids, the Olenekian/Anisian boundary in the South Kitakami Belt is located to be somewhere in the lower part of the Fukkoshi Formation.

3. The Fukkoshi ammonoid fauna exhibits some similarities in the generic composition with those of some localities exhibited in low-latitude regions in the Tethys and Panthalassa, especially with that of Qinghai, west China.

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マイクロフォーカス X 線 CT を用いた大型底生有孔虫研究

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Studies of large benthic foraminifers using microfocus X-ray CT

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Abstract: The method of microfocus X-ray computed tomography (CT) is one of novel visualizing and measuring techniques in the micropaleontology. Especially, larger benthic foraminifers have complex inner structures, and the inside morphological research of the shell has been generally used in thin section or broken individuals. The X-ray CT method enables the measurement of these inside structures with non-destruction. However, this method still remains many technical and practical problems for actual researches. Here, I reviewed the instructions of microfocus X-ray CT three-dimensional visualizing and measurement method, focusing on the microfossils' utility such as large foraminifers. I also presented examples of ecological studies of large foraminifers using microfocus X-ray CT research, and finally propose future prospects of X-ray CT methods.

1. はじめに

有孔虫は，熱帯から極域，また海洋表層から深海底に至るまで広く分布し、主に炭酸塩の殻をつくる原生動物である．この生物は大きく底生種と浮遊性種とに分類される．この底生種のうち，一般に 1mm 以上のサイズに成長し，共生藻を持つという共通の特徴を示すグループが大型底生有孔虫（Large Benthic Foraminifer）と呼ばれる．大型底生有孔虫は，サンゴ礁海域に生息し，多くの有孔虫と同様に炭酸カルシウムの房室を付加することで殻全体の容積を徐々に増加させて成長していく．殻形成による炭酸塩生産力は，サンゴ礁海域の生態系において，造礁サンゴや石灰藻に次ぐ大きさであり（Hallock, 1981），その生態の解明は，サンゴ礁の生態系や，今後の環境変動による炭素循環システムへの影響予測において非常に重要な意味をもつ．また，殻の成長速度や成長量は光量（Hallock et al., 1986; Fujita and Fujimura, 2008）や水温（Uthicke et al., 2012; Kinoshita et al., 2021），pH（Kuroyanagi et al., 2009）などの様々な環境条件の影響を受けることが明らかになっており，有孔虫殻に記録される情報は生息水域の海水環境の指標ともなりうる．

房室の付加を繰り返して成長する大型底生有孔虫において，もっとも基本となる成長量のひとつが房室数である．しかし，その数を外形から計測することは多くの種で困難であり，房室数の正確な計測には標本の破壊を伴ってしまう．このように房室数の計測には，標本の保存の問題，正確な断面を出す技術的な難易度や手間などの問題があり，従来，物理的な成長パラメータとしては，殻サイズや重量が多く用いられてきた．特に標本の破壊は，化石種の同定においては避けたい問題であり，標本の内部情報の取得と非破壊保存は，大型底生有孔虫の研究にとって常に非常に重要な課題であった．

この「大型底生有孔虫の非破壊での形態解析」を実現させたのが，X 線 CT 手法の活用である．産業用に開発された X 線 CT 装置は，近年の性能向上が著しく，マイクロメートル単位の解像度を持つマイクロフォーカス X 線 CT が現在では広く利用されるようになった．しかし，大型底生有孔虫をはじめとして，有孔虫類，あるいは微化石への X 線 CT の応用は未だに不安定な状況が続いている．本来，産業用 X 線 CT 装置の撮影に関しては，対象として微化石などの微小な（古）生物サンプルは考慮されていなかった．期待する画質の CT 像を得るためには，撮影者が標本に合わせた撮影用のステージ制作をしたり，さらに撮影条件を工夫したりするなど，適宜調整することが求められた．

本論では，最初にマイクロフォーカス X 線 CT による撮影，3 次元計測手法について，大型底生有孔虫などの微化石撮影

時における留意点を中心に概説する．また，実際に 3 次元計測手法を用いた研究例を紹介し，マイクロフォーカス X 線 CT 研究が有孔虫の生態の理解や環境解析にどのように貢献しているか，今後の展望等についても考察する．

2. マイクロフォーカス X 線 CT 手法の基礎

2.1）マイクロフォーカス X 線 CT 撮影の基本的な流れ

CT とは Computed Tomography ＝コンピュータ断層撮影の略称であり，X 線による走査によって断層撮影を行うことを X 線 CT 撮影と呼ぶ．この手法で得られる生データは，投影像であり，再構成処理などを加えて断層像（断面）や 3 次元データが取得できる．図 1 に，撮影準備から 3 次元化までの基本的な流れを示す．現在，微化石標本の撮影に利用されているマイクロフォーカス X 線 CT 装置は，その多くが産業用として開発された撮影装置である．このような撮影装置は対向する X 線管と X 線検出器，その間に配置された標本ステージから構成され，一般に標本ステージを回転させ，標本の 360° あらゆる方向からの X 線走査を行い，X 線投影像群を得る（図 1D）．したがって，標本ステージの回転角を *r* 度として走査を行うと，360/*r* 枚の投影像群が得られる．投影像の拡大率 *M* は，以下の式に従う．

$$M=D/d$$

ここで，*d* は X 線管と標本ステージ，*D* は X 線管と X 線検出器，それぞれの距離である．これは，X 線が放射状に発生する（コーンビーム）ためで，標本ステージを X 線管に接近させることで *M* は大きくなり，解像度（空間分解能）も高くなる．多くの装置では，得られた投影像群を断層像群に再構成するソフトウェアが付属しており，再構成処理を経て断層像が得られ（図 1E），一連の撮影が完了する．断層像は，撮影時における標本ステージ上での標本上部から下部にかけての連続断面像であり，再構成する範囲は一般に任意に決定できる，注目部位のみ断層像に再構成することも可能である．再構成された断層像からは，フェルドカンプ再構成法（Feldkamp et al., 1984）などによる 3 次元像への再構成が可能になる（図 1F）． 3 次元再構成や 3 次元表示，計測が可能なソフトウェアも多様化しており，研究目的に応じて選択して利用できる．

2.2）撮影条件について

断層像の空間分解能は，それぞれ独立する条件である，投影像の拡大率 *M* と，投影像 1 ピクセルあたりの X 線検出器の素子数 *n* によって決まる．上述のように，*M* が大きいほど高解像度になるが，*n* を小さくすることでも空間分解能を高めることができる．ただし *n* を小さくすると，投影像 1 ピクセルあたりの X 線検出量が小さくなり投影像が暗くなる．そのため，断層像のコントラスト低下が起こり，微化石標本を撮影する時のように比較的低エネルギーの X 線を用いて撮影する場合には注意して，設定する必要がある．*n* の設定項目は装置によって異なるが，ビニングモード，あるいは画像サイズとされていることが多い．

一方，画像コントラストは強くすることでより精密に密度差を表現することにつながるため，密度方向の解像度（密度分解能）と解釈できる．この密度分解能は，主に X 線の量に強く影響される．元来，X 線 CT は原理的には検出器へ到達した X 線の量を観測しており，検出された X 線の量の差，理想的には入射 X 線量からサンプルの X 線吸収量を減算した値が画像のコントラストとして再現される．したがって，一般的には高出力にして入射 X 線量を増やし，より吸収量の幅を取ることによってコントラストの向上を実現させることができる．しかし，高出力の X 線は透過力も向上する

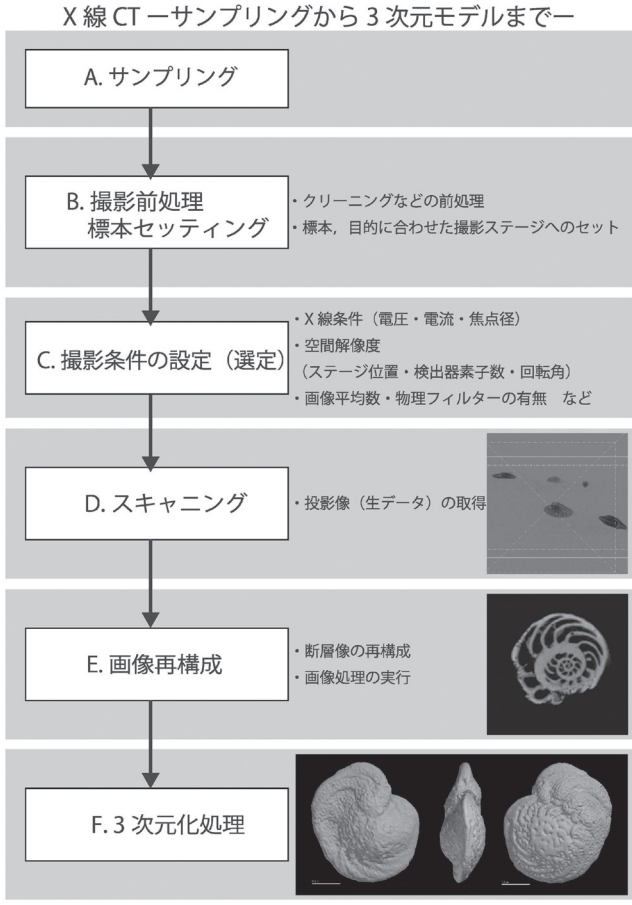

図 1. マイクロフォーカス X 線 CT による，サンプリングから 3 次元モデル化までの基本的な作業工程．D ～ F の図は，同一標本の投影像（D），断層像（E），3 次元モデル像（F）をそれぞれ表す．

ことや，大型底生有孔虫を含む微化石のような微小な標本や比較的低密度な標本では，潜在的に X 線が透過しやすいことにより，高出力条件下ではサンプルの X 線吸収量が極端に減少するため，結果的にコントラストが低くなりやすい．そのため，このような微小・低密度な標本（低コントラスト標本）においては，測定標本に最適な X 線出力の条件設定が求められる．

これらの分解能の設定は相互に干渉しあい，撮影時間にも影響する．上述のように，より高解像度を実現するために X 線検出器の素子数 *n* を小さくすると投影像が暗くなる．そこで，明るさを確保するためにもより高出力の X 線を利用したいが，密度差を詳細に測定したい場合などには，コントラスト面から出力に制限がかかるため，十分な明るさが確保できない状況が生じやすい．結果的に，高解像度・高コントラストを実現し十分な明るさを確保するためには，露光時間を長くすることになり，1 標本あたりの撮影時間が長くなりやすい．したがって，研究の目的に合わせて，空間分解能・密度分解能・撮影時間や標本数について，優先すべき要素や最低限求められる水準を明確にすることが撮影条件決定の基盤となる．

3. マイクロフォーカス X 線 CT を利用した研究例

マイクロフォーカス X 線 CT を用いた大型底生有孔虫の研究には，3 次元画像上で単純な形態計測を行ったものや，セグメンテーション（領域分割，領域抽出）などにより空間，あるいは物体の物理的なパラメータの測定を行ったものなどがある．以下に それら実際の研究例をいくつか紹介する．

3.1）大型底生有孔虫のライフサイクル

野外（自然環境下）での大型底生有孔虫の成長や寿命に関する研究は，サンゴ礁の礁縁部などの潮間帯（eulittoral zone）に生息する種や（e.g. Sakai and Nishihira, 1981; Hohenegger, 2006）比較的サンプリングが容易な数 m 程度の亜潮間帯の水深（the shallowest sublittoral zone）の種に偏っている（e.g. Zochary et al., 1980; Fujita et al., 2000; Hikami et al., 2011）．これより深い深度（deeper sublittoral zone）に生息する種の成長や生殖に関する研究は，主に室内の飼育実験で行われている．しかし，飼育実験の生育個体では，外形が正常に成長したように見えても，X 線 CT で観察すると房室内を分ける隔壁（septula）の不足や空洞の形成など，内部構造に不規則な形態がみられることがわかってきた（Hohenegger et al., 2014）．また，天然海水を利用するなど，可能な限り自然環境の再現を試みた場合であっても，飼育実験では成長が阻害されることも報告されている（Hohenegger et al., 2014）．そのため，Hohenegger et al.（2014）は，野外の定点で定期的なサンプリングを行い，統計学的な手法を用いて個体群の動態を明らかにする方法を勘案した．この方法は，“Natural laboratory approach”（N-lab 手法）とよばれ，潮間帯に分布する大型底生有孔虫の生態を解明する研究に用いられている．

大型底生有孔虫の成長に関しては，これまではサイズ（長径）や重量が主な指標となっていた．一方，有孔虫はその細胞の成長に伴って房室を付加しながら成長するため，本来は房室の付加率も成長の基礎的な指標である．しかし，多くの種では外部形態から房室数を正確に把握することはできず，切片化して薄片を作成するなど，標本の破壊や多くの手間を必要とした．ところが，マイクロフォーカス X 線 CT を使うと，非破壊で内部を観察でき，房室数など内部構造の把握が簡便となった．そのため N-lab 手法では，この測定方法が殻構造の計測手段として一般的になった（Kinoshita et al., 2017; Eder et al., 2019）．

Kinoshita et al.（2017）は，水深 50m の深度で 15 ヶ月に渡って定期的なサンプリングを毎月行い，N-lab 手法とマイクロフォーカス X 線 CT を組み合わせて，*Palaeonummulites venosus* の成長様式を検討した．収集された各個体の房室数と殻サイズを統計学的に検討すると，平均値の分布から研究期間の群集は 4 つの世代から構成されることが明らかとなった（図 2）． N-lab 手法では測定データから各標本個体の房室数やサイズと生息日との関係を検討することができる（例えば，第 2 世代では， 5 月 9 日～ 1 月 16 日の期間で約 29 室が付加されている）．そこで Kinoshita et al.（2017）では，連続的に記録を追跡できる第 2 世代と第 3 世代に焦点をあて，殻の成長率（房室形成率とサイズ増加率）を求めた（図 3）．この研究は，*P. venosus* の房室形成率を自然環境下のデータから明らかにした初めての結果となった．また，同時にサイズ増加率も得られており，いずれの成長率もこれまでの飼育実験での報告（Krüger, 1994）よりも速く，自然環境下での成長では飼育環境下での 5 か月分の成長量（房室数 40, サイズ 1.45mm）に 2 か月で到達している．

前述のように，N-lab 手法により，以下の房室形成率が得られた．

$$m = 81.3 \times t / (67.2 + t)$$

ここで，m は房室数，t は発生からの日数（生育日数）である．これを t に関する式に変換すると，

$$t = m \times 67.2 / (81.3 - m)$$

となる．この式により，各個体の生息日数を推定できるので，採集日より生育日数をさかのぼることで，個体毎の生殖時期を推定することもできる（Kinoshita et al.，2017）．研究地域の *P. venosus* は，これまでの同地域の他の大型底生有孔虫の報告例（Sakai and Nishihira 1981; Fujita et al., 2000; Hohenegger 2006）と同様に，6 月および 11 月に

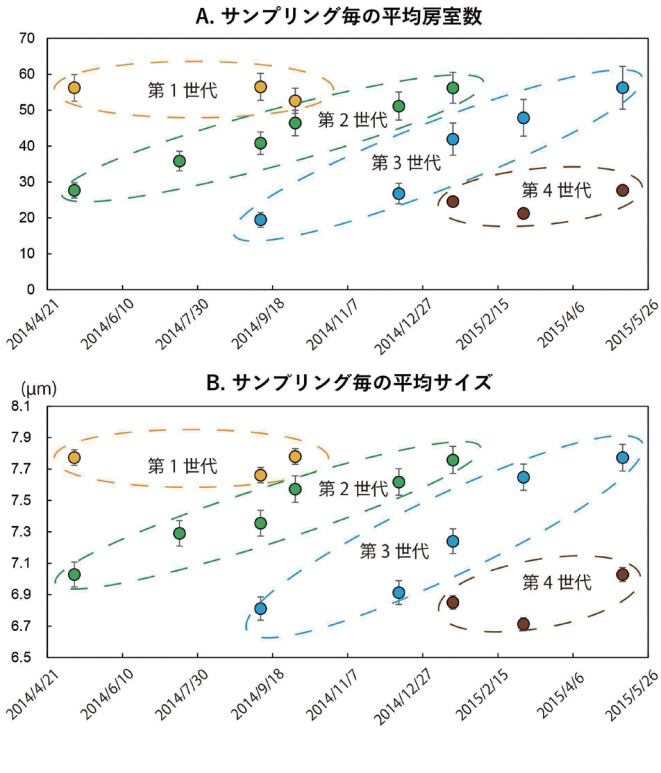

図 2. 各サンプルに含まれる *P. venosus* 個体の平均房室数と平均サイズの分布．各プロットは，各々のサンプリング試料に含まれる個体の房室数およびサイズを測定し，頻度分布の値を有意な正規分布の成分に分解して得られた平均値である．各時期には優位な 2 ～ 3 の平均値がみとめられる．房室数でもサイズでも同様の結果を示すことから，同時期に複数世代の個体群の存在が示唆され，最終的に試料中に含まれる世代は，4 世代にわたると推定される（Kinoshita et al., 2017）．

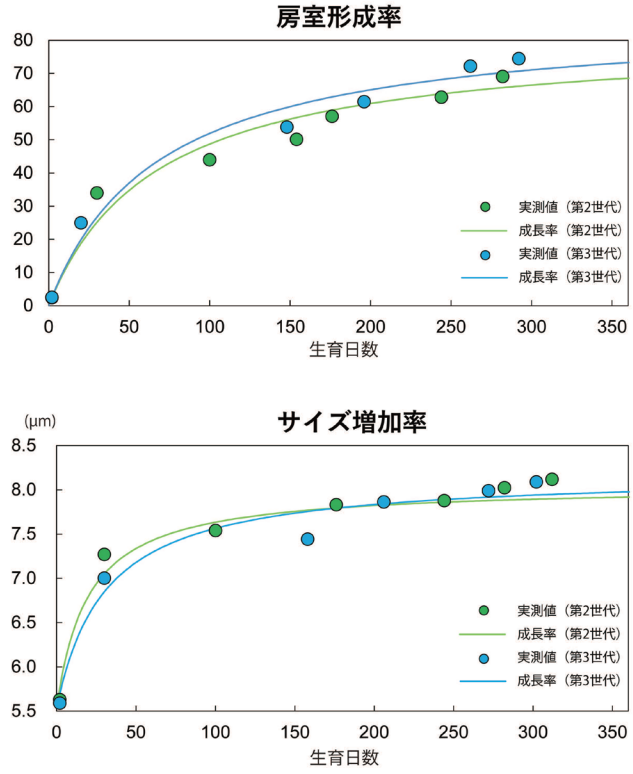

図 3. 連続的にデータが取れる *P. venosus* の第 2 および 3 世代における房室数とサイズの測定から求めた房室形成率およびサイズ増加率．N-Lab 法により図 2 の分布図から各サンプリング群集の生息日時を推定することができる（Kinoshita et al., 2017）．そこで，房室数とサイズ分布と生息日数との関係からそれぞれの成長率をもとめることができる．各世代間では有意差は検出されなかったので，両世代でほぼ差はないと思われる．

生殖のピークがみられる．一方，年間を通して常に一定以上の生殖頻度も保たれており，これまでの熱帯赤道域での報告とも類似する（Fujita et al., 2016）．ただし，熱帯赤道域では生殖に顕著なピークがみられていない．すなわち，Kinoshita et al.（2017）の結果は，これまで地域ごとに報告されていた季節性と恒常性が同時にみられる事例となった．

同様に，N-lab 手法とマイクロフォーカス X 線 CT 計測を利用した Eder et al.（2019）では，水深 20m，50m の異なる地点における *Heterostegina depressa* の房室形成率とサイズ増加率を明らかにした．異なる水深におけるサイズ増加率は，環境に応じて差が生じるのに対して房室の形成率はほぼ一致し，房室形成率が水深によらない普遍的な成長因子である可能性を示唆した．このように，マイクロフォーカス X 線 CT による形態計測は，形態の記載や定量化に留まらず，生態学的な研究にも大きく貢献している．

3.2）大型底生有孔虫の環境応答

X 線 CT の断層像は，空間部分（黒色系）と物体部分（白色系）の 2 系統に大別して見分けることができるので，閾値処理や二値化処理，画像解析ソフトによるセグメンテーションを行うことで空間の容積，あるいは物体の体積を計測することができる．大型底生有孔虫では，房室の空間部分は細胞質で満たされており，それぞれの房室容積は成長量，総容積は総細胞質量と解釈される．Hohenegger et al.（2019）は，Kinoshita et al.（2017）の研究を発展させ，CT 撮影によって得た 3D 画像から各個体の全房室の容積を算出した．前述のように Kinoshita et al.（2017）の研究から生息日時を推定することが可能となったので，生息日時と房室容積の関係を検討し，各々の成長日時における房室容積の理論値を

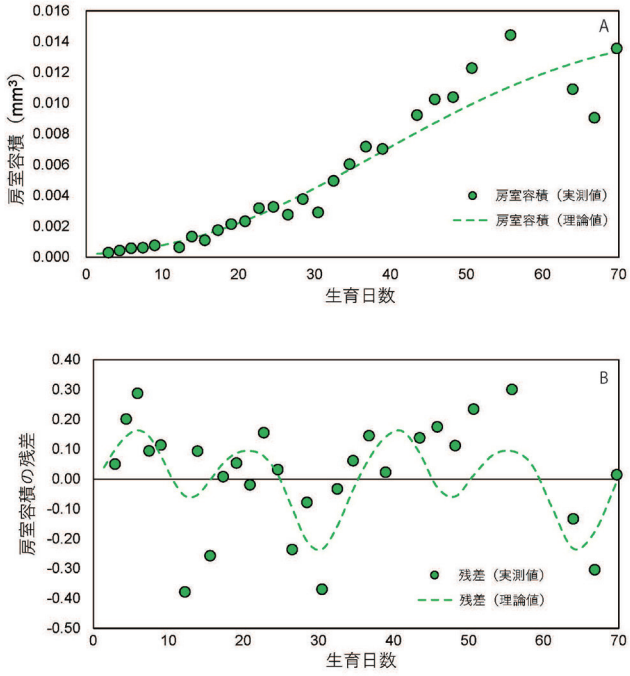

図 4. A は *P. venosus* の房室容積（実測値）と生息日数の関係とその回帰曲線（理論値）．B は A の実測値と理論値の差（残差）の割合を示した．残差の変動の回帰曲線（残差理論値）は周期解析によって得られた（Hohenegger et al.，2019）．

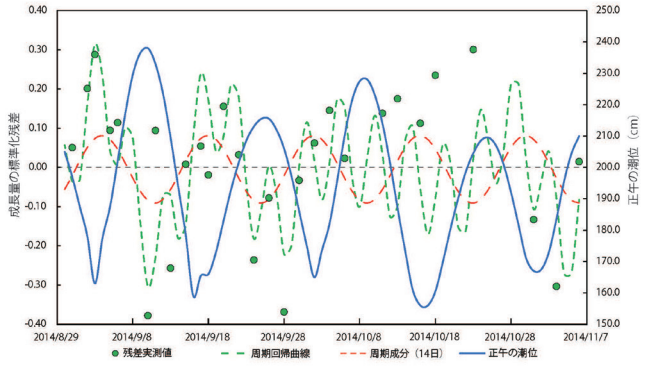

図 5. 房室容積の標準化残差と正午の潮位との関係．点プロットは実測値，緑色の破線曲線は残差の周期回帰曲線を示す．赤色の破線の曲線は理論的な 14 日周期成分で，青い周期曲線は正午の潮位の周期を表す．房室容積の変化は約 14 日変動を示し，潮位の変動と負の相関関係をもつ．

計算した（図 4A）．さらに，実際の房室容積の値（実測値）と理論値との差（残差として表現）の割合も計算した（図 4B）．この地域の *P. venosus* の各房室は，図 4 が示すように理論値に対して，より成長したり，十分な成長をしなかったりを繰り返している（成長振動という）．さらに．その周期を解析すると約 14 日が主要な値として検出された．一方，サンプリング地域の海面水位の変動も約 14 日間の周期をもっており，この成長振動とは負の相関関係をもつ（図 5）．採集地点の光合成有効放射量（Photosynthetically Active Radiation, PAR）は，平均 22.5μmol m^{-2} s^{-1} であり，干潮時と満潮時で約 5 ～ 20 μmol m^{-2} s^{-1} 程度の差が生じている（Hohenegger et al., 2019）．Nobes et al.（2008）や Ziegler and Uthicke（2011）によると，この範囲の PAR の変化は共生藻（珪藻）の活性度を大きく左右する．したがって，*P. venosus* の成長振動は，潮の干満差による僅かな水深の差がもたらす光強度の差によって生じていると思われる．

一方，CT 画像の物体部分は有孔虫においては基本的に殻にあたる．有孔虫の殻は環境と密接な関係があり，大型底生有孔虫においても，これまでに重量やサイズが環境によって変動することが明らかになっている（e.g. Hikami et al., 2011）．ところが，天然の複雑な環境条件下では有孔虫殻の 3 次元的なパラメータ（体積や密度）の変動を引き起こす環境要因を特定することは困難であるため，環境因子との因果関係は主に飼育実験によって解明されている．例えば，高すぎる水温（約 29℃以上）は，サイズや重量からみた有孔虫の成長を阻害したり（Schmidt et al., 2016; Maeda et al., 2017, 2018），生理機能に悪影響を及ぼしていることが知られている（Uthicke et al., 2012）．また Prazeres et al.（2017）は，高温条件下での飼育では，大型底生有孔虫の白化現象と死亡率が増加することを報告している．

これらの研究でも，マイクロフォーカス X 線 CT の活用によって新しい知見が得られている．Kinoshita et al.（2021）は，6 段階で水温を制御（19，21，23，25，27，29℃）した大型底生有孔虫 *Sorites orbiculus* の飼育個体をマイクロフォーカス X 線 CT を用いて測定し，殻重量やサイズに加え，房室数や殻体積についても水温による成長量の差を検討した（図 6A）．その結果，*S. orbiculus* 種は，殻の重量，サイズ，体積はいずれも互いに類似した傾向を示し，約 25℃で成長率が最大となり，より高温条件・低温条件のいずれの場合も成長が抑制されていることが示された．一方，殻重量および殻体積を用いて算出された殻密度では，各温度条件下でほぼ一定の値となっている（図 6B）．これまで殻重量の変動の仕組みに関しては，殻の体積（主に厚さ）の変動，あるいは殻の密度の変動のいずれが主要因であるか明確に解明されていなかったが，この研究から *S. orbiculus* の水温変化に対応した殻重量変動は，殻体積の変動が主要因であることが明らかにされた．さらに，Kuroyanagi et al.（2021）では，酸性度（pH）について *Amphisorus kudakajimensis* 種を用いて同様の飼育実験を行い，低 pH 条件下（pH ＝ 7.7）

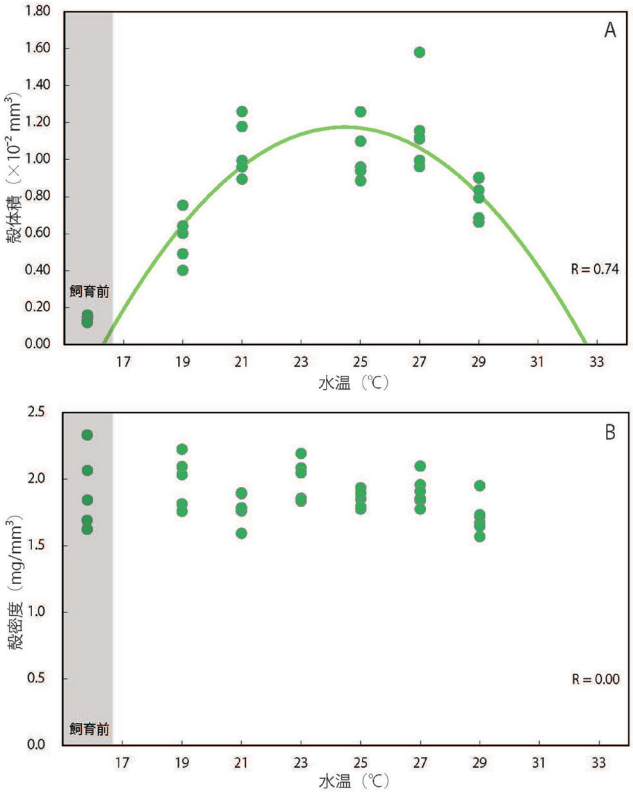

図 6. 飼育実験で得られた大型底生有孔虫の殻体積（A）および殻密度（B）と水温との関係．殻体積は約 25℃で成長率が最大となるが，殻密度は，各温度条件下でほぼ一定の値となっている．このことから，殻重量変動は，殻体積の変動が主要因であることがわかる．

では，殻の重量や体積，密度のいずれも高 pH 条件下（pH ＝ 8.3）に比べて低い値になることが示された．この結果は，海洋酸性化が進行すると大型底生有孔虫の殻生成を量的に阻害するだけでなく，生成される殻の質的な劣化も引き起こすことを示唆している．これらの詳細な殻パラメータ変動の解明は，マイクロフォーカス X 線 CT による 3 次元物体の体積の定量化によってもたらされた結果であり，本手法の利点が非常によく活かされている．

殻密度の変化については，近年の海洋酸性化への懸念の高まりとともに関心が集まっており，浮遊性有孔虫でも検討が行われている．Iwasaki et al.（2015）では，方解石の標準物質を用いて CT 画像における相対画素値を calcite CT number と定義し，殻密度に相当する指標として使用した．すなわち，画像の画素数の違いを用いて密度の指標とするのである（Iwasaki et al., 2015）．この研究では，画素数の濃淡から浮遊性有孔虫の殻溶解が 1 次形成層で選択的に起こることが示唆されている．

4. まとめ

マイクロフォーカス X 線 CT 撮影の最も重要な特徴は，標本を破壊することなく，切断面を含めたあらゆる角度からの観察を可能にする点である．実際に，化石種の大型底生有孔虫では，初室を通る水平断面，あるいは同様の垂直断面に基づいて分類するので，標本を失わずに，かつ任意の断面を描くことができるこの手法は，今後も分類や記載において非常に大きな貢献をすることは疑いない．また，非破壊計測，3 次元計測も本手法の大きな利点である．例えば，殻の体積や密度は，マイクロフォーカス X 線 CT の登場で定量性と精密性が飛躍的に向上したパラメータであり，有孔虫の成長や環境応答への定量的な解析に有力な指標としてさらに使われていくことが期待される．

微化石の撮影に利用するような産業用の CT 撮影装置の機械的な性能は 2010 年代において急速に向上しており，今後もハード・ソフト両面でさらに向上することが予測される．低コントラスト問題を中心とした微化石の CT 撮影上の問題も，撮影環境とともに改善されていくことは想像に難くない．加えて，今日の海洋の環境において温暖化と酸性化は主要な課題であり，それらの環境変動に対する石灰化生物の量的（体積）あるいは質的（密度）な変化への関心も引き続き高まることが予測される．今後は，これまで行われてきた現地モニタリングや飼育実験などによって得られた知見をさらに拡大するために，より精密な形態解析のためのツールとしてマイクロフォーカス X 線 CT がさらに広く活用されていくことが見込まれる．

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東北大学総合学術博物館紀要（Bulletin of the Tohoku University Museum）編集委員会規定

2004 年 1 月 31 日

（設置）

第 1 条　東北大学総合学術博物館（以下「博物館」という。）に東北大学総合学術博物館紀要編集委員会（以下「委員会」という。）を置く。

（任務）

第 2 条　委員会は，館長の求めに応じ，『東北大学総合学術博物館紀要』（以下「紀要」という。）に掲載する論文等の審査及び編集に当たるとともに，これに関する事項について審議する。

（組織）

第 3 条　委員会は，次に掲げる者をもって組織する。

一．博物館の教官で館長が指名した者。

二．博物館の運営委員及び兼任教官で館長が委託した者。

三．その他，特に館長が必要と認めた者。

（委員長）

第 4 条　委員会に，委員長を置く。

一．委員長は，第 3 条第 1 項，及び第 2 項の委員の互選によって定める。

二．委員長は，委員会を召集し，その議長となり，会務を掌理する。

（任期）

第 5 条　第 3 条に定める委員の任期は，1 年とし，再任を妨げない。

（議事）

第 6 条　委員会は，委員の過半数の出席がなければ会議を開くことができない。

2．委員会の議事は，出席入数の過半数をもって決し，可否同数の時は，委員長が決するところによる。

（論文等の審査）

第 7 条　委員会は，寄稿された論文等について審査をおこなう。

2．審査は掲載の可否，修正範囲，掲載分類等とする。

3．審査にあたって，査読を実施する。

（委員以外の出席）

第 8 条　委員長が必要と認めた時は，委員以外の者を委員会に出席させ，意見を求めることができる。

（査読者の委託）

第 9 条　委員会は，論文等の審査にあたり，委員以外の者に査読を委託することができる。

（審議結果の報告）

第 10 条　委員会は，審議結果について，館長に報告する。

（庶務）

第 11 条　委員会の庶務は，博物館の事務において処理する。

（雑則）

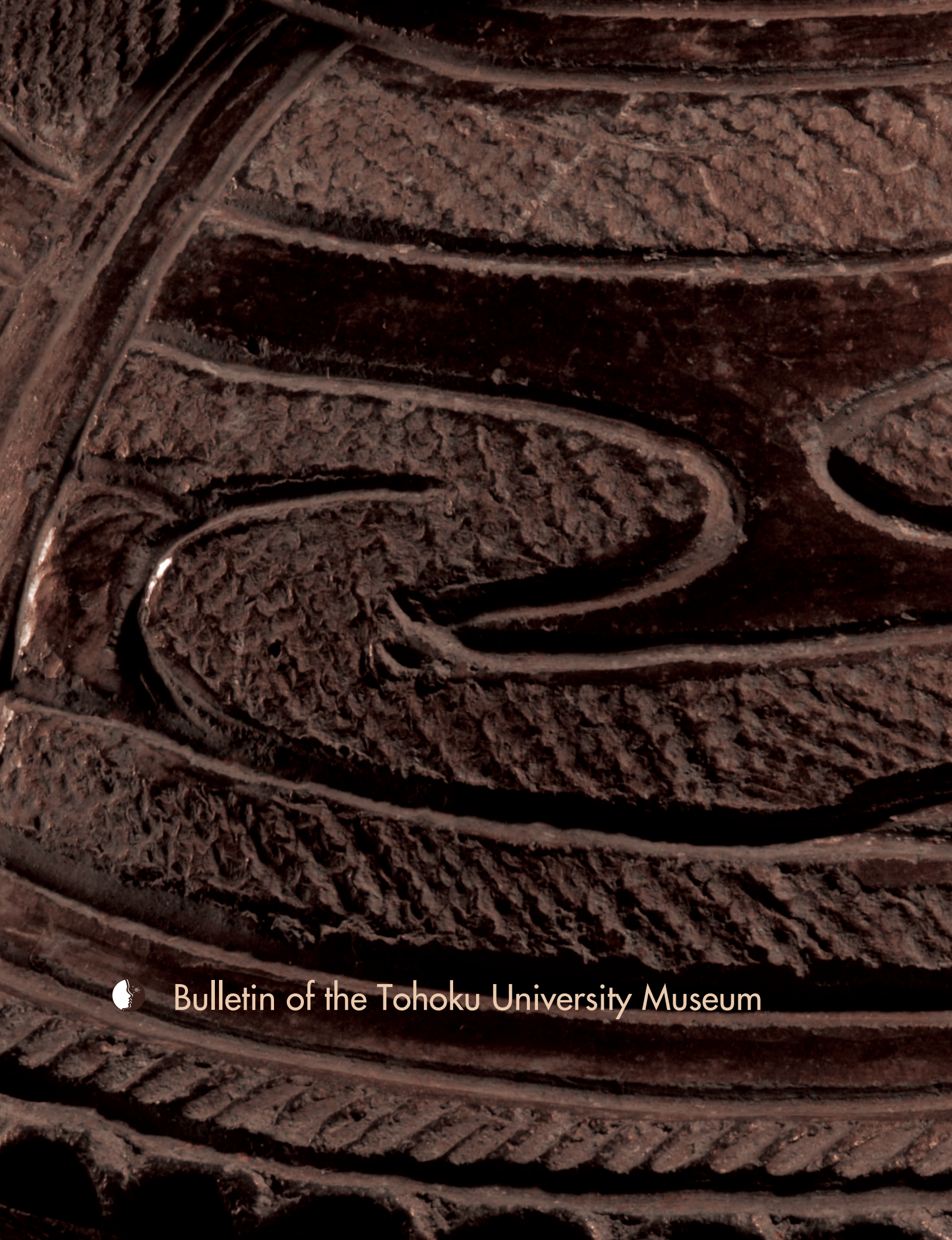
第 12 条　この規定に定めるもののほか，論文等の審査及び編集に関し必要な事項は，委員会が別に定める。

附則

この規定は，2004 年 1 月 31 日から施行する。

東北大学総合学術博物館『紀要』寄稿要項

1　東北大学総合学術博物館紀要（以下「紀要」という。）は総合学術博物館（以下「博物館」という。）に関連する諸科学に関する研究報告，調査報告等を掲載・発表することにより，それらの学問の発展に寄与するものである。
2　紀要に寄稿することができる者は，次の通りとする。
　①　東北大学の教職員（同客員教官を含む）
　②　東北大学の名誉教授
　③　その他，博物館において適当と認めた者
3　原稿執筆における使用言語は英語・日本語を原則とする。
4　寄稿する原稿には英文要旨（300 語程度）を添付する。
5　原稿はＡ 4 判横書き，1 ページ 1 段組で 1,000 字（40 字× 25 行）とし，充分な余白を取る。英文の場合はこれに準ずる。（図，写真，表，図版などはそれぞれ別ページとして準備する。さらにそれらのキャプションを別途準備する。）図，写真類のできあがりの最大の大きさは 1 ページ縦 22 ｃｍ×横 17 ｃｍとする。
6　原稿はデジタルデータで提出する。
7　原稿の提出は 10 月末とする。
8　原稿の提出は，紀要編集委員会とする。
9　原稿は編集委員会から委託した査読者の審査を経て編集委員会が採択する。
10　掲載した一論文につき，別刷り 30 部まで無償とし，それ以上は著者の負担とする。
11　紀要に掲載された論文等の著作権は，博物館に帰属するものとする。



Bulletin of the Tohoku University Museum