Bull. Tohoku Univ. Museum. No. 21, pp. 21–38, 2022

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

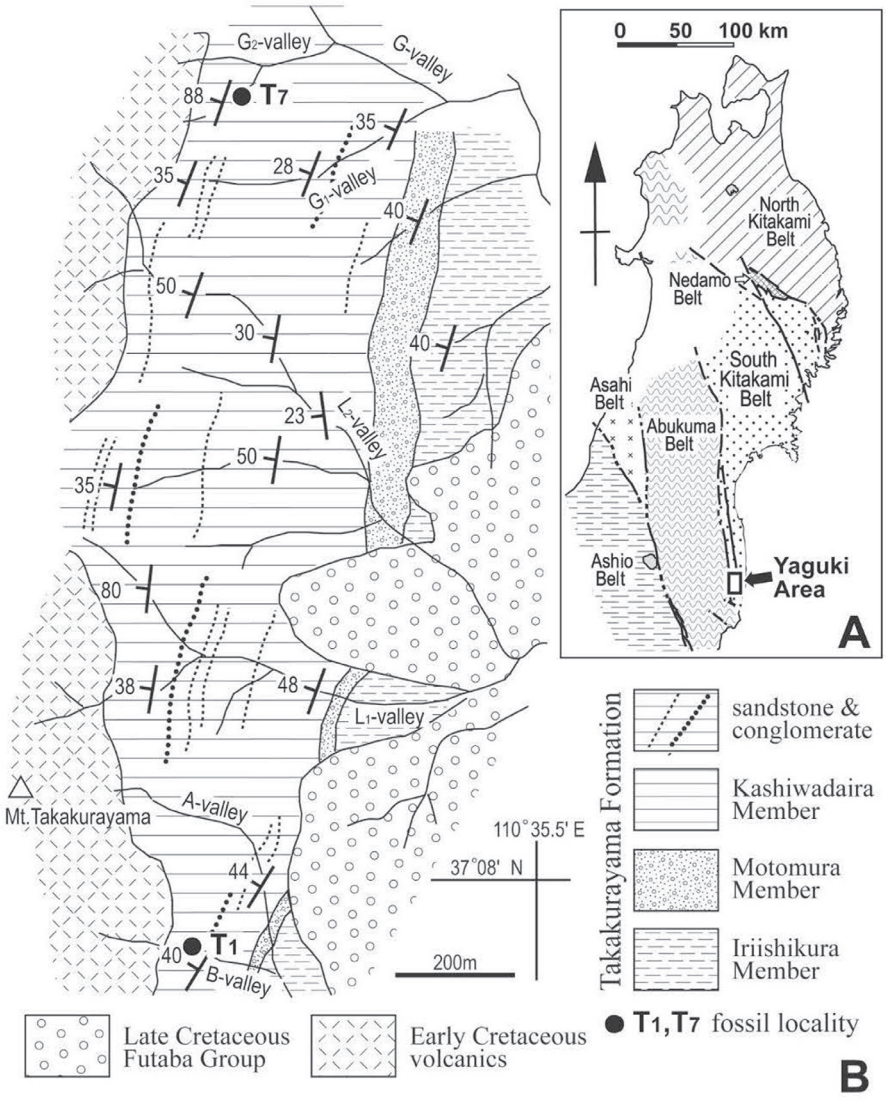

Figure 1. Geotectonic division map of Northeast Japan showing the study area (Yaguki Area) in the South Kitakami Belt (A) and geologic map of the Yaguki Area (B). Longitude and latitude are from the International Terrestrial Reference Frame.

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

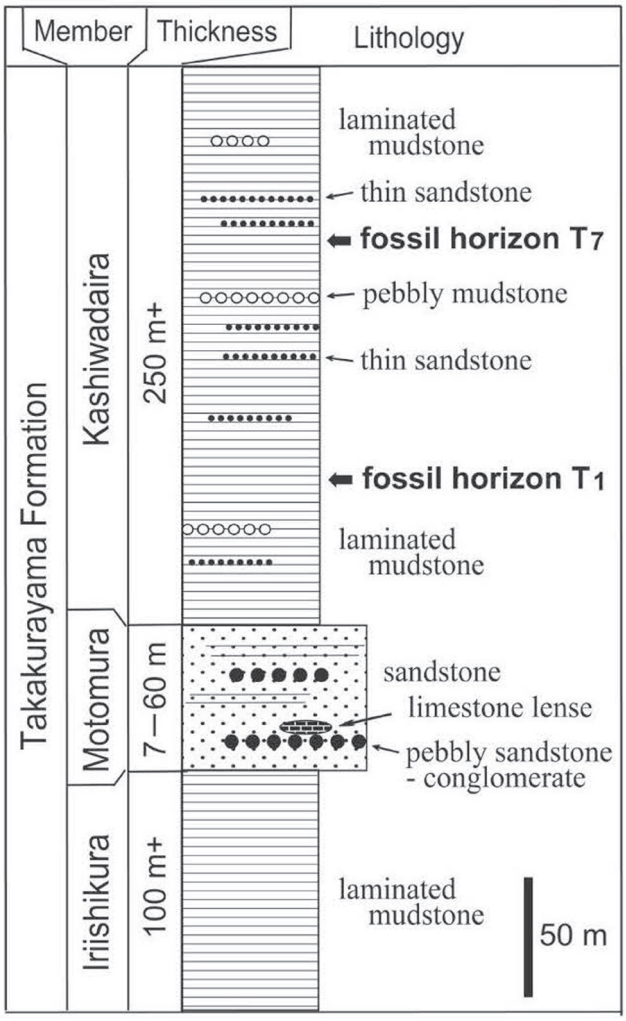

Figure 2. Generalized columnar section of the Takakurayama Formation, showing the fossil horizons.

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

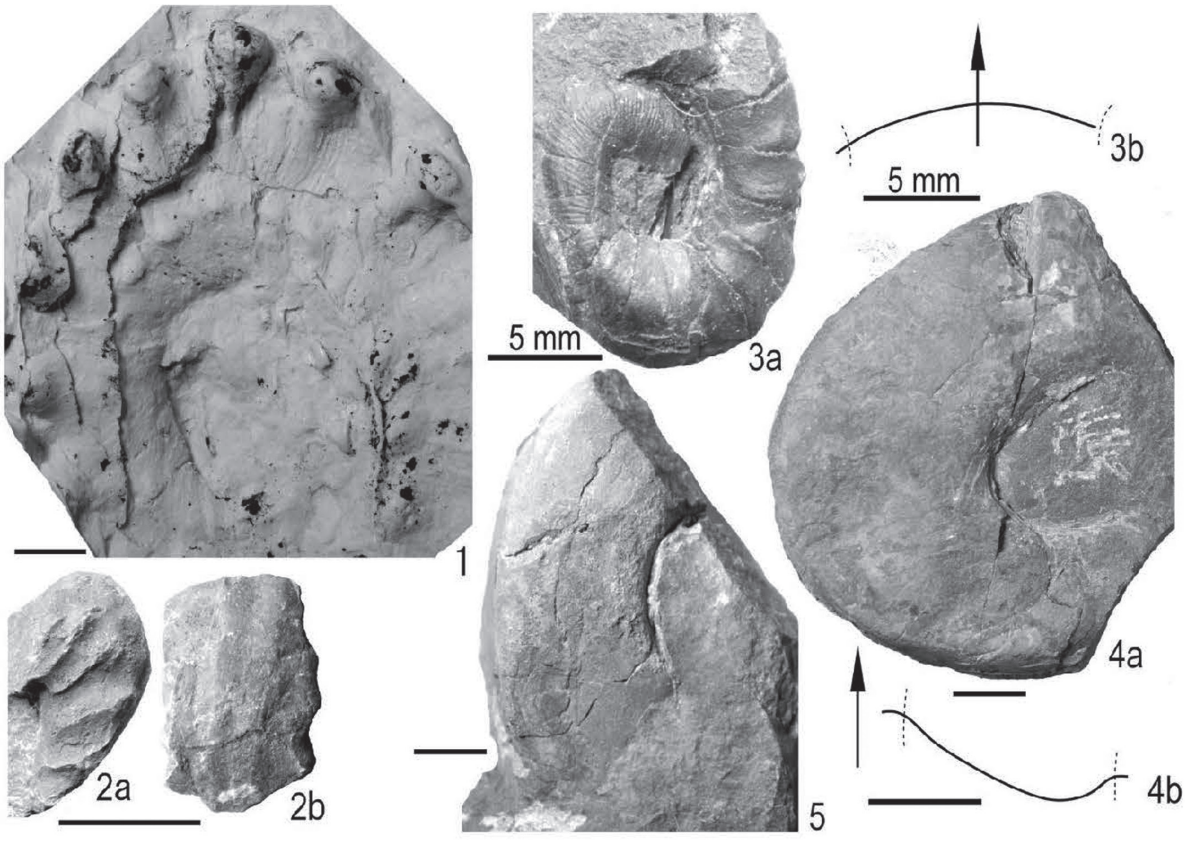

Figure 3. Nautiloids (*Tainoceras*, *Endolobus*? and *Domatoceras*) from the Takakurayama Formation.
1, *Tainoceras* cf. *abukumaense* Hayasaka, IGPS coll. cat. no. 112470, lateral view; **2**, *Tainoceras* sp., IGPS coll. cat. no. 112471, lateral (2a) and ventral (2b) views; **3**, *Endolobus*? sp., 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.

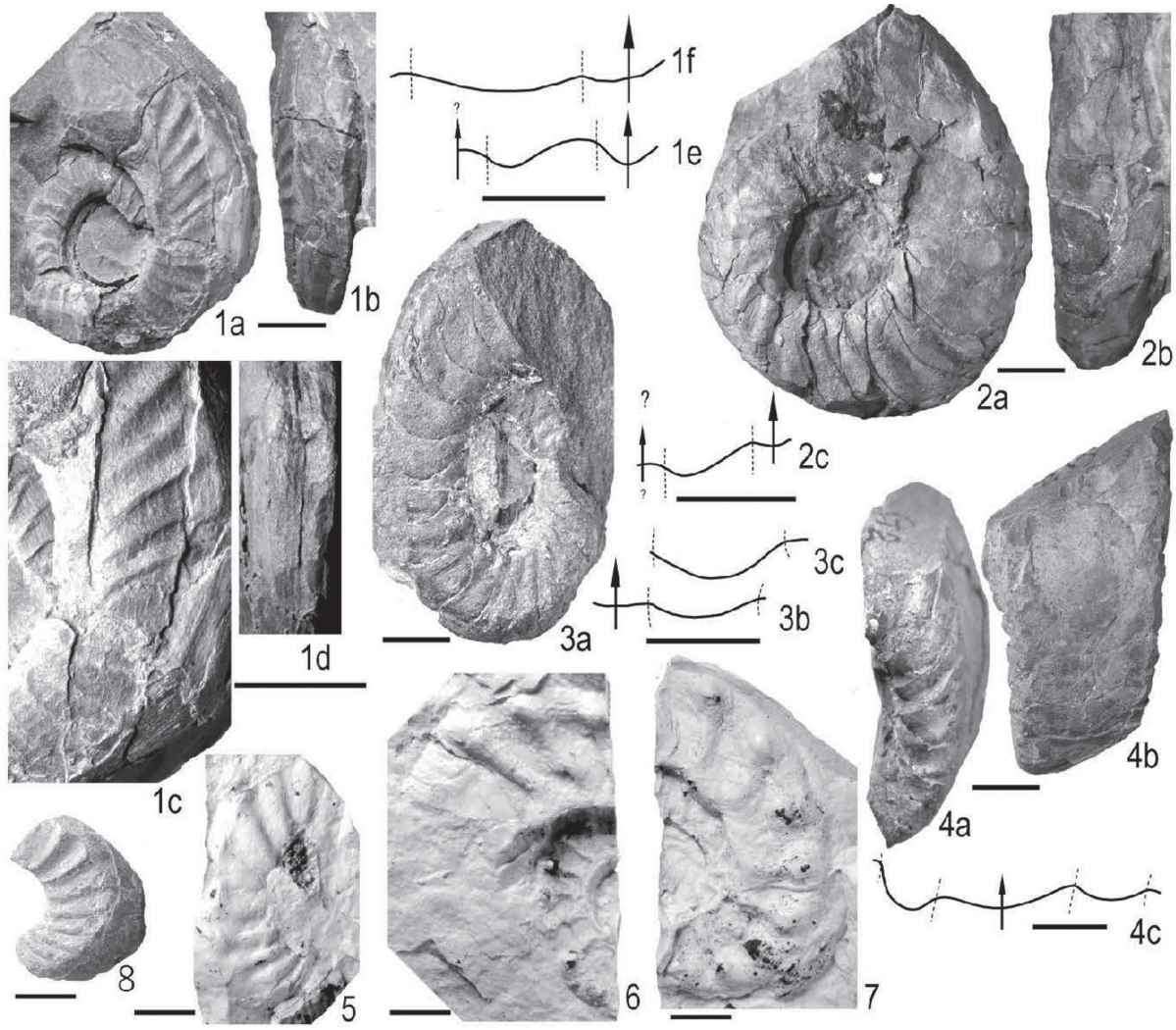

Figure 4. Nautiloids (*Pleuronautilus* and *Pleuronautilus*?) from the Takakurayama Formation.
1, *Pleuronautilus chisatoi* sp. nov., IGPS coll. cat. no. 112472 (holotype); 1a and 1b, lateral (1a) and ventral (1b) views; 1c and 1d, partial enlargements of lateral (1c) and ventral (1d) views showing longitudinal 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*

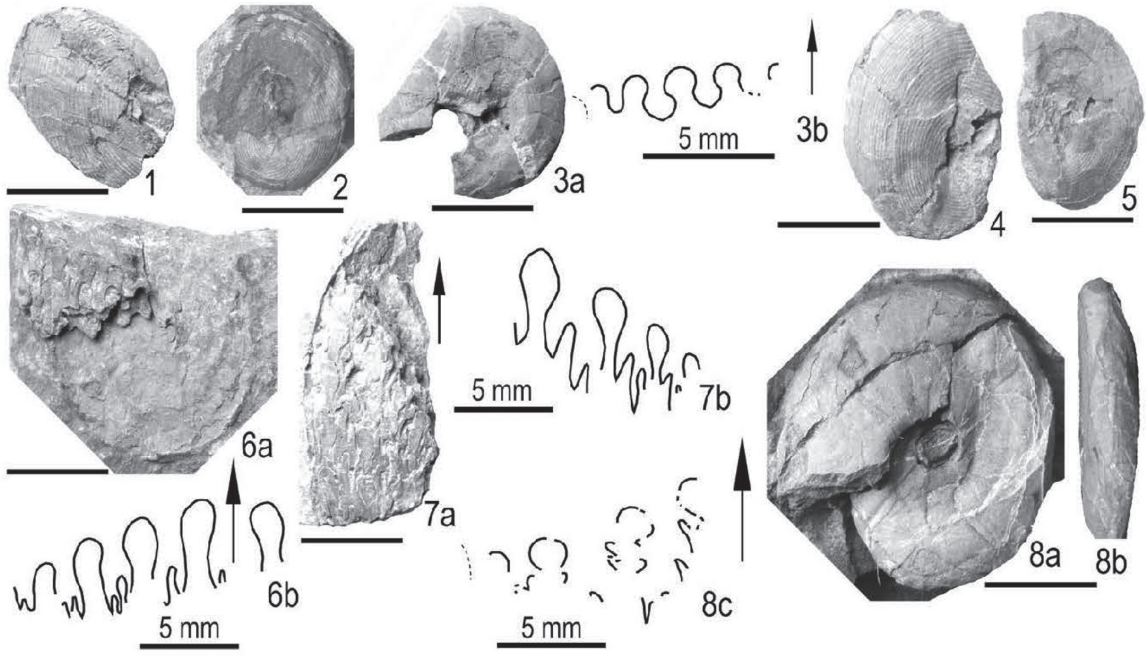

Figure 5. Ammonoids (*Agathiceras*, *Stacheoceras* and Kufengoceratinae gen. and sp. indet.) from the Takakurayama Formation.
1–**5**, *Agathiceras* sp.; 1, IGPS coll. cat. no. 112483, ventro-lateral view; 2, IGPS coll. cat. no. 112484, lateral view; 3, IGPS coll. cat. no. 112486, lateral view (3a) and 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

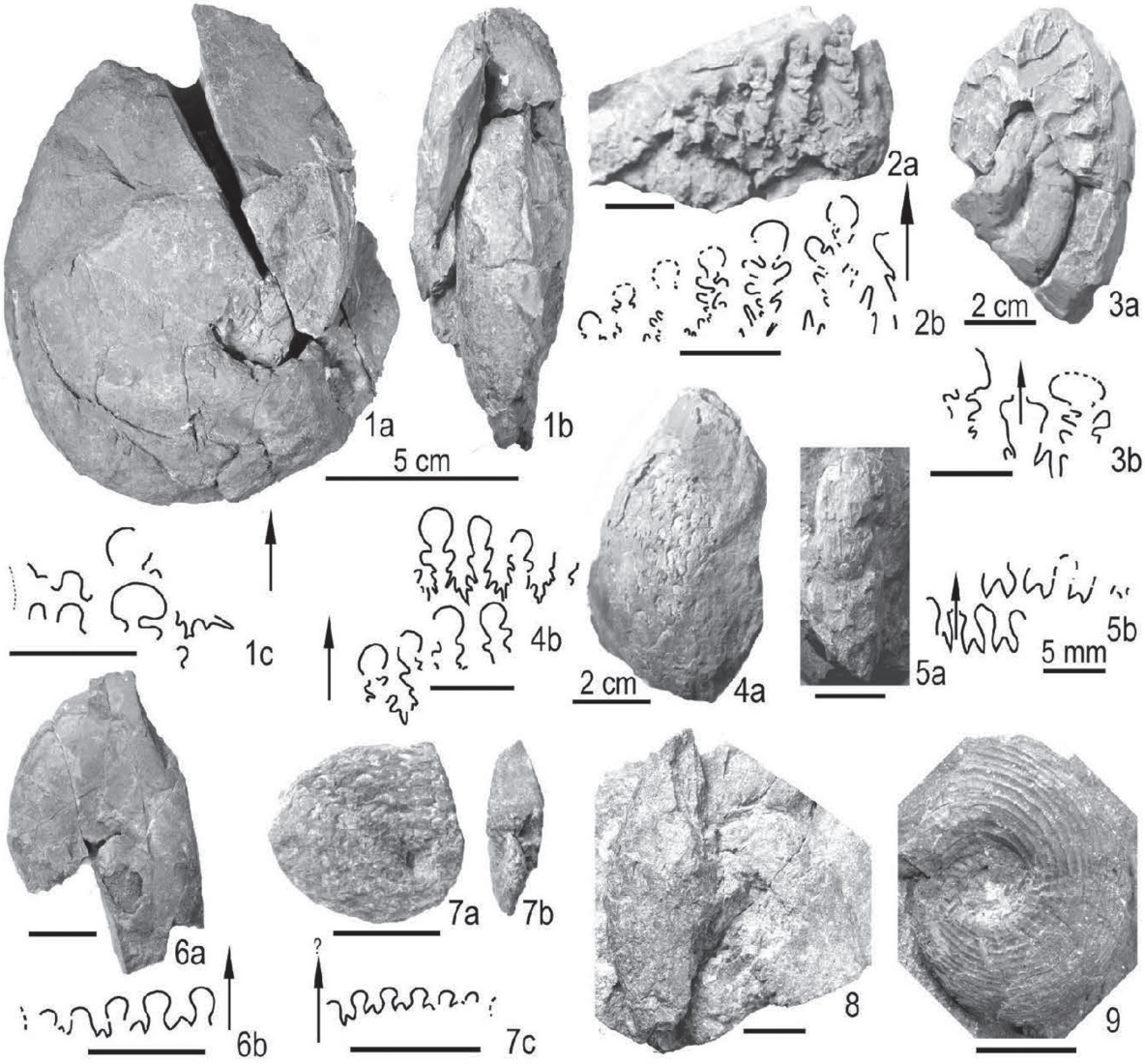

Figure 6. Ammonoids (*Waagenoceras*, *Jilingites* and *Roadoceras*) from the Takakurayama Formation.
1–**4**, *Waagenoceras* sp.; 1, IGPS coll. cat. no. 112500, lateral view (1a), ventral view (1b) and part of the suture line (1c); 2, IGPS coll. cat. no. 112503, lateral view of the fragmental inner mold (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

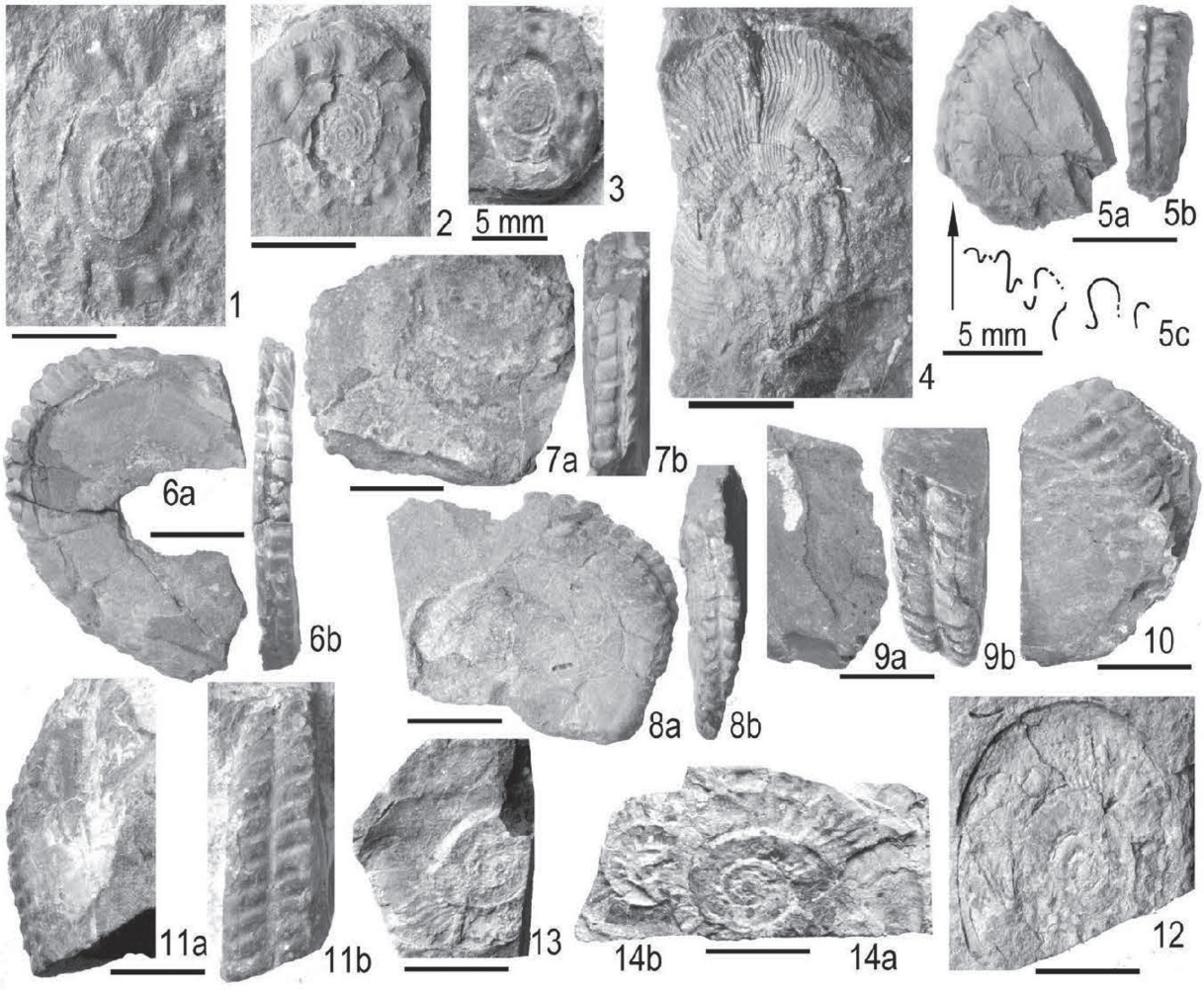

Figure 7. Ammonoids (*Neopopanoceras*, *Propinacoceras*, *Propinacoceras*? and *Paraceltites*) from the Takakurayama Formation.
1–**4**, *Neopopanoceras* cf. *scrobiculatum* (Gemmellaro), all lateral views; 1, IGPS coll. cat. no. 112513; 2, IGPS coll. cat. no. 112512; 3, IGPS coll. cat. no. 112515; 4, 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

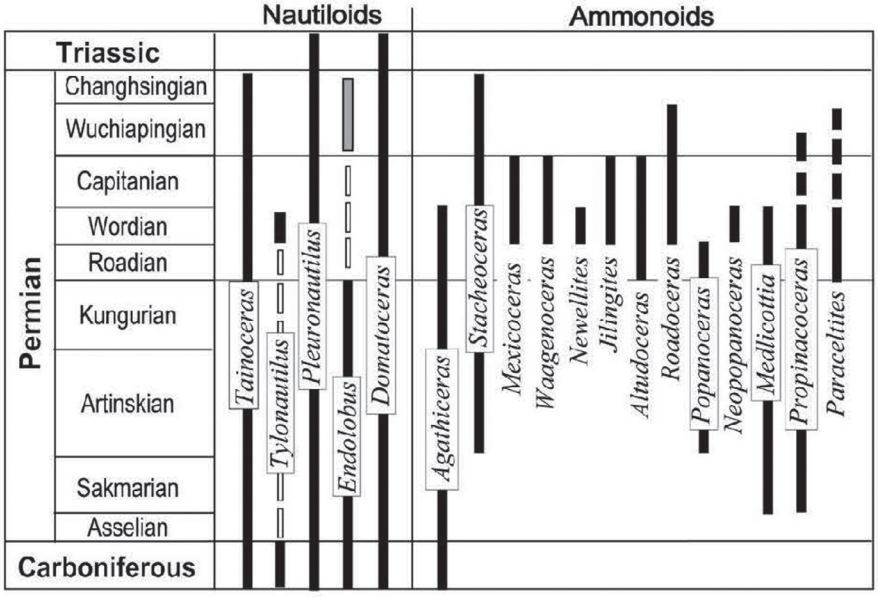

Figure 8. Stratigraphic ranges of the cephalopod genera known from the Takakurayama Formation. Data from Arkell et al. (1957), Furnish et al. (2009), Kummel (1953), Miller et al. (1957) and others.

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.

Acknowledgments

I am greatly indebted to Mr. Chisato Suzuki for donating cephalopod specimens from the Takakurayama Formation and help in the field. I also thank to the board of education, Iwaki City for allowing to conduct a geological survey in the area designated as a natural monument of Iwaki City (Takakurayama Paleozoic Strata). Sincere thanks are extended to Tatyana B. Leonova for her careful review.

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