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Microgastropods from the late Carboniferous limestone in Fukuji, Gifu Prefecture, central Japan

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Abstract

This paper describes microgastropod fossils from the Kasimovian (late Carboniferous) limestone floats collected from the Mizuboradani Valley, Fukuji, Okuhida-onsengou, Takayama City, Gifu Prefecture, central Japan. The microgastropod assemblage consists of a diversity of larval and/or early juvenile shells and represents late Palaeozoic cosmopolitan taxa, including Euomphalidae, Pleurotomarioidea, Anomphalidae, Naticopsidae, Trachyspiridae, Goniasmatidae, Orthonematidae, Pseudozygopleuridae, Subulitidae, Meekospiridae and Streptacididae. The microgastropod assemblage bears some resemblances to those from the early Carboniferous of New

South Wales, Australia, and those from the latest Permian of Guangxi Province, China.

Key words: Carboniferous, Fukuji, Japan, Limestone, microgastropod, Mollusca

Introduction

Well preserved micromolluscan fossils are known to occur in several early Palaeozoic deposits (Dzik, 1994) and there are several such assemblages from the late Palaeozoic deposits including the early Carboniferous of Australia, the Carboniferous of the United States, and the latest Permian of southern China (e.g. Yoo, 1988, 1994; Nützel and Mapes, 2001; Pan and Erwin, 2002; Nützel and Pan, 2005; Mapes and Nützel, 2009). The discovery of micromolluscs from new localities may provide valuable information about the evolutionary history and paleogeography of Palaeozoic molluscs.

Isaji and Okura (2014) reported silicified and/or chloritized micromolluscan fossils from the Carboniferous limestone floats at Fukuji, Okuhida-onsen-gou, Takayama City, Gifu Prefecture, central Japan. The fossils were characterized by a dominance of larval and/or early juvenile shells of bivalves and gastropods. The present study reports additional fossil assemblages of microgastropods that have not yet been described for other Palaeozoic deposits in Japan.

Materials and methods

Limestone floats bearing microgastropods were obtained from the downstream region of the Mizuboradani Valley, Fukuji, Okuhida-onsen-gou, Takayama City, Gifu Prefecture, central Japan (Figure 1). Limestones from this region yield a wide variety of fossils, including those of foraminiferans, fusulinids, sponges, gastropods, bivalves, ammonites, brachiopods, ostracods, trilobites, crinoids, conodonts and isolated teeth of cartilaginous fishes (Goto and Okura, 2004; Isaji and Okura, 2014; Stocker *et al*., 2016; Maekawa *et al*., 2018). In addition, microborings penetrated by endolithic organisms, such as cyanobacteria, fungi and algae, were often found in the shell of micromolluscs. These fossil evidences indicate that the limestones were deposited in an aerobic environment in the photic zone, such as a shallow reef (Isaji and Okura, 2014). Stocker *et al*. (2016) also suggested the shallow marine, high-energy environments in a fore-reef ecosystem for the Ichinotani limestones based on an ostracod fossil assemblage.

Recently, Maekawa *et al.* (2018) analysed limestone floats collected from the Mizuboradani Valley, and identified Kasimovian (late Carboniferous) conodont species from the limestones, which are lithologically identical to the rocks analysed by Isaji and Okura (2014). As a result, they concluded that the limestone floats might be from the *Triticites* Zone of the Ichinotani Formation

(Harayama, 1990) or derived from boulder-sized limestone clasts in the conglomerates of the Permian Sorayama Formation. For further details about the geological settings of the Fukuji area, see Maekawa *et al.* (2018).

In the present study, each limestone sample was dissolved using acetic acid according to standard techniques for conodont preparation. The residues were hand-sorted under a low-power binocular microscope. Most of the residues consisted of the silicified inner moulds of unidentified macroscopic molluscs. Well preserved microshells comprised approximately 5% of the total residues. Of these, most were from isolated bivalve larvae of low diversity. In contrast, gastropod shells were rare but represented a much more diverse assemblage. Some specimens were well preserved as chloritic replacements. The others were poorly preserved as inner moulds consisting of silicate minerals. In most cases, the shell surface was irregular or granular in appearance due to the dissolution of the shell or the aggregation of small secondary crystals. For further details about the molluscan fossil preservation, see Isaji and Okura (2014).

Images were obtained using a Hitachi S-800 scanning electron microscope at the Natural History Museum and Institute, Chiba. The specimens were numbered with the prefix CBM-PS and stored at the Natural History Museum and Institute, Chiba.

Abbreviations for shell dimensions.—*D*, diameter; *H*, height; *W*, width.

Systematic description

Some of the specimens treated in this paper were assigned to known genera or species. However, most were identified to higher taxonomic levels (family or superfamily) only. The classification and nomenclature used in this description is based on Nützel and Nakazawa (2012) and Bouchet *et al*. (2017).

Class Gastropoda Cuvier, 1795

Suborder Euomphalina McLean, 1981

Superfamily Euomphaloidea White, 1877

Family Euomphalidae White, 1877

Genus ***Serpulospira*** Cossmann, 1916

Type species.—*Serpularia centrifuga* Roemer, 1843, Upper Devonian Iberger Limestone in the Harz Mountains, Germany.

Serpulospira sp.

Figures 2.1, 2.2

Material.—CBM-PS 5961, 5962.

Description.—The shell is small and planispiral. The whorls are round and openly coiled, and gently increase in diameter, tending to be a narrow gap between the later whorls. The shell surface lacks distinct sculpturing. The protoconch is missing. The apertural features are unknown.

Dimensions (in mm).—CBM-PS 5961: *D* = 1.46. CBM-PS 5962: *D* = 0.81.

Remarks.—The small, planispiral and openly coiled shell is assigned to the euomphalid genus *Serpulospira,* which is widely distributed from the Devonian to Carboniferous strata. The specimens described here are similar to '*Serpulospira' scalariformis* Yoo, 1994 from the early Carboniferous (late Tournaisian) Dangarfield Formation, New South wales, Australia (Yoo, 1994, pl. 2, figs. 8–10; pl. 3, figs. 1–5).

Subclass Vetigastropoda von Salvini-Plawen, 1980

Order Pleurotomariida Cox and Knight, 1960

Superfamily Pleurotomarioidea Swainson, 1840

Family uncertain

Gen. et sp. indet.

Figure 2.3a, b

Material.—CBM-PS 5966.

Description.—The shell is small and medium-spired turbiniform. The protoconch consists of a smooth whorl and is not clearly separated from an early smooth teleoconch by demarcation. The teleoconch whorls gradually increase in diameter and are moderately convex with impressed suture. The teleoconch whorls are ornamented with more than five strong spiral carinae separated by a concave interspace of a width double that of a spiral carina. The aperture is broken.

Dimensions (in mm).—CBM-PS 5966: $W = 0.92$.

Remarks.—The specimen looks like having selenizone in the middle portion of the flank, but it remains unclear. The turbiniform profile and concavity between spirals indicate that the specimen represents pleurotomarioid gastropods.

Order Trochida Cox & Knight, 1960

Superfamily Trochoidea Rafinesque, 1815

Family Anomphalidae Wenz, 1938

Gen. et sp. indet.

Figure 2.4a, b

Material.—CBM-PS 5967.

Description.—The shell is small and turbiniform in shape. The protoconch is blunt. The teleoconch whorls gradually increase in diameter and are convex with impressed suture. The later teleoconch is ornamented with weak collabral undulations. The aperture is ovate, occupying approximately 50% of total shell height. The peristome is thick with weakly reflected basal to columellar lips. The umbilicus is opened.

Dimensions (in mm).—CBM-PS 5967: $H = 0.72$, $W = 0.84$.

Remarks.—The blunt, low-spired protoconch and the teleoconch having a round aperture indicate that the specimen represents anomphalid gastropods.

Subclass Neritimorpha Koken, 1896

Order Cycloneritida Frýda, 1998

Superfamily Naticopsoidea Waagen, 1880

Family Naticopsidae Waagen, 1880

Gen. et sp. indet. A

Figure 2.5a, b

Material.—CBM-PS 5968.

Description.—The shell is small, medium-spired ovo-conic and consists of at least three whorls. The whorls rapidly increase in diameter and are convex with impressed sutures. The aperture is broadly subovate, occupying approximately 75% of total shell height, and interrupted by the base of the previous whorl. The columellar lip is strongly arcuate. The boundary between the protoconch and teleoconch is unclear.

Dimensions (in mm).—CBM-PS 5968: $H = 0.93$, $W = 0.92$.

Gen. et sp. indet. B

Figure 2.6

Material.—CBM-PS 5969.

Description.—The shell is small, low-spired subglobose and consists of at least three whorls. The whorls rapidly increase in diameter and are convex with adpressed sutures. The aperture is subovate, occupying approximately 70% of total shell height, and interrupted by the base of the previous whorl. The boundary between the protoconch and teleoconch is unclear.

Dimensions (in mm).—CBM-PS 5969: $H = 0.64$, $W = 0.70$.

Remarks.—Pan and Erwin (2002) and Nützel and Nakazawa (2012) reported the mature individuals of the naticopsid species accompanied with the protoconch. However, mature specimens assigned to the Naticopsidae have not yet been found within the rock samples treated in our study.

Family Trachyspiridae Nützel, Frýda, Yancey and Anderson, 2007

Gen. et sp. indet.

Figure 2.7a, b

Material.—CBM-PS 5970.

Description.— The protoconch is low-spired subglobose and consists of approximately three whorls. The initial whorl of the protoconch has a diameter of approximately 100 μm and seems to be smooth in shell surface. The protoconch whorls rapidly increase in diameter, reaching approximately 500 μm in height and 580 μm in width. The later whorls of the protoconch are ornamented by sharp, prominent, collabral axial ribs separated by wide interstices of similar width. The axial ribs are strongly undulating. Each rib runs prosocline at the upper and lower part of a whorl but curves strongly backward at the central portion. The axial ribs are adpressed on the preceding whorl within a narrow zone; hence, the suture is not impressed. The small part of the last

whorl near the aperture lost the axial ribs, indicating that the teleoconch without marked sculpture is preserved. The later teleoconch whorls are unknown.

Dimensions (in mm).—CBM-PS 5970: $H = 0.50$, $W = 0.61+$.

Remarks.—The familiy Trachyspiridae was proposed by Nützel *et al*. (2007) to classify a new neritimorph gastropod family based on specimens from the Permian Sosio Limestone (Sicily, Italy) and the Pennsylvanian Finis Shale (Texas, U.S.A.), which have well preserved protoconchs that differ from those of Naticopsidae in having an axially ribbed shell sculpture. According to Nützel *et al*. (2007), isolated larval shells of this type, like our specimen, have been reported by Herholz (1990) from the Carboniferous of Germany (reproduced by Bandel, 1991, fig. 11), by Kues and Batten (2001, figs. 6.17–6.20) as *Lunuluzona*? sp. from the Pennsylvanian of New Mexico, and by Pan and Erwin (2002, figs. 4.14–4.16) as *Naticasinus sinus* from the latest Permian of China. Although these previous authors have assigned these axially ribbed larval shells to various gastropod taxa such as loxonematoids, aporrhaids, and pleurotomarioids, Nützel *et al*. (2007) suggested that the neritimorphs with axially ribbed larval shells belong to Trachyspiridae. This type of larval shell is now reported from the Late Triassic St. Cassian Formation (North Italy) (Bandel, 2007), from the Early Triassic (early Dienerian) of Far East Russia (Kaim, 2009), and from the Early Triassic (late Dienerian) of the Salt Range in Pakistan (Nützel *et al*., 2018). Thus, the

trachyspirid larval shell is known from the Carboniferous to the Late Triassic and had a global distribution (Nützel *et al*., 2018).

This is the first report of an isolated larval shell of Trachyspiridae from Palaeozoic deposits in Japan. However, mature specimens assigned to Trachyspiridae have not yet been found in the study area. In Japan, some trachyspirid species assigned to two genera such as *Trachydomia* and *Trachyspira* have been reported from the Permian Akasaka Limestone, Gifu Prefecture, Japan (Hayasaka, 1938, 1943; Hayami and Kase, 1977; Koizumi, 1995). However, no observations about the larval shells of these species have been reported, and no isolated larval shells have been found from the Permian Akasaka Limestone.

Subclass Caenogastropoda Cox, 1960

Superfamily Orthonematoidea Nützel & Bandel, 2000

Family Goniasmatidae Nützel and Bandel, 2000

Gen. et sp. indet.

Figures 3.1–3.3

Material.—CBM-PS 5963–5965.

Description.—The protoconch is conical in shape and consists of approximately three whorls. The earliest whorl is round and smooth. The later first whorl is smooth with a weak spiral stria on the periphery. The following whorls gradually increase in diameter and are moderately convex with slightly adpressed sutures. The later protoconch whorls are ornamented with three spiral carinae separated by concave interspaces of similar width. The upper carina is on the shoulder. The middle carina is sharp and prominent and is located on the periphery. The lower carina is weak and is located on the upper side of the base at the suture of the succeeding whorl. The base is almost flattened. The aperture is roundly ovate, interrupted by base of previous whorl, and reflected at the inner to basal lip. The umbilicus is slightly opened. The teleoconch is unknown.

Dimensions (in mm).—CBM-PS 5963: $H = 0.50$, $W = 0.35$. CBM-PS 5964: $H = 0.42$, $W = 0.30$. CBM-PS 5965: $H = 0.51$, $W = 0.35$.

Remarks.—Only larval shells are present. These larval shells closely resemble that of *Erwinispira jucunda* (Pan and Erwin, 2002) from the upper Permian Changhsing Formation, Yunnan Province, China (Nützel and Pan, 2005, figs. 1.7–1.11). The carinated larval shell also occur in the genus *Permocerithium* from the Permian Akasaka Limestone, Gifu Prefecture (Nützel and Nakazawa, 2012). However, the precise features of the larval shells of *Permocerithium* are unclear since they are poorly preserved and not isolated in the Akasaka Limestone.

Family Orthonematidae Nützel and Bandel, 2000

Gen. et sp. indet.

Figures 3.4–3.9

Material.—CBM-PS 5971–5976.

Description.—The protoconch is heliciform, distinctly more selender than teleoconch, and consists of approximately three round whorls with a weak spiral carina. The end of the protoconch shows a distinct sinusigera and is clearly demarcated from the teleoconch. The teleoconch is conical in shape. The whorls rapidly increase in diameter and are moderately flat with shallow sutures. The base is flat and lies at an obtuse angle to the periphery. The aperture is rounded-quadrate.

Dimensions (in mm).—CBM-PS 5971: $H = 0.27$, $W = 0.24$. CBM-PS 5972: $H = 0.33$, $W = 0.24$. CBM-PS 5973: $H = 0.34$, $W = 0.23$. CBM-PS 5974: $H = 0.51$, $W = 0.38$. CBM-PS 5975: $H = 0.61+$, $W = 0.41+$. CBM-PS 5976: $H = 0.66+$, $W = 0.54$.

Remarks.—A heliciform larval shell with a distinct sinusigera is a character shared by the families Orthonematidae and Goniasmatidae (Nützel and Bandel, 2000). Nützel and Bandel (2000) stated that Goniasmatidae differs Orthonematidae in having a slit in the teleoconch whorls. Therefore, it is inferred that the specimens described here belong to the family Orthonematidae.

The isolated protoconchs treated here are similar to the protoconch of *Microlampra heshanensis* Pan and Erwin, 2002 described from the Changhsingian (latest Permian) Heshan Formation in Guangxi Province, China (Pan and Erwin, 2002, fig. 6.3).

The early juveniles treated here exhibit an early whorl profile similar to that of *Coeloconulus panae* Nützel and Nakazawa, 2012 from the Permian Akasaka Limestone, Japan (figs. 10I–P, 11A), which was described as a genus of the family Trochidae. However, the family placement of *Coeloconulus* is unsettled since the features of its protoconch remain unclear. As Nützel and Nakazawa (2012) stated, if it presents a multi-whorled larval shell, *Coeloconulus* is placed in caenogastropoda. It is uncertain whether the treated specimens are related to *Coeloconulus* or not because the existence of a hollow columella, which is a diagnostic characteristic of *Coeloconulus*, cannot be determined from our specimens.

Among the caenogastropoda, similar form having conical shell with an acute slender apex is also known in a cassiopid from the Late Cretaceous Gosau Formation in Brandenberg, Tirol (Bandel, 1993, pl. 2, fig. 3)

Superfamily Pseudozygopleuroidea Knight, 1930

Family Pseudozygopleuridae Knight, 1930

Gen. et sp. indet.

Figure 3.10

Pseudozygopleuridae gen. et sp. indet. Isaji and Okura, 2014, p. 47, figs. 2.1–2.4

Material.—CBM-PS 5977.

Description.—The protoconch is conical and consists of about four whorls. The diameter of the first whorl is less than 100 μm. The later whorls gradually increase in diameter and are convex with impressed sutures. These whorls feature sharp, prominent parasigmoidal collabral axial ribs separated by wide interstices of similar width. The aperture is roundly ovate and reflected at the inner to basal lip. The umbilicus is slightly opened. The teleoconch is unknown.

Dimensions (in mm).—CBM-PS 5977: $H = 0.57$, $W = 0.37$.

Remarks.—Pseudozygopleuridae is a diverse late Palaeozoic family that can be identified by a characteristic axially ribbed larval shell (Knight, 1930; Hoare and Sturgeon, 1978; Anderson and Boardman, 1989; Yoo, 1994; Nützel, 1998; Pan and Erwin, 2002). The small first whorl and multi-spiral ornamented whorls of the protoconch of pseudozygopleurids indicates that the larvae are planktotrophic, as proposed by Nützel (1998, 2014).

The occurrence of isolated pseudozygopleurid larval shells similar to our specimens has been reported from the late Visean (early Carboniferous) Ruddle Shale Member of the Moorefield

Formation in north-central Arkansas, U.S.A. (Nützel and Mapes, 2001), from the Changhsingian (latest Permian) Heshan Formation in Guangxi Province, China (Pan and Erwin, 2002) and from the earliest Induan (early Triassic) Deltadalen Member of the Vikinghøgda Formation, central Spitsbergen, Norway (Foster *et al*., 2017). In Chinese deposit, they are often accompanied by mature or young mature teleoconch. In our study area, however, mature specimens assigned to Pseudozygopleuridae have yet to be found.

Superfamily Subulitoidea Lindström, 1884

Family Subulitidae Lindström, 1884

Genus ***Leptoptygma*** Knight, 1936

Type species.—Auriptygma virgatum Knight, 1931b, Pennsylvanian, Missouri, U.S.A.

Leptoptygma sp.

Figure 3.11a, b

Material.—CBM-PS 5980.

Description.—The shell is small and conical. The protoconch is blunt and low-spired with smooth and convex whorls, and it is not clearly demarcated from the teleoconch. The teleoconch whorls increase rapidly in diameter and consist of approximately five whorls with shallow suture.

The whorl profile between sutures is round in early whorls and rather straight in later whorls, with a narrow flattened band just below the suture. The periphery is situated at the lower part of the whorl. The base is rather straight, forming a gentle angle with the periphery. The shell surface is smooth with faint growth lines. The aperture is rectangular and occupies approximately 50% of the total shell height. The peristome is thin and sharp with weakly reflected basal to columellar lips. The columellar is not twisted. The umbilicus is closed.

Dimensions (in mm).—CBM-PS 5980: $H = 1.40$, $W = 0.87$.

Remarks.—The specimen resembles *Leptoptygma laetus* Pan and Erwin, 2002 from the Changhsingian (latest Permian) Heshan Formation, Guangxi Province, China (Pan and Erwin, 2002, figs. 16.1, 16.2) but differs from *L. laetus* in having the less inflated body whorl.

Superfamily Soleniscoidea Knight, 1931b

Family Meekospiridae Knight, 1956

Genus ***Girtyspira*** Knight, 1936

Type species.—Bulimella canaliculata Hall, 1858, by original designation, Salem limestone, Lower Carboniferous, Indiana, U.S.A.

Girtyspira? sp.

Figures 3.12, 3.13

Material.—CBM-PS 5978, 5979

Description.—The shell is small and fusiform. The teleoconch consists of more than four whorls. The whorls increase rapidly in diameter and are widely convex with moderate sutures. The aperture is tear-shaped. The shells are poorly preserved or eroded; thus, the protoconch and other shell features are unknown.

Dimensions (in mm).—CBM-PS 5978: $H = 1.47+$, $W = 0.72$. CBM-PS 5979: $H = 1.44+$, $W = 0.52+$.

Remarks.—The size and fusiform profile of the specimens which are internal moulds resemble those of *Girtyspira microspirula* Jeffery, Hoare, Mapes, and Brown, 1994 from the Chesterian (Upper Mississippian) Imo Formation of north-central Arkansas (Jeffery *et al*., 1994, figs. 10.17–10.20) and *Girtyspira minuta* (Stevens, 1858) from the Pennsylvanian Finis Shale of Texas (Nützel *et al*., 2000, figs, 6.11–6.16).

Subclass Heterobranchia Burmeister, 1837

Superfamily Streptacidoidea Knight, 1931a

Family Streptacididae Knight, 1931a

Remarks.—Streptacidid gastropods are common in late Palaeozoic deposits worldwide. The multi-spiral openly coiled whorls of their protoconchs indicate the larvae are planktotrophic. Bandel (1994) included the streptacidids in the newly introduced family Donaldinidae. However, Pan *et al*. (2003) claimed that the status of Donaldinidae is open to question since it is distinguished from Streptacididae only by the presence of spiral carinae on the teleoconch. In this paper, the validity of Streptacididae is accepted, in accordance with the description of Pan *et al*. (2003).

Previously, Isaji and Okura (2014) reported the heterostrophic and discoidal isolated shells from the Ichinotani limestones as the protoconchs of streptacidid gastropods. In this paper, we assign some of the specimens to genera of Streptacididae.

Genus ***Donaldina*** Knight, 1931a

Type species.—*Aclisina grantonensis* Donald, 1898, early Carboniferous, Woodhall, Scotland.

Donaldina sp.

Figures 4.1, 4.2

Material.—CBM-PS 5981, 5982.

Description.—The shell is very small and slender turritelliform. The protoconch is not preserved. The teleoconch consists of approximately six whorls, which are nearly as wide as they are high. The whorls increase gently in diameter and are convex with impressed sutures. The shell surface is ornamented with approximately three or four spiral carinae. The aperture is round. The umbilicus is closed.

Dimensions (in mm).—CBM-PS 5981: H = 1.25+, W = 0.41. CBM-PS 5982: H = 1.14+, W = 0.37+

Remarks.—Although the specimen is incomplete and not well preserved, the very small and slender turritelliform shell with spiral carinae suggest that the specimens belong to the genus *Donaldina*. Pan and Erwin (2002) reported well preserved specimens of *Donaldina* spp. from the Changhsingian (latest Permian) Heshan Formation, Guangxi Province, China. Of these, *Donaldina quinquecarina* Pan and Erwin, 2002 is similar to our specimen in having slender shell (Pan and Erwin, 2002, figs. 16.9, 16.10).

Genus ***Laxella*** Pan and Erwin, 2002

Type species.—Laxella micra Pan and Erwin, 2002, latest Permian, Guangxi Province, China.

Laxella micra Pan and Erwin, 2002

Figures 4.3; 4.4a, b

Laxella micra Pan and Erwin, 2002, p. 37, figs. 18.6, 18.7.

Material.—CBM-PS 5983, 5984

Description.—The shell is very small and vermiform. The protoconch is heterostrophic and discoidal, with more than one-half whorl, attaining a diameter of approximately 160 µm. The boundary between the protoconch and teleoconch is ambiguous. The teleoconch consists of approximately two-half whorls that increase gently in diameter. The whorls are coiled loosely in a sigmoidal shape and are widely disjunct but become tightly coiled toward at the last whorl. The aperture is roundly ovate. The shell surface lacks distinct sculpturing.

Dimensions (in mm).—CBM-PS 5983: $H = 0.79$, $W = 0.27$. CBM-PS 5984: $H = <0.73$, $W = 0.26$.

Remarks.—This is the first record of *Laxella micra* Pan and Erwin, 2002 from the Japanese Palaeozoic deposit. *L. micra* has only been reported from the Changhsingian (latest Permian) Heshan Formation, Guangxi Province, China (Pan and Erwin, 2002). Thus, the present study provides the oldest known record of *L. micra*, indicating that *L. micra* ranged in age from at least the late Carboniferous to latest Permian. The present specimens are larger than the holotype (Pan and Erwin, 2002, p. 37, figs. 18.6, 18.7) and seem to be older. They are regarded as mature

individuals because the last whorl of each specimen is closely adjacent to the previous whorl. Judging from their small size and disjunct whorl coiling shell, it is reasonable to assume that *L. micra* has planktonic mode of life even in the adult stage.

Regarding the genus *Laxella*, Pan and Erwin (2002) mentioned that the specimens assigned to *Laxella* were first recorded in Namurian (Carboniferous) strata from Ningxia, China (Pan, 1997) and were not named at that time because their poor preservation. Pan *et al*. (2003) also reported *Laxella* sp. from Changhsing Formation (latest Permian) and Dayie Formation (early Triassic), Jiangxi Province, China.

Genus ***Streptacis*** Meek, 1872

Type species.—Streptacis whitfieldi Meek, 1872, late Carboniferous, Danville, Illinois, U.S.A.

Streptacis sp. A

Figure 4.5

Material.—CBM-PS 5985.

Description.—The shell is very small and slightly inflated turritelliform. The protoconch is not preserved. The shell exhibits three whorls. The early teleoconch is broken. The whorls gradually

increase in diameter and are widely convex with moderate sutures. The aperture appears to be elliptical. The shell surface lacks distinct sculpturing.

Dimensions (in mm).—CBM-PS 5985: *H* = 0.85+, *W* = 0.38.

Remarks.—The present specimen differs from *Donaldia* sp. described here in having a smooth shell and also from the other *Streptacis* sp. described here in having a slightly inflated turritelliform shell. The specimen is somewhat similar to *Streptacis regularis* Pan and Erwin (2002, figs. 18.3, 18.4)

Streptacis sp. B

Figures 4.6

Material.—CBM-PS 5986.

Description.—The shell is small, somewhat loosely coiled, and slender turritelliform. The protoconch is not preserved. The teleoconch consists of at least five whorls. The whorls gradually increase in diameter and are convex. The shell surface is unknown.

Dimensions (in mm).—CBM-PS 5986: *H* = 1.36+, *W* = 0.46+.

Remarks.—An internal mould of the teleoconch is at hand. This specimen is similar to *Streptacis* sp. A, but differs in having a wider and more loosely coiled shell.

Streptacis sp. C

Figure 4.7

Material.—CBM-PS 5987.

Description.—The shell is small and slightly inflated turritelliform. The protoconch is not preserved. The teleoconch consists of at least five whorls, which are somewhat tightly coiled. The whorls are wider than they are high, and gradually increase in diameter. The shell surface is unclear since the shell is poorly preserved.

Dimensions (in mm).—CBM-PS 5987: H = 1.37+, W = 0.56+.

Remarks.—An internal mould of the teleoconch is at hand. The specimen differs from the other streptacids described here in having a large and tightly coiled shell.

Discussion

Most of the well preserved microgastropod fossils extracted from the examined Kasimovian (late Carboniferous) limestone are larval and/or early juvenile shells. Although precise taxonomic assignment is difficult for these microgastropods, the specimens are identifiable to a wide variety of late Palaeozoic cosmopolitan taxa, including Euomphalidae, Pleurotomarioidea, Anomphalidae,

Naticopsidae, Trachyspiridae, Goniasmatidae, Orthonematidae, Pseudozygopleuridae, Meekospiridae, Subulitidae and Streptacididae. The microgastropod assemblage bears some resemblances to those from the Early to Middle Mississippian limestones in the Tamworth Belt, New South Wales, Australia, and those from the latest Permian Heshan Formation, Guangxi Province, China. The similarity might simply imply that gastropod faunal composition has remained stable at the higher taxon levels from the late Carboniferous to the latest Permian.

Further search for expected macroscopic gastropod fossils at the studied site is needed to understand the diversity of Carboniferous–Permian gastropod fauna by comparison with those of other well studied strata, which are deposited at the Panthalassic eastern margin of Pangaea, reported from Australia (Yoo, 1988; 1994), China (Pan, 1997; Pan and Erwin, 2002), Japan (Nützel and Nakazawa, 2012), Thailand (Ketwetsuriya *et al*., 2016) and other areas.

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Figure Captions

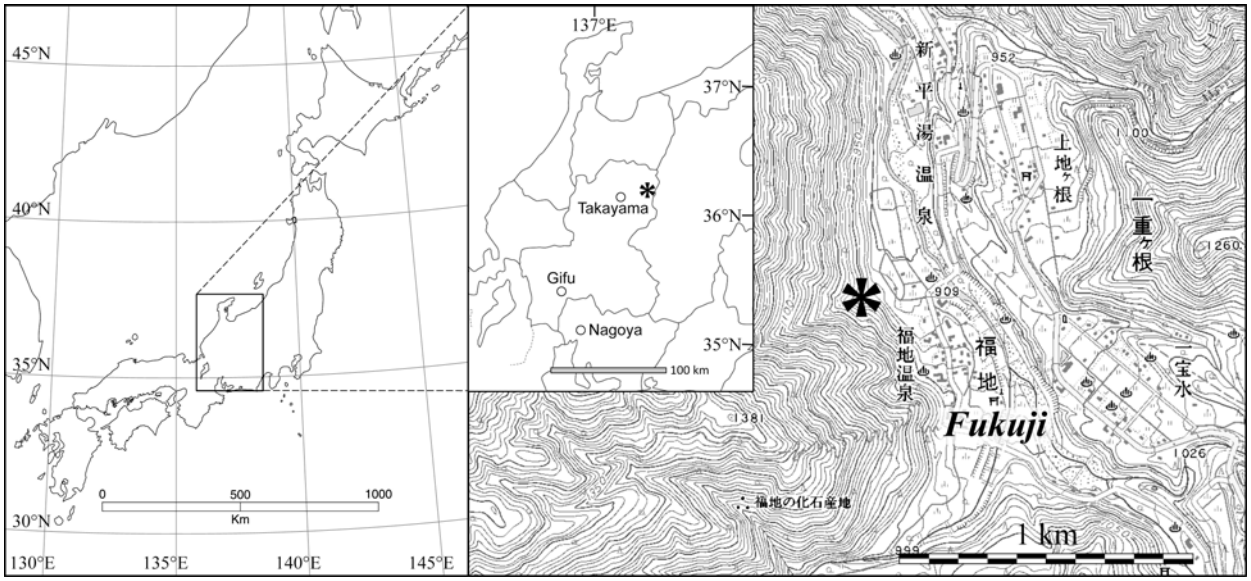
Figure 1. Map showing the fossil locality (asterisk; 36˚13' 37" N, 137˚31'36" E) on 1:25,000 scale topographic map Quadrangle "Yakedake" of the Geospatial Information Authority of Japan (GSI). After Isaji and Okura (2014).

Figure 2. Microgastropods from Kasimovian (late Carboniferous) limestone in Fukuji, Gifu Prefecture, central Japan. **1, 2**, *Serpulospira* sp.; 1, apical view (PS 5961); 2, apical view (PS 5962). **3**, pleurotomarioid gastropod; 3a, oblique lateral view (PS 5966); 3b, apical view (PS 5966). **4**, anomphalid gastropod; 4a, apertural view (PS 5967); 4b, oblique lateral view (PS 5967). **5, 6**, naticopsid gastropods; 5a, apertural view (PS 5968); 5b, abapertural view (PS 5968); 6, apertural view (PS 5969); **7**, trachyspirid gastropod; 7a, lateral view (PS 5970); 7b, apical view (PS 5970); arrowheads indicating the protoconch-teleoconch boundary. All scale bars = 0.1 mm.

Figure 3. Microgastropods from Kasimovian (late Carboniferous) limestone in Fukuji, Gifu Prefecture, central Japan. **1–3**, goniasmatid gastropods; 1, apertural view (PS 5963); 2, apertural view (PS 5964); 3, abapertural view (PS 5965); **4–9**, orthonematid gastropods; 4,

apertural view (PS 5971); 5, lateral view (PS 5972); 6, lateral view (PS 5973); 7, apertural view (PS 5974); 8, apertural view (PS 5975); 9, apertural view (PS 5976); arrowheads indicating the sinusigera of protoconch; **10**, pseudozygopleurid gastropod; apertural view (PS 5977); **11**, *Leptoptygma* sp; 11a, lateral view (PS 5980); 12b, enlarged oblique apical view (PS 5980). **12, 13**, *Girtyspira*? sp.; 12, apertural view (PS 5978); 13, lateral view (PS 5979). All scale bars = 0.1 mm.

Figure 4. Streptacidid gastropods from Kasimovian (late Carboniferous) limestone in Fukuji, Gifu Prefecture, central Japan. **1, 2**, *Donaldina* sp.; 1, apertural view (PS 5981); 2, apertural view (PS 5982); **3, 4**, *Laxella micra* Pan and Erwin, 2002; 3, apertural view (PS 5983), 4, apertural view (PS 5984), showing one individual broken into two pieces (4a and 4b); **5–7**, *Streptacis* sp.; 5, apertural view (PS 5985); 6, apertural view (PS 5986); 7, lateral view (PS 5987). All scale bars = 0.1 mm.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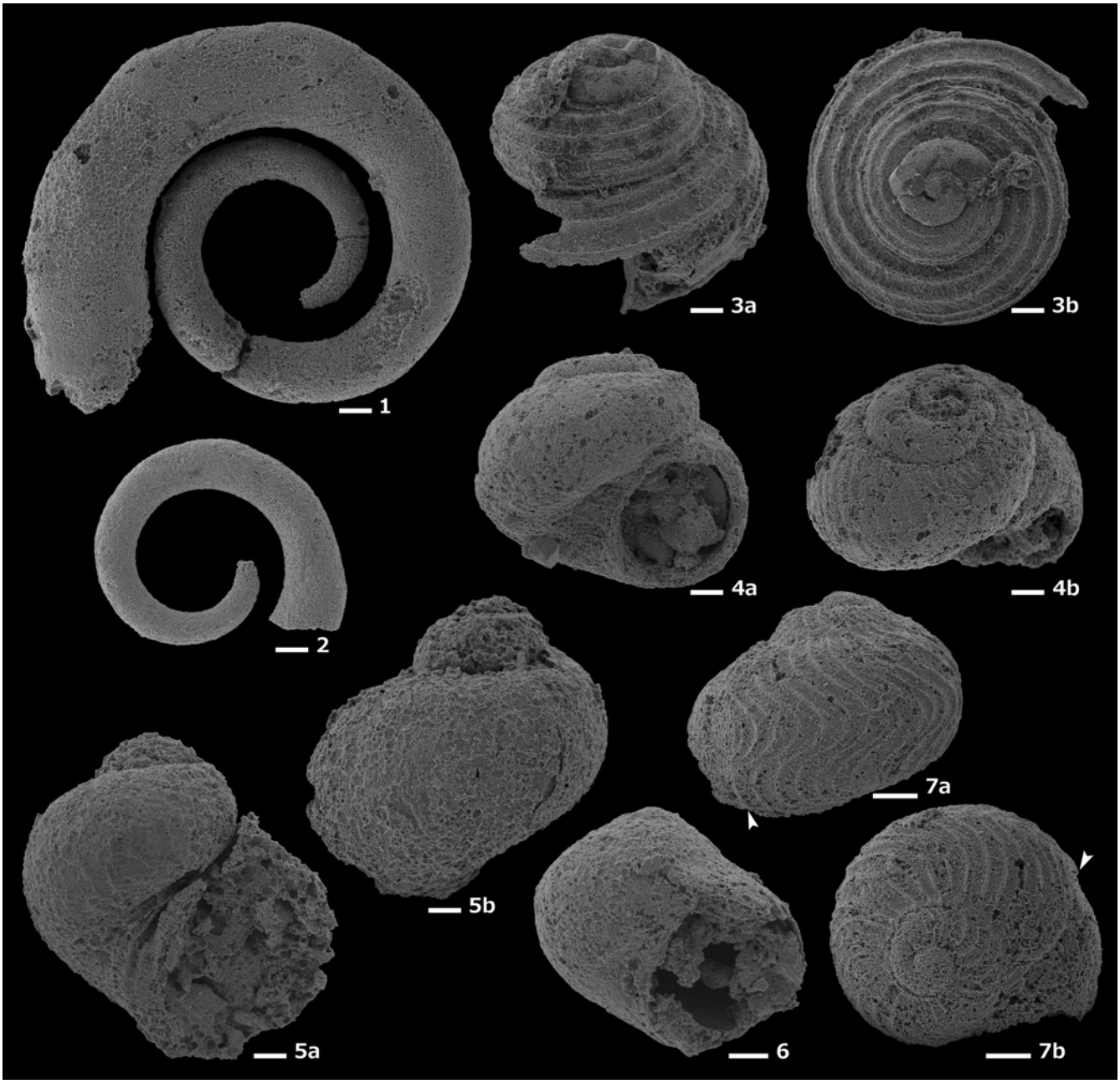
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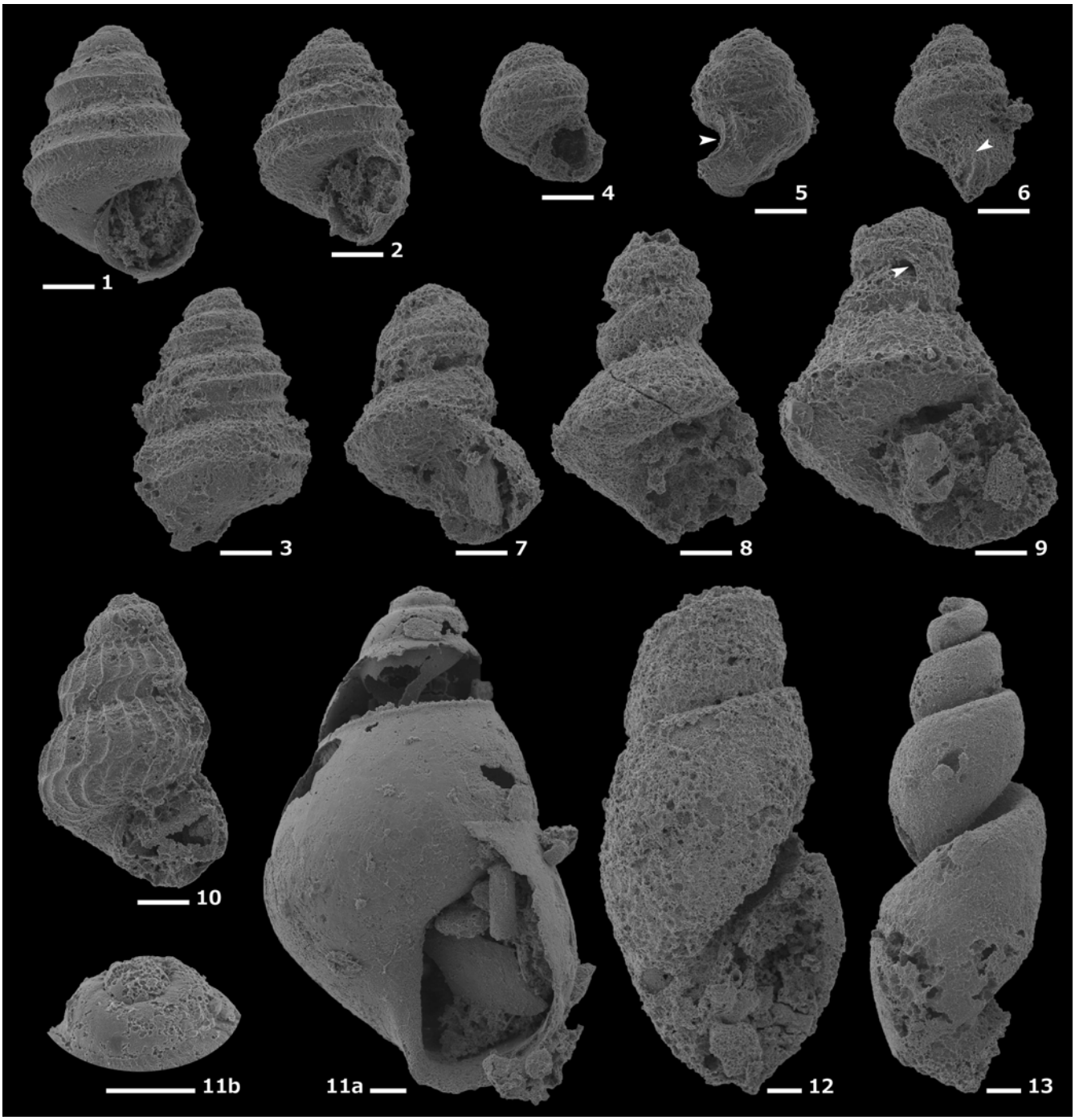
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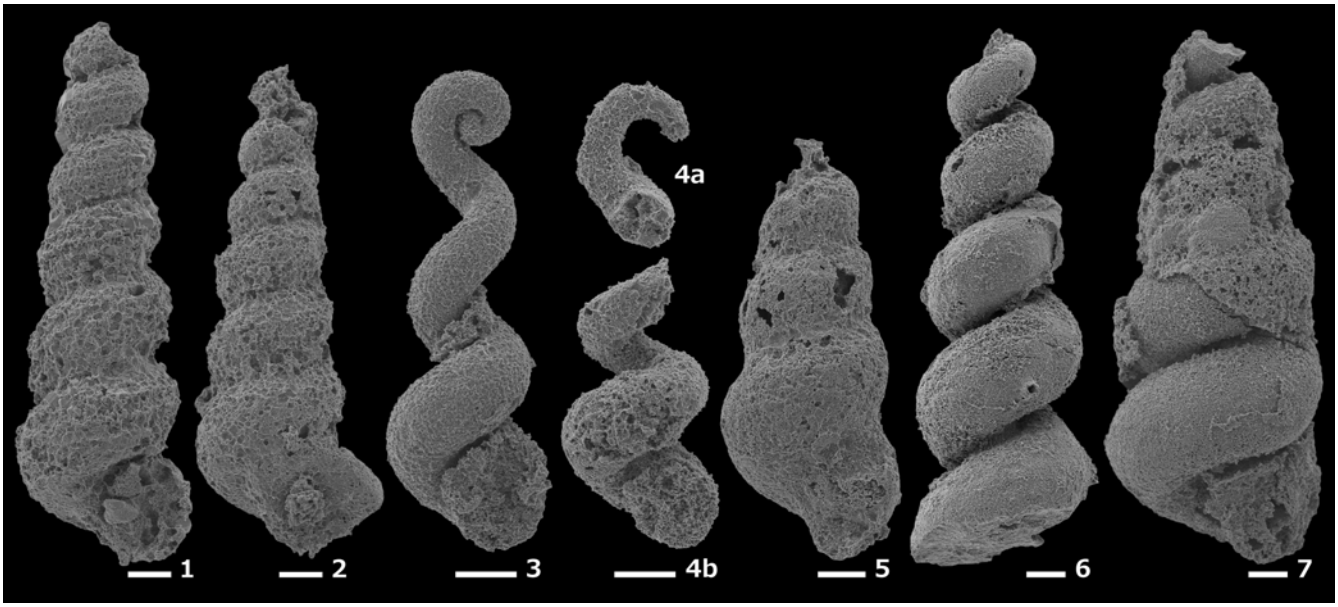
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