ISSN 1349-1237

SCIENCE REPORTS
OF
NIIGATA UNIVERSITY

(GEOLOGY)

No. 28 (2013)

Published
by
The Department of Geology, Faculty of Science
Niigata University, Niigata, Japan

31 March 2013

All communications relating to this report should be addressed to:
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"Science Reports of Niigata University (Geology)"
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Four brachiopod species newly described from the Middle Permian of Kesennuma, South Kitakami Belt, northeast Japan

Jun-ichi TAZAWA* and Hideo ARAKI**

Abstract

Four brachiopod species, *Orbiculoidea jangarensis* Ustritsky, *Yakovlevia kaluzinensis* Fredericks, *Gypospirifer kobiyamai* Tazawa and Araki sp. nov. and *Licharewina arakii* (Hayasaka), are described from the Middle Permian (Wordian) of Kesennuma, South Kitakami Belt, northeast Japan. Among the species, *O. jangarensis, Y. kaluzinensis* and *G. kobiyamai* are Boreal-type species.

Key words: Boreal-type species, brachiopod, Kesennuma, Middle Permian, South Kitakami Belt.

Introduction

The area of Kesennuma in the South Kitakami Belt, northeast Japan (Fig. 1-1) has been a renowned and classic locality for Permian marine invertebrate fossils since the pioneering works of Harada (1890), Yabe (1900) and Yabe and Hayasaka (1915). Many brachiopod species have been previously described from the Permian formations of the Kesennuma area by the following authors: Yabe (1900), Hayasaka (1917, 1922, 1925, 1937, 1960, 1963a, 1963b, 1964, 1966, 1967), Minato (1955), Minato and Nakamura (1956), Nakamura (1972a, 1972b, 1979), Tazawa (1974a, 1974b, 1975, 1979, 1999, 2012), Tazawa and Araki (1984a, 1984b, 1999), Tazawa and Takaizumi (1987), Shen and Tazawa (1997) and Shiino (2009). The stratigraphy of the Permian formations in the Kesennuma area has been studied by Shiida (1940), Kambe and Shimazu (1961), Tazawa (1973, 1975, 1976), Ehiro (1974, 1977) and Misaki

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(Manuscript received 19 December, 2012; accepted 20 January, 2013)

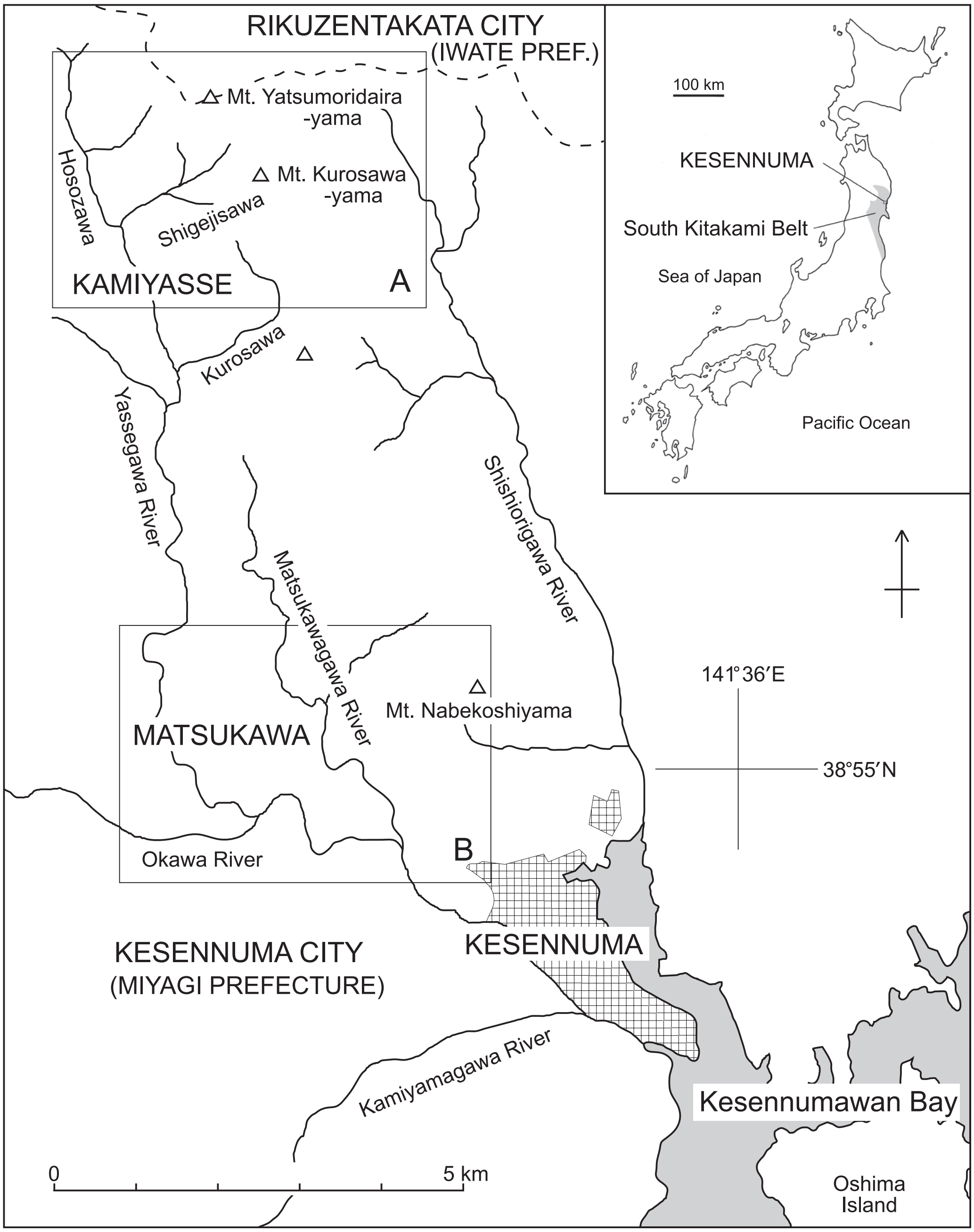

Fig. 1–1. Index map showing the fossil localities of Kamiyasse (A) and Matsukawa (B) in the Kesennuma area, South Kitakami Belt, northeast Japan.

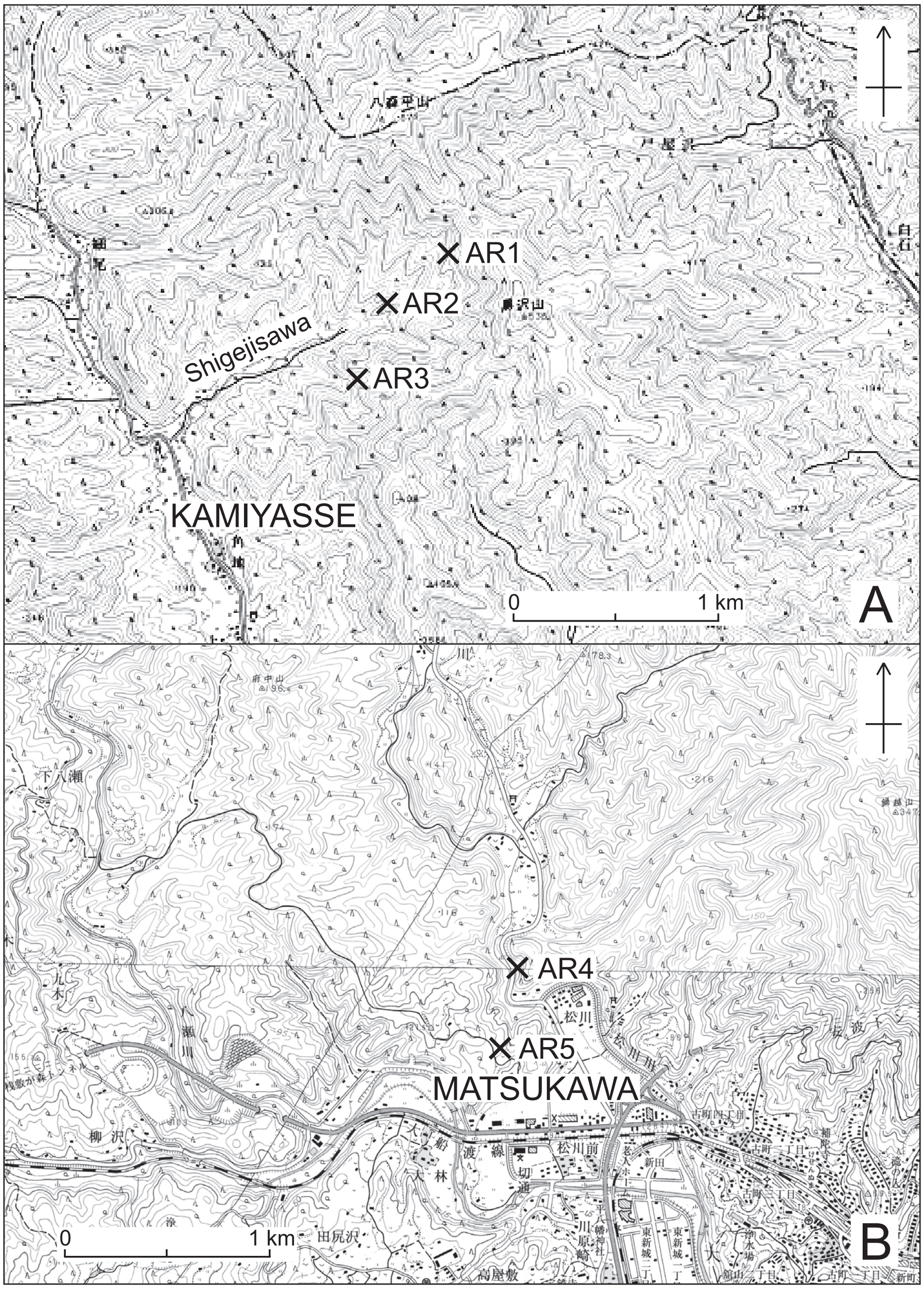

Fig. 1–2. (Continue) Index map showing the fossil localities AR1, AR2 and AR3 in Kamiyasse (A), and AR4 and AR5 in Matsukawa (B). Using the topographical maps of "Shishiori" and "Kesennuma" scale 1 : 25,000 published by the Geospatial Information Authority of Japan.

and Ehiro (2004).

The brachiopod fossils treated in the present paper were collected by the second author (H. A.) from grey to greenish grey, fine-grained sandstone of the upper part of the lower Kanokura Formation (equivalent to the lower part of the Kamiyasse Formation of Misaki and Ehiro, 2004) at Shigejisawa (AR1, AR2, AR3) in Kamiyasse, and at Anabuchi (AR4) and Matsukawamae (AR5) in Matsukawa (see Figs. 1-1, 1-2). The fossil horizons are within the *Monodiexodina matsubaishi* Zone of Tazawa (1976) and the *Leptodus nobilis* Zone of Minato et al. (1979). These fossil zones are now correlated with the Wordian or Midian, based on the assemblages of ammonoids (Ehiro and Misaki, 2005) and fusulinids (Kobayashi et al., 2009), respectively.

The brachiopods described herein are *Orbiculoidea jangarensis* Ustritsky, 1960, *Yakovlevia kaluzinensis* Fredericks, 1925, *Gypospirifer kobiyamai* Tazawa and Araki sp. nov. and *Licharewina arakii* (Hayasaka, 1963a). It is noteworthy that the three of these species, *O. jangarensis, Y. kaluzinensis* and *G. kobiyamai* are Boreal-type species that inhabited in the middle- to high-latitude areas of the Northern Hemisphere in the Middle Permian. The palaeobiogeographical data support the Middle Permian reconstruction reported by Tazawa (2000, 2007), in which the South Kitakami region was located immediately east of North China (Sino-Korea) at mid-latitudes in the Northern Hemisphere.

All the specimens described in this paper are housed in the Kesennuma Board of Education (tentatively at Old Tsukitate Junior High School), Kesennuma City, Miyagi Prefecture, as indicated by the prefix to the registered numbers (KCG).

Systematic descriptions

Order Lingulida Waagen, 1885
Superfamily Discinoidea Gray, 1840
Family Discinidae Gray, 1840
Genus *Orbiculoidea* d'Orbigny, 1847

Type species.—*Orbicula forbessi* Davidson, 1848.

Orbiculoidea jangarensis Ustritsky, 1960
Fig. 2.1

Orbiculoidea jangarensis Ustritsky, 1960, p. 98, pl. 1, figs. 10–12; Ustritsky and Tschernyak, 1963, p. 68, pl. 1, figs. 5–9; Ifanova, 1972, p. 84, pl. 1, figs. 26, 27; Kalashnikov, 1983, p. 204, pl. 45, figs. 3, 4; Kalashnikov, 1986, pl. 116, fig. 2; Kalashnikov, 1993, p. 14, pl. 2, fig. 13; pl. 3, fig. 5; pl. 4, fig. 3.

Orbiculoidea sp. Hayasaka, 1963a, p. 479, fig. 1.
Orbiculoidea cf. *jangarensis* Ustritsky: Tazawa, 2001, p. 288, fig. 6.11.

Material.—One specimen from locality AR3, external mould of a ventral valve, KCG007.

Description.—Shell large size for genus, subcircular in outline, widest at slightly anterior to midlength; length 24 mm, width 19 mm. Ventral valve almost flat; pedicle opening about 7 mm length, occupying about a quarter valve length in posteriorly; concentric growth lines fine, regular and numerous, numbering 13–14 in 5 mm at anterior portion of valve.

Remarks.—This specimen is referred to *Orbiculoidea jangarensis* Ustritsky, 1960, originally described by Ustritsky (1960) from the upper Talatin Formation (upper Artinskian or Kungurian) of Pay Khoy, northern Russia in size and shape of the shell and in having numerous fine growth lines on the ventral valve. Both species, *Orbiculoidea* sp., described by Hayasaka (1963a) from the lower Kanokura Formation of Omotematsukawa in the Kesennuma area, South Kitakami Belt, northeast Japan, and *Orbiculoidea* cf. *jangarensis* Ustritsky, 1960, described by Tazawa (2001) from the Moribu Formation of the Moribu area, Hida Gaien Belt, central Japan may be conspecific with the present species.

Distribution.—Lower Permian (Artinskian) to Middle Permian (Wordian): northern Russia (northern Urals, Pay Khoy, Pechora Basin, Taimyr), northeast Japan (Kesennuma in the South Kitakami Belt) and central Japan (Moribu in the Hida Gaien Belt).

Order Productida Sarytcheva and Sokolskaya, 1959
Suborder Productidina Waagen, 1883
Superfamily Linoproductoidea Stehli, 1954
Family Yakovleviidae Waterhouse, 1975
Genus *Yakovlevia* Fredericks, 1925

Type species.—*Chonetes* (*Yakovlevia*) *kaluzinensis* Fredericks, 1925.

Yakovlevia kaluzinensis Fredericks, 1925
Fig. 2.2

Chonetes (*Yakovlevia*) *kaluzinensis* Fredericks, 1925, p. 7, pl. 2, figs. 64–66.
Yakovlevia kaluzinensis Fredericks: Kotlyar, 1961, text-figs. 1–3; Licharew and Kotlyar, 1978, pl. 14, figs. 1, 2; Manankov, 1998, pl. 8, figs. 18, 19; Tazawa, 1999, p. 90, figs. 3.7–3.15; Tazawa, 2001, p. 291, figs. 6.20–6.25; Tazawa, 2008b, p. 49, fig. 7.14.
Yakovlevia sp. Horikoshi et al., 1987, fig. 3.

Material.—One specimen from locality AR5, internal mould of a ventral valve, KCG008.

Remarks.—The single ventral valve specimen from Matsukawamae in the Kesennuma area is large in size (length 49 mm, width 58 mm), transversely rectangular in outline, and strongly convex in lateral profile. Interior of ventral valve with a pair of small, elongate subtrigonal and dendritic adductor scars and two large, flabellate and radially striated

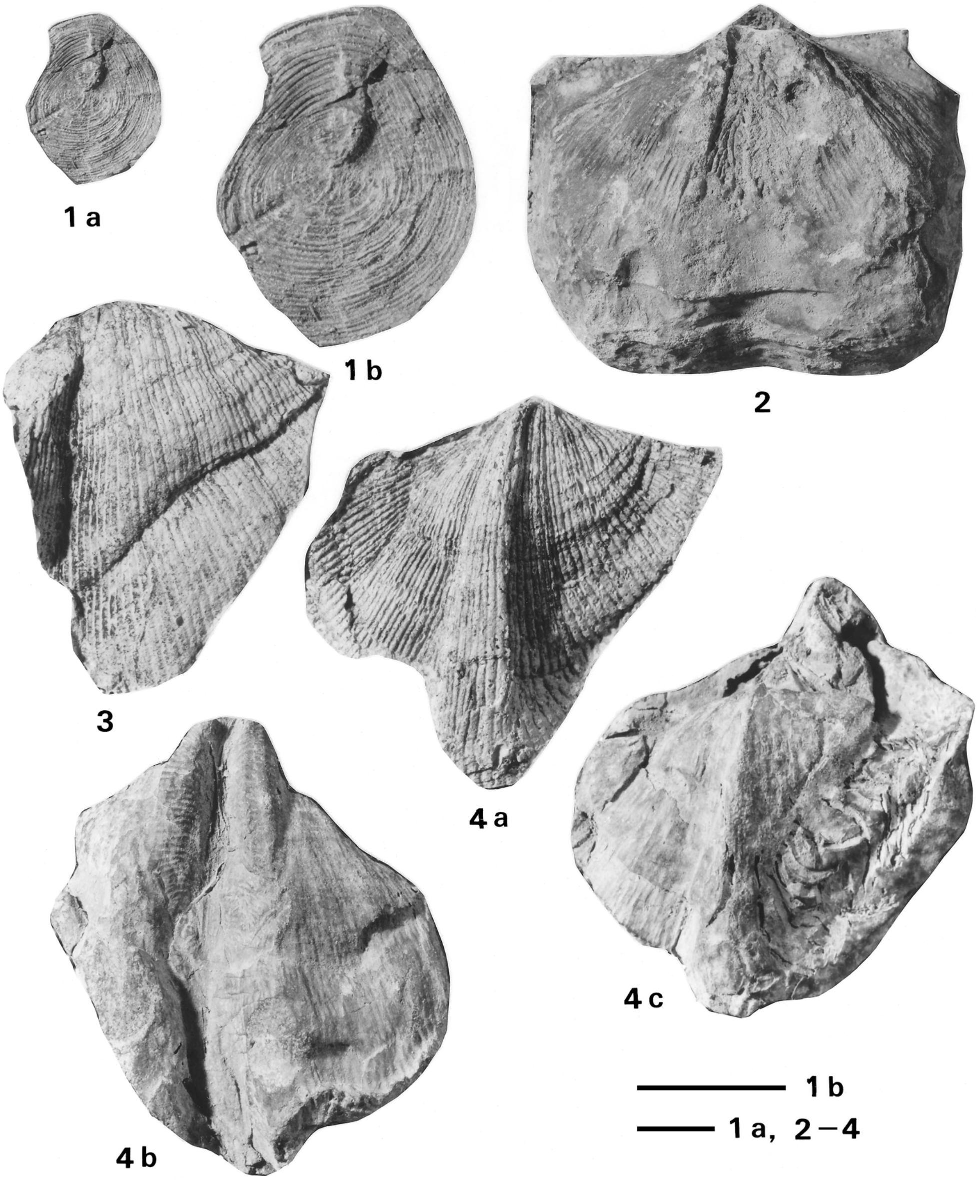

Fig. 2. 1. *Orbiculoidea jangarensis* Ustritsky, 1a, 1b: external mould of ventral valve, KCG007. 2: *Yakovlevia kaluzinensis* Fredericks, internal mould of ventral valve, KCG008. 3, 4: *Gypospirifer kobiyamai* Tazawa and Araki sp. nov., 3: external latex cast of ventral valve, KCG002 (paratype), 4a, 4b, 4c: external latex cast of dorsal valve, internal mould of ventral valve, and internal mould of dorsal valve, KCG001 (holotype). Scale bars represent 1 cm.

diductor scars. This specimen is referred to *Yakovlevia kaluzinensis* Fredericks, 1925, from the Chandalaz Formation of the Vladivostok area, South Primorye, eastern Russia, in size, shape and internal structures of the ventral valve.

Yakovlevia impressa (Toula, 1875, p. 236, pl. 5, fig. 11), from the Middle Permian of Spitsbergen, differs from *Y. kaluzinensis* in having larger and more prominent ears.

Distribution.—Middle Permian (Kungurian) to Upper Permian (Lopingian): southeastern Mongolia (Mt. Dzhirem-Ula), eastern Russia (South Primorye), northeast Japan (Kesennuma in the South Kitakami Belt), central Japan (Moribu in the Hida Gaien Belt) and southwest Japan (Mizukoshi, central Kyushu, western extension of the Hida Gaien Belt).

Order Spiriferida Waagen, 1883
Suborder Spiriferidina Waagen, 1883
Superfamily Spiriferoidea King, 1846
Family Trigonotretidae Schuchert, 1893
Subfamily Neospiriferinae Waterhouse, 1968
Genus *Gypospirifer Cooper* and Grant, 1976

Type species.—*Gypospirifer nelsoni* Cooper and Grant, 1976.

Gypospirifer kobiyamai sp. nov.
Figs. 2.3, 2.4

Spirifer fasciger var. *simplex* Grabau: Kobiyama, 1956, fig. 4.
Neospirifer fasciger (Keyserling): Hayasaka, 1960, p. 42, pl. 2, figs. 1, 2 only; Yanagida, 1963, p. 71, pl. 8, figs. 3, 6; pl. 9, fig. 3 only; Koizumi, 1979, pl. 1, fig. 16 only.
Neospirifer aff. *cameratus* Morton: Yanagisawa, 1967, p. 91, pl. 2, fig. 11.
Neospirifer striato-paradoxus (Toula): Licharew and Kotlyar, 1978, pl. 18, fig. 1; Lee et al., 1980, p. 412, pl. 177, figs. 3, 6, 9.
Gypospirifer volatilis Duan and Li: Tazawa, 2001, p. 302, figs. 8.23–8.26; Tazawa and Hasegawa, 2007, p. 7, figs. 4.8–4.12, 5.1, 5.2; Tazawa, 2008a, p. 39, fig. 6.17; Tazawa, 2008b, p. 54, figs. 9.3–9.7.

Etymology.—Named for Mr. Moto Kobiyama who first documented the present species as *Spirifer fasciger* var. *simplex* Grabau, 1936 from the Upper Permian of the Takakurayama area, Abukuma Mountains, northeast Japan.

Material.—Two specimens from locality AR1: (1) internal mould of a conjoined shell, with external mould of the dorsal valve, KCG001 (holotype); (2) external mould of a ventral valve, KCG002 (paratype).

Diagnosis.—Large *Gypospirifer* with narrow, deep ventral sulcus and narrow, high dorsal fold, and ornamented with relatively fine costae (10–11 in 10 mm at midlength of ventral valve) on both valves.

Description.—Shell large size for genus, transversely semielliptical in outline, with greatest width at hinge; length 49 mm, width about 65 mm in the better preserved dorsal valve specimen (KCG001). Ventral valve moderately convex in lateral profile, most convex at umbonal region; umbo strongly incurved; interarea high for genus, slightly concave; sulcus narrow and deep, originating at umbo and rapidly widening anteriorly. Dorsal valve gently convex in lateral profile; fold narrow and high. External surface of ventral valve ornamented with numerous fine costae and concentric ornament of a few, strong, irregular rugae and very fine growth lines; costae subridged and subtly fasciculate; numbering 10–11 costae in 10 mm at about midlength. External ornament of dorsal valve similar to that of opposite valve. Ventral interior with a pair of thick, short dental plates and a deeply impressed, large, elongate ovate muscle field. Dorsal interior with a pair of widely divergent hinge sockets and small, striated cardinal process.

Remarks.—Shells of *Gypospirifer kobiyamai* sp. nov. were first figured by Kobiyama (1956) from the Takakurayama Formation of the Takakurayama area, Abukuma Mountains, northeast Japan as *Spirifer fasciger* var. *simplex* Grabau, 1936, and subsequently described by Hayasaka (1960) from the lower Kanokura Formation of Tagara and Takayashiki in the Kesennuma area as *Neospirifer fasciger* (Keyserling, 1846). The neospiriferid species, *Neospirifer simplex* and *Neospirifer fasciger* are, however, readily distinguished from *G. kobiyamai* by their much smaller dimensions.

Gypospirifer kobiyamai sp. nov. most resembles *Gypospirifer gryphus* Cooper and Grant (1976, p. 2211, pl. 591, figs. 1–5), from the Graham Formation of west Texas, in size and shape of the shell, but the Texas species differs from the present new species in having shallower sulcus and coarser costae on the ventral valve.

Gypospirifer volatilis Duan and Li (1985, p. 127, 207, pl. 48, figs. 1, 2; pl. 49, figs. 1, 2), from the Zhesi (Jisu) Formation of Zhesi, Inner Mongolia, north China, differs from *G. kobiyamai* in having much broader and higher fold on the dorsal valve.

Distribution.—Middle Permian (Wordian) to Upper Permian (Lopingian): northeast China (Heilongjiang), eastern Russia (South Primorye), northeast Japan (Kesennuma and Takakurayama in the South Kitakami Belt), central Japan (Moribu in the Hida Gaien Belt) and southwest Japan (Mizukoshi, central Kyushu, western extension of the Hida Gaien Belt).

Order Spiriferinida Ivanova, 1972

Suborder Cyrtinidina Carter and Johnson, 1994

Superfamily Cyrtinoidea Fredericks, 1911

Family Cyrtinidae Fredericks, 1911

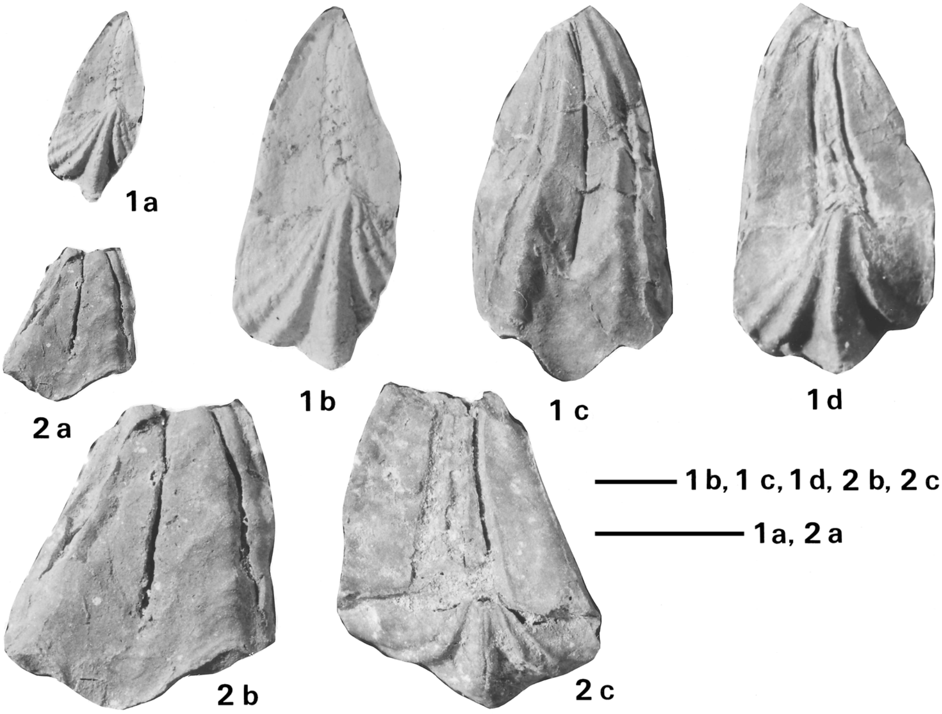

Fig. 3. 1, 2: *Licharewina arakii* (Hayasaka), 1a, 1b, 1c, 1d: external latex cast of dorsal valve with interarea of ventral valve, internal mould of ventral valve, and internal mould of dorsal valve with interarea of ventral valve, KCG004, 2a, 2b, 2c: internal mould of ventral valve, and internal mould of dorsal valve with interarea of ventral valve, KCG006. Scale bars represent 1 cm.

Genus *Licharewina* Kotlyar, Zakharov and Polubotko, 2004

Type species.—*Licharewina praetriassica* Kotlyar, Zakharov and Polubotko, 2004.

Licharewina arakii (Hayasaka, 1963a)
Figs. 3.1, 3.2

Geyerella arakii Hayasaka, 1963a, p. 481, figs. 2, 3.

Material.—Two specimens from localities AR2 and AR4: (1) internal mould of a conjoined shell, with external mould of the dorsal valve and interarea of the ventral valve, KCG004; (2) internal mould of a conjoined valve, KCG006.

Description.—Shell large size for genus, elongate subtrigonal in outline; hinge straight, wide, slightly shorter than greatest width which occurring at about four-fifths length from umbo, in another way, at about midlength of dorsal valve; length about 27 mm, width 19 mm in the better preserved specimen (KCG004). Ventral valve highly pyramidal and slightly bent; interarea very high, flat to slightly concave, with narrow delthyrium covered by imbricated plates; sulcus narrow and deep. Dorsal valve gently convex in lateral profile; fold narrow and high. External surface of dorsal valve ornamented by simple, strong costae with subangular crests, counted 3 on each lateral slope. Ventral interior with a long, thin median septum, extending to about three-quarters length of valve and short, strong, subparallel dental plates. Internal surface of both valves covered by numerous very fine pustules (indicate punctate shell).

Remarks.—*Licharewina arakii* (Hayasaka, 1963a) was first described by Hayasaka (1963a) as *Geyerella arakii* Hayasaka, 1963a, from the lower Kanokura Formation of Omotematsukawa (Anabuchi) in the Kesennuma area, South Kitakami Belt. In the present paper, the genus is changed to *Licharewina* from *Geyerella*, on the basis of its external and internal characters, highly pyramidal and slightly bent ventral valve, very high interarea with delthyrium covered by imbricated plates, and in having some simple strong costae, but lacking concentric rugae or growth lines on the both ventral and dorsal valves.

The type species, *Licharewina praetriassica* Kotlyar, Zakharov and Polubotko (2004, p. 522, figs. 6.13–6.20), from the Upper Permian (Changhsingian) of the northwestern Caucasus Mountains, differs from the present species in its much smaller size.

Licharewina josephinae (Gemmellaro, 1899), redescribed and refigured by Shen and Clapham (2009, p. 732, pl. 6, figs. 1–15), from the Episkopi Formation (Wuchiapingian) of Hidra Island, Greece, differs from *L. arakii* in its smaller size and less pyramidal outline of the shell.

Distribution.—Middle Permian (Wordian): northeast Japan (Kesennuma in the South Kitakami Belt).

Acknowledgements

We thank Toshiyuki Kurihara of the Graduate School of Science and Technology, Niigata University for drawing the figures; Atsushi Matsuoka of the Department of Geology, Niigata University for his critical review of the manuscript; staff of the Kesennuma Board of Education for registration of the brachiopod fossil specimens.

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Early Carboniferous tabulate corals from the *Endothyra* Zone of the Omi Limestone, Niigata Prefecture, central Japan

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Abstract

Four species of tabulate corals were found from impure limestone, which characteristically contains lithoclasts of basaltic rocks, occurring within the late Visean (middle Early Carboniferous) *Endothyra* Zone of the Omi Limestone near Fukugakuchi Cave in the Omi area, Niigata Prefecture, central Japan. They include *Acaciapora* sp. indet., *Sinkiangopora*? sp. indet., *Mandulapora*? sp. indet., and *Multithecopora fukugakuchiensis* sp. nov. A possible phylogenetic relationship between the new species and *Multithecopora hiratai* Niko, 2006, from the Akiyoshi Limestone Group is recognized. Previously, the genera, *Acaciapora* and *Multithecopora*, were not recorded from the Omi Limestone.

Kew words: *Acaciapora, Mandulapora, Multithecopora fukugakuchiensis* sp. nov., *Sinkiangopora*, Tabulata, Visean.

Introduction

Following our previous paper, Niko et al. (2010), this concerns additional four species of tabulate corals from the late Visean (middle Early Carboniferous) *Endothyra* Zone (Tazawa et al., 2002) of the Omi Limestone. Specimens examined in this study were collected from locality E4 near Fukugakuchi Cave in the Omi area, Itoigawa, Niigata Prefecture, central Japan (Fig. 1). Lithofacies of this locality is reddish to brownish impure limestone that characteristically contains lithoclasts of basaltic rocks and is generally brecciated. Repository of the present material is the Fossa Magna Museum, under the catalog numbers FMM2041 – 2065.

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(Manuscript received 2 February, 2013; accepted 3 March, 2013)

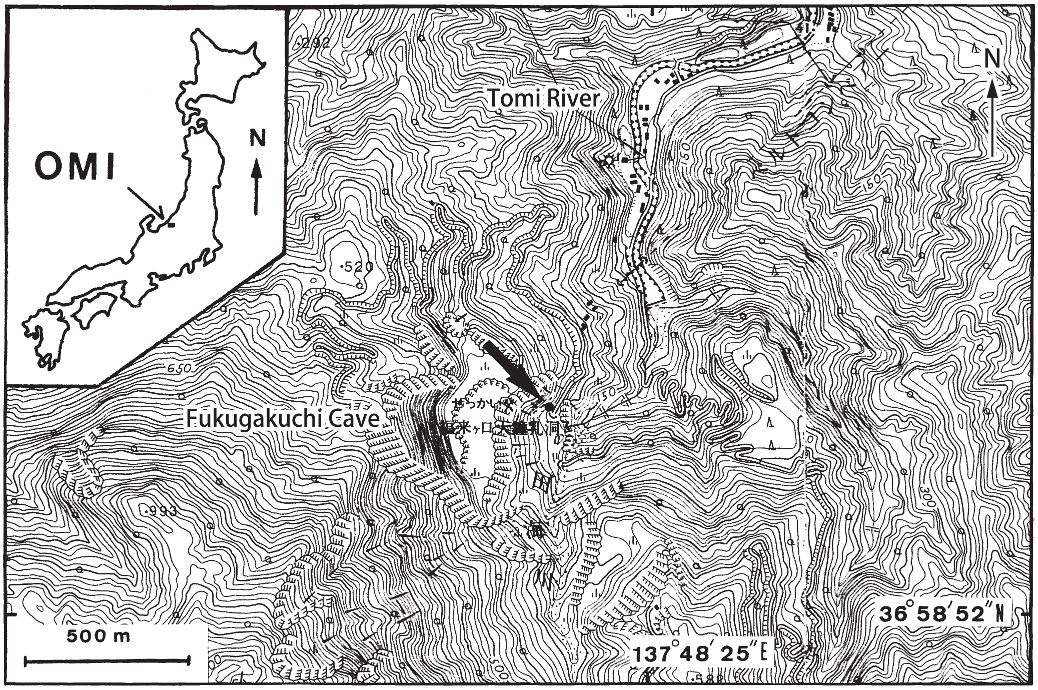

Fig. 1. Index map showing the fossil locality (arrow; loc. E4) in the Omi area, Niigata Prefecture on the topographical map of "Kotaki" scale 1:25,000 published by the Geospatial Information Authority of Japan.

Systematic Paleontology

Subclass Tabulata Milne-Edwards and Haime, 1850

Order Favositida Wedekind, 1937

Suborder Favositina Wedekind, 1937

Superfamily Pachyporoidea Gerth, 1921

Family Pachyporidae Gerth, 1921

Genus *Acaciapora* Moore and Jeffords, 1945

Type species.—Michelinia subcylindrica Mather, 1915.

Acaciapora sp. indet.

Figs. 2-1, 2

Material.—FMM2041 – 2043.

Description.—Three fragmentary branches indicating cylindrical outlines are available for study; their diameters exceptionally small, 2.4 – 2.9 mm; there are 8 – 10 corallites in transverse sections. Corallites subprismatic to nearly cylindrical in parts, gradually

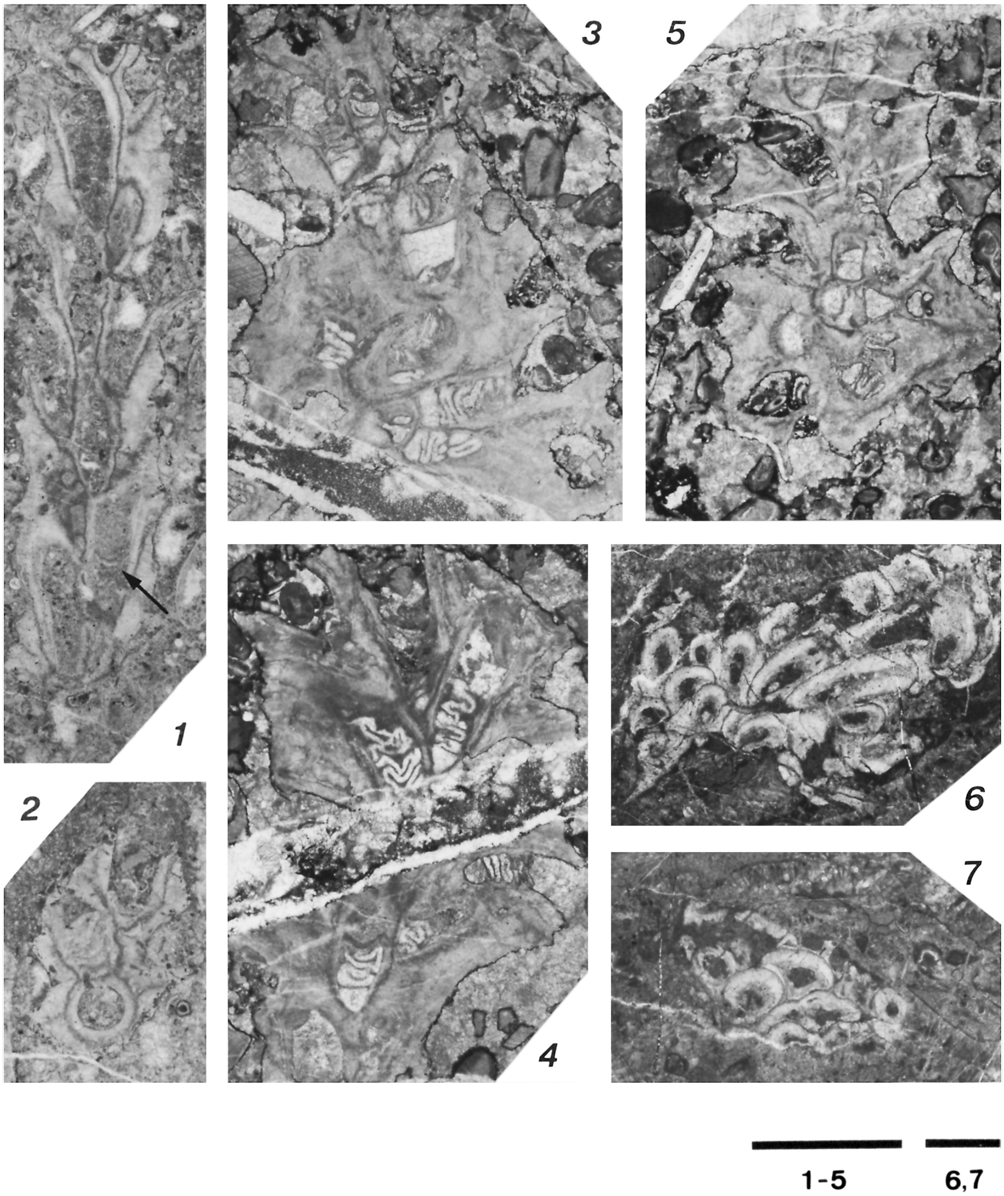

Fig. 2. 1, 2: *Acaciapora* sp. indet., thin sections. **1**, FMM2041, longitudinal section of branch, arrow indicates squamula, **2**, FMM2042, oblique (near transverse) section of branch. **3–5**: *Sinkiangopora*? sp. indet., thin sections, FMM2044, oblique sections of branch. **6, 7**: *Mandulapora*? sp. indet., thin sections, FMM2045, longitudinal sections of corallum. Scale bars = 2 mm.

divergent, and cerioid in arrangement; approximate diameters of corallites are 0.6–1.2 mm; calices strongly oblique. Intercorallite walls thickened, attaining 0.44 mm in peripheral zone of branch; mural pores occur on corallite faces; squamulae uncommon, relatively wide;

profiles of squamulae indicate weak proximal concavities; no apparent septal spine and tabula are recognized.

Discussion.—This species is attributed to *Acaciapora* based on its slender branches consisting of a small number of corallite counts in transverse sections and the presence of the squamulae. *Acaciapora* sp. indet. represents the first record of the genus from the Omi Limestone.

Acaciapora kanmerai Niko (2011, p. 10, 11, pl. 1, figs. 1 – 7) from the transitional facies (Early Carboniferous; probably late Tournaisian) of the lowest pyroclastic and the main limestone units in the Akiyoshi Limestone Group, Yamaguchi Prefecture is sufficiently similar to the present Omi species except for differences of corallum and corallite diameters. Although there is a possibility that the both species represent different growth stages of an identical taxon, the material is not enough to solve the problem.

Genus *Sinkiangopora* Chi, 1961

Type species.—*Sinkiangopora sinkiangensis* Chi, 1961.

Sinkiangopora? sp. indet.

Figs. 2-3 – 5

Material.—FMM2044.

Remarks.—A single specimen is present, which probably represents a fragment of the cylindrical(?) branch. Accurate corallite shape is not clear due to its insufficient preservation and poor orientation of examined thin sections. The questionable assignment to *Sinkiangopora* is based upon the possession of the strongly thickened intercorallite walls, the well-developed squamulae, and the complete tabulae.

Order Auloporida Sokolov, 1947

Superfamily Syringoporoidea Fromentel, 1861

Family Periphaceloporidae Hill, 1981

Genus *Mandulapora* Ding *in* Ding et al., 1984

Type species.—*Mandulapora permica* Ding *in* Ding et al., 1984.

Mandulapora? sp. indet.

Figs. 2-6, 7

Material.—FMM2045.

Remarks.—This species is represented by a single fragmentary specimen. Its adherent nature of the corallum and alveolitoid-like corallites suggest a relationship with *Mandulapora*, but available material is too limited to the generic identification.

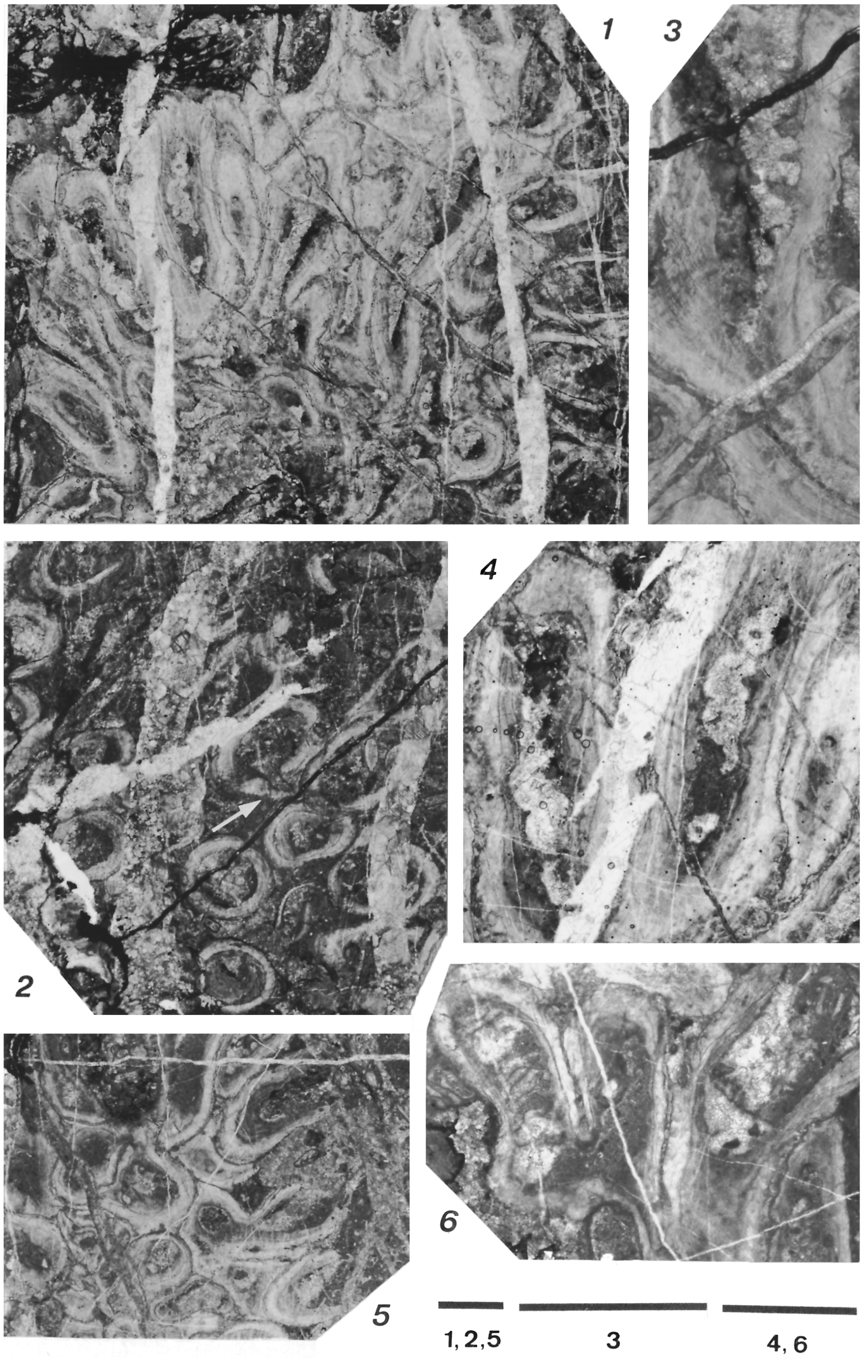

Fig. 3. *Multithecopora fukugakuchiensis* sp. nov., thin sections. **1 – 4**: holotype, FMM2061. **1,** longitudinal section of corallum, **2**, transverse section of corallum, arrow indicates connecting process, **3**, partial enlargement to show intercorallite wall structure and details of septal spines, longitudinal section, **4**, partial enlargement of Fig. 3-1, showing thickened intercorallite walls and well-developed septal spines. **5, 6**: paratype, FMM2063. **5**, transverse section of corallum, **6**, partial enlargement to show details of connecting process and tabulae. Scale bars = 2 mm.

Family Multithecoporidae Sokolov, 1950

Genus *Multithecopora* Yoh, 1927

Type species.—Multithecopora penchiensis Yoh, 1927.

Multithecopora fukugakuchiensis sp. nov.

Figs. 3-1 – 6

[?] *Pseudoromingeria kotoi* (Yabe and Hayasaka); Yoshida et al., 1987, p. 229 (listed without illustration and description).

Etymology.—The specific name is derived from a famous limestone cave, named Fukugakuchi, near the type locality.

Material.—Holotype, FMM2061, from which two thin sections were prepared. Thirteen thin sections were studied from the three paratypes, FMM2052, 2063, 2065. In addition, 16 fragmentary and poorly preserved specimens, FMM2046 – 2051, 2053 – 2060, 2062, 2064, were also examined.

Diagnosis.—Species of *Multithecopora* with phacelo-cerioid coralla and approximately 2.0 mm in diameter of adult corallites; usual corallite walls have 0.27 – 0.79 mm in thickness in phaceloid portion; septal spines common to well-developed; tabulae occurrence variable, almost absent to crowded; complete tabulae most common.

Description.—Coralla have somewhat variable growth forms indicating nodular, domical to turf-like, whose approximate measurements are 51 mm in diameter and 15 mm in height in the holotype and 25 mm in diameter and 7 mm in height in the largest paratype (FMM2065); contiguous corallites frequently occur to form phacelo-cerioid colonies. Corallites prostrate in basal portion of corallum, then they turn upward in growth direction; transverse sections of corallites are circular in phaceloid or subtrapezoidal, fan-shaped to indistinct polygonal in cerioid portions; corallite diameters 1.03 – 2.51 mm, with 2.0 mm mean in adult ones; calices faintly inflated in their rims with very deep calical pits; increase of new corallite is probably bifurcate; connecting processes very rare, relatively thick in diameter with approximately 0.6 – 0.9 mm; length of processes are variable, ranging approximately 0.1 – 0.5 mm; diameters of connecting canals are 0.13 – 0.36 mm. Corallite walls composed of thin epitheca and inner layer of stereoplasm in phaceloid and median dark line (fused epitheca) and stereoplasm on its each side in cerioid portions; in addition, stereoplasm differentiated inner darker and outer more transparent layers; microstructure of stereoplasmic layers is lamellar; tabularia (lumina) narrowed by thickening of stereoplasm; wall thicknesses usually range 0.27 – 0.79 mm in phaceloid and attain 1.00 mm as intercorallite wall in cerioid portions; septal spines common to well-developed having thick rod- to needle-like shapes of protrude portions into tabularium, 0.15 – 0.25 mm in length; tabulae variable in mode of occurrence, almost absent to crowded, commonly complete with nearly flat to weakly sagging (concave proximally) profiles.

Discussion.—The new species records the first occurrence of *Multithecopora* from the Omi Limestone. The other named species of the genus from Japan, *M. hiratai* Niko (2006, p. 2, 3, pl. 1, figs. 1 – 5) from the Akiyoshi Limestone Group, Yamaguchi Prefecture and *M. yabei* Niko (1998, p. 124, 126, figs. 3 A, 7G, 8 A – D) from the Ichinotani Formation, Gifu Prefecture, have less developed cerioid portions than does *M. fukugakuchiensis* sp. nov. Among the previously known two species, the Early Carboniferous (late Tournaisian) species, *M. hiratai*, indicates a possible phylogenetic relationship with *M. fukugakuchiensis* because of its corallite diameters (approximately 1.9 mm) and wall thickness (0.10 – 0.73 mm) are nearly identical with measurements of *M. fukugakuchiensis*. The mode of occurrence and shape of the septal spines of *M. hiratai* are also similar to those of the new species.

Locality of *Pseudoromingeria kotoi* in the Yoshida et al. (1987)'s list situates stratigarphically a few meters above of the present locality E4 and also belongs to the *Endothyra* Zone (Yoshida and Okimura, 1992). They were unaware of the living period of this aulocystid species whose types were described from the Capitanian (late Middle Permian) strata of the Akasaka Limestone, Gifu Prefecture (Yabe and Hayasaka, 1915; Niko, 2009). Because gross corallite and corallum morphologies in *Pseudoromingeria* and *Multithecopora* show some similarities, there is a possibility that *P. kotoi* in the Omi Limestone was a misidentification for *M. fukugakuchiensis*.

Acknowledgments

We sincerely thank Messrs. M. Okura, Y. Furumi and Y. Ota for making available collections in the Omi area. Our appreciations are also extended to Myojo Cement Co., Ltd. for allowing us access to locality E4. Kind reviews by Drs. I. Niikawa and A. Matsuoka served to improve this paper.

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Late Jurassic radiolarians from the Zhongba melange in the Yarlung–Tsangpo suture zone, southern Tibet

Xin LI*, Yalin LI*, Chengshan WANG* and Atsushi MATSUOKA**

Abstract

The Zhongba melange along the Yarlung–Tsangpo suture zone, southern Tibet, is composed mainly of red bedded chert and sandstone in addition to subordinate mudstone with blocks of augite peridotite, gabbro, basalt, limestone, and chert. The chert from the mélange yields well-preserved radiolarian fossils that can be assigned to the *Hsuum maxwelli* zone (JR 7) of Kimmeridgian (Late Jurassic) age. This evidence enables the biostratigraphic age determination of this melange. The radiolarian assemblage is older than microfossils previously reported from this melange.

Key words: Radiolaria, melange, Kimmeridgian, Jurassic, Tibet.

Introduction

The Yarlung–Tsangpo suture zone in southern Tibet, which separates Eurasian and Indian continents, has been interpreted as marking the history of the Neo-Tethys Ocean. The former >4000–km-wide Tethys Ocean was closed along the Indus–Yarlung–Tsangpo suture zone during the Cenozoic collision between the two continents (Fig. 1). Much of this oceanic crust was lost or destroyed during its collision and subduction. The application of radiolarian biostratigraphy along this suture zone sheds light on the evolution of the Neo-Tethys Ocean.

Much data about radiolarians from the remnants of the Neo-Tethys Ocean have been reported in many studies: Zedong (Wang et al., 2002; McDermid et al., 2002; Aitchison et al.,

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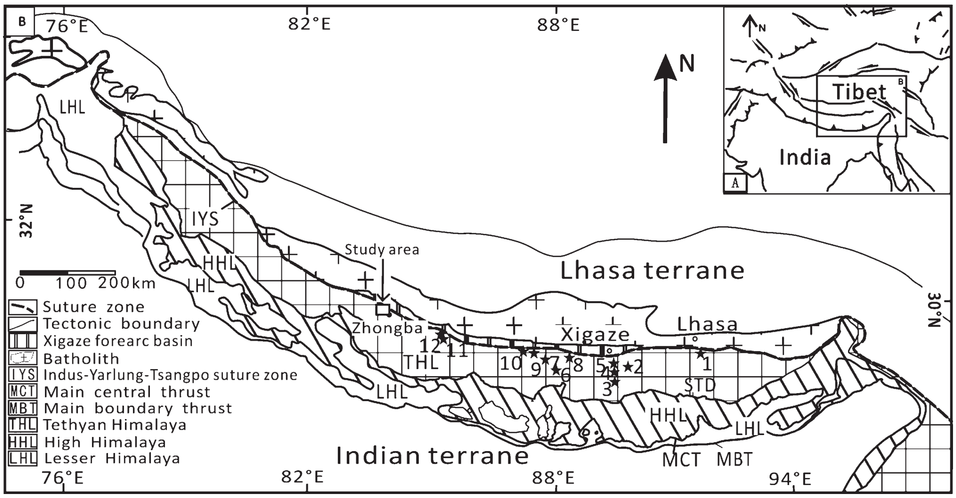

Fig. 1. A map of the Himalayan region showing the location of the Indus, Yarlung–Tsangpo suture zone, and the radiolarian localities.
1. Zedong (Wang et al., 2002; McDermid et al., 2002; Aitchison et al., 2007); 2. Congdu (Wu et al., 1984); 3. Sa'gya (Li et al., 2003); 4. Xialu (Wu, 1993; Matsuoka et al., 2001, 2002, 2005; Ziabrev et al., 2004); 5. Dazhuqu (Ziabrev et al., 2003); 6-10. Zhongbei, Pomunong, Jiding, Tangga and Angren (Zhu et al., 2005); 11. Sangdanlin (Ding, 2003; Ding et al., 2005); 12. Saga (Li et al., 2007).

2007); Congdu (Wu et al., 1984); Sa'gya (Li et al., 2003); Xialu (Wu, 1993; Matsuoka et al., 2001, 2002, 2005; Ziabrev et al., 2004); Dazhuqu (Ziabrev et al., 2003); Zhongbei, Pomunong, Jiding, Tangga and Angren (Zhu et al., 2005); Sangdanlin (Ding, 2003; Ding et al., 2005); Saga (Li et al., 2007) (Fig. 1). Most data are from the middle and eastern part of the Yarlung–Tsangpo suture zone. However, geological and paleontological data from the western part of the suture zone are still scarce. To know the evolution of the Neo-Tethys clearly, we need detailed geological and paleontological data along the whole suture zone.

This paper presents well-preserved and clearly imaged radiolarians from the Zhongba melange, which lies on the western part of the Yarlung–Tsangpo suture zone. This is the first report of Late Jurassic radiolarians from the Zhongba mélange.

Geological Setting

The Yarlung–Tsangpo suture zone lies between the Xigaze forearc basin to the north and the Tethyan Himalaya to the south (Fig. 1). For a section from the Xigaze forearc basin 30 km north of Zhongba, Wan et al. (2001) reported the upper Cretaceous to lower Eocene sequence, which is the youngest shallow marine sedimentary sequence, according to studies conducted on foraminifers. The Tethyan Himalaya is a thick succession of Cretaceous–Paleogene marine sediments (Garzanti, 1999). Ding (2003) and Ding et al. (2005) reported a

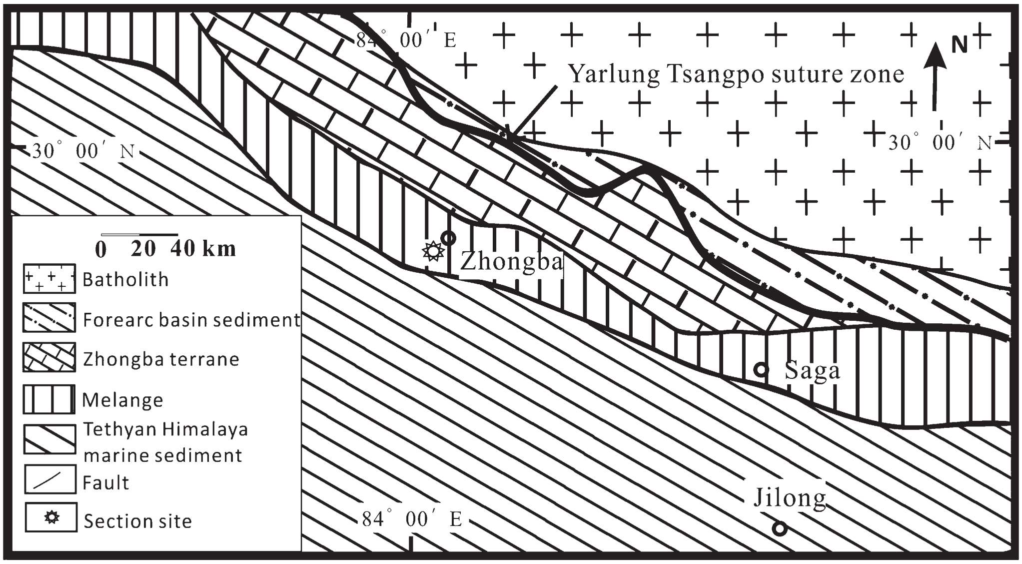

Fig. 2. A geological map showing the region around Zhongba County.

Paleocene deep-marine sedimentary section in Saga County, on the north of the Tethyan Himalaya. All of these features indicate the closure of the Yarlung–Tsangpo suture zone.

The Yarlung–Tsangpo suture zone is divided into two branches from Saga to the west. Our investigations focused on the southern branch of the suture zone near Zhongba, which has been little studied. In our study area, the Zhongba terrane, which is composed of Permian to Triassic mudstone, sandstone, and limestone sequences, lies between the Xigaze forearc basin and the Tethyan Himalaya. The Xiagaze forearc basin, Zhongba terrane and Tethyan Himalaya are in fault contact with each other (Fig. 2). A complete ophiolite succession has been found by both a previous study (Sun et al., 2002) and our field investigations. The melange is composed of chert, sandstone, and subordinate mudstone with blocks of augite peridotite, gabbro, basalt, limestone, and chert. Sun et al. (2002) reported Late Cretaceous radiolarians from the ophiolitic melange.

The section in this report is located ca. 9 km southwest of Zhongba County (Fig. 2). In this section (Fig. 3), dominant strata are red bedded chert and medium-grained sandstone. Many blocks of basalt, limestone and chert can be found together with thick chert, sandstone and mudstone sequences. The limestone is recrystallized. No fossils can be found in the limestone. Two faults—a north-dipping fault and a south-dipping inferred fault—are recognized in this section. Folds are observed in the red chert that lies to the south of the inferred fault (Fig. 3).

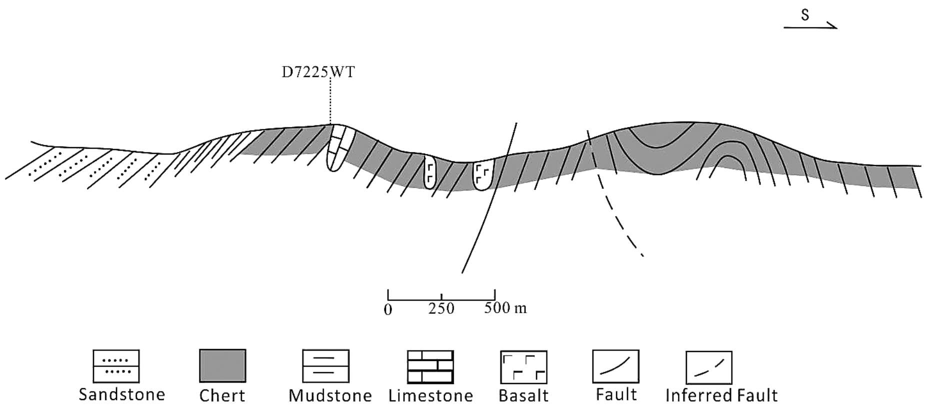

Fig. 3. The cross section of the sampling site.

Samples

Sample D7225WT was collected from the red chert bed, which is tectonically connected with the limestone block in the section (Fig. 3). The sample yielded well-preserved radiolarian shells.

Rock samples were disaggregated by 4% hydrofluoric acid for 20–24 h. The 61–380 μm fractions were used for micropaleontological research. Radiolarian shells are mounted on a stub with synthetic medium for scanning electron microscope observation. The fossil specimens reported in this paper have been deposited in the China University of Geosciences (Beijing).

Radiolarian assemblage and its age assignment

Age assignments of Jurassic radiolarians are based mainly on the zonal scheme established in Japan and the western Pacific (Matsuoka, 1995).

The radiolarians obtained in this report are as follows (Fig. 4): *Hsuum brevicostatum* gr. Ozvoldova, *Stichocapsa* sp., *Eucyrtidiellum* sp. cf. *E. unumaense* (Yao), *Pseudoeucyrtis* sp., *Archaeodictyomitra* sp., *Parahsuum* sp., *Laxtorum*(?) sp., *Podobursa* sp., and *Tritrabs* sp.

Hsuum brevicostatum gr. Ozvoldova is a typical Late Jurassic radiolarian species that exists from the *Striatojaponocapsa conexa* zone through the *Kilinora spiralis* zone to the *Hsuum maxwelli* zone (Matsuoka, 1995). *Stichocapsa* sp., *Eucyrtidiellum* sp., *Pseudoeucyrtis* sp., and *Podobursa* sp. are also the dominant taxa in these zones. The absence of *Striatojaponocapsa conexa* (Matsuoka) and *Kilinora spiralis* (Matsuoka) gives a clue that our sample is younger than the *Kilinora spiralis* zone. The faunal composition of our sample

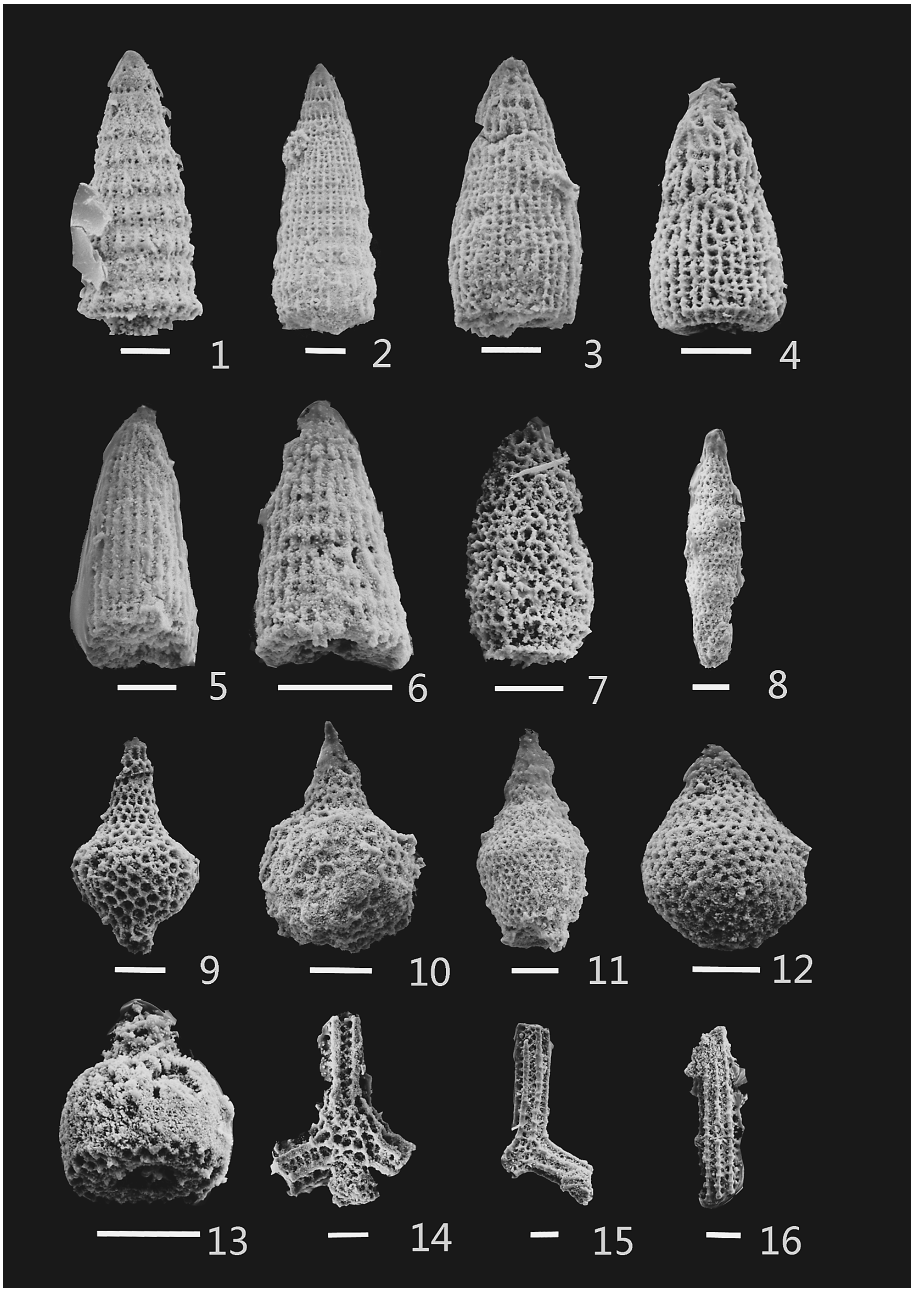

Fig. 4. Radiolarian fossils from sample D7225WT. All the scale bars are 50 μm.
1: *Hsuum brevicostatum* gr. Ozvoldova, 2: *Hsuum* sp., 3–4: *Parahsumm* sp., 5–6: *Archaeodictyomitra* sp., 7: *Laxtorum*(?) sp., 8: *Pseudoeucyrtis* sp., 9: *Podobursa* sp., 10: *Podobursa* sp., 11: *Pseudoeucytis* sp., 12: *Stichocapsa* sp., 13: *Eucyrtidiellum* sp. cf. *E. unumaense* (Yao), 14–16: *Tritrabs* sp.

from Tibet matches very well with sample 32R-CC, Leg 129, Site 801, western Pacific Ocean (Matsuoka, 1992). These indicate that the radiolarians from this sample are restricted to the *Hsuum maxwelli* zone (JR 7), which suggests a Kimmeridgian age.

Discussion

The melange in southwestern Zhongba is mainly red bedded chert and sandstone which contains basalt, limestone and chert blocks. Radiolarians from the chert are the first robust indication of a Kimmeridgian age. This finding significantly extends the age range of this region, from the Late Jurassic to the Late Cretaceous (Sun et al., 2002). Furthermore, although radiolarian-bearing strata along the Yarlung–Tsangpo suture zone range in age from Middle Triassic (Anisian) or earlier through to Late Cretaceous (Turonian) (Yang et al., 2002), Jurassic radiolarian data have only been reported from Xialu (Matsuoka et al., 2001, 2002, 2005; Ziabrev et al., 2004). Radiolarian taxa from the Zhongba melange are chronologically consistent with those from the Xialu chert and Naga ophiolite (Baxter et al., 2011), indicating that the Zhongba melange, Xialu chert and Naga ophiolite were once part of the same Neo-Tethys Ocean. Given the fact that this sedimentary melange is in fault contact with both the northern ophiolite sequence and southern normal marine sediments, more detailed stratigraphic and paleontological investigations of radiolarian in this region are needed.

Acknowledgements

This research was financially supported by the National Basic Research Program of China (973 Program; Grant No. 2011CB822001), the National Natural Science Foundation of China (Grant Nos. 41172129) and the Project of Geological Survey of China (Grant Nos. 1212011221103, 1212011121229). We sincerely thank Zhong Hanting, Ma Pengfei and Han Zhongpeng for their support in the field work. We are grateful for the constructive review to Prof. Satish-Kumar, M. (Niigata University).

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Semiplanus (Productida, Brachiopoda) from the Carboniferous limestone of Kotaki, Niigata Prefecture, central Japan

Yousuke IBARAKI* and Kiichi SATO**

Abstract

An Early Carboniferous large-sized productid brachiopod species, *Semiplanus semiplanus* (Schwetzow, 1922), is described from the Tsuchikurazawa Limestone (upper Visean–Serpukhovian), a limestone block within a Permian accretionary complex, distributed in the Kotaki area, Itoigawa City, Niigata Prefecture, central Japan. This is the first record of *Semipanus* species from Japan.

Key words: Brachiopoda, Carboniferous, Kotaki, *Semiplanus*, Tsuchikurazawa Limestone.

Introduction

The genus *Semiplanus* is a large Carboniferous productid brachiopod genus belonging to the subfamily Gigantoproductinae Muir-wood and Cooper, 1960. This genus was established by Sarytcheva and Sokolskaya (1952), with *Semiplanus semiplanus* (Schwetzow, 1922) from the middle–upper Visean of the Moscow Basin as the type species. Until now 15 species of *Semiplanus* have been described from the middle Visean–Serpukhovian of England, Poland, Russia and China. Among the genera in the subfamily Gigantoproductinae, *Latiproductus* Sarytcheva and Legrand-Blain, 1977 is distinguished from *Semiplanus* by its larger size and more round outline; *Gigantoproductus* Prentice, 1950 differs in its smaller size and in having coarser costae on ventral valve.

The Tsuchikurazawa Limestone (Takenouchi, 2005) is a large exotic limestone block within a Permian accretionary complex, the Kotaki Complex, distributed in and around the

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(Manuscript received 14 February, 2013; accepted 8 March, 2013)

lower Tsuchikurazawa Valley, a tributary of the Kotakigawa River, Kotaki, Itoigawa City, Niigata Prefecture, central Japan (Fig. 1). The age of the Tsuchikurazawa Limestone is assigned to a late Visean–Serpukhovian on the basis of smaller foraminifers (Nakazawa et al., 1998), corals (Kamiya and Niko, 1996; Niko and Yamagiwa, 1998), brachiopods (Tazawa, 2004; Ibaraki et al., 2008, 2010) and calcareous algae (Konishi, 1956). The following four gigantoproductid species have been previously described from the Tsuchikurazawa Limestone: *Gigantoproductus* sp. by Tazawa (2004), *Gigantoproductus tujucsuensis* Gladchenko and *Gigantoproductus meridionalis* Legrand-Blain by Ibaraki et al. (2008) and *Gigantoproductus aurita* (Bolkhovitinova) by Ibaraki et al. (2010). But none of the species of *Semiplanus* have been described from the limestone.

Brachiopod specimens described herein as *Semiplanus semiplanus* (Schwetzow, 1922) were collected by the second author (K. Sato) from the Tsuchikurazawa Limestone at the mouth of the Tsuchikurazawa Valley. This is the first described *Semiplanus* species from Japan. The age middle Visean–Serpukhovian indicated by *Semiplanus semiplanus* is consistent with the previous studies of the Tsuchikurazawa Limestone. The specimens described herein are registered with the prefix FMM and housed in the Fossa Magna Museum, Itoigawa City, central Japan.

Systematic descriptions

Order Productida Sarytcheva and Sokolskaya, 1959
Suborder Productidina Waagen, 1883
Superfamily Linoproductoidea Stehli, 1954
Family Linoproductidae Stehli, 1954
Subfamily Gigantoproductinae Muir-Wood and Cooper, 1960
Tribe Semiplanini Sarytcheva, 1960
Genus *Semiplanus* Sarytcheva and Sokolskaya, 1952

Type species.—*Productus latissimus* (Sowerby, 1822).

Semiplanus semiplanus (Schwetzow, 1922)
Figs. 2.1–2.3

Productus semiplanus Schwetzow, 1922, p. 10.

Productus (*Gigantella*) *semiplanus* (Schwetzow): Sarytcheva, 1928, p. 57, pl. 5, figs. 6–7; Rotai, 1941, p. 100, pl. 19, figs. 4–6.

Semiplanus semiplanus (Schwetzow): Sarytcheva in Sarytcheva and Sokolskaya, 1952, p. 120, pl. 23, fig. 157; Nalivkin and Fotieva, 1973, p. 50, pl. 15, fig. 3; Kalashnikov, 1974, p. 66, pl.

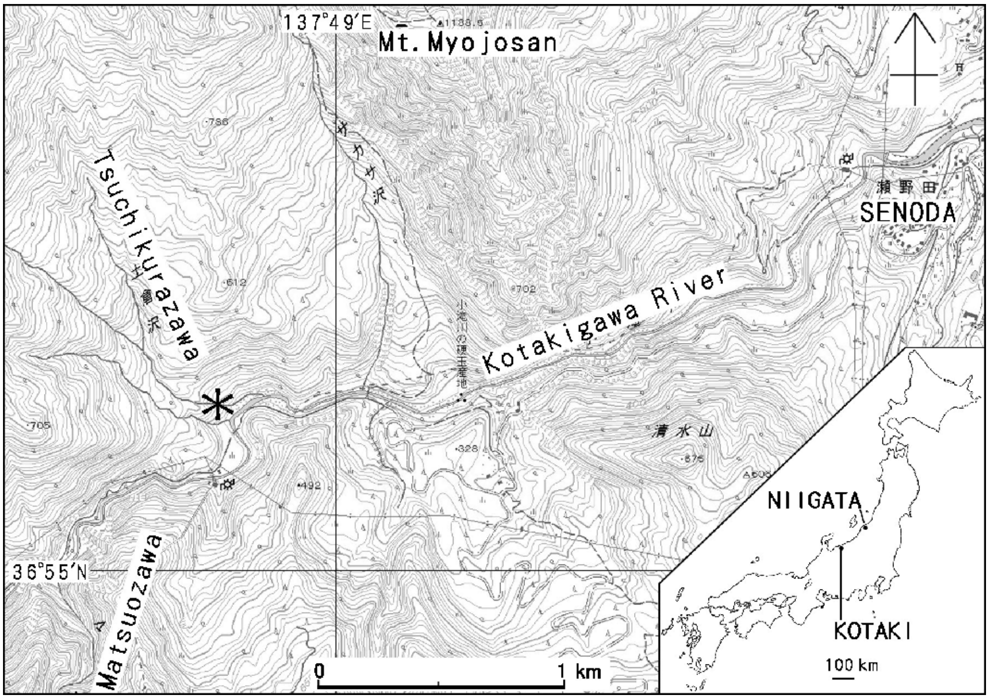

Fig. 1. Map showing the fossil locality (asterisk). Using the topographical maps of "Kotaki" and "Echigohiraiwa" scale 1:25,000 published by the Geospatial Information Authority of Japan.

18; fig. 3, pl. 19, figs. 2–7; Semichatova et al., 1975, p. 175, pl. 69, fig. 4; Sarytcheva and Legrand-Blain, 1977, p. 74, pl. 7, figs. 1–4; Donakova, 1978, p. 213, pl. 1, fig. 13; Yang, 1978, p. 119, pl. 33, fig. 4; Pattison, 1981, p. 11, pl. 2, fig. 4; pl. 9, fig. 21; Zakowa, 1986, p. 55, pl. 1, figs. 1–9; pl. 7, figs. 1–2; text-fig. 3; Tan, 1987, p. 123, pl. 17, fig. 12; Yang and Gao, 1996, p. 217, pl. 31, fig. 3; Jiang, 1997, pl. 3, fig. 3; Chen and Shi, 2003, p. 158, pl. 8, figs. 3–4, 6, 9.

Semiplanus semiplanus var. *plicata* Janischewsky: Beloussova, 1970, p. 100, pl. 3, figs. 1–2.

Material.—Three ventral valves, FMM2035, 2036, 2037.

Description.—Shell medium size for genus, transversely fusiform in outline, with greatest width at hinge; length 40 mm, width 85 mm in the largest specimen (FMM2035); length 32 mm, width about 77 mm in the smallest specimen (FMM2036). Ventral valve moderately convex in lateral profile, strongly incurved at umbo; flanks gently inclined; umbo moderately large, broad, rounded and inflated; ears small, triangular in shape and not clearly demarcated from visceral region; sulcus shallow and broad on anterior part of valve. External surface of ventral valve ornamented with numerous costae; costae regular in anterior part, numbering 8–9 per 10 mm at about midlength; spines or spine bases not

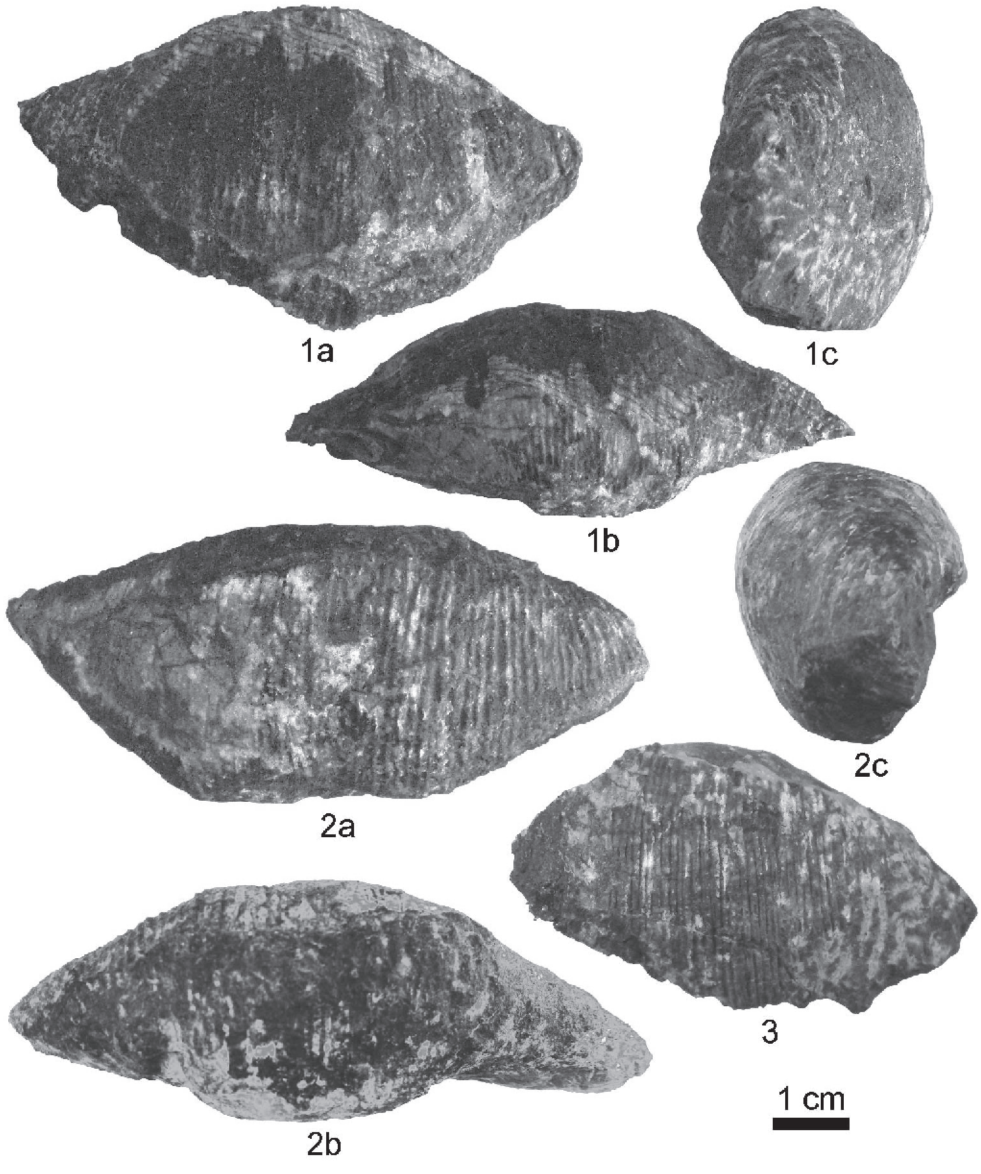

Fig. 2. *Semiplanus semiplanus* (Schwetzow, 1922), three ventral valve specimens; 1a, 1b, 1c: ventral, posterior and lateral views, FMM2035; 2a, 2b, 2c: ventral, posterior and lateral views, FMM2036; 3: ventral view, FMM2037.

preserved; shell thickness about 1 mm in both anterior and posterior parts.

Remarks.—The Tsuchikurazawa specimens are referred to *Semiplanus semiplanus* (Schwetzow, 1922), originally described from the upper Visean of the Moscow Basin, Russia, in size, shape and external ornament, especially the straight costae and small umbo in the ventral valve.

Semiplanus fragilis (Prentice, 1956, p. 246, pl. 21, figs. 1–2, pl. 22, fig. 3), from the Upper Visean of Derbyshire, England, differs from S. *semiplanus* in its more round outline, stronger convex ventral valve and slightly undulating costae.

Distribution.—Upper Visean of England (Pennine Mts.), Poland (Holy Cross Mts.), Ukraine (Prypyat), Russia (Moscow Basin, Pechora and Urals) and China (Tien-Shan Mts., Guizhou and Hunan); Serpukhovian of China (Kunlun Mts.); upper Visean–Serpukhovian of Japan (Kotaki).

Acknowledgements

We sincerely thank Jun-ichi Tazawa of Professor Emertus of Niigata University and Atsushi Matsuoka of the Department of Geology, Niigata University for critical review of the manuscript by which this paper is greatly improved.

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Radiolarian faunal change in the Middle Permian Gufeng Formation in the Liuhuang section, Chaohu, South China

Tsuyoshi ITO*, Qinglai FENG** and Atsushi MATSUOKA***

Abstract

Middle Permian (Guadalupian) radiolarians were obtained from bedded siliceous rocks collected from the Gufeng Formation in the Liuhuang section in Chaohu, Anhui Province, South China. Three radiolarian assemblages, named as *Pseudoalbaillella fusiformis, Follicucullus monacanthus,* and *Ruzhencevispongus uralicus,* were recovered from the Liuhuang section in an ascending stratigraphic order. The quantitative analysis of radiolarian fauna in the Liuhuang section shows the following characteristics. Albaillellarians and spherical radiolarians occurred more commonly than stauraxon radiolarians, in the lower part; spherical radiolarians are extremely dominant in the middle part; and spherical and stauraxon radiolarians dominate the upper part. In other words, albaillellarians decrease upward in the Liuhuang section, whereas stauraxon and spherical radiolarians increase. This vertical radiolarian faunal change has been reported from the Gufeng Formation in other sections and areas in the Lower Yangtze region. Our findings are in keeping with previous reports, which supports a conclusion that radiolarian faunal change is common throughout the Gufeng Formation in the Lower Yangtze region.

Keywords: Radiolarian assemblage, Middle Permian (Guadalupian), Gufeng Formation, Lower Yangtze region, South China.

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(Manuscript received 25 February, 2013; accepted 12 March, 2013)

Introduction

The Gufeng Formation, distributed in South China, is composed mainly of radiolarian-bearing deposits on the Yangtze platform formed during the Middle Permian. Some researchers have pointed out the radiolarian vertical faunal change in the Gufeng Formation in the Lower Yangtze region (e.g., Sheng and Wang, 1985; Kametaka et al., 2009). However, few quantitative researches showed the precise nature of this faunal change.

We carried out a field survey of the Chaohu area, Anhui Province, South China and collected samples for radiolarian research. We describe a new section composed mainly of siliceous rock of the Gufeng Formation. This paper reports on the occurrence of radiolarians from the new section, named the Liuhuang section, and shows quantitative faunal change.

Geological outline and study section

The Gufeng Formation, distributed across South China, is well-exposed in the lower reaches of the Yangtze River, which is called the Lower Yangtze region. The Gufeng Formation in this region conformably joins with the underlying Qixia and overlying Longtan (Yinping) formations (Bureau of Geology and Mineral Resources of Anhui Province, 1987; Jiang et al., 1994). Kametaka et al. (2005) divided the Gufeng Formation in the Anmenkou section into the Phosphate Nodule-bearing Mudstone Member (PNMM) and the Siliceous Rock Member (SRM) in an ascending stratigraphic order. The former is composed of mudstones including abundant phosphate nodules; the latter consists mainly of alternating beds of black cherts, mudstones, and siliceous mudstones, with minor tuffaceous mudstones and porous cherts.

The Liuhuang section (31° 37' 04.36" N, 117° 48' 30.69"E) is situated 5 km northwest of Chaohu, Anhui Province, South China (Figs. 1.A–1.C). The section outcrops at an east slope of a hill just west of Liuhuang Village. The Anmenkou section, which has been surveyed by some researchers (e.g., Nagai et al., 1998; Kametaka et al., 2002, 2005, 2009; Takebe et al., 2007), is located just southwest of the Liuhuang section. The Maokou, Gufeng, and Longtan formations are exposed in the Liuhuang section. The Maokou Formation is composed of white limestones including some brachiopods and fusulinids and conformably underlies the Gufeng Formation. The Gufeng Formation consists mainly of cherts, siliceous mudstones, mudstones, and phosphate-nodule-bearing mudstones. The Longtan Formation, consisting of sandstones and mudstones with coal beds, conformably overlies the Gufeng Formation. These strata approximately strike N50°E and dip 60°NW with some small folds and are overturned (Fig. 1.D). We divided the Gufeng Formation in this section into 12 subsections. The features of each subsection are as follows in an ascending stratigraphic order (numbers in parenthesis indicate the thickness of each subsection) (Fig. 2): subsection 1: mudstones

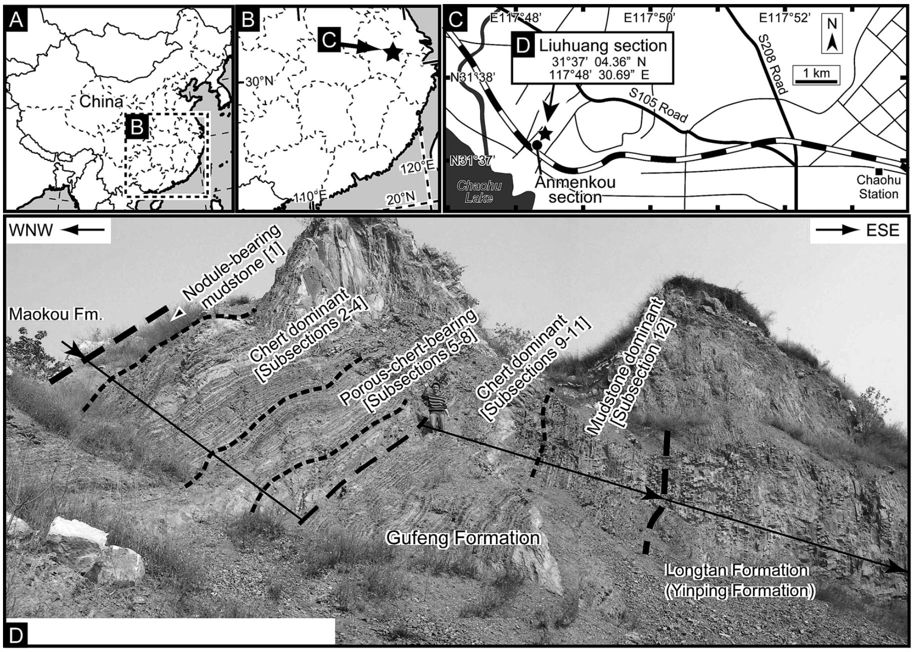

Fig. 1. A–C: Index map of the Liuhuang section. D: Field occurrence of the Liuhuang section.

including phosphate nodules with ammonoids and bivalves (330 cm); subsection 2: alternating beds of black cherts and siliceous mudstones interbedding dark-brown mudstones (160 cm); subsection 3: dark-brown mudstones interbedding black cherts (42 cm); subsection 4: thin bedded cherts interbedding mudstones (210 cm); subsection 5: gray porous cherts interbedding mudstones (40 cm); subsection 6: black cherts interbedding mudstones (160 cm); subsection 7: alternating beds of mudstones and cherts (40 cm); subsection 8: alternating beds of cherts and mudstones (75 cm); subsection 9: thin bedded black cherts interbedding mudstones (145 cm); subsection 10: alternating beds of siliceous mudstones and mudstones (165 cm); subsection 11: mudstones interbedding cherts and siliceous mudstones (550 cm); subsection 12: mudstone interbedding siliceous mudstones (510 cm). Subsection 1 corresponds to the PNMM in the Anmenkou section; subsections 2–12 correspond to the SRM in the Anmenkou section.

Materials and Methods

We collected 49 samples from the Liuhuang section (Fig. 2). The samples were crushed then soaked in an approximately 3% hydrofluoric acid (HF) solution for 24 hours at room temperature. The HF solution was removed and the containers holding the etched samples were subsequently refilled with fresh HF solution. Adequate residues were then collected

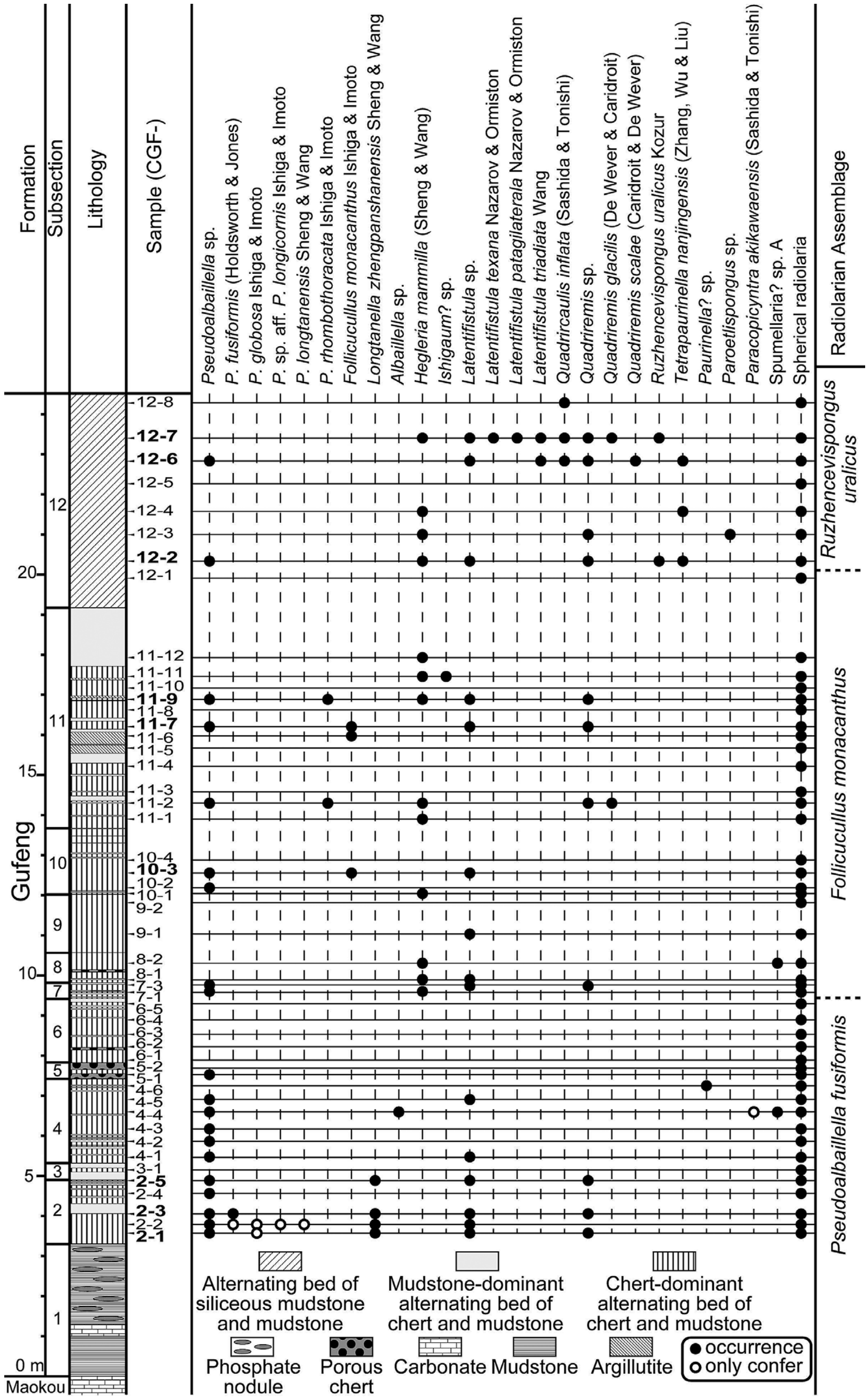

Fig. 2. Columnar section of the Liuhuang section and vertical distribution of collected radiolarians. Boldface represents samples used for quantitative analysis.

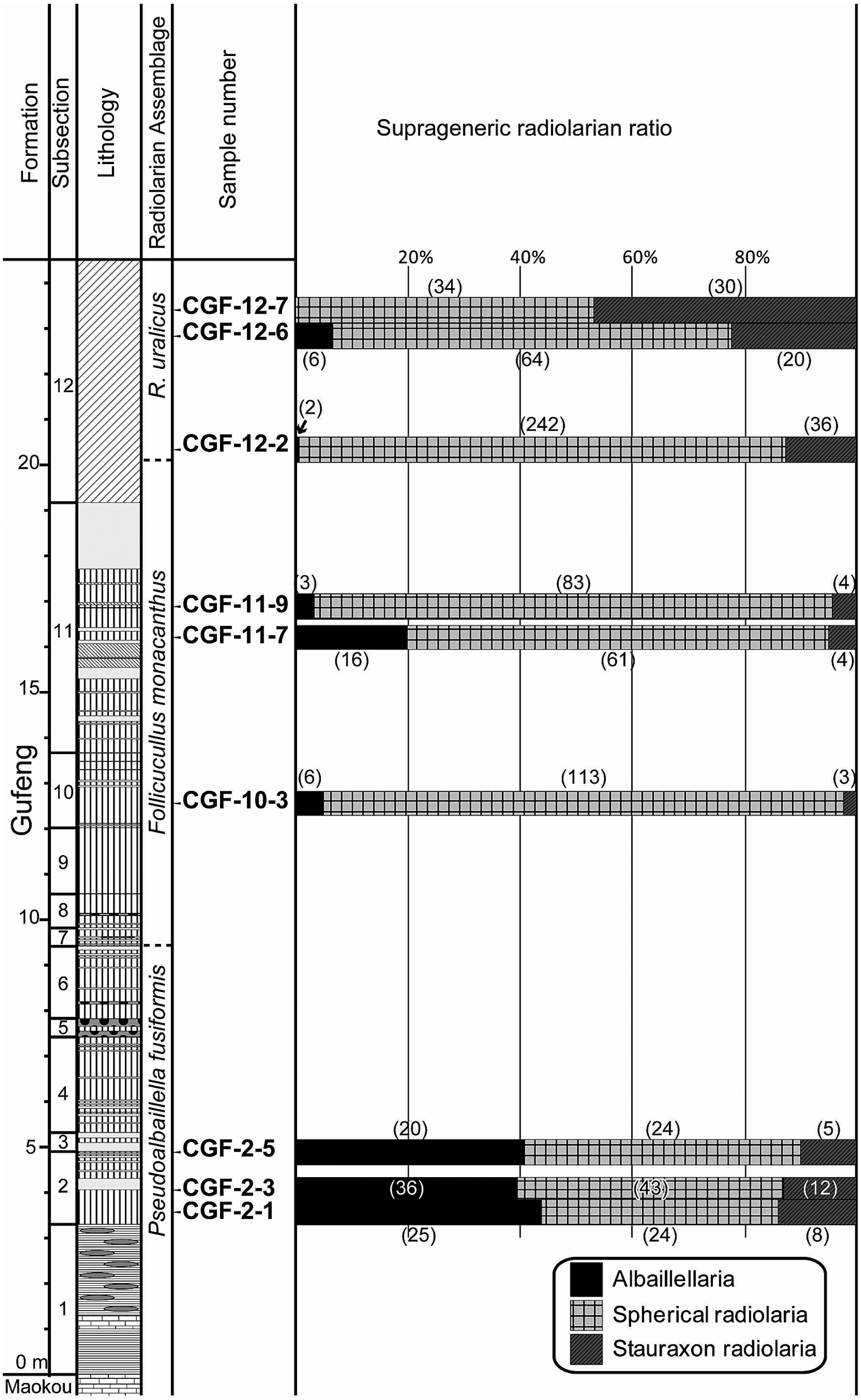

Fig. 3. Suprageneric compositional ratios of radiolarians in the selected samples of the Liuhuang section. Figures in parentheses indicate numbers of counted individuals.

through a sieve with a mesh diameter of 0.054 mm. Some of the well-preserved radiolarians in the residues were mounted on stubs and photographed with a scanning electronic microscope (Quanta 200). Selected radiolarian photomicrographs are shown in Plate 1.

Among the samples collected from the Liuhuang section, nine samples including better-preserved radiolarians (Fig. 3) underwent the above-mentioned processes. These residues were enclosed within one or several slides prepared with a mounting medium (Entellan new) for every sample. Quantities of the following suprageneric radiolarians in each slide were counted under a transmitted light microscope: albaillellarians, spherical radiolarians (involve spumellarians and entactinarians), and stauraxon radiolarians.

Radiolarian occurrences

Some samples from the lower part of the Liuhuang section are moderately preserved, while most samples from the upper part are poorly preserved.

Several researchers had reported occurrence of radiolarians in the Gufeng Formation in the Lower Yangtze region (e.g., Sheng and Wang, 1985; Kametaka et al., 2009). Most researchers since Wang and Qi (1995) have divided the Gufeng Formation into three radiolarian assemblage-zones. We also recognize three radiolarian assemblages in the Liuhuang section in the following ascending order: *Pseudoalbaillella fusiformis*, *Follicucullus monacanthus*, and *Ruzhencevispongus uralicus* (Fig. 2). The characteristic species of the *Ps. fusiformis* assemblage are *Ps. fusiformis* (Holdsworth and Jones) and *Longtanella zhengpanshanensis* Sheng and Wang. This assemblage corresponds to those of the *Ps. globosa* Assemblage-Zone of Wang et al. (1994) and Ishiga (1990), and the *Ps. longtanensis–Ps. fusiformis* Assemblage-Zone of Kametaka et al. (2009). The characteristic species of the *F. monacanthus* assemblage are *F. monacanthus* Ishiga and Imoto and *Hegleria mammilla* (Sheng and Wang). This assemblage corresponds to those of the *F. monacanthus* Assemblage-Zone of Wang et al. (1994) and Kametaka et al. (2009), and the *F. monacanthus* Range-Zone of Ishiga (1990). The characteristic species of the *R. uralicus* assemblage are *R. uralicus* Kozur, *Tetrapaurinella nanjingensis* (Zhang, Wu, and Li), *Latentifistula triadiata* Wang, *Quadricaulis inflata* (Sashida and Tonishi), and *H. mammilla*. This assemblage corresponds to those of the *F. scholasticus–F. ventricosus* Interval-Zone of Wang et al. (1994), the *F. scholasticus* m. I Assemblage-Zone of Ishiga (1990), and the *F. scholasticus-R. uralicus* Assemblage-Zone of Kametaka et al. (2009).

The counts showed the following results (Fig. 3). Albaillellarians and spherical radiolarians occurred more commonly than stauraxon radiolarians from the lower Liuhuang section (CGF-2-1, CGF-2-3, and CGF-2-5; *Ps. fusiformis* assemblage). Spherical radiolarians are extremely dominant in the middle Liuhuang section (CGF-10-3, CGF-11-7, CGF-11-9, and CGF-12-2; *F. monacanthus* assemblage). In the upper Liuhuang section (CGF-12-6 and CGF-

12-7; *R. uralicus* assemblage), spherical and stauraxon radiolarians are dominant.

Radiolarian faunal change

Suprageneric composition of the radiolarian fauna differs by horizons in the Liuhuang section (Fig. 3). Albaillelarians decrease upward, while stauraxon and spherical radiolarians increase upward. This tendency has been reported from the Gufeng Formation in other sections in the Lower Yangtze region. Sheng and Wang (1985) brought up the observation that radiolarians from the Longtan area are divided into two faunas: *Pseudoalbaillella* and *Phanicosphaera* in ascending order. Kametaka et al. (2009) showed that albaillellarians decrease and latentifistularians increase upward in the Anmenkou section. In the Gufeng Formation in the Tongling area, the upper parts of some sections yielded abundant spherical radiolarians (Kuwahara et al., 2007). The results of this study and interpretations of previous studies indicate that this compositional change is a common tendency of the Gufeng Formation in the Lower Yangtze region.

It has been suggested that the ratio of suprageneric composition is indicative of paleoenvironmental conditions, such as water-depth (e.g., Kozur, 1993; Kuwahara, 1999). Kametaka et al. (2009) referred to these studies, but they pointed out that changes in water depth cannot be the chief cause of faunal change, because there are no remarkable changes in significant sedimentological features from the Anmenkou section. If water-depth change is a critical factor for faunal change, the water-depth of the Anmenkou section had changed by several hundred meters. In the Gufeng Formation of the Tongling area, radiolarian faunal and lithological changes were also not strongly correlated with each other (Kuwahara et al., 2007).

Although dominant rock facies change upward from cherts to muddy rocks in the Liuhuang section, a decrease of albaillelalrians and an increase of spherical radiolarians are shown in chert-dominant parts (any horizon between CGF-2-5 and CGF-10-3). Hence, this faunal change has no remarkable correlation with lithological change. In contrast, stauraxon radiolarians seem to increase between CGF-11-9 and CGF-12-2. The lithological boundary between chert-dominant parts and muddy-rock-dominant parts (between the subsections 11 and 12) is also located between CGF-11-9 and CGF-12-2. Increase of stauraxon radiolarians may have a correlation with lithological change. Further quantitative study is necessary to better understand the relationship between lithological and radiolarian faunal changes.

Acknowledgements

We wish to thank Mr. Lei Yong, Mr. Hu Qing, and Ms. Shi Lei of China University of Geosciences, Wuhan, for their kind help in our fieldwork. We are grateful for the constructive review to Dr. Kurihara Toshiyuki (Niigata University). This study was supported financially by the NSFC (40839903 and 40921062), the "111" project (B08030) of China University of Geosciences, Wuhan, and Niigata University's scholarship program for graduate school students conducting research abroad. This study was conducted under the double degree program between Niigata University and China University of Geosciences, Wuhan.

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Plate 1

1–3: *Longtanella zhengpanshanensis* Sheng and Wang: 1, 2: CGF-2-3; 3: CGF-2-5

4, 5: *Pseudoalbaillella fusiformis* (Holdsworth and Jones): CGF-2-3

6: *Pseudoalbaillella* sp. cf. *P. globosa* Ishiga and Imoto: CGF-2-2

7, 8: *Follicucullus monacanthus* Ishiga and Imoto: CGF-10-3

9: *Pseudoalbaillella longtanensis* Sheng and Wang: CGF-2-2

10: *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga and Imoto: CGF-2-3

11: *Pseudoalbaillella scalprata* (Holdsworth and Jones): CGF-11-9

12: *Albaillella* sp.: CGF-2-3

13: *Paroetlispongus* sp.: CGF-12-3

14, 15, 19: *Tetrapaurinella nanjingensis* (Zhang, Wu and Liu): 14, 15: CGF-12-7; 19: CGF-12-6

16, 17: *Paracopicyntra* sp. cf. *P. akikawaensis* (Sashida and Tonishi): CGF-4-4

18: *Paurinella*? sp.: CGF-4-6

20, 21: *Hegleria mammilla* (Sheng and Wang): 20: CGF-10-1; 21: CGF-7-1

22, 23: Spumellaria? sp. A: 22: CGF-4-4; 23: CGF-8-2

24, 25: *Ruzhencevispongus uralicus* Kozur: 24: CGF-12-7; 25: CGF-12-2

26: *Ishigaum*? sp.: CGF-11-11

27: *Latentifistula texana* Nazarov and Ormiston: CGF-8-1

28, 29: *Latentifistula patagilaterala* Nazarov and Ormiston: CGF-12-7

30: *Latentifistula* sp.: CGF-12-7

31, 32: *Latentifistula triadiata* Wang: 31: CGF-12-7; 32: CGF-12-6

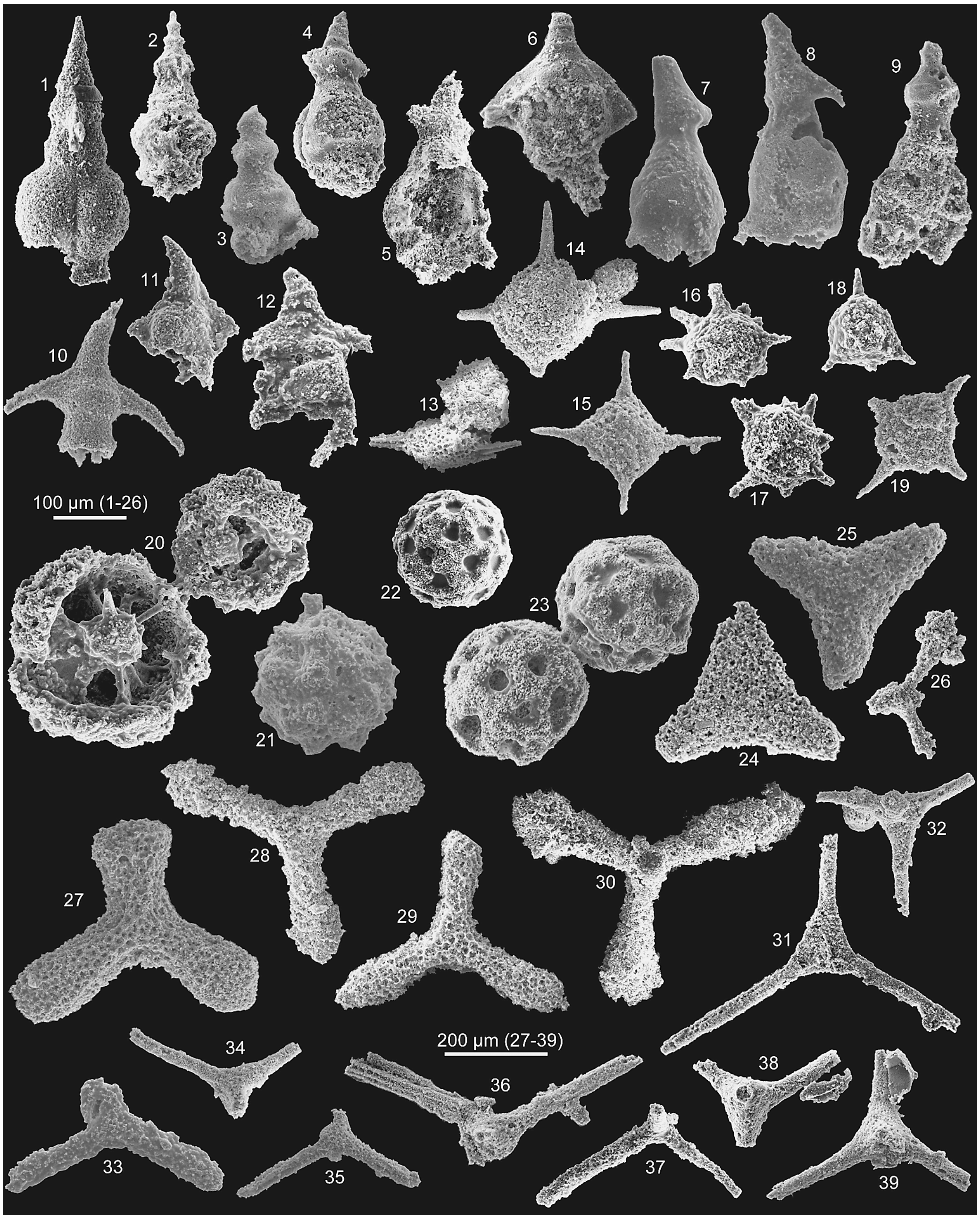
33: *Latentifistula*? sp.: CGF-4-5

34: *Quadriremis scalae* (Caridroit and De Wever): CGF-12-6

35, 36: *Quadriremis glacilis* (De Wever and Caridroit): 35: CGF-11-2; 36: CGF-12-7

37: *Quadriremis* sp.: CGF-2-1

38, 39: *Quadricaulis inflata* (Sashida and Tonishi): CGF-12-7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Revision of clam shrimp ("conchostracan") genus *Tylestheria* from Late Cretaceous deposits of China

Gang LI* and Atsushi MATSUOKA**

Abstract

Restudy of the type species of *Tylestheria* from the First Member of the Upper Cretaceous Nenjiang Formation in Nenjiang County, north-east China under a scanning electron microscope (SEM) revealed morphological features on the carapace that had not been recognized previously: growth lines with serrated lower margins; growth bands near the umbo and in the middle part of the carapace with intercalated fine reticulation between relatively widely spaced radial lirae; growth bands in the ventral part of the carapace ornamented with radial lirae and punctae. According to the recent radiometric dating and magnetostratigraphic data of the Late Cretaceous deposits in the Songliao Basin, the *Tylestheria*-bearing horizons of the Nenjiang Formation (Songliao Basin) and the Majiacun Formation (dinosaur egg bearing Xixia Basin, Henan) were revised to be late Santonian in age.

Key words: fossil clam shrimps, taxonomy, biostratigraphy, Late Cretaceous, China.

Introduction

Tan and Wang (1929) established the Nenjiang Formation in the north-east of Nenjiang County, which is extensively developed in the Songliao Basin, north-east China. It is 500 –1,235 m thick, and consists mainly of deep-water lacustrine dark grey mudstones with intercalations of very light grey fine-grained sandstones, but with red mudstones dominating the uppermost part (Chen, 2003). It has been subdivided into five members, labelled First to Fifth in ascending order. Fossil clam shrimps ("Conchostracans") are

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(Manuscript received 7 February, 2013; accepted 20 March, 2013)

abundant in the formation. The first paper on specimens of these crustaceans recovered from it was that of Chi (1931) who described *Estheria nengkiangensis* (now *Brachygrapta nengkiangensis* (Chi, 1931) Novojilov, 1954). This was followed by the publications of Kobayashi and Huzita (1942, 1943), Tani (1943), Chang (1957), Chang and Chen (1964), Zhang et al. (1976), Cui (1987), Li and Batten (2004b, 2005) and Li et al. (2004b, 2009b).

<table>
<tr><th>Age</th><th>Formation</th><th>Members</th><th>Clam shrimp zones</th></tr>
<tr><td rowspan="5">Campanian</td><td rowspan="7">Nenjiang Formation</td><td>5</td><td rowspan="2">Mesolimnadiopsis anguangensis Z.</td></tr>
<tr><td>4</td></tr>
<tr><td>3</td><td></td></tr>
<tr><td rowspan="2">2</td><td>Calestherites sertus Z.</td></tr>
<tr><td>Euestherites bifurcatus Z.</td></tr>
<tr><td rowspan="2">L. San.</td><td rowspan="2">1</td><td>Halysestheria yui Z.</td></tr>
<tr><td>Dictyestheria elongata Z.</td></tr>
</table>

Fig. 1. Clam shrimp zones of the Nenjiang Formation (revised after Li and Batten, 2005).

Zhang and Chen (in Zhang et al., 1976) recognized four clam shrimp zones in the Nenjiang Formation (Fig. 1): the *Halysestheria yui* Zone in the First Member; the *Euestherites bifurcatus* and *Calestherites sertus* zones in the basal and upper parts respectively of the Second Member; and the *Mesolimnadiopsis anguangensis* Zone in the Fourth and Fifth members (Chen, 2003; Li et al., 2004a; Li, 2005; Li and Batten, 2005). Recently, Li et al. (2009b) recovered that the *Dictyestheria elongata* Zone, originally recognized in the underlying Yaojia Formation, extends into the basal part of the First Member of the Nenjiang Formation in the Yaojia area of Dehui, Jilin Province. All of the clam shrimp assemblages in the formation were considered by Zhang et al. (1976) to belong to the *Euestherites* fauna.

The clam shrimp genus *Tylestheria* Zhang and Chen in Zhang et al., 1976, an important associate occurring in the *Halysestheria yui* Zone, was erected based on specimens from the First Member of the Nenjiang Formation of Jilin and Heilongjiang provinces (both northeastern China). A re-examination of the type species *Tylestheria shanhoensis* (Chang,

1957) under SEM revealed some morphological features not previously seen, as recorded below. Recent research progress on the Nenjiang Formation of the Songliao Basin, and the recovery of *Tylestheria* from the well-known, dinosaur egg bearing Xixia Basin in Henan Province, central China make further age determination and correlation of the fossil clam shrimp bearing beds possible.

Geological age of the Nenjiang Formation

The Third and Fourth members of the Nenjiang Formation belong to the important Heitimiao oil layer, which is the shallowest oil layer of the Songliao Basin. The sedimentary character and fossil contents of the formation have been studied in great detail since the early 20th century (Tan and Wang, 1929 ; Kabayashi, 1942a, b; Chen, 1983; Yu et al., 1983; Liu, 1990; Sha, 2007). However, its age determination has been disputed. Gu (1962, 1982) postulated possible seawater incursions into the Songliao Basin during the Cenomanian or Turonian high sea level period because of the discovery of marine or marginal marine bivalves *Musculus, Mytilus* and *Fulpioides* from the Nenjiang Formation. As a result, the base of the Upper Cretaceous in the Songliao Basin was defined at the base of the Nenjiang Formation. These early Late Cretaceous marine links with the Songliao Basin got supported by the discovery of marine water related fossil fish in the formation, including *Sungarichthys longicephalus* (Takai, 1942), *Hama macrostoma* Chow, 1976 and *Jilingichthys rapax* Chow, 1976 (Chang and Chow, 1978). Furthermore, the Cenomanian–Turonian age determination of the Nenjiang Formation got supported by the biostratigraphy of the palynomorph flora recovered from the Nenjiang Formation (Development and Research Institute of Daqing Oil Field, 1976). But the recovery of abundant Late Cretaceous megospore *Balmeisporites* assemblages from the underlying Yaojia and Qingshankou formations made the lowering of the base of the Upper Cretacoeus to the base of the Quantou Formation (Institute of Scientific Research and Designing, Daqing Oil Field, 1976). Thus, a late Turonian–Santonian age was proposed for the Nenjiang Formation (Chen, 2000, 2003). Later, according to more detailed palynomorph data, Gao et al. (1999) revised a much younger Santonian–Campanian (Late Cretaceous) age for the Nenjiang Formation. Recent years, the newest research achievement on the Cretaceous Continental Scientific Drilling borehole SK-1 in the Songliao Basin offers a unique opportunity to establish a more precise chronostratigraphic framework for the Upper Cretaceous sequence in the Songliao Basin (Wang et al., 2008, in press; Li et al., 2011; Scott et al., 2012; Feng et al., in press). The late Coniacian–Santonian foraminifers recovered from the First and Second members of the Nenjiang Formation are direct evidence of middle Late Cretaceous seawater incursions into the Songliao Basin (Xi et al., 2011). A bentonite bed yielding a weighted mean $^{238}U/^{206}Pb$ age of 83.7 ± 0.8 Ma (He et al., 2012) is 2 m above the boundary between the First Member and the Second Member of the

Nenjiang Formation. The C33r/C33n geomagnetic reversal, which was determined to be 79.3 Ma (Mitchell et al., 2006), was recorded 1.2 m above the boundary between the Nenjiang and Sifangtai formations. Thereby, the Nenjiang Formation would be late Santonian–middle Campanian in age (Deng et al., in press).

During the Santonian the *Nemestheria* clam shrimp fauna evolved into four distinct faunas occupying three clam shrimp biogeographic provinces identified in Chinese Late Cretaceous non-marine deposits: (1) the North China Province, represented by the *Euestherites* Fauna in the Songhua Lake drainage system; (2) the South-East China Province containing the *Linhaiella* and *Tenuestheria* faunas in the Yunmeng Lake drainage system; and (3) the South-West China Province represented by the *Aglestheria* fauna in the south-western palaeolake drainage system (Chen, 1994). *Tylestheria shanhoensis* (Chang, 1957) and other two species mentioned below are known from the *Halysestheria yui* Zone of the *Euestherites* Fauna in the late Santonian First Member of the Nenjiang Formation. *Tylestheria xixiaensis* Li et al., 2009a is the only spinicaudatan species to have been recovered from the Majiacun Formation in the well-known dinosaur egg bearing Xixia Basin, which was a part of the Yunmeng Lake drainage system during the Late Cretaceous. The occurrence of *Tylestheria* in both the Nenjiang and Majiacun formations suggests a late Santonian age for the fossil-bearing horizons of the North and South-East biogeographic provinces.

Materials and methods

The type specimens examined are deposited in the collection of the Nanjing Institute of Geology and Palaeontology, Chinese Academy of Sciences (NIGPCAS). They are all natural external moulds, and were originally collected from the Upper Cretaceous Nenjiang Formation at Shanhe, Nenjiang County of north-west Heilongjiang Province.

Most of the previous studies on the palaeotology of fossil clam shrimps have used a light microscope. This means that some potential characters of taxonomic value were difficult to see clearly. Here the authors have relied on examination of specimens using an SEM, a Leo 1530 VP, and a Leica light microscope. At the same time we also used the invert function of the software Adobe Photoshop to reverse images taken from external moulds of the specimens, as if they were taken directly of the carapace, so that the detailed ornamentation on the carapace could be clearly shown (Fig. 2).

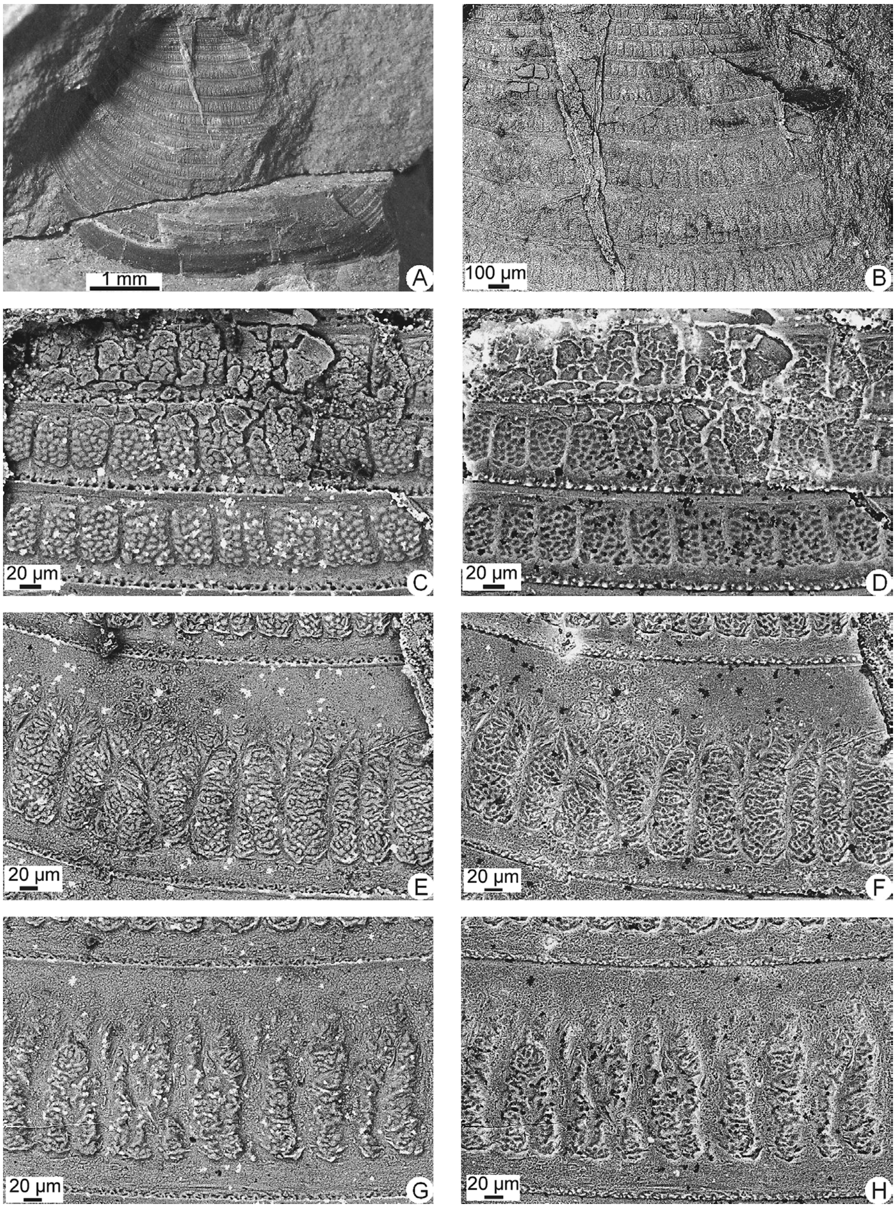

Fig. 2. A–H, *Tylestheria shanhoensis* (Chang, 1957) Zhang and Chen, in Zhang et al., 1976 emend., SEM images of damaged external mould of a right valve, from the First Member of the Nenjiang Formation, Nenjiang County, Heilongjiang Province. A, the counter part of the holotype, NIGPCAS 8549A. B, growth bands near umbo. C, external mould, showing growth bands near the umbo. D, reversed image of Fig. 2C, growth bands near the umbo showing fine reticulation between widely spaced radial lirae and serrated lower margins of growth lines. E, external mould, showing growth bands in the antero-middle part of carapace. F, reversed image of Fig. 2E, showing ornamentation located in the lower two-thirds of each growth band in the antero-middle part of carapace, leaving the upper one-third smooth, fine reticulation intercalated between widely spaced pronounced radial lirae, branching laterally. G, external mould, growth bands in the lower part of carapace. H, reversed image of Fig. 2G, prominent radial lirae intercalated with irregular reticulation, cross bar, punctae and short, fine ridial lines located in the lower one-third of the growth band.

Systematic palaeontology

The classification of recent spinicaudatans of Martin and Davis (2001) is followed here. Because *Cyclestheria* Sars, 1887 has been removed from the suborder Spinicaudata Linder, 1945 and placed in the suborder Cyclestherida Sars, 1899, which is on an equal footing with the remaining Spinicaudata and Cladocera Latreille, 1829, the Conchostraca Sars, 1867 as a taxonomic unit has been abandoned.

Class: Branchiopoda Latreille, 1817
Subclass: Phyllopoda Preuss, 1951
Order: Diplostraca Gerstaecker, 1866
Suborder: Spinicaudata Linder, 1945
Superfamily: Estheriteoidea Zhang and Chen, in Zhang et al., 1976
Family: Halysestheriidae Zhang and Chen, in Zhang et al., 1976
Genus *Tylestheria* Zhang and Chen, in Zhang et al., 1976 emend.

1976 *Tylestheria* Zhang and Chen gen. nov., Zhang et al., p. 217.
1980 *Tylestheria* Zhang and Chen, Wang, p. 107.

Type species. *Estherites shanhoensis* Chang, 1957, now *Tylestheria shanhoensis* (Chang, 1957) Zhang and Chen, in Zhang et al., 1976.

Occurrence. First Member of the Nenjiang Formation, Heilongjiang and Jilin provinces, north-east China; the Majiacun Formation, Henan Province; upper Santonian (Upper Cretaceous).

Diagnosis. Carapace small or of moderate size, elongate-elliptical, elliptical or oval in outline; growth lines prominent, with serrated lower margins; growth bands near the umbo ornamented with widely spaced long radial lirae with intercalated fine reticulation, sporadically occurring of one short fine radial line between two neighboring radial lirae in the lower part of each growth band; growth bands in the middle part of the carapace ornamented with more widely spaced, prominent long radial lirae with intercalated fine reticulation, and short fine radial lines occuring both in the lower and upper parts of each growth band, some pairs of fine radial lines even being radially connected to form long radial lines; on the external mould of the specimen every pair of rows of radially arranged, grouped tubercles on the middle part of the carapace are separated by deep grooves; growth bands in the lower part of the carapace ornamented with more pronounced radial lirae intercalated with cross bars and irregular reticulation or punctae.

Discussion. When the genus *Tylestheria* Zhang and Chen in Zhang et al., 1976 was erected, the microphotographs were taken under a light microscope, thus some morphological features could not be seen clearly in the low resolution images. Unfortunately, the holotype (NIGPCAS 8549, an external mould of a left valve) of the type species has been coated by varnish to protect it from damage, which means that it is impossible to re-examine it under SEM; as a result, all the images of the holotype are photographs taken under a light microscope (Fig. 3. A–F). It was, however, possible to re-examine the broken counter part of the holotype under SEM, i.e. an external mould of a damaged right valve. Our examination under SEM have revealed features not previously seen, namely: (1) serrated lower margins of growth lines; (2) reticulation intercalated between widely spaced, long radial lirae in the umbonal and middle parts of the carapace; (3) punctae between pronounce irregular radial lirae in the lower part of the carapce.

Although serrations along the lower margins of growth lines were originally considered as a diagnostic feature for the family Afrograptidae Novojilov, 1957 (Chen and Shen, 1977, 1982, 1985; Shen and Chen, 1979, 1982; Cui, 1987; Chen and Hudson, 1991), recent studies on living clam shrimps (Shen, 2003) have shown that they are remains of broken setae or points at or through which setae articulated along the lower margins of growth lines. It has also been demonstrated that this feature is of taxonomic significance at generic or subgeneric level but not at higher (family) groupings of fossils (Li, 2004, 2005; Li and Batten, 2004a, b, 2005; Li et al., 2004b, 2006). Hence, *Tylestheria* is, as originally determined, maintained here in the family Halysestheriidae Zhang and Chen, in Zhang et al., 1976.

Tylestheria shanhoensis (Chang, 1957) emend.
Figs. 2–3.

1957 *Estherites shanhoensis* Chang sp. nov., p. 485, pl. 6, figs. 1–2.
1976 *Tylestheria shanhoensis* (Chang), Zhang et al., p. 217, pl. 100, figs. 1–6.

Material. Holotype NIGPCAS 8549, and a damaged counter part of the holotype, NIGPCAS 8549A, Shanhe Farm, Nenjiang County, north-west Heilongjiang Province, north-east China.

Emended diagnosis. In addition to the diagnosis of the genus, the type species has an elongate-elliptical outline, and the ornament of the growth bands located in the lower two-thirds of each growth band in the middle and lower parts of the carapace.

Dimension of the holotype. In order: specimen no.; number of growth lines; length of carapace (mm); heigh of carapace (mm): NIGPCAS 8549; 24; 5.6; 3.2.

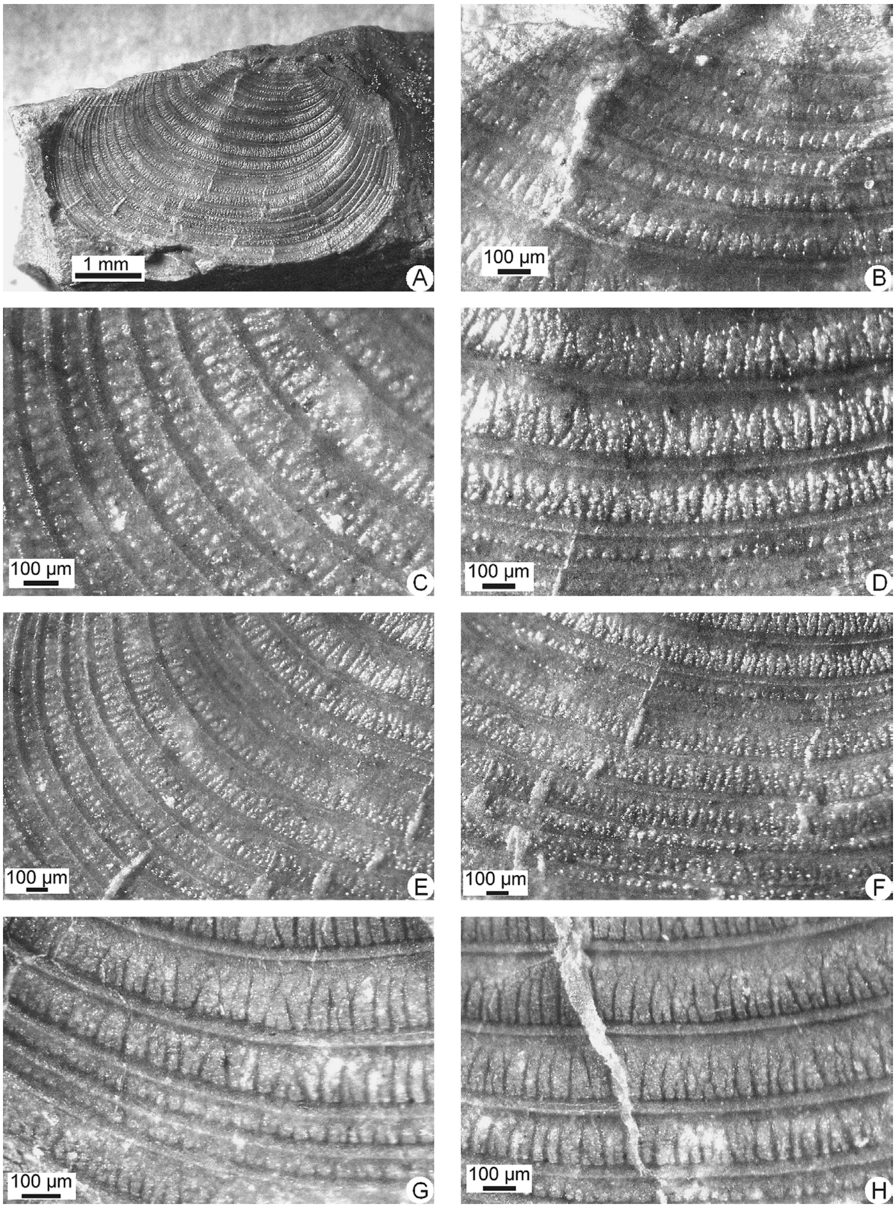

Fig. 3. A–H, *Tylestheria shanhoensis* (Chang, 1957) Zhang and Chen, in Zhang et al., 1976 emend., light microscope images of specimens, from the First Member of the Nenjiang Formation, Nenjiang County, Heilongjiang Province. A–F, holotype, NIGPCAS 8549. A, external mould of a left valve. B, narrow growth bands near umbo, showing widely spaced grooves. C, E, ornament on growth bands in antero-ventral part of carapace. D, F, ornament on growth bands in ventral part of carapace. G–H, ornamentation of counterpart specimen of the holotype, NIGPCAS 8549A. G, ornament on growth bands in antero-ventral part of carapace. H, ornament on growth bands in middle part of carapace.

Description. Carapace of small to moderate size, gently convex, elongate-elliptical in outline; umbo small, slightly projecting beyond the anterior one-third of the long and straight dorsal margin; 24 or more prominent growth lines have serrated lower margins. Growth bands in the umbonal area narrow, wider below, and become narrower again in the lower part of the carapace. Growth bands in the umbonal area ornamented by relatively widely spaced long radial lirae with intercalated reticulation, normally one short fine radial line occurs within the reticulation between two neighboring widely spaced long radial lirae. Growth bands in the middle part of the carapace are wider with smooth upper part of each growth band, while the lower two-thirds of each growth band decorated with ornaments including more widely spaced, more prominent, upwardly branching long radial lirae with intercalated reticulation, short fine radial lines occurring either in the lower part or middle part of each growth band, some pairs of fine radial lines extends to meet in the middle part of each growth band, as a result, on the external mould of the holotype every pair of rows of radially arranged grouped tubercles in the middle part of the carapace are separated by deep grooves; growth bands in the ventral part of the carapace are relatively narrow, ornamented with more pronounce irregular radial lirae with intercalated fine radial lines, cross bars and punctae, so that in the external mould the growth bands are decorated by radially arranged tubercles, i.e. a kind of chain-like ornament.

Discussion. Tylestheria shanhoensis is similar to *T. xixiaensis* Li et al., 2009a from the Upper Cretaceous Majiacun Formation of the dinosaur egg bearing Xixia Basin in Henan. Both have carapaces that are elongate-elliptical in outline. However, the carapace of *T. shanhoensis* is larger, the ornaments are restricted to the lower two-thirds and making the upper one-third smooth of each growth band in the middle and lower parts of the carapace. *Tylestheria shanhoensis* is easily differentiated in carapace outline from *T. kanqinshikouensis* Zhang and Chen, in Zhang et al., 1976 from Nenjiang and *T. compta* Zhang and Chen, in Zhang et al., 1976 from Da'an in Jilin, both of which are either elliptical or oval (not elongate) in outline respectively. No other species have been described.

Acknowledgments

This study was supported by the Major Basic Research Projects of the Ministry of Science and Technology, China (National 973 Project 2012CB822004), National Natural Science Foundation of China (41172010), and State Key Laboratory of Palaeobiology and Stratigraphy (SKLPS), Nanjing (20101104). The SEM microphotographs were taken through the courtesy of the LEO 1530 VP facility of SKLPS.

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