

Permian brachiopods from Yamasuge in the Kuzu area, Ashio Mountains, central Japan, Part 2

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Abstract

In this second manuscript in a series, additional brachiopods, consisting of 14 species in 13 genera, are described from the lower part of the Nabeyama Formation (*Parafusulina yabei* Zone) of Yamasuge in the Kuzu area, Ashio Mountains, central Japan. This fauna includes a new species, *Metriolepis kuzuensis*. Reassessment of the Yamasuge fauna indicates an Early Permian (Kungurian) age. In terms of palaeobiogeography, the fauna is characterized by a mixture of North American (West Texas) and Tethyan elements, and without Boreal elements. The observations suggest that in the Early Permian (Kungurian) the depositional site of the Nabeyama Formation was located in an equatorial region of the Panthalassa, proximal to West Texas.

Key words: Ashio Mountains, brachiopod, Early Permian, palaeobiogeography, Panthalassa, Yamasuge.

Introduction

In a recent study (Tazawa et al., 2010), we described a brachiopod collection from a Permian limestone block in a Jurassic accretionary complex, Nabeyama Formation, from locality KY1 in Yamasuge, Sano City, Tochigi Prefecture, i.e., Kuzu area, Ashio Mountains, central Japan (Fig. 1). The present paper is a follow-up report on Permian brachiopods from Yamasuge.

Hayasaka (1926) first reported Permian brachiopods from Nabeyama in the Kuzu area. Subsequent studies described brachiopods of 10 species in 8 genera from the Permian of Nabeyama and Yamasuge in the Kuzu area (Hayasaka, 1932, 1933, 1967; Minato, 1949a,

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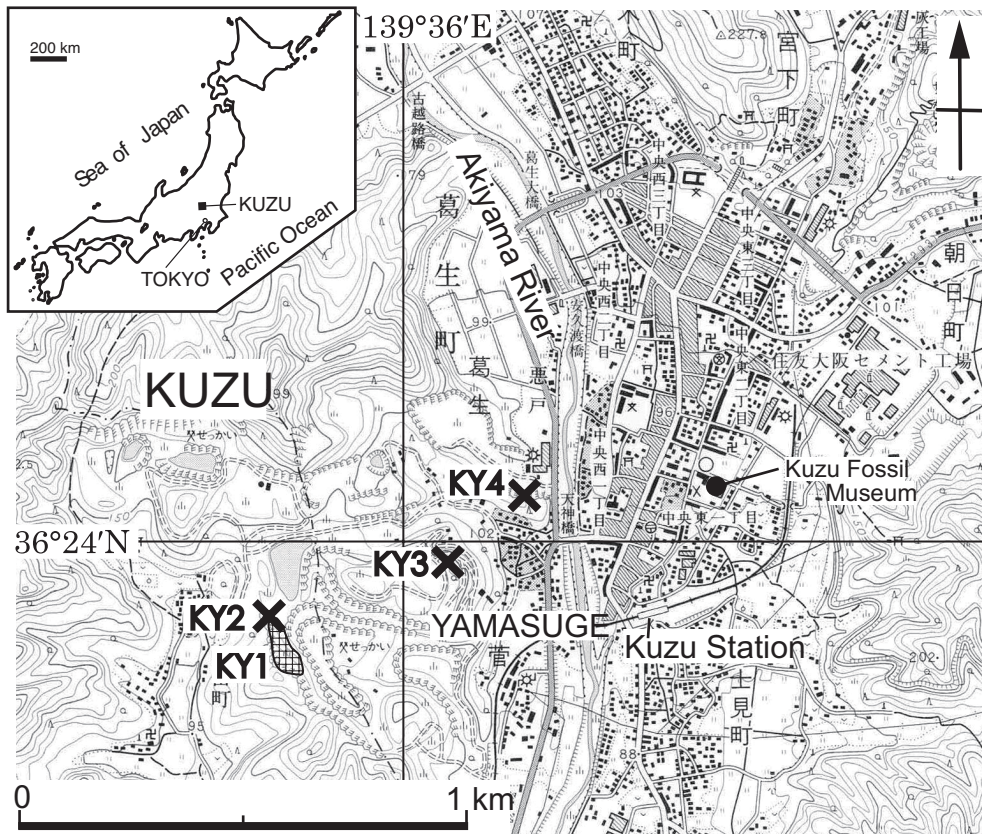


Fig. 1. Index map showing the fossil localities KY1, KY2, KY3 and KY4 in Yamasuge, Kuzu area, Ashio Mountains, central Japan. Using the topographical map of “Tanuma” scale 1:25,000 published by the Geospatial Authority of Japan.

b; Tazawa et al., 2010): *Vediproductus* sp., *Meekella gigantea* Hayasaka, *Streptorhynchus tubiphora* Minato, *Streptorhynchus* sp., *Tropidelasma yamasugensis* Tazawa, *Enteletes acutiplicatus* Hayasaka, *Orthotichia japonica* Hayasaka, *Cleiothyridina hayasakai* Tazawa, *Cleiothyridina* sp. and *Arionthia* cf. *lamaria* Cooper and Grant.

In this paper, we describe brachiopods of 14 species in 13 genera, including 9 species in 9 genera that are reported from the area for the first time, collected from three localities (KY2, KY3 and KY4) in Yamasuge (Figs. 1, 2), and discuss the age and palaeobiogeography of the Yamasuge fauna. The material was prepared by the junior authors of the present study, Y. Okumura and M. Shimizu.

All specimens described below are registered with the prefix KFM, and are housed in the Kuzu Fossil Museum in Kuzu, Sano City, Tochigi Prefecture, central Japan.

Stratigraphy and Localities

Recently, Kobayashi (2006a, b) studied fusulinaceans from limestone blocks in the

Nabeyama Formation, in the Kuzu area, and subdivided the formation into three zones: the *Parafusulina nakamigawai* Zone, the *Parafusulina yabei* Zone and the *Parafusulina tochiensis* Zone, in ascending order. All brachiopod specimens described herein and in our previous study (Tazawa et al., 2010) were collected from the following four localities at Yamasuge, within the lower Nabeyama Formation (*Parafusulina yabei* Zone). The lithologies, topographies and horizons of the fossil localities are explained below and shown in Figs. 1, 2.

KY1: Hill that runs between two limestone quarries operated by Yamanoi Crushed Stone Co. Ltd. and Tokyo Sekkai Kogyo Co. Ltd. (36°23'80" N, 139°35'73" E), grey and light grey bedded limestone of the lower Nabeyama Formation, with the following brachiopods described by Tazawa et al. (2010): *Vediproductus* sp., *Tropidelasma yamasugensis*, *Enteleles acutiplicatus*, *Cleiothyridina hayasakai*, *Cleiothyridina* sp. and *Arionthia* cf. *lamaria*.

KY2: North edge of KY1 (36°23'86" N, 139°35'72" E), black and dark grey bedded limestone of the lower Nabeyama Formation (about 10 m above the top of the Izuru Formation), with *Parafusulina yabei* Hanzawa, 1942 (Fig. 3) and two brachiopod species, *Orthotichia japonica* and *Cleiothyridina* sp.

KY3: Hill located northeast of limestone quarry operated by Tokyo Sekkai Kogyo Co. Ltd. (36°23'94" N, 139°36'11" E), light grey and brown bedded limestone of the lower Nabeyama Formation, with *Parafusulina yabei* and two brachiopod species, *Echinauris lateralis* Muir-Wood and Cooper and *Cleiothyridina hayasakai*.

KY4: Hill along the southern margin of limestone quarry operated by Komagata Inc. (36°24'08" N, 139°36'31" E), grey to dark grey bedded limestone of the lower Nabeyama Formation, with all species of brachiopods described in the present paper.

The Yamasuge fauna

The brachiopods from Yamasuge, which consist of 14 species in 13 genera, are listed below along with the number of the specimens:

<i>Echinauris lateralis</i> Muir-Wood and Cooper, 1960	5
<i>Transennatia</i> sp.	6
<i>Goniarina permiana</i> (Stehli, 1954)	1
<i>Bothrostegium</i> sp.	1
<i>Rhipidomella hessensis</i> King, 1931	2
<i>Enteleles acutiplicatus</i> Hayasaka, 1932	3
<i>Acosarina rectimarginata</i> Cooper and Grant, 1976	1
<i>Orthotichia japonica</i> Hayasaka, 1932	19
<i>Cleiothyridina hayasakai</i> Tazawa in Tazawa et al., 2010	238
<i>Cleiothyridina</i> sp.	1
<i>Hustedia culcitula</i> Cooper and Grant, 1976	1
<i>Cartorhium coristum</i> Cooper and Grant, 1976	2
<i>Metriolepis kuzuensis</i> sp. nov.	34
<i>Arionthia</i> cf. <i>lamaria</i> Cooper and Grant, 1976	1

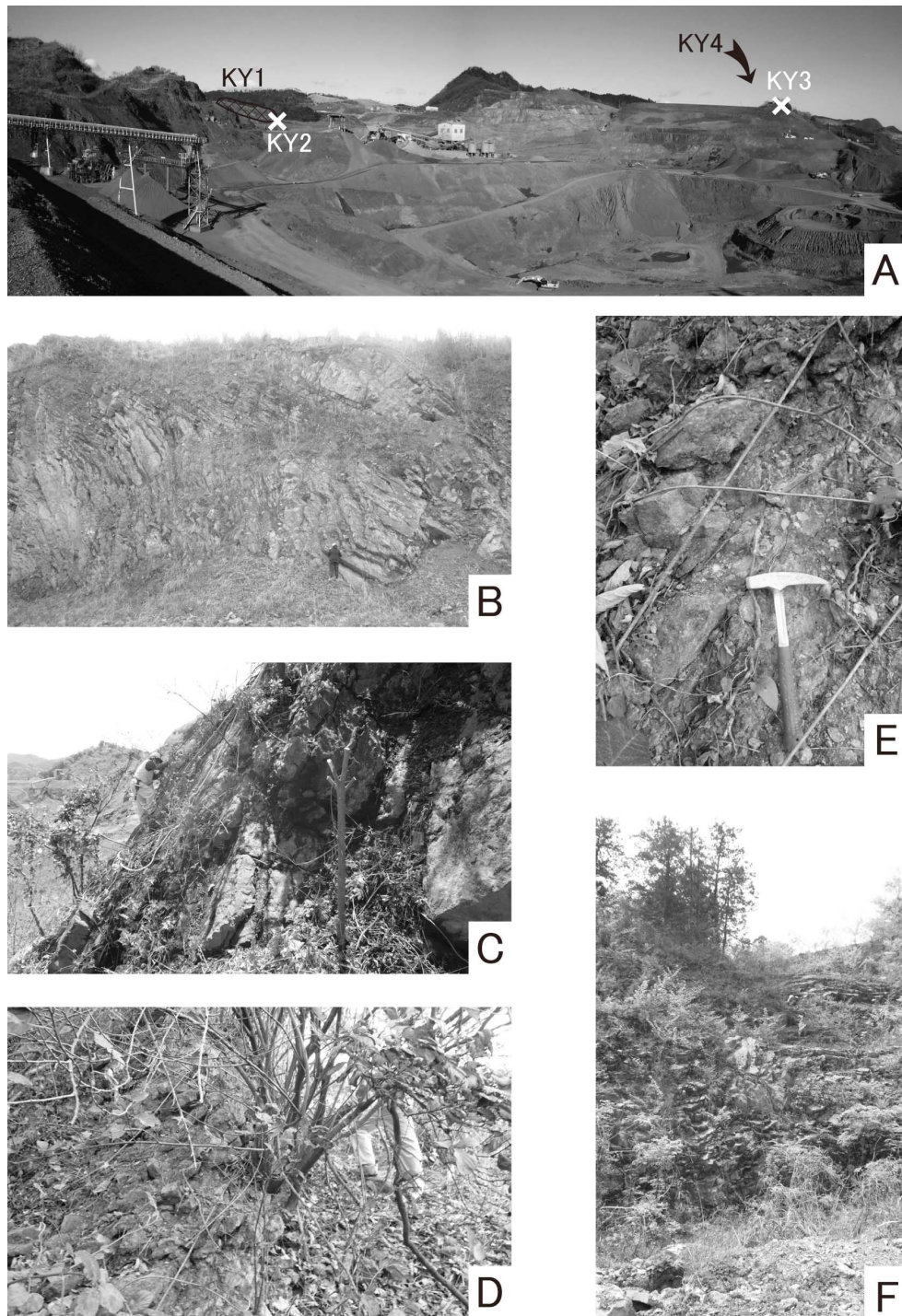


Fig. 2. A distant view (A) and close views (B–F) of the fossil localities in Yamasuge. B: locality KY1, C: locality KY2, D, E: locality KY3, F: locality KY4.

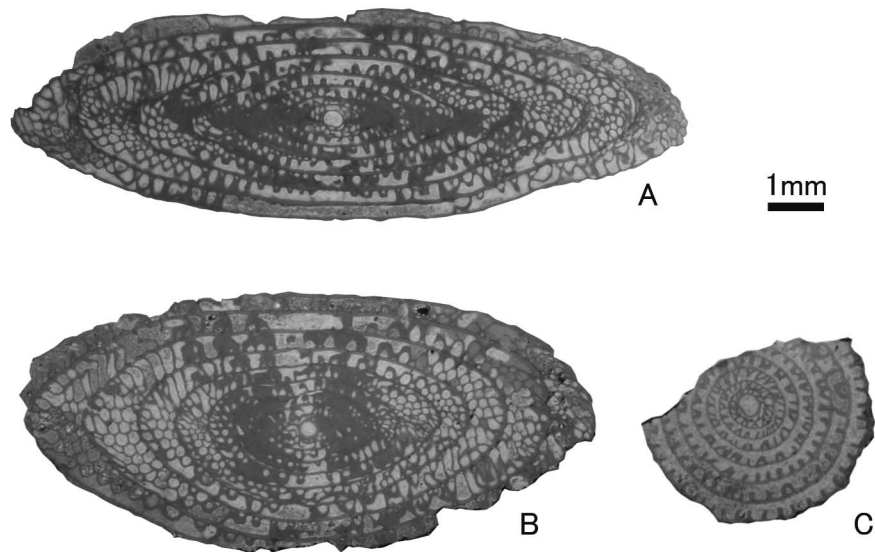


Fig. 3. *Parafusulina yabei* Hanzawa, from localities KY2 and KY3 of Yamasuge. A: axial section from KY2, B: axial section from KY3, C: sagittal section from KY3.

Among these species, *Cleiothyridina hayasakai* is the most abundant. Both *Orthotichia japonica* and *Metriolepis kuzuensis* are also abundant, while *Echinauris lateralis*, *Transennatia* sp., *Rhipidomella hessensis*, *Enteletes acutiplicatus* and *Cartorhium coristum* are common, and *Goniarina permiana*, *Bothrostegium* sp., *Acosarina rectimarginata*, *Cleiothyridina* sp., *Hustedia culcitula* and *Arionthia* cf. *lamaria* are rare.

Age of the Yamasuge fauna

Among the species and genera of the Yamasuge fauna, *Echinauris lateralis* is known from the Lower Permian (Kungurian) to Middle Permian (Wordian) of West Texas, the United States and from the Lower Permian (Kungurian) of Hatahoko in the Mino Belt, central Japan. *Goniarina permiana* is known from the Lower Permian (Artinskian) of West Texas and from the Lower Permian (Kungurian) of Hatahoko. The genus *Bothrostegium* has been described from only the Lower Permian (Kungurian) of West Texas. *Rhipidomella hessensis* is known from the Lower Permian (Sakmarian–Artinskian) of West Texas. *Enteletes acutiplicatus* (= *Enteretes costellatus*) is known from the Lower Permian (Sakmarian) of West Texas and from the Lower Permian (Kungurian) of Hatahoko and Nabeyama, central Japan. *Acosarina rectimarginata* is known from the Lower Permian (Asselian) of West Texas and from the Lower Permian (Kungurian) of Hatahoko. Both *Orthotichia japonica* and *Cleiothyridina hayasakai* are known from the Lower Permian (Kungurian) of Nabeyama, and *Hustedia culcitula* is known from the Lower Permian (Asselian) of West Texas. *Cartorhium coristum* is known from the Lower Permian (Artinskian) of West Texas and from the Middle Permian (Roadian) of Hiyomo, Mino Belt, central Japan.

In summary, the age of the Yamasuge fauna is Artinskian to Kungurian, most probably Kungurian. This age determination is slightly older than those proposed by Kobayashi (2006a, b) and Tazawa et al. (2010), who regarded the age of the Yamasuge fauna (= *Parafusulina yabei* Zone) as Murgabian or Wordian. Concerning this problem, it must be noted that Igo (pers. com., Dec. 2011) mentioned that the age of the *Parafusulina yabei* Zone in the Kuzu area is older than Wordian, probably Leonardian on the basis of his evolutionary taxonomy of the genus *Parafusulina*.

Palaeobiogeography of the Yamasuge fauna

In terms of palaeobiogeography, the Yamasuge fauna includes the following species in common with the West Texas fauna, described by King (1931), Stehli (1954), Muir-Wood and Cooper (1960) and Cooper and Grant (1969, 1974, 1975, 1976) from the Lower and Middle Permian of West Texas: *Echinauris lateralis*, *Goniarina permiana*, *Rhipidomella hessensis*, *Acosarina rectimarginata*, *Hustedia culcitula*, *Cartorhium coristum* and *Arionthia* cf. *lamaria*. The species *Enteleles acutiplicatus*, *Orthotichia japonica*, *Cleiothyridina hayasakai* and *Metriolepis kuzuensis* are endemic to Yamasuge and Nabeyama in the Kuzu area, and the genera *Bothrostegium* and *Metriolepis* are endemic to West Texas. The genera *Transennatia*, *Enteleles* and *Orthotichia* are Tethyan elements; no Boreal element have been reported from the Yamasuge fauna.

Consequently, the Yamasuge fauna has an affinity to the Texas fauna, although Boreal elements are absent. This finding supports the Permian palaeogeography of the Yamasuge fauna described by Tazawa et al. (2010) that the depositional site of the Nabeyama Formation was located in an equatorial region of the Panthalassa, proximal to West Texas in the Early Permian (Kungurian).

Systematic descriptions

(by J. Tazawa)

Order Productida Sarytcheva and Sokolskaya, 1959
 Suborder Productidina Waagen, 1883
 Superfamily Productoidea Gray, 1840
 Family Productellidae Schuchert, 1929
 Subfamily Overtoniinae Muir-Wood and Cooper, 1960
 Tribe Costispiniferini Muir-Wood and Cooper, 1960
 Genus *Echinauris* Muir-Wood and Cooper, 1960

Type species.—*Echinauris lateralis* Muir-Wood and Cooper, 1960.

Echinauris lateralis Muir-Wood and Cooper, 1960
 Figs. 4.4–4.6

Avonia subhorrida King, 1931, p. 84, pl. 20, figs. 10, 11.

Echinauris lateralis Muir-Wood and Cooper, 1960, p. 222, pl. 68, figs. 1–13; Cooper and Grant, 1975, p. 1011, pl. 333, figs. 1–34; pl. 334, figs. 1–33; pl. 335, figs. 36–51; pl. 468, figs. 5–9; Shen et al., 2011, p. 557, figs. 3.3–3.6, 3.10–3.21.

Material.—Five specimens from localities KY3, KY4: (1) two conjoined shells, KFM1660, 1601; (2) three ventral valves, KFM1662–1664.

Description.—Shell medium size for genus, equidimensional to slightly transverse, subcircular in outline; length 12 mm, width more than 12 mm in the largest specimen (KFM1660). Ventral valve strongly and unevenly convex in lateral profile, most convex at posterior one-third; no sulcus; both umbo and ears not well preserved. Dorsal valve deeply concave, with maximum convexity at about midlength; no fold. External surface of ventral valve ornamented with numerous stout spines, numbering 3–4 in 5 mm width at about midlength. External ornament of dorsal valve being poorly preserved and obscure.

Remarks.—These specimens can be referred to *Echinosauris lateralis* Muir-Wood and Cooper, 1960, from the Road Canyon and Word formations (upper Leonardian–lower Guadalupian) of West Texas, by their size, outline and external ornament of ventral valve, although the Yamasuge specimens are slightly smaller than the Texan specimens.

Echinosauris productelloides Cooper and Grant (1975, p. 1015, pl. 339, figs. 1–35), from the Cherry Canyon Formation (lower Guadalupian) of West Texas, differs from *E. lateralis* in having more numerous and finer spines on the ventral valve.

Echinosauris opuntia (Waagen, 1884, p. 707, pl. 79, figs. 1, 2), from the Wargal Formation of the Salt Range, Pakistan, is distinguished from the present species by its larger and slightly longer shell.

Distribution.—Lower Permian (Kungurian) of central Japan (Hatahoko in the Mino Belt and Yamasuge in the Kuzu area, Ashio Mountains); Lower Permian (Kungurian) to Middle Permian (Wordian) of the United States (West Texas).

Subfamily Marginiferinae Stehli, 1954
Tribe Paucispiniferini Muir-Wood and Cooper, 1960
Genus *Transennatia* Waterhouse, 1975

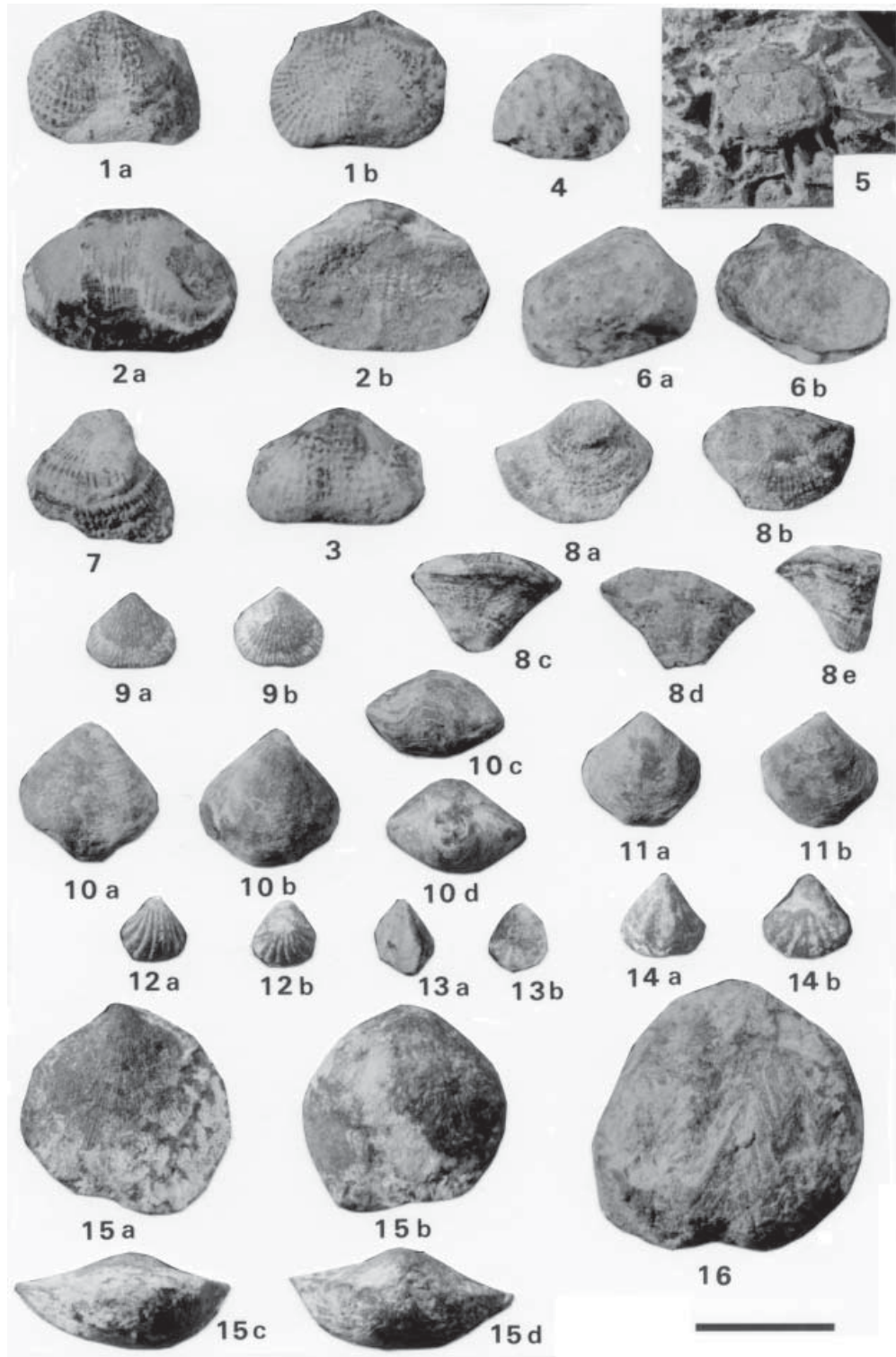
Type species.—*Productus graciosus* Waagen, 1884.

Transennatia sp.
Figs. 4.1–4.3

Material.—Six specimens from locality KY4, six conjoined shells, KFM1665–1670.

Remarks.—These specimens are safely assigned to the genus *Transennatia* by their small, transverse shell (length 11 mm, width about 16 mm in the best preserved specimen, KFM1665) and strong reticulate ornament on visceral portion of both ventral and dorsal valves. In size, shape and external ornament, the Yamasuge specimens resemble *Transennatia graciola* (Waagen, 1884, p. 691, pl. 72, figs. 3–7), from the Wargal and Chhidru formations of the Salt Range, but the poor preservation of the present material makes accurate comparison difficult.

Order Orthotetida Waagen, 1884
Suborder Orthotetidina Waagen, 1884
Superfamily Orthotetoidea Waagen, 1884
Family Schuchertellidae Williams, 1953
Subfamily Schuchertellinae Williams, 1953
Genus *Goniarina* Cooper and Grant, 1969



Type species.—*Goniarina pyelodes* Cooper and Grant, 1969.

Goniarina permiana (Stehli, 1954)

Fig. 4.8

Schuchertella permiana Stehli, 1954, p. 298, pl. 17, figs. 19–23.

Goniarina permiana (Stehli): Cooper and Grant, 1974, p. 267, pl. 36, figs. 1–34; pl. 37, figs. 1–27; Shen et al., 2011, p. 563, figs. 5.1–5.19.

Material.—One specimen from locality KY4, a conjoined shell, KFM1671.

Remarks.—This specimen is represented by an imperfect conjoined shell lacking the umbonal region. However, the single specimen from Yamasuge can be referred to *Goniarina permiana* (Stehli, 1954), originally described from the Leonardian of the Sierra Diablo Mountains, West Texas, by its medium size (length 8 mm, width about 12 mm), highly cup-shaped ventral valve, flattish dorsal valve, and relatively strong costellae (numbering 10–11 in 5 mm at midlength of ventral valve; 11–13 in 5 mm at about midlength of dorsal valve) on both ventral and dorsal valves.

The type species, *Goniarina pyelodes* Cooper and Grant (1969, p. 3, pl. 4, figs. 26–30), from the Neal Ranch Formation (Wolfcampian) of the Glass Mountains, West Texas, differs from *G. permiana* in its smaller size, shallower ventral valve, and finer costellae on the both ventral and dorsal valves.

Distribution.—Lower Permian (Artinskian) of the United States (West Texas); Lower Permian (Kungurian) of central Japan (Hatahoko in the Mino Belt and Yamasuge in the Kuzu area, Ashio Mountains).

Subfamily Streptorhynchinae Stehli, 1954

Genus *Bothrostegium* Cooper and Grant, 1974

Type species.—*Bothrostegium derbyoideum* Cooper and Grant, 1974.

← **Fig. 4.** 1–3: *Transennatia* sp., 1a, 1b: ventral and dorsal views of conjoined shell, KFM1667, 2a, 2b: ventral and dorsal views of conjoined shell, KFM1665, 3: ventral valve, KFM1666. 4–6: *Echinaris lateralis* Muir-Wood and Cooper, 4: ventral valve, KFM1661, 5: ventral valve, KFM1664, 6a, 6b: ventral and dorsal views of conjoined shell, KFM1660. 7: *Bothrostegium* sp., ventral valve, KFM1672. 8: *Goniarina permiana* (Stehli), 8a, 8b, 8c, 8d, 8e: ventral, dorsal, anterior, posterior and lateral views of conjoined shell, KFM1671. 9: *Acosarina rectimarginata* Cooper and Grant, 9a, 9b: ventral and dorsal views of conjoined shell, KFM1678. 10, 11: *Cleiothyridina hayasakai* Tazawa, 10a, 10b, 10c, 10d: ventral, dorsal, anterior and posterior views of conjoined shell, KFM1698, 11a, 11b: ventral and dorsal views of conjoined shell, KFM1700. 12: *Hustedia culcitula* Cooper and Grant, 12a, 12b: ventral and dorsal views of conjoined shell, KFM1725. 13, 14: *Metriolepis kuzuensis* sp. nov., 13a, 13b: ventral and dorsal views of conjoined shell, KFM1728 (holotype), 14a, 14b: ventral and dorsal views of conjoined shell, KFM1733. 15: *Rhipidomella hessensis* King, 15a, 15b, 15c, 15d: ventral, dorsal, anterior and posterior views of conjoined shell, KFM1673. 16: *Enteleles acutiplicatus* Hayasaka, anterior view of conjoined shell, KFM1676. Scale bar represents 1 cm.

Bothrostegium sp.

Fig. 4.7

Material.—One specimen from locality KY4, a ventral valve, KFM1672.

Remarks.—This specimen is safely assigned to the genus *Bothrostegium* by its small, conical ventral valve (length 9 mm, width 11 mm, height 9 mm), high apsacline interarea, grooved pseudodeltidium and external ornament consisting of numerous fine costellae and several strong concentric lamellae. The Yamasuge species most resembles *Bothrostegium compactum* Cooper and Grant (1974, p. 330, pl. 62, figs. 22–36), from the Road Canyon Formation (upper Leonardian) of West Texas, in its outline and external ornament, but it differs from the Texan species in its narrower hinge.

The type species, *Bothrostegium derbyoideum* Cooper and Grant (1974, p. 331, pl. 62, figs. 5–14; pl. 63, figs. 1–46), from the Road Canyon Formation of West Texas, differs from the present species in having finer costellae on the ventral valve.

Bothrostegium pussillum Cooper and Grant (1974, p. 332, pl. 118, figs. 8–21), from the Road Canyon Formation of West Texas, differs from the present species in its much smaller size.

Order Orthida Schuchert and Cooper, 1932
 Suborder Dalmanellidina Moore, 1952
 Superfamily Dalmanelloidea Schuchert, 1913
 Family Rhipidomellidae Schuchert, 1913
 Subfamily Rhipidomellinae Schuchert, 1913
 Genus *Rhipidomella* Oehlert, 1890

Type species.—*Terebratula michelini* L veil , 1835.

Rhipidomella hessensis King, 1931

Fig. 4.15

Rhipidomella hessensis King, 1931, p. 43, pl. 1, figs. 2–4; Stehli, 1954, p. 291, pl. 17, figs. 1–6; Cooper and Grant, 1976, p. 2610, pl. 663, figs. 11, 12, 23–26, 32–68; pl. 665, figs. 1–66; pl. 666, figs. 1–33; pl. 667, figs. 27–43.

Material.—Two specimens from locality KY4, two conjoined shells, KFM1673, 1674.

Description.—Shell large size for genus, subcircular in outline, with greatest width at midlength; anterior commissure rectimarginate to very subtly uniplicate; length 16 mm, width 17 mm in the larger specimen (KFM1674). Ventral valve gently convex, and almost flattened near anterolateral margins; umbo small, pointed; interarea not well preserved and obscure. Dorsal valve slightly, but more strongly convex than ventral valve. External surface of both ventral and dorsal valves ornamented with numerous costellae and few, irregular concentric rugae; costellae numbering 8–9 in 2 mm at about midlength of ventral valve.

Remarks.—These specimens are referred to *Rhipidomella hessensis* King, 1931, from the upper Wolfcampian to lower Leonardian of West Texas, by their large, subcircular, and

flatly dorsibiconvex shells, with rectimarginate to very faintly uniplicate anterior commissure. Shells described as *R. hessensis* from the Upper Permian of Vietnam (Shi and Shen, 1998, p. 504, figs. 3.1–3.4, 4.7B) and South China (Shen and Shi, 2007, p. 37, pl. 14, figs. 6–13) differ from the present species in their elongate or subtrigonal outline.

Rhipidomella corallina (Waagen, 1884, p. 572, pl. 56, fig. 1), from the Wargal Formation of the Salt Range, differs from *R. hessensis* in its much larger size.

Rhipidomella cordialis Grant (1976, p. 37, pl. 2, figs. 31–41; pl. 3, figs. 1–53), from the Rat Buri Limestone of southern Thailand, differs from the present species in its smaller size and longer outline.

Distribution.—Lower Permian (Sakmarian–Artinskian) of the United States (West Texas); Lower Permian (Kungurian) of central Japan (Yamasuge in the Kuzu area, Ashio Mountains).

Superfamily Enteletoidea Waagen, 1884

Family Enteletidae Waagen, 1884

Genus *Enteletes* Fischer de Waldheim, 1825

Type species.—*Enteletes glabra* Fischer de Waldheim, 1830.

Enteletes acutiplicatus Hayasaka, 1932

Figs. 4.16, 5.6

Enteletes acutiplicatus Hayasaka, 1932, p. 551, pl. 5, fig. 2; Hayasaka, 1933, p. 23, pl. 8, fig. 1; Tazawa et al., 2010, p. 41, fig. 3.3.

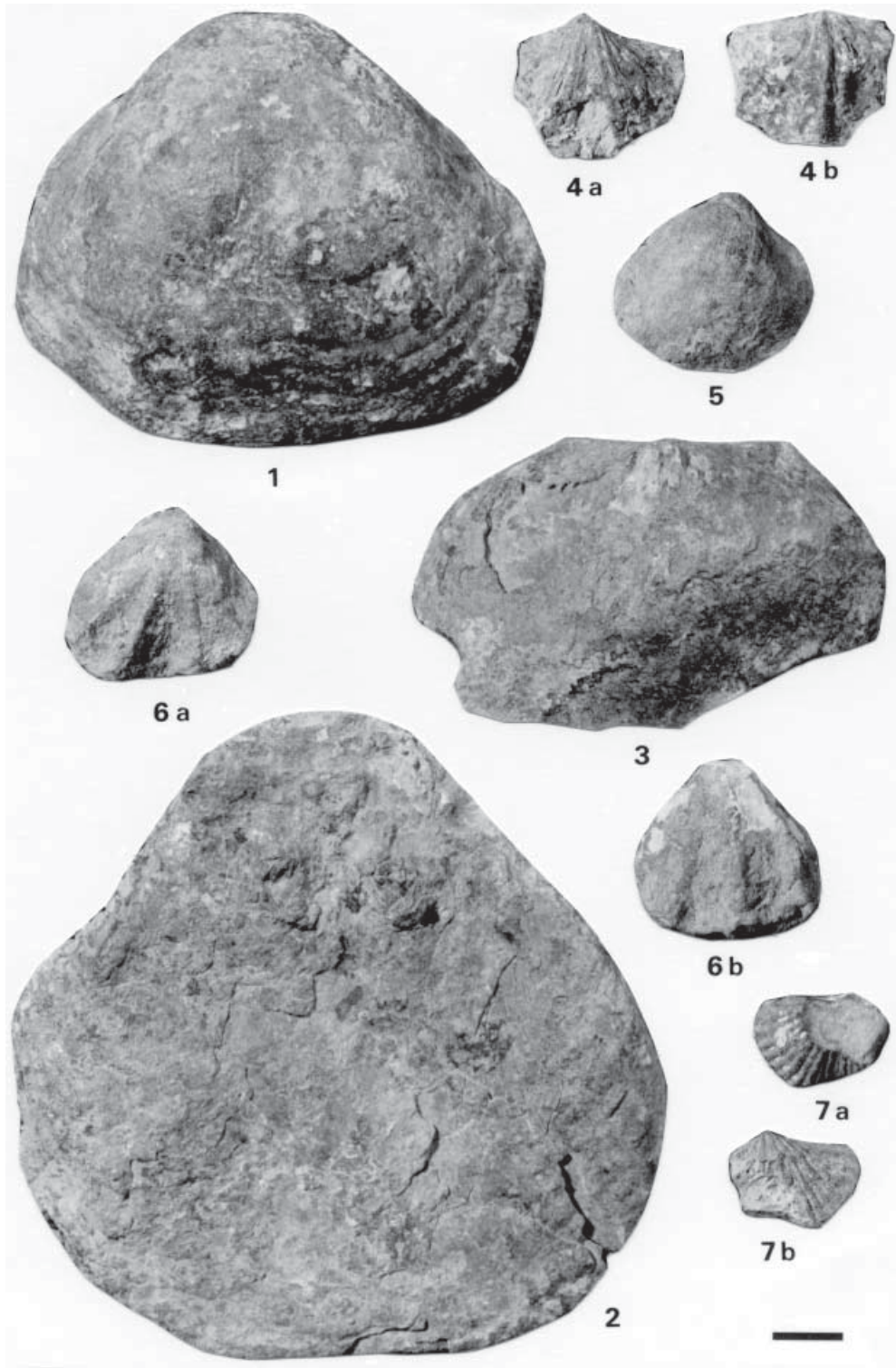
Enteletes costellatus Cooper and Grant, 1976, p. 2629, pl. 686, figs. 1–10; Shen et al., 2011, p. 563, figs. 6.19–6.37.

Material.—Three specimens from locality KY4, three conjoined shells, KFM1675–1677.

Remarks.—The specimens from Yamasuge are not well preserved, but they can be identified with *Enteletes acutiplicatus* Hayasaka, 1932, redescribed by Hayasaka (1933, p. 23, pl. 8, fig. 1) based on the specimens from the Lower Permian (Kungurian) Nabeyama Formation of Nabeyama in the Kuzu area, by their medium size (length about 25 mm, width about 26 mm in the better preserved specimen, KFM1675), a few (6 in ventral valve, 5 in dorsal valve) strong costae with acute crests, and zig-zag growth lamellae developed near antero-lateral margins. *Enteletes costellatus* Cooper and Grant, 1976, from the Hueco Formation of West Texas, is probably a junior synonym of the present species in having a few costae not reaching umbo, and strongly serrate anterior commissure.

Enteletes angulatus Girty (1908, p. 295, pl. 26, fig. 3), from the Hueco Formation of the Diablo Mountains, West Texas, resembles *E. acutiplicatus* in having a few costae with acute crests, but the Texan species is distinguished from the latter by its smaller size and more transverse outline.

Distribution.—Lower Permian (Sakmarian) of the United States (West Texas); Lower Permian (Kungurian) of central Japan (Hatahoko in the Mino Belt, and Nabeyama and Yamasuge in the Kuzu area, Ashio Mountains).



Family Schizophoriidae Schuchert and Le Vene, 1929

Genus *Acosarina* Cooper and Grant, 1969

Type species.—*Acosarina dorsisulcata* Cooper and Grant, 1969.

Acosarina rectimarginata Cooper and Grant, 1976

Fig. 4.9

Acosarina rectimarginata Cooper and Grant, 1976, p. 2624, pl. 674, figs. 1–46; Shen et al., 2011, p. 564, figs. 6.1–6.18.

Material.—One specimen from locality KY4, a conjoined shell, KFM1678.

Description.—Shell small for genus, transversely oval in outline, with greatest width at about midlength; hinge rather wide; anterior commissure rectimarginate; length 6 mm, width 7 mm. Ventral valve gently convex in lateral profile, most convex at umbonal region and flattened anteriorly, and having no sulcus. Dorsal valve also gently convex, having no fold. External surface of both valves ornamented with numerous rounded or slightly flattened costellae and a few strong concentric lamellae; costellae often bifurcate at anterior half of valve, and numbering 3–4 in 1 mm at about midlength of ventral valve.

Remarks.—The single specimen from Yamasuge can be referred to *Acosarina rectimarginata* Cooper and Grant, 1976, from the Neal Ranch Formation (lower Wolfcampian) of West Texas, by its size, outline and external ornament of both ventral and dorsal valves, particularly, by the rectimarginate anterior commissure.

Acosarina indica (Waagen, 1884, p. 568, pl. 56, figs. 7, 8, 14–16), from the Amb and Wargal formations of the Salt Range, differs from *A. rectimarginata* in its subquadrate outline and slightly sulcate anterior commissure.

Distribution.—Lower Permian (Asselian) of the United States (West Texas); Lower Permian (Kungurian) of central Japan (Hatohaoko in the Mino Belt and Yamasuge in the Kuzu area, Ashio Mountains).

Genus *Orthotichia* Hall and Clarke, 1892

Type species.—*Orthis? morganiana* Derby, 1874.

Orthotichia japonica Hayasaka, 1932

Figs. 5.1–5.3, 6.1

← **Fig. 5.** 1–3: *Orthotichia japonica* Hayasaka, 1: ventral valve, KFM1695, 2: ventral valve, KFM1684, 3: abraded ventral valve, KFM1685. 4: *Cartorhium coristum* Cooper and Grant, 4a, 4b: ventral and dorsal views of conjoined shell, KFM1726. 5: *Cleiothyridina* sp., ventral valve, KFM1724. 6: *Enteletes acutiplicatus* Hayasaka, 6a, 6b: ventral and dorsal views of conjoined shell, KFM1675. 7: *Arionthia* cf. *lameria* Cooper and Grant, 7a, 7b: ventral and dorsal views of conjoined shell, KFM1762. Scale bar represents 1 cm.

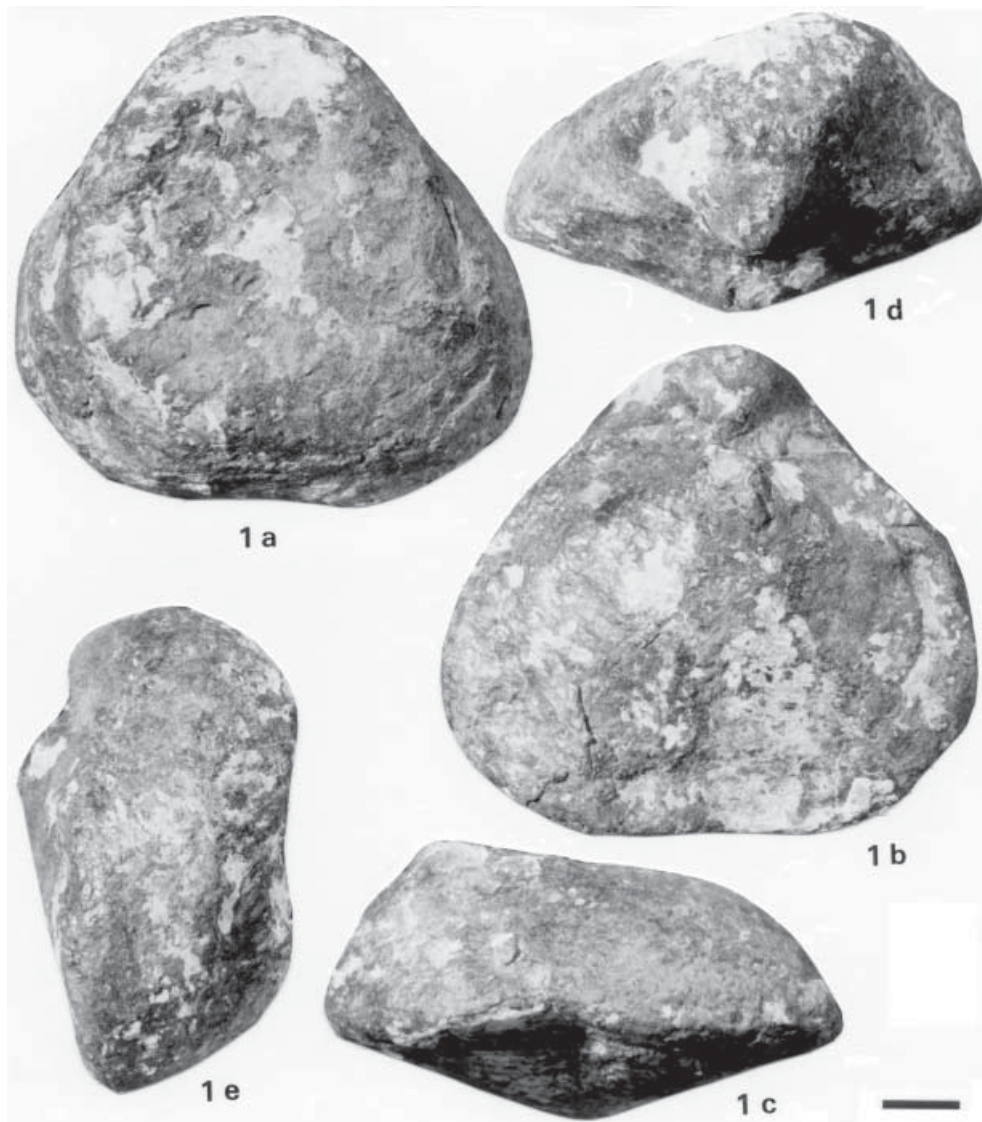


Fig. 6. *Orthotichia japonica* Hayasaka, 1a, 1b, 1c, 1d, 1e: ventral, dorsal, anterior, posterior and lateral views of conjoined shell, KFM1679. Scale bar represents 1 cm.

Orthotichia japonica Hayasaka, 1932, p. 551, pl. 5, fig. 3; Hayasaka, 1933, p. 20, pl. 3, fig. 1; pl. 4, figs. 1, 2; pl. 5, figs. a–d; pl. 6, fig. 1; text-fig. 3; Hayasaka and Hayasaka, 1953, pl. 5, fig. 2; Tazawa in Tazawa et al., 2010, p. 42, figs. 4, 5.

Orthotichia japonica striata Hayasaka, 1933, p. 22, pl. 7, fig. 1.

Material.—Nineteen specimens from localities KY2, KY4: (1) two conjoined shells, KFM1679, 1680; (2) five ventral valves, KFM1681–1685; (3) twelve dorsal valves, KFM1686–1697.

Remarks.—These specimens are referred to *Orthotichia japonica* Hayasaka, 1932, from the Nabeyama Formation of Nabeyama in the Kuzu area, by their fairly large size (length 79 mm, width 91 mm in the largest ventral valve specimen, KFM1684; length 66 mm, width 71 mm in the best preserved specimen, KFM1679), moderately to slightly inflated dorsibiconvex shell, and external ornament of both ventral and dorsal valves consisting of numerous capillae (4–5 in 2 mm at about midlength of dorsal valve) and irregular concentric rugae.

Orthotichia japonica striata Hayasaka, 1933, described by Hayasaka (1933, p. 22) as subspecies of *O. japonica* from the same locality of Nabeyama, is consistent with referral to the present species.

Orthotichia jiangxiensis Hu and Jin in Hu (1983, p. 342, pl. 2, fig. 1), from the Hsiao Chiangpien Limestone (upper Chihsian–lower Maokouan) of Jiangxi, South China, somewhat resembles *O. japonica* in having relatively large and moderately convex dorsal valve, but the former is much larger than the latter.

Distribution.—Lower Permian (Kungurian) of central Japan (Nabeyama and Yamasuge in the Kuzu area, Ashio Mountains).

Order Athyridida Boucot, Johnson and Staton, 1964
 Suborder Athyrididina Boucot, Johnson and Staton, 1964
 Superfamily Athyridoidea Davidson, 1881
 Family Athyrididae Davidson, 1881
 Subfamily Cleiothyridininae Alvarez, Rong and Boucot, 1998
 Genus *Cleiothyridina* Buckman, 1906

Type species.—*Atrypa pectinifera* Sowerby, 1840.

Cleiothyridina hayasakai Tazawa in Tazawa et al., 2010
 Figs. 4.10, 4.11

Cleiothyridina aff. *pectinifera* (Sowerby): Hayasaka, 1967, p. 46, fig. 1.
Cleiothyridina hayasakai Tazawa in Tazawa et al., 2010, p. 43, figs. 3.4–3.6.

Material.—Two hundred thirty-eight specimens from localities KY3, KY4 are available for study. Of these twenty-six conjoined shells from localities KY3, KY4 are registered, KFM1698–1723.

Remarks.—These specimens are referred to *Cleiothyridina hayasakai* Tazawa in Tazawa et al., 2010, from the Lower Permian (Kungurian) of Yamasuge (locality KY1), in their small (length about 10 mm, width 10 mm in the largest specimen, KFM1698), moderately biconvex shells with weakly uniplicate commissure. Comparison with the other *Cleiothyridina* species has been fully discussed by Tazawa in Tazawa et al. (2010, p. 43–45).

Distribution.—Lower Permian (Kungurian) of central Japan (Nabeyama and Yamasuge in the Kuzu area, Ashio Mountains).

Cleiothyridina sp.
 Fig. 5.5

Material.—One specimen from locality KY2, a ventral valve, KFM1724.

Remarks.—This specimen is severely abraded, but somewhat resembles the shell, described and figured by Tazawa in Tazawa et al. (2010, p. 45, fig. 4.1) as *Cleiothyridina* sp., from the Lower Permian (Kungurian) of Yamasuge (locality KY1), in its medium size (length 26 mm, width 27 mm), subcircular outline and moderately convex ventral valve without sulcus. However, poor preservation of the present material makes accurate comparison difficult.

Suborder Retziidina Boucot, Johnson and Staton, 1964

Superfamily Retzioidea Waagen, 1883

Family Neoretziidae Dagys, 1972a

Subfamily Hustediinae Grunt, 1986

Genus *Hustedia* Hall and Clarke, 1893

Type species.—*Terebratula mormoni* Marcou, 1858.

Hustedia culcitula Cooper and Grant, 1976

Fig. 4.12

Hustedia culcitula Cooper and Grant, 1976, p. 2775, pl. 734, figs. 41–76.

Material.—One specimen from locality KY4, a conjoined shell, KFM1725.

Description.—Shell small size for genus, slightly longer subovate in outline, with greatest width at or slightly anterior to midlength; length 5 mm, width 4 mm. Ventral valve moderately convex in lateral profile, having no sulcus. Dorsal valve slightly less strongly convex, having no fold. External surface of both valves ornamented with strong, simple costae, numbering 10 on ventral valve, 11 on dorsal valve; a pair of median costae on ventral valve and median costa on dorsal valve slightly depressed.

Remarks.—This specimen may be a juvenile of *Hustedia culcitula* Cooper and Grant, 1976, from the Neal Ranch Formation (lower Wolfcampian) of West Texas, in size, shape and external ornament of the shell, particularly in having slightly depressed median costa on the brachial valve, and slightly depressed median costae on the ventral valve.

Hustedia trita Cooper and Grant (1976, p. 2804, pl. 742, figs. 20–70), from the Neal Ranch and Lenox Hills formations, West Texas, differs from *H. culcitula* in having more numerous costae on both ventral and dorsal valves.

Distribution.—Lower Permian (Asselian) of the United States (West Texas); Lower Permian (Kungurian) of central Japan (Yamasuge in the Kuzu area, Ashio Mountains).

Order Spiriferida Waagen, 1883

Suborder Spiriferidina Waagen, 1883

Superfamily Spiriferoidea King, 1846

Family Trigonotretidae Schuchert, 1893

Subfamily Neospiriferinae Waterhouse, 1968

Genus *Cartorhium* Cooper and Grant, 1976

Type species.—*Cartorhium retusum* Cooper and Grant, 1976.

Cartorhium coristum Cooper and Grant, 1976

Fig. 5.4

Cartorhium coristum Cooper and Grant, 1976, p. 2193, pl. 613, figs. 36–39; pl. 614, figs. 1–25; Tazawa and Shen, 1997, p. 10, pl. 2, fig. 1.

Material.—Two specimens from locality KY4, incomplete two conjoined shells, KFM1726, 1727.

Description.—Shell medium size for genus, transversely subelliptical in outline, with greatest width at about midlength; length about 20 mm, width about 30 mm in the better preserved specimen (KFM1727). Ventral valve moderately convex in lateral profile, most convex at umbonal region; sulcus broad and deep, with V-shaped bottom, originating just anterior to umbo, and rapidly widening anteriorly. Dorsal valve moderately convex in lateral profile; fold broad and low, with angular crest. External surface of both valves ornamented with numerous bundled costae and fine growth lines; costae strong, rounded, distinctly fasciculate, numbering 3–5 per fasciculate, total numbering 22 or more on the better preserved dorsal valve specimen (KFM1727).

Remarks.—These specimens are poorly preserved, but can be referred to *Cartorhium coristum* Cooper and Grant, 1976, from the Cathedral Mountain Formation (lower Leonardian) of the Glass Mountains, West Texas, in its transverse subelliptical outline and low dorsal fold with angular crest.

The type species, *Cartorhium retusum* Cooper and Grant (1976, p. 2200, pl. 617, figs. 21–26; pl. 618, figs. 1–29), from the Cherry Canyon and Word formations (Wordian) of West Texas, is also a medium-sized, transverse *Cartorhium*, but this species is distinguished from *C. coristum* in its emarginated anterior margin of both ventral and dorsal valves.

Distribution.—Lower Permian (Artinskian) of the United States (West Texas); Lower Permian (Kungurian) of central Japan (Yamasuge in the Kuzu area, Ashio Mountains); Middle Permian (Roadian) of central Japan (Hiyomo in the Mino Belt).

Suborder Spiriferinidina Ivanova, 1972
Superfamily Pennospiriferinoidea Dagys, 1972b
Family Spiriferellinidae Ivanova, 1972
Genus *Metriolepis* Cooper and Grant, 1976

Type species.—*Metriolepis pulvinata* Cooper and Grant, 1976.

Metriolepis kuzuensis sp. nov.

Figs. 4.13, 4.14

Etymology.—Named after the fossil locality, Kuzu, Ashio Mountains, central Japan.

Material.—Thirty-four specimens from locality KY4, thirty-four conjoined shells, KFM1728 (holotype), 1729–1761.

Diagnosis.—Small, slightly transverse *Metriolepis*, with 6 costae on ventral valve and 5 costae on dorsal valve.

Description.—Shell small size for genus, slightly transverse, widest at or slightly anterior to hinge, not alate; length about 5 mm, width about 7 mm in the largest specimen (KFM1733); length about 4 mm, width about 4 mm in the holotype (KFM1728). Ventral valve deep, conical, and moderately convex, with maximum convexity at umbonal region; umbo small, pointed and incurved; interarea high, triangular, flatly concave, increasingly concave toward beak; delthyrium broad, wedge-shaped; sulcus broad and deep, with flattened bottom. Dorsal valve moderately to strongly convex; fold broad and high. External surface of both ventral and dorsal valves ornamented with a few strong, rounded costae and numerous regularly developed, narrowly spaced concentric lamellae; numbering 6 costae on ventral valve, and 5 costae on dorsal valve.

Remarks.—*Metriolepis kuzuensis* sp. nov. resembles *Metriolepis larina* Cooper and Grant (1976, p. 2721, pl. 712, figs. 1–21; pl. 715, figs. 29–34), from the Cathedral Mountain and Road Canyon formations (Leonardian) of West Texas, in its small size, deep ventral valve, and a few costae on both ventral and dorsal valves, but the Yamasuge species is less transverse in outline.

Metriolepis pedicosa Cooper and Grant (1976, p. 2723, pl. 717, figs. 1–17), from the Bell Canyon Formation (upper Guadalupian) of West Texas, is distinguished from *M. kuzuensis* by its larger and more transverse shell.

The type species, *Metriolepis pulvinata* Cooper and Grant (1976, p. 2725, pl. 714, figs. 32–63; pl. 730, figs. 18–21), from the Word Formation of West Texas, differs from the present species in its much larger, transverse shell with alate cardinal extremities.

Family Pennospiriferinidae Dagys, 1972b
Subfamily Punctospiriferellinae Dagys, 1974
Genus *Arionthia* Cooper and Grant, 1976

Type species.—*Arionthia blothrhachis* Cooper and Grant, 1976.

Arionthia cf. *lamaria* Cooper and Grant, 1976
Fig. 5.7

Arionthia cf. *lamaria* Cooper and Grant: Tazawa in Tazawa et al., 2010, p. 45, fig. 4.3.

Material.—One specimen from locality KY4, an incomplete conjoined shell, KFM1762.

Remarks.—This specimen is represented by a fragmentarily preserved conjoined shell. Although ill preservation, it resembles well the shell, described by Tazawa in Tazawa et al. (2010, p. 45, fig. 4.3) as *Arionthia* cf. *lamaria* Cooper and Grant, 1976, from the lower Nabeyama Formation of Yamasuge (locality KY1) in size (length about 15 mm, width about 28 mm), transversely trapezoidal outline and the external ornament consisting of numerous (numbering 9 on each side of dorsal lateral slopes) rounded costae, mostly simple but bifurcate just aside the dorsal fold.

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