Missourian (Kasimovian, Late Pennsylvanian) Conodonts from Limestone Boulders, Mizuboradani Valley, Gifu Prefecture, Central Japan

Authors: Maekawa, Takumi, Komatsu, Toshifumi, Tanaka, Gengo, Williams, Mark, Stocker, Christopher P., et al.

Source: Paleontological Research, 22(3) : 279-289

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2017PR023

Paleontological Research, vol. 22, no. 3, pp. 279–289, July 1, 2018

doi:10.2517/2017PR023

Missourian (Kasimovian, Late Pennsylvanian) conodonts from limestone boulders, Mizuboradani Valley, Gifu Prefecture, central Japan

TAKUMI MAEKAWA[1], TOSHIFUMI KOMATSU[2], GENGO TANAKA[3], MARK WILLIAMS[4], CHRISTOPHER P. STOCKER[4], MASATOSHI OKURA[5] AND AKIHIRO UMAYAHARA[6]

[1]*Center for Water Cycle, Marine Environment, and Disaster Management, Marine Science Laboratory, Kumamoto University, 2-39-1 Kurokami, Chuo-ku, Kumamoto 860-8555, Japan (e-mail: t.m.127d@gmail.com)*
[2]*Faculty of Advanced Science and Technology, Kumamoto University, 2-39-1 Kurokami, Chuo-ku, Kumamoto 860-8555, Japan*
[3]*Institute of Liberal Arts and Science, Kanazawa University, Kakuma, Kanazawa, Ishikawa 920-1192, Japan*
[4]*School of Geography, Geology and Environment, University of Leicester, University Road, Leicester, LEI 7RH, UK*
[5]*Naka 86, Minamiyama-cho, Konan, Aichi 483-8155, Japan*
[6]*Graduate School of Science and Technology, Kumamoto University, 2-39-1 Kurokami, Chuo-ku, Kumamoto 860-8555, Japan*

Received February 23, 2017; Revised manuscript accepted November 20, 2017

Abstract. **Two Late Pennsylvanian conodont species, *Gondolella sublanceolata* Gunnell and *Idiognathodus sulciferus* Gunnell, were extracted from limestone boulders in the Mizuboradani Valley, Fukuji district, central Japan. These provide the first evidence of Missourian (Kasimovian) cosmopolitan conodonts in the Akiyoshi and Hida Gaien belts, Inner Zone of Japan. The limestone boulders might be derived from the Ichinotani Formation and/or from limestone clasts in conglomerates of the Permian Sorayama Formation that crop out in the Mizuboradani Valley.**

Key words: conodont, Ichinotani Formation, Late Pennsylvanian, limestone boulders, Mizuboradani Valley, Sorayama Formation

Introduction

The Fukuji district, Takayama City, Gifu Prefecture, central Japan, is well known as a locality of Paleozoic sedimentary rocks that form a component of the Hida Gaien belt (Figures 1.1, 1.2). The Devonian Fukuji, Carboniferous Ichinotani, and Permian Mizuyagadani formations comprise mainly fossiliferous limestone beds that have been investigated for over 60 years for their paleontological and lithological signature (e.g. Igo, 1956; Niikawa, 1978, 1980; Harayama, 1990). Both macro- and microfossils, including fusulinids, corals, brachiopods, cephalopods, trilobites, ostracods and conodonts have been reported from the three formations (Igo, 1956; Niikawa, 1978, 1980; Kuwano, 1987; Niko and Hamada, 1987; Tazawa *et al*., 2010; Tanaka *et al*., 2013; Stocker *et al*., 2018). In the Mizuboradani Valley (Figure 1.3), located on the northwest side of Okuhidaonsen Village, Carboniferous macro- and microfossils are reported from gray, greenish gray and dark gray limestone boulders (Goto and Okura, 2004; Tazawa *et al*., 2010; Isaji and Okura, 2014; Stocker *et al*., 2018). Goto and Okura (2004) reported 14 isolated teeth of Carboniferous and Permian cartilaginous fish. Isaji and Okura (2014) described well preserved molluscan larval shells, including gastropods and bivalves, from the Ichinotani Formation. Stocker *et al*. (2018) reported an ostracod assemblage from the Carboniferous Ichinotani Formation consisting of silicified carapaces of *Amphissites*, *Kirkbya*, *Bairdia*, *Aechmina* and *Healdia* species. According to Stocker *et al*. (2018), the ostracods indicate a shallow-marine ‘Eifelian type’ ecological assemblage of Becker (1971), which is characteristic of mid-Palaeozoic fore-reef ecosystems.

In this paper, we report newly discovered Carboniferous conodonts from float limestone boulders in the Mizuboradani Valley. Provenance of the boulders and the biostratigraphic distribution of the species/fauna are also discussed herein.

Geological setting

The three southern islands of Japan (Honshu, Shikoku

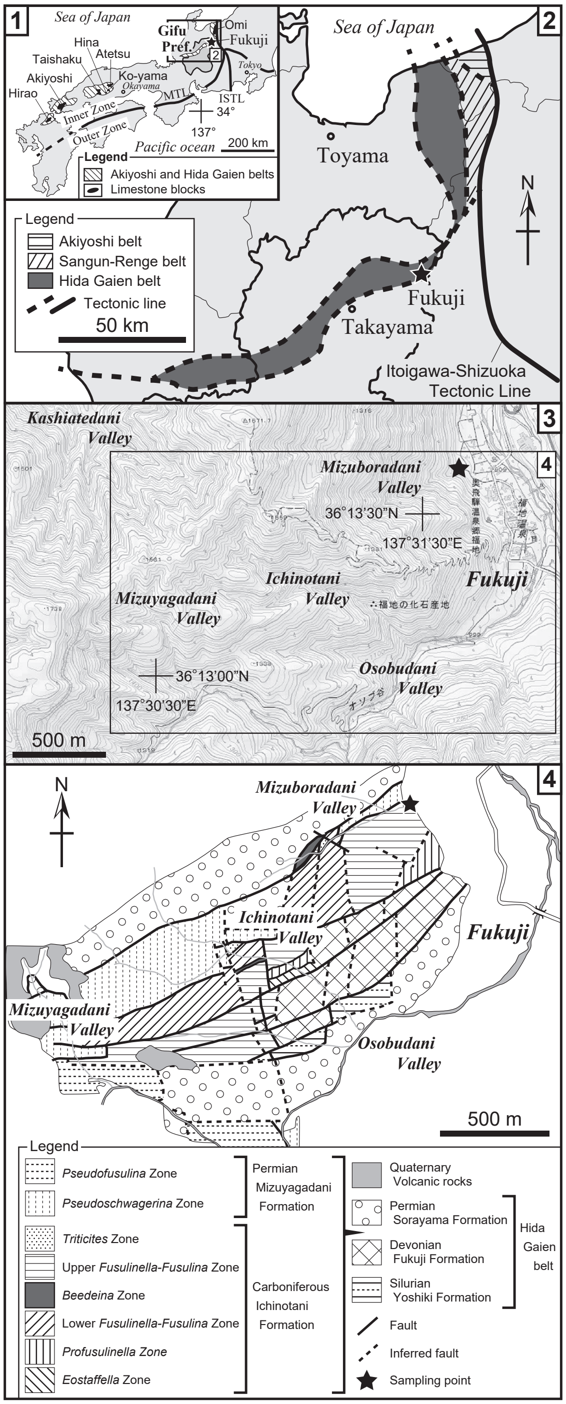

Figure 1. **1,** map showing southwest and central Japan with distribution of limestone blocks in the Akiyoshi and Hida Gaien belts, modified from Ishida *et al*. (2013). Abbreviations: MTL, Median Tectonic Line; ISTL, Itoigawa-Shizuoka Tectonic Line. **2,** distribution of Hida Gaien belt, modified from Tsukada *et al*. (2004). **3,** map showing the study area with the locality of conodont-bearing limestone boulders (marked by the star), Gifu Prefecture, central Japan modified from 1:25,000 scale topographic map 'Yakedake' of the Geospatial Information Authority of Japan (GSI). **4,** geological map of the Fukuji area modified from Harayama (1990).

and Kyushu) are comprised predominantly of Paleozoic, Mesozoic and Cenozoic accretionary complexes (Isozaki and Maruyama, 1991; Isozaki *et al*., 2010). The Jurassic to Cenozoic accretionary complexes form elongate tectonic belts bounded by major structural lineaments. The Median Tectonic Line, one of the major tectonic lineaments of Japan, subdivides rocks of the 'Outer Zone', composed of the Sambagawa metamorphic belt, Chichibu belt, Kurosegawa belt, and Shimanto belt, from those of the 'Inner Zone' consisting mainly of the Ryoke metamorphic belt, and Mino, Akiyoshi, Hida and Hida Gaien tectonic belts on Honshu Island (Taira, 1990; Isozaki *et al*., 2010).

The Fukuji district is situated in the eastern part of the Fukuji-Hongo-Furukawa area, which is the stratotype area of the Hida Gaien belt (Kamei and Igo, 1957; Tsukada *et al*., 2004). According to Tsukada *et al*. (2004), in the Fukuji-Hitoegane district, Ordovician to Permian sedimentary rocks are divided into six formations in ascending order: the Ordovician to Silurian Hitoegane Formation, the Silurian Yoshiki Formation, the Devonian Fukuji Formation, the Carboniferous Ichinotani Formation, the Permian Mizuyagadani Formation, and the Permian Sorayama Formation (Figure 1.4). The physical stratigraphical relationships between these formations are summarized by Niikawa (1978, 1980), Harayama (1990), Tsukada *et al*. (1999, 2004) and Williams *et al*. (2014). The Ichinotani Formation, mainly composed of fossiliferous marine carbonate rocks, is subdivided into six fusulinid zones, namely, *Eostaffella*, *Profusulinella*, Lower *Fusulinella*-*Fusulina*, *Beedeina*, Upper *Fusulinella*-*Fusulina*, and *Triticites* zones in ascending order. The Mizuyagadani Formation consists of carbonates and siliciclastic rocks, in which the *Pseudoschwagerina* and *Pseudofusulina* fusulinid zones are recognised (Figure 1.4; Niikawa, 1980; Harayama, 1990). The Sorayama Formation conformably overlies the Mizuyagadani Formation, and is dominated by massive pyroclastic rocks and intercalating conglomerates, sandstones and mudstones (Tsukada *et al*., 1999).

In the Mizuboradani Valley, carbonate and siliciclastic rocks of the Lower *Fusulinella*-*Fusulina* Zone to *Triticites* Zone of the Ichinotani Formation, carbonate rocks of the *Pseudoschwagerina* Zone of the Mizuyagadani Formation, and tuffaceous rocks of the Sorayama Formation crop out (Figure 1.4; Harayama, 1990). The Ichinotani and Mizuyagadani formations dominate the southern part of the valley, with the Sorayama Formation in the northern part. In the downstream of the valley, Carboniferous and Permian float limestone boulders that contain abundant macro- and microfossils have been reported (e.g. Goto and Okura, 2004). In this study, we collected float limestone boulders from the upstream of the valley

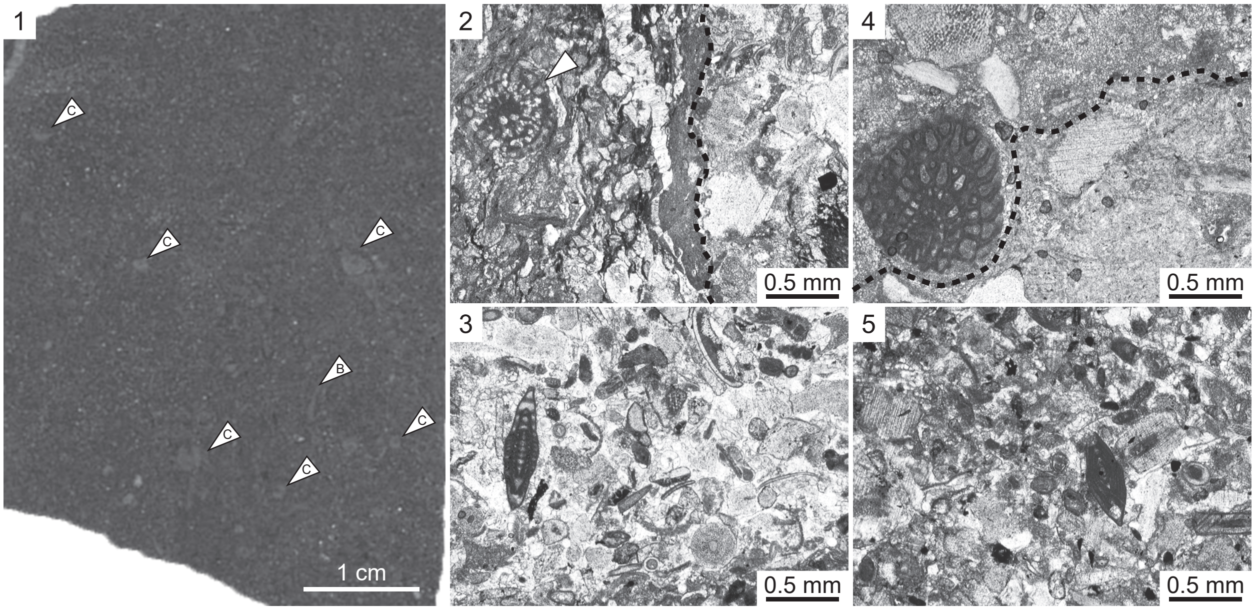

Figure 2. **1,** polished slab of conodont-bearing greenish gray float limestone boulder (T-01). Abbreviations: C, crinoid stems; B, brachiopod shell. **2–5,** photomicrographs of thin section of float limestone boulders. 2, bioclastic limestone (right side) covered by tuffaceous mudstone (left side) including fusulinid foraminifera (white arrow) (T-01). Dashed line shows the boundary between limestone and mudstone. 3, bioclastic limestone (T-01). 4, bioclastic limestone covered by tuffaceous mudstone (I-02). Dashed line shows the boundary between limestone and mudstone. 5, bioclastic limestone (K-01).

to extract conodont microfossils.

Material and methods

We analyzed four greenish-gray limestone boulders (numbered I-01, I-02, K-01, T-01) collected as float in the downstream of the Mizuboradani Valley (Figures 1–3). These limestone boulders, 10–40 cm in diameter, associated with greenish-gray tuff and tuffaceous mudstone (Figures 2.2, 2.4). Goto and Okura (2004), and Isaji and Okura (2014) yielded well preserved microfossils from I-01, and Stocker *et al*. (2018) reported well preserved ostracods from three boulders (I-01, I-02, K-01: Figure 3). In the laboratory, these limestones were crushed into pellets 2–3 cm in diameter and immersed in 5–6% acetic acid to extract the phosphatic microfossils. Conodont elements were obtained from I-01, K-01 and T-01 (Figure 3). This process also recovered abundant silicified fusulinid foraminifers, gastropods, bivalves, brachiopods and ostracods from the limestones.

We used the Olympus SZX7 light microscope (Olympus Co., Ltd., Tokyo) for picking microfossils. Conodonts were coated with platinum using the magnetron sputter MSP-1S (Vacuum Device Co., Ltd., Ibaraki) for capturing images with an Ace-700-S Scanning Electron Microscope (Sanyu Electron Co., Ltd., Tokyo).

Systematic paleontology

Species were identified based on the P_1 element. The specimens studied in this paper are stored in the Micropaleontology Collection (MPC) of the National Museum of Nature and Science, Tsukuba, Japan. Orientation, terminology and measurement of P_1 elements are shown in Figure 4, following Clark and Mosher (1966), Sweet (1988), Purnell *et al*. (2000), and Rosscoe and Barrick (2009). All elements are well preserved and of a dark-gray color.

Order Prioniodinida Sweet, 1988
Superfamily Gondolelloidea (Lindström, 1970)
Family Gondolellidae Lindström, 1970
Genus ***Gondolella*** Stauffer and Plummer, 1932

Type species.—*Gondolella elegantula* Stauffer and Plummer, 1932.

Remarks.—Genus *Gondolella*, a distinctive platform type, was described on the basis of the gondola-shaped P_1 element (Stauffer and Plummer, 1932; Clark and Mosher, 1966). According to Henderson and Orchard (1991), the genus evolved from *Mesogondolella clarki* (Koike, 1967), which has a wide segminiplanate element and lacks ornamentation on the platform, and is of early Moscovian, Early Pennsylvanian age. The oldest known

Previous studies		Tazawa *et al.*, 2010	Goto and Okura, 2004; Isaji and Okura, 2014 / Stocker *et al.*, 2018	Stocker *et al.*, 2018	Stocker *et al.*, 2018	
Fossils	Sample no.		I-01	I-02	K-01	T-01
Fusulinids	*Eostaffella*? sp.	●				
Fusulinids	*Ozawainella mosquensis* Rauser-Chernoussova, 1951		○	◎	○	○
Fusulinids	*Ozawainella* sp.	●				
Fusulinids	*Millerella* aff. *marblensis* Thompson, 1942	●				
Brachiopods		●	○	○	○	○
Gastropods			●	○	○	○
Bivalves			●	○	○	○
Ostracods	*Kirkbya sarusawensis* Ishizaki, 1968		◎	◎	◎	○
Ostracods	*Kirkbya nanatsumoriensis* Ishizaki, 1968		◎	◎	◎	○
Ostracods	*Amphissites centronotus* Girty, 1910		◎	◎	◎	○
Ostracods	*Aechmina akumame* Stocker *et al.*, 2018		◎	◎	◎	○
Ostracods	*Bairdia* cf. *nanbiancunensis* Wang, 1988		◎	◎	◎	○
Ostracods	*Healdia mizuboradanensis* Stocker *et al.*, 2018		◎	◎	◎	○
Conodonts	*Gondolella sublanceolata* Gunnell, 1933		○		○	○
Conodonts	*Idiognathodus sulciferus* Gunnell, 1933		○		○	○
Fish teeth			●			

Figure 3. Conodonts and other fossil from the four float limestone boulders (I-01, I-02, K-01 and T-01) in the downstream of the Mizuboradani Valley (this and previous studies), and from a dark gray limestone boulder reported by Tazawa *et al.* (2010). Open circles show our original data. Solid circles show the fossils figured in previous studies. Double circles show the fossils observed by Stocker *et al*. (2018).

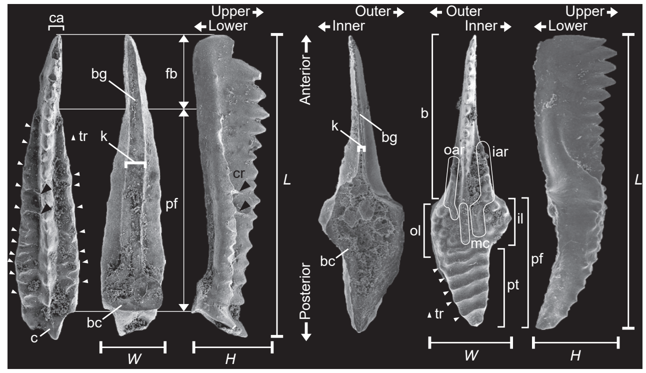

Figure 4. Orientation, terminology and measurement for P_1 elements of *Gondolella* and *Idiognathodus*. Abbreviations: *L*, length; *H*, height; *W*, width; b, blade; bc, basal cavity; bg, basal groove; c, cusp; ca, carina; cr, crest; fb, free blade; iar, inner adcarinal ridge; il, inner lobe; k, keel; mc, medial carina; oar, outer adcarinal ridge; ol, outer lobe; pf, platform; pt, posterior tip; tr, transverse ridge.

species of *Gondolella* (*Gondolella laevis* Kossenko and Kozitskaya in Kossenko, 1975), which was described from early Moscovian strata, lacks transverse ridges on the platform, but late Moscovian to Gzhelian species (e.g. *Gondolella bella* Stauffer and Plummer, 1932) have conspicuous transverse ridges on the platform (Clark and Mosher, 1966; von Bitter and Merrill, 1980). The egminate types (e.g. *Gondolella gymna* Merrill and King, 1971) range from the early Moscovian to Gzhelian, and subsequently evolved into the segminiplanate type and genus *Gondolelloides* Henderson and Orchard, 1991 in the early Permian (Henderson and Orchard, 1991).

Multielement apparatuses of some species of *Gondolella* (e.g. *Gondolella sublanceolata*) are reconstructed by von Bitter (1976), von Bitter and Merrill (1980), and Merrill and von Bitter (2007).

Gondolella sublanceolata Gunnell, 1933

Figure 5

Gondolella bella Stauffer and Plummer, 1932. Clark and Mosher, 1966, p. 383, pl. 45, figs. 5–9.
Gondolella sublanceolata Gunnell, 1933, p. 287, pl. 32, figs. 53–55; Ellison, 1941, p. 122, pl. 21, figs. 18, 19, 22, 23, 34, 35; Lindström, 1964, fig. 55C; Clark and Mosher, 1966, p. 387, pl. 45, figs. 20–22, 24–30; von Bitter, 1976, p. 5, 7, 10, fig. 3G–K.
Gondolella symmetrica Ellison, 1941, p. 121, pl. 21, figs. 3, 4, 17, 21, 26, 30; Lindström, 1964, p. 61, figs. 21K, 40C.
Gondolella dubia Ellison, 1941, p. 124, pl. 21, figs. 8, 12, 16.

Material examined.—Three specimens, MPC32956–32958, from I-01, and one specimen, MPC32959, from K-01.

Description.—Four slender gondola-like segminiplanate elements; platform shows isosceles triangle-like outline with sharply pointed anterior end and rounded or square posterior end. 1.02–1.22 mm, average 1.11 mm in length; 0.24–0.32 mm, average 0.28 mm in height; 0.17–0.27 mm, average 0.23 mm in width; giving a length to width ratio of 4.2–4.8 in four specimens. In upper view, carina bears 13–17 short pointed and erect denticles which contain a posterior node-like cusp; surface of denticulation covered by striations; platform ornamented with amorphous transverse ridges which makes denticulation on the platform margin; weak lateral furrow; posterior end of the platform fused with cusp. In lateral view, highest point situated in anterior one-fourth of length; height of denticulation gradually decreases to cusp; straight

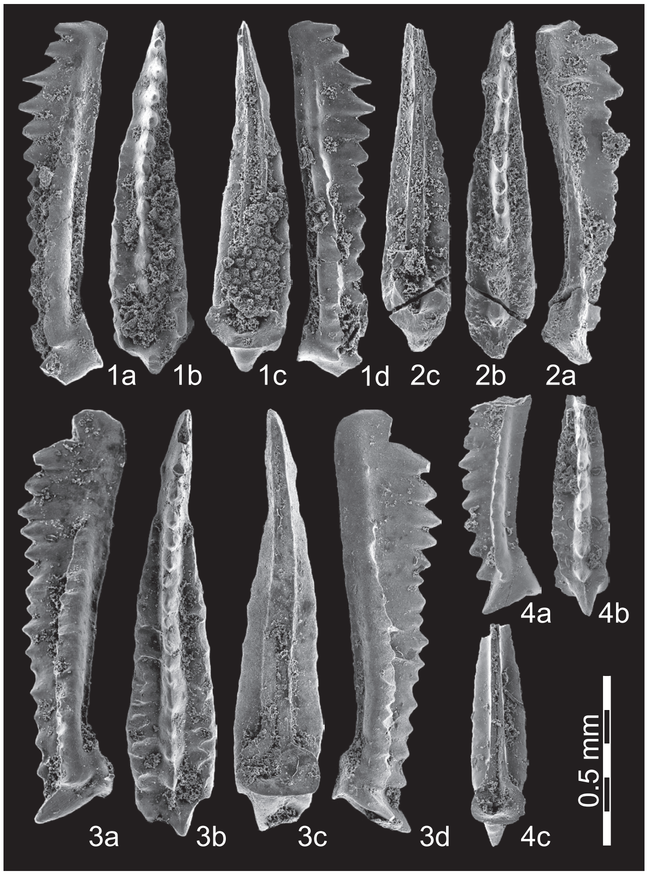

Figure 5. SEM images of P_1 elements of *Gondolella sublanceolata* Gunnell, 1933. **1**, MPC32956; **2**, MPC32957; **3**, MPC32958; **4**, MPC32959. 1–3 from I-01; 4 from K-01. For 1–4; a, d, lateral views; b, upper view; c, lower view.

basal margin downturned just anterior to flange; cusp declined posteriorly; platform margin undulated. In lower view, wide keel (one-third of element width) runs from oval or rectangular flange to anterior end; groove splits the keel, starts from basal pit; width of flange achieves that of element. Largest specimen (MPC32958) has a well developed free blade and transverse ridges on the platform; these ridges form crests along the lateral side of the carina.

Remarks.—*Gondolella sublanceolata* is characterized by a slender lanceolate segminiplanate P_1 element with developed free blade (Clark and Mosher, 1966). These features distinguish this species from the other species of *Gondolella* (e.g. *Gondolella bella*). In this study, both small and large specimens of *G. sublanceolata* were collected, but the free blade is only developed in the largest specimen. However, the other features: outline of the platform, transverse platform ridges, denticulation of carina, downturned flange, straight and wide keel with furrow, are shared by all specimens.

Gondolella cf. *sublanceolata* reported by Kusunoki *et al*. (2004) is characterized by distinct denticulation of the carina on a broad platform and is distinguished from *G. sublanceolata* by lack of transverse platform ridges and free blade. The form of the former species is similar to that of the species of genus *Mesogondolella*.

Occurrence.—Missourian of North America (Stauffer and Plummer, 1932; Gunnell, 1933; Ellison, 1941; Clark and Mosher, 1966; von Bitter, 1976) and Carboniferous limestone boulders from the Mizuboradani Valley, Gifu Prefecture, central Japan (this study).

Order Ozarkodinida Dzik, 1976
Family Idiognathodontidae Harris and Hollingsworth, 1933
Genus ***Idiognathodus*** Gunnell, 1931

Type species.—*Idiognathodus claviformis* Gunnell, 1931.

Remarks.—*Idiognathodus* was established by Gunnell (1931) based on segminiscaphate P_1 elements, showing complex ornamentation on the platform surface. The type material is from the Fort Scott Limestone, Missouri, USA. According to Sweet (1988), larger P_1 elements are characterized by a broader platform, transverse ridges on the posterior tip, and lobate areas occupied by nodes developed on the anterolateral shoulders of the platform. These features distinguish *Idiognathodus* from *Streptognathodus* Stauffer and Plummer, 1932. The biostratigraphic range of species in *Idiognathodus* is from the Pennsylvanian to the Permian (Sweet, 1988).

Idiognathodus sulciferus Gunnell, 1933

Figure 6

Idiognathodus sulciferus Gunnell, 1933, p. 271, pl. 31, fig. 16; Barrick and Boardman, 1989, p. 185, pl. 1, figs. 9, 23, 24; Barrick and Walsh, 1999, p. 154, fig. 6.1; Ritter *et al*., 2002, p. 508, figs. 8.21, 8.25; Barrick *et al*., 2004, p. 241, pl. 4, fig. 13; Rosscoe and Barrick, 2009, p. 127, 128; Barrick *et al*., 2013, pl. 3, fig. 12.

Idiognathodus sulciferus sulciferus Gunnell, 1933. Rosscoe and Barrick, 2009, p. 127, pl. 3, figs. 12–17, pl. 6, fig. 2a.

Idiognathodus chiriformis Gunnell, 1933, p. 272, pl. 31, fig. 23.

Idiognathodus cuneiformis Gunnell, 1933, p. 270, pl. 31, fig. 8; Barrick and Walsh, 1999, p. 153, fig. 5.2.

Idiognathodus swadei Rosscoe and Barrick, 2009. Qi *et al*., 2013, fig. 9i, j.

Idiognathodus n. sp. 1. Goreva *et al*., 2009, fig. 6B–F.

Material examined.—Six specimens, MPC32960, 32961, 32963–32965, 32967, from I-01, and six specimens, MPC32962, 32966, 32968–32971, from K-01.

Description.—Medium- to large-sized elements (MPC32962–32971): ten segminiscaphate elements;

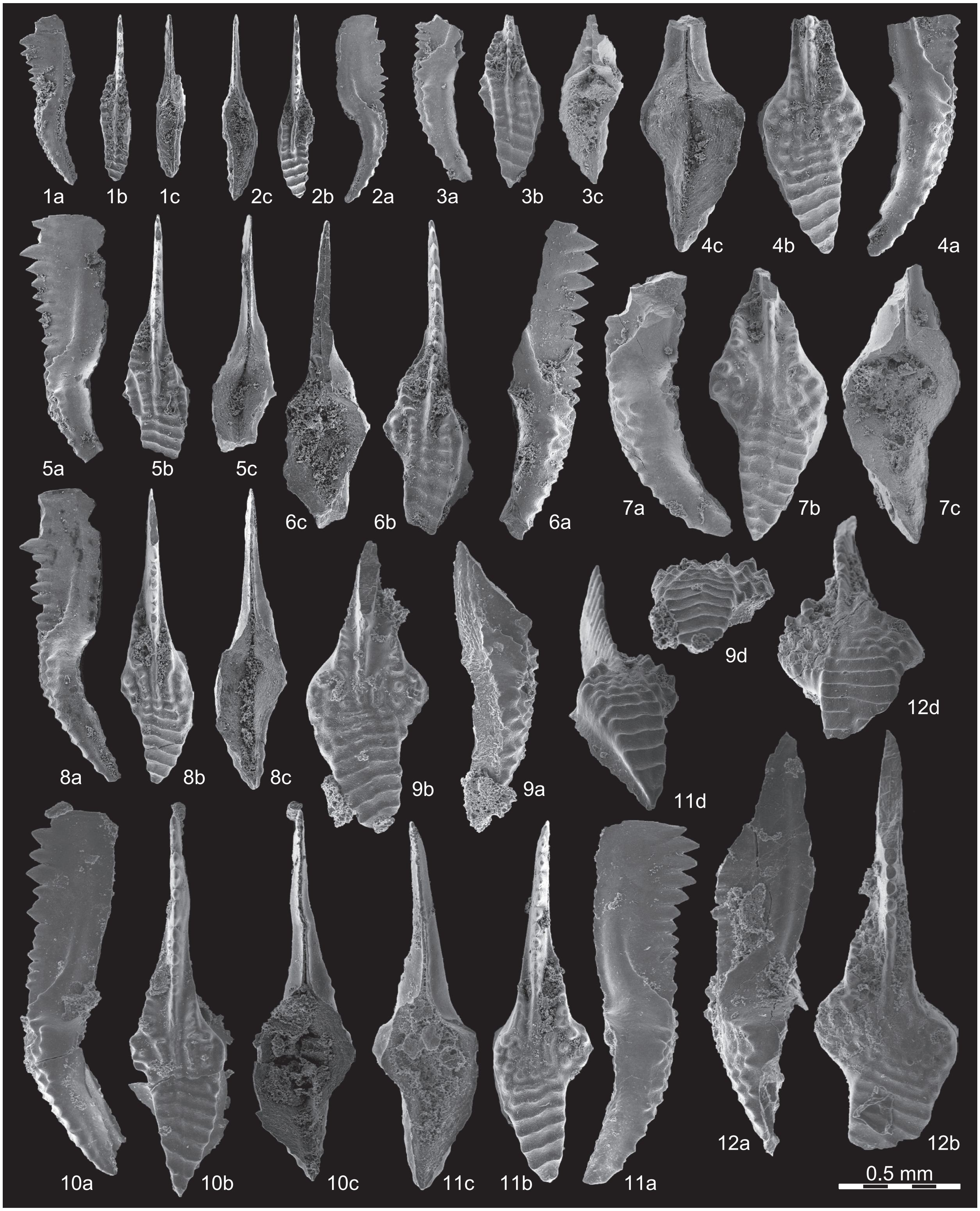

Figure 6. SEM images of P_1 elements of *Idiognathodus sulciferus* Gunnell, 1933. **1**, MPC32960; **2**, MPC32961; **3**, MPC32962; **4**, MPC32963; **5**, MPC32964; **6**, MPC32965; **7**, MPC32966; **8**, MPC62967; **9**, MPC32968; **10**, MPC32969; **11**, MPC32970; **12**, MPC32971. 1, 2, 4–6, 8 from I-01; 3, 7, 9–12 from K-01. For 1–12; a, lateral view; b, upper view; c, lower view; d, postero-upper view.

1.21–1.49 mm in length; 0.42–0.48 mm in height; 0.35–0.4.0 mm in width; length to width ratio 3.5–4.0 (measurements based on three complete specimens). Largest specimen (MPC32971) probably achieves 2.0 mm in length. Laterally compressed free blade bears 10–12 triangular-shaped denticles which continue to medial carina, and length of blade achieves over one-third of element length; highest point situated in anterior. Both adcarinal ridges extend from central part of platform to blade; bearing short pointed or node-like denticles in anterior; constricted to central side at both the inner and outer lobes; gradually disrupted on platform. Width of inner adcarinal ridge is twice that of outer one. Platform surface covered by microreticulation. Outer lobe moderately restricted; bears one or two rows of nodes, which align with medial carina. Laterally subrounded or pointed inner lobe bears one to two rows of nodes or ring of discrete nodes. Relatively narrow pointed posterior tip; covered by 5–7 widely spaced transverse ridges; shows normal surface or weak eccentric groove. Basal margin straight under free blade; arched under platform; strongly downturned to platform end. Deep basal cavity continues to anterior basal groove. Attachment surface shows facet of concentric layer.

Small-sized elements (MPC32960, 32961): segminiscaphate elements; 0.70 and 0.77 mm in length; 0.21 and 0.24 mm in height; 0.13 and 0.16 mm in width; length to width ratio 4.0 and 4.9 in two specimens. Laterally compressed free blade bears 8 triangular-shaped pointed denticles, which continue to medial carina. The carina continues to half to two-thirds of platform length. Both adcarinal ridges bear pointed denticles and continue to over half the length of the platform. Inner ridge slightly flanged. Inner and outer lobes are incompletely developed. Slender subrounded posterior tip; covered by 2–4 transverse ridges; shows normal surface. Basal margin straight and gradually upturned anteriorly under free blade; arched under platform. Basal cavity continues to anterior basal groove.

Remarks.—According to Rosscoe and Barrick (2009), *Idiognathodus sulciferus* is characterized by a moderately restricted outer lobe, better developed inner lobe which protrudes in a triangular shape, pointed posterior tip covered by coarse transverse ridges, and moderately outward flared inner adcarinal ridge forming a high collar around free blade. *Idiognathodus expansus* Stauffer and Plummer, 1932 is identified by its restricted outer lobe, and subrounded posterior tip covered by a closely spaced transverse ridge. *Idiognathodus swadei* Rosscoe and Barrick, 2009, bears an expanded and highly developed outer lobe covered by discrete hemispherical nodes.

Idiognathodus sulciferus is distinguished from *I. expansus* and *I. swadei* by its moderately restricted outer lobe, outward flared adcarinal ridge and widely spaced transverse ridges on the platform. Medium-sized specimens of *I. swadei* (Rosscoe and Barrick, 2009, pl. 2, figs. 5, 6, 12) are discriminated by their larger number of spherical nodes on both the inner and outer lobes.

Idiognathodus n. sp. 1 from Russia (Goreva *et al*., 2009, fig. 6B–F), and *I. swadei* from South China (Qi *et al*., 2013, fig. 9i, j), are both characterized by their moderately restricted lobes and widely spaced transverse ridges on the posterior tip. These are considered conspecific with *I. sulciferus*.

Occurrence.—The first occurrence datum of this species is in the Lower Checkerboard Limestone of the Helper Formation, South Mound Checkerboard Cyclothem, USA (uppermost Desmoinesian); its last occurrence datum is in the Swope Cyclothem, USA (lower Missourian) (Rosscoe and Barrick, 2009; Barrick *et al*., 2013). This range encompasses the *Idiognathodus eccentricus*, *I. turbatus*, and *I. cancellosus* conodont zones and corresponds to the lower Kasimovian, Upper Pennsylvanian. *Idiognathodus sulciferus* is also known from the lower Kasimovian in South China (Qi *et al*., 2013) and Russia (Goreva *et al*., 2009).

Biostratigraphy of the conodonts

The conodont species *Gondolella sublanceolata* and *Idiognathodus sulciferus* from limestone boulders I-01, K-01 and T-01, derived from the upstream of the Mizuboradani Valley (Figure 1.3), indicate an early Missourian (Kasimovian, Late Pennsylvanian) age. Previously, Kuwano (1987) reported Devonian and a few Carboniferous conodonts from the Fukuji and Ichinotani formations, in the Ichinotani Valley located about 500 m south of the Mizuboradani Valley (Figure 1.4): the Carboniferous conodonts he reported are *Idiognathodus sinuosus* Ellison and Graves, 1941 and *Streptognathodus lateralis* Higgins and Bouckaert, 1968, from the Ichinotani Formation. These conodonts indicate an Early Pennsylvanian, Bashkirian age (Barrick *et al*., 2013). Niikawa (1978, 1980) established fusulinid range zones in the Ichinotani and Mizuyagadani formations in the Fukuji district, and estimated the age to be from Visean (Middle Mississippian) to Asserian (earliest Permian). However, Kasimovian strata have not been reported, because the Moscovian (Middle Pennsylvanian) and Gzhelian (uppermost Pennsylvanian) parts of the lithostratigraphy are structurally juxtaposed (Niikawa, 1980). Thus, this is the first report of Kasimovian conodonts in the Hida Gaien belt.

In Japan, Carboniferous conodonts have mainly been reported from Carboniferous to Permian massive limestone olistoliths in the Akiyoshi belt by several authors: Mississippian to Middle Pennsylvanian conodont assemblages were reported from the Omi Limestone, Niigata (Igo and Koike, 1964), the Akiyoshi Limestone, Yamaguchi (Igo, 1973), the Atetsu Limestone, Okayama (Koike, 1967), the Hina Limestone, Okayama (Mizuno, 1997), and the Ko-yama Limestone, Okayama (Ishida *et al*., 2012, 2013). An Early Pennsylvanian conodont assemblage was also reported from limestone blocks in the Chichibu belt (Ishida *et al*., 2005), and Gzhelian (latest Pennsylvanian) conodonts were reported from the Tamba belt (Kusunoki *et al*., 2004). However, prior to this study, Kasimovian conodonts have not been reported, and their discovery is important for biostratigraphic correlation with other global areas.

Possible source of the conodont-bearing limestone boulders

In the Mizuboradani Valley, Carboniferous marine fossils have been documented from limestone boulders (Goto and Okura, 2004; Tazawa *et al*., 2010; Isaji and Okura, 2014; Stocker *et al*., 2018). The dark gray limestone blocks reported by Tazawa *et al*. (2010) contain fusulinids (*Eostaffella*? sp., *Millerella* aff. *marblensis* Thompson, 1942, *Ozawainella* sp.) that indicate the upper Bashkirian (Lower Pennsylvanian), probably within the *Profusulinella* Zone that exists in the Ichinotani Formation. Isaji and Okura (2014) reported larval shells of gastropods and bivalves from greenish-gray limestone boulders (I-01) that contain fusulinids, brachiopods, ostracods, trilobites, crinoids, conodonts and isolated teeth of cartilaginous fish described by Goto and Okura (2004). Isaji and Okura (2014) suggested that the limestone was possibly derived from the interval of the *Fusulinella*-*Fusulina* Zone within the Ichinotani Formation. Sample I-02, reported by Stocker *et al*. (2018) contains the fusulinid *Ozawainella mosquensis* Rauser-Chernoussova in Rauser-Chernoussova *et al*. (1951), which was only reported from the *Beedeina* Zone, just below the Upper *Fusulinella*-*Fusulina* Zone of Niikawa (1980) in the upstream of the Mizuboradani Valley.

We have been unable to find exposures of greenish-gray tuff and tuffaceous mudstone in the *Beedeina* Zone of the Ichinotani Formation. Thus, the Missourian conodont-bearing limestone boulders might be derived from uninvestigated exposures and sections in the valley.

In this study, we focused on the Sorayama Formation as one of the possible sources of the conodont-bearing float limestone boulders. According to Igo (1956), Tsukada and Takahashi (1998), and Tsukada *et al*. (1999), the Sorayama Formation is widely distributed in the Fukuji district and consists mainly of mafic to intermediate pyroclastic rocks with intercalated conglomerates, sandstones and mudstones. The conglomerates are clast-supported and contain pebble- to boulder-sized limestone

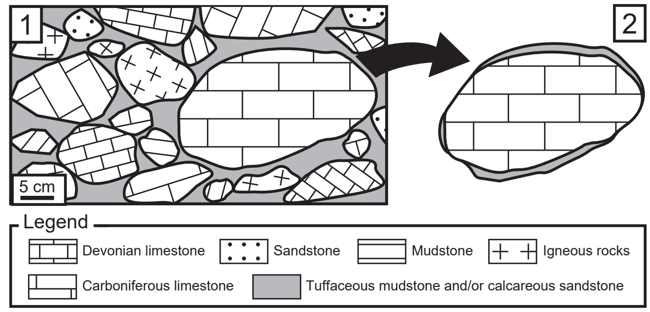

Figure 7. **1,** stylised image of a conglomerate bed of the Permian Sorayama Formation. These beds are clast-supported and contain abundant pebble- to boulder-sized subangular and subrounded clasts of sandstone, mudstone, various igneous rocks, and Devonian and Carboniferous fossiliferous limestones in a tuffaceous mudstone and/or calcareous sandstone matrix. The limestones were probably derived from the Devonian Fukuji and Carboniferous Ichinotani formations. **2,** float limestone boulder as it would appear if reworked from the conglomerates of the Sorayama Formation.

clasts. The limestones contain Devonian corals *Favosites* and *Heliolites*, and Carboniferous fusulinids such as *Ozawainella* sp., *Beedeina ichinotaniensis* (Igo, 1957), *Quasifusulina longissima* (Möller, 1878), and *Triticites* sp. (Igo, 1956; Tsukada *et al*., 1999). In contrast, the matrix (tuffaceous mudstone and/or calcareous sandstone) of the conglomerates contains middle Permian fusulinids such as *Nankinella* sp., *Parafusulina* aff. *gigantea* (Deprat, 1913) and *Russiella pulchra* Miklukho-Maclay, 1958. Tsukada *et al*. (1999) suggested that the limestone clasts of the Sorayama Formation were derived from both the Devonian Fukuji and Carboniferous Ichinotani formations. The limestone boulders documented for our paper are lithologically similar to the above-mentioned limestone clasts of Carboniferous age. According to Tsukada *et al*. (1999), tuffaceous clastic materials which are components of the matrix of the conglomerate of the Sorayama Formation fill the chambers of some Permian fusulinids. This feature is observed in our sample T-01 (Figure 2.2). These observations enable us to consider the conglomerates of the Sorayama Formation as one of the likely sources of our Carboniferous-age limestone boulders (Figure 7).

Biogeography

The Missourian (Kasimovian, Late Pennsylvanian) conodont species *Gondolella sublanceolata* and *Idiognathodus sulciferus*, are commonly reported in the Pennsylvanian of the USA (Gunnell, 1933; Clark and Mosher, 1966; Barrick *et al*., 2004; Rosscoe and Barrick, 2009). *Idiognathodus sulciferus* is also known from the Moscow

Basin of Russia (Goreva *et al*., 2009), and from Guizhou, South China (Qi *et al*., 2013). The similarity of the Kasimovian conodonts of Japan with those of southern China and the USA continues a trend that is also apparent from Early and Middle Pennsylvanian faunas. Ishida *et al*. (2012, 2013) reported Bashkirian to early Moscovian (Early to Middle Pennsylvanian) conodonts from the Ko-yama Limestone Group, Akiyoshi Belt, Okayama, Japan. The Moscovian conodont assemblage consists of *Mesogondolella clarki* (Koike, 1967), *Idiognathoides attenuatus* (Harris and Hollingsworth, 1933), *Id*. *convexus* (Ellison and Graves, 1941), *Id*. *macer* (Wirth, 1967), *Idiognathodus delicatus* Gunnell, 1931, *Streptognathodus suberectus* Dunn, 1966, *Neognathodus bothrops* Merrill, 1972 and *N*. *symmetricus* (Lane, 1967). Seven species (*M*. *clarki*, *Id*. *attenuatus*, *Id*. *convexus*, *I*. *delicatus*, *S*. *suberectus*, *N*. *bothrops* and *N*. *symmetricus*) from the Ko-yama Limestone are reported from the Midcontinent area of the western USA (Ellison and Graves, 1941; Dunn, 1966, 1970; Merrill, 1972; von Bitter and Merrill, 1977; Barrick *et al*., 2013). *Mesogondolella clarki*, *Id*. *convexus*, *I*. *delicatus*, *S*. *suberectus*, *N*. *bothrops* and *N*. *symmetricus* are also known from Guizhou, South China (Qi *et al*., 2013). *Mesogondolella clarki*, *N*. *bothrops* and *N*. *symmetricus* appear to be cosmopolitan species in the Moscovian (Middle Pennsylvanian).

Concluding remarks

In this study, we report the Missourian (Carboniferous) conodonts *Gondolella sublanceolata* Gunnell, 1933 and *Idiognathodus sulciferus* Gunnell, 1933 from float limestone boulders collected in the downstream of the Mizuboradani Valley, Fukuji district, central Japan. According to the conodont age, the float limestone boulders might be from the *Triticites* Zone of the Ichinotani Formation, or derived from boulder-sized limestone clasts in the conglomerates of the Permian Sorayama Formation.

Gondolella sublanceolata has previously been reported only from the Carboniferous of North America, and this is the first report of the species from a western Panthalassic setting. This suggests that *Gondolella* was a widespread pan-Panthalassic Ocean species during the Middle to Late Pennsylvanian, and thus of biostratigraphical value for international correlation.

Acknowledgements

We are grateful to Tatsuya Hayashi (Kyushu University) and Naoki Ikegami (Mifune Dinosaur Museum) for taking SEM images of conodonts. We thank Keisuke Ishida (Tokushima University), an anonymous reviewer and the associate editor Yasunari Shigeta (National Museum of Nature and Science) for valuable comments on the draft. Part of this study was supported by the JSPS-VAST Joint Research Program, Grants-in-Aid from the Japan Society for the Promotion of Science (16K05593 to Komatsu). Mark Williams and Christopher P. Stocker thank the Leverhulme Trust (International Network Grant IN-2014-025 ‘Assembling the Early Palaeozoic terranes of Japan’).

References

Barrick, J. E. and Boardman II, D. R., 1989: Stratigraphic distribution of morphotypes of *Idiognathodus* and *Streptognathodus* in Missourian–Lower Virgilian strata, north-central Texas. *Texas Tech University Studies in Geology*, vol. 2, p. 167–175.

Barrick, J. E., Lambert, L. L., Heckel, P. H. and Boardman, D. R., 2004: Pennsylvanian conodont zonation for Midcontinent North America. *Revista Española de Micropaleontología*, vol. 36, p. 231–250.

Barrick, J. E., Lamert, L. L., Heckel, P. H., Rosscoe, S. J. and Boardman, R., 2013: Midcontinent Pennsylvanian conodont zonation. *Stratigraphy*, vol. 10, p. 55–72.

Barrick, J. E. and Walsh, T. R., 1999: Some older North American types of *Idiognathodus* and *Streptognathodus*. *In*, Heckel, P. H. *ed*., *XIVth ICCP Field Trip #8: Middle and Upper Pennsylvanian (Upper Carboniferous) Cyclothem Succession in Midcontinent Basin*, *USA*. *Kansas Geological Survey Open-file Report 99–27*, p. 162–169. Kansas Geological Survey, Lawrence.

Becker, G., 1971: Paleoecology of Middle Devonian ostracods from the Eifel region, Germany. *In*, Oertli, H. J. *ed*., *Paléoécologie des Ostracodes*, p. 801–816. *Bulletin du Centre de Recherches Pau-SNPA 5*, Société Nationale des Pétroles d’Aquitaine, Paris.

Bitter, P. H. von, 1976: The apparatus of *Gondolella sublanceolata* Gunnell (Conodontophorida, Upper Pennsylvanian) and its relationship to *Illinella typica* Rhodes. *Royal Ontario Museum Life Science Contributions*, vol. 109, p. 1–44.

Bitter, P. H. von and Merrill, G. K., 1977: Neogondolelliform conodonts of Early and Middle Pennsylvanian age. *Royal Ontario Museum Life Science Occasional Paper*, no. 29, p. 1–10.

Bitter, P. H. von and Merrill, G. K., 1980: Naked species of *Gondolella* (Conodontophorida): their distribution, taxonomy, and evolutionary significance. *Royal Ontario Museum Life Science Contributions*, vol. 125, p. 1–49.

Clark, D. L. and Mosher, L. C., 1966: Stratigraphic, geographic, and evolutionary development of the conodont genus *Gondolella*. *Journal of Paleontology*, vol. 40, p. 376–394.

Deprat, J., 1913: Étude des fusulinidés de Chine et d’Indochine et classification des calcaires à fusulines (2ème mémoire.). Les Fusulinidés des calcaires carbonifériens et permiens du Tonkin, du Laos et du Nord-Annam. *Mémoires du Service Géologique de l’Indochine*, vol. 2, p. 1–74.

Dunn, D. L., 1966: New Pennsylvanian platform conodonts from southwestern United States. *Journal of Paleontology*, vol. 40, p. 1294–1303.

Dunn, D. L., 1970: Middle Carboniferous conodonts from western United States and phylogeny of the platform group. *Journal of Paleontology*, vol. 44, p. 312–342.

Dzik, J., 1976: Remarks on the evolution of Ordovician conodonts. *Acta Palaeontologica Polonica*, vol. 21, p. 395–453.

Ellison, S., 1941: Revision of the Pennsylvanian conodonts. *Journal of*

Paleontology, vol. 15, p. 107–143.
Ellison, S. P. and Graves, R. W., 1941: Lower Pennsylvanian (Dimple Limestone) conodonts of the Marathon region, Texas. *Missouri University School of Mine and Metallurgy*, *Bulletin*, *Technical Series*, vol. 14, p. 1–13.
Girty, C. H., 1910: New genera and species of Carboniferous fossils from the Fayetteville shale of Arkansas (part 2). *New York Academy of Science Annals*, vol. 20, p. 189–238.
Goreva, N., Alekseev, A., Isakova, T. and Kossovaya, O., 2009: Biostratigraphical analysis of the Moscovian–Kasimovian transition at the neostratotype of Kasimovian Stage (Afanasievo section, Moscow Basin, Russia). *Palaeoworld*, vol. 18, p. 102–113.
Goto, M. and Okura, M., 2004: The chondrichthyan tooth remains from the Carboniferous and Permian of Fukuji, Gifu Prefecture, central Japan. *Earth Science (Chikyu Kagaku)*, vol. 58, p. 215–228. (*in Japanese with English abstract*)
Gunnell, F. H., 1931: Conodonts from the Fort Scott Limestone of Missouri. *Journal of Paleontology*, vol. 5, p. 244–252.
Gunnell, F. H., 1933: Conodonts and fish remains from the Cherokee, Kansas City, and Wabaunsee Groups of Missouri and Kansas. *Journal of Paleontology*, vol. 7, p. 261–297.
Harayama, S., 1990: *Geology of the Kamikochi area, with Geological Sheet Map at 1: 50,000*, 175 p. Geological Survey of Japan, Tsukuba. (*in Japanese with English abstract*)
Harris, R. W. and Hollingsworth, R. V., 1933: New Pennsylvanian conodonts from Oklahoma. *American Journal of Science*, vol. 25, p. 193–204.
Henderson, C. M. and Orchard, M. J., 1991: *Gondolelloides*, a new Lower Permian conodont genus from western and northern Canada. *In*, Orchard, M. J. and McCracken, A. D. *eds*., *Ordovician to Triassic Conodont Paleontology of the Canadian Cordillera*, p. 253–267. *Geological Survey of Canada Bulletin*, *417*, Canada Communication Group, Ottawa.
Higgins, A. C. and Bouckaert, J., 1968: Conodont stratigraphy and palaeontology of the Namurian of Belgium. *Mémoires pour Servir à l'Explication des Cartes Géologiques et Miniéres de la Belgique*, vol. 10, p. 1–64.
Igo, H., 1956: On the Carboniferous and Permian of the Fukuji District, Hida Massif, with special reference to the fusulinid zones of the Ichinotani Group. *Journal of the Geological Society of Japan*, vol. 62, p. 217–240. (*in Japanese with English abstract*)
Igo, H., 1957: Fusulinids of Fukuji, southeastern part of the Hida Massif, Central Japan. *Science Report of the Tokyo Kyoiku Daigaku*, *Section C*, vol. 5, p. 153–246.
Igo, H., 1973: Lower Carboniferous conodonts from the Akiyoshi Limestone Group, southwest Japan. *Transactions and Proceedings of Palaeontological Society of Japan*, *New Series*, no. 92, p. 185–199.
Igo, H. and Koike, T., 1964: Carboniferous conodonts from the Omi Limestone, Niigata Prefecture, Central Japan. *Transactions and Proceedings of the Palaeontological Society of Japan*, *New Series*, no. 53, p. 179–193.
Isaji, S. and Okura, M., 2014: Molluscan larvae from the Carboniferous Ichinotani Formation, Fukuji, Gifu Prefecture, Central Japan. *Paleontological Research*, vol. 18, p. 45–50.
Ishida, K., Motoyama, S., Yoshioka, M., Okamoto, H., Nishiyama, K., Hashimoto, T., Morie, T., Nakao, K., Ozawa, T., Kasai, T. and Tsujino, Y., 2005: Compositions of the erupted products of ancient sea-floor volcano and geological ages of microfossils from associated sedimentary rocks in the Chichibu and Kurosegawa belts, Kizawamura Village, Tokushima Prefecture. *Bulletin of the Awa Academic Society*, vol. 51, p. 9–16. (*in Japanese; original title translated*)
Ishida, K., Suzuki, S. and Inada, N., 2013: Visean–Moscovian conodont biostratigraphy of the Ko-yama Limestone Group, Akiyoshi Belt, SW Japan. *Natural Science Research*, *University of Tokushima*, vol. 27, p. 29–52.
Ishida, K., Suzuki, S., Inada, N. and Yamashita, S., 2012: Carboniferous (Visean–Moscovian) conodont faunal succession in the Ko-yama Limestone Group, Akiyoshi Belt, SW Japan: the biostratigraphic resolution in the clastic carbonate sedimentary field, *Acta Geoscientica Sinica*, vol. 33, p. 25–28.
Ishizaki, K., 1968: On some Carboniferous ostracods from the Takezawa Formation, northeast Japan. *Saito Ho-on Kai Museum Research Bulletin*, vol. 37, p. 11–16.
Isozaki, Y. and Maruyama, S., 1991: Studies on orogeny based on plate tectonics in Japan and new geotectonic subdivision of the Japanese Islands. *Journal of Geology*, vol. 100, p. 697–761. (*in Japanese with English abstract*)
Isozaki, Y., Maruyama, S., Nakama, T., Yamamoto, S. and Yanai, S., 2010: Growth and shrinkage of an active continental margin: updated geotectonic history of the Japanese Islands. *Journal of Geology*, vol. 120, p. 65–99. (*in Japanese with English abstract*)
Kamei, S. and Igo, H., 1957: The geological feature of the Hida Gaien structural belt. *Journal of the Geological Society of Japan*, vol. 63, p. 413. (*in Japanese; original title translated*)
Koike, T., 1967: A Carboniferous succession of conodont faunas from the Atetsu limestone in Southwest Japan (Studies of Asiatic conodonts, Part VI). *Science Report of the Tokyo Kyoiku Daigaku*, *Series C*, *Geology*, *Mineralogy and Geography*, no. 93, p. 279–318.
Kossenko, Z. A., 1975: New species of conodonts of the Moscovian Stage of the southwestern part of the Donets Basin. *Geologicheskii Zhurnal*, vol. 35, p. 126–133. (*in Russian; original title translated*)
Kusunoki, T., Ohara, M. and Musashino, M., 2004: Carboniferous–Permian microbiostratigraphy in chert sequence from the southwestern part of the Tamba Belt, Shizukawa district, Uji City (outline note). *Earth Science (Chikyu Kagaku)*, vol. 58, p. 37–54. (*in Japanese with English abstract*)
Kuwano, Y., 1987: Early Devonian conodonts and ostracodes from Central Japan. *Bulletin of the National Science Museum*, *Series C*, *Geology and Paleontology*, vol. 13, p. 77–105.
Lane, H. R., 1967: Uppermost Mississippian and Lower Pennsylvanian conodonts from the type Morrowan region, Arkansas. *Journal of Paleontology*, vol. 41, p. 920–942.
Lindström, M., 1964: *Conodonts*, 196 p. Elsevier, Amsterdam.
Lindström, M., 1970: A suprageneric taxonomy of the conodonts. *Lethaia*, vol. 3, p. 427–445.
Merrill, G. K., 1972: Taxonomy, phylogeny, and biostratigraphy of *Neognathodus* in Appalachian Pennsylvanian rocks. *Journal of Paleontology*, vol. 46, p. 817–829.
Merrill, G. K. and Bitter, P. H. von, 2007: The Pennsylvanian conodont genus *Gondolella* Stauffer and Plummer, 1932: reinterpretation of the original type specimens and concepts. *Journal of Micropalaeontology*, vol. 26, p. 41–46.
Merrill, G. K. and King, C. W., 1971: Platform conodonts from the lowest Pennsylvanian rocks of northwestern Illinois. *Journal of Paleontology*, vol. 45, p. 645–664.
Miklukho-Maclay, A. D., 1958: Stage subdivisions of marine Permian deposits in the southern USSR. *Doklady Akademii Nauk SSSR*, vol. 120, p. 175–178.
Mizuno, Y., 1997: Conodont faunas across the Mid-Carboniferous boundary in the Hina Limestone, Southwest Japan. *Paleontological Research*, vol. 1, p. 237–259.
Möller, V., 1878: Die spiral-gewundene Foraminiferen der russischen Kohlen-Kalks. *Mémoires de l'Académie Impériale des Sciences de*

St.-Pétersbourg, *7e Série*, vol. 25, p. 1–147.

Niikawa, I., 1978: Carboniferous and Permian fusulinids from Fukuji, central Japan. *Journal of the Faculty of Science*, *Hokkaido University*, *Series 4*, *Geology and Mineralogy*, vol. 18, p. 553–610.

Niikawa, I., 1980: Geology and biostratigraphy of the Fukuji district, Gifu Prefecture, central Japan. *Journal of the Geological Society of Japan*, vol. 86, p. 25–36. (*in Japanese with English abstract*)

Niko, S. and Hamada, T., 1987: *Adnatoceras* from Middle Carboniferous of the Ichinotani Formation, Fukuji District, central Japan. *Transactions and Proceedings of the Palaeontological Society of Japan*, *New Series*, no. 148, p. 223–227.

Purnell, M. A., Donoghue, P. C. J. and Aldridge, R. J., 2000: Orientation and anatomical notation in conodonts. *Journal of Paleontology*, vol. 74, p. 113–122.

Qi, Y., Hu, K., Wang, Q. and Lin, W., 2013: Carboniferous conodont biostratigraphy of the Dianzishang section, Zhenning, Guizhou, South China. *Geological Magazine*, vol. 151, p. 311–327.

Rauser-Chernoussova, D. M., Gryzlova, N. D., Kireeva, G. D., Leontovich, G. E., Safonova, T. P. and Chernova, E. I., 1951: *Middle Carboniferous Fusulinids of the Russian Platform and Adjacent Areas*, 380 p. Izdatel'stvo Akademii Nauk SSSR, Moskva. (*in Russian; original title translated*)

Ritter, S. M., Barrick, J. E. and Skinner, M. R., 2002: Conodont sequence biostratigraphy of the Hermosa Group (Pennsylvanian) at Honaker Trail, Paradox Basin, Utah. *Journal of Paleontology*, vol. 73, p. 495–517.

Rosscoe, S. J. and Barrick, J. E., 2009: Revision of *Idiognathodus* species from the Desmoinesian–Missourian (Moscovian–Kasimovian) boundary interval in the Mid-Continent Basin, North America. *Palaeontographica Americana*, vol. 62, p. 115–147.

Stauffer, C. R. and Plummer, H. J., 1932: Texas Pennsylvanian conodonts and their stratigraphic relations. *University of Texas Bulletin*, vol. 3201, p. 13–50.

Stocker, C. P., Komatsu, T., Tanaka, G., Williams, M., Siveter, D. J., Bennett, C. E., Wallis, S., Oji, T., Maekawa, T., Okura, M. and Vandenbroucke, T. R. A., 2016: Carboniferous ostracods from central Honshu, Japan. *Geological Magazine*, vol. 155, p. 98–108.

Sweet, W. C., 1988: *The Conodonta: Morphology, Taxonomy, Paleoecology, and Evolutionary History of a Long-Extinct Animal Phylum*, 212 p. Oxford Monographs on Geology and Geophysics, no. 10, Clarendon Press, Oxford.

Taira, A., 1990: *The Birth of the Japanese Islands*, 226 p. Iwanamishinsyo, no. 148, Iwanami Shoten, Tokyo. (*in Japanese; original title translated*)

Tanaka, G., Siveter, D. J. and Williams, M., 2013: A new bivalve arthropod from the Devonian of Japan. *Paleontological Research*, vol. 17, p. 236–240.

Tazawa, J., Miyake, Y. and Niikawa, I., 2010: *Purdonella* (Spiriferida, Brachiopoda) from the Carboniferous Ichinotani Formation, Fukuji, Hida Gaien Belt, central Japan, and its palaeobiogeographical significance. *Journal of the Geological Society of Japan*, vol. 116, p. 127–133. (*in Japanese with English abstract*)

Thompson, M. L., 1942: New genera of Pennsylvanian fusulinids, *American Journal of Science*, vol. 240, p. 403–420.

Tsukada, K. and Takahashi, Y., 1998: Stratigraphy and structure of Sorayama Formation, Fukuji area in the "Hida-Gaien" tectonic zone, Kamitakara Village, Gifu Prefecture. *Abstracts with Programs*, *the 1998 Annual Meeting of the Geological Society of Japan*, p. 47. (*in Japanese; original title translated*)

Tsukada, K., Takahashi, Y. and Ozawa, T., 1999: Stratigraphic relationship between the Mizuyagadani and Sorayama formations, and age of the Sorayama Formation, in the Hida-gaien Tectonic Zone, Kamitakara Village, Gifu Prefecture, central Japan. *Journal of the Geological Society of Japan*, vol. 105, p. 496–507. (*in Japanese with English abstract*)

Tsukada, K., Takeuchi, M. and Kojima, S., 2004: Redefinition of the Hida Gaien belt. *Journal of the Geological Society of Japan*, vol. 110, p. 640–658. (*in Japanese with English abstract*)

Wang, 1988: Ostracods. *In*, Yu, C. *ed.*, *Devonian-Carboniferous Boundary in Nanbiancun, Cuilin China—Aspects and Records*, p. 209–364. Science Press, Beijing.

Williams, M., Wallis, S., Oji, T. and Lane, P. D., 2014: Ambiguous biogeographical patterns mask a more complete understanding of the Ordovician to Devonian evolution of Japan. *Island Arc*, vol. 23, p. 76–101.

Wirth, M., 1967: Zur Gliederung des Höheren Paläozoikum (Givet-Namur) in Gebiet des Quinto Real (Westpyrenaen) mit Hilfe von Conodonten. *Neues Jahrbuch für Geologie und Paläontologie*, *Abhandlungen*, Band 127, p. 179–244.

Author contributions

T. Maekawa described conodonts collected from limestone boulders and discussed their biostratigraphic age. T. Komatsu, G. Tanaka, M. Okura, and A. Umayahara investigated the Ichinotani Formation in the Mizuboradani Valley and collected limestone boulders. T. Maekawa, C. P. Stocker and M. Okura collected microfossils from prepared residues of the boulders. T. Maekawa, T. Komatsu, M. Williams and C. P. Stocker identified the biogeographical significance of the Pennsylvanian conodonts. All authors contributed to writing the paper.