Kasimovian (Late Pennsylvanian) conodont fauna from a limestone block in the Ōtani Formation, Kuzuryu area of the Hida Gaien belt, Fukui Prefecture, central Japan

Yui Takahashi¹, Yuichi Fukushima², Gengo Tanaka³ and Yukio Miyake⁴

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¹ Keio Yochisha Elementary School, Shibuya, Tokyo 150-0013, Japan
² Graduate School of Life and Environmental Sciences, University of Tsukuba, Tsukuba, Ibaraki 305-8572, Japan
³ Center for Water Cycle, Marine Environment and Disaster Management, Kumamoto University, Kumamoto, Kumamoto 860-8555, Japan
⁴ Takayama, Gifu 509-3505, Japan

Corresponding author: Y. Takahashi, y.takahashi.geol@gmail.com

Abstract: A conodont fauna characterized by Streptognathodus species was recovered from a limestone block (previously called Ōboradani Formation) of the Ōtani (=Ohtani or Otani) Formation belonging to the Hida Gaien belt distributed in the Kuzuryu area, Fukui Prefecture, central Japan. The fauna consists of Streptognathodus corrugatus, S. elegantulus, S. excelsum, S. gracilis, Idiognathodus sp., Gondolella bella, G. cf. elegantula and G. cf. pohli. These streptognathodids have a wide geographic distribution and indicate a middle–late Kasimovian (Late Pennsylvanian) age, which is slightly older than the Gzhelian (latest Pennsylvanian) age inferred from fusulinid fossils in previous studies. Thus, the limestone block of the Ōtani Formation probably contains the Upper Pennsylvanian carbonate succession.

Keywords: conodont, Kasimovian, Kuzuryu area, Ōtani Formation (Ohtani Formation), Pennsylvanian

Introduction

The Carboniferous was a period of rapid marine biota evolution (e.g. Wang et al., 2019). The generally regressive trend during the Pennsylvanian (= Late Carboniferous), combined with low sea levels, promoted endemism in marine animals, including benthic and pelagic fauna (Goreva and Alekseev, 2010). Nevertheless, fusulinids and conodonts have been recognized as the primary index fossils for subdivisions in and correlations among Pennsylvanian sections, and as fusulinids have been used for shallow-water facies, conodonts have acquired significance for global biostratigraphic correlations. Thus, the study for the conodont succession is an important stem research for revealing changes of the Pennsylvanian marine biodiversity.

However, records of the Kasimovian (Late Pennsylvanian) marine fauna are few in Japan because there likely be a practical problem that the Kasimovian strata themselves are limited. Nakashima and Sano (2007) indicated the hiatus between the middle Kasimovian and overlying Gzhelian sections in the Akiyoshi Limestone of the Akiyoshi belt, and fusulinids exhibit decline and taxonomic turnover at the family level during the middle to late Kasimovian. The hiatus and drastic taxonomic turnover of fusulinids are supposed to have resulted from the prominent and prolonged subaerial exposure with low sea levels (Sano et al., 2004; Nakashima and Sano, 2007). Sano et al. (2004) suggested that this middle to late Kasimovian hiatus is in the series of the Moscovian to Kasimovian emergence events. For that reason, the Japanese Kasimovian successions themselves are rare, and conodonts of this stage have also been derived from allochthonous limestone blocks in the younger strata (e.g. Koike, 1967; Maekawa et al., 2018).

Locality

The Hida Gaien belt is a geologically complex area distributed narrowly around the Hida belt (Fig. 1A). It has had various definitions. According to the redefinition by Tsukada et al. (2004), the Hida Gaien belt consists of weakly metamorphosed or unmetamorphosed Paleozoic rocks and the Unazuki metamorphic rocks. The Ōboradani (=Oboradani in Niko et al. [1997] and Niko [2000]; Ohboradani in Kurihara [2003]) Formation, defined by Yamada et al. (1958), is a part of the belt. The formation consists of 200 m long × 50 m wide and 50 m long × 20 m wide (thickness uncertain) limestone blocks distributed in the Ōboradani and Akubaradani valleys, respectively in the northern slope of Kuzuryu Lake, Kuzuryu area, Fukui Prefecture, central Japan (Yamada, 1967). The Ōboradani Formation is
characterized by successions of dark-gray, fossiliferous bedded and/or massive limestones. However, some researchers (e.g. Kurihara, 2003) treat the formation as huge limestone blocks in the Ōtani (= Ohtani in Kurihara [2003]; Otani in Kawagoe et al. [2013]) Formation which generally consists of conglomerates and sandstones and is distributed in the northern slope of Kuzuryu area. Detrital zircon crystals derived from the sandstone of this formation give 243 Ma based on U-Pb geochronology (Kawagoe et al., 2013). Thus, the Ōtani Formation is probably deposited during the Triassic and contains allochthonous Paleozoic rocks in the conglomerates. In the present study, we follow the stratigraphic interpretation of Kurihara (2003).

Yamada (1967) reported the occurrence of Pseudoschwagerina morikawai Igo, 1957 from the limestone blocks (= the Ōboradani Formation) in the Ōtani Formation, and correlated it to the Sakmarian (Cisuralian, early Permian). As fusulinid taxonomy and biostratigraphy progressed, P. morikawai was reassigned to the genus Carbonoschwagerina of Ozawa et al. (1992), and indicates the middle Gzhelian in (latest Pennsylvanian) age (Kobayashi, 2017). In addition, rugose and tabulate corals have been described from the same limestone block at the Ōboradani Valley, together with a new genus of tentaculitoids (Niko et al., 1997; Niko, 2000).

The sampling locality (35°52′58″N, 136°42′25″E) is situated in the limestone block (15 m thick) of the Ōboradani Valley (Fig. 1B). Our studied section corresponds to a southern part of the same limestone block of the above paleontological studies. Sandstone is distributed around the limestone block, but the geological structure between these two units (sandstone and limestone block) is unclear. The studied limestone is divided into two parts (Fig. 2). The lower part is 1.7 m thick, and mainly consists of alternating beds of thinly bedded dark gray to light gray lime-mudstone and packstone, and contains a grainstone in the base; the upper part is over 13 m thick and consists of massive light gray to white calcareous algae and rugose coral boundstones. Conodont fossils were recovered only from the packstone in the lower part (0.7 m above the base). The packstone includes also peloids, crinoidal and algal fragments, ostracodes, fusulinids, and small hollow tubes (Fig. 3). The classification of limestone follows Dunham (1962).

**Material and Method**

About 10 kg of a limestone sample from the lower part of the limestone block was collected. The limestone sample was crushed into small pieces, and for dissolving the sample, we used diluted 4 % formic acid to obtain limestone residues. The residues were dried and checked under a stereoscopic microscope (SCZ; Shimadzu Rika Co., Tokyo). Under the microscope, conodonts were collected by using a thin brush. Approximately 200 disarticulated conodont elements which compose of P, S, and M elements, were obtained. Most of them were fragmentary, and P1 elements are dominant in the collection. Destruction of elements may have occurred during the above procedures. Among these elements, relatively well-preserved ones, a total of 47...
Kasimovian conodonts from Fukui Pref. specimens, were studied. They show black color and correspond to CAI 4–5 of Epstein et al. (1977). Micro-images of these fossils were taken by a scanning electron microscope in the Earth Evolutionary Science, University of Tsukuba (JSM-5500LV; JEOL Ltd., Tokyo).

**Geological age of the studied sample**

The obtained fauna was composed of *Streptognathodus corrugatus*, *S. elegantulus*, *S. excelsus*, *S. gracilis*, *Idiognathodus* sp., *Gondolella bella*, *G. cf. elegantula* and *G. cf. pohli*. Among them, *Streptognathodus* species are predominant (Fig. 4). Brief remarks and the repository numbers of each species are represented in Systematic Note.

The *Streptognathodus gracilis* Zone was first established in the Late Pennsylvanian conodont biostratigraphy of North American Midcontinent Basin by Ritter (1995) and generally indicates the middle–late Missourian (= the middle Kasimovian). The conodont zone starts with the first appearance (FA) of the eponymous taxon and ends with the FA of *S. firmus* (Ritter, 1995). Barrick et al. (2004, 2013) redefined that the zone ends with the FA of *Idiognathodus eudoraensis* Barrick, Heckel and Boardman, 2008 (= *Idiognathodus aff. simulator* [Ellison, 1941]). The zone was characterized by the radiation and dominance of a closely related *Streptognathodus* species, such as *S. corrugatus*, *S. elegantulus*, *S. excelsus*, and *S. gracilis*. Thus, the conodont assemblage of the present study is strongly related to the middle–late Kasimovian *S. gracilis* Zone. In addition, *S. elegantulus*, *S. excelsus* and *S. gracilis* were recently reported from the middle to late Kasimovian conodont zones in South China (Hu et al., 2020). Therefore, the streptognathodid assemblage of this study probably indicates the middle–late Kasimovian.

The range of obtained few gondolellid specimens is debatable. Barrick et al. (2013), for instance, mentioned that *G. bella* occurred in the late Desmoinesian (= the late Moscovian) Excello Shale. *Gondolella elegantula* and *G. pohli* were from the early Missourian (= the early Kasimovian) Posideon Shale and the middle–late Desmoinesian (= the late Moscovian) strata in some localities, respectively (Merrill and von Bitter, 2007; von Bitter and Merrill, 1998). It, however, should be notable that gondolellids are not used for biostratigraphic subdivisions in recent Late Pennsylvanian conodont studies due to lacking detailed evolutionary information. Addition to this, dominance of closely related streptognatho-
Fig. 4. Digital scanning electron micro images of the P, elements. 1–10, upper views of *Streptognathodus elegantulus* Stauffer and Plummer, 1932; 11, 18, upper views of probable transitional forms between *S. elegantulus* and *S. exclusus* Stauffer and Plummer, 1932. These specimens possess irregular nodes but do not have accessory nodes on both sides; 12, 13, upper views of *S. excelsus*; 14, *Gondolella cf. pohli* von Bitter and Merrill, 1998, a and b represent upper and lower views, respectively; 15, *Gondolella cf. elegantula* Stauffer and Plummer, 1932, a and b represent upper and lower views, respectively; 16, 17, 19, upper views of *S. gracilis* Stauffer and Plummer, 1932; 20, upper view of *S. corrugatus* Gunnell, 1933; 21, upper view of *Idiognathodus* sp.; 22, *Gondolella bella*, a and b represent upper and lower views, respectively; 1, EESUT-TY-0545; 2, EESUT-TY-0546; 3, EESUT-TY-0547; 4, EESUT-TY-0548; 5, EESUT-TY-0549; 6, EESUT-TY-0550; 7, EESUT-TY-0551; 8, EESUT-TY-0552; 9, EESUT-TY-0553; 10, EESUT-TY-0554; 11, EESUT-TY-0555; 12, EESUT-TY-0556; 13, EESUT-TY-0557; 14, EESUT-TY-0558; 15, EESUT-TY-0559; 16, EESUT-TY-0560; 17, EESUT-TY-0561; 18, EESUT-TY-0562; 19, EESUT-TY-0563; 20, EESUT-TY-0564; 21, EESUT-TY-0565; 22, EESUT-TY-0566.
did's indicates that the middle–late Kasimovian is more reliable.

The Gzhelian faunas have already been reported from the studied limestone block such as fusulinids and invertebrates as mentioned above. In contrast, the conodont fauna of this study indicates the middle–late Kasimovian age. The limestone block consists of carbonate succession and contains abundant marine fossils, and the conodont fauna recovered from the lower part of the section. This facts suggest that the further research can be expected to construct the Late Pennsylvanian conodont and fusulinid biostratigraphies and will find the Kasimovian–Gzhelian boundary in this section.

Concluding remarks

In this study, we firstly reported the Streptognathodid dominated conodont fauna from a limestone block of the Ōtani Formation. The fauna was composed of well-known cosmopolitan species, such as *Streptognathodus corrugatus*, *S. elegantulus*, *S. excelsus*, and *S. gracilis* and probably correlates to the middle–late Kasimovian (Late Pennsylvanian). In Japan, the Kasimovian successions themselves are rare (Nakashima and Sano, 2007), and the Kasimovian conodont faunas has only been reported from the float limestone boulder or an exotic rocks in the Permian conglomerates (e.g. Koike, 1967; Maekawa et al., 2018). Therefore, it is difficult to construct the Japanese Kasimovian biostratigraphy to correlate the other worldwide sections. However, our studied result demonstrated that an exotic limestone block of the Ōtani Formation probably contains the middle Kasimovian–Gzhelian succession and abundant marine fossils with conodonts and fusulinids. Thus, the studied section is a potential source to construct the Japanese Late Pennsylvanian biostratigraphy.

Systematic Note

The terminology used to describe conodonts follows Sweet (1988) and Purnell et al. (2000), and species were identified based on their P1 elements. The digital microimages of 22 specimens are shown in Fig. 4, and studied 47 specimens were stored at the Earth Evolutionary Science, University of Tsukuba, with each repository numbers from EESUT-TY-0545 to 0591.

Order Ozarkodinida Dzik, 1976
Family Idiognathodontidae Harris and Hollingsworth, 1933
Genus *Streptognathodus* Stauffer and Plummer, 1932

*Type species:* *Streptognathodus elegantulus* Stauffer and Plummer, 1932.

Remarks: The characteristics of a P1 element of the genus is presence of the deep median trough splitting the transverse ridges on the platform, and reduced or absence of lobes (Barrick and Boardman, 1989).

In Japan, the genus *Streptognathodus* has been used to the Bashkirian (Early Pennsylvanian) to Moskovian (Middle Pennsylvanian) species. According to recent researches (e.g. Hu et al., 2019), the Early to Middle Pennsylvanian “*Streptognathodus*” are assigned to the other taxa. Here, we mention the re-assignment of some Japanese species belonging to the Early to Middle Pennsylvanian “*Streptognathodus*” species. The Bashkirian “*Streptognathodus*” species in the 1960s–80s period, such as “S. japonicus” Igo and Koike, 1964, and “S. lateralis” Higgins and Bouckaert, 1968, now belong to a different genus, *Declinognathodus* (Hu et al., 2019). The late Bashkirian to Moskovian “*Streptognathodus*” such as “S.” *expansus* Igo and Koike, 1964 and “S.” *saberectus* Dunn, 1966 were described from several areas, mainly in the Akiyoshi terrane, Southwest Japan (e.g. Takahashi et al., 2020). They are splitted from the true *Streptognathodus* (Late Pennsylvanian to Permian) by the lack of deep median trough (Nemyrovska, 2011).

*Streptognathodus corrugatus* Gunnell, 1933

Figs. 4.20

*Streptognathodus corrugatus* Gunnel, 1933, p. 281, pl. 32, fig. 13; Ritter, 1995, p. 1149, fig. 9.11; Ritter et al., 2002, p. 510, fig. 9.10; Barrick et al., 2013, p. 63, pl. 3, fig. 6.

Material: Three P1 elements.

Remarks: The P1 element possesses a deep trough, slightly curved, and two or more inner accessory nodes. According to Barrick and Boardman (1989), *S. corrugatus* is distinguished from *S. gracilis* by the presence of more than one inner accessory node. Thus, we treat the elements as *S. corrugatus*.

*Streptognathodus elegantulus* Stauffer and Plummer, 1932

Figs. 4.1–4.10

*Streptognathodus elegantulus* Stauffer and Plummer, 1932, p. 47, pl. 4, figs. 6, 7, 22, 27; Ellison, 1941, p. 127, pl. 22, figs 1–6 only; Kozitsukaya et al., 1978, p. 93, pl. 28, figs 5–11; Barrick and Boardman, 1989, pl. 2, figs 7, 13, 14; Ritter, 1995, p. 1149, figs 9.9, 9.13; Barrick et al., 2013, p. 63, pl. 3, fig. 4.
Material: Twenty nine P1 elements.

Remarks: The studied P1 elements bear deep median trough, and carinal line on the platform consisting of nodes continuing from the fused carina. The specimens had little or no distinct lateral inflections of the platform. Streptognathodus elegantulus resembles other unornamented streptognathodids—such as S. virgilicus Ritter, 1995, S. simplex Gunnell, 1933, and S. pawhuskaensis (Harris and Hollingsworth, 1933)—. However, subtle distinctions can generally be made between these three species. Streptognathodus elegantulus has a thinner platform with shorter transverse ridges than S. virgilicus and do not have so slender and relatively symmetrical platform unlike S. simplex (Ritter, 1995). This species also differs from S. pawhuskaensis by its narrower trough (Ritter, 1995).

Koike (1967) reported "Streptognathodus elegantulus" from the Atetsu Limestone, Okayama Prefecture, Japan. According to the report, a specimen was recovered from the Idiognathodus delicatus-Gnathodus ateetsuensis Zone (Moscovian, Middle Pennsylvanian) of the Kodani Formation, and other two specimens were recovered from the intra-micrudite of the Permian Iwamoto Formation. Putative Permian specimens were recovered with the Middle to Late Pennsylvanian conodonts such as I. delicatus Gunnell, 1931, Gondolella bella Stauffer and Plummer, 1932, G. clarki Koike, 1967 (= Mesogonodolella clarki [Koike, 1967]). Thus, the intra-micrudite contains the Pennsylvania limestone clasts, and these conodonts including "S. elegantulus" probably derived from there. In addition, the figured specimens show generally short carinal line only consisting of fused carina, node-like transverse ridges and narrow median troughs. According to these facts, "S. elegantulus" of Koike (1967) is probably different species which may belonging to the Moscovian "Streptognathodus".

Streptognathodus excelsus Stauffer and Plummer, 1932
Figs 4.12, 4.13

Streptognathodus excelsus Stauffer and Plummer, 1932, p. 48, pl. 4, figs. 2, 5; Kozitskaya et al., 1978, p. 94, pl. 29, figs. 7–9; Barskov et al., 1987, p. 88, pl. 20, figs. 22–24; Ritter, 1995, p. 1149, fig. 9.16; Barrick et al., 2013, p. 63, pl. 3, figs. 7, 8.

Material: Three P1 elements.

Remarks: Streptognathodus excelsus is distinguished from almost all other Missourian (= middle–late Kasimovian) and early Virgilian (= latest Kasimovian) streptognathodids by the presence of inner and outer accessory lobes each consisting of a single or a few nodes (Barrick and Boardman, 1989). Thus, our studied specimens, bearing both inner and outer accessory lobes, are easily identified as S. excelsus. This species can also be distinguished from S. zethus Chernykh and Reshetkova, 1987 by the characteristic wide trough of the latter species (Ritter, 1995).

Streptognathodus gracilis Stauffer and Plummer, 1932
Figs. 4.16, 4.17, 4.19

Streptognathodus gracilis Stauffer and Plummer, 1932, p. 48, pl. 4, figs. 12, 23; Ellison, 1941, p. 128, pl. 22, figs. 7, 11; Kozitskaya et al., 1978, p. 98, pl. 30, figs. 8, 9; Barskov et al., 1987, p. 89, pl. 21, figs. 13; Barrick and Boardman, 1989, pl. 2, figs. 1, 6, 12, 18; Ritter, 1995, p. 1150, fig. 9.8; Barrick et al., 2013, p. 63, pl. 3, fig. 5.

Material: Seven P1 elements.

Remarks: Stauffer and Plummer (1932) originally described Streptognathodus gracilis as an element which is characterized by a single denticle on one or both lateral sides of the platform. Ellison (1941) treated the species as an element with one accessory lobe. Later, S. gracilis was restricted to having a single node as the inner accessory lobe, and elements with a few nodes as an accessory lobe were assigned to S. corrugatus (Barrick and Boardman, 1989). Ritter (1995) and Ritter et al. (2002) used S. gracilis and S. corrugatus in this manner, and we follow the diagnosis of these two species. Thus, the relatively slender P1 elements of this study, have a single node as the inner accessory lobe, are treated as S. gracilis.

Genus Idiognathodus Gunnell, 1931

Type species: Idiognathodus claviformis Gunnell, 1931.

Remarks: The characteristics of a P1 element of the genus is flat platform bearing transverse ridges. The anterior part of the platform has inner and outer accessory lobes ornamented by nodes (Rosscoe and Barrick, 2009). Unlike Streptognathodus, a P1 element of this genus lacks deep median trough.

Idiognathodus sp.
Figs. 4.21

Material: One P1 element.
Remarks: Slender platform curved inwardly. Both inner and outer lobes are not developed and almost same sized. Lobes are ornamented with one low of 3-4 nodes. Carina is long near half of the platform. Transverse ridges are thin, not dense. The absence of developed lobes of studied specimen is similar to those of I. corrugatus Gunnel, 1933, but the carina of latter species is shorter. We tentatively identified the specimen as Idiognathodus sp.

Order Prioniodinida Sweet, 1988
Family Gondolellidae Lindström, 1970
Genus Gondolella Stauffer and Plummer, 1932

Type species: Gondolella elegantula Stauffer and Plummer, 1932.

Remarks: The characteristics of a P1 element is gondola-shaped platform with a prominent cusp at the posterior end. The upper surface of the platform bears carina with or without ridges and other ornamentations. A keel with a basal groove opening into a loop-shaped basal cavity is present on the lower side of the platform (Stauffer and Plummer, 1932; von Bitter and Merrill, 1998).

Gondolella bella Stauffer and Plummer, 1932
Figs. 4.22

Gondolella bella Stauffer and Plummer, 1932; Merrill and von Bitter, 2007, p. 43, pl. 1, figs. 1–12 [see for synonymy].

Material: Two P1 element.

Remarks: Gondolella bella is characterized by the slender platform with strong transverse ridges, some of which extend over the edge of the platform. The ridges may also bifurcate laterally (Merrill and von Bitter, 2007). The studied specimen well shows similar features. Thus, we identified the specimen as G. bella. This species can be easily distinguished from G. elegantula by the presence of distinct transverse and web-like ridges widely ornamenting the platform.

Gondolella cf. elegantula Stauffer and Plummer, 1932
Figs. 4.15

Material: One P1 element.

Remarks: The surface of the platform is ornamented with a row of nodes along both lateral margins of the platform. Each node shows a connection with adjacent nodes. The basal loop shows oval outline. These characters of the specimen are similar to those of Gondolella elegantula. Due to lacking the anterior tip, we identified this specimen as G. cf. elegantula. This species differs from G. bella by the weaker transverse ridges on the platform. It also differs from G. sublanceolata Stauffer and Plummer, 1932 by the smaller number of denticles and smaller basal loop.

Gondolella cf. pohli von Bitter and Merrill, 1998
Figs. 4.14

Material: One P1 element.

Remarks: The studied specimen is characterized by unornamented platform surface. The character is well correlated to Gondolella pohli or G. laevis Kossenko and Kozitsukaya in Kossenko, 1975. The platform is widest near the posterior end and gradually narrower to anterior. The loop around the basal pit is sub-triangular outline, as wide as the platform. Due to the poor preservation, we identified this specimen as Gondolella cf. pohli. It differs from G. laevis by relatively wider platform.

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1) in Russian  
2) in Japanese with English abstract  
3) in Japanese

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用語対比  
Akubaradani　恶原谷  
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