Reconstruction of Pelagic Reef Ecosystem of the Carboniferous Omi Limestone, Niigata Prefecture, Central Japan

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Contents

Abstract

Reefs are most biodiversified ecosystems of the modern ocean and their intricate three-dimensional landscapes promote elaborate adaptations of marine animals and complex interactions of them. However, the reefs are the most threatened ecosystems in the world, and the transitions of the reefs from geological time up to the present is one of the major interests of reef studies. Paleozoic pelagic reefs are distributed as reef carbonates in Japanese Islands. I study the Carboniferous Omi Limestone belonging to the Akiyoshi Terrane as one representative here. The Omi Limestone occupies the eastern end of the Akiyoshi Terrane is located in the Itoigawa City, Niigata Prefecture, central Japan. Due to containing rich fossils, the Omi Limestone has been subject to paleontological studies since in the early 1900's and the limestone is a historic place of the Japanese paleontology. The oldest work conducted in 1918 by Hayasaka reported some Carboniferous brachiopod fossils and revealed the presence of the Carboniferous strata in Japan for the first time, and Japanese conodont studies were started in 1960's by Igo and Koike. This study aims to reconstruction of the Carboniferous pelagic reef ecosystem based on the integration of micro and macrofossils.

Totally 77 species microfossils belonging to 12 classes of 6 phylum are described. They are composed of following taxa: conodonts, ostracods, actinopterygians and chondrichthyans, mollusks, echinoids, holothuroids, ophiuroids, sponge spicules, chitinozoas and “microproblematicas”. Classes Ostracoda, Actinopterygii, Chondrichthys, Echinoidea, Holothuroidea, Ophiuroidea and Chitinozoa are first report from the limestone, and ophiuroid fossil *Frucaster* sp. is the oldest record in Japan. Based on obtained conodonts, four middle Carboniferous conodont biozones are established. I reconstruct the paleoecosystem of the middle Carboniferous Omi Limestone from the perspectives of paleoecology of fossil taxa. I also investigates the origin of the paleogeography of the middle Carboniferous Omi Limestone based on the correlations of benthic faunas, and I suggest that “Stepping stone” idea may be reasonable for the origin of at least holothuroids. I study microfossils from the middle Carboniferous Akiyoshi Limestone, and the diversified microfossil fauna of the Omi Limestone may be common in the entire Akiyoshi Terrane. This also indicates the support of Taishaku-Akiyoshi-South China bioprovince in the Carboniferous time. Lastly, reefs of the Omi Limestone are thought to be developed during the middle Carboniferous from the Late Devonian mass extinction, and diversified microfossils of this study supports the recovery of three-dimensional structure of the reef. It has passed 100 years since the start of the oldest paleontological study of Hayasaka, this study reveals the reef ecosystem of the Carboniferous Omi Limestone.

Key words: Carboniferous, Akiyoshi Terrane, Omi Limestone, microfossil, conodont biostratigraphy, paleogeography, reef ecosystem, Tsuchikurazawa Limestone

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1. Introduction

Reefs are the most biodiversified ecosystems of modern oceans, estimated to support about one-third of all described marine species on the planet (e.g. Reaka-Kudla et al., 1997). Their intricate, three-dimensional structures promote elaborate adaptations in marine animals and complex interactions among them (e.g. Hoekstra et al., 2005). The ramparts of barrier reefs protect coastlines from wave erosion, forming lagoonal environments behind them, often scattered with patch reefs. However, the reefs are one of the most threatened ecosystems in the world. An estimated 19% of the world's reefs have been lost and another 35% are seriously threatened (Wilkinson, 2008). A more precise estimate by Hooidonk et al. (2016) predicts that more than half of the world's reefs will be lost by the 2050s. Expansions and contractions of reefs have occurred throughout geological time. Consequently, the geologic fluctuations of reef ecosystems have been a major focus of reef studies (e.g. Hongo, 2011). The aim of this study approaches the Carboniferous pelagic fossil reef to elucidate its ecosystem.

Reefs are stationary biogenic structures, often exhibiting complex topographic relief, built by the growth and activity of sessile benthic organisms (Flügel, 2010). Many extant and geologically-recent reefs possess easily-recognizable fossils, but remnants in ancient reef ecosystems are less distinctive. For instance, macrofossils are well-recognized in during the field surveys, but microfossils which are important components of reef ecosystem are difficult for recognitions in outdoors. For that reason, the primary reports themselves of microfossils are few except for ones with biostratigraphical importances. In this study, I have focused to appear not well known microfossil fauna in the reef ecosystem. Many Paleozoic, pelagic reefs are distributed as reef carbonates of Japanese Islands. I have studied limestone reefs of the Akiyoshi Terrane, one type of reef occurring in that region.

The Japanese Islands in southwestern Japan are characterized by a zonal distribution of subduction-related accretionary complexes that have formed along a subduction trench since the late Paleozoic Era (Isozaki et al., 2010). The Akiyoshi Terrane, which occurs along this trench, supports an ancient reef-type composed of pelagic reef carbonate (Ota, 1968). The terrane is known as the Permian, subduction-generated, accretionary complex, which consists of a tectonic aggregate of Lower Carboniferous to middle–late Permian oceanic and terrigenous rocks (Kanmera and Nishi, 1983). The rocks of the Akiyoshi Terrane are distributed in several separate areas of southwest Japan (Fig. 1). Kanmera et al. (1990) interpreted that the terrane was derived from a tectonic collision and subsequent accretion of seamounts capped by shallow reef carbonate rocks, which were flanked by deep marine chert and intermingled with trench-filled sediments. The accretion events that formed the terrane are presumed to have occurred in late middle to early late Permian, due to the youngest age of the trench-filled sediments. The Akiyoshi Terrane is lithologically composed of (mainly) shallow reef limestone, basaltic rocks, chert, graywacke, mudstone, and silicic tuff (Sano, 2006). Sano and Kanmeta (1988) divided the rocks of the Akiyoshi Terrane into two tectonostratigraphic groups: one comprised of a terrigenous rock assemblage of the upper middle to lower upper Permian graywacke, mudstone, and silicic tuff with slump blocks, which have been interpreted as being composed of trench-filled deposits. The other group is composed of oceanic rocks of the Lower Carboniferous to middle Permian shallow reef carbonates and deep-marine spicular radiolarian chert covering basaltic rocks, which has been interpreted as biogenetic rocks of mid-oceanic atolls overlying oceanic island basalt (Fig. 2). In this study, I focus on the reconstruction of mid-oceanic atoll carbonate of the Omi Limestone and reef-living biotas located in the easternmost part of the Akiyoshi Terran as a representative.

2. Geological setting and previous studies of the Omi Limestone

In this chapter, I summarize the previous paleontological and stratigraphic studies of the Omi Limestone. An overview of the Omi Limestone is provided in Chapter **2.1**. Previous paleontological works are summarized in Chapter **2.2** and biostratigraphic transitions are introduced in Chapter **2.3**. Lastly, lithological and sedimentological studies are reviewed in Chapter **2.4**.

2.1 Location and geologic history of the Omi Limestone

The Omi Limestone which occupies the eastern end of the Akiyoshi Terrane, is located in Itoigawa City, Niigata Prefecture, in central Japan (Fig. 1). The limestone forms a huge block along the Omi River, the elongated extent of which 8-km long and 2-km wide. The limestone is characterized by massive, white to gray colored, carbonate rocks, widely recognized in Japan as an outstanding assemblage of Paleozoic fossils. The area in which this limestone occurs is also known for its cement and chemical industries.

The Omi Limestone is lithologically composed of two complexes: the Omi and Himekawa complexes, with the Omi thrust over the Himekawa (Nagamori et al., 2010). The Omi complex is composed of reef carbonate and basalt, which exemplifies reef carbonate rocks of mid- oceanic atolls overlying oceanic island basalt. The Himekawa complex preserves oceanic plate stratigraphy including trench- filled deposits. Based on paleomagnetic and paleobiogeographical records, the atoll reef of the Carboniferous Omi Limestone is thought to have been paleogeographically located in a low-to-middle latitudinal region in the ancient Panthalassa Ocean (Fujiwara, 1967; Tazawa et al., 2004; Ibaraki, 2017) (Fig. 3). The Omi Limestone, estimated to be more than 1000 m thick, is separated from the adjacent rocks by faults (Hasegawa and Goto, 1990). Typically, the limestone unconformably overlies the basalt, but in places, it gradually transitions from the basalt layer.

The Omi Limestone was first named by Hayasaka (1921) after Omi Town, because the limestone was distributed in Itoigawa City, a municipal amalgamation of Omi and other towns. Hasegawa (1969) designated the assemblage of limestone and basalt as the “Omi Limestone Group.” However, in response to a contradiction in the code of stratigraphic nomenclature [Geological Society of Japan (2000)], Nagamori et al. (2010) assigned the name Omi Limestone only to the carbonate component and re-defined it as the Omi complex due to it being a complex of limestone and basalt (Fig. 4)

After Hasegawa and Goto (1990) studied entire extent of the Omi Limestone, they biostratigraphically divided it into 10 biozones spanning the Visean, Lower Caboniferous to Midian, and Middle Permian time frame. They proposed the broader geologic structure of the southwestward dipping of the limestone on the basis of its zonal distributions. However, the true structure is quite complicated due to the presence of the numerous faults throughout the limestone complex (Nagamori, 2010).

2.2 Previous paleontological works

Due to its rich assortment of fossils, the Omi Limestone has been subject to paleontological studies since in the early 1900s. The oldest study by Hayasaka (1918) was the first to describe Carboniferous brachiopod fossils and reveal the presence of Carboniferous strata in Japan. Thereafter, he determined that the age of the Omi Limestone spans Early Carboniferous to late Permian periods and described a number of fossilized taxa (some new to science), such as brachiopods, molluscs, foraminifers, crinoids, rugosa corals, and bryozoans (Hayasaka, 1924). Later, Kawada (1954a, b, c,) and Fujita (1958) also described these fossil taxa in more detail. Numerous reports on fossil distributions have now been published for this complex. I summarize reports of Carboniferous fossils in the next section and organize these reports in tables (Appendices 1–19). These appendices include some unreported fossil taxa deposited in the Fossa Magna Museum (FMM).

2.2.1 Carboniferous fossils known from the Omi Limestone

This section summarizes studies of fossil taxa that occur in the Carboniferous Omi Limestone. These taxa include brachiopods, corals, molluscs, foraminifers, bryozoans, scyphozoans, trilobites, etc. Studies of conodonts are reviewed in detail in the Chapter 2.3.2.

Occurrences of brachiopods first reported by Hayasaka (1924) have been confirmed by more recent studies (e.g. Fujita, 1958; Hasegawa et al., 1982), which expanded Hayasaka's species list. Tazawa et al. (1983) described *Delepinea* cf. *sayamaensis* and *Rhipidomella* sp. from the lower-to-mid Carboniferous. Tazawa et al. (2004) described another brachiopod species, *Isogramma millepunctata*, from the *Fusulina-Fusulinella* zone (Moscovian) in the Omi Limestone. *Isogramma millepunctata* was distinctive in the northern-to-middle latitudinal regions during the Carboniferous, and so its occurrence suggests that atoll reefs were distributed throughout this region of the Panthalassa Ocean (Tazawa et al., 2004). More recently, Ibaraki (2017) reportedthe occurrence of another brachiopod species in this area, *Choristites mosquensis*, and by so doing, confirmed the paleogeographical reconstruction of Tazawa et al. (2004). The brachiopod fossils of Omi Limestone are summarized in Appendices 1–3.

Hayasaka (1921, 1922, 1924, 1932, 1939) reported some species of corals from the lower part of the Omi Limestone, such as *Lonsdaleia foloriformis crassiconus*, *L. (Waagenophyllum) omiensis*, *Echigophyllum giganteum*, *Axophyllum gracile*, *Lithostrotion samaense*, and *Orionastrae* sp. Following Hayasaka's works, Minato (1955) summarized the previously-described Carboniferous–

Permian corals of Japan, describing a few additional species, and revised the prior descriptions of Hayasaka. Later, Kato (1967) described *Omiphyllum confertum*, while Rowett and Minato (1968) added two new species of pseudopavonid corals to the list: *Taisyakuphyllum rostfer* and *Pseudopavona* cf. *P. taisyakuana*. Kato and Minato (1975) provided an overview of the psedopavonid corals and described a new species, *Ibukiphyllum densum*. The late Visean coral fauna, consisting of 13 species, was reported by Yoshida et al. (1987), while Yoshida and Okimura (1992) described eight species of *Amigdalophylloides* from the same locality (Fukugakuchi). Most recently, Niikawa (2001) described *E. giganteum* in detail, while Niko and Hasegawa (2000) and Niko et al. (2009, 2010, 2011, 2013) added some new species to the fossil record of Carboniferous tabulate corals. A complete list of known anthozoan fossils is summarized in Appendices 4 and 5.

After a short report on the occurrence of the ammonoid genus, *Gastrioceras*, by Yabe (1906), Hayasaka (1924), and Fujita (1958) described bivalve and gastropod species from the Omi Limestone. Thereafter, Kato and Nakamura briefly reported on an ammonoid, *Eoasianites* cf. *orientale*, from the limestone. Some nautilid and orthoconic fossils have been described by Niko (2001, 2002) as well. However, there are still many cephalopods not yet described in the limestone (Appendices 6 and 7).

A number of studies characterizing the stratigraphy of the limestone have examined small Carboniferous foraminifers and fusulinaceans in the limestone because they provide the most reliable indicators of the limestone's age. In this context, I only summarize several studies here and review their biostratigraphic in Chapter 2.4. Watanabe (1973) described more than 15 species of fusulinaceans from two assemblage zones: the *Profusulinella omiensis*-*P. daiyamensis* zone and the *Akiyoshiella ozawai* zone. Hasegawa et al. (1982) reported biostratigraphic subdivisions using small foraminifers and fusulinaceans associated with these zones. Hasegawa and Goto (1990) revised the work of Hasegawa et al. (1982). Ueno and Nakazawa (1993), focusing on the lowermost part of the Omi Limestone, described more than 70 species of foraminifers. Nakazawa (1997) more-finely subdivided the *Endothyra–Fusulinella* zone of Hasegawa and Goto (1990) and described the small foraminifers and fusulinaceans associated with them. A species list of small foraminifer and fusulinacean fossils occurring in the zones is shown in Appendices 8–13.

A detailed species list of bryozoans is provided in Appendix 16. Some bryozoan fossils were first reported by Hayasaka (1924) and later by Fujita (1958). Subsequently, Sakagami (1962, 1963) re-identified some of those fossils and discovered more than 20 new species.

Studies of conodont fossils are summarized in Chapter 2.3. Makiguchi (1993) described the scyphozoan, *Paraconularia* sp. (Appendixes 5). The trilobite, *Humilogriffithides taniguchii*, was first described by Endo and Matsumoto (1962). Later, Kobayashi and Hamada (1980) added species of *Brachymetopus*, *Cummingella*, and *Linguaphillipsia* to the list (Appendix 14). Hayasaka (1924) reported the crinoid fossil, *Megistocrinus* sp. Additional species, a *Platyplateium* sp. and perhaps a *Nymphaeoblastus* sp., were recently discovered by Yokoi (2013) (Appendix 15). Endo (1952) described an algal (Chlorophyta) species, *Anthracoporella spectabilis*, while Nakazawa (1997) reported several Cyanobacteria and Rhodophyta fossil species (Appendix 19).

2.2.2 Conodonts in the Omi Limestone

Japanese conodont studies have been initiated in the Omi Limestone. The first report of fossil conodonts in Japan was provided by Igo and Koike (1963). The next year they published a report on the Bashkirian conodont fauna, collected from the Nishiyama Mine (Igo and Koike, 1964). The fauna includes *Declinognathodus noduliferous*, *Idiognathoides sinuatus, Id. sulcatus*, *Idiognathodus togashii*, *Streptognathodus expansus*, *Hindeodus minutus*, and *Idioprioniodus* sp., and what is probably *Lonchodina nipponica* (this species was re-identified by me following current nomenclatural norms, see Appendix 17, 18 for synonymy). Later, Watanabe (1975) reported on the Visean conodont fauna from the *Endothyra* zone of a section of the limestone complex along the Omi River. The fauna includes *Hindeodus minutus*, *Cavusgnathus unicornis*, *C*. sp., *Vogelgnathus campbelli*, *Gnathodus bilineatus*, *G*. cfr. *bilineatus*, *Subbryanthodus subaequalis*, *Lochriea multinodosa*, *Lochriea commutata*, *Kladoganathus* sp., and what is probably *Lonchodina* sp. (it was also re-identified by me using current nomenclatural standards, see Appendix 17, 18 for synonymy). More recent conodont studies were conducted in the 1990s. Mizuno and Nakazawa (1993) presented data on the middle Carboniferous conodonts associated with foraminifers. They reported on *Gnathodus bilineatus*, *Declinognathodus noduliferous*, *Neognathodus symmetricus*, and *N. bassleri* and inferred the biostratigraphic efficacy of using occurrences of these species to characterize strata. Isomura (1995) reported on fused clusters of some genera, such as *Idiognathoddus*, *Idiognathoides*, *Streptognathodus*, and what was presumed to be *Neogondolella,* located from the *Profudulinella* zone to the *Fusulinella-Fusulina* zone, described by Hasegawa and Goto (1990). The presumed genus *Neogondolella* has now been assigned the genus *Mesogondolella*. At the following annual meeting, they announced their establishment of a conodont biostratigraphy of the Carboniferous Omi Limestone complex (Isomura, 1996). In their biostratigraphical study of the upper Visean to upper Gzelian, they established eight conodont fossil biozones, in biostratigraphically-ascending order: the *Gnathodus girty* zone, *Gnathodus billineatus* zone, *Declinognathodus noduliferous* zone, *Streptognathodus expansus* zone, *Mesogondolella clarki* zone (genus uncertain), *Idiognathoides pacificus* zone, *Streptognathodus elegantulus* zone, and the *Mesogondolella dentiseparata* zone. Table 1 summarizes the relationships among these biozones.

2.3 Transitions in the Carboniferous biostratigarophic divisions of the Omi Limestone

This chapter reviews representative biostratigraphic works that focus on the Carboniferous Omi Limestone. Because relationships among biozones are complex, a comprehensive chart is provided in Table 1.

Kawada (1954a–c) divided the Omi Carboniferous limestone into three zones: the Coral-brachiopod (C1), *Fusulinella* (C2), and *Triticites* (C3) zones in ascending order. The C1 zone contains many coral and brachiopod fossils. The described specimens of Hayasaka (1924) were mainly collected in the C1 zone. The C2 zone of the Upper Mississippian to Namurian unit, in which Hayasaka (1924) described the foraminifer *Fusulinella biconica,* is characterized by the occurrence of the genus *Fusulinella*. The C3 zone, containing Middle Pennsylvanian (or Moscovian) fossils, is characterized by the occurrence of *Triticites*, which occures in the Uralian. Fujita (1958) modified the Coral-brachiopod zone (C1) to the *Millerella*-coral-brachiopod zone because of the abundance of fusulinacean *Millerella*.

In studying the Itagamine area, Hasegawa (1969) divided the Carboniferous part of the limestone into three zones based on fusulinacean and small foraminifers: the *Eostaffella-Millerella*, *Profusulinella*, and *Fusulinella* zones in ascending order. Furthermore, Watanabe (1973) divided the Carboniferous Omi limestone into eight biozones in ascending order: the *Eostaffella kanmerai*, *Pseudostaffella antiqua*, *Profusulinella omiensis-P. daiyamensis*, *Akiyoshiella ozawai*, the *Fusulinella simplicata-F. itoi*, *Fusulinella biconica*, *Fusulinella pulchra*, and *Triticites montiparus* zones. However, Watanabe (1973) only fully described the *Profusulinella omiensis-P. daiyamensis* and the *Akiyoshiella ozawai* zones in his work, and other biozones are lacking descriptions of their definitions and component species.

Hasegawa et al. (1982) divided Carboniferous strata of the Omi Limestone into five zones based on the occurrence of fusulinids and smaller foraminifers in ascending order: the *Endothyra* zone, the *Eostafella-Millerella*, *Profusulinella*, *Fusulinella-Fusulina*, and *Triticites* zones. Later, Hasegawa and Goto (1990) subdivided the *Triticites* zone into two subzones: a *Triticites simplex* and *Triticites* sp. A subzone in ascending order. The *Endothyra* zone was defined by the occurrence of a small foraminiferal species *Endothyra* and an abundance of coral and brachiopod fossils. Based on the occurrence of *Gigantoproductus* and conodonts described by Watanabe (1975), this zone was correlated with the middle or upper Visean. The abundance of *Eostaffella* spp. and *Millerella* spp., suggested that the lower limit of the *Eostaffella-Millerella* zone was established in the lower Visean. According to Early Pennsylvanian conodonts described by Igo and Koike (1964), the upper limit of the zone is the upper Visean to lower Bashkirian. The *Profusulinella* zone is characterized by the occurrence of *Profusulinella* spp. This zone dates to the late Bashkirian-to-early Moscovian age. The *Fusulinella-Fusulina* zone is defined by abundant species of *Fusulinella* and *Fusulina*, and characterized by a species-rich brachiopod assemblage. This zone was established in the Moscovian. The last *Triticites* zone (corresponding to the Kasimovian-Gzhelian layer) description was based on the occurrence of *Triticites* spp., in which the lower part is dominated by the *Triticites* sp. A and the upper part dominated by *T. simplex.*

Kano and Yoshida (1994) studied the Fukugakuchi area, focusing on the *Endothyra* and *Eostaffella-Millerella* zones of Hasegawa and Goto (1990), and subdivided these two zones into five biozones: the *Endothyra*, *Medicoris mediocoris*, *Eostafella kanmerai*, *Eostaffella-Millerella*, and *Pseudostaffella antiqua* zones in ascending order. The lower two zones correspond to the *Endothyra* zone of Hasegawa and Goto (1990), while the upper three zones correspond to the *Eostaffella-Millerella* zone. The *Medicoris mediocoris* zone was defined by the occurrences of *M. mediocoris* and *M. breviscula*. The *Eostaffella kanmerai* zone was characterized by the dominance of species in the genus *Eostaffella* (without the presence of *Millerella*). Definitions of the other zones corresponded to definitions provided by Watanabe (1973) and Hasegawa and Goto (1990).

Nakazawa (1997) followed the biostratigraphic divisions defined by of Watanabe (1973) and Kano and Yoshida (1994), subdividing the *Fusulina-Fusulinella* zone of Hasegawa and Goto (1990). He established nine biozones in ascending order: the *Endethyra* spp., *Mediocris breviscula*, *Eostaffella mosquensis*, *Millerella marblensis*, *Pseudostaffella antiqua*, *Akiyoshiella ozawai*, *Fusulinella biconica*, and *Beedeina* sp. zones. The *Endethyra* spp. zone is correlated with the lower part of the *Endothyra* zone, of Hasegawa and Goto (1990), and spans the middle Visean or lower Meramecian ages. The *Mediocris breviscula* zone of Nakazawa (1997) corresponds to the upper part of the middle to late Visean or the upper Meramecian *Endothyra* zone of Hasegawa and Goto (1990). The *Eostaffella mosquensis* zone corresponded to the lower part of the *Eostaffella-Millerella* zone of Hasegawa and Goto (1990), which was the Visean to Serpuhkovian or Chesterian. The *Millerella marblensis* zone corresponds to the middle part of the *Eostaffella-Millerella* zone as defined by Hasegawa and Goto (1990), which was the lower Bashkirian or Morrowan. The *Pseudostaffella antiqua* zone corresponds to the upper part of the *Eostaffella-Millerella* zone of Hasegawa and Goto (1990), ranging the lower Bashkirian or lower Atokan. The *Profusulinella daiyamensis* zone corresponds with the lower part of the late Bashkirian or middle Atokan *Profusulinella* zone of Hasegawa and Goto (1990). The *Akiyoshiella ozawai* zone corresponds to the upper part of the *Profusulinella* zone of Hasegawa and Goto (1990) and coincides with the lowest part of Moscovian or middle Atokan. The *Fusulinella biconica* zone was identical with the lower part of the *Fusulina-Fusulinella* zone of Hasegawa and Goto (1990) and dated the lower to upper Moscovian or upper Atokan to the lower Desmoinesian age.

The lowest *Beedeina* sp. zone corresponds to the upper part of the *Fusulina-Fusulinella* zone of Hasegawa and Goto (1990), raging the upper Moscovian or upper Desmoinesian.

Yoshida et al. (1984) studied Visean and Bashkirian corals and established the following four coral assemblage zones in ascending order: the *Akiyoshiphyllum Stylophorum-Carcinophyllum* spp., *Echigophyllum giganteum-Amygdalophylloides gracilis*, *Hiroshimaphyllum toriyamai-Amygdalophylloides gracilis*, and the *Pseudopavonid assemblage* zones. The first two zones correspond to the Visean *Endothyra* zone. The last two zones correspond to the Bashkirian *Eostaffella-Milerlla* zone and the *Pseudostaffella antiqua* zone, respectively.

2.4 Lithology and sedimentology of the Omi Limestone

The lithology of the Omi Limestone generally consists of massive white to gray limestone and so detailed field observations for sedimentary structures of the limestone are quite difficult to obtain. Therefore, researchers depend on laboratory works, such as observations of thin sections and polished surfaces of limestone (e.g., Kano and Yoshida, 1994). Although paleontological studies began in the early 1900s, sedimentological studies of the Omi Limestone only began relatively recently. This chapter reviews these sedimentological studies of the Omi Limestone.

Kano and Yoshida (1994) found a discontinuous deposition based on the occurrences of lithoclasts and associated faunal changes in fossil biotas. They established four units from the *Endothra* zone to the *Pseudostaffella antiqua* zone and discussed the transitions between depositional environments. Unit 1 in the *Medicoris mediocris* zone is dominated by ooid grainstone, indicating the quite shallow environment. Unit 2 is characterized by the occurrence of the *Eostaffella*, included lime clasts. *Millerella* spp. occurs in Unit 3, wherein rich sessile organisms, such as corals and bryozoans (which needed hard substrates for attachment) are present throughout the unit. The facies of Units 2 and 3 suggest that an erosional surface developed between these units, thus, enabling sessile organisms to attach to newly-formed hard bottom substrates. Unit 4, occurring in the *P. antiqua* zone, also included oolitic grainstone with lime clasts at its base.

Nakazawa (1997) classified the lithology of the Carboniferous Omi Limestone into the following 10 types and seven sub-types of boundstone, based on the kind of component particles in the limestone and their grain sizes, degree of roundness, and extent of sorting of the components: calcarenite, lime-clastic rudstone, lime-clastic bioclastic grain/rudstone, bioclastic-oncoidal rudstone, oolitic grainstone, fusulinid grainstone, *Ortonella* grainstone, fusulinid pack/wackestone, peloidal wacke/mudstone, and on boundstone subtypes, which consist of bryozoan-coral boundstone, coral–algal bryozoan boundstone, coral-chaetetid boundstone, stromatolitic boundstone, chaetetid boundstone, phylloid-algal boundstone, and *Hikorocodium* boundstone. The lime-clastic bioclastic grainstone/rudstone overlaying basic tuffs are stratigraphically distributed in the *Endothyra* spp. zone in the Fukugakuchi area. The calcarenite is also distributed in the area and lime-clastic bioclastic grainstone/rudstone and bryozoan-coral boundstone can be observed in the galley of the Nishiyama Mine in the *M. breviscula* zone. The calcarenite and lime-clastic bioclastic grainstone/rudstone can be observed in the Fukugakuchi area, while lime-clastic bioclastic grainstone/rudstone with insertions of oolitic grainstone can be observed at the galley of Nishiyama Mine, where it is stratigraphically distributed in the *E. mosquensis* zone. The lithologies at Fukugakuchi Mine (in the *M. marblensis* zone) are composed mainly of calcarenite. This also includes lime-clastic rudstone, chaetetid boundstone, and coral–algal bryozoan boundstone. The northern Higashiyama Mine is also characterized by calcarenite, while the galley of the Nishiyama Mine occurs in the lime-clastic, bioclastic grainstone/rudstone of the lower Bashkirian biozone. Stratigraphically, in the next *P. antiqua* zone, Fukugakuchi area is dominated by calcarenite with occasional occurrence of lime-clastic bioclastic grainstone/rudstone. The Higashiyama Mine is also occupied mainly by calcarenite facies with insertions of chert layers. At the central Nishiyama Mine, bioclastic-oncoidal rudstone and stromatolitic boundstone can be observed, while the southern part of Nishiyama Mine has oolitic grainstone and peloidal wacke/mudstone facies stratigraphically distributed in the biozone. Calcarenite and lime-clastic rudstone are stratigraphically distributed at the Higashiyama Mine in the *P. daiyamensis* zone. The northern part of the Nishiyama Mine is dominated by lime-clastic bioclastic grainstone/rudstone and coral–algal bryozoan boundstone, while the central Nishiyama Mine has bioclastic-oncoidal rudstone and stromatolitic boundstone lithofacies. Oolitic grainstone is distributed in the southern part of the mine, stratigraphically located in the *P. daiyamensis* zone. In the *A. ozawai* zone, lime-clastic rudstone is distributed at the northern section of the Higashiyama Mine, while the oolitic grainstone, peloidal wacke/mudstone, stromatolitic boundstone, and chaetetid boundstone occur at the southern section of the Nishiyama Mine. The *F. biconica* zone, in the southern section of the Higashiyama Mine, consists of lime-clastic bioclastic grainstone/rudstone, chaetetid boundstone, coral–algal bryozoan boundstone, phylloid-algal boundstone, and *Hikorocodium* boundstone. Northern sections of the Nishiyama Mine also contain lime-clastic bioclastic grainstone/rudstone, while the southern sections of the mine are composed of oolitic grainstone, fufulinid grainstone, *Ortonella* grainstone, fusulinid pack/wackestone, peloidal wacke/mudstone with coral-chaetetid boundstone, and chaetetid boundstone. In the *Beedeina* sp. zone, the lithology of southern section of Higashiyama Mine is occupied by lime-clastic, bioclastic grainstone/rudstone, and *Hikorocodium* boundstone, while the former facies is also distributed in the northern section of the Nishiyama Mine.

Nakazawa (2001) revised his previous work, and defined five facies associations with 18 limestone types and interpreted each of them as listed below:

Facies association A (fore reef facies)

Densely-packed grainstone and lithoclastic, micritic rudstone

Facies association B (reef-front facies)

Intraclastic-bioclastic rudstone/grainstone, bryozoan-coral boundstone, chaetetid boundstone, coral-chaetetid boundstone, coral-bryozoan-microencruster boundstone, phylloid-algal boundstone and solenoporacean boundstone.

Facies association C (reef crest facies)

bioclastic rudstone and stromatolitite-like laminar boundstone.

Facies association D (sand shoal facies)

oolitic grainstone and bioclastic grainstone.

Facies association E (lagoon facies)

bioclastic packstone, peloidal wackestone, microbial boundstone, chaetetid boundstone and coral-chaetetid boundstone.

The densely-packed grainstone is distributed at the Fukugakuchi and northern Higashiyama Mines from the *M. breviscula* zone to the *A. ozawai* zone. The lithoclastic-micritic rudstone facies occur in the Fukugakuchi and northern sections of the Higashiyama mines from the *Milerella*. sp. zone to the *A. ozawai* zone. Intraclastic-bioclastic rudstone/grainstone can be observed at the Fukugakuchi Mine, in the southern section of the Higashiyama Mine, and in the gallery and northern sections of the Nishiyama Mine in the *Endothyra*. spp zone to the *Beedeina*. sp. zones. Bryozoan-coral boundstone is distributed in the gallery of the Nishiyama Mine in the *M. breviscula* zone. Chaetetid boundstone can be observed only in the southern sections of the Higashiyama Mine in the *F. biconica* zone. Coral-chaetetid boundstone is also distributed only in this *F. biconica* biozone section of the mine. Coral-bryozoan-microencruster boundstone is distributed in the Fukugakuchi Mine, southern Higashiyama Mine, and northern Nishiyama Mines from the *Milerella* sp. zone to the *F. biconica* zone. The southern Higashiyama also contains phylloid-algal boundstone and solenoporacean boundstone in the *F. biconica* zone. The bioclastic rudstone is present only in the central Nishiyama Mine from the *P. antiqua* zone to the *P. dayamensis* zone. (Stromatolitite-like laminar boundstone is also distributed in the central Nishiyama Mine in in this biozone.) Oolitic grainstone can be observed in the gallery and southern section of the Nishiyama Mine from the *Med. breviscula* zone to the *F. biconica* biozone. Bioclastic grainstone is distributed in the southern Nishiyama Mine from the *Pse. antiqua* zone to the *Pro. dayamensis* zone. This bioclastic packstone also occurs in the southern Nishiyama Mine from the *Pse. antiqua* zone to the *Pro. dayamensis* zone. Peloidal wackestone is present at the southern Nishiyama Mine from the *A. ozawai* zone to the *F. biconica* zone. At the southern Nishiyama Mine, microbial boundstone, chaetetid boundstone, and coral-chaetetid boundstone are stratigraphically distributed from the *Pse. antiqua* zone to the *F. biconica* zone. Based on the stratigraphic distributions of boundstones, the Bashkirian and Moscovian Omi Limestones show distinctive reef facies that confirm that the Omi Limestone complex is a reef complex. Nakazawa (2001) also focused on the development of reef builders associated with the Omi Limestone during the early to mid-Carboniferous period.

3. Material and Method

For reconstructing fossil biota of the Carboniferous Omi Limestone complex, it was necessary to aggregate micro and macrofossil records. Macrofossils are much better-known than microfossils, except for the small foraminiferans and fusulinaceans (as reviewed in Chapter 2.2). For that reason, I focus on the reconstruction of the microfossil fauna (from limestone sampling conducted during field surveys) to obtain microfossils (see Sections 3.1 and 3.2 for sampling localities). On the other hand, accumulations of macrofossil data from other sources could also be relevant, and so in addition to literature surveys, I examined museum collections to uncover unreported fossils (see Section 3.3).

3. 1 Field Survey

I conducted fieldwork to collect limestone samples in the Fukugakuchi area (i.e., in the Nishiyama Mine and in the Omi River complex), which required recording the stratigraphic horizons and associated lithofacies associated with those formations. Both areas occupied the middle Carboniferous *Eostaffella-Millerella* to *Fusulinella* zones as described by Hasegawa and Goto (1990). Three sections were studied in both respectively, and these sections were united into one long section in each area. The lithologies of these united sections are explained in more detail in the next sections (3.1.1 and 3.1.2). Collected limestone samples that weighed 2–4 kg each were used to extract microfossils using an acid treatment. Thinned sections and polished surfaces were created to examine detailed lithology of the limestone in the laboratory (see Section 3.2).

I adopted the limestone classification of Dunham (1962) and its emendation by Embry and Klovan (1972). In this study, limestones were classified into six types: lime-mudstone, grainstone, rudstone, cement-rich rudstone, stylo-breccia, and boundstone. Most of the studied limestones consist of grainstone and lithoclastic rudstone, while the other types were observed less frequently.

3. 1. 1 Fukugakuchi

The limestone in this area is composed of boundstone, grainstone, rudstone, and lime- mudstone. Boundstone is characterized by rich corals, such as *Taisyakuphyllum* and *Amygdalophylloides* spp., encrusted and bound to each other by thick layers of microbial fossils. These layers are sometimes exemplified by biogenetic, laminated structures. The corals are also associated with bryozoans and chaetetids, which initially built the reef frameworks. The matrix of the facies is grainstone, which includes bioclasts of crinoids, foraminifers, bryozoans, and peloids. The boundstone of these samples corresponds to the coral-bryozoan-microencruster boundstone described by Nakazawa (2001). Grainstone is composed of densely packed bioclasts, lithoclasts, ooids, and peloids, but ooids sometimes dominated the samples. Bioclasts consist of fragments of crinoids, bryozoans, foraminifers, and large-sized splinters of corals, such as *Psedopavona* and *Ozakiphyllum* spp. This limestone also contains lithic and bioclastic fragments that are relatively well sorted, but sometimes bear centimeter-sized fragments that show grading-type structures, which can be observed in the lower parts of the section. This limestone can be matched to the densely-packed grainstone described by Nakazwa (2001).

Rudstone in Fukugakuchi consists of centimeter-sized, angular-to-rounded, lithic fragments of limestones and a matrix of grainstone to lime-mudstone. However, lithic fragments sometimes include black pebbles. These matrices are comprised of small bioclasts, such as foraminifers, crinoids, bryozoans, ooids, and peloids. This type of limestone corresponds to the lithoclastic-micritic rudstone and intraclastic-bioclastic rudstone/grainstone of Nakazawa (2001). Lastly, lime-mudstone includes few bioclasts in its micritic matrix.

Strikes and dips were measured relative to the coral directions of the boundstone and graded beds. The graded characteristics of grainstone in this study are diagnostic of sedimentary structures of turbidite, while poor cementations of limestone facies suggest low-water circulation below the wave base level. In addition to these indicators, boundstone possesses a rigid framework. Nakazawa (2001) interpreted this framework as indicating reef-front to fore reef environments.

3. 1. 2 Nishiyama

The limestone of this area is composed of grainstone and rudstone. These lithologies and paleoenvironments are similar to those of the Fukugakuchi. Strikes and dips were measured relative to a inserted basalt bed.

3. 1. 3 Omi River

Float rocks that contained abundant macrofossils from the Omi River were also sampled. The floats were composed of cement-rich rudstone, characterized by various-sized bioclasts and intraclasts filled with syndepositional submarine cement, such as radial-fibrous calcite. The bioclasts consist of crinoids, bryozoans, brachiopods, ammonoids, and gastropods, while intraclasts were mainly composed of grainstone. This type of limestone corresponds to the intraclastic-bioclastic rudstone described by Nakazawa (2001). The distinctiveness of the cement and associated various-sized bioclasts suggest that the limestone components were deposited in a shallowly-buried, syndepositional marine environment (*sensu* Flügel, 2010). The lithology suggested the float could be derived from a reef-front facies distributed across Nishiyama and Higashiyama (Nakazawa, 2001).

3. 2 Laboratory Works

Collected limestone samples were treated with acetic acid to recover microfossil fauna. The general disaggregating technique applied to limestone samples are outlined by Collinson (1963). To effectively obtain limestone residues, I crushed 1–3 kg of limestone into small pieces and dissolved the pieces with 5–10% acetic acid. It appeared that acid diluted by more than 10% was best for preserving microfossil samples. I then sieved limestone residues with a no. 150 metal mesh, which consolidated limestone residues and their associated microfossils. Because the limestone samples were so pure, it was not necessary to use heavy liquid and magnetic separation methods for collecting microfossils. The limestone residues were dried in a drying oven and examined under stereoscopic microscope (Nikon SMZ645). Under the microscope, microfossils were picked up with a thin brush and stored on slides. Micro-photoimages of these fossils were taken with a digital microscope (Keyence VH-Z100R) in order to examine original colors of fossils in detail. I used descriptions from the literature to help identify the microfossil samples.

My limestone samples were also used to create thin-section and polished surface specimens. For interpreting limestone lithology, three to five thin sections and a polished surface were prepared for each sample. The explanations of limestone lithologies are provided in Chapter 3.1.

3. 3 Museum Survey

For reconstructing the fossil biotas of the Carboniferous Omi Limestone, I accumulated previous paleontological works and created occurrence lists of these taxa. I also conducted a museum survey at the FMM to uncover unreported fossils there. I selected this museum, located in Itoigawa City, Niigata Prefecture, because it preserves the most-extensive fossil collection of the Omi Limestone complex. Previously, the Omi Natural History Museum also held fossils from the Omi Limestone, but when it closed, its collection was deposited in FMM. I added the unreported fossils to the occurrence lists. These lists are provided in Appendices 1–19.

4. Fossil data of Carboniferous Omi Limestone

4.1 Obtained microfossils

In chapter 8, I summarize the microfossils obtained from the middle Carboniferous Omi Limestone. Twenty six species of 9 genera of the following Bashkirian–Moscovian conodonts are obtained: *Hindeodus minutus, Mesogondolella clarki, Declinognathodus noduliferus, D. praenoduliferus, D*. sp. A, *D*. sp. B, *Idiognathodus covadongae, I. delicates, I*. cf. *incurvus, I. sinuosus, Idiognathoides corrugatus, Id. macer, Id. pacificus, Id*. aff. *pacificus, Id. sulcatus, Neognathodus atokaensis, N. kanumai, N. symmetricus N*. sp. A, *Streptognathodus einori S. expansus, S. suberectus, S*. cf. *suberectus S. subsimplex, Neolochriea glaber, Idioprioniodus* sp. Most of them are newly reported from the Omi Limestone (see Appendix 17, 18). Ostracoda includes 10 species of 8 genera such as *Polycope* sp. A, B, *Kellettina* cf. *robusta, Bairdia* sp., *Silenites* sp., *Bythocypris* sp., *Spinomicrocheilinella?* sp., *Deloia* sp. Gen. et sp. indet. A, B. Occurrence of the class is even a first report from the Omi Limestone (Appendix 14). Actinopterygian and chondrichthyan fossils are also first discoveries. They are belonging to totally seven species as follows; Actinopterygii indet. A, B, Protacrodontidae gen. et sp. indet., *Bransonella* sp.?, Ctenacanthidae? gen. et sp. indet., *Cladodus* sp.? and Gen et sp. indet. A, B (Appendix 19). Totally following eight species of mollusks are obtained: *Annuliconcha* sp., Veneroida fam. gen. et sp. indet., *Glabrocingulum* sp., *Mourlonia* aff. *hayasakai*, Eotomariidae gen. et sp. indet., Microdomatidae gen. et sp. indet., Anomphalidae gen. et sp. indet. and Bellerophontidae gen. et sp. indet. Some of them are not micro- sized, and all of them are first reports from the Omi Limestone (Appendix 6, 7). New reports are extended to echinoderms, such as Echinoidea indet. A, B, holothurian sclerites *Thalattocanthus consonus*, *Microantyx botoni*, *Clavallus* sp, *Eocaudina subhexagona* and tentacle scales of ophiuroid *Furcaster* sp. (Appendix 15). The occurrence of *Furcaster* sp. represents the oldest fossil record of Ophiuroidea in Japan. Totally following three species of porifera are identified by the form of spicules; Calcarea indet., Calcaronea indet. and Heteroscleromorpha indet. They are also first reports from the Omi Limestone (Appendix 19). Fossil records of chitinozoas are lacking in Japan, but this study reveals two prosomatifera chitinozoans Prosomatifera indet. A and B from the Omi Limestone (Appendix 19). This indicates the first discovery of the chitinozoan fossils in Japan. Lastly eight “microproblematicas” are obtained (Appendix 19).

4.2 Data filing of micro and macrofossils

Addition to microfossils of this study, I accumulated the mico and macrofossil data obtained by the museum and literature surveys (see Appendixes 1–19). Mollusucan fossils are totally 61 species, including six species of bivalves, one of rostroconcha, 22 of gastropods and 32 of cephalopods. Arthropod fossils have 19 species composed of ten species of ostracods and nine species of trilobites. Brachiopods are totally 81 species, mainly consisting of two classes Rhynchonellata and Strophomenata. Cnidaria is occupied by 50 species of corals, the group also contain one species of scyphozoan. Echinoderm fossils are totally 18 species, consisting of one species of blastoid, 10 of crinoids, 2 of echinoids, 4 of holothuroids and one of ophiuroid. Bryozoans are 29 species in total. Foraminifers are the most diverse group in the limestone and contain 160 species. Chordata fossils are totally 8 species, consisting of 2 actinopterygians and 6 chondrichthyans. Porifera is composed of 2 species of Calcarea, one species of Demospongia and Sclerospongia each. Generally called algae includes totally 4 species composed of Chlorophyta, Cyanobacteria and Rhodophyta. Conodonts have 45 species in total. Onthers are two species of chitinozoan and 8 microproblematicas.

5. Discussion

In this chapter I discuss the biota and paleoecosystem of the Carboniferous pelagic reef of Omi Limestone based on the micro and macrofossil data. First, conodont biostratigaraphy is examined in the Chapter 5. 1. On the basis of the paleoecologies of each taxon, paleoecosystem of the Carboniferous pelagic reef of Omi Limestone is reconstructed in the Chapter 5. 2. The Carboniferous is thought to be the recovery phase from the Late Devonian mass extinction. The ecosystem recovery of the Omi Limestone is examined in the Chapter 5. 3. The paleogeographical views based on the microfossils are suggested in Chapter 5. 4. And in the Chapter 5. 5, I test my hypothesis that diverse microfossils are common in the middle Carboniferous Akiyoshi Terrane.

Itoigawa City has two types of Paleozoic limestone as whitish Omi Limestone and blackish Tsuchikurazawa Limestone. Lastly, I reports first conodont fossils from the latter limestone in Chapter 5. 6.

5.1 Conodont biostratigaraphy

The GSSP of the Bashkirian Stage and the lower Pennsylvanian Series is placed in the lower Bird Spring Formation at Arrow Canyon, Nevada, USA (Lane et al., 1999). The First Appearance Datum (FAD) of *Declinognathodus noduliferus* sensu lato indicates the beginning of the Bashkirian. *Idiognathoides* appears later and *Neognathodus* generally arise after the entry of *Idiognathoides*. *Idiognathodus*, one of the most diverse genera in Pennsylvanian period, appears near the middle of the Bashkirian, and *Streptognathodus* and gondollelids species occurrs in the late Bashkirian by recent studies (e.g. Hu et al. 2017; Qi et al. 2016). Based on these facts, I think it is possible to establish the middle Carboniferous conodont stratigraphy at the studied sections.

Totally four conodont zones are recognized in the middle Carboniferous part of the Omi Limestone. In ascending order, these are respectively designated as follows; the *Declinognathodus noduliferus* (lower Bashkirian), *Idiognathoides sulcatus* (lower—middle Bashkirian), *Streptognathodus expansus* (upper Bashkirian) and *Mesogondolella clarki* (lower Moscovian) zones in ascending order. The zonal correlations of domestic and foreign are shown in Table 2, 3.

5.1.1 Definitions and characteristics of the established conodont zones

Declinognathodus noduliferus Zone

The lower boundary of this zone is defined by the FAD (First Appearance Datum) of *Declinognathodus noduliferus* and its upper boundary coincides with the FAD of *Idiognathoides sulcatus*. The zone is also characterized by the occurrence of *Declinognathodus praenoduliferus* and association with *Neolochriea glaber* and *Neognathodus symmetricus*. The FAD of *D. noduliferus* represents the beginning of the Pennsylvanian.

Idiognathoides sulcatus Zone

The lower boundary of this zone is marked by the FAD of *Idiognathoides sulcatus*. The upper boundary of the zone is by the FAD of *Streptognathodus expansus*. This zone is characterized by the initiation of diversifications of species of *Idiognathoides* and Neognathodus. *Idiognathoides sulcatus* is a relatively long-raging Pennsylvanian conodont. Other associated conodonts consist of *Hindeodus minutus*, *Dclinognathodus noduliferous*, *Idiognathoides corrugatus*, *Idiognathoides pacificus*, *Idiognathoides* aff. *pacificus*, *Neolocharie glaber*, *Neognathodus atokaensis* and *Neognathodus symmetricus*.

Streptognathodus expansus Zone

The base of this zone is defined by the FAD of *Streptognathodus expansus*. The top of this zone is marked by the FAD of *Mesogondolella clarki*. This zone is characterized by association *Declinognathodus noduliferous*, *Idiognathodus* sp. A, *Idiognathoides. corrugatus*, *Idiognathoides macer, Idiognathoides sulcatus, Idiognathoides pacificus, Neognathodus atokaensis, Neognathodus kanumai, Streptognathodus suberectus, Streptognathodus* cf. s*uberectus, Streptognathodus. subsimplex* and *Idioprioniodus* sp.

Mesogondolella clarki Zone

The base of this zone is defined by the FAD of *Mesogondolella clarki*. This conodont is the index species for definition of the Bashkirian–Moscovian boundary in the Akiyoshi Terrane (e.g. Ishida et al., 2013). Associated fauna is composed of *Idiognathoides sulcatus, Idiognathoides macer, Idiognathodus delicatus, Idiognathodus covadongae, Idiognathodus sinuousus, Idiognathodus* sp. A, *Idiognathodus* cf. *incurves, Streptognathodus einori, Streptognathodus expansus, Neognathodus symmetricus* and *Hindeodus minutus*.

5.1.2 Correlations of the conodont biozones

Declinognathodus noduliferus Zone

This zone is correlated with the *Millerella yowerensis* zone in the Akiyoshi Limestone because of the occurrence of *D. noduliferus* (Haikawa, 1988). In the Hina Limestone, Mizuno (1997) also settled the *Declinognathodus inaequalis-Gnathodus bilineatus* zone and *D. nosuliferus* zone based on the occurrences of the *Declinognathodus* spp. *D. inaequalis* and *D. nosuliferus* are assigned to *D. noduliferus* sensu lato (e.g. Hu et al., 2017), and these two zones are corresponded to the *Dclinognathodus noduliferus* zone of this study. The *Gnathodus bilineatus-Gnathodus nodulifera* zone of Koike (1967) in the Atetsu limestone is characterized by the occurrences of *G. bilineatus* and *G.*

nodulifera (synonym of *D. noduliferus*). This study lacks *G. bilineatus* in the *D. noduliferus* zone, but co-occurrences can be observed in the lowermost part of the *D. noduliferus* zone in domestic and foreign regions (e.g. Qi et al. 2016). Studied limestones are probably lacking the lowermost part of *D. noduliferus* zone of the Atetsu Limestone. Hence, the *Gnathodus bilineatus-Gnathodus nodulifera* zone of Koike (1967) can be correlated to this zone. Mizuno (1990) established *Gnathodus bilineatus–Declinognathodus noduliferus* zone based on the co-occurrence of both species. This zone is also corresponded to the *D. noduliferus* zone of my study as the same reason of the Atetsu Limestone. In the South Kitakami, Nakamura in Minato et al. (1979) proposed the *Idiogntholdes noduliferus* zone in the Nagaiwa Formation. The lower part of the zone is characterized by the occurrences of *Idiognathoides noduliferus* (synonym of *Dclinognathodus noduliferus*), and upper part co-occurrences of the *Streptognathpodus expansus* and *Idiognathoides* spp. Thus, the *D. nodulifurus* zone of this study is correlatable to the lower part of the *Idiogntholdes noduliferus* zone. In his study, occurrence of *Idiognathoides sulcatus* is stratigraphically upper than the occurrence of *Streptognathodus expansus*, and established the *Idiognathoides sulcatus* zone. This is not common in other regions. In the Omi Limestone, Isomura (1996) settled the *Declinognathodus noduliferus* zone by the occurrence of the *D. noduliferus* and limited the upper spanning of the zone by the occurrence of *Streptognathodus expansus*. Therefore, *D. noduliferus* zone of this study can be corresponded to the lower part of the *D. noduliferus* zone of Isomura (1996). As in domestic regions, *Declinognathodus noduliferus* zones of foreign countries are also defined by the *Dclinognathodus noduliferus* and associated *Dclinognathodus* spp. as *Declinognathodus noduliferus* sensu lato. These zone is characterized by the occurrence of *D. noduliferus*, associated with other common forms such as *D. inaequalis, D. lateralis, D. bernesgae*, *Lochriea* spp. and *Gnathodus* spp. The upper limits of these *Declinognathodus noduliferus* zones in the foreign regions are defined by the diversifications of genus *Idiognathoides*. The *Declinognathodus noduliferus* zone of this study is also limited its upper limit by the occurrence of *Idiognathoides sulcatus*. Hence, this zone can be correlated with the *Declinognathodus noduliferus* zones of foreign regions and the age of the zone suggests the early Bashkirian (earliest Pennsylvanian) (e.g. Nemyrovska, 1999; Nemyrovska et al., 2011; Nemirovskaya and Alekseev, 1994; Barrick et al., 2013; Hu et al., 2017).

Idiognathoides sulcatus Zone

The most characteristics of the zone is the initiation of the diversifications of *Idiognathoides* associated with occurrences of *Neognathodus* species. In the Atetsu Limestone, *Gnathodus wapanuckensis* zone of Koike (1967) is characterized by the occurrence of *Gnathodus wapanuckensis* (re- identified as *Neognathodus* spp. by me) and associated *Gnathodus nodulifera* (synonym of

Dclinognathodus noduliferus) and *Gnathodus opimus* (synonym of *Idiognathoides sulacatus*). Hence, the *Gnathodus wapanuckensis* zone of Koike (1967) corresponds to the *Idiognathoides sulcatus* zone of this study. In the Taishaku Limestone, *Neognathodus bassleri-Idiognathoides opimus* zone of Mizuno (1990) is characterized by the *Neognathodus* and *Idiognathoides* species, which is a characteristic of the *Idiognathoides sulcatus* zone of this study. In the Hina Limestone, Mizuno (1997) established the *Neolochriea nagatoensis, Neolochriea koikei, Neognathodus symmetricus* zones. Although this study lacks *Neolochriea nagatoensis* and *Neolochriea koikei,* Mizuno (1997) correlated these zones to *Gnathodus wapanuckensis* zone of Koike (1967), which corresponds to the *Idiognathoides sulcatus* zone of this study by the occurrence of G. *wapanuckensis.* In the Ko-yama Limestone, *Neognathodus symmetricus-Idiognathodus primulus* zone of Ishida et al. (2013) include *Neognathodus* and *Streptognathodus* species, and the lower part of the zone can be correlated to the *N. symmetricus* zone of Mizuno (1997). The latter is corresponded to the *Idiognathoides sulcatus* zone of this study as previously mentioned. In the Akiyoshi Limestone, Igo (1973) reported *Neognathodus bassleri symmetricus- Paraganthodus nagatoensis* zone characterized by the occurrence of *N. bassleri symmetricus* (synonym of *N. symmetricus*) and *P. nagatoensis* (synonym of *Neolochriea nagatoensis*). This zone is corresponded to the *Neolochriea nagatoensis, Neolochriea koikei, Neognathodus symmetricus* zones of Mizuno (1997), which is correlated to the *Idiognathoides sulcatus* zone of this study. In the Omi Limestone, the upper *Declinognathodus noduliferus* zone of Isomura (1996) can be corresponded to the *Idiognathoides sulcatus* zone of this study. *Idiognathoides sulacatus* and *Idiognathoides sinuatus* are recently noticed conodonts for the lower–middle Bashkirian biostratigraphy (e. g. Hu et al., 2017). Unfortunately, the latter species is not obtained in this study. Hence, the only *Idiognathoides sulcatus* is valuable in the Omi Limestone. This zone corresponds to *Idiognathoides sulcatus sulacatus* zone to *Idiognathoides sulcatus parvus* zones of South China (Hu et al., 2017), *Idiognathoides sinutatus- Idiognathoides sulcatus* zones of Eastern Europe (e.g. Nemyrovskaya, 1999), *Idiognathoides asiaticus* and *Idiognathoides sinuatus* zones of Western Europe (Nemyrovskaya, 2011), *Idiognathoides sinuatus* zone to *Neognathodus bassleri* zones of USA (e.g. Barrick et al. 2013). Therefore, the age of the *Id. sulcatus* zone of this study spans the early-middle Bashkirian.

Streptognathodus expansus Zone

The zone is characterized by the initiation of occurrences of *Streptognathodus* species. The *Idiognathodus parvus- Gnathodus nodulifera* zone of Koike (1967) in the Atetsu Limestone is defined its lower limit by the occurrence of *Idiognathodus parvus* (synonym of *Streptognathodus parvus*), and occurrence of *Mesogondolella? clarki* defines the upper limit. Unfortunately, *S. parvus* is not obtained in this study, but this zone of Koike (1967) can be correlated to the *Streptognathodus expansus* zone of this study by the occurrences of *Streptognathodus* species. In the Taishaku Limestone, *Neognathodus bassleri-Idiognathoides opimus* zone of Mizuno (1990). These conodonts are co-occurred with *S. expansus* in the other regions (e.g. Nemyrovskaya, 1999; Qi et al., 2016). Hence, this zone of Mizuno (1990) can be partly correlated with the *S. expansus* zone of this study. Ishida et al. (2013) reported the *S. expansus* in the *Neognathodus symmetricus-Idiognathodus primulus* zone. Thus, the upper part of the zone can be corresponded to the *Streptognathodus expansus* zone. In the South Kitakami, *S. expansus* first appeared in the upper part of the *Idiognathoides nodulifera* zone (Nakamura in Minato et al., 1979), and the upper part is correlatable to the *S. expansus* zone. In the European, Russia, North and South American regions, high diversity of *Idiognathodus* and *Idiognathoides* species make them valuable for age indications. But species of *Streptognathodus* appears the upper Morrowan zones, and I consider these zones in the European, Russia, North and South American regions are correlatable to the *S. expansus* zone of this study. In the South China, diversities of the *Idiognathodus* and *Idiognathoides* species are not high as in Japan, and *S. expansus* is used for biostratigraphy. *S. expansus* is morphologically subdivided into M1 and M2 in the South China (e.g. Qi et al., 2011), and these species are associate with other species of *Streptognathodus*. Although these morphological differences of *S. expansus* are obscure in Japan, *S. expansus* M1 and M2 zones can be corresponded to the *S. expansus* zone of this study. These correlations suggest the zone corresponds to the upper Bashkirian.

Mesogondolella clarki zone

Because *Polygnathodella ouachitensis* (junior synonym of *Idiognathoides corrugatus*) is a relatively long ranged conodont co-occuring with *Gondolella clarki* (synonym of *M. clarki*) (e.g. Qi et al., 2011; Hu et al. 2017). The *Gondolella clarki-Polygnathodella ouachitensis* zone of Koike (1967) is corresponded to the *Mesogondolella clarki* zone. *Neogondolella clarki*-*Idiognathodus delicates* Zone of Mzuno (1990) in the Taishaku Limestone is characterized by the occurrence of *Neogondolella clarki* (synonym of *M. clarki*) and *Idiognathodus delicatus*. These co-occurrence is recognized in the *Mesogondolella clariki* zone of my study. Ishida et al. (2013) established the *Idiognathoides convexus-Gondolella clarki* zone based on the first occurrence of them. *Idiognathoides convexus* (synonym of *Id. pacificus*) is only appeared in the upper Bashikirian *S. expansus* zone of this study. This species is probably has long-ranged conodont due to the occurrence from the Moscovian in the South China (e.g. Hu et al., 2017), and it does not matter the co-occurrence in Ishida et al. (2013). The *Idiognathoides convexus-Gondolella clarki* zone of Ishida et al. (2013) is correlatable to the *Mesogondolella clariki* zone of this study. In the foreign regions, only two species, *Declinognathodus* *donetzianus* and *Diplognathodus ellesmerensis* have been used for correlating the boundary of the base of the Moscovian Stage. The FAD of *Mesogondolella* is thought to be stratigraphically slightly higher than the traditional Bashkirian–Moscovian boundary (Qi et al., 2016). Therefore, the *Mesogondolella clariki* zone of this study is correlated with *D. donetzianus* zone of Russia and Eastern Europe and *Dip. ellesmerensis* zone of South China (e.g. Nemirovskaya, 1990; Qi et al., 2016), and the zone corresponds to the lower Moscovian.

5. 2 Reconstruction of the ecosystem of the Carboniferous Omi Limestone

Ecosystem is a community of living organisms and their environment that function as an integrated unit. Previous paleontological studies generally reconstructed integrations of biotas and their habitat environments as paleoecosystems (e.g. Falcon-Lang et al. 2006). From a different perspective, ecosystem also has been formed by complicated interactions of living organisms. But predator–prey interactions and its consequences are often difficult to assess in Recent communities and even more so in the fossil record. In this study, fore- reef paleoecosystem of the Carboniferous Omi Limestone are reconstructed from the perspectives of paleoecology of fossil taxa, and drawing image and schematic image of substance cycle of marine ecosystem of the limestone is also shown in Fig. 11, 12. The paleoecologies of each taxon are recovered based on the biological or ecological studies of them (e. g. Nixon, 1988; Kabot, 1990; Purnell, 1993; Brandt et al., 1995; Fukuda, 1996; Brett and Walker, 2002).

Producer may have been only composed of algae based on the fossil data. Unlike modern reefs, Paleozoic corals lacked zooxanthellae symbiosis and the corals of Omi Limestone cannot be assigned to producers (e.g. Coates and Jackson, 1987). Coates and Jackson (1987) suggested the coral-zooxanthellae symbiosis started by the Jurassic, and Stanley and Swart (1995) indicated the symbiosis began during Triassic by correlations of growth, reef formation and geochemistry. Grazers consist of gastropods and echinoids. On the other hand, predatory carnivores include ammonoids, nautiloids, chondrichthyans, actinopterygians, conodonts, trilobites and gastropods. Detritus feeder is divided into two types as suspension and deposit feeder. The former feeds detritus floating in water and latter takes deposits which contain detritus on the bottom of the water. Corals, crinoids, sponges, brachiopods, gastropods and bivalves are assigned to suspension feeders. The deposit feeders are composed of foraminifers, trilobites, ostracods, ophiuroids, holothuroids, echinoids, gastropods and bivalves. Their relationships from a perspective of substance cycle is shown in Fig.12. The cycle is composed of grazing food chain and detritus food chain. The former chain starts from the producers, then grazers feed them and predators consume these grazers. The detritus food chain starts the productions of the detritus by the living organisms and detritus feeders use it (e.g. Omori, 2003; Polvina, 1984). The latter chain is incorporated in the grazing food chain because the detritus feeders are predated by the predatory carnivores in the end. Furthermore, excrements and carcasses of animals are decomposed into detritus, and the grazing food chain is also incorporated in the detritus food chain. The producer algae have a roll for nutrient fixations (e.g. Sorokin, 1990), and detritus is of also sufficient for matter cycle in the ocean ecosystems (e.g. Sorokin, 1973). Young (1971) indicated the developing of bacteria at the suspended detritus increased detritus nutrition, and it helped suspension feeders to absorb nutrition from the suspended detritus. He also shows the nutrition- rich detritus settle as deposit, and deposit feeders feed on it. Resuspended particles by water currents is subject to the developing of bacteria again (Young, 1971).

Due to presence of the coral-zooxanthellae symbiosis corals contribute as producers in modern coral reefs. Sorokin (1990) presumed that they have approximately one-third of primary production of entire modern reef ecosystems. The mucus secreted by corals form of their primary production having rich nutrient. It create a nitch of coral and coral mucus feeders, and also contribute detritus feeders by the fragmented mucus (Sorokin, 1990; Tsuchiya and Fujita, 2009). In case of the Carboniferous. mucus derived by corals probably did not contain rich nutrients as modern ones. Therefore, the reef of the middle Carboniferous Omi Limestone maight have been lacked that type of nitch, and diverse vertebrates such as sea birds, seals and sea turtles. Signor and Brett (1984) recognized several Middle–Late Paleozoic adaptive trends that served to strengthen invertebrate skeletons and make them more difficult to attack. Brett and Walker (2002) reviewed Paleozoic predators and confirmed occurrences of new predatory taxa such as ammonoids, decapods, stomatopods, elasmobranchiis and basal actinopterygians in the Devonian–Carboniferous. They called the trend that included defensive adaption of invertebrate skeletons and new origin of active predators in the Devonian- Carboniferous age, Middle Paleozoic marine revolution. The newly joined nektonic predators such as chondrichthyans and actinopterygians were present in the Omi Limestone, suggesting the Middle Paleozoic marine revolution had also occurred in the atoll distributed the center of the Panthalassa in the middle Carboniferous. It is desireable to correlate the Omi reef ecosystem with reefs in continental margins in the same age, but there are some study focused only on the reef-building faunas and imformation about entire animal faunas of the reef ecosystems are lacking even today.

The grazing food chain of the Omi reef was maybe much simpler than the modern reef because of the small size of nektonic predatos as ammonoids and fish and their few occurences. Besides, the detritus feeders occupying around 80% of the diversity of Omi reef animals (see Appendixes). Sediment supplier as crinoids, bryozoans and corals, and relatively large-sized fossils as brachiopods are consupicious in the limestone, which leads an overestimation thir occurences. But there have been no records of chondrichthyans and actinopterygians since 1900s, it imply the lack of abundance of these taxa. These facts suggest that the grzing food chain is weaker and the detritus food chain of the Omi reef is heavier than modern reefs. This may also indicates that the detritus food chain supplement the weakness of simple grazer food chain and a nitch of coral and coral mucus feeders in the Carboniferous pelagic reef.

5. 3 Reef recoveries of the Carboniferous Omi Limestone from the F-F mass extinction

Prosperities and declines of reefs have been repeated since the Phanerozoic up to the present time. The reefs have been largely flourished five times as in the Cambrian, Devonian, Late Jurassic to Early Cretaceous, Late Cretaceous and Neogene to present time (Cooper, 1988). Later work of Kiessling (2002) verified the three times peaks of prosperities of the Phanerozoic organic reef by the statistical methods. These peaks were situated in the Late Devonian, Late Jurassic and middle Miocene. Conversely, there have been times of undeveloped reefs in the history of life. Cooper (1988) presumed that organic reefs following mass extinctions such as F-F and P-T mass extinction events had been undeveloped due to the severe destructions. His observations of the three stages of fossil reefs, deeply damaged from the extinction events, the gradual recovery of biodiversities and complexity, and the last climax reef suggested erathemic succession of reef community from pioneer community to climax community.

Nakazawa (1999) evaluated the reef recovery of the Carboniferous Omi Limestone from the perspective of development of reef-complex facies. According to Longman (1981), modern reef facies is composed of fore reef, reef front, reef crest, sand shoal and lagoon. These facies were indistinctive in the Omi Limestone in the Early Carboniferous, but they were reconstructed in the middle Carboniferous (Nakazawa, 1997). The presence of reef boundstones and diverse reef facies occurred in the middle Carboniferous formed the reef-complex of the Omi Limestone in the time (Nakazawa, 1999). The reef-complex facies of the middle Carboniferous Omi Limestone can be correlated to the modern reef-complex facies, and he pointed the erathemic suncession of reefs of the Early to middle Carboniferous Omi Limestone. Therefore, the reef community of the Omi Limestone was recovered to some degree at least in the middle Carboniferous time (Nakazawa, 1999). Recent studies of the South China reveal that reefs of continental margin were recovered even in the Early Carboniferous before the recovery of the Omi Limestone located in the pelagic ocean（Yao and Wang, 2016）.

In different views of fossil reef recovery, Machiyama (1995) suggested the changes of the mass of nutrient salt affect the reef builders adopt the new environment and flourished, as the idea of nutrient limitation model of Wood (1993). The middle Carboniferous had a worldwide marine regression event observed in most shelf sequences, and following transgression event associated with intense pour of nutrient salt into marine (Saunders and Ramsbottom, 1986). Sakata et al. (2015) focused on the phosphorus content in limestones of the Akiyoshi Terrane, and substantially they revealed that the mass of nutrient salt increased after Mid-Carboniferous boundary (MCB). Kano and Yoshida (1994) also pointed out the importance of the erosional surface formed by the regression event of MCB, because the necessity of appropriate conditions of hard substrates for the new sessile organisms to settle.

In this study, diverse microfossils of the middle Carboniferous Omi Limestone are obtained and many species not known so far are discovered. Specifically, classes Ostracoda, Actinopterygii, Chondrichthyes, Echinoidea, Holothuroidea, Ophiuroidea and group a Chitinozoa are newly added. Therefore, my result showing the rich reef-living animals at the time is consistent with the recovery idea of Nakazawa (1999). Conversely, Nakazawa (1999) pointed out the complexity of reef in the middle Carboniferous Omi Limestone.

5. 4 Paleogeographical imprications of the Carboniferous Omi Limestone.

Fujiwara (1967) suggested the seamounts of the Akiyoshi Terrane were located at the lower to middle northern paleolatitudinal area in the Panthalassa Ocean in the Early Carboniferous, based on the paleomagnetic data for the basaltic tuff of Akiyoshi Limestone. This data was supported by the occurrence of the brachiopod fossils such as *Delepinea* and *Davisiella* from the Early Carboniferous Akiyoshi and Omi Limestone (Yanagida, 1968; Tazawa et al., 1983; Tazawa et al., 2005).

For the middle Carboniferous part of the Omi Limestone, Tazawa et al. (2004) also suggested the middle-latitudinal paleogeography on the basis of occurrences of brachiopod species such as *Isogramma millepunctata,* the occurences of which has been restricted in the latitudinal area: Nebraska, Illinois and Ohio of North America (Dunker and Condra, 1932; Meek and Worthen, 1870; Morningstar, 1922; Sturgeon and Hoare, 1968), eastern Uzbekistan (Licharew, 1936; Volgin, 1957, 1960) and North China (Wang and Yang, 1998). This view was recently also supported by the occurrence of another brachiopod *Coristites mosquensis* suggested by Ibaraki (2017). Their results were confirmed by the other fossil taxa, Yoshida and Okimura (1992) studied the middle Carboniferous corals fossils belonging to genus *Amygdarophyloides*, and indicated the commonality to the distributions of the genus in the Boreal and Tethyan regions. This genus has been reported from Spitsbergen (Forbes et al., 1958), northern Spain (de Groot, 1963; Rodriguez, 1984), the Carnic Alps (Heritsch, 1936), Yugoslavia (Kostic- Podgorska, 1955). Northeastern Egypt (Herbig and Kuss, 1988), Moscow Basin (Dobrolyubova, 1937; 1940; 1948; Dobrolyubova and Kabakovich, 1948), Kazakhstan

(Bikova, 1974), North China (Guo, 1983), South China (Yu, 1980; Ding and Yu, 1987; Wang and Zhao, 1989; Wu and Zhao, 1989), North Vietnam (Fontaine, 1961), Akiyoshi (Yamagiwa and Ota, 1963; Minato and Kato, 1975; Haikawa, 1986) and Fukuji (Niikawa, 1981).

I discuss the obtained fossil faunas composed of benthos of the middle Carboniferous Omi Limestone. Benthic fauna suggests the low-middle latitudinal area in northern hemisphere (Fig. 13). For example, holothuroid sclerites, *Thalattocanthus consonus* and *Microantyx botoni* are identified as species-levels from the limestone. *Thalattocanthus consonus* has been reported from the Carboniferous-Permian of Oklahoma, Texas, Montana and Missouri of North America (Carini, 1962; Gutschick et al., 1967; Wernlund, 1977), and Paleo-Tethyan reagion such as Bulgaria of Eastern Europe (Stefanov, 1970), Afghanistan (Mostler, 1971), South China (Hui, 1985) and Japan (Kanasugi, 1979). *Microantyx botoni* also from Indiana, Montana and Missouri of North America (Gutschick, 1959; Gustchick et al. 1967), Poland of Eastern Europe (Alexandrovsdcz, 1971), Afghanistan (Mostler, 1971), Iran (Nabavi and Hambi; Mostler and Rahimi-Yazd, 1976), South China (Hui, 1985). Both species are common in low-mid latitudinal area in the northern hemisphere.

Obtained ostracods are mostly cosmopolitan genera except for a few genera such as *Deloia, Spinomicrocheilinella* and *Kellettina*. Genus *Deloia* has been reported only from the Carboniferous of following North American regions as Arkansas, Ohio, Oklahoma and Texas (Croneis and Thurman, 1939; Elias, 1958; Hoare, 1993; Hoare and Mapes, 2000). *Spinomicrocheilinella* from the Permian–Triassic of Italy (Kozur, 1991), Carnic Alps (Mette et al., 2015) and South China (Yuan et al., 2007; Yuan et al., 2009). *Kellettina* from the Upper Carboniferous to Permian of Ohio, Missouri and Texas of North America (Hoare et al., 1994; Knight, 1928; Kellett, 1933; Hamilton, 1942; Christipher et al., 1990), Italy (Kozur, 1991), Carnic Alps (Foher et al. 2005), South China (Yuan et al., 2007) and Japan (Ishizaki, 1967; Tanaka, 2012).

Previous studies of fossil corals and brachiopods indicated the faunal commonality between the Omi and the low-middle latitude of Tethyian regions (Tazawa et al., 2004; Yoshidaet al., 1992). Addition to the these fossils, holothuroids and ostracods of this study reveals that benthic Omi fauna has similarity especially North America and South China.

Tozer (1982) studied Triassic marine fossils within multiple taxa and noticed the similarities of fossil fauna between North America and the Tethys regions. Due to the explanations of such facts, he presented “Stepping stones” idea for dispersal of fossil faunas. Actually, approximately 80 % of modern benthic animals have planktonic larval periods (Thorson, 1964), and Briggs (1987) indicated “Stepping stone” radiation beyond the eastern pacific barrier for modern trans-pacific species using sea mounts as stepping stones. Miller and Wright (1987) used the idea for accounting the faunal similarities between Permian Tethyan corals and the same taxa distributed in California. Additionally, Stanley (1994) introduced the idea and showed the hypothetical oceanic currents and trade winds within the Late Paleozoic paleogeography. I am paying attention to the “Stepping stones” idea for the origin of fossil fauna in the Omi Limestone because this idea is superior in emphasizing chance of dispersal with in the biogeographic settings of atolls- interspersed Panthalassa. Additionally, the modern oceanic currents help dispersal of reef-living organism (e.g. Scheltema, 1971; Concepcion et al., 2016). The "Stepping stones" idea permits reef organisms to easily bridge the barriers of deep ocean waters by the atolls serving as stepping stones. But there is a practical problem that the fossil records and pleogeographic evidences of atolls could be destroyed by sea floor consumptions at convergent margins (Stanely, 1994). Therefore, the idea still lacks enough records and evidences of atolls.

Most of the modern benthic organisms have planktonic larval stage (Thorson, 1964). The planktonic periods of each taxa are not well known, but breeding experiments of holothuroids suggests the floating time of the group spans 1 day to several weeks (e.g. Minami, 2011). One of the fastest ocean current Kuroshio records at most 180km/ day by the data of Japan Meteological Agency. The paleocontinents was mostly assemblage in to the supercontinent Pangea in the Carboniferous time forming the vast Panthalassa Ocean. The trans-Panthalassa time is too long for the planktonic larval stage of at least holothuroids even with the fastest ocean current. Therefore, trans- Panthalassa species need relay points in the ocean, and common fauna between the mid-Panthalassa area of the Omi Limestone and continental regeions suggested the possibility of the "Stepping stone". Actually, the oldest record of *M. botani* was from Early Carboniferous of North America, and record of this species from the Omi Limestone the middle Carboniferous. The report of this species in South China spanned the Late Carboniferous time. The results of my study also implies the "Stepping stones" idea for dispersal of fossil faunas in the Paleozoic time. In other words, this dispersal strategy of marine animals was completed at the age of the Carboniferous.

5. 5 Is rich microbiota common in the middle Carboniferous Akiyoshi Terrane? or not?

This study reveals that the microbiota of the middle Carboniferous Omi Limestone, and multiple taxa such as ostracods, holothuroids, actinopterygians, chondrichthyans, ophiuroids, chitinozoans are newly reported here. This thought-provoking result may imply that the seamounts located in the real pelagic ocean may have built richer marine ecosystem in the middle Carboniferous time than we thought. I formulate a hypothesis that the entire part of Akiyoshi Terrane, not only Omi Limestone, embraces rich microbiotas as the middle Carboniferous Omi Limestone. For proving the idea, I study the middle Carboniferous Maruyama Mine of the Akiyoshi Limestone to obtain microfossils. In this part I briefly review the geological background of the Maruyama Mine in the Chapter 5.5.1 and obtained microfossils from the mine and their implications are explained in the Chapter 5.5.2.

5.5.1 Brief outline of studied section of Maruyama Mine.

The Maruyama Mine of Ube Industry is located in the southern margin of the Akiyoshi Limestone, Mine City, Yamaguchi Prefecture. Due to the mining, the Lower Carboniferous limestone was lost, and the middle Carboniferous part is cropping out now (Hashimoto, 2014). The lithology of the limestone is composed of bryozoan-crinoid biospartite and shell-crinoid biosparudite (Nishida and Kyuma, 1982). Based on the lithologies, they suggested the fore reef environment. In the mine, well-preserved crinoids, blastoids, and annmonoids have been pewviously described (e.g. Hashimoto and Takahshi, 2009; Takahashi et al., 2008; Nishida et al., 2013).

I study northern face of the mine and collect limestone samples. The section is dominated by the white to gray massive limestone overlying the black lime-mudstone layer (Fig.14). Under the observations of thin-sections and polished surfaces, the limestone section is occupied by the stylobreccia, bioclastic grainstone and cement-rich rudstone (Fig. 15, 16). The stylobreccia includes conglomerate consisted of bioclastic grainstone-rudstone. The bioclastic grainstone-rudstone correspond to bryozoan-crinoid biospartite of Nishida and Kyuma (1982) and the cement-rich rudstone is correlated to shell-crinoid biosparudite of their study. Fore-reef environment was recovered by them, and my observations are consistent with their result.

5.4.2 Microfossils from the Maruyama Mine and their implications.

The middle Moscovian conodonts such as *Hindeodus cristulus*, *H.* aff. *cristulus*, *H. minutus, Idiognathodus covadongae, Idiognathoides sulcatus, Diplognathodus? orphanus* are obtained. Addition to them, fish remains such as actinopterygii indet. A, B, actinopterygian scale and chondrichthyan scales, holothurian sclerites as *Microantyx botoni* and *Eocaudina subhexagona,* ophiuroid sclerites as *Furcaster* sp., chitinozoan fossil prosomatifera indet. C and microproblematica G yield. Due to the occurrence of *I. covadongae*, this middle Moscovian conodont is a younger than the reported conodonts characterized by the occurrence of *Idiognathodus delicatus* by Igo (1974) from the southern margin of the Yobara Plateau in the Akiyoshi Limestone. Associated other microfossils are across the board new reports from the Akiyoshi Limestone. These new discoveries suggest that more diverse microbiota existed in the reef of the middle Carboniferus Akiyoshi Limestone. As I previously mentioned, the middle Carboniferous Omi Limestone embraced rich microbiota and the discovery implies these microbiotas were common in the Akiyoshi Terrane, located at the center of the Panthalassa Ocean in the middle Carboniferous time. Kobayashi (1988) studied the Permian foraminifers of the Omi Limestone and obtained species are almost identical in species-level with those of Akiyoshi Terrane limestone. Addition to this, some studies represent similarity of fossil faunas. For instance, *Brachymetopus* is distinctive trilobite genus in the Akiyoshi Terrane limestones, the Early Carboniferous brachiopod faunas in the Akiyoshi Terrane limestones are quite similar (Kobayashi and Hamada, 1979; Ibaraki et al., 2014).

Tanaka et al. (2012) suggested the existence of the Panthalassa bio-province by the occurrence of many new species of ostracods from the lower Permian of Mugi, Mino Terrane. In the Carboniferous time, the specific existence of Panthalassa bio-province was well not understood, but Niko (2001) reported the orthoconic cephalopods and pointed out the Omi Limestone belongs to the Taishaku-Akiyoshi-South China Province. Far eastern Carboniferous orthocerids and bactritids have shown that two isolated faunal provinces were present through the period; Taishaku-Akiyoshi-South China province characterized by *Bogoslovskya* and *Bactrites* lineage and southern Kitakami- Fukuji Province characterized by *Adnatoceras* lineage (Niko, 2000). Furthermore, the faunal similarity of Pseudopavonid corals between the Akiyoshi Terrane limestones and South China was recognized from 1970's (Kato and Minato, 1975). Tabulate coral genus *Donetzites* has been reported from the Carboniferous Palaeo-Tethysian regions and Akiyoshi Terrane such as Donetz Basin, Vietnam, North and South China and the Hina and Omi Limestone (Dampel, 1940; Dubatolov and Tong-dzuy, 1965; Lin, 1985; Wu and Zhao, 1974; Niko, 1999; Niko et al. 2010). The earliest representative *Donetzites miyakei* was described from the late Visean of the Omi Limestone (Niko et al. 2010), and they indicated the origin of the genus in the central Panthalassa and western expansion to the continental regions. The microfossil fauna of the Omi and Akiyoshi Limestone of this study also supports the idea of Taishaku-Akiyoshi- South China province.

5.6 First Conodont fossils from the Carboniferous Tsuchikurazawa Limestone, Itoigawa City, Niigata Prefecture

Itoigawa City has two types of Paleozoic limestone as whitish Omi Limestone and blackish Tsuchikurazawa Limestone. The former is previously summarized in detail in this study. The latter is an exotic limestone block within a Permian accretionary complex, distributed in and around Tsuchikurazawa Valley, Itoigawa City, Niigata Prefecture (Takenouchi, 2005). The limestone may have preserved biofauna of the Carboniferous continental margin (e.g. Niko and Ibaraki, 2011), and I discovered first conodont fossils from the limestone. The limestone consists of wackestone with dark gray-black color (Niko and Yamagiwa, 1998; also see Pl. 15 in this study). The age of the limestone is provided to the late Visean-Serpukhovian based on the fossil faunas such as smaller foraminifers (Nakzawa et al. 1998), corals (Kamiya and Niko; Niko and Yamagiwa, 1998), brachiopods (Tazawa et al. 2004; Ibaraki et al. 2008, 2010; Ibaraki and Saito, 2013). This limestone also yielded sufficient fossils as oldest shark tooth *Petalodus* sp. in Japan, and first record of cyclid crustacean *Cyclus tazawai* in the East Asia (Niko and Ibaraki, 2011). Unfortunately, the outcrops of the limestone have been already disappeared due to the mining. A bit of remaining limestone blocks are deposited in FMM, Y. Ibaraki, a curator of the museum, kindly provide some limestone samples to me. I found conodont fossils by the acid treatment and give a description of it here.

Adetognathus lautus and fragment of M? element are obtained by the acid treatment of more than 5 kg of limestone blocks (Pl. 15). *A. lautus* is a long ranged species reported from the middle Carboniferous to lower Permian of North America, Eastern Europe and Russia (Nemirovskaya, 1999). The occurrence of the species suggests the age corresponds to the Sepukhovian as previous works. This species has never been reported from the Carboniferous Akiyoshi Terrane limestones. Further conodont discoveirs may give us the faunal differences by paleogeographic distributions.

6. Conclusion

Totally 77 species of microfossils belonging to 12 classes of 6 phylum are described in this study. They are composed of Conodonta, Ostracoda, Actinopterygii and Chondrichthyes, Mollusca, Echinodermata, Porifera, Chitinozoa and "Microproblematica". Based on these microfossils and accumulated fossil data by reviewing publishes and museum surveys, I reconstruct the Carboniferous pelagic reef ecosystem and establish four conodont biozones. Addition to them, following implications are obtained: benthic microfossils such as holothuroids and ostracods suggests the middle latitudinal paleogeography of the Omi atoll, and "Stepping stone" idea may be eligible for explaining the origin of the biota of the Omi Limestone. The "stepping stone" may have played an important role for animal radiations from the Carboniferous to present. The Carboniferous is the recovery phase from the Late Devonian mass extinction, and the middle Carboniferous reef recovery of the Omi Limestone was confirmed by the development of reef building organisms by previous works. This study implies that complicated three-dimensional landscapes of the middle Carboniferous reef contribute to high diversity of microfossil faunas, and it indicates the middle Carboniferous reef recovery from a different angle.

Considering the microfossils from the middle Carboniferous Akiyoshi Limestone, the entire Akiyoshi Terrane which was located at the center of the Panthalassa Ocean has diverse microfossil faunas in the middle Carboniferous age. It suggests that mid- oceanic atolls have played roles for important animal habitat from the Carboniferous to present.

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8. Systematic Paleontology

In this chapter, 77 species belonging to 6 phyla 12 classes are described. This chapter is composed of following subchapters; 8.1 Conodonta, 8.2 Ostracoda, 8.3 Chordata, 8.4 Mollusca, 8.5 Echinodermata, 8.6 Porifera, 8.7 Chitinozoa and 8.8 Microproblematica. These described collections are deposited in the Earth Evolutionary Science, University of Tsukuba without registered numbers.

8.1 Phylum Conodonta

Conodonts are minute fossils resembling spines, combs or teeth of the Cambrian to Triassic age. They are formed of calcium phosphate like vertebrate teeth, scales and bones. This characteristic makes them earliest representatives of mineralized, vertebrate-like skeletal structures (Donoghue et al., 2000). Generally, the affinity of them is thought to be earliest jawless fish after discovery of conodont-bearing animals (Briggs et al. 1983). The conodont elements have been widely used for dating marine sedimentary rocks. Here, totally 31 species of 10 genera belonging to 6 families of the middle Carboniferous conodonts are described.

Class Conodonti Branson and Mehl, 1938

Order Ozarkodinida Dzik, 1976

Family Anchignathodontidae Clark, 1972

Genus *Hindeodus* Rexroad and Furnish, 1964

***Type species*—** *Spathognathodus cristula* Youngquist and Miller, 1949.

Remarks — The genus is originally derived from Sa element *Trichonodella imperfecta* Rexroad, 1957 of apparatus including Pa element of *Spathognathodus cristula*. Hence, the latter has priority as the type species of multielement of *Hindeodus*. The P1 element of the genus commonly bears a prominent and huge cusp in the anterior end of the blade. The blade continues posteriorly as a denticulated carina to tip of the platform. The sub-triangular to elliptical platform occupies more than half-length of the element.

Hindeodus cristulus (Youngquist and Miller, 1949)

Fig. 17. 1

Spathognathodus cristula: Youngquist and Miller (1949): p. 621, pl. 101, figs. 1–3; Rexroad and Burton (1961): p. 1156, pl. 141, fig. 9; Rexroad and Furnish (1964): p. 674, pl. 111, fig. 15; Globensky (1967): p. 447, pl. 57, figs. 15, 16.

Hindeodus cristula: Plint and von Bitter (1986): p. 358, 359, pl. 2, fig. 9; pl. 3, figs. 11, 15, 16; Rexroad and Horowitz (1990): p. 502–504, pl. 1, figs. 21–42; Stone (1991): p. 12, 13, pl. 1, figs. 1, 2, 5, 8; Somerville and Somerville (1999): pl. 4, figs. 6–14; Abplanalp et al. (2009): p. 95, fig. 7, 1–4.

Hindeodus cristulus: von Bitter and Plint- Geberl (1982): p. 207, pl. 4, figs. 17, 18; Skompski (1996): pl. 5, fig. 15; Nemyrovska et al. (2006): pl.6, fig. 1-3, 5; Habibi et al. (2008): p. 769, fig. 4. 3; Qi et al. (2014): p. 259, fig. 4e.

Referred Specimen —Five P_1 elements: 2 from AI-1 and AI-4, 1 from AI-2.

Description — P_1 element is characterized by a robust triangular cusp in lateral view, at the most anterior part of the blade. The cusp is much larger than denticles. The denticles are more inclined to the posterior margin of the element. The posterior margin is rounded to slightly acute. The element has relatively wide basal cavity occupying poster two-thirds of the element.

Remarks — This species is similar to *H. scitulus* (Hinde, 1900), but the former is more elongate element. *H. scitulus* is characterized by sharp flexure about midpoint along its length. *Hindeodus cristulus* is also reported from the Lower Carboniferous of North America, Canada and Europe. This species is associated with the Moscovian index conodont *Idiognathodus covadongae* in the Akiyoshi Limestone.

Occurrence —Moscovian from the Akiyoshi Limestone in the Maruyama Area.

Hindeodus* aff. *cristulus

Fig. 17. 2, 3.

Referred Specimen — One juvenile and one mature P_1 element from AI-2

Description — The prominent cusp projects anteriorly, and the projection of a mature element is larger and greatly exceeds the basal margin of the platform. The cusp is much larger than denticles. The denticles decrease and are more inclined to the posterior margin of the element. The posterior margin is slightly acute. The basal cavity occupies almost entire length of the platform.

Remarks — This species is different from other *Hindeodus* spcies by a combination of the largely projected cusp and wide basal cavity. *H. cristulus* and *H. minutus* are reported from the Maruyama Mine. The former is similar to *H*. aff. *cristulus* to some extent, but the latter having a few small denticles in front of the cusp is a quite different from *H*. aff. *cristulus*. This species may be a new affinity of *H. cristulus.* I tentatively identify the conodont as *H*. aff. *cristulus* here.

Occurrence — Moscovian from the Akiyoshi Limestone in the Maruyama Area.

Hindeodus minutus (Ellison, 1941)

Fig. 17. 4-6

Spathodus minutus: Ellison (1941): p. 120, pl. 20, figs.50–52

Spathognathedus minutus: Youngquist and Downs (1949): p. 169, pl, 30, fig. 4; Sturgeon and Youngquist (1949): p. 385, pl. 74, figs. 9–11; Rexroad and Burton (1961): p. 1156, pl. 141, figs. 10, 11; Hass (1962): p, 209, pl. 34, fig.36; Murray and Chronie (1965): p. 606, pl. 72, figs. 29, 30; Igo and Koike (1965), p. 88, pl. 9, figs.16–18; Dunn (1965): p. 1149, pl. 140, figs.15, 21, 24;

Koike (1967): p. 311, pl. 3, figs.39–42; Webster (1969): p. 44, pl. 7, fig. 4; Dunn (1970): p. 339, pl. 61, figs. 27, 30; Merrill (1973): p. 305, pl. 1, figs.1–14; pl. 2, figs.1–28; Lane and Straka (1974): p. 101, fig. 44. 7, 44. 12; Spassov (1976): p. 135, pl. 2, fig.1.

Spathognathedus cfr. *S. minutus*: Huckriede (1958), p. 162, pl. 10, fig. 8 ; Rhodes (1963), p. 408, pl. 47, fig.3

Anchignathodus minutus: von Bitter (1972): p. 65 , pl. 6, fig. 2a–i; Sweet in Ziegler (1973): p. 15–17, Anchignathodus-pl. 1, fig. 2a, b; Behnken (1975): p. 297, pl. 1, figs.16–18; Kozur (1975): p. 5–7, pl.1, figs. 1–16; Kozur et al. (1975): p. 3, pl.1, figs. 2, 3, 5, 7- 11; pl. 2, figs. 1, 3, 5, 7- 9, pl. 7, figs. 2, 10; Kozur (1977): p. 1118, pl. 1, figs. 1–16; Tynan (1980): p. 1300, pl. 2, figs. 8, 9; Wang and Wang (1981): p. 229, pl. 2, figs. 6, 7; Wang and Dai (1981): pl. 1, figs.3, 4; Igo (1981): p. 26, pl. 10, figs. 5, 8, 11; Zhao et al. (1984): p. 114, pl. 28, figs. 21, 22, 24, 26, 28; Tian (1983): p. 338, pl. 77, fig. 4; Wang and Li (1984): pl. 2, figs. 9, 16, 17.

Anchignathodus minutus permicus: Igo (1981): p. 26, pl. 10, figs.1– 4.

*Anchignathodus typicali*s: Sweet (1970a): p. 7, pl. 1, figs. 13, 22; Sweet (1970b): p. 222, pl. 1, figs.13, 20; Sweet et al. (1971): pl. 1, fig. 34; Behnken (1975): p. 297, 298, pl. 2, fig, 12; Sweet (1976): p. 52, pl. 16, figs,6–8, 9?; Wang (1978): p. 215, pl. 1, figs.26–28; Tian (1983): pl. 77, fig. 9, pl. 79, fig. 4; Zhao et al. (1984): p. 114, pl. 28, figs.18–20, 23, 27, 29, 31.

Hindeodus minutus: Matsuda (1981): p. 80–84, pl. 1, figs, 1–13; Savage and Barkeley (1985): p. 1472, figs. 12.1–12.8; Wang and Higgins (1989): p. 279, pl. 13, figs. 6, 7; Wang (1991): p. 23, pl. 3, fig. 1; Fohrer et al. (2007): p. 20, fig. 15, 16; Nemyrovska (2011): p. 497, pl. 2 fig. 3; Brown et al. (2013): p. 114, pl. 1, fig. 12; Scomazzon et al. (2016): p. 35, fig. 15- 18; Hu et al. (2017): p. 15, fig. 8o.

Referred Specimen — Six P_1 elements: 2 from AI-2, 1 from AI-4, M-8, M-9, Mk2-15.

Description — P1 element is characterized by a large cusp with a few small denticles in front of it, situated the most anterior part of the blade. The cusp is much larger than denticles which are almost same in size. The posterior margin slightly acute. The element has relatively wide basal cavity occupying poster two-thirds of the entire length.

Remarks — The presence of the small 1-3 denticles on the anterior bar is a typical feature of this species. This species is a long-ranged conodont, reported from the Upper Carboniferous-Lower Triassic of North America, Europe, Russia, Central Asia, South China and Japan.

Occurrence —Bashkirian–Moscovian from the Omi Limestone in the Fukugakuchi, Akiyoshi Limestone in the Maruyama area.

Family Cavusgnathidae

Genus *Adetognathus* (Gunnell, 1933)

Type species— *Cavusgnathus lautus* Gunnell, 1933.

Remarks — This genus has quite deep median trough between two parapets, and it continues to posterior tip of platform. These parapets ornamented by nodes or ridges occupy the entire length on the lanceolate and slightly incurved platform. The short blade, which is slightly fixed or not, joins the outer parapet. *Adetognathu*s differs from the ancestral, very similar genus *Cavusgnathus* by the longer free blade and a shorter fixed one.

Adetognathus lautus (Gunnell, 1933)

Fig. 31.1

Adetognathus giganta: Lane (1967): p. 931, p1. 120, figs, 16, 18, 19, pl. 121, figs. 8, 12, 13, 16.

Adetognathus gigantus: Dunn (1970): p. 326, P1. 61, figs. 2, 3.

Adetognathus lauta: Lane (1967): p. 933, p1. 121, figs. 1–3, 7, 10, 11, 15, 17

Adetognathus lautus: Dunn (1970): p. 327, p1. 61, figs. 1, 4; von Bitter (1972): pl. 5, fig. 1–3; lane and Straka (1974): fig. 36, 17, 21, 22, 25–31, fig. 38: 1–4, 6–8, 10–15, 20, fig. 39: 1–3, 7–14; Perlmutter (1975): p. 101, pl. 3, figs. 34–39, 42–45; Bender (1980): p. 8, pl. 4, figs. 26–33; Grayson (1984): pl. 2, fig. 6, pl. 3, figs. 8, 9, 26, 27; Nemirovskaya and Alekseev (1994): p. 128, pl. 2, figs. 6; Nemirovskaya (1999): pl. 1, fig. 4; Brown et al. (2013): p. 114, pl. 1, fig. 6; Scomazzon et al. (2016): p. 32, 35, fig.7. A, fig. 10. 10, 10. 11

Cavusgnathus flexa: Ellison (1941): p. 126, p1. 21, figs. 42, 43, 46.

Cavusgnathus gigantus: Gunnell (1933): p. 286, p1. 33, figs, 7, 8; Webster (1969): P1. 4, figs. 6.

Cavusgnathus giganta: Ellison (1941): p. 126, p1. 21, figs. 44, 45, 49; Ellison and Graves (1941): p1. 3, fig. 3; Youngquist and Downs (1949): p. 162, p1. 30, figs. 18–20; McLaughlin (1952) p. 620, P1. 83, figs. 3, 4, 6, 7.

Cavusgnathus missouriensis: Gunnell (1933): p. 286, p1. 33, figs, 10, 11.

Cavusgnathus lauta: Ellison (1941): p. 126, p1. 21, figs, 47, 48.

Cavusgnathus lautus: Gunnell (1933): p. 286, p1. 31, figs. 67, 68, p1. 33, fig. 9; Webster (1969): p. 28, Pl. 4, fig. 9a, 9b.

Cavusgnathus regularis: Stibane (1967): p. 333, taf. 35, figs. 8–11, 14- 16.

Cavusgnathus unicornis: Stibane (1967): p. 333, taf. 35, figs. 1–3, 5.

Referred Specimen — One P_1 element from the Tsuchikurazawa limestone.

Description — The lanceolate platform of sinistral P_1 element occupies two-thirds of entire length of the element. The deep and long median trough is the deepest at the anterior part. The parapets are ornamented by faint ridges. The platform has flanges in the both inner and outer basal parts. The denticles on the blade is almost equal in size, but a lager one may occur at the junction point.

Remarks — Sinistral *Ad. lautus* and dextral *Ad. gigantus* (Gunnell, 1933) are assigned to paired species (Lane, 1967). Later, Nemirovskaya (1999) separated these species. *Ad. lautus* differs from its pair *Ad. gigantus* by lacking the fixed blade. This is a long-ranged species reported from the middle Carboniferous to Lower Permian of North America, Eastern Europe and Russia (e.g. Nemirovskaya, 1999). This is the first conodont from the Tsuchikurazawa Limestone.

Occurrence —Sepukhovian from the Tsuchikurazawa Limestone.

Family Gondolellidae Lindström, 1970

Genus *Mesogondolella* Kozur, 1989

Type species— *Gondolella bisselli* Clark and Behnken, 1971.

Remarks — The P1 element has broad smooth platform with rounded posterior edge. All species of *Gondolella* known from Pennsylvanian unexceptionally carry distinctive transverse ridges on the surface of the platform, thus it is easy to distinguish the genus from other gondolellids. This genus was established for Lower Permian gondolellids with smooth platform by Kozur (1988). These species had once belonged to *Neogondolella*, but He pointed that difference of lower profiles of them and the Triassic species were assigned to *Neogondolella*. Later, smooth surfaced gondolellids of the Late Carboniferous and Permian is subdivided into two genera, *Mesogondolella* for the Late Carboniferous-early Late Permian and *Clarkina* for the Late Permian.

Mesogondolella clarki Koike, 1967

Fig. 17. 7, 8

Gondolella clarki: Koike (1967): p. 321, pl. 2 figs. 1–6; Ishida et al. (2013): p. 44, pl. 2, figs. 29, 30

Mesogondolella clarki: Wang and Qi (2003): p. 393, pl. 3, figs. 24–26; Nemyrovska (2011):pl.1 fig, 16; Qi et al. (2014): p. 320, fig. 7, i, j; Qi et al. (2016): p. 8, fig. 7, Q

Neogondolella clarki: von Bitter and Merrill (1977): fig.1; Manger and Sutherland (1984): pl. 1, figs. 5, 6; Orchard and Struik (1985): p. 550, pl. 2, figs. 23, 30; Igo (1985): p. 262, pl. 8. 3, figs. 8, 9; Sada et al. (1985): pl. 1, figs. 22, 23; Grayson et al. (1985): pl. 1, fig. 30; Wang and Higgins (1989): p. 283, pl. 7, figs, 6–10; Wang (1991): p. 26, pl. 2, fig. 2; Cui and Yu (1994): p. 36, pl. 1, figs. 14–19; Méndez (2012): p. 67, fig. 4, k, l; Qi et al. (2013): p. 320, fig. 7, i, j

Referred Specimen — Six juvenile and four mature P1 elements: 5 from Mk2-15. 1 from Mk2-17, NR-26. 3 from Mk2-19.

Description — The sub-symmetrical and slightly arched element bears broad platform which is rounded at posterior and tapers towards anterior. The surface of the platform is smooth. The carina is occupied by nodes-like denticles except for some anterior blade-like ones. The denticles of posterior end is more conspicuous and the small basal pit is situated beneath the largest denticle at the posterior end. The narrow basal keel continues from the pit to the anterior end.

Remarks — This species resembles to *M. subclarki* Wang and Qi (2003), but latter has broader brim between cusp and posterior edge. The occurrence of this species is the index of the Moscovian Stage in Japan (e.g. Koike, 1967; Ishida et al., 2013). But the FAD of *Mesogondolella* is higher than the traditional Bashkirian–Moscovian boundary which is provided by the occurrence of two species *Diplognathodus ellesmerensis* Bender (1980) and *Declinognathodus donetzianus* Nemirovskaya (1990).

Occurrence —Moscovian from the Omi Limestone in the Fukugakuchi and Nishiyama area.

Family Idiognathodontidae Harris and Hollingsworth, 1933

Genus *Declinognathodus* Dunn, 1966

Type species— *Gnathodus noduliferus* Ellison and Graves, 1941.

Remarks — The P1 element has an elongate, narrow and oval platform which pointed posterior end. The carina inclines outwardly and usually. The outer and inner parapets are nodular or ridged and parallel to each other. The shallow median groove is situated between these parapets. The genus was first assigned to *Idiognathoides,* and Dunn (1966) differentiated *Declinognathodus* from that genus by the presence of rostral isolated node/s. This genus is the oldest example of Idiognathodontidae.

Declinognathodus noduliferus (Ellison and Graves, 1941)

Fig. 18. 2–5

Cavusgnathus nodulifera: Ellison and Graves (1941): p. 4, pl. 3, fig. 4; Koike (1967): p. 297, pl. 3, fig. 10.

Declinognathodus inaequalis: Riley et al. (1987): pl. 3, figs. 28–40; Kulagina et al. (1992): pl. 30, figs. 5, 6, 11.

Declinognathodus japonicus: Kulagina et al. (1992): pl. 30, figs. 12–15, 17.

Declinognathodus nevadensis: Dunn (1966): p. 1300, pl. 158, figs. 4, 8.

Declinognathodus noduliferus: Dunn (1970): p. 330, pl. 62, fig. 1, 2; Park (1983), p. 63, pl. 5, figs. 1–3; Grayson et al. (1985): p. 163, pl. 1, figs. 1, 5 ,10; Lane et al. (1985): figs. 7. 0, E, F, G; Riley et al. (1987): pl. 3, figs. 41–47; Grayson et al. (1990), p. 363, pl. 1, figs. 21, 22; Kulagina et al. (1992): pl. 30, figs. 2–4, 7–10; Nigmadganov and Nemirovskaya (1992), pl. 3, figs. 6–14, 16–17;

Nemirovskaya and Alekseev (1993), pl. 3, figs. 4, 12; Nemirovskaya and Alekseev (1994), pl. 1, figs. 2–4, 7; Brenckle et al. (1997), pl. 1, figs. 2–4; Nemyrovska et al. (2011): p. 183, pl. 4, figs. 21, 22; Kulagina et al. (2014): p. 279, fig. 5, 1–4; Bahrami et al. (2014); p. 195, fig.7, 14–22; Sanz-Lopez and Blanco-Ferrera (2015): p. 8, fig.7, A–F.

Declinognathodus noduliferus inaequalis: Higgins (1975), p. 53, pl. 12, figs. 1–7, 12, pl. 14, figs. 11–13, pl. 15, figs. 10, 14; Méndez and Menéndez-Álvarez (1981), pl. 1, fig. 1; Nemirovskaya (1983), pl. 1, fig. 27; Higgins (1985), pl. 6.2, figs. 11, 12, 14, pl. 6.3, figs. 1, 4; Nemirovskaya (1987), pl. 1, figs. 6, 13, 14, 19; Wang et al. (1987a): p. 126, pl. 3, figs. 1, 2, pl. 6, fig. 10 ;Wang et al., (1987b): pl. 2, fig. 1 ; Wang and Higgins (1989), p. 276, pl. 13, figs. 5, 12; Nemirovskaya et al. (1990), pl. 4, figs. 3–18, 20–22, 24–28; Fallon and Murphy (2015): p. 1035, fig. 7. b, c, fig. 9, a, b.

Declinognathodus noduliferus japonicus: Higgins (1975), p. 54, p. 14, figs. 7–10; Metcalfe (1980): p.306, pl. 38, figs. 14, 17; Higgins (1985): pl. 6. 3, figs. 2, 9; Nemirovskaya (1987): pl. 1, figs. 12, 15, 19; Wang and Higgins (1989): p.276, pl. 1, figs. 6–9.

Declinognathodus noduliferus noduliferus: Higgins (1975): p. 53, 54, pl. 12, 1–7, 12, pl. 14, fig. 11–13; Metcalfe (1980), p. 306, pl. 38, figs. 10–12, 15; Méndez and Menéndez-Álvarez (1981), pl. 1, fig. 2; Nemirovskaya (1983), pl. 1, fig. 28; Higgins (1985): pl. 6.2, fig. 13, pl. 6.3, fig. 7; Li et al. (1987): pl. 1, fig. 1; Nemirovskaya (1987), pl. 16, figs. 7, 9, 11, 20, 21; Wang et al. (1987a): p.127, pl. 3, figs. 3–5, pl 7, fig. 1; Wang et al. (1987b): pl. 1, figs. 4, 5, 8; Wang and Higgins (1989), p. 276, pl. 2, figs. 5–9; Boncheva et al. (2007): p.344, 347, pl. 2 figs. 1, 2, 5, 11, 14.

Gnathodus japonicus: Higgins and Bouckaert (1968): p. 35, pl. 4, figs. 1, 2, 4.

Gnathodus nodulifera: Koike (1967): p.297, 298, pl. 3, figs. 9–12.

Gnathodus noduliferus: Higgins and Bouckaert (1968): p. 33, pl. 2, figs. 6, 12.

Idionathoides noduliferus: Igo and Koike (1968): p. 28, 29, pl. 3, figs. 7–11; Thompson (1970): p.1046, pl. 139, figs. 2, 3, 5, 6, 8, 16, 20; Lane and Straka (1974): p. 85–87, fig. 35, 1–15, fig. 41, 15–17.

Idionathoides noduliferus noduliferus: Higgins (1975): p. 54, pl. 14, figs. 15, 16; Metcalfe (1980): p. 306, pl. 38, figs. 16, 18.

Idionathoides aff. *noduliferus*: Lane (1967): p.938, pl. 123, figs. 9–11, 13, 16, 17.

Streptognathodus japonicas: Igo and Koike (1964): p. 188, pl. 28, figs. 5–23.

Streptognathodus noduliferus: Webster (1969): p. 48, pl. 4, fig. 7, 8.

Referred Specimen — Twenty two P_1 elements: 1 from MF-1, M-4, 14, 20, Mk-33, NG-5, 6, NR-12. 2 from MF-4, M-2, M-1, M-18, N210-3. 3 from a float in the Omi Riv. 4 from N210-4.

Description — P_1 elements has a slender lanceolate platform with pointed posterior end. The platform occupying more than half of the element is ornamented by nodular parallel parapets and carina. The carina is relatively short, inclines outwardly and merges with outer parapet. It forms isolate several nodes at the anterior part of the merging point. The median groove is shallow and continues to the posterior tip.

Remarks —*D. noduliferous* is consists of three subspecies (Nemirovskaya, 2011), *D. nod. inaequalis* (Higgins, 1975) has the longest carina, which merges with the outer parapet behind the middle of the platform or close to the posterior end of this element. *D. nod. noduliferus* (Ellison and Graves, 1941), is characterized by a shorter carina that slopes and merges with the parapet in the middle of the platform or even closer to the anterior end of the platform. *D. nod. japonicus* (Igo and Koike, 1964) possesses a very short carina and a strongly reduced outer parapet, up to one node at the anterior end of the platform. *D. noduliferous* is similar to *D. bernesgae* (Sanz-López et al., 2006), but the latter has mostly ridged parapets. *D. noduliferous* is the index of the Mid- Carboniferous boundary (Lane, 1990).

Occurrence — Bashkirian from the Omi Limestone in the Fukugakuchi and Nishiyama area and a float from the Omi River.

Declinognathodus praenoduliferus Nigmadganov and Nemirovskaya, 1992

Fig. 18. 1

Declinognathodus lateralis: Varker (1994): pl. 3, fig.5

Declinognathodus praenoduliferus: Nigmadganov and Nemirovskay (1992): p. 53, pl. 7, figs. 1, 2, 3–6, 8, 9; Sanz-López et al. (2006), pl. 1, fig. 7; Nemyrovska et al. (2008): pl. 2, figs. 1, 5; Nemyrovska et al. (2011): p. 183, pl. 4, figs. 1-3, 5, 9-11, 15, 18, 20; Kulagina et al. (2014): p. 279, fig. 5, 5, 6; Sanz-López and Blanco-Ferrera (2013): p. 7, fig.5, P–S; Bahrami et al. (2014); p. 195, fig.7, 23–25

Referred Specimen — One P_1 element: 1 from the MF-1.

Description — P_1 element has a transverse-ridged slender platform with pointed posterior end. The carina is almost straight or laterally sloping to the outer side of the element, which forms an isolate node located at the anterior part of the platform. The short median groove is present only at the anterior end of the platform.

Remarks — *Declinognathodus praenoduliferus* is distinguished from *D. noduliferus* by its transversely-ridged platform and the lack of a long medial trough. This species is similar to *D. bernesgae* Sanz-López et al. (2006), but *D. bernesgae* has a long medial trough and only the most posterior part of the platform is covered by some transverse ridges. This species is reported from lowermost Bashkirian of south Tienshan (Uzbekistan), the Urals (Russia) and the Cantabrian Mountains (Spain).

Occurrence —Fukugakuchi (Bashkirian)

Declinognathodus sp. A

Fig. 18. 6

Referred Specimen — One P_1 element from a float in the Omi Riv.

Description — P_1 elements has a slender lanceolate platform with pointed posterior end. The platform is ornamented by nodular parallel parapets and carina. The carina is relatively short, inclines outwardly and merges with outer parapet at the anterior one-third. It forms isolate several nodes at the anterior part of the merging point. The median groove is shallow and continues to the posterior tip. Additional low of small nodes is located inner part of the element.

Remarks — *Declinognathodus* sp. A resembles to *D. noduliferus*, but it is distinguished from the latter by the presence of additional nodes in its inner part. This character also distinguishes this species from other *Declinognathodus* species.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Declinognathodus sp. B

Fig. 18. 7

Referred Specimen — One P_1 element from a float in the Omi Riv.

Description — P_1 elements has a slender lanceolate platform with pointed posterior end. The platform is ornamented by parallel parapets and carina. The carina is short, inclines outwardly and merges with outer parapet at the anterior 1/2. This forms an isolate low of nodes at the anterior part of the merging point as an "outer low". The posterior part of these parapets is changed to ridges, and the change is occurred more anteriorly in the inner parapet. The median groove is shallow. Additional discreet small nodes are located between the outer parapet and, "outer low" and inner parapets. The small nodes are fused in the anterior platform to longitudinal ridges as pioneers of adcarinal ridges.

Remarks — *Declinognathodus* sp. B is quite different from other *Declinognathodus* species by the presence of additional nodes and pioneers of adcarinal ridges. This species has a transitional morphology of *Declinognathodus* and *Idiognathodus*.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Genus *Idiognathodus* Gunnell, 1931

Type species— *Idiognathodus claviformis* Gunnell, 1931

Remarks — the P_1 element of the genus has following characters; the lanceolate platform is straight or slightly arched. The blade joins the median position of the platform, and continues on the platform as a short carina. The surface of the platform is covered with continuous transverse ridges. The lateral lobes which are occupied by nodes are present or absent on one or both sides at the anterior part of the platform. *Idiognathodus* differs from the genera *Swadelina* and *Streptognathodus* by its lack of a well-developed medial trough on the platform. *Idiognathodus* also has a shortened medial carina on the P1 element compared to that of *Streptognathodus*.

Idiognathodus covadongae Méndez, 2006

Fig. 18. 8, 19. 5

Idiognathodus covadongae: Méndez (2006): p. 250, fig. 5, 1, 6; Nemyrovska (2011): p. 494, pl. 1, fig. 4, 5.

Referred Specimen —Eleven P_1 elements: 1 from AI-1, AI-8, AI-12, Mk-2-19, F-13. 6 from AI-9.

Description — P_1 elements has a slightly curved lanceolate platform with pointed posterior end. The carina is relatively short, not over than half length of the platform. The lobes are not equally developed, and inner one is more developed with several organized nodes semicircular in outline and outer is a row of a few nodes. The platform bears many transverse ridges, and the ridged area is subrhombic in outline and epressed, greatest width at the part of anterior one third.

Remarks — *Idiognathodus covadongae* is similar to *I. podolskensis* Goreva, 1984, but the former bear a more elongate platform and the area of transverse ridges is subrhombic, not subtriangular like latter. This species is reported from the later Moscovian of Spain (Méndez, 2006). This is the first report of this species in Japan.

Occurrence —Moscovian from the Akiyoshi Limestone in the Maruyama are, Omi Limestone Fukugakuchi area.

Idiognathodus delicatus Gunnell, 1931

Fig. 19. 1–3

Idiognathodus delicatus: Gunnell (1931): p. 250, pl. 29, figs. 23, 52; Ellison and Graves (1941): pl. 3, figs. 20, 23; Branson and Mehl (1941): p. 246, pl. 94, figs. 56–58; Koike (1967): p. 304, pl. 2, figs. 18–23; Webster (1969): p. 35, pl. 6, figs. 6–12; von Bitter (1972): pl. 3, fig. 4; Baesemann (1973): pl. 1, figs. 10–17, 19–20, 23, 24; Igo (1974): p. 234, pl. 1, figs. 1–9; Barskov and Alekseev (1975): pl. 2, figs. 7–9; Barskov and Alekseev (1979): p. 112, pl. 8, figs. 30–34; pl. 9, figs. 1–4; Landing and Wardlaw (1981): p. 1260. Pl. 2, figs. 2, 3; Barskov and Kononova (1983): pl. 3, fig. 13; Wan et al. (1983): pl. 2, figs. 13–14; Grayson (1984): p. 49, pl. 1, figs. 1, 2, 12; pl. 3, 2, 3, 5, 6, 21–23, 25, pl. 4, figs. 1, 6–8, 17, 24; Wang et al. (1987): p. 128, pl. 4, fig. 4; Chernykh and Reshetkova (1987): pl. 1, figs. 1, 2; Wang and Higgins (1989): p. 279, pl. 6, figs. 1–6; Nemyrovska (1999): pl. 9, figs. 5–8, 10; pl. 10, fig. 6; pl. 11, fig. 17; Chernykh et al. (2006): p. 210, pl. 1, fig. 6; Brown et al. (2013):p. 114, pl. 1, figs. 25, 26; Barrick et al. (2013):p. 60, pl. 2, fig. 6; Bahrami et al. (2014): p. 196, fig. 8, 2, 7.

Idiognathodus magnificus: Bahrami et al. (2014): p. 196, fig. 8. 1, 8. 3.

Referred Specimen — Sixteen sinistral and one dextral P_1 elements: 2 from Mk2-19. 15 from Mk2-15.

Description — The sinistral P_1 element has an asymmetrical and incurved platform with pointed posterior end. Two accessory lobes are well developed and covered with nodes. The posterior half of the platform is ornamented by the transverse ridges. The outer adcarinal ridge extends the anterior limit of the platform and continues slightly to outwards away from the blade, and forms a collar–like junction of the blade and the platform. The dextral element is slenderer platform with less developed lobes.

Remarks —*Idiognathodus delicatus* is similr to *I. praedelicatus* Nemyrovska, 1999, but the outer adcarinal ridge of the former is more developed. *I. delicatus* has developed outer ridge that extends beyond the anterior margin of the platform and curving outwards away from carina forming the collar, which is still not developed in *I. praedelicatus*. *I. delicatus* differs from *I. sinuosus* by having two well developed, shifted posteriorly lobes. This species can be easily distinguished from *I. incurvus* by much smaller curvature of the platform inwardly. This species is reported from the upper Bashkirian-Kasimovian of Eastern Europe and Urals; Pennsylvanian (upper Morrowan–Desmoinesian) of North America; the Kodani Formation of Japan; Weiningian of China.

Occurrence —Moscovian from the Omi Limestone in the Fukugakuchi area.

Idiognathodus* cf. *incurvus Dunn, 1966

Fig. 19. 4

Referred Specimen — One sinistral P_1 elements from NR-26.

Description — Assymetrical and slender P_1 elements has an inwardly curved platform with pointed posterior end. Two narrow nodular accessory lobes and the carina continue to the anterior half of the platform. The nodes of lobes are arranged as longitudinal rows parallel to the platform margins. The adcarinal ridges are parallel to carina, and inner one is longer than the outer. The posterior part of the platform is covered by parallel transverse ridges. A shallow groove is situated at the posteriormost part of the platform.

Remarks — This species quite similar to *Idiognathodus incurvus* Dunn, 1966, but differs from the latter by the length of the carina. The carina of *I. incurvus* takes 1/3 of the platform length. *I.* cf. *incurvus* is also different from *I. praedelicatus* Nemyrovska, 1999 by the graeter curvature of the slender platform. Because *I. incurvus* is reported from the Upper Bashkirian of Russia and Lower Pennsylvanian of North America, this species may suggest the Lower Pennsylvanian.

Occurrence —Bashkirian from the Omi Limestone in the Nishiyama area.

Idiognathodus sinuosus Ellison and Graves, 1941

Fig. 19. 6

Idiognathodus humerus: Dunn (1966): p. 1300, pl. 158, figs. 6, 7; Nemirovskaya (1978): p. 49, pl. 21, fig. 1.

Idiognathodus sinuosis: Dunn (1970): 334, pl. 63, figs. 3–4; Bender (1980): 11, pl. 3, figs. 17–19.

Idiognathodus sinuosus: Ellison and Graves (1941): p. 6, pl. 3, fig. 22; Lane and Straka (1974): p. 81, fig. 37, 10–13, 21; fig. 42, 1–11; fig. 43, 1, 4- 8, 10–13, 20; Nemirovskaya (1978): pl. 1, figs. 37–38; Wang et al. (1987): pl. 6, fig. 9; Grayson et al. (1987): pl. 4, figs. 1, 13, 15–16, 19; Barskov et al. (1987): p. 80, pl. 18, figs. 4–9; Wang and Higgins (1989): p. 280, pl. 9, figs. 1, 2; pl. 15, figs. 1, 2; Grayson (1900): pl. 4, figs. 36- 39; Grayson et al. (1990): p. 369, pl. 2, fig. 1; Nemirovskaya and Alekseev (1994): p. 130, pl. 3, figs. 4, 6, 8, 9, 11; Nemirovskaya (1999): pl. 8, figs. 3, 4, 6, 10, 12, 15, pl. 11, 13; Barrick et al. (2013):p. 60, pl. 2, fig. 16.

Referred Specimen — One P_1 element from F-10.

Description — P_1 elements has an almost straight asymmetrical platform with pointed posterior end. The carina occupies almost one-third of the length of the platform. One nodular accessory lobe is present at the only inner part. The posterior part of the platform is covered by parallel and slightly sinuous transverse ridges.

Remarks — *I. sinuosus* differs from the other *Idiognathodus* species by having only one accessory lobe and by sinuous ridges on the posterior part of the platform. The sinuous ridges of this species in this study is relatively indistinct compared to *I. sinuosus* in other regions. But the entire proportion of carnia, accessary robe and platoform of *I. sinuosus* in this study is common This species is reported from upper Bashkirian- lower Moscovian of Russia, North America and China.

Occurrence —Moscovian from the Omi Limestone in the Fukugakuchi area.

***Idiognathodus* sp. A**

Fig. 19. 7

Idiognathodus sp. 1: Nemyrovska (1999): p. 107, pl. 7, figs. 7–12, 14, 16, 18.

Idiognathodus sp. A: Qi et al. (2015): p. 12, fig. 10, M, N.

Referred Specimen —Eight P_1 elements: 1 from NR-7. 3 from NR-26. 4 from NR-5.

Description — The platform of the P_1 element is small, narrow and incurved with pointed posterior end. The inner lobe consists of a row of nodes and the outer one represented by a couple of nodes. The carina is long, extending more than half of the platform. The adcarinal ridges are also long, and the rostral ridge is high. The posterior part of the platform is covered by some transverse ridges.

Remarks — The long high rostral ridge and long carina distinguish this species from other *Idiognathodus* species. These features make *I.* sp. A close to *Streptognathodus*, but absence of a median groove, position of lobes and general outlines support the assignment of this species to *Idiognathodus*. This species is reported from the upper Bashkirian of Russia and South China (Nemyrovska, 1999; Qi et al., 2015).

Occurrence —Bashkirian from the Omi Limestone in the Nishiyama area.

***Idiognathodus* sp. B**

Fig. 19. 8

Referred Specimen —One P_1 element from M-16.

Description — The P1 element has straight wide platform ornamented almost entirely with transverse ridges. The platform lacks robes and a median furrow. The quite short carina is consisted of a node. Both adcarinal ridges are also incipient and composed of some nodes.

Remarks — This species differs from other *Idioganthodus* species by the combination of characters such as absence of robes and short carina and adcarinal ridges. *I. primuls* Higgins (1975) and *I. nashuiensis* Wang and Qi (2003) also lack robes, but they are slenderer than *I.* sp. B. This species is similar to *I. paraprimulus* Wang and Qi (2003), but the latter bears an anterior V-shaped trough and a deep median furrow.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Genus *Idiognathoides* Harris and Hollingsworth, 1933

Type species— *Idiognathoides sinuata* Harris and Hollingsworth, 1933

Remarks — The Pa element of the genus is characterized with lateral junction of free blade with platform and, bearing two ridged or nodular parapets, and outer one has a continuation of the blade onto the platform and extends to the posterior end of the platformt. The genus differs from gnathodids by the lateral junction of blade with a platform.

Idiognathoides corrugatus (Harris and Hollingsworth, 1933)

Idiognathoides attenuata: Harris and Hollingsworth (1933): p. 202, pl. 1, fig. 9.

Idiognathoides convexa: Higins and Bouckaert (1968): p. 39, pl. 5, fig. 3; Webster (1969): p. 37, pl. 5, figs. 17, 18.

Idiognathoides convexus: Dunn (1970): p. 334, pl. 63, fig. 20; Ebner (1977): p. 20, pl. 2, figs. 5, 7–10, 13; Kozitskaya et al. (1978): p. 59, pl. 18, figs. 7, 8; Grayson (1984): p. 50, pl. 4, figs. 9, 15; Grubbs (1984): p. 70, pl. 2, figs. 7, 8.

Idiognathoides corrugata: Harris and Hollingsworth (1933): p. 202, pl. 1, figs. 7, 8; Lane (1967): p. 939, pl. 122, figs. 1, 2, 4–7; Higins and Bouckaert (1968): p. 39, pl. 5, fig. 9

Idiognathoides corrugatus: Palieri (1969): p. 7, pl. 2, figs. 4, 5; Dunn (1970): p. 335, pl. 63, figs. 16-18, 25; Higgins (1975): p. 48, pl. 15, fig. 1; Ebner (1977): p. 472, pl. 5, fig. 10, pl. 6, fig. 7; Kozitskaya et al. (1978): p. 60, pl.16, figs. 1–8; Bender (1980): pl. 1, fig. 23; Méndez and Menéndez-Álvarez (1981): pl. 1, fig. 6; Barskov et al. (1981): pl. 1, fig. 4; Nemirovskaya (1983): pl. 1, fig. 39; Wang and Wang (1983): p. 441, pl. 1, fig. 7; Goreva (1984): pl. 16, figs. 28, 35; Grayson (1984): pl. 4, figs. 4, 10; Wang et al. (1987): pl. 2, figs. 1–2, 6–11; Nemirovskaya (1987): pl. 2, figs. 10, 21, 25- 26, 30–31; Wang and Higgins (1989): p. 280, pl. 2, figs. 10–13; Nigmadganov and Nemirovskaya (1992): pl. 5, figs. 6–11; Nemirovskaya and Alekseev (1993): pl. 3, fig. 3, 15; Mizuno (1993): pl. 2, fig. 7; Nemirovskaya and Alekseev (1994): p. 124, pl. 1, figs. 1, 13, 15; Sobolev and Nakrem (1996): p. 102, pl. 2, B, C; Nemirovskaya (1999): p. 98, pl. 3, figs. 2, 4, 21; Nemirovskaya et al (1999): p. 176, fig. 3. 6, fig. 4. 10; Nemirovskaya et al (2011): p. 180, pl. 3, figs. 17, 19; Sanz-Lopez et al. (2012): p. 402, Fig. 6. 10–14; Sanz-Lopez and Blanco-Ferrera (2013): p. 936,fig. 8, E–T; Qi et al. (2016): p. 179, fig. 8, B–G; Cradoso et al. (2017): Fig. 4. 8.

Idiognathoides ouachitensis: Harrlton (1933): p. 15, pl. 4, fig. 14; Ellison and Graves (1941): p. 8, 9, pl. 3, figs. 8, 9; Koike (1967): p. 308, 309, pl. 3, figs. 3–5; Wirth (1967): p. 223, pl. 20, figs. 12, 14; Grubbs (1984): p. 70, pl. 2, fig. 12.

Idiognathoides sinuatus: Lane and Straka (1974): figs. 37. 14, 15, 20, 36, figs. 41. 1–8, 13, 14, 21–25, 27; Landing and Wardlaw (1981): p. 1262, pl.2, figs. 15–20; Park (1983): p. 104, pl. 5, figs. 21–24; Grubbs (1984): p. 70, pl. 2, figs. 3–4.

Oxinagnathus corrugatus: Igo and Kobayashi (1974): p. 423, pl. 56, fig. 19.

Polyganathodella attenuata: Ellison and Graves (1941): p. 8, 9, pl. 3, figs. 11, 13–15.

Polyganathodella convexa: Ellison and Graves (1941): p. 8, 9, pl. 3, figs. 10, 12, 16.

Polyganathodella cf. *convexa*: Koike (1967): p. 308, 309, pl. 3, figs. 1, 2.

Polyganathodella tenuis: Clarke (1960): p. 28, 29, pl. V, figs. 12, 13.

Referred Specimen — Two P_1 elements: 1 from M-4 and Mk2-4.

Description — The dextral P_1 element with wide lanceolate platform. Most of the platform is occupied by continuous parallel transverse ridges. In the anterior end, these ridges are interrupted by a short deep groove. The blade merges with the right side of the platform and continues as an outer side of the platform.

Remarks —*Id. corrugatus* is dextral element paired with sinistral *Id. sinuatus*. This species is different from other species of *Idiognathoides* by having most of the platform covered by continuous transverse ridges and shorter antero-medial groove between the parapets. This species have been reported from the Bashkirian and lower Moscovian of Eastern and Western Europe, Urals and Central Asia, China North America and Japan.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Idiognathoides macer (Wirth, 1967)

Fig. 20. 4–6

Gnathodus macer: Wirth (1967): p. 14, 15, figs. 11a–d; pl. 20, figs. 6–10.

Idiognathoides macer: Straka and Lane (1970): figs. 1A, 1B; Lane et al. (1971): pl. 1, figs. 3, 4; Higgins (1975): p. 49, pl. 10, fig. 10; pl. 13, fig. 17; pl. 16, fig. 8; Méndez and Menéndez-Álvarez (1985): p. 78, text-fig. 6; Nemirovskaya et al. (2011): p. 181, pl. 3, figs. 3, 4, 12, 18; Ishida et al. (2013): p. 45, pl. 2 fig. 26 ?; Sanz-Lopez and Blanco-Ferrera (2013): p. 7, text-fig. 6, U; Qi et al. (2015): p. 10, fig. 8, P.

Referred Specimen — Four P_1 elements: 1 from NR-26. 3 from N210-4.

Description — P_1 element have a very deep median sulcus between two parapets of equal length. The inner parapet is low, nodular or flared. These parapets can bear transversely ridges in its anterior end. The platform is narrow and pointed posteriorly.

Remarks — This species is similar to *Id. sulcatus* Higgins and Bouckaert, 1968, but differs from the latter by the low inner parapet and presence of ridges in the anterior part of the platfom. This species has been reported from the lower Pennsylvanian of Europe, North America and Russia and Bashkirian-Moscovian of South China (e.g. Nemirovskaya et al. 2011; Qi et al. 2015). In Japan Ishida et al. (2013) report it from the Moscovian of the Koyama Limestone, Akiyoshi Terrane. This is the first report of this species from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Nishiyama area.

Idiognathoides pacificus Savage and Barkeley, 1985

Fig. 20. 2

Idiognathoides pacificus: S (1985): p. 1467, figs. 9.9–9.25; Wang and Higgins (1987): p.280–281, pl. 11, figs. 3, 4, pl. 16, fig. 4; Cui and Yu (1994): p.35, pl. 2, figs. 23, 26, 32; Wang and Qi (2003): p. 393, pl. Savage and Barkeley 3, figs. 13, 14; Qi et al (2015): p. 10, fig. 8, I, J; Hu et al. (2017): p. 72, figs. 5, R, S.

Idiognathoides convexus: Ishida et al. (2013)*:* pl. 2, figs. 19?, 20.

Idiognathoides cf. *convexus*: Sada et al. (1985): pl. 1, fig. 15.

Idiognathoides planus: Nemirovskaya and Alekseev (1994): pl. 1, fig. 18.

Idiognathoides sp. A: Dong and Ji (1988): pl. 6, figs. 10.

Idiognathoides attenuatus: Cui and Yu (1994): p.35, pl. 2, figs. 15–18, 25.

Referred Specimen —Ten P_1 elements: 1 from M-14, Mk-35, Mk-40. 7 from Mk-34.

Description — P_1 element with narrow and straight to slightly incurved platform. The platform bears narrow-spaced transverse ridges that are straight or slightly convex posteriorly. The blade joins the outer side of the platform forming the short anterior median sulcus which makes isolate small nodes inward.

Remarks —This species quite similar to *Id. asiaticus* Nigmadganov and Nemirovskaya, 1992, but each space of transverse ridges of *Id. asiaticus* are wider. *Id. pacificus* is different from *Id. attenuatus* (Harris and Hollingsworth, 1933), *Id. convexus* (Ellison and Graves, 1941) and *Id. planus* Furduj, 1977 by having slenderer platform and less dense of ridges. Although this species has some similarities to *Neolcharie glaber* (Wirth, 1967), *Neol. glaber* lacks median sulcus forming isolate small nodes. The species are reported from early to middle Pennsylvanian of North America; Bashkirian- Moscovian of China.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Idiognathoides* aff. *pacificus (Savage and Barkeley, 1985)

Fig. 20. 3

Referred Specimen — Two P_1 element from M-2.

Description —P_1 elements with broad, rounded and almost symmetrical platform. The element bear two straight parapets of equal length, extending to the pointed posterior end of platform. These parapets are nodular in the anterior part, and remaining posteriors are covered with convex ridges. The median sulcus is not deep continuing to the one-third of the platform.

Remarks — This species is characterized by its broad symmetrical platform. Although parapets of this species are similar to *Id. pacificus*, the morphology of the platform quite differs from *Id. pacificus* and other *Idiognathoides* species. The median sulcus of this species is also longer than *Id. pacificus.* This species is probably a new affinity of *Id. pacificus* with restricted distribution in Carboniferous pelagic limestone as the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Idiognathoides sulcatus Higgins and Bouckaert, 1968

Fig. 20. 7, 8

Gnathodus opimus: Igo and Koike (1964): p. 189-190, pl. 28, 15–17; Igo and Koike (1965): p. 89, pl. 9, fig. 1–4; Koike (1967): p. 298, pl. 1, figs. 20, 21; Igo and Kobayashi (1974): p. 421, pl. 56, fig. 18; Webster (1969): p. 33, pl. 5, fig. 20.

Idiognathoides opimus: Dunn (1970): p. 335, pl. 63, figs. 24, 28–30; Ebner (1977): p. 473, pl. 6, figs. 1–3, 8, 9; Park (1983): 101, pl. 5, figs. 6–11; Igo (1985): pl. 8.3, figs. 4- 6.

Idiognathoides aff. *I. nodurifera*: Lane (1967), p. 938, pl. 123, fig. 16.

Idiognathoides cf. *I. sinuatus*: Palmieri (1969): p. 7, pl. 4, figs. 6–9.

Idiognathoides sp. A: Lane (1967): p. 938, pl. 123, figs. 14, 15, 18, 19.

Idiognathoides sulcata: Higgins and Bouckaert (1968): p. 41, pl. 4, figs. 6–7; Nemirovskaya, in Kozitskaya et al. (1978): p. 66, pl. 18, figs. 4–6.

Idiognathoides sulcatus: Straka and lane (1970): p. 42, fig. 1, A; Lane and Straka (1974): Nemirovskaya (1983): pl. 1, fig. 36; Nemirovskaya (1987); pl. 2, figs. 13–14, 16, 23, 28; Nemirovskaya and Nigmadganov (1993): pl. 5, figs. 1–3; Nemirovskaya and Alekseev (1993): pl. 3, figs. 14, 25; Nemirovskaya and Alekseev (1994): p. 126, pl. 1, figs. 12, 17.

Idiognathoides sulcatus sulcatus: Lane and Straka (1974): p. 92, figs. 36: 1–16, 18–20, 23–24; Higgins (1975): p. 56, pl. 13, figs. 11, 12, 16; pl. 15, fig. 15; Higgins (1985): pl. 6.3, fig. 6; Wang and Qi (2003): p.389, pl. 1, fig. 3; Qi et al. (2013): p. 319, fig. 6, d; Qi et al. (2016): p. 14, fig. 11, E–I; Qi et al. (2016): p. 181, fig. 10, E- I; Hu et al. (2017): p. 73, fig. 8, C, D.

Referred Specimen —Twenty-five P_1 elements: 1 from AI-4, M-2, 4, Mk-33, 37, 40, Mk2-4, 2-19, F-12, N210-3, NR-12, 17, 26. 2 from M-18, Mk-35, 39, Mk2-15, F-10, float from the Omi Riv. 3 from M-14. 4 from AI-9, Mk-34.

Description —P_1 elements with two straight, nodular parapets of equal length, extending to the posterior end of the platform. The narrow platform is pointed posteriorly on which a deep sulcus occurs between the parapets. In the posterior end, these parapets can be fused as a few transverse ridges.

Remarks — This species differs from *Id. sinuatus* Harris and Hollingsworth, 1933 by having nodular, not ridged parapets of equal height, and from *Id. macer* by presence of two nodular parapets, whereas the anterior part of the inner parapet of *Id. macer* is ridged. It also differs from *Id. postsulcatus* Nemirovskaya, 1999 by thick platform morphology. *Id. sulcatus* are is divided into two subspecies, *Id. sulcatus parvus* Higgins and Bouckaert, 1968 and *Id. sulcatus sulcatus* Higgins and Bouckaert, 1968, by the inner parapet morphology. The former has much shorter inner parapet. In that point, *Id. sulcatas* in this study is corresponded to the subspecies *Id. sulcatus sulcatus*. The species have worldwide distribution as Bashkirian- lower Moscovian of Europe, Russia and Central Asia; Lower Pennsylvanian (Morrowan-Atokan) of North America; Bashkirian- lower Moscovian of Japan and

China.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi and Nishiyama area and Omi Riv. Moscovian from the Akiyoshi Limestone in the Maruyama area.

Genus *Neognathodus* Dunn, 1970

Type species— *Polygnathus bassleri* Harris and Hollingsworth, 1933.

Remarks — The P1 element has lanceolate, subtriangular or arrow-like platform with medial position of the blade-platform junction. The high platform is consisted of a medial carina, which extends to the posterior tips, and two parapets. The carina is nodular and the parapets is occupied by ridges or nodes. The outer parapet is commonly more reduced than the inner. Deep adcarinal grooves between the carina and parapets are developed. *Neognathodus* differs from *Gnathodus* Pander, 1856 which is closely related ancestor of the former genus by the presence of deep adcarinal grooves and relatively high parapets. The parapets are of greater height in *Neognathodus* but carina is higher in *Gnathodus*. This genus is different from *Ferganaegnathodus* Nemirovskaya and Nigmadganov, 1993 by much longer parapets.

Neognathodus atokaensis Grayson, 1984

Fig. 21. 1

Neognathodus atokaensis: Grayson (1984): p. 52, pl. 1, fig. 8; pl. 2, figs. 1, 5, 10–12, 16, 23; pl. 3, figs. 1, 7, 11, 16, 18, 22; Grayson et al. (1985): p. 126, pl. 1, figs. 2, 34; Grayson (1990): pl. 4, figs. 14–16; Sutherland and Grayson (1992): pl. 2, fig. 15; Nemirovskaya and Alekseev (1993): pl. 4, figs. 20, 21; Nemirovskaya and Alekseev (1994):p. 132, pl. 4, fig. 9; Nemirovskaya and Alekseev (1999): p. 177, fig. 3, 5; Fohrer et al. (2007): p. 16, fig. 12, 6, 11, 12; Kulagina et al. (2009): p. 60, 61, pl. 8 fig. 4; Mendez (2012): p. 67, fig. h, i; Barrick et al. (2013):p. 58, pl. 1, fig. 6, 7; Qi et al. (2015): p. 12, fig. 10, C, E, F; Scomazzon et al. (2016): p. 35, fig. 10.3, 10.4.

Neognathodus aff. *atokaensis*: Hu et al. (2017): p. 72, fig. 6, E.

Referred Specimen — Two P_1 elements: 1 from M-11 and N210-4.

Description — The wide platform of P_1 element is asymmetrical and pointed posteriorly. Both of the parapets are ridged, and outer parapet is shorter and a little lower than the inner. The long and high carina is consisted of fused nodes and extends to the posterior end of the platform.

Remarks — This species is similar to *N. kanumai*, but inner and outer parapets of *N. atokaensis* are almost equal in height. The latter bears much low outer parapet. This species has been reported from lowermost Moscovian of Russia and Atokan of North and South America.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi and Nishiyama area.

Neognathodus kanumai Igo, 1974

Fig. 21. 2, 3

Gnathodus cf. *roundyi*: Koike (1967): p. 299–300, pl. 1, figs. 27, 28.

Gnathodus kanumai: Igo (1974): p. 233, pl. 1, figs. 10–14.

Neognathodus kanumai: Igo (1985): p. 52, pl. 8. 2, fig. 4, 5; Qi et al. (2014): p. 319, fig.6, m ; Qi et al. (2015): p. 12, fig. 10, A, B; Qi et al. (2016): p. 181, fig. 10, A, B; Hu et al. (2017): p. 72, fig. 6C, D.

***Referred Specimen* —** Fourteen P_1 elements: 1 from Mk-40, N210-4, 210-6, a float from Omi Riv. 2 from Mk-35. 6 from Mk-34

Description — Asymmetrical P_1 element bears the posteriorly pointed platform with the blade slightly curved inward. The platform occupies the almost half length of the entire element. The inner parapet is higher and longer than the outer. Radially arranged ridges are developed on inner parapet, and outer one has faint of ridges mainly in its rim.

Remarks —This species is similar to *N. atokensis*, but differs from the later by the height of parapets. The inner parapet is much higher than the outer in *N. kanumai*. *N. kanumai* is also similar to *Neognathodus uralicus* Nemirovskaya and Alekseev, 1994, but the platform of the latter species is slenderer. This species is reported from the Bashkirian of South China (Qi et al., 2015), Japan (e.g. Igo, 1973).

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi, Nishiyama area and a float in the Omi Riv.

Neognathodus symmetricus Lane, 1967

Fig. 21. 4

Gnathodus bassleri symmetricus: Lane (1967): p. 935, pl. 120, fig. 2, 13, 14, 17; pl. 121, figs. 6, 9; Lane et al. (1971): pl. 1, figs. 7, 8.

Gnathodus wapanuckansis: Koike (1967): p. 300, pl. 1, figs. 22, 24.

Gnathodus bassleri: Webster (1969): p. 29, pl. 5, figs. 14.

Gnathodus bassleri symmetricus: Lane (1967): p. 935, pl. 120, figs. 2, 13, 14, 17.

Neognathodus bassleri: Dunn (1970): p. 336, pl. 64, figs. 13; Merrill (1980): pl. 6, figs. 10–12.

Neognathodus bassleri symmetricus: Lane and Straka (1974): p. 96, fig. 37, 22, 31, 32, 37–39. Figs. 39, 16–18, 21–24; Kozitskaya et al. (1978): p. 70, pl. 19, figs. 1–8; Sada et al. (1985): pl. 1, figs. 18–21.

Neognathodus symmetricus: Nemirovskaya (1983): pl. 1, figs. 29, 31; Manger and Sutherland (1984):

pl. 1, figs. 9, 10; Ying (1984): p. 22, pl.3 fig. 15; Barskov et al. (1987): p. 73, pl. 17, figs. 1–6; Nemirovskaya (1987): pl. 2, figs. 1–5, 7, 9, 11, 18, 19; Wang et al. (1987): p. 130, pl. 3, figs. 6, 7; pl. 7, figs. 3–4, 12; pl. 8, figs.3- 4; Wang and Higgins (1989): p. 282, pl. 2, figs. 1–4; Grayson (1990): pl. 3, figs. 8–13; Grayson et al. (1990): p. 378, pl. 3, fig. 23; Nigmadganov and Nemirovskaya (1992): pl. 4, figs. 1, 7; Mizuno (1993): pl. 2, fig. 4; Nemirovskaya and Alekseev (1994): p. 128, pl. 2, fig. 8–14; Wang and Qi (2003): p. 388, 389, pl. 1, figs. 8, 14; Barrick et al. (2013):p. 58, pl. 1, fig. 10; Ishida et al. (2013) : p. 44, 45, pl. 2, fig. 16; Qi et al. (2014): p. 319, fig.6, e ;Fallon and Murray (2015): p. 1035, fig. 7, m; Scomazzon et al. (2016): p. 35, fig. 10, 1, 2; Hu et al.(2017), p. 72, figs. 6, A, B; Cardoso et al. (2017): p.15, fig. 7, 14–16.

Streptognathodus wapanuckansis: Wirth (1967): p.236, pl. 20, fig. 11, 13.

***Referred Specimen* —** Three P_1 elements: 1 from F-10. 2 from M-1.

Description —P_1 element has narrow elongate and almost symmetrical platform pointed posteriorly. Parapets are almost equal in length and height, and nodular or ridged, parallel to each other. The nodular carina which is relatively low in height extends to the posterior end of platform. The adcarinal grooves between two parapets and the carina is deep.

Remarks —This species is quite similar to *N. askynensis* Nemirovskaya and Alekseev, 1994. It is distinguished from the latter in having low carina and deep adcarinal grooves. The platform morophology of *N. symmetricus* resembles to *N. bassleri* (Harris and Hollingsworth, 1933). But the P1 elements of *N. bassleri* are defined by a carina that does not extend to the posterior end of the platform. This species is reported from the Bashkirian of Eastern Europe, Urals and Central Asia; Alportian-Kinderscoutian of Western Europe; Lower Pennsylvanian (Morrowan) of North America; lower part of the Kodani Formation of Japan; Weiningian of China.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi and Nishiyama area.

Neognathodus sp. A

Fig. 21. 5

***Referred Specimen* —** One P_1 element from NR-26.

Description — Asymmetrical P1 element bears the posteriorly pointed platform with the blade slightly curved inward. The platform occupies the one-third of the entire length of the element. The inner parapet is much higher than the outer. Both parapets are ornamented by the radially arranged numerous and weak ridges. The anterior part of the platform tapers rapidly. It makes a notch in the outer parapet.

Remarks —This species can be distinguished from other species of *Neognathodus* by the presence of a notch in the outer parapet and numerous weak ridges.

Occurrence —Moscovian from the Omi Limestone in the Nishiyama area.

Genus *Streptognathodus* Gunnell, 1933

Type species— *Streptognathodus excelsus* Stauffer and Plummer, 1932: Pennsylvanian (Missourian) of North America.

Remarks — The P_1 element of the genus is characterized by the straight to arched and slightly curved lanceolate platform. The blade joins to the platform in in a median position and continues posteriorly onto the platform as a carina for about anterior one-third the length of the platform. The median trough on the posterior part of the platform divides the transvers ridges as *Idiognathodus*, forming the parapets on both sides of the median trough with transverse corrugations. The anterior platform has nodes accessory lobes. Although *Streptognathodus* has similar forms to *Idiognathodus,* it differs from the latter by having a median trough and parapets and by the absence of continuous transverse ridges on most of the platform. This genus also differs from *Swadelina* by its longer carina and more undeveloped accessory lobes.

Streptognathodus einori Nemirovskaya and Alekseev, 1994

Fig. 21. 6

Idiognathodus excelsus: Savage and Barkeley (1985): figs. 8.5–8.12.

Idiognathodus subdelicatus: Wang and Qi (2003): p. 390, pl. 2, fig. 6.

Streptognathodus einori: Nemirovskaya and Alekseev (1994): p. 130, pl. 3, fig. 13, 15; Qi et al. (2016): fig. 10, K.

Streptognathodus aff. *einori*: Kulagina et al. (2009): p. 59, pl. 4, figs. 9–13.

Referred Specimen — One P_1 element from F-10.

Description — The P_1 element has lanceolate, wide long carina. The posterior half of the platform is covered with some transverse ridges dissected by a shallow narrow medial trough. In the anterior part of the platform, the adcarinal ridges are almost straight and parallel to the carina. Each accessory lobes are composed of one simple low of nodes. These are also parallel to the carina.

Remarks — This species is distinguished from *S. suberectus* by less dorsally shifted lobes and lack of high outer parapet. *S. einori* can be easily distinguished from *S. bashkiricus* Nemirovskaya and Alekseev (1994) by the slender platform and long carina. This species has been reported from the upper Bashkirian–lower Moscovian of China, Russia and North America.

Occurrence —Moscovian from the Omi Limestone in the Fukugakuchi area.

Streptognathodus expansus Igo and Koike, 1964

Fig. 21. 7, 8

Idiognathodus expansun: Grayson (1984): pl. 4, fig. 18; Grayson (1990): pl. 4, fig. 28.

Idiognathodus sp. 3: Ishida et al. (2013): p. 44, pl. 2, fig. 9.

Streptognathodus expansus: Igo and Koike (1964): p. 189, pl. 28, fig. 14; Dun (1970): p. 339, pl. 62, figs. 3, 4; Lane and Straka (1974): p. 102, figs. 43: 9, 16–18, 21–26; Kozitsukaya et al. (1978): p. 96, pl.25, figs. 1, 2; Wang and Higgins (1979): p. 286, pl. 3, figs. 8–11; Park (1983): pl. 5, figs. 33, 34; Rui et al. (1987): pl.1, fig. 27; Wang (1991): p. 31, pl. 4, figs. 6, 7; Mizuno (1993): pl. 12, fig. 12; Nemyrovska (1999): p. 104, pl. 6, figs. 1, 2 ;Wang and Qi (2003): p. 388, pl. 1, figs. 2; Ishida et al. (2013): p. 44, pl. 2, fig. 11(not 10); Qi et al. (2014): p. 319, fig.6, e–I; Qi et al. (2016): p. 176, fig. 6, H–J.

Referred Specimen — Fourteen P_1 elements: 1 from M-14, 16, Mk-34, 35, 40, Mk2-17, NG-6, NR-1, 12, 18. 2 from N210-3, 210-4.

Description — The sinistral P_1 element has lanceolate, wide and asymmetrical platform with short carina. Most part of the platform is covered with many transverse ridges and shallow narrow medial trough which dissects the ridges. In the anterior part of the platform, the adcarinal ridges are almost parallel to the carina. The adcarinal grooves are deep. Laterally the element is strongly angular with the highest point in the anterior part of the platform.

Remarks — This species is different from the other species of genus *Streptognathodus* by its wide transversely ridged platform with split-like groove along the axis. *S.expansus* is reported from the upper Bashkirian of North America, Central Asia, Western Europe, South China and Japan.

Occurrence —Moscovian from the Omi Limestone in the Fukugakuchi and Nishiyama ares.

Streptognathodus suberectus Dunn, 1966

Fig. 22. 1

Streptognathodus suberectus: Dunn (1966): p. 1303, pl. 157, figs. 4–6, 10; Dunn (1970): p. 340. Pl. 64, figs. 5–7; Lane and Straka (1974): fig. 40, 20; Kozitsukaya et al. (1978): p. 96, pl.25, figs. 3; Zhao et al. (1986): p. 220, pl. 1, figs. 1–5, 18–22, pl. 2, figs 16–18; Barskov et al. (1987): p. 92, pl. 20, figs. 1–3; Dong et al. (1987): pl. 2, fig. 19 ; Dong and Ji (1988) : pl. 7, figs. 5, 6 ; Wang and Higgins (1989): p. 287, pl. 13, figs. 8–11; Mizuno (1993) : pl. 2, fig. 11 ; Nemyrovska and Alekseev (1994): p. 131, pl. 3, figs. 14; Nemyrovska (1999): p. 104, pl. 6, figs. 3–5, 7 ; Ishida et al. (2013) : p. 44, pl. 2, figs 23, 24 ; Qi et al. (2016): p. 176, fig. 6, A, B.

Referred Specimen —Nine P_1 elements: 1 from F-10. 2 from M-14, N210-4, 4 from N210-3.

Description — The platform of the dextral P_1 element is lanceolate, asymmetrical and incurved with pointed posterior end. The carina is very short and hellacious medial trough continues from the carina to the posterior tip of the platform. The long and developed nodular inner accessory lobe is considerably expanding and shifted posteriorly. The outer lobe is quite faint. The height of the outer parapet is much higher than the inner.

Remarks — *S. suberectus* differs from the other species of *Streptognathodu*s by its strongly posteriorly shifted lobes. The dextral Pa element of this species and sinistral S. expansus may be paired (Dunn, 1970). This species is reported from the upper Bashkirian of the Donets Basin, Urals and Central Asia. *S. suberectus* was also found in the Cantabrian Mountains, Spain; Lower Pennsylvanian (Morrowan) of North America; Weiningian of China. In japan, this is the first report of the species.

Occurrence — Bashkirian–Moscovian from the Omi Limestone in the Fukugakuchi and Nishiyiama areas.

Streptognathodus* cf. *suberectus (Dunn, 1966)

Fig. 22. 2

Referred Specimen —One P_1 element from N210-4.

Description — The wide platform of the P1 element is sub-lanceolate, asymmetrical and slightly incurved with pointed posterior end. The carina is very short and hellacious medial trough continues from the carina to the posterior tip of the platform. The long developed nodular accessory lobes is considerably expand and shifted posteriorly, and well fused with parapets. The outer parapet is much higher than the inner one. The low caudal adcarinal ridge is flared widely.

Remarks — *S.* cf. *suberectus* is similar to *S. suberectus* in its posteriorly shifted lobes, short carina and unconscious deep median trough. But this species is quite distinctive by the presence of fused lobes and flared caudal adcarinal ridge. These characters easily distinguish this species from other *Streptognathodus* species.

Occurrence —Bashkirian from the Omi Limestone in the Nishiyama area.

Streptognathodus subsimplex Wang and Qi, 2003

Fig. 22. 3

Streptognathodus subsimplex: Wang and Qi (2003): p. 393, pl. 3, figs. 15, 21.

Referred Specimen — One P_1 element drom M-16.

Description — The platform of the P_1 element is narrow elongate, asymmetrical and slightly incurved with short carina occupying one-fourth of the platform. The median trough is shallow and V-shaped.

Remarks — This species is similar to *S. simplex* Gunnell, 1933, but can be distinguished from the latter by the short carina and shallow trough. *S subsimlex* in this study is smaller and shorter than the originally described specimens of Wang and Qi (2003), probably because of the immatureness. This species is reported from the Lower Pennsylvanian of South China (Wang and Qi, 2003).

Occurrence —Bashkirian of the Omi Limestone in the Fukugakuchi area.

Family Spathognathodontidae Hass, 1959

Genus *Neolochriea* Mizuno, 1997

Type species— *Neolochriea hisaharui* Mizuno, 1997.

Remarks — The element of the genus is characteristics with oval or elliptical platform which is mostly smooth or bears additional ornamentation such as small nodes parallel to the carina. The carina is ornamented by nodes, which are becoming thicker posteriorly. It is sometimes ornamented by short transverse ridges. The carina extends down to the posterior end of the element. This genus is similar in shape to *Lochriea* Scott, 1942 but generally differs from the latter by a longer and better-developed platform.

Neolochriea glaber (Wirth, 1967)

Fig. 22. 4

Gnathodus glaber: Wirth (1967): p. 210–211, textfig. 10a–d, pl. 20, figs. 1–5; Spassov (1976): p. 132, pl. 1, figs. 3, 6; Ebner (1977): p. 469, pl. 5, figs. 1–3; Perret (1993), pl. 109, figs. 2, 5, 6?, 7.

Lochriea glaber: Sanz-Lo´pez and Blanco-Ferrera (2013): p. 4, fig. 400, 12–18.

Neolochriea glaber: Nemirovskaya et al (2011): p, 181, pl. 2, fig. 9; Qi et al. (2016): p, 183, fig. 11, C; Hu et al. (2017): p. 9, fig. 6, G.

Paragnathodus glaber: Méndez and Menéndez-Álvarez (1985), p.76, fig. 4.

Referred Specimen — Five P_1 elements: 1 from MF-4, M-1, 2 ,4, 9.

Description — The P_1 element has an oval-triangular shaped smooth platform. The blade joins the platform in mid-line of the anterior margin of the platform. It transforms into a carina bearing small low nodes and more posteriorly short transverse ridge.

Remarks —This species differs from *Neol. hisaharui* Mizuno, 1997, *Neol. hisayoshii* Mizuno, 1977 and *Neol. nagatoensis* Mizuno, 1977 by absence of additional nodes parallel to the carina, and the shallow sulcus between the existing two rows of nodes. It is also different from *Neol. koikei* Mizuno, 1997 by absence of developed transverse ridges covering the platform completely. *Neol. glaber* is similar to *Id. pacificus* and *Id. planus*, but differs from them by the median junction of blade, and by the absence of a short median sulcus between carina and an indistinct parapet at the anterior part of the platform. This species is reported from the lowermost Pennsylvanian of Western Europe, Russia and

South China. This is the first report of this species from the Omi Limestone.

Occurrence —Bashkirian of the Omi Limestone in the Fukugakuchi area.

Family Sweetognathidae Ritter, 1986

Genus *Diplognathodus* Kozur and Merrill, 1975

Type species— *Spathognathodus coloradoensis* Murray and Chronic, 1965.

Remarks — The P_1 element of the genus is characterized by the distinctive fixed carina called spatula, which is modified to fused denticles over a slightly expanded dorsal basal cavity. There is also a notch or gap at the junction point of blade and carina. This genus has a long range, having been reported from the Lower Carboniferous to Middle Permian (von Bitter and Merrill, 1990). Occurrence of *Diplognathodu*s is sometimes associated with *Diplognathodus?*, the genus with similar morphology except spatulated carina is defined by von Bitter and Merrill (1990). This study follows their view.

Diplognathodus? orphanus (von Bitter and Merrill, 1990)

Fig. 22. 5, 6

Diplognathodus ophanus: Wang and Qi (2003): p. 394, 395, pl. 4, fig. 1, 2.

Diplognathodus? ophanus: von Bitter and Merrill (1990): p118, pl. 1, J–K.

Diplognathodus aff. *ophanus*: Hu et al. (2016): p. 15, fig. 8, L.

Referred Specimen — Seventeen P_1 elements: 5 for AI-4. 12 for AI-2.

Description — The P_1 element with poorly developed gap between the carina and high blade, and upper outline in lateral is gently sloped. The element has oval to lanceolate, smooth unornamented, and almost symmetrical platform. The carina continues to the posterior end of the platform and bears unconscious denticulation without dveloped "spatula" over the carina. The platform occupies more than a half of the element.

Remarks — The poorly developed spatula and gap which situated between the carina and blade is distinctive characteristics of this species. By these features this species is easily distinguished from other *Diplognathodus* species. It resembles to *D. orphanus* (Merrill, 1973), but latter has sparser denticulation over the carina and more conspicuous notch between the carina and blade. Furthermore *D. colloradoensis* (Murray and Chronic, 1965) is different in having a relatively non- denticulated carina. This species is rather similar to later form of *Lcharie commutata* (Branson and Mehl, 1941), but differs from the latter by the large size and wide lanceolate shape of platform. The presence of a gap assigned this species to a member of genus *Diplognathodus?*. In North America and China, this species is reported from the Bashkirian-Moscovian.

Occurrence —Moscovian from the Akiyoshi Limestone in the Maruyama area.

Not Pa elements of Ozarkodinida

Fig. 23. 2 –11

Referred Specimen — Two Sa elements, one Sb element, three Sc elements, five M elements, five Pb elements, one S? element and many fragments.

Remarks — These elements are common in Ozarkodinida and they cannot be identified in detailed. Here, I briefly describe obtained these elements.

Sa elements (Fig. 23. 2, 3) are alate with acute to obtuse angle between lateral processes. It can bear long posterior process. Denticulation of each processes are less prominent than the cusp.

This Sb element belongs to anchignathidae due to the presence prominent cusp and sub-cusp on the posterior process.

Sc elemnt (Fig. 23. 5) is characterized by the slender and thin fragile element. It has short antero-lateral process and long posterior process ornamented with densely arranged acute short denticles. The main cup can be remarkable.

M elements (Fig. 23. 8–10) bears a massive cusp, and lateral processes which form strong arch. The length of the one process varies and denticulation on the process is weaker than another.

Pb element (Fig. 23. 6, 7) is flattened laterally but massive element with huge cusp. One of the processes is longer than another. These form slow arc and bear densely denticulation.

S? elemnt (Fig. 23. 11) is undetermined digyrate ramiform element with one developed denticulated lateral process and another undeveloped short lateral process. The main cusp is prominent.

Order Prioniodinida Sweet, 1988

Family Prioniodinidae Bassler, 1925

Genus *Idioprioniodus* Gunnel, 1933

Type species— *Idioprioniodus typus* Gunnel, 1933.

Remarks — Idioprionidodus was reconstructed in a multielement sense by Merrill and Merrill (1974). Watanabe (1975) reported *Synprioniodina collinsoni* which is synonymized to element of *Idioprioniodus* from the Omi Limestone.

Idioprioniodus sp.

Fig .22. 7, 23. 1

Referred Specimen — One M and three Sc elements: 1 M element from M-20. 1 Sc elements from

NR-26, 2 from M-18.

Description — The element is slender ramiform bipennate with antero-lateral and posterior processes. The each processes have sparse denticles. The cusp high and recurved posteriorly, and the margins of the cusp is laterally compressed as keels. The rounded basal cavity is situated immediately beneath the cusp and continues within the processes as thin grooves.

Remarks —the general morphologies, presence of the rounded basal cavity and laterally compressed keels of the cusp and with lateral keels allow to assign the specimen to *Idioprioniodus*.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi and Nishiyama areas.

8. 2 Class Ostracoda

Ostracoda is a small aquatic crustacean taxon characterized by a chitinous-calcareous bivalved carapace. Their small calcified carapaces are mostly less than 1 mm and completely envelop the reduced body. Due to the strongly calcified bivalve carapace, ostracods are dominant in microfossil record from the Ordovician to present time (Moore, 1961). Ten species of 8 genera belonging to 8 families in 3 orders of the middle Carboniferous ostracods are described here.

Phylum Arthropoda von Siebold, 1848

Class Ostracoda Latreilla, 1806

Order Halocyprida Dana, 1852

Family Polycopidae Sars, 1866

Genus *Polycope* Sars, 1866

Type species* — *Polycope orbicularis Sars, 1866.

Remarks — The carapace is almost circular in outline. The surface of the valve is smooth, punctate or reticulate. The reticulate species of genus is similar to *Discoidella* Croneis and Garey (1939) but differs from the latter by the fine reticulation. The carapace of *Discoidella* is more coarsely reticulated. The genus is reported from Devonian—Recent of cosmopolitan regions (e.g. Moore, 1961).

***Polycope* sp. A**

Fig. 24. 7, 8

Referred Specimen —One complete left valve and four broken valves: 2 from N210-4. 3 from N210-3.

Remarks— The measurements of the length are about 320–400 μm, and height 320–370 μm. The finely reticulate carapace has some sub-concentric crests. The width of the shell is large. The small rostrum is slightly down- curved. This species differs from *Polycope* sp. B by large-sized valve with reticulated and crested surface. This is the first report of the genus from the Omi Limestone.

Occurrence — Bashkirian of the Omi Limestone in the Nishiyama area.

***Polycope* sp. B**

Fig. 24. 9, 10

Referred Specimen —Five valves: 1 from M-20, N210-3, NR-26. 2 from N210-3.

Remarks— The measurements of the length are about 220–260 μm, and height 190–230 μm. The small sub-rounded carapace bears smooth surface. The width of the shell is small. This species is different from *Polycope* sp. A by small-sized valve without any surface structures. Because the valve lacks any distinctive morphologies, determination of left-and-right is quite obscure.

Occurrence — Bashkirian of the Omi Limestone in the Fukugakuchi and Nishiyama areas.

Order Palaeocopida Henningsmoen, 1953

Family Kellettinidae Sohn, 1954

Genus *Kellettina* Swartz, 1936

Type species — *Ulrichia robusta* Kellett, 1933.

Remarks — Two large nodes located on the upper half of the valve without a well-defined kirkbyan pit are the distinctive features of the genus. Other characters are as follows; carapace with acute dorsal posterior angle; posterior node extending to or just above hinge-line which is straight; sulcus between two nodes relatively wide; ventral margin rounded; surface reticular. This genus has been reported from the Upper Carboniferous—middle Permian strata in North America, Europe, China and Japan (e.g. Kellett, 1933; Kozur, 1991; Hoare et al., 1994; Yuan et al., 2007). In Japan, a couple of species are described from the Permian of South Kitakami and Mugi (Ishizaki, 1967; Tanaka, 2012)

Kellettina* cf. *robusta

Fig. 24. 11

Referred Specimen —One right valve from M-2.

Remarks— The measurements of the length are about 940 μm, and height 590 μm. This species is assigned to be *K*. cf. *robusta* because the entire morphology and large-sized carapace are similar to *K. robusta* Kellet (1933). But this species is shorter than *K. robusta.* It is also different from *K. prolata* Hoare et al. (1994) by the shorter carapace. *Kellettina montosa* Knight (1928) differs from *K*. cf. *robusta* by having more acute dorsoposterior angle. This species resembles in the outline to *K.? japonica* Ishizaki (1967), but the latter has more massive nodes. This is the first report of the genus from the Omi Limestone.

Occurrence — Bashkirian of the Omi Limestone in the Fukugakuchi area.

Order Podocopida Sars, 1866

Family Bairdiidae Sars, 1887

Genus *Bairdia* McCoy, 1844

Type species — *Bairdia curta* McCoy, 1844.

Remarks — The carapace is mostly elongated fusiform with broadly arched dorsum, and the dorsum becomes concave terminally. The ventral line in the center is straight but curved upward terminally.

Fossils of the genus are readily distinguished by their lengthened, ovate form, and ends suddenly tapering blunt, recurved points. The Anterior end is generally higher and more rounded than the acuminate posterior. The species of the genus have a cosmopolitan distribution from the Ordovician–Recent (e.g. Moore, 1961). In Japanese Paleozoic, some species of *Bairdia* is described from the Carboniferous to Permian of the South Kitakami (Ishizaki, 1963, 1964 and 1967), recently Tanaka et al. (2012, 2013) newly added several species occurred from the Permian of Mugi and Akasaka.

Bairdia sp.

Fig. 24. 6

Referred Specimen —One left valve from M-2.

Remarks— The measurements of the length are about 560 µm, and height 260 µm. The elongate ovate and smooth valve with tapered both sides of the specimen indicate an affinity of species of *Bairdia*. This is the first report of the genus from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Family Bairdiocyprididae Shaver, 1961

Genus _Silenites_ Coryell and Booth, 1933

Type species — *Silenites silenus reniformis* Coryell and Booth, 1933.

Remarks —The carapace has convex dorsal as bythocypridid shape mostly without any ornamentation and sculpturing. The valve with great height in middle part makes the distinctive dorsal convexity. The left valve is larger than the right. This genus lacks timidity of the valves such as *Pachydomella* Ulrich (1981). This is the cosmopolitan genus of the Lower Carboniferous–upper Permian (Moore, 1961).

Silenites sp.

Fig. 24. 2

Referred Specimen —One left valve from M-2.

Remarks—The measurements of the length are about 460 µm, and height 300 µm. The large carapace is slightly reniform with smooth surface. This species is the highest in mid-line and not angular in both ventral ends. The dorsum is relatively flat. Such features enable me to assign it wiith reasonable confidence of the genus. However, I decline to make a definitive species assignment becase of lacking the imformation of the hinge part and musle scars. This is the first report of the genus from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Family Bythocyprididae Maddocks, 1969

Genus *Bythocypris* Brady, 1880

Type species — *Bythocypris reniformis* Brady, 1880.

Remarks — The carapace is reniform with slightly straight ventral part and rounded dorsum. The surface of valve is smooth, and lacks angulation and asymmetry as species of *Birdia*. This genus also a worldwide distribution of the Ordovician- Recent (Moore, 1961), and modern species are defined partly on the basis of soft parts.

***Bythocypris* sp.**

Fig. 24. 1

Referred Specimen —One right valve from M-2.

Remarks—The measurements of the length are about 260 μm, and height 140 μm. The reniform valve with smooth surface indicates that this species belongs to genus *Bythocypris*. The small and thin carapace may imply the immatureness of the specimen. However, species-level identification is difficult due to its immatureness. This is the first report of the genus from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Family Pachydomellidae Berdan and Sohn, 1961

Genus *Spinomicrocheilinella* Kozur, 1985

Type species — *Spinomicrocheilinella spinosa* Kozur, 1985.

Remarks —The genus is characterized by the small elliptical carapace with postero-ventral spine. The spine can be strongly prominent. The surface of the carapace is smooth. This genus is reported from the Permian-Triassic of Europe (e.g. Kozur, 1991; Mette et al., 2015) and South China (Yuan et al., 2007, 2009).

***Spinomicrocheilinella?* sp.**

Fig. 24. 4

Referred Specimen —One left carapace from M-2.

Remarks— The measurements of the length are about 530 μm, and height 240 μm. Elliptical and elongate small carapace is the highest in mid-length. This elongate species bears small spine in the postero-ventral part of the valve, indicating an affinity of the *Spinomicrocheilinella.* The postero-dorsal margin of the carapace is slightly angular. The surface of the carapace ornamented by

latitudinal ridges which change to longitudinal in the anterior part of the carapace as *Barychilina*. These ornamentations are not common in *Spinomicrocheilinella*. Therefore, I decide its systematic position as *Spinomicrocheilinella*?. This is the first report of this species from the Omi Limestone.
Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Family Incertae sedis

Genus *Deloia* Croneis and Thurman, 1938

Type species — *Deloia srrata* Croneis and Thurman, 1938

Remarks — Carapace bear straight hinge-line with the vertical sulcus in mid-length. The anterior, posterior and ventral margin are forward swung slightly. This genus has been reported from only the Carboniferous of North America (e.g. Croneis and Thurman, 1939; Hoare and Mapes, 2000)

***Deloia* sp.**

Fig. 24. 5

Referred Specimen —One juvenile right carapace from M-2.

Remarks— The measurements of the length are about 200 µm, and height 110 µm. Small carapace is the highest in mid-length with weak forward-swing. The surface of the carapace is smooth and bear vertical sulcus in its mid-line. The posteroventral part of the valve is angular. The small and thin carapace may imply the immatureness of the specimen. However, species-level identification is difficult due to its immatureness. This is the first report of the genus from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Genus Unknown

Gen. et sp. indet. A

Fig. 24. 3

Referred Specimen —One jointed carapaces with defect in mostly right valve from M-2

Remarks— The measurements of the length are about 400 µm, and height 210 µm. The sub-rectangular carapace has smooth surface without any ornamentations. It lacks timidity and is highest in the anterior part of the valve. Right valve overlaps the left. This is the first report of this species from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Gen. et sp. indet. B

Fig. 24. 12

Referred Specimen —One carapace from N210-4.

Remarks— The measurements of the length are about 230 μm, and height 150 μm. The elongate elliptical carapace has smooth surface without any ornamentations. The carapace is highest in the anterior part of the valve. This is the first report of this species from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Nishiyama area.

8. 3 Class Actinopterygii and Chondrichthyes

Two classes Actinopterygii (ray-finned fishes) and Chondrichthyes (cartilaginous fish) in Chordata are described based on the tooth morphology, and associated dermal denticles are also described. Totally seven species of Chordata are reported in this study.

Phylum Chordata

Class Actinopterygii Klein, 1885

Actinopterygii indet. A

Fig. 25. 7–9

Referred Specimen —Fourteen teeth: 1 from M-18, N210-3and AI-8. 2 from MF-1 and F-13. 3 from N210-4. 4 from AI-9.

Remarks— The slender conical tooth bears erect to recurved posture. The tip of the tooth is pointed. The H/L ratio is about 3-5. It is different from Actinopterygii indet. B by the tip morphology and relatively slender posture. The tip of the Actinopterygii indet. B is blunt.

Occurrence —Bashkirian—Moscovian from the Omi Limestone in the Fukugakuchi and Nishiyama area, Akiyoshi Limestone in the Maruyama area.

Actinopterygii indet. B

Fig. 25. 10

Referred Specimen —Four teeth: 1 from AI-2 and F-13. 2 from AI-9.

Remarks— The erect conical tooth is thinned rapidly from it upper one-third. The H/L ratio is less than 3. The tip of the specimen is not pointed, but blunt implying a crushing function. It is different from Actinopterygii indet. A by absence of sharp tips.

Occurrence —Moscovian from the Omi Limestone in the Fukugakuchi area and Akiyoshi Limestone Maruyama area.

Actinopterygian scale

Fig. 25. 8

Referred Specimen —One specimen from AI-4.

Remarks— The outline of the specimen is rhombic in shape with partial defection. The growth lines are also rhombic. The shape of the specimen implies the ganoid scale of primitive actinopterygians.

Occurrence —Moscovian from the Akiyoshi Limestone in the Maruyama area.

Class Chondrichthyes Huxley, 1880

Subclass Elasmobranchii Bonaparte, 1838

Cohort Euselachii Hay, 1902

Family Protacrodontidae Cappetta et al. 1993

Protacrodontidae gen. et sp. indet.

Fig. 25. 1

Referred Specimen —One defective tooth from F-13.

Remarks— This specimen lacks two lateral cusps, originally it has two pairs of lateral cusps in both side. The specimen is characterized by the lateral crushing teeth which is composed of low pyramidal median cusp and two pairs of lateral cusps. The lower parts of the cusps are fused together. The cusps bear coarse, straight or slightly wavy cristae, coalescing at the tip. The heights of the cusps decrease laterally. These characteristics are well suggested as an affinity of protacrodontidae. This family comprises Middle Devonian- Late Carboniferous euschelian sharks characterized by the lateral crushing teeth with low pyramidal morphologies.

Occurrence —Moscovian from the Omi Limestone in the Fukugakuchi area.

Order Bransonelliformes Hampe and Ivanov, 2007

Family incertae sedis

Genus *Bransonella* Harlton, 1933

Type species — *Bransonella tridentata* Harlton 1933.

Remarks — This genus was initially described as a conodont by Harlton (1933) due to the tricuspid morphology. The teeth of the genus are equipped with a tricuspid crown with a low median cusp and high lateral two cusps. The cusps have distinctive V-nested ornamentations. The genus is reported from the Lower-Upper Carboniferous of USA, Russia, Europe, China and Brazil (Ginter et al., 2010).

***Bransonella* sp.?**

Fig. 25. 2

Referred Specimen —One cusp from F-13.

Remarks— This specimen is a robust cusp bearing waved V-nested ornamentation of cristae. This is the distinctive features of *Bransonella.* Although the specimen lacks most of the original teeth, the cristae probably suggests the affinity of the genus.

Occurrence —Moscovian from the Omi Limestone in the Fukugakuchi area.

Order Ctenacanthiformes Glikman 1964

Family Ctenacanthidae Dean 1909

Ctenacanthidae? gen. et sp. indet.

Fig. 25. 3

Referred Specimen —One defective tooth from M-18.

Remarks— This specimen has a robust, compressed and sub-triangular median cusp, which is slightly recurved and have waved weak cristae. Although this specimen lacks most of the base and lateral cusps, these characters suggest relation of family ctenacanthidae.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Genus *Cladodus* Agassiz, 1843

Type species — *Cladodus mirabilis* Agassiz 1843.

Remarks — This genus has following features: the crown consists of a prominent median cusp and a pair of short lateral cusps (usually between 1/2-1/3 of the height of the median cusp), and some intermediate cusplets which are absent sometimes. The ornamentation of the cusp is varied from no ornamentation to dense striations. The highest median cusp is triangular in labial view, and has relatively wide base. More than 85 species have been assigned to the genus, which are all reported from the Carboniferous North America, Europe, Russia and China (Ginter et al., 2010).

***Cladodus* sp.?**

Fig. 25. 4

Referred Specimen —One juvenile tooth lacking basal part from NR-7.

Remarks— This small compressed specimen has a robust sub- triangular median cusp, which is slightly recurved and laterally deflected. Only one pair of short lateral cusps are present. These cusps have no ornamentation and the surface of them is smooth. These features are common to *C. vanhornei* John and Worthen (1875), but latter is much huge.

Occurrence —Bashkirian from the Omi Limestone in the Nishiyama area.

Order unknown

Family unknown

Gen et sp. indet. A

Fig. 25. 5

Referred Specimen —Two teeth: 1 from N210-4 andAI-9

Remarks— This specimen is tricuspid which consisted of one unconscious central cusp and two small lateral cusp on the sub-circular platform.

Occurrence —Bashkirian from the Omi Limestone in the Nishiyama area and Moscovian from the Akiyoshi Limestone in the Maruayama area.

Gen et sp. indet. B

Fig. 25. 6

Referred Specimen —One tooth from a float in the Omi Riv.

Remarks— This specimen is also tricuspid but the directions of cusps are quite different each other like fingers of human hand. These cusps are almost equal in size.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Chondrichthyan scales

Fig. 26. 1–7

Referred Specimen —Thirteen specimens: 3 from MF-1. 10 from AI-9.

Remarks— Chondrichthyan scales are divided into four types A–D. Here, each of them is described.

Type A (Fig. 26. 1–3) has elongate base with elevated platform crown, which have elevated transverse narrow ridges. The surface of crown is smooth and the elevated ridges can bear longitudinal ridges.

Type B (Fig. 26. 4, 5) has raised diamond to triangular-shaped crown with some ridges. In some specimens, these ridges can reach the posterior edge of the specimen. The crown shallowly inclined anteriorly and is much larger than the base.

Type C (Fig. 26. 6) is characterized by the sub-circular and low crown. The surface of the crown is ornamented by some ridges.

Type D (Fig. 26. 7) is composed of some cusps connected by an undefined base. The number and size of cusps are varied.

Occurrence —Fukugakuchi (Bashkirian), Maruyama (Moscovian).

8. 4 Phylum Mollusca

In Mollusca, two classes, Bivalvia and Gastropoda, are described based on the shell morphology. The former is characterized by two-valved symmetrical shells, and the latter torsioned shell. They generally are dominant in fossil records among macrofossils. But in Omi Limestone, a few species have ever known. In this study, totally eight species are reported.

Class Bivalvia Linnaeus, 1758

Order Pectenida Gray, 1854

Family Aviculopectenidae Meek and Hayden, 1864

Genus *Annuliconcha* Newell, 1938

***Type species* —** *Aviculopecten interlineatus* Meek and Worthen, 1860.

Remarks —The shell outline is orbicular with sub-equal and acute auricles. The shell surface is ornamented by concentric ridges, and there are regular spaced fine fila between the ridges. Radial ornamentation is weak or absent. The genus has cosmopolitan distribution from the Lower Carboniferous—upper Permian strata. In Japan Murata (1964) reported *Annuliconcha kitakamiensis* from the Middle Permian of South Kitakami and Yamaguchi Mus. (1985) reported *Annuliconcha* sp. from the *Fusulinella biconica* zone of the Akiyoshi Limestone.

***Annuliconcha* sp.**

Fig. 27. 4

Referred Specimen —One left valve from a float in the Omi River.

Remarks— The measurements of the height are 5.7 mm, and length 5.5 mm. The small orbicular shell with sharp auricles. The anterior auricle is slightly larger than the posterior. The surface of the shell is ornamented by several concentric ridges without any radial ornamentations. Absence or ambiguity of fine fila is probably due to the diagenesis process. This is the first report of the genus from the Omi Limaestone.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Order Veneroida H. Adams and A. Adams, 1856

Veneroida fam. gen. et sp. indet.

Fig. 27. 1

Referred Specimen —One left valve from M-18.

Remarks— The measurements of the height are 0.22 mm, and length o.27 mm. The very small thin shell without any ornamentations on the surface indicates the immature stage of the specimen. The shell outline is trigonal to elliptical and transversely elongated. The beak is slightly prominent. Due to the poor preservation, hinge is nor observed. This shell morphology is common in veneroid bivalves. Most veneroids without a few superfamilies are originated after Paleozoic age, this species may belong to a superfamily Lucinacea by the observable characteristics.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Class Gastropoda Cuvier, 1795

Order Vetigastropoda Salvini-Plawen, 1980

Family Eotomariidae Wenz, 1938

Genus *Glabrocingulum* Thomas, 1940

Type species– *Glabrocingulum (Glabrocingulum) beggi* Thomas, 1940.

Remarks - The genus bears the small turubiniform shell with gradate to conical spire. The surface of the shell is ornamented by the transverse and spiral threads with small nodes at their intersections. These ornamentations are more conspicuous near upper suture and at base. This genus is reported from the cosmopolitan Lower Carboniferous- Middle Permian strata. In Japan this genus is recently reported from the Permian Akasaka Limestone (Nützel and Nakazawa, 2012).

***Glabrocingulum* sp.**

Fig. 27. 7

Referred Specimen — One specimen whose dorsal part is attached with host rock from a float in the Omi River.

Remarks— The measurements of the height are 4.0 mm, and maximum diameter 3.6 mm. The spire is low and slightly gradate. The ornamentation is transverse and spiral threads with small nodes at their intersections, which is common in the genus. This is the first report of the genus from the Akiyoshi Terrane.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Genus *Mourlonia* de Koninck, 1883

Type species — *Helix carinata* Sowerby, 1812.

Remarks —The shell is turbiniform with relatively shallow labral sinus and deep fissure as a slit. The ornament dominantly conforms the shape of outer lip as the growth lines prosocline. *Mourlonia* is cosmopolitan gastropods throughout the Ordovician- Permian. In Japan, there are a few repots of the genus. *M. hayasakai* was reported from the Lower Carboniferous *Millerella yowarensis* zone-the Upper Carboniferous *Fusulinella biconica* zone in the Akiyoshi Limestone (Shikama and Nishida, 1968), and Sakagami (1973) also reported this species from the Lower Carbpniferous part of the Kanto Massif. Murata (1969) reported *M. toyomensis* from the Upper Permian of South Kitakami.

Mourlonia aff. _hayasakai_

Fig. 27. 6

Mourlonia sp.: FMM display

Referred Specimen —One specimen from a float in the Omi River.

Remarks— The measurements of the height are 30.7 mm, and maximum diameter 33.5 mm. The moderate sized shell is turbiniform with a narrow labral slit, which forms a concave selenizone located at almost mid- height of whorl. The angle of the spire is approximately 90°. The umbilicus is deep and phaneromphalous. The shell is ornamented with numerous fine growth line which are strongly prosocline. This species is similar to *M. hayasakai* but differs from the latter by the step-like whorls and quite deep umbilicus.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Eotomariidae gen. et sp. indet.

Fig. 27. 5

Referred Specimen —One specimen attached with host rock rom a float in the Omi River.

Remarks— The measurements of the height are 2.5 mm, and maximum diameter 1.9 mm. The small sized shell has a high spire with conspicuous gradate whorls. The surface is ornamented by the transverse and spiral threads. This species is certainly belonging to the family eotomariidae, but further identification is difficult.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Family Microdomatidae Wenz, 1938

Microdomatidae gen. et sp. indet.

Fig. 27. 3

Referred Specimen —One specimen attached with host rock from a float in the Omi River.

Remarks— The measurements of the height are 1.4 mm, and maximum diameter 1.1 mm. The specimen has very small turbiniform shell with simple rounded whorls and moderately high spire. The umbilicus is minute. These characteristics suggest that this species is assigned to a member of microdomatid gastropods. This family is reported from the cosmopolitan Middle Ordivician—middle Permian strata. In the Akiyoshi Terrane, this is the first report of the family.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Order Trochida Cox and Knight, 1960 (in Knight et al. 1960)

Family Anomphalidae Wenz, 1938

Anomphalidae gen. et sp. indet.

Fig. 27. 8

Referred Specimen —One specimen whose lower part is attached with host rock from a float in the Omi River.

Remarks— The measurements of the height are 4.4 mm, and maximum diameter 10.6 mm. The Small shell is discoidal and almost flat with slightly elevated spire. The surface of the whorls is smooth without any ornamentations and they increase in diameter rapidly. Although characters of aperture and umbilicus of the specimen cannot be observed due to the covering by host rock, the observable morphology is quite similar to the Paleozoic gastropod family Anomphalidae. Therefore, this study assigns the specimen to Anomphalidae gen. et sp. indet.

Occurrence —Bashkirian from the Omi Limestone in the Omi River.

Order Incertae sedis

Family Bellerophontidae McCoy, 1851

Bellerophontidae gen. et sp. indet.

Fig. 27. 2

Referred Specimen —One fragmentary specimen from 8.

Remarks—The very small specimen is fragmentary and lacks most of a shell, but heterostrophic protoconch is observable in its inner part. The whorls rounded and probably broad with prosocline ridges. The umbilicus is narrow. Because the most of important characteristics are lost, but above features are compatible with bellerophontid gastropods. Bellerophontidae gen. et sp. indet. deposited in FMM is quite different from this very small species with the presence of umbilicus.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

8. 5 Phylum Echinodermata

In Phylum Echinodermata, this study reports three classes as Holothuroidea, Ophiuroidea and Echinoidea. Fossils of these groups from the Omi Limestone are identified by the small ossicles. Totally seven species are described here.

Class Echinoidea Leske, 1778

Echinoidea indet. A

Fig. 28. 10–12

Referred Specimen — Nine spines: 3 from M-18. 6 from MF-1.

Remarks— This spine consisted of the base and shaft. The base is composed of stereom structure (see pl. 12. 13). In cross section, the shaft is formed by an aggregation of radial thin and paralleled ribs and well defined basal plate with central axial cavity. The number of ribs is about 20 and these ribs are originated from the thick basal plate.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Echinoidea indet. B

Fig. 28. 8, 9

Referred Specimen — One spine from MF-1.

Remarks— This spine shows the shaft part. The thick ribs bear smooth surface. In cross section, the shaft is composed of 10 radial solid wedges without the axial cavity. This species is deferent from Echinoidea indet. A by presence of solid wedged ribs and absence of axial cavity.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Class Holothuroidea de Blainville, 1834

Order Apodida Brandt, 1835

Parafamily Theelidae Frizzell and Exline, 1955

Genus Thalattocanthus Carini, 1962

Type species — *Thalattocanthus consonus* Carini, 1962

Remarks — This genus is characterized by the wheel sclerite with variable number of long spokes. The interspoke perforation is subpolygonal and the hub is imperforate and with an upper surface of that is broadly arched. This genus has only one species *T. consonus*. This species has been reported from the Carboniferous- Permian North America, Europe and eastern Asia.

Thalattocanthus consonus Carini, 1962

Fig. 28. 3

Thalattocanthus consonus: Carini (1962): p. 392–394, pl. 1, figs. 1–23, 28–29; Gutschick et al .(1967): p. 1471 , 1472, pl. 186, figs. 1–8, pl. 187, figs. 28, 35; Stefanov (1970) : p. 48, pl. 1, fig. 20; Mostler (1971), p. 10, pl. 2, figs. 9-14; Wernlund (1977), p. 81–86, pl. 4, figs. 14–21, Text-fig. 9 ; Kanasugi (1979) : p.165, pl. 20, fig. 5 ; Hui, 1985, p. 344, Text-fig. 3, ills. 1–2, pl. 1, figs. 7, 10, 11.

Referred Specimen — One specimen from MF-1.

Remarks— This species has six long spokes arching to small the hub. The interspoke perforation is subpolygonal. The rim is slightly raised without denticulation. This species of Carboniferous North Amrcian have denticulations on the rim, but the denticulation is lacking in this specimen. *T. consonus* is differentiated from the species of *Microantyx* by the lack of a hub crossbar and presence of long spokes. In Japan, this species was reported from the Carboniferous Ichinotani F. m., Gifu Pref. and Onimaru F. m., Iwate Pref. (Kanasugi, 1979), and this is the first report of the species in Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Order Elasipoda Theel, 1882

Parafamily Protocaudinidae Deflandre-Rigaud, 1962

Genus *Microantyx* Komicker and Imbrie, 1958

Type species —*Microantyx permiana* Komicker and Imbrie, 1958

Remarks —This genus is characterized by the wheel sclerite having concavo-convex profile. Short spokes are connected to raised rim and central hab which bears rounded boss in its dorsal part and ventral X-shaped cross bars.

Microantyx botoni Gutschick, 1959

Fig. 28. 1, 2

Microantyx botoni: Gutschick (1959): p. 135, pl. 26, figs. 22, 23, 28, 29; Gustchick et al. (1967): p. 1471, pl. 186, fig. 41–53, pl. 187, figs. 16; Alexandrovsdcz (1971) p. 288, fig. 2, ill. 3 a–c, 4 a–c; Mostler (1971), p. 10, pl. 2, figs. 15; Nabavi and Hambi (1975): p. 14, pl. 3, figs. 1–4; Mostler and Rahimi-Yazd (1976): p. 22, pl. 1, figs. 1–5, 7, 11; Mostler (1983): p. 36, Text-fig. 1, pl. a, figs. 2, 3, 5, 6, 9–12; Hui (1985): p. 344, Text-fig. 4, pl. 1, figs. 12, 13, 16; Zhang (1993), p. 111, pl. I, figs. 1–6.

Referred Specimen —Fourteen specimens: 1 from AI-4, M-20, N210-4, NR-26. 2 from AI-2. 8 from MF-1.

Remarks— The specimen is a wheel sclerite bearing eight short spokes that arch between rim and hab. These form circular interspoken perforations. The rim is circular and raised. In dorsal view, the hub has conical rounded boss in its center. In ventral view, there are four depressions in a rectangular pattern forming X-shaped crossbar. This species differs from *M. permiana* by the numbers of spokes. This species has been reported from the Carboniferous-Permian North America, Europe and East Asia (e.g. Durham et al., 1966). Interestingly, most of modern elasipods are found in deep sea, but the Carboniferous ones have been reported from not deep environments.

Occurrence —Bashkirian–Moscovian from the Omi Limestone in the Fukugakuchi and Nishiyama areas, Akiyoshi Limestone Maruyama area.

Order Dactylochirotida Pawson and Fell, 1965

Parafamily Priscopedatidae Frizzell and Exline, 1955

Genus *Clavallus* Gilliland, 1992

Type species — *Priscopedatus spicaudina* Gutschick et al. 1967.

Remarks — The sclerite is a spired plate. Spire is relatively tall without perforations along most of its length. The distal end of the spire is variable in shape. The plate is single-layer of perforated lattice. The junction of plate and spire is formed by elevation of lattice.

***Clavallus* sp.**

Fig. 28. 4

Referred Specimen —One specimen from MF-1.

Remarks— The specimen is a spire without the plate due to poor preservation. The spire is tall and thin with pointed distal end. The cross-section of the spire is tri-radiated, and longitudinal ribs radiate centrifugally from a central core. Each ribs bears small denticulations.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Order Dendrochirotida Grube, 1840

Parafamily Calclaminidae Frizzell and Exline, 1955

Genus *Eocaudina* Martin, 1952 emend. Gutschick and Canis, 1971

Type species — *Eocaudina septaforaminalis* Martin, 1952 emend. Gutschick and Canis, 1971

Remarks —Holothurian sclerites forming sieve plates that are flat to concavo-convex in profile and variable in outline. Plate perforations are circular to polygonal in shape, closely packed.

Eocaudina subhexagona Gutschick et al., 1967

Fig. 28. 7

Eocaudina subhexagona: Gutschick et al. (1967): p. 1469, pl. 186, figs. 16–21, pl. 187, fig. 18; Mostler. (1968a): p. 12, pl. 2, fig. 4 ; Mostler. (1968b): p.55, pl. 2, figs.1–4; Zawidzka (1971), p. pl. I, figs. 8–11.

Referred Specimen —Two specimen from AI-4 and NR-26.

Remarks— Sieve plate is weakly to moderately concavo-convex in profile, and has an almost hexagonal outline. Plate perforations are sub-circular and densely packed. This species has long range occurrence and usually reported form the Carboniferous to Triassic strata of North America and Europe (e.g. Molster, 1968; Zawidzka, 1971). In Japan, *Eocaudina* cf. *subhexagona* was reported from the Silurian Yokokurayama Limestone (Kanasugi, 1979). This is the first report of the species from the Omi and Akiyoshi Limestone.

Occurrence — Moscovian from the Omi Limestone in the Nishiyama and Akiyoshi Limestone in the Maruyama area.

Class Ophiuroidea Gray, 1840

Order Oegophiurida Matsumoto, 1915

Family Furcasteridae Stürtz, 1886

Genus *Furcaster* Stürtz, 1886

Type species — *Furcaster palaeozoicus* Stürtz, 1886.

Remarks — The sclerites with lyra form were assigned to holothurian sclerites, placing these in the genus *Prosynapta* (Spandel, 1898), and later the genus was emended as *Calclyra* (Frizzell and Exline, 1955). More recently, the sclerite was revealed to be tentacle scales of the ophiuroid (Boczarowski, 2001). The genus *Furcaster* is cosmopolitan of the Upper Ordovician- Carboniferous (Durham et al. 1966) and famous for its complete figures from the Devonian Bundenbach locality.

***Furcaster* sp.**

Fig. 28. 5, 6

Prosynapta eiseliana: Spandel (1898): p. 44, taf. XIII, fig. 10.

Calclyra eiseliana: Frizzell and Exline (1955): p. 100, pl. 4, fig. 34; Mostler (1971): p. 18, Table.

1.16–19.

Furcaster sp.: Boczarowski (2001): p. 37, fig. 15, AM–AN.

Referred Specimen —Eleven specimens: 1 from AI-2, AI-4, F-13, N210-3, 2 from M-18 and NR-26, 3 from MF-1.

Remarks— The scale has a form of lyra with two tear− shaped elongated slits in the arched part. The scale consisted of lower arched part and upper neck. The neck is slightly thicker in its upper end, and occupies 1/2-1/4 of entire height of the specimen. In the lower portion is composed of central shaft and two arms. The arms slope moderately out from the junction with central shaft and curve broadly. This is the first report of ophiuroid fossil from the Omi Limestone and is also the oldest fossil record of ophiuroids in Japan.

Occurrence —Bashkirian–Moscovian from the Omi Limestone in the Fukugakuchi and Nishiyama areas, and Akiyoshi Limestone Maruyama.

8. 6 Phylum Porifera

Sponges are many-celled aquatic animals constituting Porifera characterized by bulky internal skeletons. These skeletons are composed of spicules of opaline silica or calcium carbonate. In fossil sponges, the morphologies of spicules are of taxonomically importance. This study describes three species by the form of spicules.

Phylum Porifera Grant, 1836

Class Calcarea Bowerbank, 1864

Calcarea indet.

Fig. 29. 1, 4

Referred Specimen —Three diactines: 1 from M-20. 2 from MF-1.

Remarks— The spicule have single axis with both ends pointed. This type of spicule is common in Calcarea.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Subclass Calcaronea Bidder, 1898

Calcaronea indet.

Referred Specimen —Seven triactines: 1 from AI-4 and M-20. 2 from AI-2. 3 from MF-1.

Remarks— The spicule have three rays of equal-length and the rays are separated by angles of 120°. The class calcarea is divided into two subclass calcaronea and calcinea. Spicules of regular tetractine and regular tetractine are distinctive in Calcaronea. This is the first report of calcaronea fossils from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area, and Moscovian form the Akiyoshi Limestone in the Maruyama area.

Class Demospongia Sollas, 1885

Subclass Heteroscleromorpha Cárdenas et al., 2012

Heteroscleromorpha indet.

Fig. 29. 5, 6

Referred Specimen —Three sanidasters from MF-1.

Remarks— Microstrongyle with large strongylote spicules representing the variants of small sanidaster. Heteroscleromorpha include all spicule-bearing groups of Demospongia without Chondrosiida. The characteristics of morphology, arrangement and size of spicules necessary for further detailed identification. This is the first report of heteroscleromorpha fossils from the Omi Limestone.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

8. 7 Group Chitinozoa

Chitinozoans are a group of vase- shaped and thin organic- walled microfossils which occur in marine sedimentary rocks of the Early Ordovician to Carboniferous age. They are common from the Ordovician to Devonian periods and are valuable biostratigraphic markers. The group is divided into two orders, Operculatifera and Prosomatifera, by the presence of the neck structures. Prosomatifera species has an oral tube above a chamber as a neck. In the Omi Limestone, only mineralized void is preserved without a wall, the taphonomic case of which was proposed by Porter and Knoll (2000).

Phylum incertae sedis

Group Chitinozoa Eisenack 1931

Order Prosomatifera Eisenack, 1972

Prosomatifera indet. A

Fig. 29. 7

Referred Specimen —Two specimen from M-2 and M-18.

Remarks—The small vase- shaped fossil bearing an ovoid to spherical chamber, and a cylindrical neck. The neck is of medium length (represents about 1/3 of the total vesicle length). The collarette is flared and the aperture is wide. It is different from Prosomatifera indet.B, C by the short neck with larger aperture.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Prosomatifera indet. B

Fig. 29. 8

Referred Specimen —One specimen from AI-9.

Remarks—The small vase- shaped fossil bears an ovoid chamber, and a cylindrical thin neck. The neck is of medium length (represents about 1/4 of the total vesicle length). The collarette is slightly flared and the aperture is quite thin. It is different from Prosomatifera indet. A, C by the thinner width of the aperture.

Occurrence —Moscovian from the Akiyoshi Limestone in the Maruyama area.

Prosomatifera indet. C

Fig. 29. 9

Referred Specimen —one specimen from M-18.

Remarks—The small vase- shaped fossil bears an ovoid chamber with inconspicuous neck (represents about 1/3 of the total vesicle length). The collarette is slightly flared and the aperture is thin (represents about 1/2 of the width of chamber). It is different from Prosomatifera indet. A, B by the ambiguous neck.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

8. 8 "Microproblematica"

"Microproblematicas" are microfossils with problematic taxonomic postions. The affinities of them are unclear. This study treats unknown microfossils as "microproblematicas" and describes eight species.

Microproblematica A

Fig. 30. 1

Referred Specimen —One specimen from M-2.

Remarks— The hemispheroidal shell with numerous small radiant spines on its surface. The back side of the shell is smooth.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Microproblematica B

Fig. 30. 2

Referred Specimen —One specimen from M-2.

Remarks— The specimen is small and sphaerical with finely reticular surface. At first glance, it resembles spumellaria radiolarians, but the reticulation is too fine and the morphologies of pits are different.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Microproblematica C

Fig. 30. 3, 4

Referred Specimen —three specimens from M-18.

Remarks— The specimen is small, slender and elongate cup- shaped fossil with a thin stem. The height of the cup varies and sometimes the cup has a brunching. Kozur (1993) suggested it might be bryozoan fossil.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Microproblematica D

Fig. 30. 5

Referred Specimen —Eleven specimens from MF-1.

Remarks— The specimen is elongate cylindrical with slightly thicker both ends. The cross- section is circular. Bad- preservation makes the surface of it rough, but no pits or cavities are present. The ratio of height/ length varies from 2.5 to 4. It may be small components of echinoderms.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Microproblematica E

Fig. 30. 6, 7

Referred Specimen —Four specimens from M-16.

Remarks— The specimen is elongate tubular fossils consisting of some short clausal. The cross-section is circular and the inner part of the specimen is occupied by cavity. One specimen show a probable end of the fossil which tapers the tip, and whole morphology of the specimen is slender conical.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Microproblematica F

Fig. 30. 8

Referred Specimen —One specimen from MF-1.

Remarks— The slightly recurved conical shell having an inside cavity. The ratio of H/L is approximately 3. The surface of the shell is smooth. It differs from the Microproblematica G and H by the lacks of surface ornamentations.

Occurrence —Bashkirian from the Omi Limestone in the Fukugakuchi area.

Microproblematica G

Fig. 30. 9

Referred Specimen —One specimen from AI-9.

Remarks— The erected conical shell having a cavity inside. The ratio of H/L is approximately 3. The surface of the shell is ornamented by latitudinal rows of very small nodes. The row are closely spaced and occupies the almost entire height.

Occurrence —Moscovian from the Akiyoshi Limestone in the Maruyama area.

Microproblematica H

Fig. 30. 10

Referred Specimen —One specimen from N210-3.

Remarks— The thin conical shell having an inside cavity. The ratio of H/L is about 3. The surface of the shell is ornamented by many longitudinal striations. The striations are fine and limited on the middle part of the shell probably due to the poor preservation.

Occurrence —Bashkirian from the Omi Limestone in the Nishiyama area.

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Period	Subperiod	Stage: Russia	Stage: North America	smaller foraminifer and fusulinacean based: Kawada (1954)	Fujita (1958)	Hasegawa (1969)	Watanabe (1973)	Hasegawa(1982)	Hasegawa and Goto (1990)	Kano and Yoshida (1994)	Nakazawa (1997)	conodont based: Isomura (1996)	coral based: Yoshida et al. (1984)
Carboniferous	Pennsylvanian	Gzhelian	Virgilian	*Triticites* zone (C3)	*Triticites* zone (C3)		*Triticites montiparus* zone	*Triticites* zone	*Triticites* sp. A zone			*Mesogondolella dentiseparata* zone	
		Kasimovian	Missourian										
			Desmoinesian						*Triticites simplex* subzones.		*Beedeina* sp. zone	*Streptognathodus elegantulus* zone	
		Moscovian		*Fusulinella* zone (C2)	*Fusulinella* zone (C2)	*Fusulina-Fusulinella* zone	*Fusulinella purchra* zone	*Fusulina-Fusulinella* zone	*Fusulina-Fusulinella* zone				
							Fusulinella biconica zone				*Fusulinella biconica* zone	*Idiognathoides pacificus* zone	
			Atokan				*Fusulinella simplicata- F. itoi* zone						
				Coral-brachiopod zone (C1)	*Millerella*-coral-brachiopod zone (C1)	*Profusulinella* zone	*Akiyoshiella ozawai* zone	*Profusulinella* zone	*Profusulinella* zone		*Akiyoshiella ozawai* zone	*Mesogondolella? clarki* zone	
		Bashkirian					*Profusulinella omiensis- P. daiyamensis* zone				*Profusulinella daiyamensis* zone	*Streptognathodus expansus* zone	
						Eostaffella-Millerella zone	*Pseudostaffella antiqua* zone	*Eostaffella-Millerella* zone	*Eostaffella-Millerella* zone	*Pseudostaffella antiqua* zone	Pseudostaffella antiqua zone		Pseudopavonid assemblage zone
			Morrowan				*Eostaffella-Millerella* zone			*Eostaffella-Millerella* zone	*Millerella marblensis* zone	*Declinognathodus noduliferous* zone	*Hiroshimaphyllum toriyamai-Amygdalophylloides gracilis* assemblage zone
	Mississippian	Serpukhovian	Chesterian							*Eostaffella kanumai* zone	*Eostaffella mosquensis* zone	*Gnathodus billineatus* zone	
		Visean										*Gnathodus girty* zone	
			Meramecian					*Endothyra* zone	*Endothyra* zone	*Mediocris breviscula* zone	*Mediocris breviscula* zone		*Echigophyllum giganteum-Amygdalophylloides gracilis* assemblage zone
										Endothyra zone	*Endothyra* spp. zone		*Akiyoshiphyllum stylophorum- carcinophyllum* spp. assemblage zone

Table 1. Correlation chart of biozones of the Carboniferous Omi Limestone. These biozones are based the occurrences of foraminifers and conodonts.

Subperiod	Stage		Akiyoshi						South Kitakami	Akiyoshi
			Omi	Atetsu	Taishaku	Hina	Ko-yama	Akiyoshi		Omi
	Russia	North America	Isomura (1996)	Koike (1967)	Mzuno (1990)	Mzuno (1997)	Ishida et al. (2013)	Igo (1973); Haikawa (1988)	Nakamura in Minato et al. (1979)	**This study**
Pennsylvanian	Kasimovian	Desmoinesian								
	Moscovian									
		Atokan								
			M?. clarki zone	Gon. clarki-Polygnathodella ouachitensis zone	Neogondolella clarki-Idiognathodus delicatus		Id. convexus- Gon. clarki zone			M. clarki zone
	Bashkirian		S. expansus zone	Idiognathodus parvus-Gnathodus nodulifera zone	Neognathodus bassleri-Idiognathoides opimus zone		N. symmetricus-Idiognathodus primulus zone		Idiognathoides sulcatus zone	S. expansus zone
									Idiognathoides noduliferus zone	
		Morrowan								
			Declinognathodus noduliferous zone	Gnathodus wapanuckensis zone						Id. sulcatus zone
						N. symmetricus zone				
								Neognathodus bassleri symmetricus-Paragnathodus nagatoensis zone		
						Neol. koikei zone				
						Neol. nagatoensis zone				
				Gnathodus bilineatus-Gnathodus nodulifera zone	Gnathodus bilineatus-Declinognathodus noduliferous zone	Declinognathodus noduliferous zone		Milerlla yowarensis zone		Declinognathodus noduliferous zone

Table 2. Biostratigraphic correlation chart of Pennsylvanian conodonts in the domestic regions. Hilighlitened part is this study.

<table>
<tr><th rowspan="3">Period</th><th rowspan="3">Subperiod</th><th colspan="2" rowspan="2">Stage</th><th>South America</th><th>midcontinent</th><th>Western Europe</th><th>Eastern Europe</th><th>Siberia</th><th>Eastern Asia</th><th>Akiyoshi</th></tr>
<tr><th>Brazil</th><th>USA</th><th>Spain</th><th>Ukraine</th><th>Russia</th><th>South China</th><th>Omi</th></tr>
<tr><th>Russia</th><th>North America</th><th>Scomazzon et al. (2016)</th><th>Barrick et al. (2004, 2013)</th><th>Nemyrovska et al. (2011)</th><th>Nemyrovska (1999)</th><th>Nemyrovska and Aleseev (1994); Kulagina et al. (2009)</th><th>Qi et al., 2011;Hu et al. (2017)</th><th>This study</th></tr>
<tr><td rowspan="15">Caboniferous</td><td rowspan="15">Pennsylvanian</td><td>Kasimovian</td><td rowspan="2">Desmoinesian</td><td rowspan="5"></td><td rowspan="5"></td><td rowspan="11"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td><td rowspan="3"></td></tr>
<tr><td rowspan="3">Moscovian</td></tr>
<tr><td rowspan="5">Atokan</td></tr>
<tr><td>Dec. donetzianus zone</td><td>Dec. donetzianus zone</td><td>Dip. elesmerensis zone</td><td>M. clarki zone</td></tr>
<tr><td rowspan="11">Bashkirian</td><td>Dec. marginodosus zone</td><td>Dec. marginodosus zone</td><td>S. expansus M2 zone</td><td rowspan="5">S. expansus zone</td></tr>
<tr><td rowspan="2">I. incurvus</td><td>I. incurvus</td><td>Id. tuberculatus- Id. fosatus zone</td><td rowspan="6">I. sinuousus</td><td rowspan="4">S. expansus M1 zone</td></tr>
<tr><td>Id. convexus</td><td rowspan="2">S. expansus zone</td></tr>
<tr><td rowspan="8">Morrowan</td><td rowspan="3">Rh. muricatus</td><td>I. klapperi</td></tr>
<tr><td>I. sinuousus</td><td rowspan="3">I. sinuosus- Id. sulcatus parvus zone</td></tr>
<tr><td>N. bassleri</td><td rowspan="2">Id. sulcatus parvus zone</td><td rowspan="5">Id. sulcatus zone</td></tr>
<tr><td rowspan="2">N. symmetricus</td><td rowspan="2">N. symmetricus</td></tr>
<tr><td rowspan="2">Id. sinuatus</td><td rowspan="3">Id. sinuatus- Id. sulcatus sulcatus zone</td><td>N. askynensis</td><td rowspan="2">Id. sinuatus</td></tr>
<tr><td rowspan="3"></td><td rowspan="2">Id. sinuatus</td><td rowspan="2">Id. corrugatus zone</td></tr>
<tr><td>Id. asiaticus</td><td>Id. sulcatus sulcatus zone</td></tr>
<tr><td>Dec. noduliferus zone</td><td>Dec. noduliferus zone</td><td>Dec. noduliferus zone</td><td>Dec. noduliferus zone</td><td>Dec. noduliferus zone</td><td>Declinognathodus noduliferous zone</td></tr>
</table>

Table 3. Biostratigraphic correlation chart of Pennsylvanian conodonts in the foreign regions. Hilighlitened part is this study.

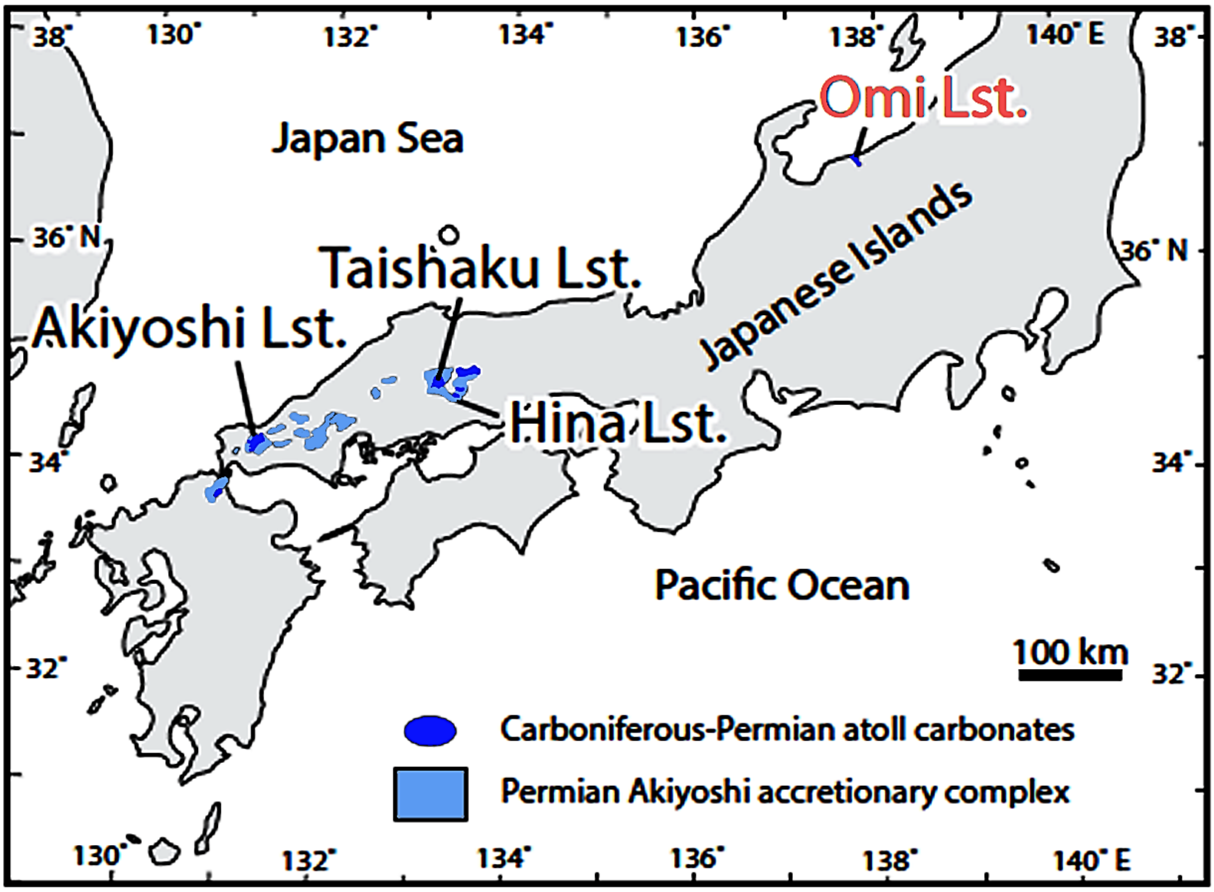

Figure 1

The distributions of the atoll-reef limestones in the Akiyoshi Terrane. The Omi Limestone is located in the easternmost part of the terrane in Niigata Prefecture (after Sakata et al., 2015).

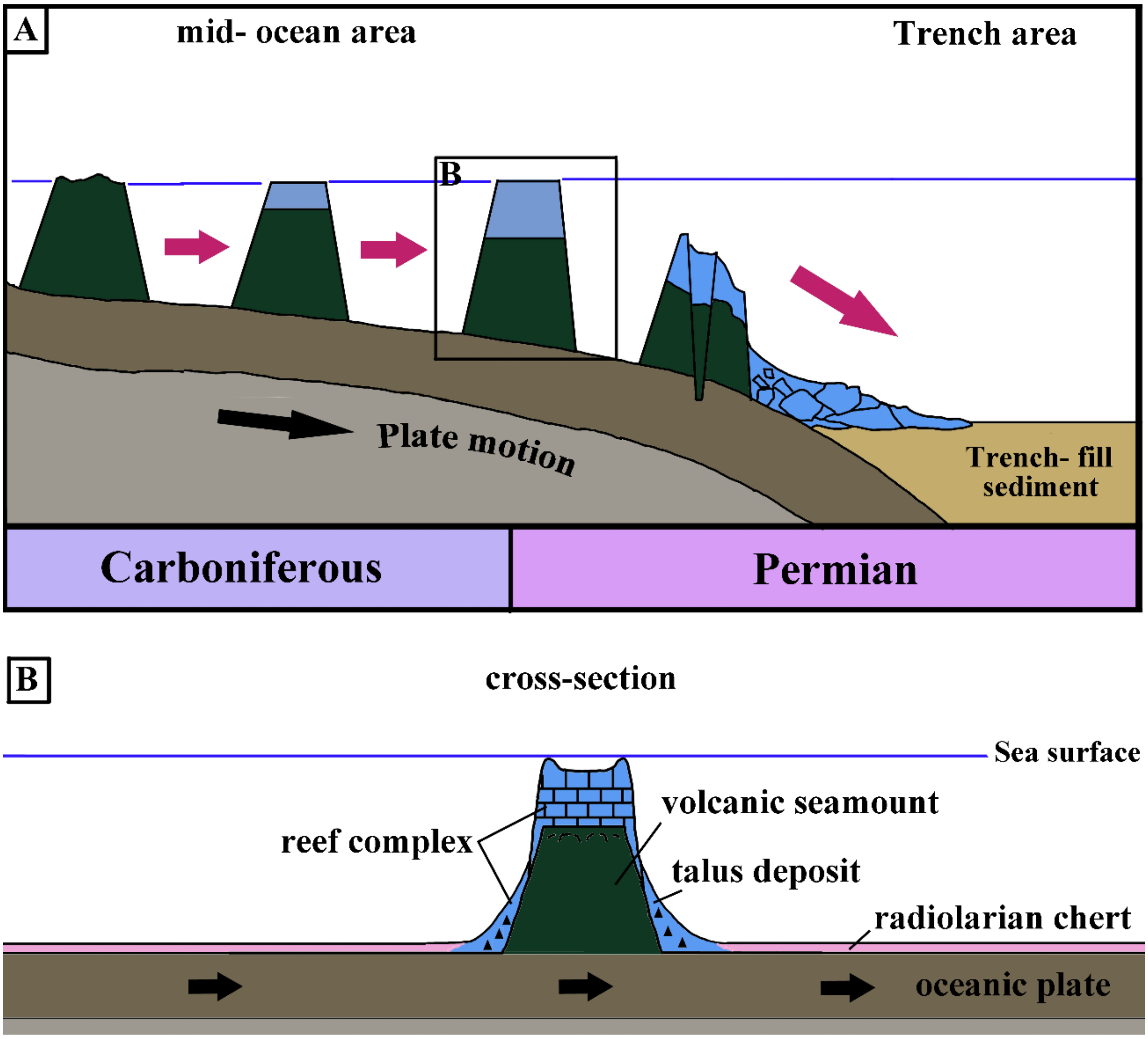

Figure 2

A, Schematic illustration depicting sedimentary history of atolls of Akiyoshi Terrane from Early Carboniferous birth in mid-oceanic realm, to middle Permian death at convergent margin (after Sano et al., 2006). **B**, the simplified model of atoll –cross section (afyer Higa, 2009).

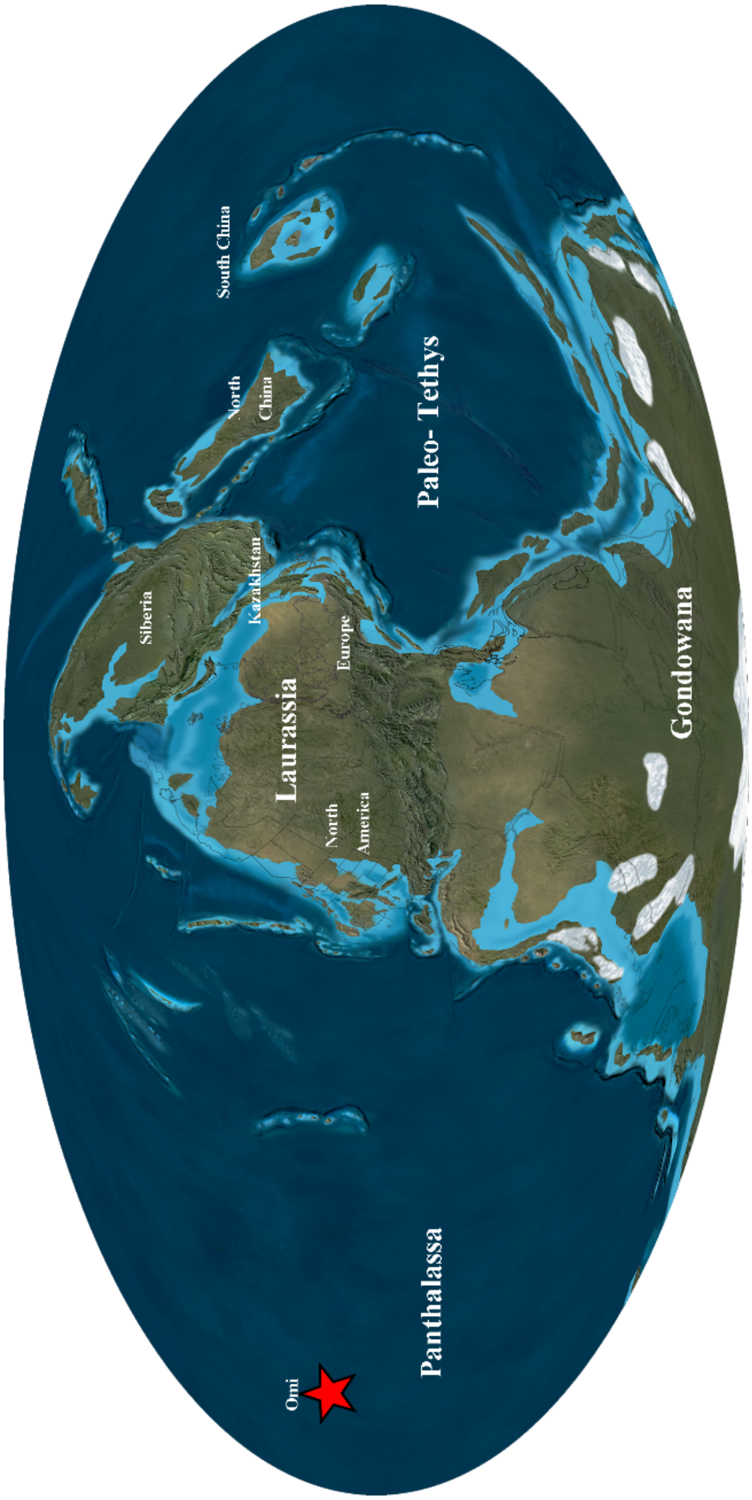

Figure 3

The paleogeography of the Carboniferous Omi Limestone. The atoll reef of the limestone is thought to be paleogeographically located low to middle latitudinal area in the Panthalassa (e.g. Fujiwara, 1967; Tazawa et al. 2004). The base map is from Deep Time Maps™.

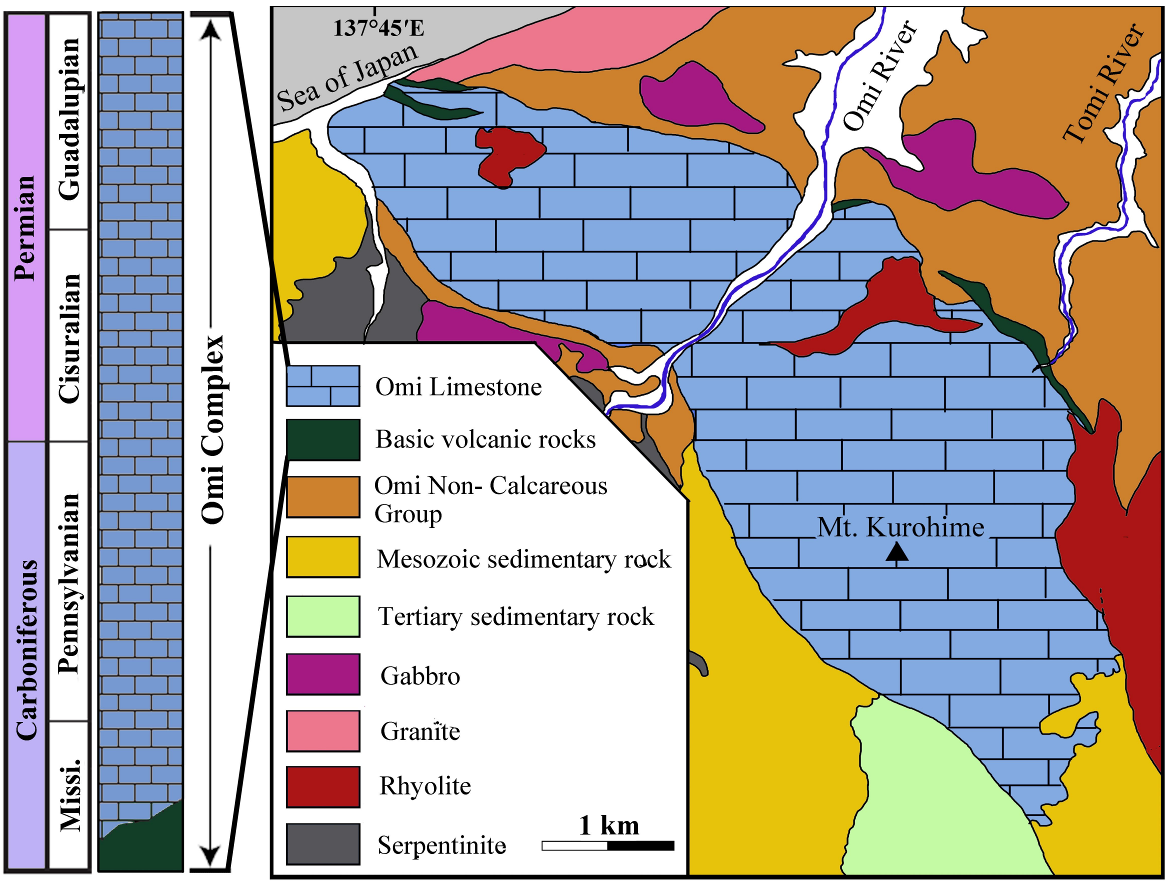

Figure 4

The geological map of the Omi area (after Nagamori et al., 2010). Omi Limestone huge block bearing an elongate extent of 8 km length and 2 km width along the Omi River. Nagamori et al (2010) gives the name Omi Limestone for only the carbonate part and they defined the Omi Complex for the collaboration of limestone and basalt.

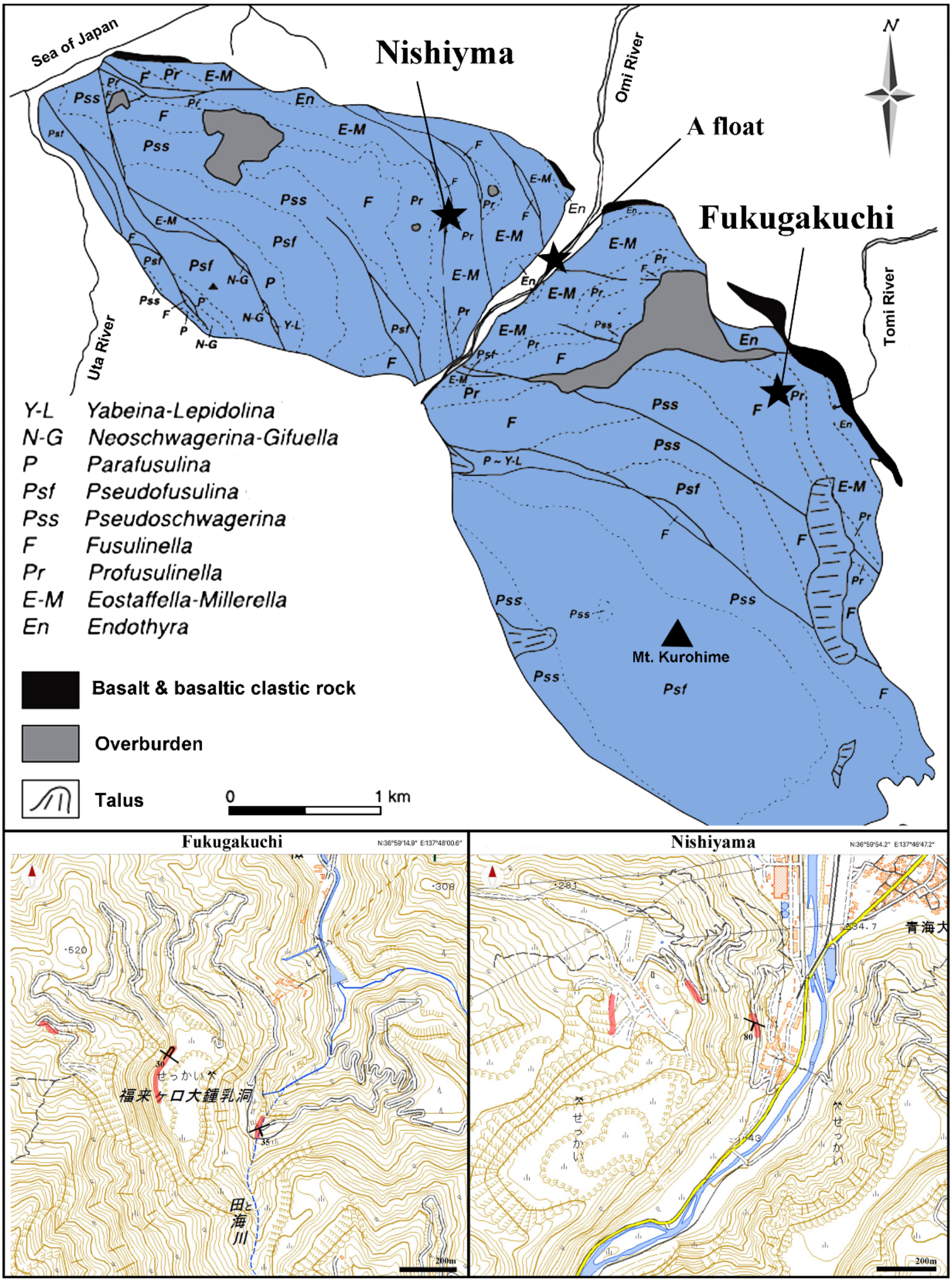

Figure 5

Sampling localities of the Carboniferous Omi Limestone. Upper map is the destributions of biozones of Hasegawa and Goto (1900). Lower maps are 1/25,000 topographic scale maps issued by Geographical Survey Institute. Red lines on these lower maps represent studied sections.

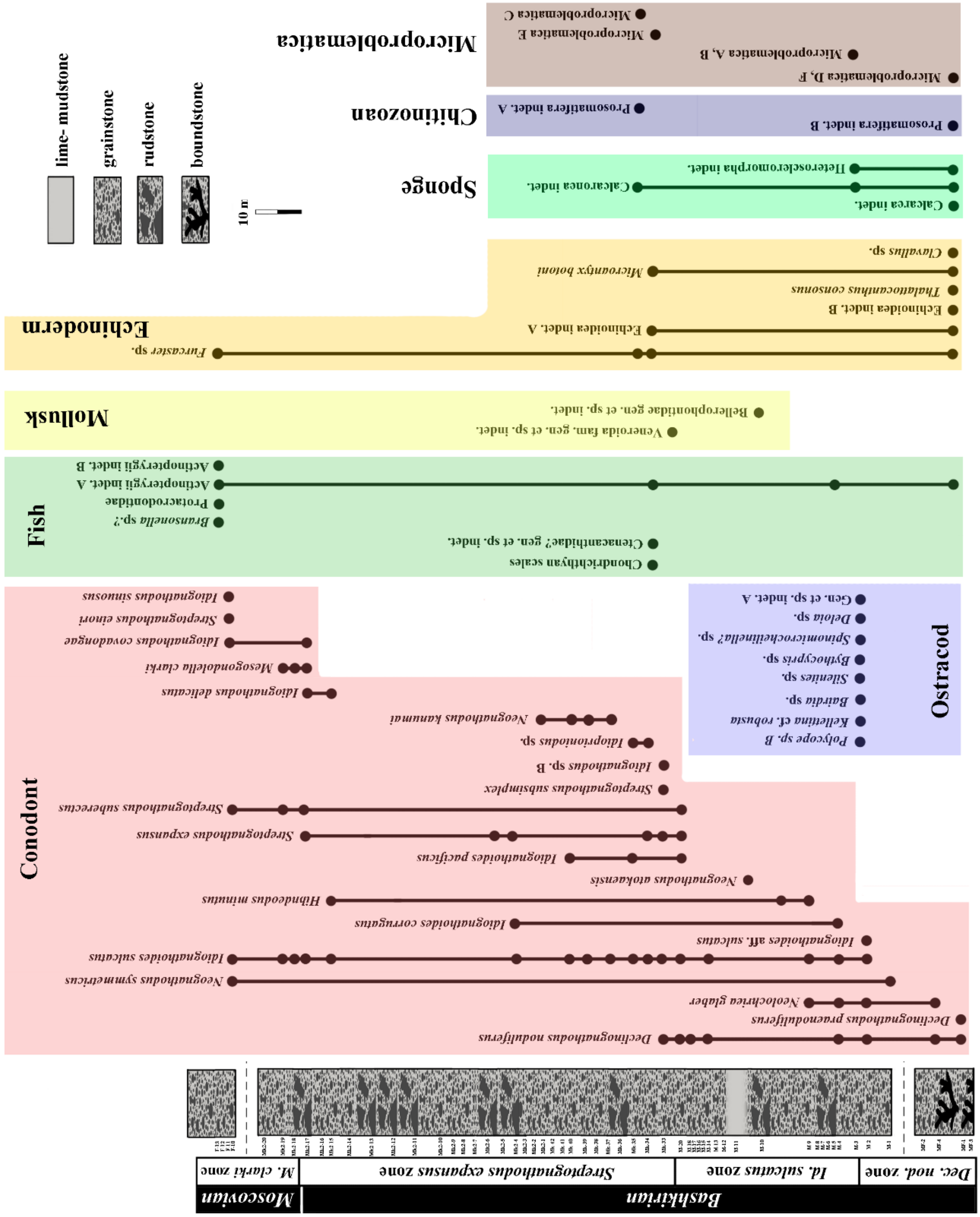

Figure 6

The columnar section and associated microfossils of the Fukugakuchi area.

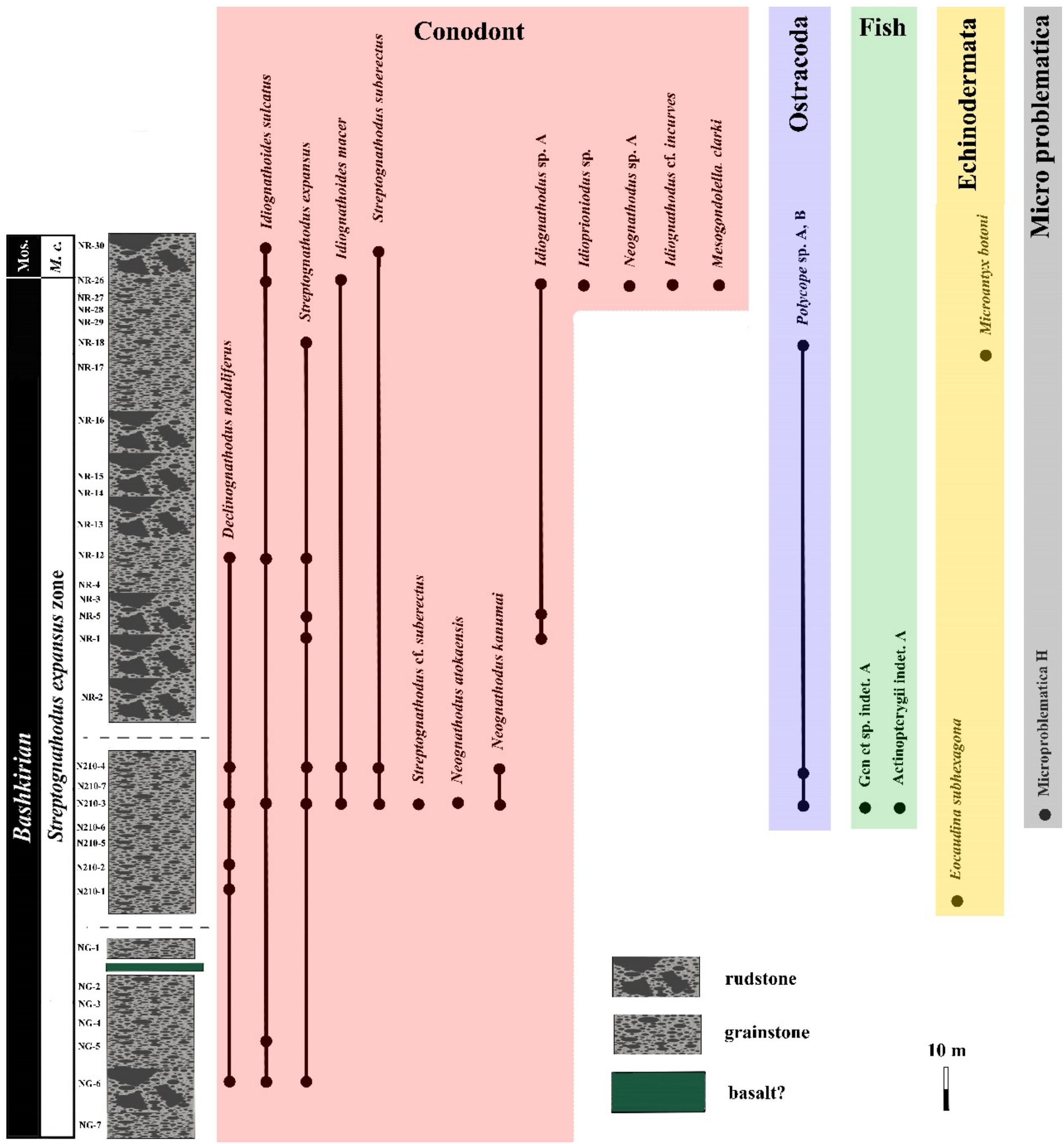

Figure 7

The columnar section and associated microfossils of the Nishiyama area.

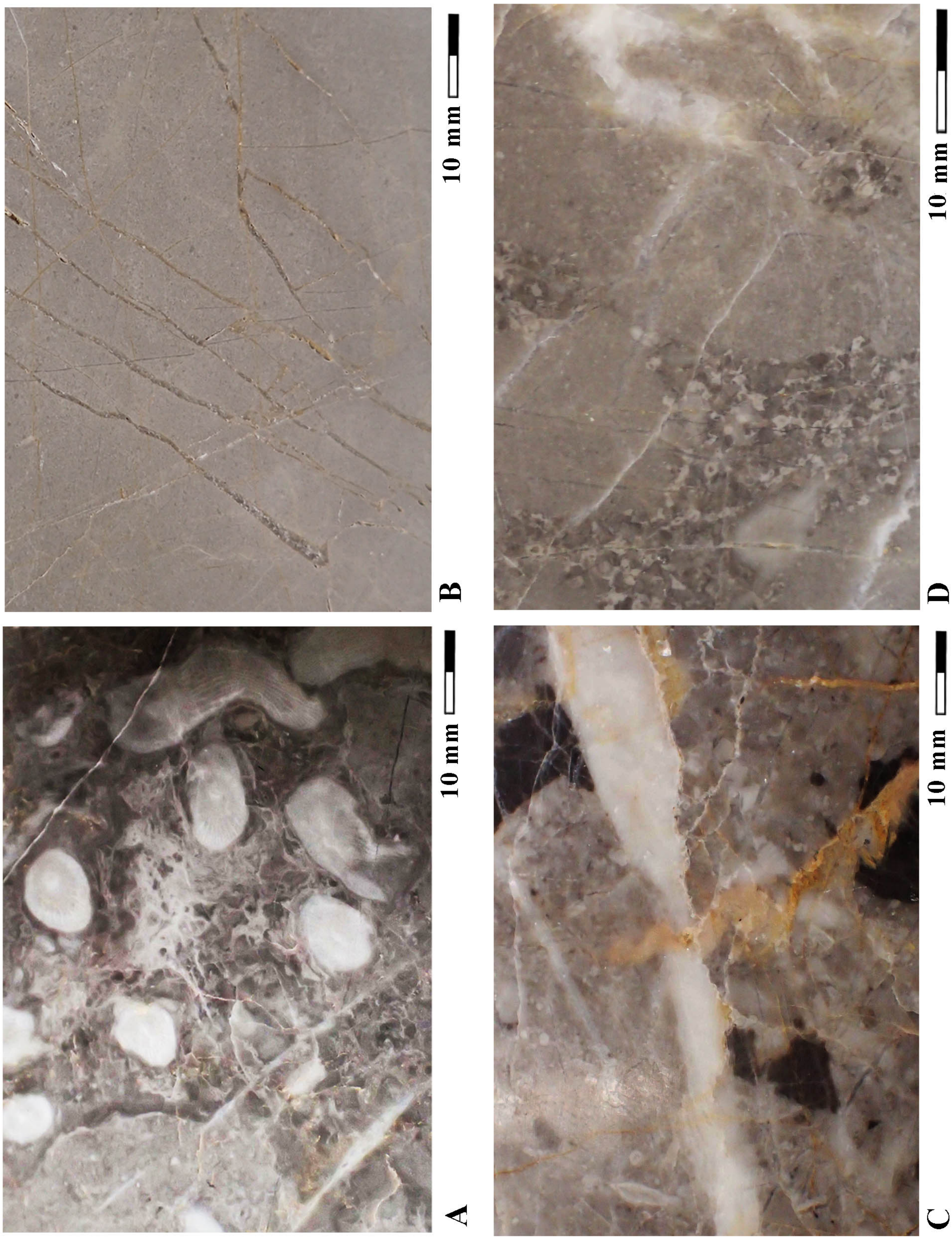

Figure 8

Polished surfaces of the limestones. A, boundstone. Corals are encrusted and bounded by the algae. B, lime-mudstone. C, D, rudstones. Rudstones are composed of lithoclasts, black pebbles and bioclasts.

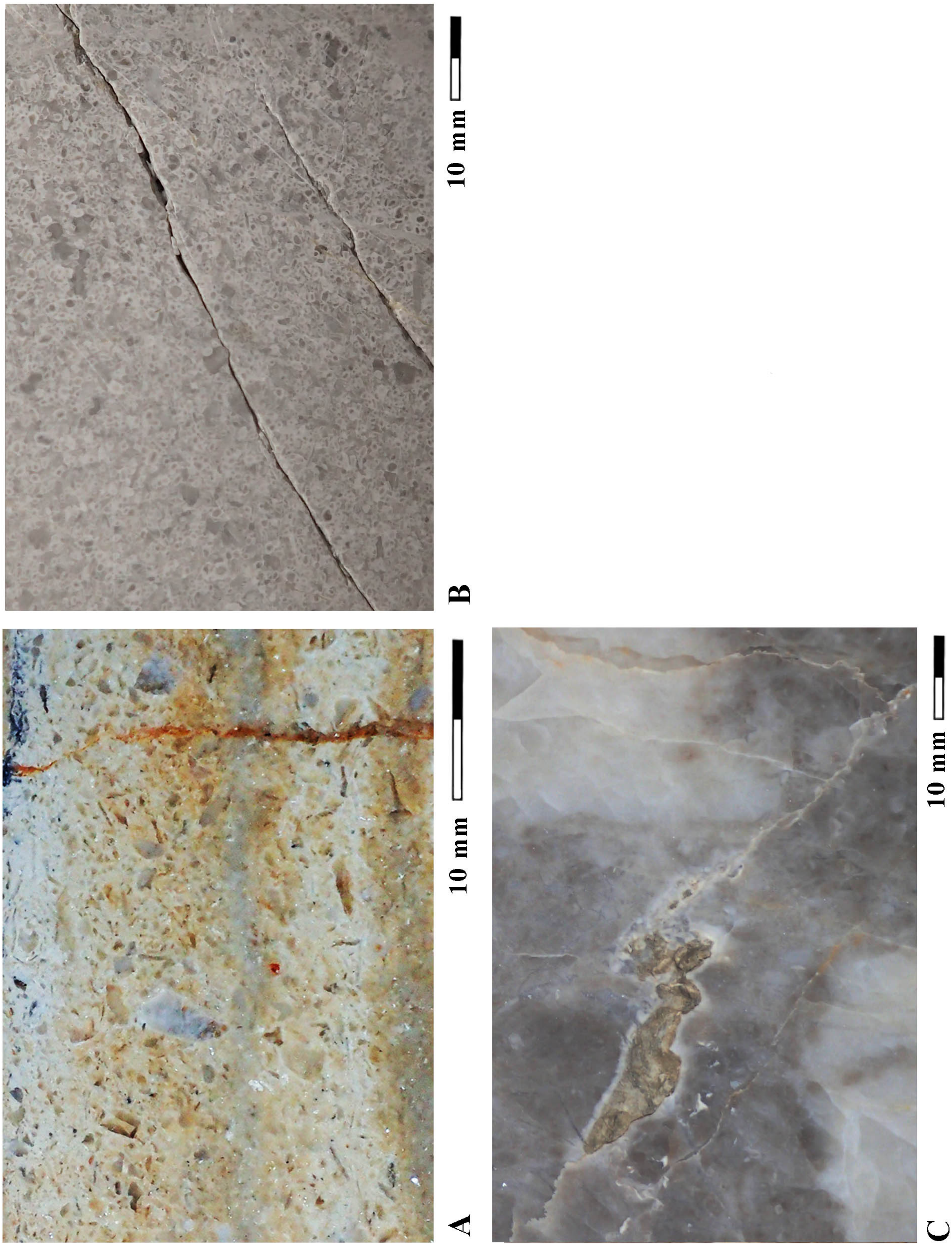

Figure 9

Photo images of polished surfaces of the grainstone. A, graded grainstone which includes larges sized lithoclasts. B, oolitic grainstone. C, grainstone including fragmented corals *Ozakiphyllum*.

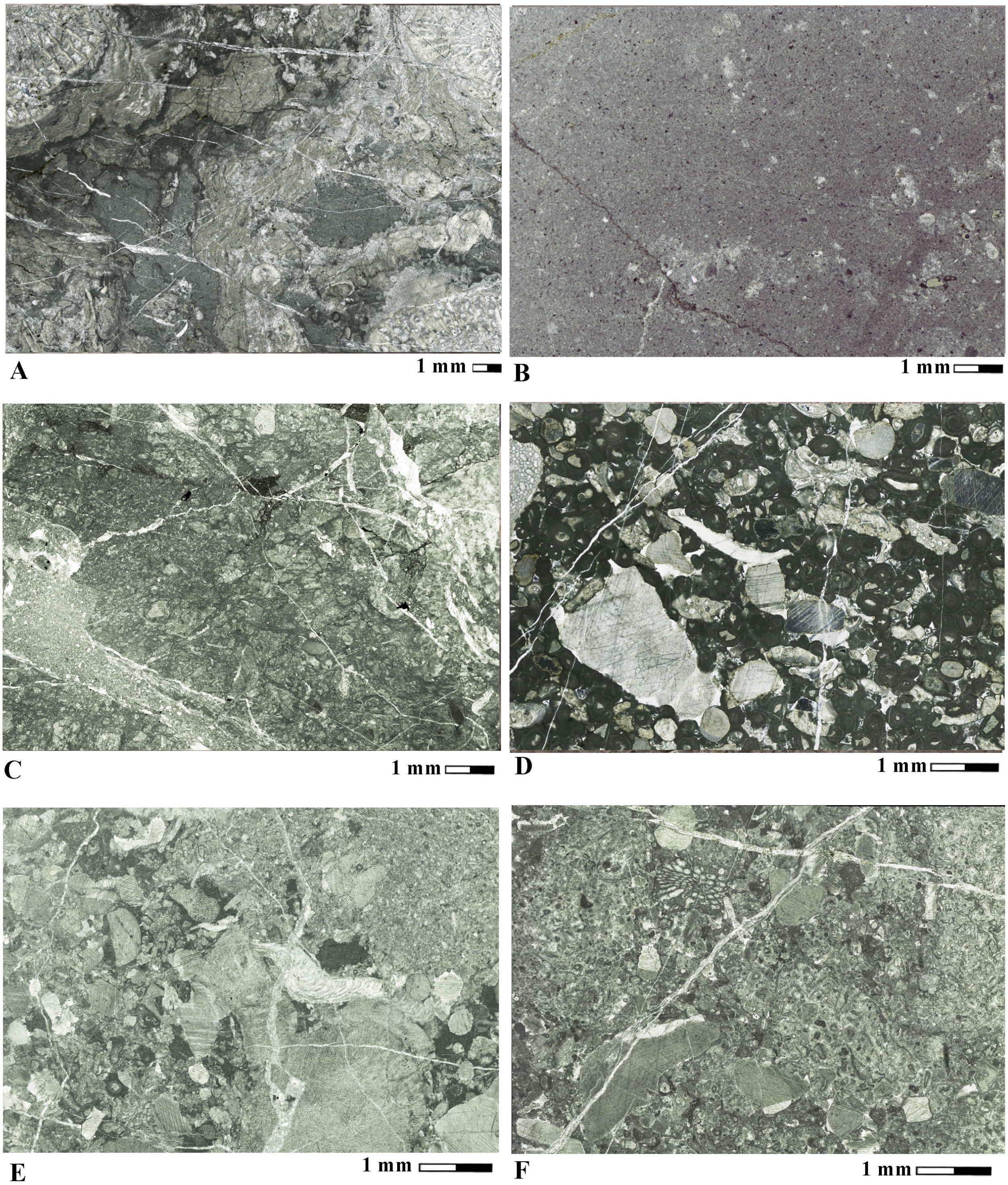

Figure 10

Thin sections of the limestones. A, boundstone. B, lime-mudstone. C, E, rudstone. C represents lithoclastic rudstone and E bioclastic-lithoclastic rustone. D, oolitic grainstone. F, bioclastic grainstone. Scale bars represent 1mm.

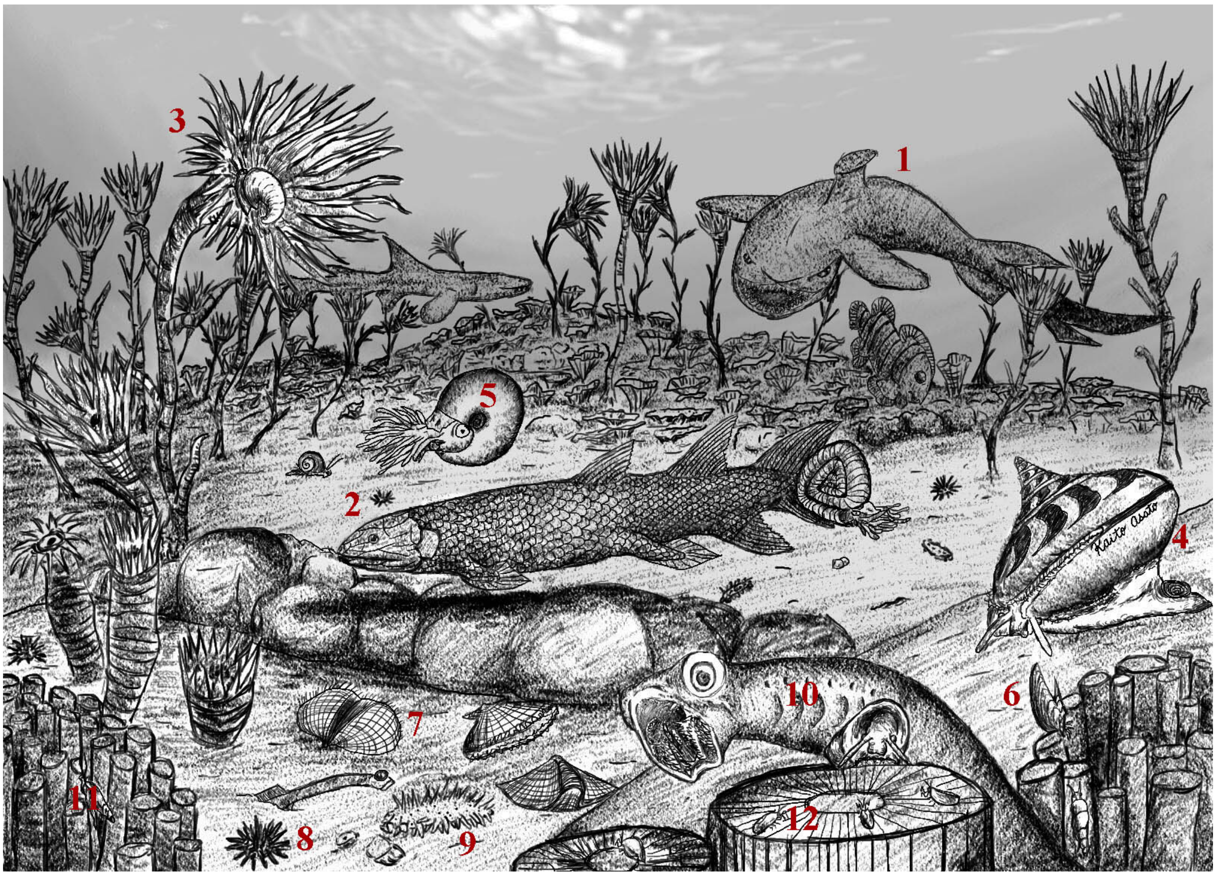

Figure 11

Reconsturuction of the Carboniferous pelagic reef, as inferred from the Omi Limestone. This ecosystem includes newly reported taxa such as actinopterygians, chondrichthyans, holothurian, echinoids and so on.1, chondrichthyan; 2, actinopterygian; 3, crinoid; 4, gastropod; 5, cephalopod; 6 bivalvia; 7, brachiopod; echinoid; 9, holothuroid; 10, conodont animal; 11, coral; 12, ostracod.

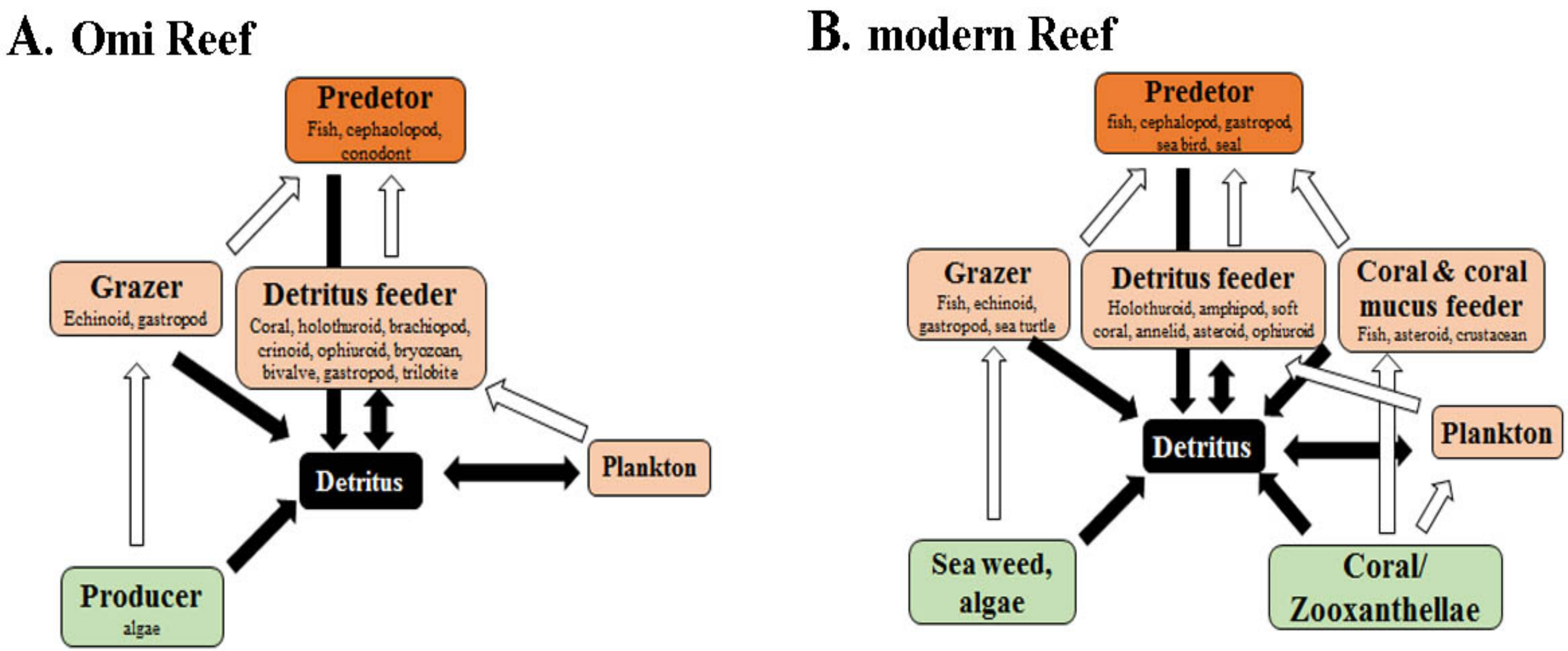

Figure 12

The schematic image of substance cycle of reef ecosystem. A, pelagic reef of the middle Carboniferous Omi Limestone; B, modern reef (after Omori, 2003; Polvina, 1984). White arrows indicate grazer food chain, and black detritus food chain.

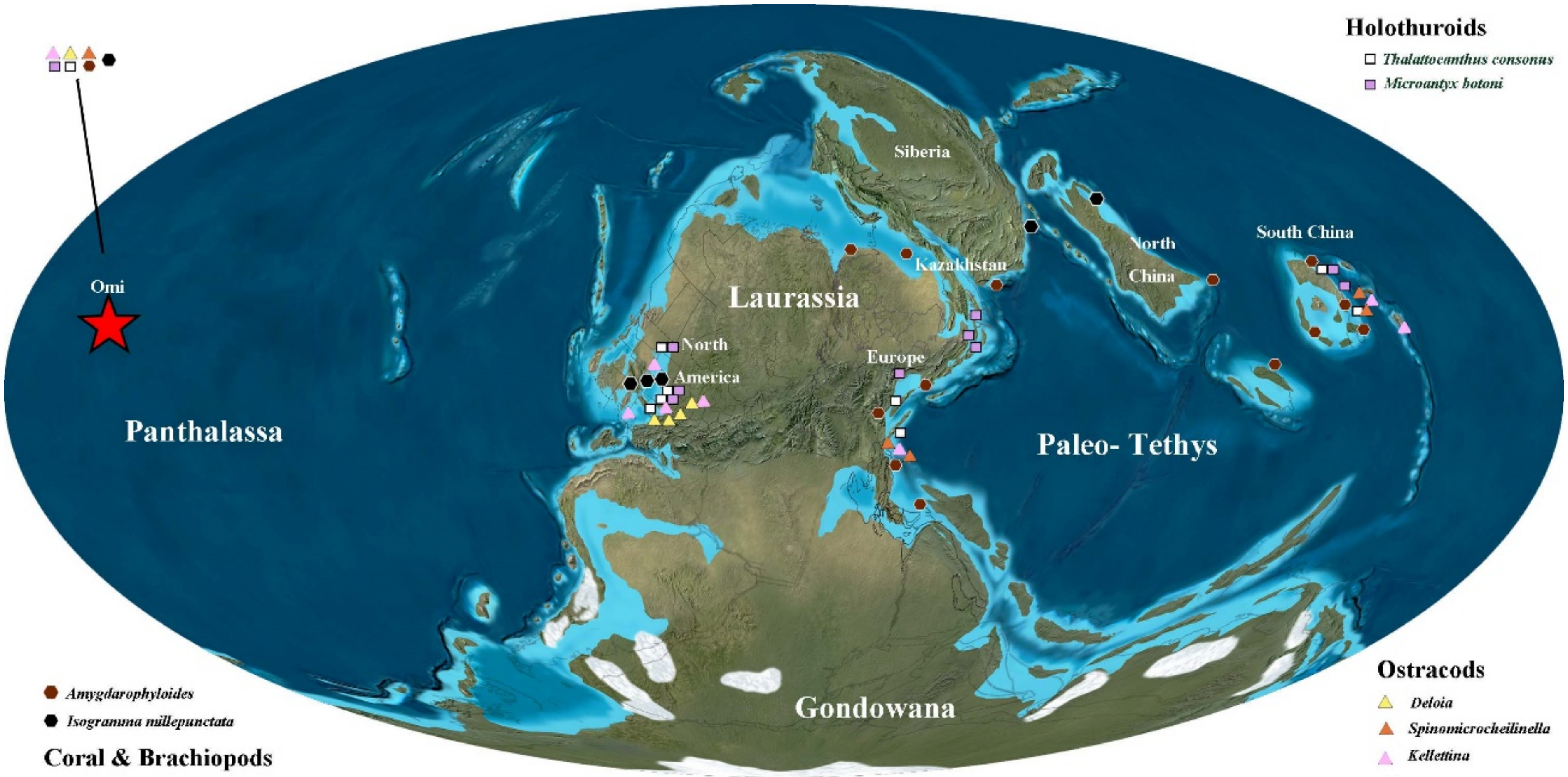

Figure 13

Geographic distributions of benthic animals consisting the Omi fauna. In benthos, holothuroid sclerites (*Thalattocanthus consonus* and *Microantyx botoni*) and ostracods (*Deloia, Spinomicrocheilinella* and *Kellettina*) are plotted addition to *Amygdarophyloides* of Yoshida and Okimura (1992) and *Isogramma milleppunctuta* of Tazawa et al. (2004). are also plotted.

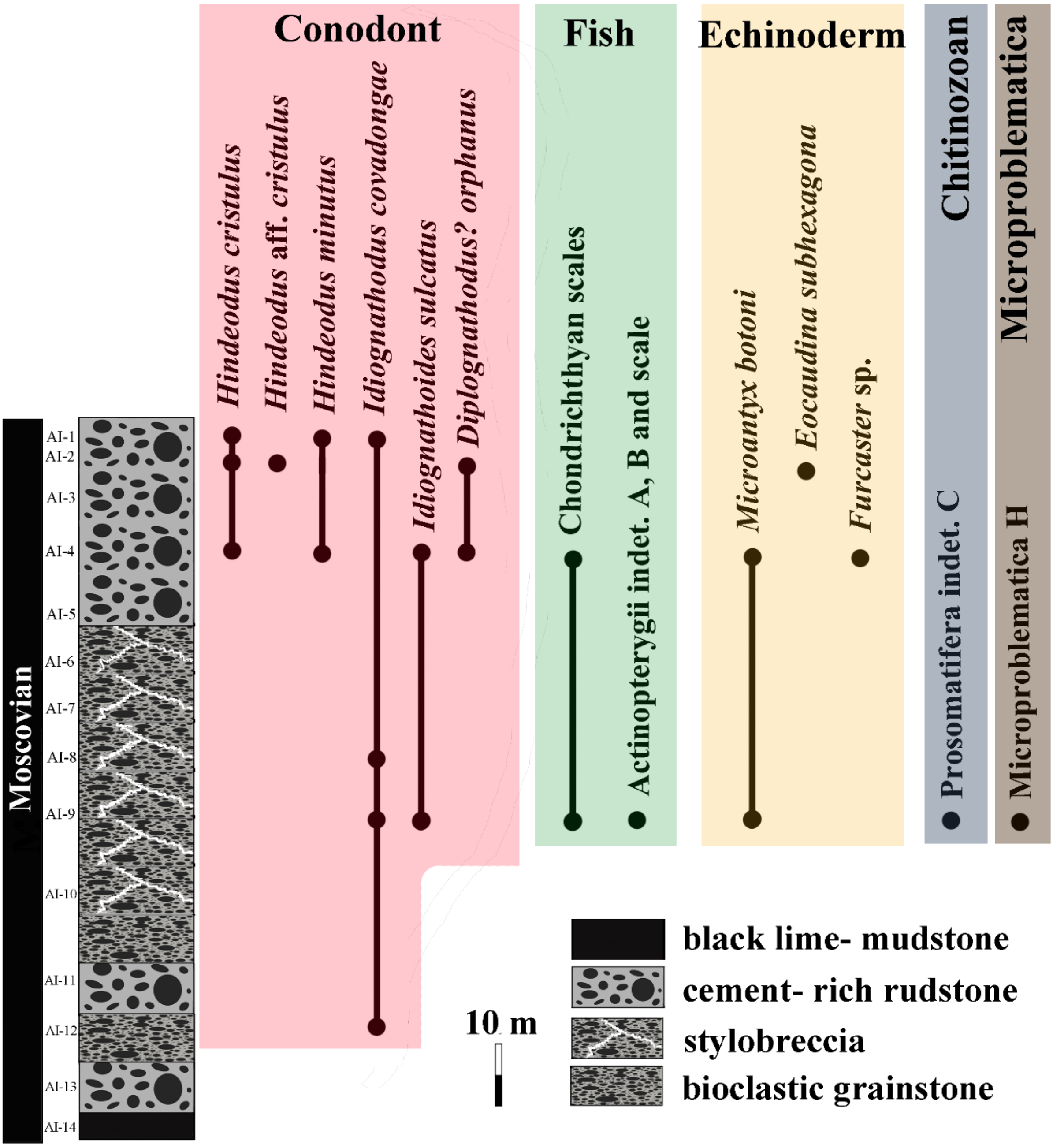

Figure 14

The columnar section and associated microfossils of the Maruyama area, Akiyoshi Limestone.

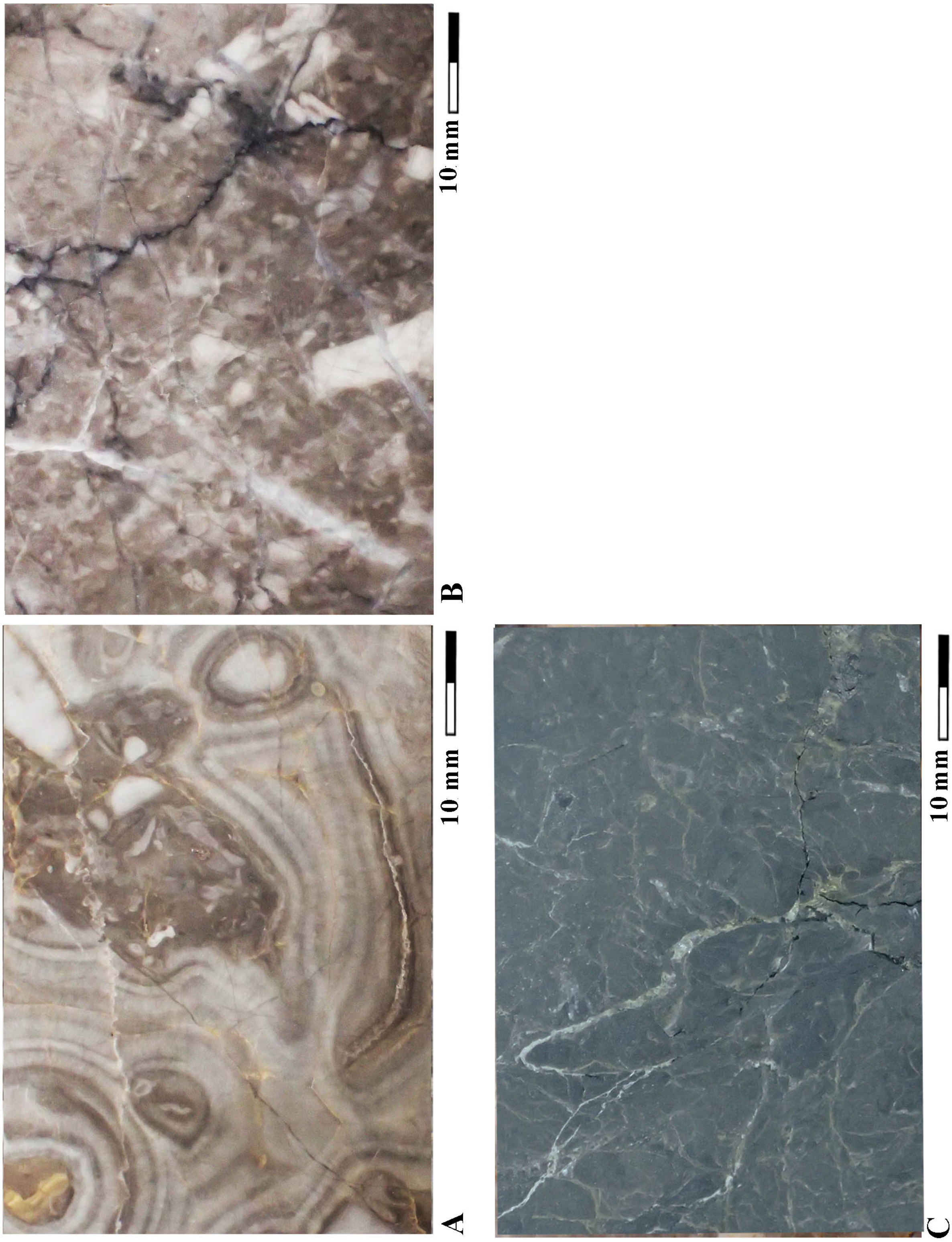

Figure 15

Polished surfaces of the limestones. A, cement-rich rudstone. B, Stylo breccia, which is composed of lithoclasts of bioclastic rudstone and grains stone. C, black lime-mudstone.

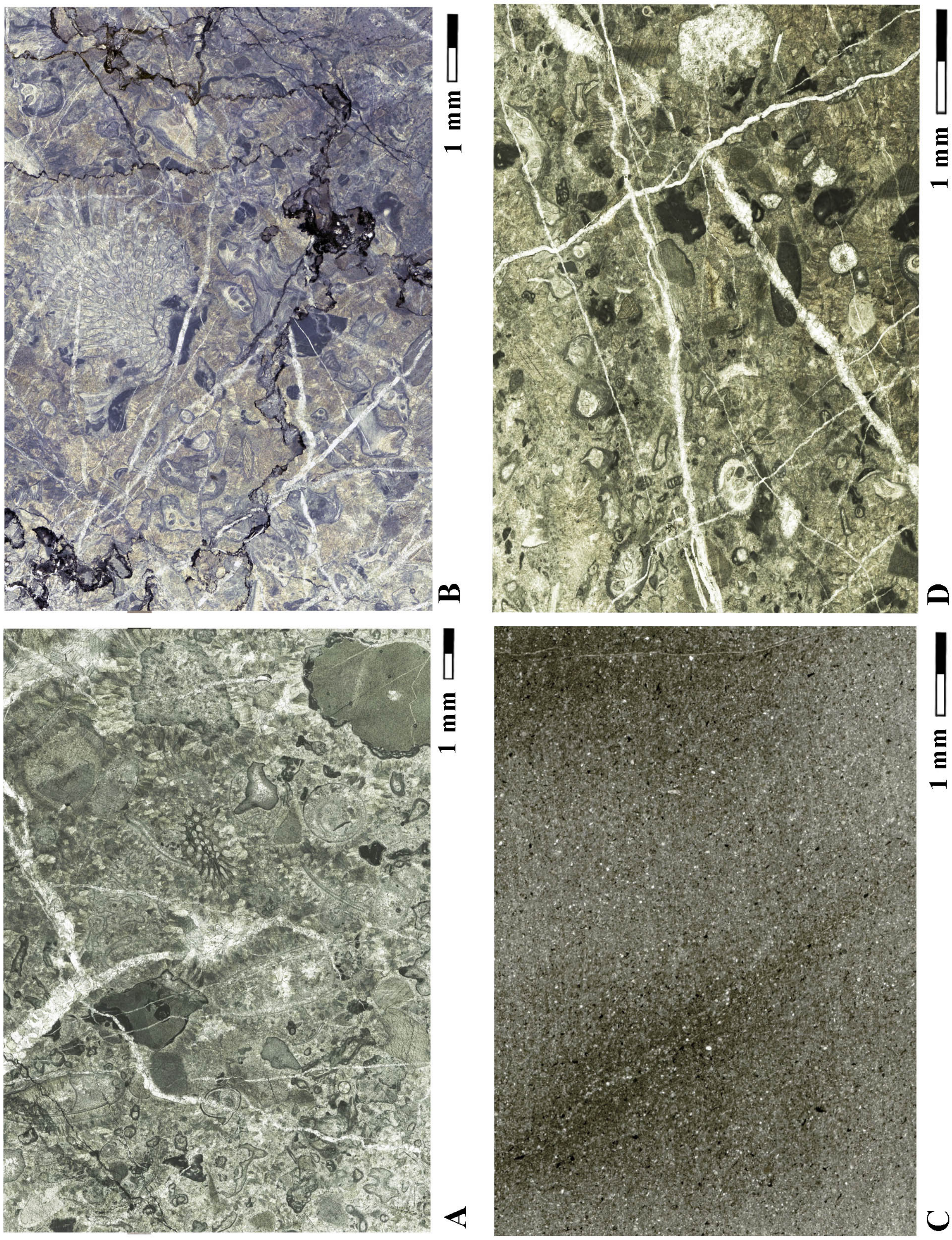

Figure 16

Thin sections of the limestones. A, cement-rich rudston. B, Stylo breccia. C, lime-mudston. D, bioclastic grainstone.

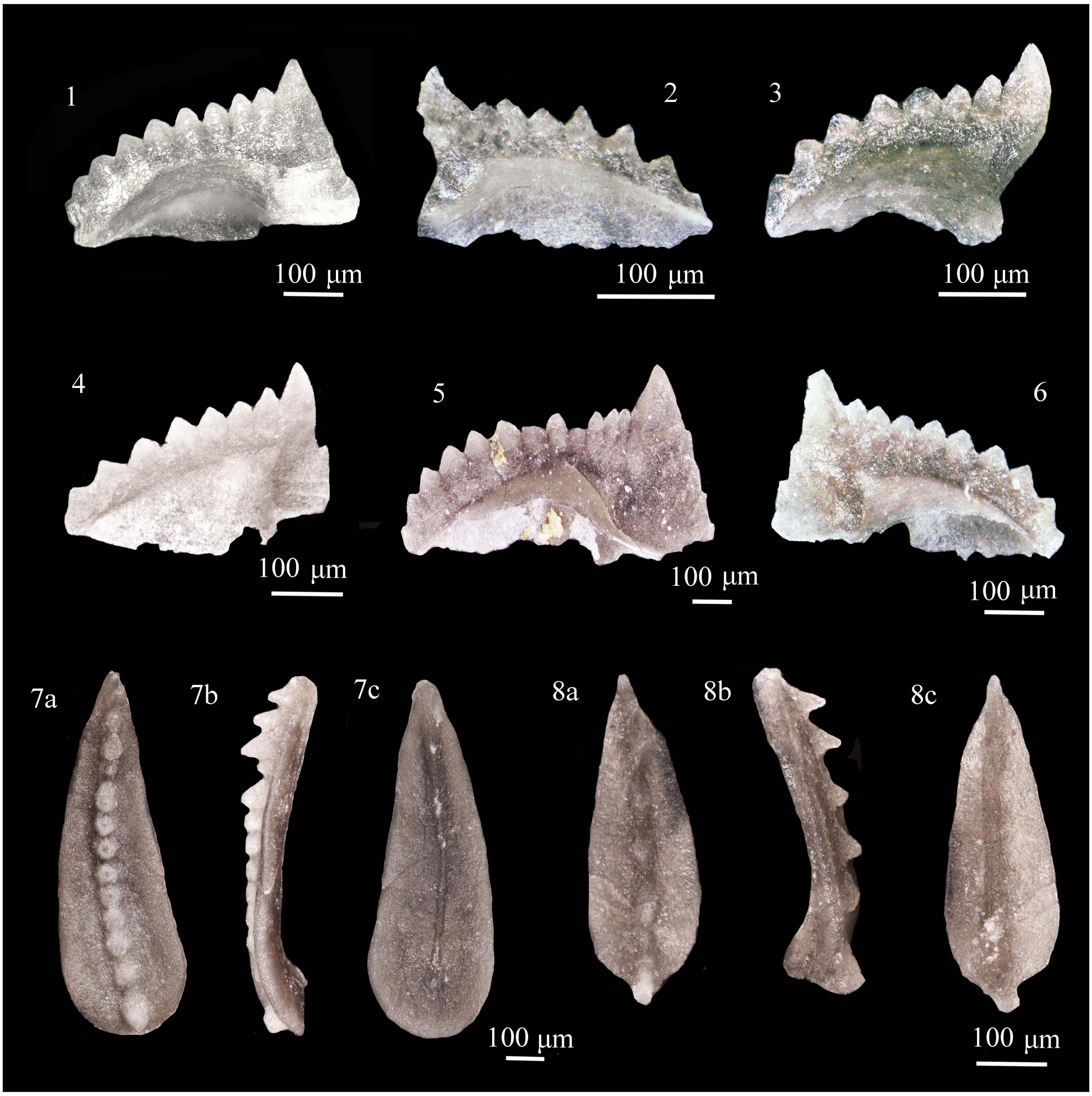

Figure 17

Conodonts. **1**, lateral view of ***Hindeodus cristulus*** from the Maruyama area; **2**, **3**, lateral views of ***Hindeodus* aff. *cristulus*** from the Maruyama area; 2, immature, 3, mature; **4–6**, lateral views of ***Hindeodus minutus***; 4, 6 from the Maruyama area; 5, from the Fukugakuchi area; **7, 8**, oral, lateral and aboral views of ***Mesogondolella clarki*** from the Fukugakuchi area. Each scale bar represents 100µm.

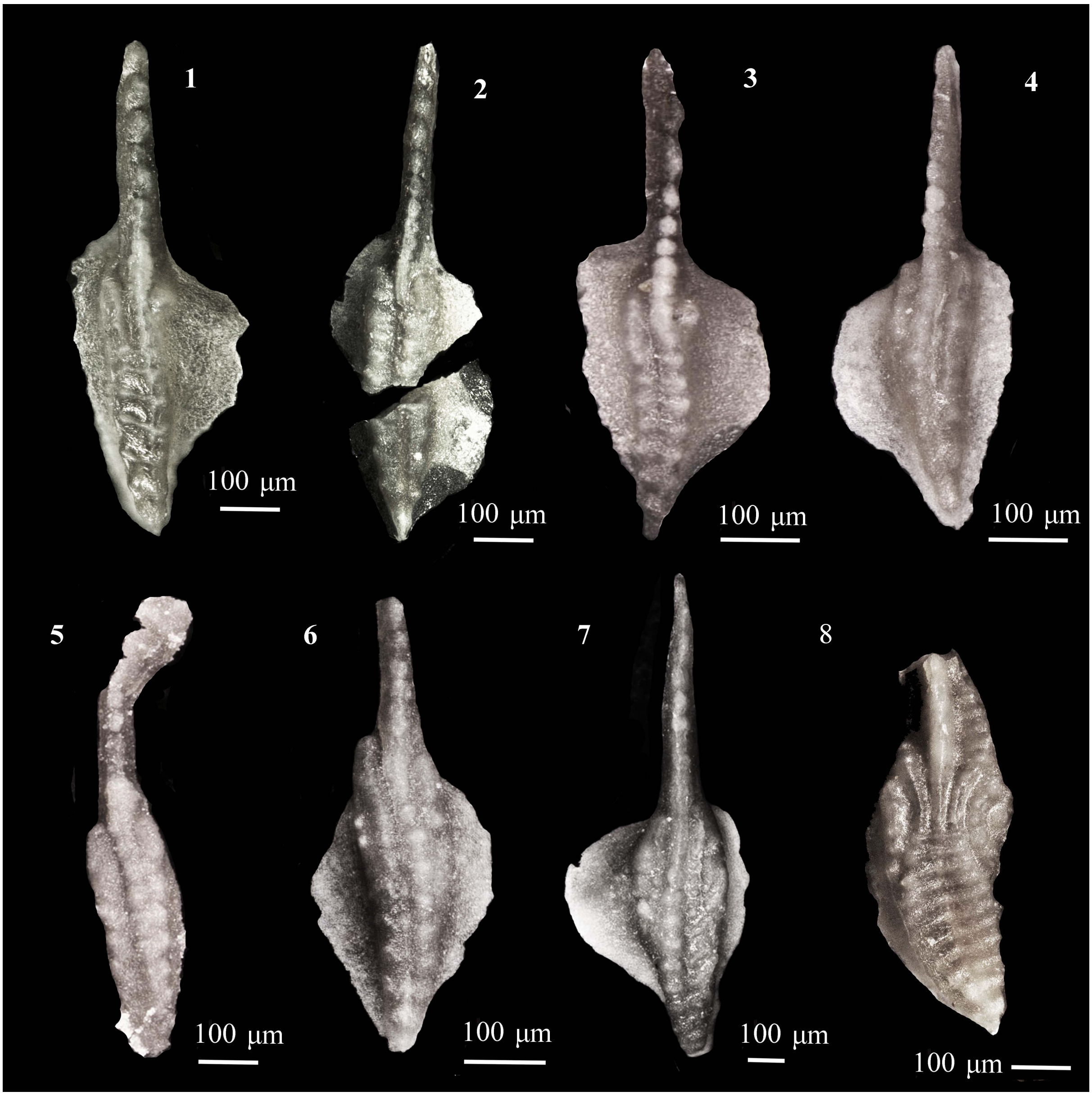

Figure 18

Conodonts. **1**, oral view of ***Declinognathodus praenoduliferus*** from the Fukugakuchi area; **2–4**, **5**, oral views of ***Declinognathodus noduliferus***; 2, 3, 5 from the Fukugakuchi area, 4, from the Nishiyama area; **6**, oral view of ***Declinognathodus* sp. A** from the float at the Omi River; **7**, oral view of ***Declinognathodus* sp. B** from the float at the Omi River; **8**, oral view of ***Idiognathodus covadongae*** from the Maruyama area. Each scale bar represents 100μm.

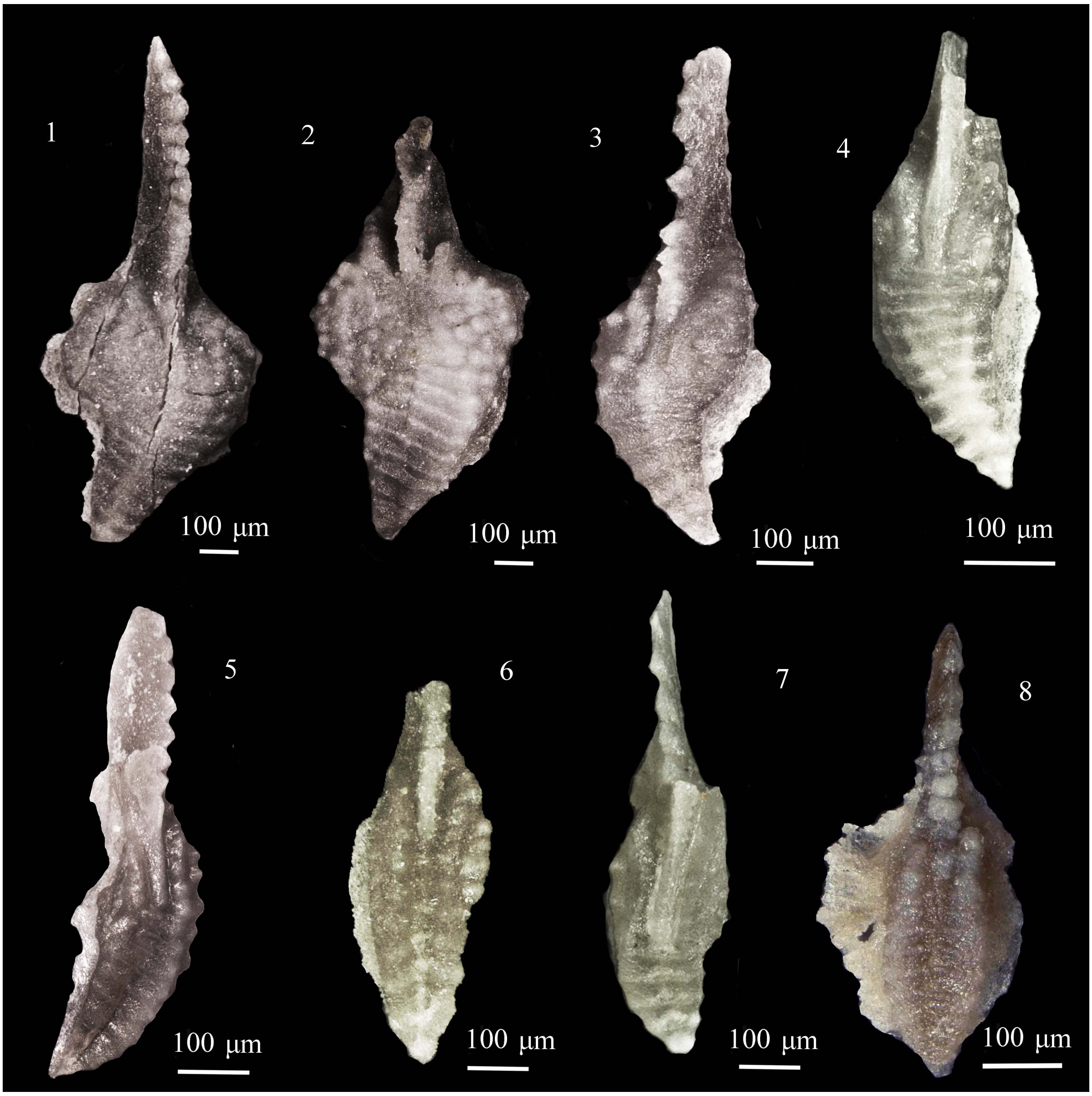

Figure 19

Conodonts. **1–3**, oral views of ***Idiognathodus delicatus*** from the Fukugakuchi area; 1, 2 dextral epements, 3, sinistral; **4**, oral view of ***Idiognathodus* cf. *incurvus*** from the Nishiyama area; **5**, oral view of immature specimen of ***Idiognathodus covadongae*** from the Maruyama area; **6**, oral view of ***Idiognathodus sinuosus*** from the Fukugakuchi area; **7**, oral view of ***Idiognathodus* sp. A** from the Nishiyama area; **8**, oral view of ***Idiognathodus* sp. B** from the Fukugakuchi area. Each scale bar represents 100µm.

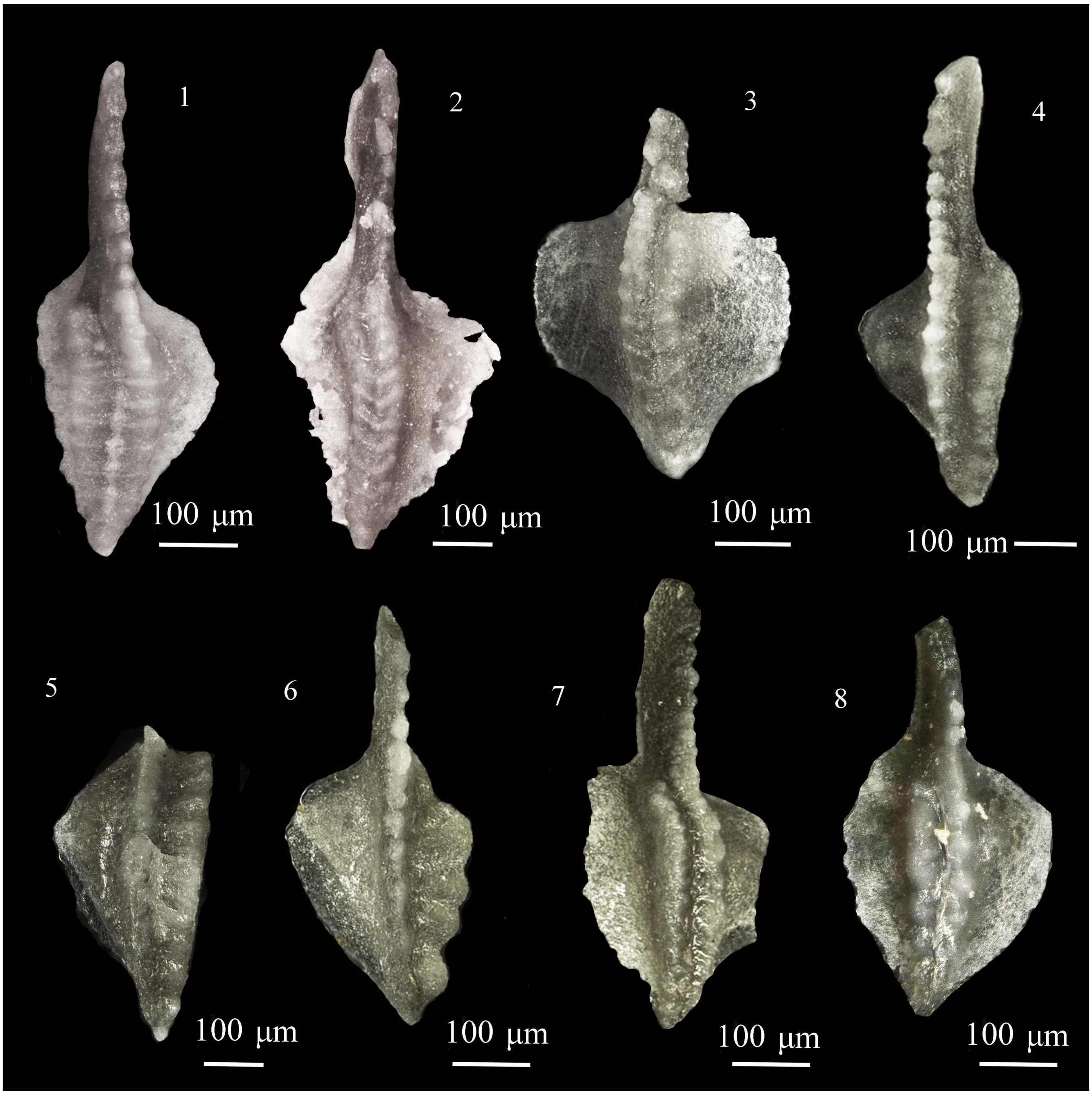

Figure 20

Conodonts. **1**, oral view of ***Idiognathoides corrugatus*** from the Fukugakuchi area; **2**, oral view of ***Idiognathoides pacificu*s** from the Fukugakuchi area; **3**, oral view of ***Idiognathoides* aff. *pacificus*** from the Fukugakuchi area; **4–6**, oral views of ***Idiognathoides macer*** from the Nishiyama area; **7**, **8**, oral views of ***Idiognathoides sulcatus***. 7 from the Fukugakuchi area, 8, from Maruyama area. Each scale bar represents 100μm.

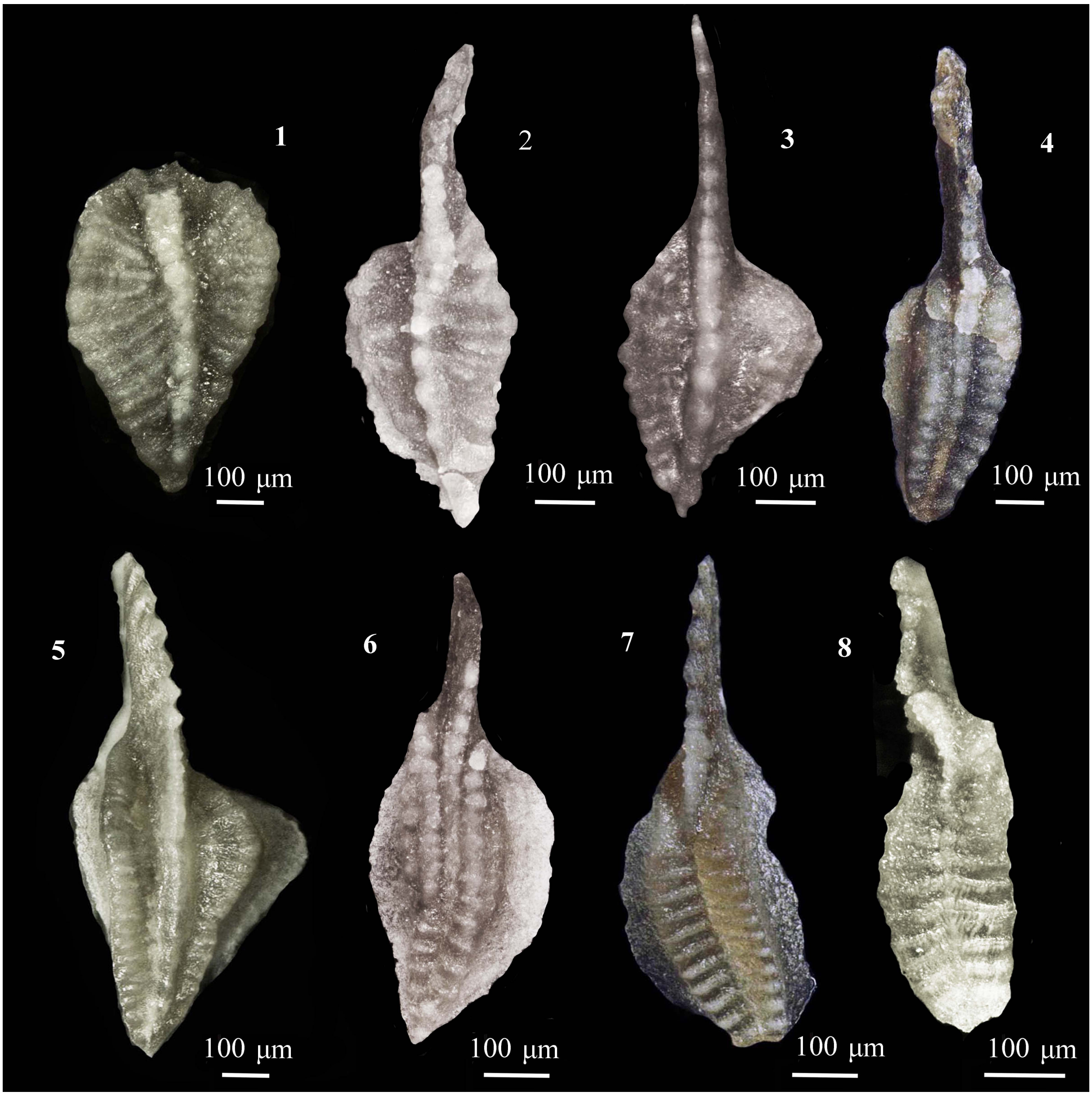

Figure 21

Conodonts. **1**, oral view of ***Neognathodus atokaensis*** from the Fukugakuchi area; **2**, **3**, oral views of ***Neognathodus kanumai***. 2, from the Fukugakuchi area, 3, from the float at the Omi River; **4**, oral view of ***Neognathodus symmetricus*** from the Fukugakuchi area; **5**, oral view of ***Neognathodus* sp. A** from the Nishiyama area; 6, oral view of ***Streptognathodus einori*** from the Fukugakuchi are; **7**, **8**, oral views of *Streptognathodus expansus* from the Nishayama and Fukugakuchi area; 7, from Nishiyama area, 8, from Fukugakuchi area. Each scale bar represents 100µm.

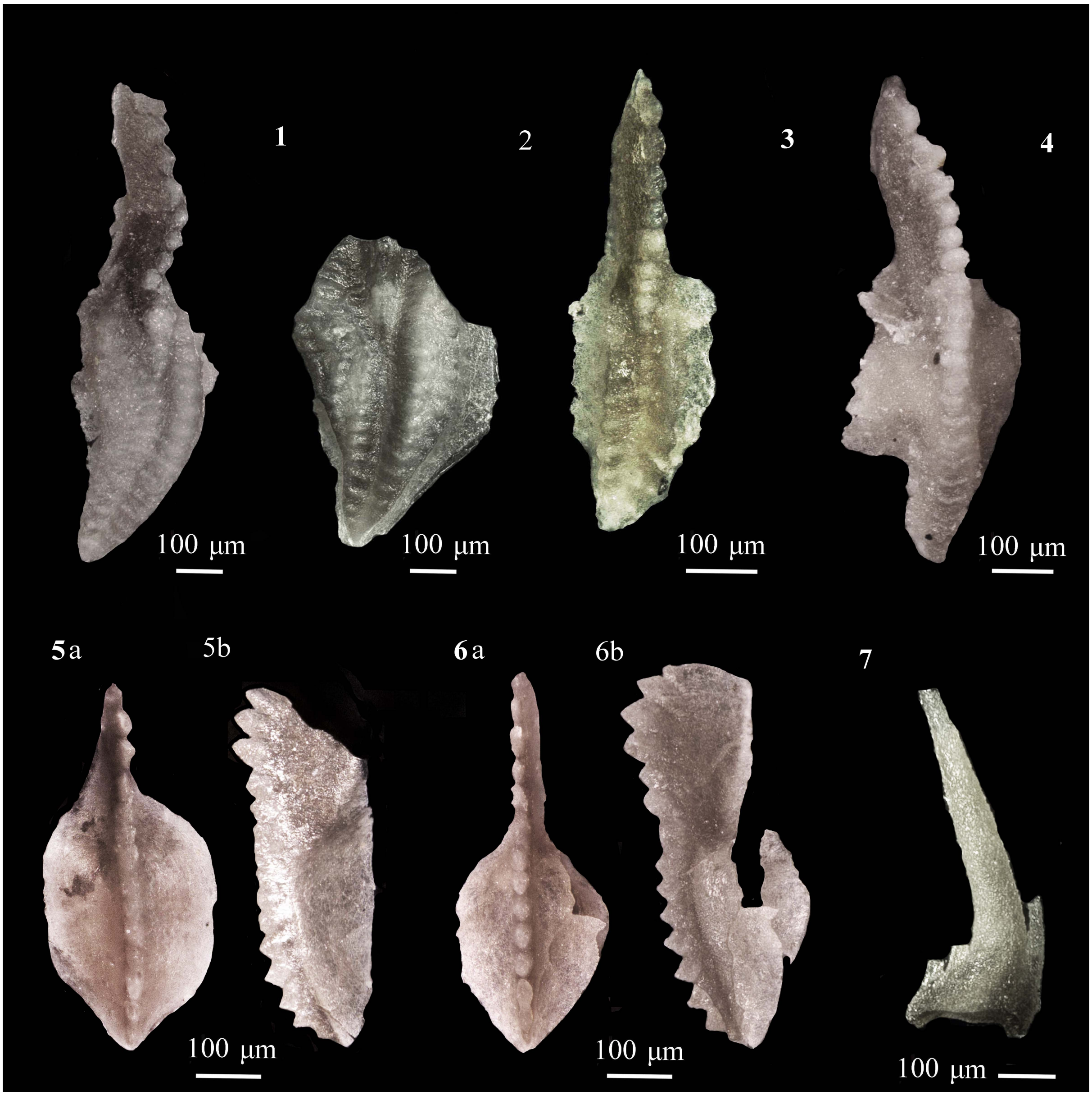

Figure 22

Conodonts. **1**, oral view of ***Streptognathodus suberectus*** from the Fukugakuchi area; **2**,oral view of ***Streptognathodus* cf. *suberectus*** from the Nishayama area; **3**, oral view of ***Streptognathodus subsimplex*** from the Fukugakuchi area; **4**, oral view of ***Neolochriea glaber*** from the Fukugakuchi area; **5**, **6,** *Diplognathodus? orphanus* from the Maruyama area. a represents oral view and b lateral view. **7**, lateral view of ***Idioprioniodus*** sp. from the Fukugakuchi area. Each scale bar represents 100µm.

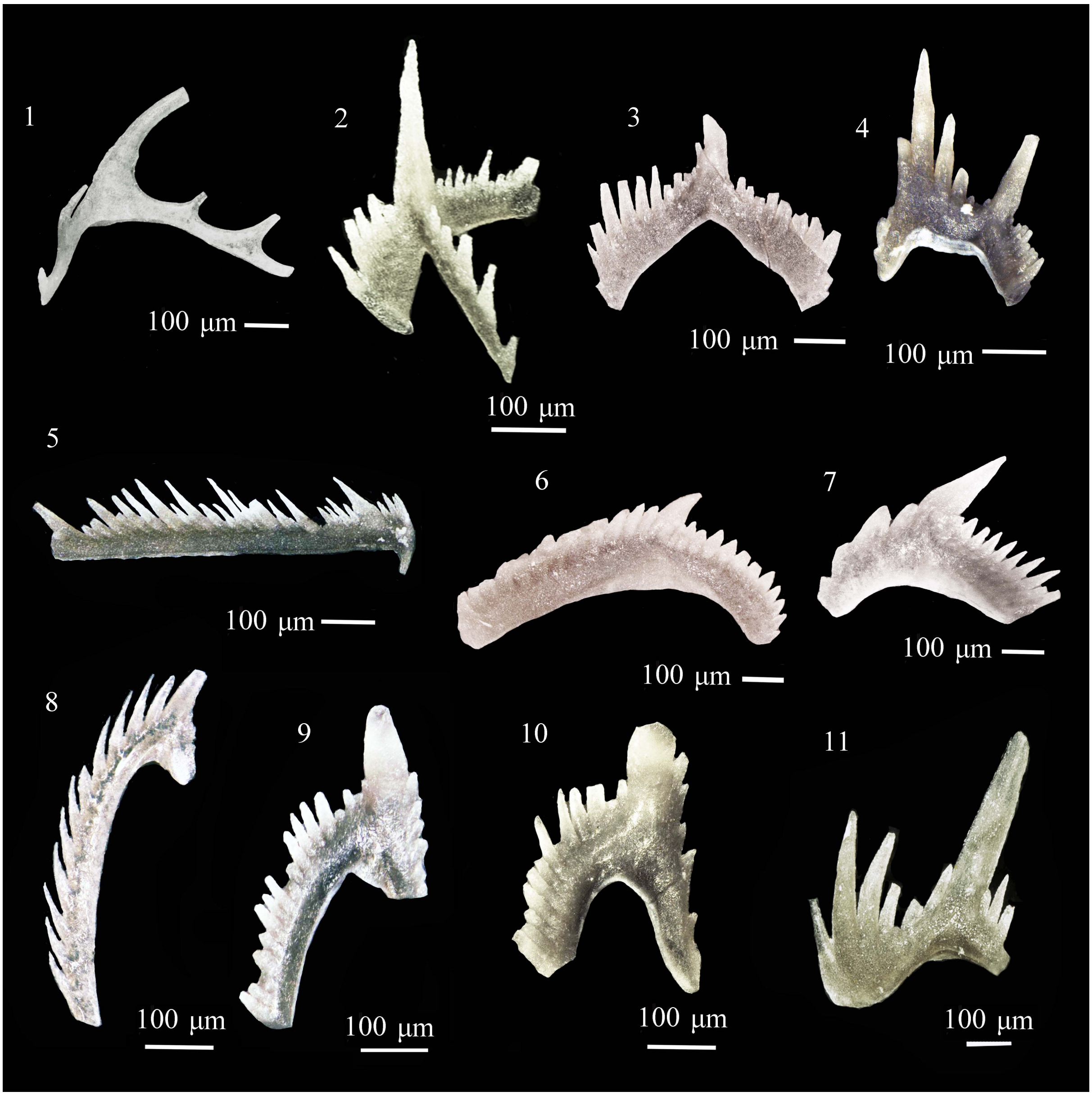

Figure 23

Conodonts. **1**, lateral view of Sc element of ***Idioprioniodus* sp.** from the Fukugakuchi area; **2, 3**, anterior view of **Sa element** of Ozarkodinida from the Niashiyama and Maruyama area; **4,** lateral view of **Sb element** of anchignathidae from the Maruyama area; **5,** lateral view of **Sc element** of Ozarkodinida from the Maruyama area; **6, 7,** lateral views of **Pb elements** of Ozarkodinida from the Fukugakuchi and Maruyama area; **8–10**, lateral views of **M elements** of Ozarkodinida from the Nishiyama and Maruyama area; **11,** lateral views of unknown **S? element** from the Nishiyama and Maruyama area. Each scale bar represents 100μm.

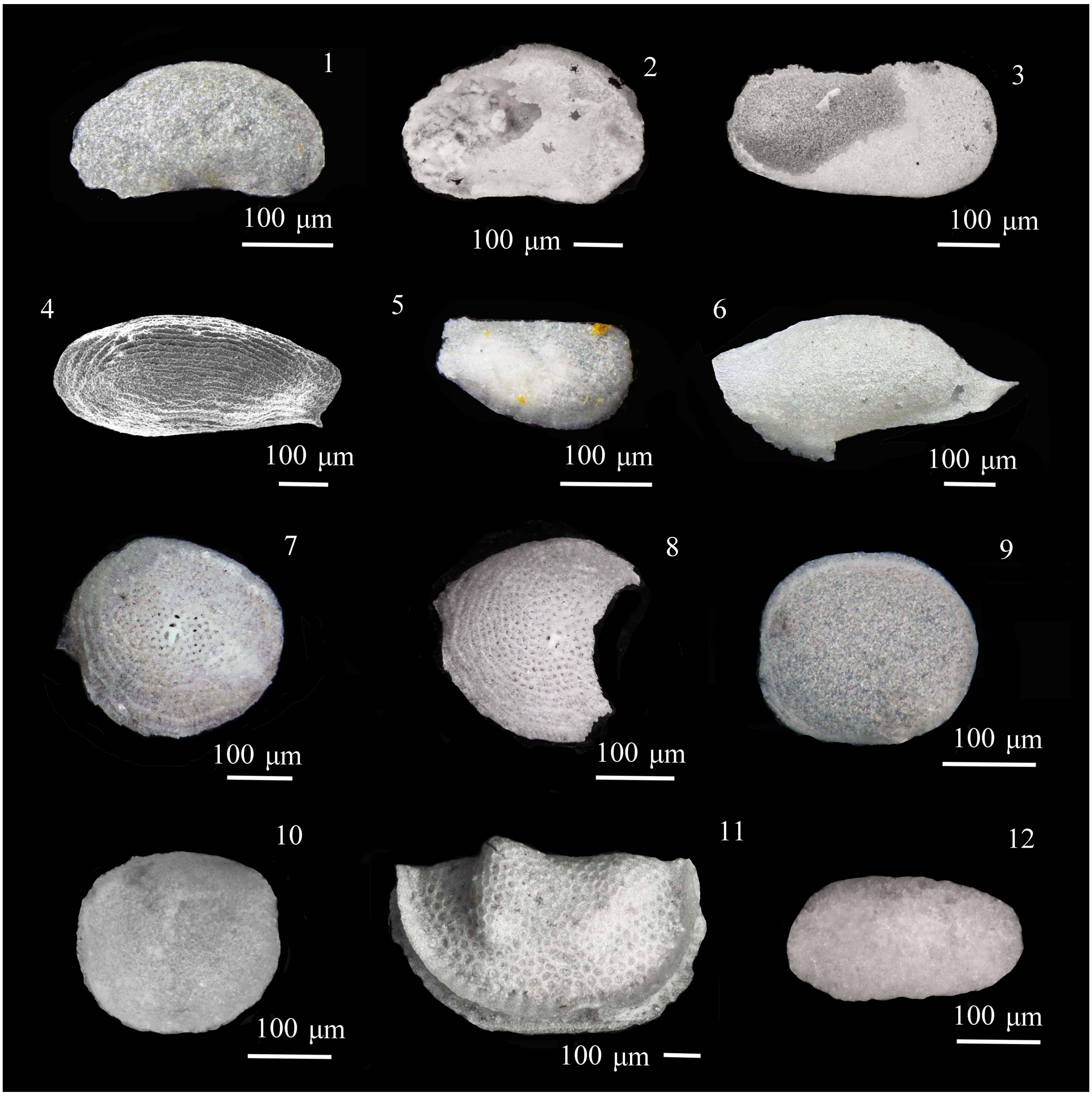

Figure 24

Ostracods. **1,** lateral view of ***Bythocypris* sp.**. from the Fukugakuchi are; **2,** lateral view of ***Silenites* sp.**, from the Fukugakuchi area; **3,** lateral view of **Gen. et sp. indet. A** from the Fukugakuchi are; **4,** lateral view of ***Spinomicrocheilinella?* sp.**, from the Fukugakuchi are**;** **5,** lateral view of ***Deloia* sp.**. from the Fukugakuchi are; **6,** lateral view of ***Bairdia* sp**. from the Fukugakuchi area; **7, 8,** lateral view of 1 ***Polycope* sp. A** from the Nishiyama area; **9**, **10**, lateral view of ***Polycope* sp. B** from the Nishiyama area; **11**, lateral view of 1 ***Kellettina* cf. *robusta*** from the Fukugakuchi area; **12**, lateral view of **Gen. et sp. indet. B** from the Nishiyama area. Each scale bar represents 100µm.

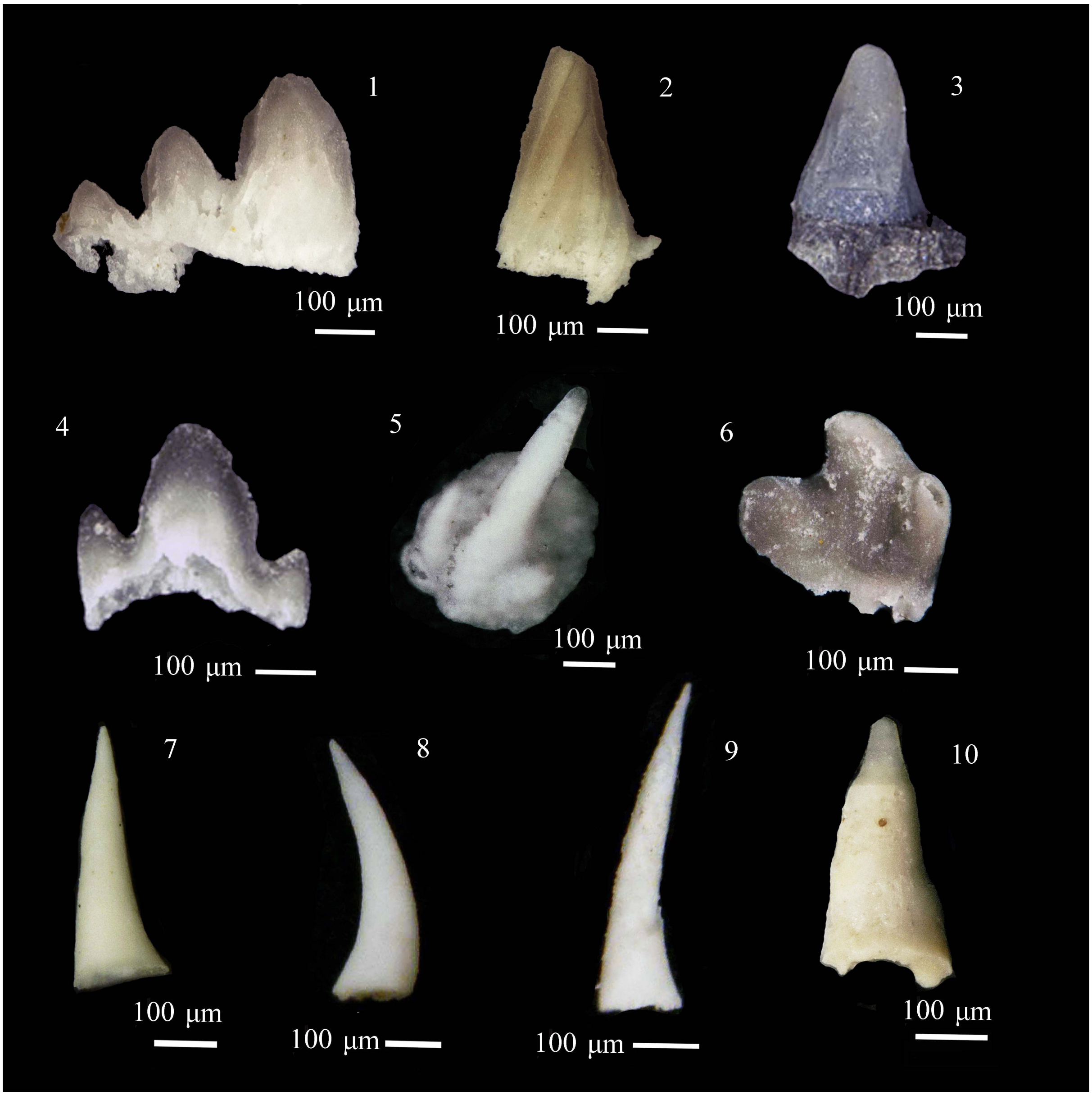

Figure 25

Actinopterygian and chondrichtyan teeth. **1,** lateral view of **Protacrodontidae gen. et sp. indet.**. from the Fukugakuchi area; **2,** lateral view of ***Bransonella*** **sp.?** from the Fukugakuchi area; **3,** lateral view of **Ctenacanthidae? gen. et sp. indet.** from the Nishiyama area; **4,** lateral view of ***Cladodus*** **sp.?** from the Nishiyama area; **5,** oral view of **Gen et sp. indet. A** from the Nishiyama area; **6,** lateral view of **Gen et sp. indet. B** from the Omi River; **7–9,** lateral views of **Actinopterygii indet. A**; 7, from the Nishiyama, 8 from the Maruyama, 9 from the Fukugakuchi area. 10. lateral view of **Actinopterygii indet. B f**rom the Fukugakuchi area. Each scale bar represents 100µm.

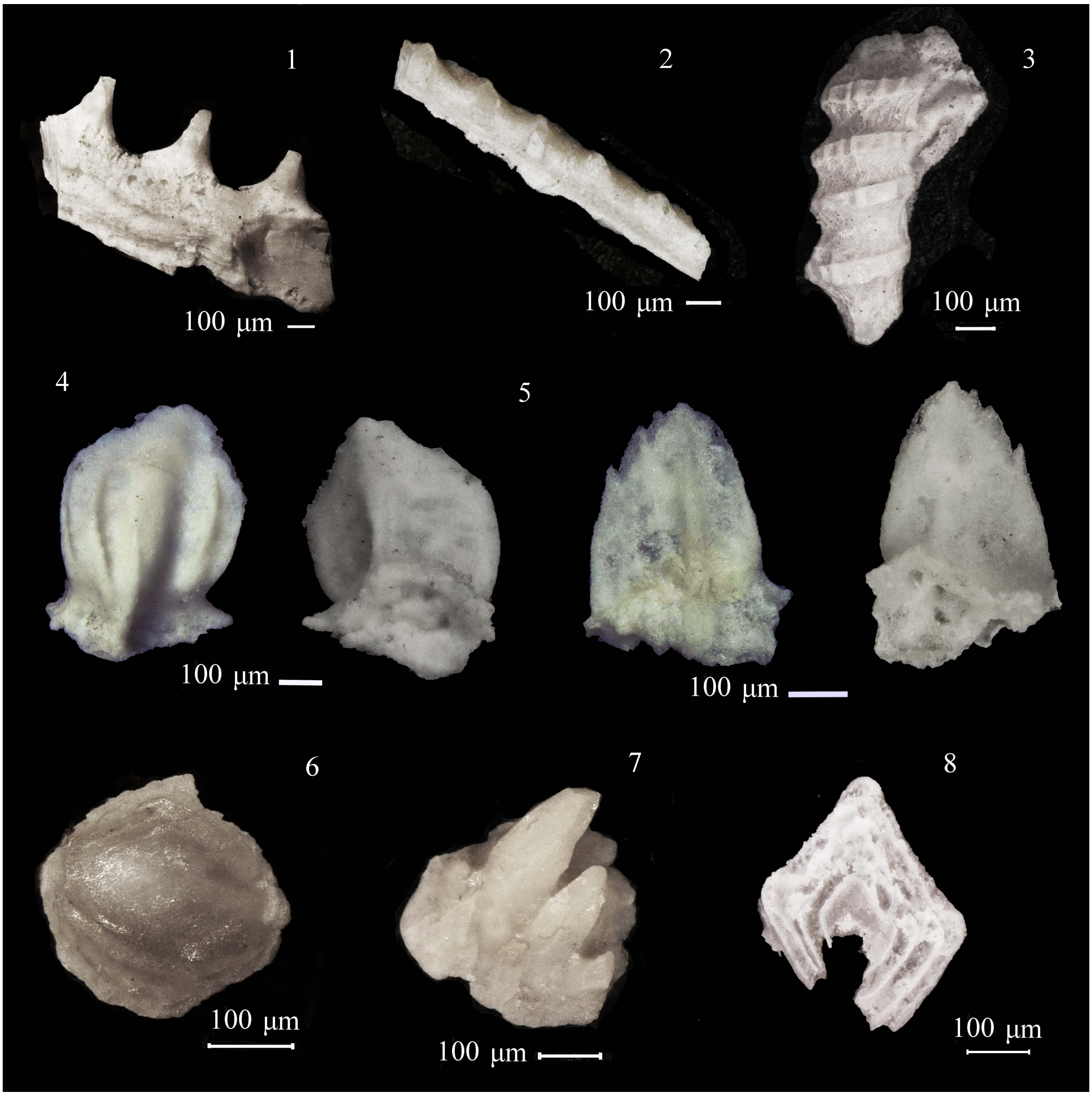

Figure 26

Actinopterygian and chondrichtyan scales. **1–3,** lateral and upper views of **Chondrichthyan scales Type A** from the Fukugakuchi and Maruyama area; **4, 5,** upper and lower views of **Chondrichthyan scales Type B** from the Fukugakuchi area; **6,** upper view of **Chondrichthyan scales Type C** from the Maruyama area; **7,** upper view of **Chondrichthyan scales Type D** from the Maruyama area; **8**, upper view of Actinopterygian scale from the Maruyama area. Each scale bar represents 100µm.

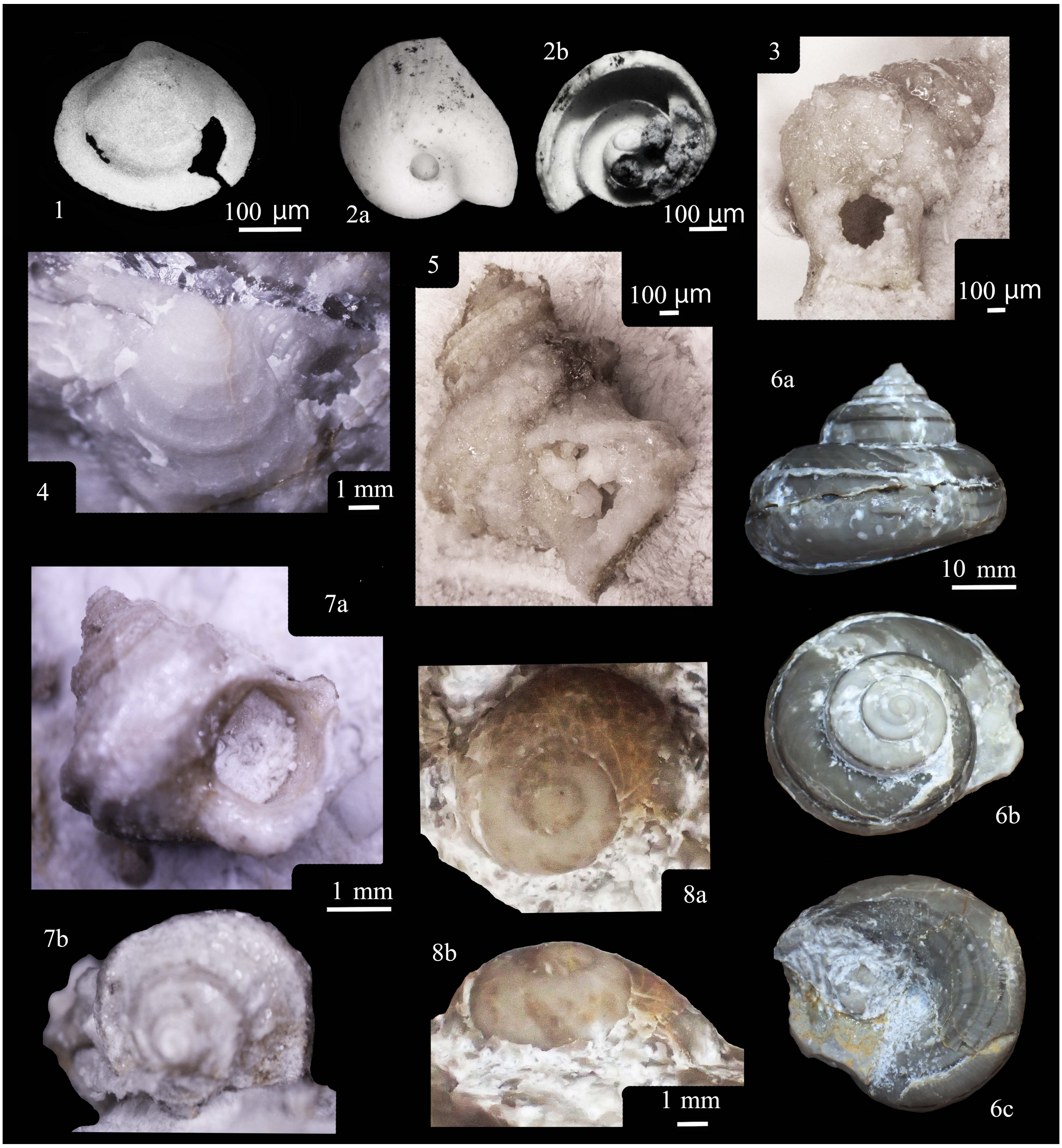

Figure 27

Molluscan fossils**. 1, Veneroida fm. gen. et sp. indet.** from the Fukugakuchi area; **2, Bellerophontidae gen. et sp. indet.** from the Fukugakuchi area; **3**, **Microdomatidae gen. et sp. indet.**from the Omi River; **4,** ***Annuliconcha*** **sp.** from the Omi River; **5**, **Eotomariidae gen. et sp. indet.** from the Omi River; **6,** ***Mourlonia*** **aff.** ***hayasakai*** from the Omi River; **7,** ***Glabrocingulum*** **sp.** from the Omi River; **8, Anomphalidae gen. et sp. indet.** from the Omi River.

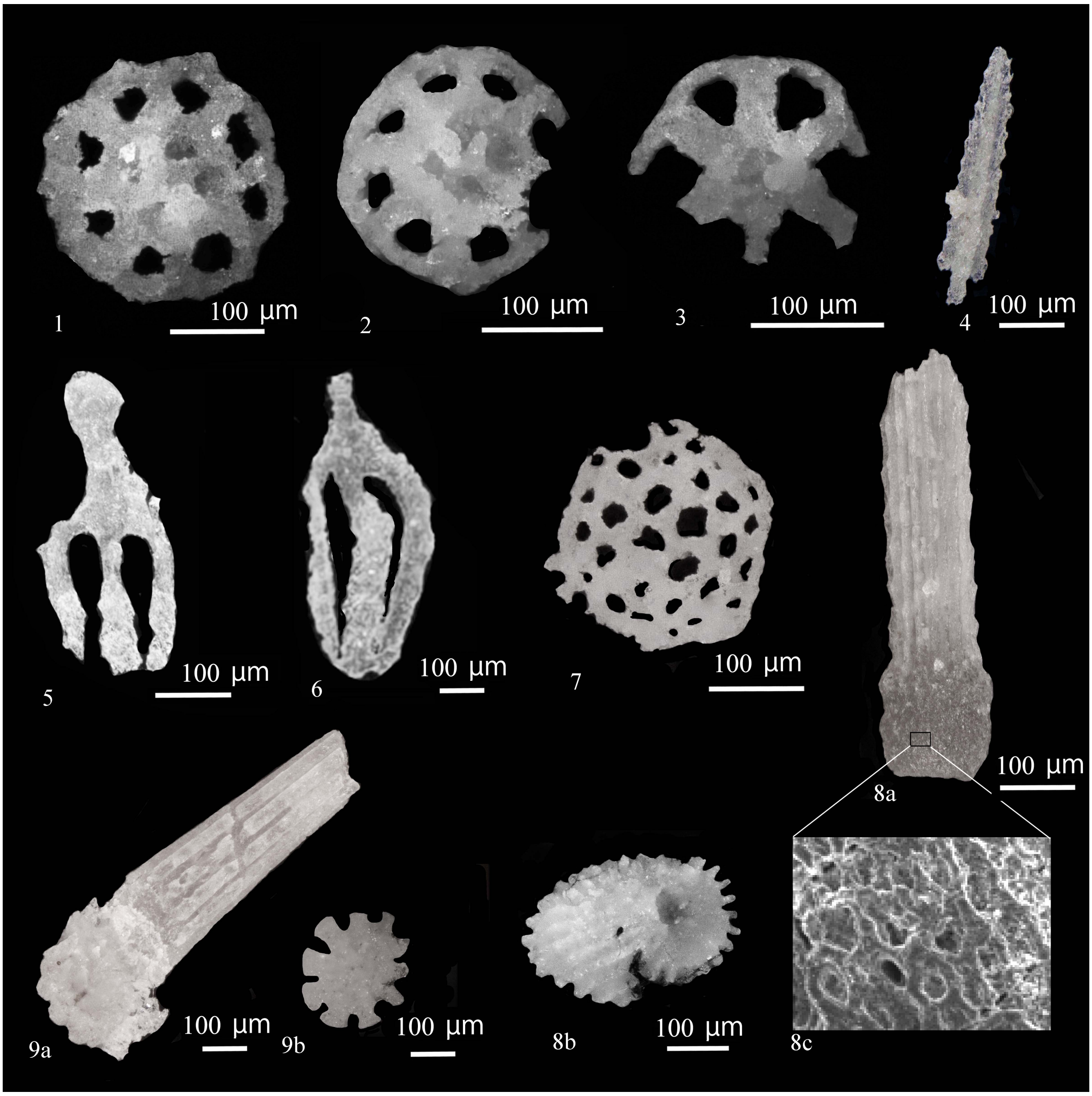

Figure 28

Ossicles of echinoderms. **1, 2,** upper views of ***Microantyx botoni*** from the Fukugakuchi area; **3,** upper view of ***Thalattocanthus consonus*** from the Fukugakuchi area; **4,** lateral view of ***Clavallus* sp.** from the Fukugakuchi area; **5, 6,** upper views of ***Furcaster* sp.** from the Fukugakuchi area **7,** upper view of ***Eocaudina subhexagona*** from the Maruyama area; **8, Echinoidea indet. B** from the Fukugakuchi area. 8a. lateral view of a spine; 8b, Cross section of the spine; 8c, magnification of the stereom structure of the base of spine; **9, Echinoidea indet. A** from the Fukugakuchi area; 9a, lateral view of a spine; 9b, Cross section of the spine. Each scale bar represents 100µm.

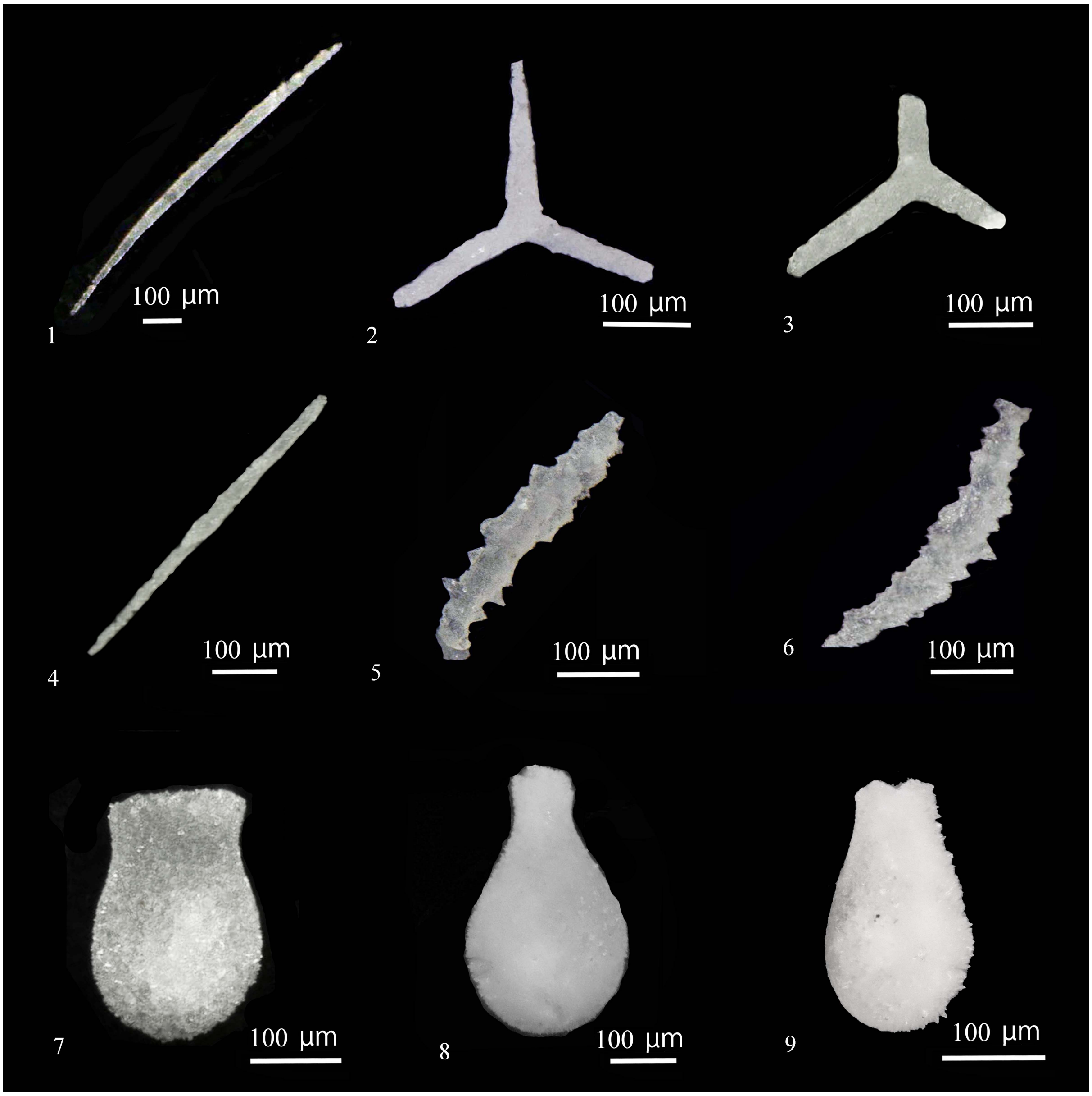

Figure 29

Sponge spicules and chitinozoan fossils**. 1, 4. Calcarea indet.** from the Fukugakuchi area; **2, 3. Calcaronea indet.** from the Fukugakuchi area; **5, 6. Heteroscleromorpha indet.** from the Fukugakuchi area; **7. Prosomatifera indet. A** from the Fukugakuchi area; **8. Prosomatifera indet. B** from the Marutama area; **9**. **Prosomatifera indet. B** from the Fukugakuchi area. Each scale bar represents 100μm.

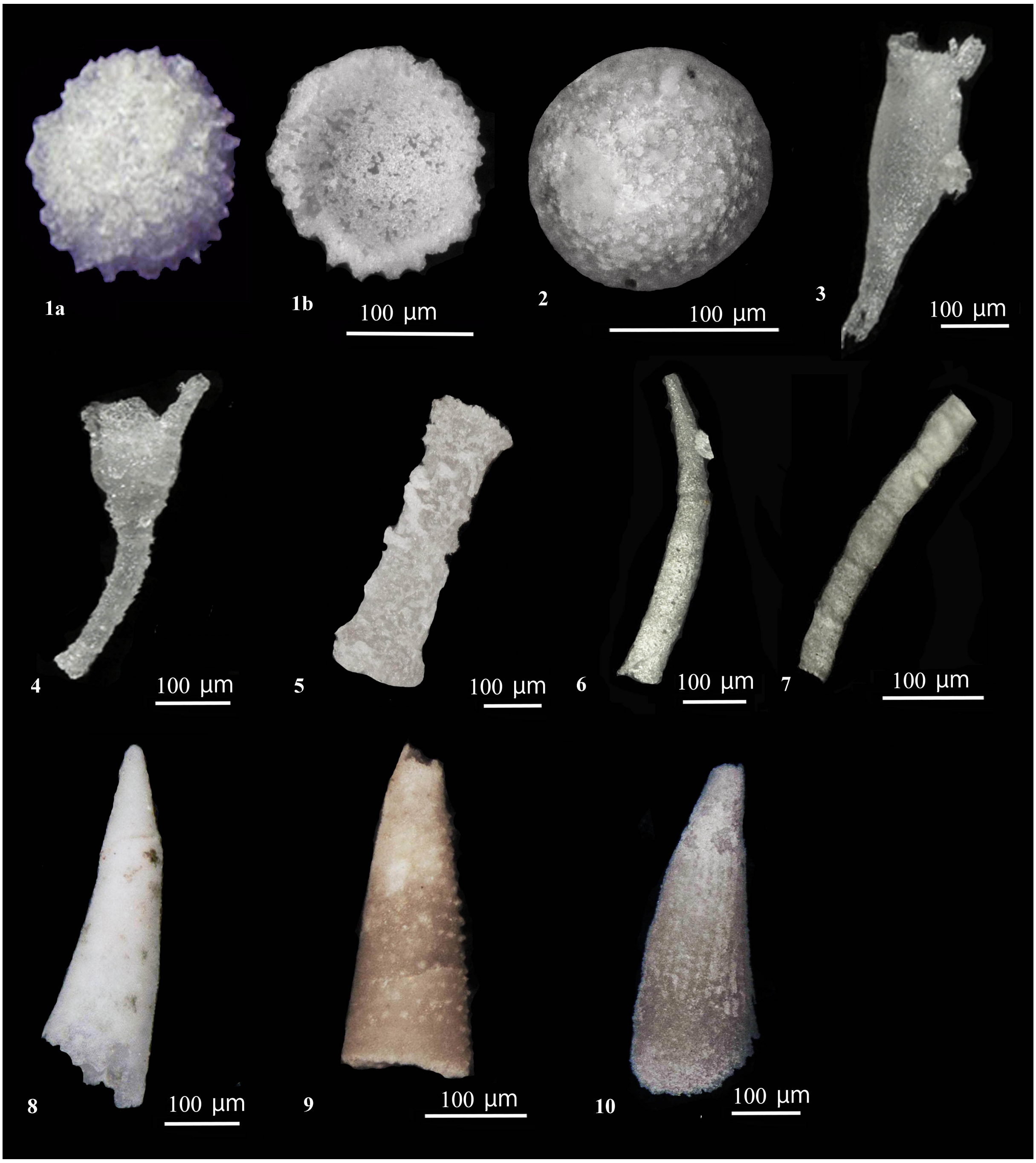

Figure 30

Microimages problematic fossils**. 1,** upper and lower views of **Microproblematica A** from the Fukugakuchi area; **2, Microproblematica B** from the Fukugakuchi area; **3, 4,** lateral views of **Microproblematica C** from the Fukugakuchi area; **5,** lateral view of **Microproblematica D** from the Fukugakuchi area; **6, 7,** lateral views of **Microproblematica E** from the Fukugakuchi area; **8,** lateral view of **Microproblematica F** from the Fukugakuchi area; **9,** lateral view of **Microproblematica G** from the Maruyama area; **10,** lateral view of **Microproblematica H** from the Nishiyama area. Each scale bar represents 100µm.

Pl. 15

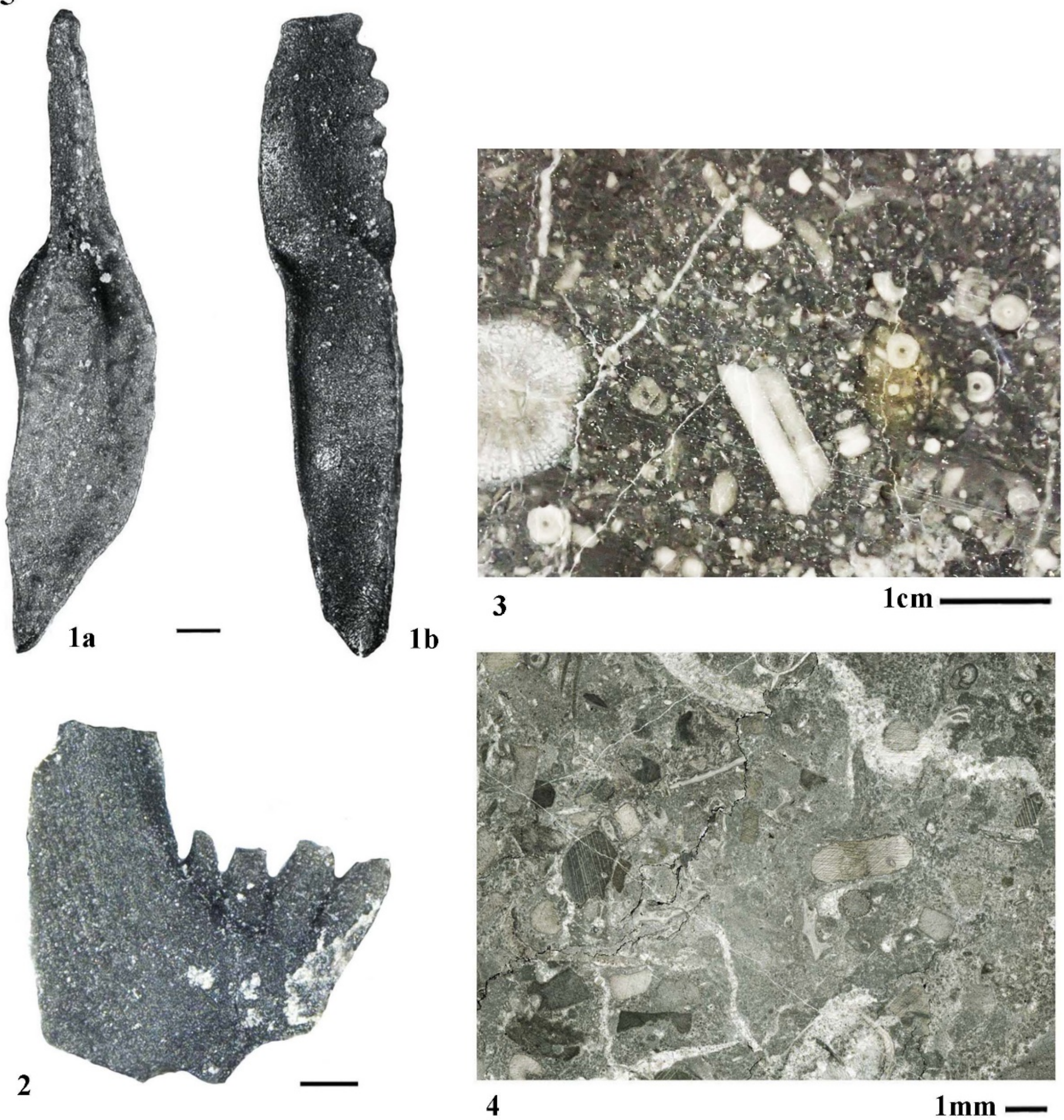

Figure 31

Conodonts from the Tsuchikurazawa Limestone, and the lithologies of the limestone**. 1, *Adetognathus lautus***, 1a. oral view, 1b. lateral view. **2.** lateral view of fragmented M? element. **3.** polished surface of the Tsuchikurazawa Limestone. **4.** thin section of the limestone indicates wackestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Brachiopod	Chileata	Dictyonellida	Isogrammidae	*Isogramma millepunctutata*	Tazawa et al. (2004)	Higashiyama	*Fusulina* - *Fusulinella* zone	
	Craniata	Craniida	Craniidae	gen. et sp. indet.	FMM display	unknown	Carboniferous	
	Rhynchonellata	Athyridida	Athyrididae	*Actinoconchus?* sp.	FMM unregistered specimen	Higashiyama	*Profsulinella* -*Fusulinella* Zone	
				Cleiothyridina? sp	FMM unregistered specimen	Omi River; Higashiyama	*Profsulinella* -*Fusulinella* Zone	
		Orthida	Enteletidae	*Rhipidomella* sp.	Tazawa et al. (1983)	under Higashiyama	Visean- Namurian	
				gen. et sp. indet	FMM unregistered specimen	unknown	Carboniferous	
			Schizophoriidae	*Schizophoria* sp.	FMM unregistered specimen	Higashiyama	*Fusulinella* zone, Late Carboniferous	
				gen. et sp. indet	FMM unregistered specimen	Higashiyama	*Profsulinella* -*Fusulinella* Zone	
		Rhynchonellida	Camarotoechiidae	*Camarotoechia* sp.	Yokoi (2013)	uncertain	Carboniferous	
			Psilocamaridae	*Cyrolexis* sp.	Yokoi (2013)	uncertain	Carboniferous	
			Pugnacidae	*Pugnax* acuminatus	Hayasaka (1924)	Omi River	Carboniferous	
				Pugnax pugnus	Hayasaka (1924)	uncertain	Carboniferous	
				Pugnax sp.	FMM unregistered specimen	uncertain	Carboniferous	
			Rhynchonellidae	*Rhynchonella sp.*	Fujita (1958)	eastern Uta	*Millerella* - Coral Brachiopod Zone	
				gen. et sp. indet	FMM unregistered specimen	Higashiyama	Carboniferous	
			Stenoscismatidae	*Camarophoria globulina*	Hayasaka 1924	Omi River	Carboniferous	
			Stenoscismatidae	*Nantanella?* sp.	Fujita (1958)	Nishiyama; Shinetsu Chemical Industry	*Millerella* - Coral Brachiopod Zone	
			Tetracameridae	*Yanishewskiella japonica*	Yokoi (2013)	uncertain	Carboniferous	
			indet	gen. et sp. indet	FMM unregistered specimen	uncertain	Carboniferous	
		Spiriferida	Brachythyrididae	*Brachythyris* sp.	Yokoi (2013)	uncertain	Carboniferous	
			Choristitidae	*Choristites mosquensis*	Ibaraki (2017)	Higashiyama	Fusulina-Fusulinella zone	*Spilifer humerosus* of Hayasaka (1924)?
				Choristites sp.	Hasegawa and Goto (1990)	Higashiyama	*Fusulina*- *Fusulinella* zone	
				Tangshanella sp.	Yokoi (2013)	uncertain	Carboniferous	
			Elythidae	*Phricodothyris* sp.	Hasegawa and Goto (1990)	Higashiyama	*Fusulina*- *Fusulinella* zone	Squammularia sp. of Fujita (1958)
			Martiniidae	*Martinia* glabra var. *decore*	Hayasaka (1924)	Omi River	Carboniferous	
				Martinia linguiferoidea	Hayasaka (1924)	uncertain	Carboniferous	
				Martinia sp.	FMM unregistered specimen	Higashiyama	Carboniferous	
			Punctospiriferidae	*Punctospirifer* sp.	FMM unregistered specimen	Higashiyama	Carboniferous	

Appendix 1. The occurrence list of brachiopod fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Brachiopod	Rhynchonellata	Spiriferida	Spiriferidae	*Anthracospirifer?* sp.	FMM unregistered specimen	Higashiyama	Carboniferous	
				Brachythyrina sp.	FMM unregistered specimen	Higashiyama	Carboniferous	
				Spirifer cf. *crassus*	Hayasaka (1924)	uncertain	Carboniferous	
				Spirifer humerosus	Hayasaka (1924); Fujita (1958)	Nishiyama	*Millerella* - Coral Brachiopod Zone	
				Spirifer duplicostus	Hayasaka 1924; Fujita (1958)	Omi River; eastern Uta	*Millerella* - Coral Brachiopod Zone	
				Spirifer sp.	Fujita (1958); FMM unregistered specimen	Omi River; Higashiyama; Shinetsu Chemical Industry	Carboniferous	
			Trigonotretidae	*Neospirifer* sp.	Hasegawa and Goto (1990)	Higashiyama	*Fusulina*- *Fusulinella* zone	
			Syringothyrididae	*Syringothyris cuspidatus*	Hayasaka (1924)	uncertain	Carboniferous	
				Syringothyris sp.	FMM unregistered specimen	uncertain	Carboniferous	
		Techidelinida	Techidelinidae	*Marginifera* sp.	FMM unregistered specimen	Higashiyama	Carboniferous	
		Terebratulida	Dielasmatidae	*Dielasma kingi*	Yokoi (2013); Hayasaka 1924	Higashiyama	*Fusulinella* Zone	
				Dielasma sp. cf. *D. kingi*	Hayasaka 1924; Hasegawa and Goto (1990)	uncertain	*Fusulinella* Zone	
				Dielasma sp. cf. *D. insigune*	Hayasaka 1924; Hasegawa and Goto (1990)	uncertain	*Fusulinella* Zone	
				Dielasma itaitabense	Fujita (1958); Hasegawa and Goto (1990)	Nishiyama; Higashiyama	*Millerella* - Coral Brachiopod Zone; Fusulina-Fusulinella zone	
				Dielasma sp.	Fujita (1958); FMM display	Denka; Itagamine	*Fusulinella* Zone	
	Strophomenata	Orthotetida	Derbyiidae	*Derbyia?* sp.	FMM unregistered specimen	Higashiyama	*Profsulinella*-*Fusulinella* Zone	
			Orthotetidae	*Orthotetes* sp.	Fujita (1958)	Nishiyama	*Millerella* - Coral Brachiopod Zone	
			Pulsiidae	*Schellwienella cf. radialis*	FMM unregistered specimen	Higashiyama	*Profsulinella*-*Fusulinella* Zone	
		Productida	Chonetidae	*Chonetes?* sp.	FMM unregistered specimen	Higashiyama	*Profsulinella*-*Fusulinella* Zone	
			Chonetacea	gen. et sp. indet	FMM unregistered specimen	uncertain	Carboniferous	
			Daviesiellidae	*Daviesiella omiensis*	Tazawa et al. (2005)	Kotaki	upper Visean	
				Reticulatia lineata	Hayasaka 1924	Omi River	Carboniferous	
				Reticulatia sp.	Fujita (1958); FMM unregistered specimen	Nishiyama; Higashiyama	*Millerella* - Coral Brachiopod Zone; *Profsulinella*-*Fusulinella* Zone	
				Waagenoconcha sp.	FMM unregistered specimen	Higashiyama	*Profsulinella*-*Fusulinella* Zone	
			Echinoconchidae	*Echinaria* sp.	FMM unregistered specimen	Nishiyama	*Fusulinella* zone	
				Echinoconchus cfr. *defensus*	Fujita (1958)	eastern Uta	*Millerella* - Coral Brachiopod Zone	
				Echinoconchus sp.	Fujita (1958); Yokoi (2013); FMM display	eastern Uta	*Millerella* - Coral Brachiopod Zone	
				Pustula? sp.	FMM unregistered specimen	Omi River	Carboniferous	
			Linoproductidae	*Cancrinella?* sp.	FMM unregistered specimen	Nishiyama	Carboniferous	
				Linoproductus cora	Fujita (1958)	Nishiyama	*Millerella* - Coral Brachiopod Zone	

Appendix 2. The occurrence list of brachiopod fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Brachiopod	Strophomenata	Productida	Linoproductidae	*Linoproductus?* sp.	FMM unregistered specimen	Omi River	Carboniferous	
			Monticuliferidae	*Gigantoproductus edelburgensis*	Hasegawa and Goto (1990)	Nishiyama	Visean-Namurian	
				Gigantoproductus sp.	Hasegawa and Goto (1990)	Omi River	Visean-Namurian	
				Latiproductus edelburgensis	FMM display	uncertain	Carboniferous	
				Striatifera sp.	FMM unregistered specimen	Higashiyama	Carboniferous	
				Striatifera striata	FMM unregistered specimen	Omi River	Carboniferous	
			Productidae	*Levitusia* sp.	FMM display	uncertain	Carboniferous	
				Marginatia sp.	FMM unregistered specimen	Nishiyama	Carboniferous	
				Buxtonica sp.	FMM unregistered specimen	Higashiyama	Carboniferous	
				Productus semireticulatus	Hayasaka 1924	Omi River	Carboniferous	
				Productus giganteus var. *edelburgensis*	Hayasaka 1924	Omi River	Carboniferous	
				Productus striatus	Hayasaka 1924	Omi River	Carboniferous	
				Productus punctuatus	Hayasaka 1924	uncertain	Carboniferous	
				Productus elegans	Hayasaka 1924	uncertain	Carboniferous	
				Productus cfr. *aculeatus*	Hayasaka 1924	Omi River	Carboniferous	
				Productus sp.	Fujita (1958)	Nishiyama; Shinetsu Chemical Industry; eastern Uta	*Millerella* - Coral Brachiopod Zone; *Fusulinella* zone	
				gen. et sp. indet.	FMM unregistered specimen	uncertain	Carboniferous	
			Rugosochonetidae	*Delepinea sayamaensis*	FMM unregistered specimen	Higashiyama	*Profsulinella* -*Fusulinella* Zone	
				Delepinea cf. *sayamaensis*	Tazawa et al. (1983)	under Higashiyama	Visean- Namurian	probablly *Delepinea sayamaensis*
				Delepinea sinuata	Tazawa et al. (2005)	Kotaki	upper Visean	
			indet	gen. et sp. indet	FMM unregistered specimen	uncertain	Carboniferous	

Appendix 3. The occurrence list of brachiopod fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Cnidaria	Anthozoa	Auloporida	Periphaceloporidae	*Mandulapora yamagiwai*	Niko (2000)	Higashiyama	late Bashkirian	
				Mandulapora? sp. indet.	Niko (2013)	Fukugakuchi	*Endothyra* zone	
			Pyrgiidae	*Cladochonus ozawai*	Niko (2011)	Omi River, Fukugakuchi	*Eostaffella-Millerella* zone	
		Favositida	Favositidae	*Sutherlandia hasegawai*	Niko (2009)	Fukugakuchi	*Fasulina* – *Fusulinella* zone	
			Pachyporidae	*Sinkiangopora kurohimensis*	Niko (2000)	Higashiyama	late Bashkirian	
				Acaciapora sp.	Niko (2013)	Fukugakuchi	*Endothyra* zone	
				Sinkiangopora? sp. indet.	Niko (2013)	Fukugakuchi	*Endothyra* zone	
			Cleistoporidae	*Donetzites* cf. *D. kibiensis*	Niko (2011)	Omi River	*Eostaffella-Millerella* zone	
				Donetzites miyakei	Niko (2010)	Nishiyama quarry	*Endothyra* zone	
			Micheliniidae	*Michelinia japonica*	Niko (2011)	Fukugakuchi	*Eostaffella-Millerella* zone	
			Pseudofavositidae	*Pseudofavosites hinaensis*	Niko (2011)	Omi River	*Eostaffella-Millerella* zone	
				Pseudofavosites sp.	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
		Stauriida	Axophyllidae	*Axophyllum centrotum*	Fujita (1958)	Denka: Uta River	*Millerella* - Coral Brachiopod Zone	
			Aulophyllidae	*Clisiophyllum kurohimense*	Yoshida et al. (1987); Yokoi (2013)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
				Corwenia? omiensis	Fujita (1958)	Shinetsu Chemical Industry; Nishiyama	*Millerella* - Coral Brachiopod zone	*Lonsdaleia (Waagenophyllum) omiensis* of Hayasaka (1924)
				Dibunophyllum? sp.	Fujita (1958)	Shinetsu Chemical Industry	*Millerella* - Coral Brachiopod zone	
				Echigophyllum giganteum	Hayasaka (1924); Fujita (1958); Niikawa, (2001)	Fukugakuchi; Nishiyama and Higashiyama; Itagamine	Visean?- Fusulinella zone	*Amygdalophyllum giganteum* of Fujita (1958); *Clisaxophyllum awa* of Minato (1955)
			Bothrophyllidae	*Carcinophyllum hasegawai*	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
			Cyathaxoniidae	*Cyathaxonia* cfr. *C counu*	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
			Geyerophyllidae	*Amygdalophylloides densus*	Yoshida and Okimura (1992)	Fukugakuchi	*Eostaffella-Millerella* zone	
				Amygdalophylloides denticulatus	Yoshida and Okimura (1992)	Fukugakuchi	*Eostaffella-Millerella* zone	
				Amygdalophylloides gracilis	Yoshida and Okimura (1992)	Fukugakuchi	*Eostaffella-Millerella* zone	*Axophyllum gracile* of Hayasaka(1924)
				Amygdalophylloides longiseptatus	Yoshida and Okimura (1992)	Fukugakuchi	*Eostaffella-Millerella* zone	
				Amygdalophylloides omiensis	Yoshida and Okimura (1992)	Fukugakuchi	*Eostaffella-Millerella* zone	
				Amygdalophylloides parvus	Yoshida and Okimura (1992)	Fukugakuchi	*Eostaffella-Millerella* zone	
				Amygdalophylloides uzurensis	Yoshida and Okimura (1992)	Fukugakuchi	*Eostaffella-Millerella* zone	
				Amygdalophylloides sp. A	Yoshida and Okimura (1992)	Fukugakuchi	*Endothyra* zone	
				Amygdalophylloides sp. B	Yoshida and Okimura (1992)	Fukugakuchi	*Eostaffella-Millerella* zone	
			Lithostrotionidae	*Aulina* sp.	Fujita (1958)	Itagamine	*Fusulinella* zone	

Appendix 4. The occurrence list of cnidarian fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Cnidaria	Anthozoa	Stauriida	Lithostrotionidae	*Lithostrotion kamiyai*	Yokoi (2013)	uncertain	Carboniferous	
				Lithostrotion somaense	Hayasaka (1924); Fujita (1958)	Fukugakuchi	*Millerella* - Coral Brachiopod zone	
				Lithostrotion sp.	Fujita (1958)	Nishiyama	*Millerella* - Coral Brachiopod zone	
			Lophophylidae	*Lophophyllum pendulum*	Fujita (1958)	Nishiyama; eastern Uta	*Millerella* - Coral Brachiopod zone	
			Metriophyllidae	*gen. et sp. indet.*	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
			Protozaphrentidae	*Neaxon sp.*	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
			Polycoelidae	*"Polycoelia" japonica*	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
			Pseudopavonidae	*Hiroshimaphyllum simpiex*	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
				Ibukiphyllum densum	Kato and Minato (1975)	Shinetsu Chemical Industry; Daiseru	*Fusulinella* zone	
				Omiphyllum confertum	Kato (1967)	uncertain	C1 zone	
				Ozakiphyllum compactum	Yokoi (2013)	uncertain	Carboniferous	
				Ozakiphyllum sp.	Hayasaka (1924)	Fukugakuchi	Visean-Bashkirian	*Lonsdaleia floriformis crassiconus* of Hayasaka (1924)
				Pseudopavona cf. *P. taisyakuana*	Rowett and Minato (1968)	Fukugakuchi	Lower Carboniferous	
				Pseudopavona ?	Hayasaka (1932)	uncertain	Carboniferous	*Orionastraea* sp. of Hayasaka (1932)and Fujita (1958)
				Taisyakuphyllum rostfer	Rowett and Minato (1968); Yokoi (2013)	Fukugakuchi	Lower- Upper Carboniferous	
			Stereophrentidae	*Plerophyllum* spp.	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
			Zaphrentoididae	*Zaphrentoides* sp.	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
			incertae sedis	*Pentaphyllum* sp.	Yoshida et al. (1987)	Fukugakuchi	*Endostaffella delicata* Zone and *Mediocris mediocris* Zone of Akiyoshi (Ota, 1977)	
		Syringoporida	Syringoporidae	*Multithecopora fukugakuchiensis*	Niko (2013)	Fukugakuchi	*Endothyra* zone	Pseudoromingeria kotoi of Yoshida et al. (1987)?
		indet.	indet.	*Stylidophylllum yokoyamai*	Fujita (1958)	Nishiyama quarry	*Millerella* - Coral Brachiopod zone	
				Stylidophyllum? sp.	Hayasaka (1924)	Fukugakuchi	Visean	
	Scyphozoa	Conulariida	Conulariidae	*Paraconularia sp.*	Makiguchi (1993); FMM display	uncertain	Carboniferous	

Appendix 5. The occurrence list of cnidarian fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality
Mollusca	Bivalvia	Myalinida	Miyalinidae	gen. et sp. indet	FMM display	unknown
				Posidoniella cfr. *pyriformis*	Hayasaka (1924)	unknown
		Pectinoida	Aviculopectenidae	*Annuliconcha* sp.	This study	Omi River
			Aviculopectenidae	*Aviculopecten* sp.	Fujita (1958)	Higashiyama
			Limipectinidae	*Acanthopecten* sp.	FMM display	unknown
		Veneroida	indet.	fam. gen. et sp. indet.	This study	Omi River
	Rostroconchia	Conocardiida	Conocardiidae	*Conocardium* sp.	Yokoi (2013); FMM display	unknown
	Gastropoda	Incertae sedis	Bellerophonidae	*Bellerophon* sp.	Fujita (1958)	Nishiyama
				gen. et sp. indet.	FMM display	unknown
				gen. et sp. indet. A	This study	Fukugakuchi
			Loxonematidae	gen. et sp. indet	FMM unregistered specimen	uncertain
		Cycloneritimorpha	Neritopsidae	*Turbonitella yamagidai*	FMM display	uncertain
		Dentaliida	Dentaliidae	*Dentalium?* sp.	Omi Town Bord of Education (1984)	Kurohime
		Eogastropoda	Euomphalidae	*Straparollus* sp.	FMM display	uncertain
		Euomphalina	Platyceratidae	*Platyceras* sp.	FMM display	uncertain
		Neritoida	Neritopsidae	*Naticopsis* cfr. *Variata*	Hayasaka 1924	Omi river
				Naticopsis sp.	Hayasaka 1924	uncertain
		Orthogastropoda	Soleniscidae	*Soleniscus* sp.	FMM display	uncertain
		Vetigastropoda	Anomphalidae	gen. et sp. indet.	This study	Omi River
			Eotomsriidae	*Glabrocingulum sp.*	This study	Omi River
				Mourlonia carinata	Yokoi (2013); Hayasaka (1924)	uncertain
				Mourlonia hayasakai	FMM display	uncertain
				Mourlonia aff. *hayasakai*	This study	Omi River
				Mourlonia sp.	Fujita (1958)	eastern Uta
				gen. et sp. indet.	This study	Omi River
			Gosseletinidae	*Angyomphalus hashimotoi*	FMM display	uncertain
			Microdomatidae	gen. et sp. indet.	This study	Omi River
			Phymatopleuridae	*Phymatopleura?* sp.	FMM unregistered specimen	Higashiyama
			Trochoidea	gen. et sp. indet	FMM unregistered specimen	uncertain

Appendix 6. The occurrence list of molluscan fossils from the Carboniferous Omi Limestone. The high- lightened species are reported and described in this study.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age
Mollusca	Cephalopoda	Bactrida	Bactritidae	*Bactrites nsagatoensis*	Niko (2002); Yokoi (2013)	Higashiyama	Middie Carboniferous (probable late Bashkirian)
				Bactrites sp.	Niko (2002)	Higashiyama	Middie Carboniferous (probable late Bashkirian)
		Goniatitida	Agathiceratidae	*Agathiceras toriyamai*	Yokoi (2013)	uncertain	Carboniferous
				Agathiceras sp.	FMM display	uncertain	Carboniferous
			Bisatoceratidae	*Bisatoceras* sp.	Yokoi (2013); FMM unregistered specimen	uncertain	Carboniferous
				Neoglaphyrites sp.	Yokoi (2013)	uncertain	Carboniferous
			Gastrioceratidae	*Gastrioceras* sp.	Yokoi (2013); FMM unregistered specimen	uncertain	Carboniferous
				Gastrioceras aff. *reticulatus*	Igo and Koike (1964)	Nishiyama	*Profusulinella* zone?
			Glaphyritidae	*Clistoceras* sp.	FMM display	uncertain	Carboniferous
				Syngastrioceras orientale	FMM display	uncertain	Carboniferous
			Gonioloboceratidae?	gen. et sp. indet	FMM unregistered specimen	Higashiyama	*Profsulinella* -*Fusulinella* Zone
			Neoicoceratidae	*Eoasianites orientalis*	Yokoi (2013)	uncertain	Carboniferous
				Eoasianites cf. *orientaie*	Kato and Nakamura (1962)	Nishiyama	*Eostaffella*- *Millerella* zone to*Profusulinella* zone
				Eoasianites sp.	Igo and Koike (1964)	Nishiyama	*Profusulinella* zone?
			Pseudoparalegoceratidae	*Pseudoparalegoceras kesslerense*	FMM display	uncertain	Carboniferous
				Pseudoparalegoceras compressum	Yokoi (2013)	uncertain	Carboniferous
				Pseudoparalegoceras sp.	Oyagi (2000); FMM display	uncertain	Carboniferous
			Reticuloceratidae	*Reticuloceras?* sp.	Igo and Koike (1964)	Nishiyama	*Profusulinella* zone?
			Schistoceratidae	*Branneroceras* sp.	Yokoi (2013)	uncertain	Carboniferous
				Diaboloceras sp.	Yokoi (2013)	uncertain	Carboniferous
				Paralegoceras sp.	Igo and Koike (1964)	Nishiyama	*Profusulinella* zone?
				Winslowoceras sp.	FMM display	Higashiyama	*Profsulinella* -*Fusulinella* Zone
			Welleritidae	*Eowellerites* sp.	FMM unregistered specimen	Higashiyama	*Profsulinella* -*Fusulinella* Zone
				Faqingoceras nagatoense	FMM display	uncertain	Carboniferous
		Nautilida	Trigonoceratidae	*Echigoceras sasakii*	Niko (2002)	Higashiyama	Middie Carboniferous (probable late Bashkirian)
				Leuroceras sp.	FMM display	uncertain	Carboniferous
				Subclymenia sp.	FMM unregistered specimen	uncertain	Carboniferous
		Orthocerida	Orthoceratidae	*Orthoceras* sp.	Yokoi (2013)	uncertain	Carboniferous
		Pallioceridae	Bogoslovskyidae	*Bogoslovskya omiensis*	Niko (2002)	Higashiyama	Middie Carboniferous (probable late Bashkirian)
		Pseudorthocerida	Pseudorthoceratidae	*Pseudorthoceras* sp.	Koizumi, 1975	uncertain	Carboniferous
		Prolecanitida	Pronoritidae	*Minepronorites takahashii*	FMM display	uncertain	Carboniferous
		Prolecanitida		gen. et sp. indet	FMM display	uncertain	Carboniferous

Appendix 7. The occurrence list of molluscan fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Foraminifera	Fusulinidia	Fusulinida	Archaediscidae	*Archaediscus ex gr. A. gigas*	Kano and Yoshida (1994)	Fukugakuchi	*Endothyra* zone	
				Archaediscus sp. A	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Archaediscus sp. B	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Asteroarchaediscus sp.	Niko (2011)	Omi River	*Eostaffella-Millerella* zone	
				Neoarchaediscus parvus	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Neoarchaediscus cf. *subbashikiricus*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Neoarchaediscus spp.	Kano and Yoshida (1994)	Fukugakuchi	*Eostaffella kanmerai* zone	
				Paraarchaediscus koktjubensis	Nakazawa (1997); Ueno & Nakazawa 1993	Fukugakuchi; Nishiyama; Higashiyama; Omi River	*Mediocris breviscula* zone	
				Paraarchaediscus cf. *pauxillus*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Paraarchaediscus sp. A	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Paraarchaediscus sp. B	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Paraarchaediscus? sp. C	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Neotuberitina sp.	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
			Biseriamminidae	*Biseriella* spp.	Kano and Yoshida (1994)	Fukugakuchi	Eostaffella kanmerai zone- Eostaffella- Millerella zone	
				Globivalvulina spp.	Yoshida et al. (1987); Kano and Yoshida (1994); Niko (2011)	Fukugakuchi	*Eostaffella kanmerai* zone- *Eostaffella-Millerella* zone	
			Bradyinidae	*Janischewskina* cf. *isotovae*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Janischewskina spp.	Kano and Yoshida (1994)	Fukugakuchi	*Eostaffella kanmerai* zone- *Eostaffella-Millerella* zone	
			Earlandiidae	*Earlandia elegans*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Earlandia cf. *moderata*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Earlandia sp.	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
			Endothyridae	*Endostaffella sp.*	Yoshida et al, (1987); Ueno and Nakazawa (1993)	Fukugakuchi; Nishiyama	Late Visean	
				Endothyra gigantea	Yoshida et al. (1987); Kano and Yoshida (1994)	Fukugakuchi	*Endothyra* zone- *Mediocris mediocris* zone	
				Endothyra masanae	Yoshida et al. (1987); Kano and Yoshida (1994)	Fukugakuchi	*Endothyra* zone- *Mediocris mediocris* zone	
				Endothyra spinosa	Yoshida et al. (1987); Kano and Yoshida (1994)	Fukugakuchi	*Mediocris breviscula* zone	
				Endothyra aff. *E. hortonensis*	Yoshida and Okimura (1992); Kano and Yoshida (1994)	Fukugakuchi	*Eostaffella-Millerella* zone	
				Endothyra aff. *E. apposita*	Kano and Yoshida (1994)	Fukugakuchi	*Eostaffella-Millerella* zone	
				"Endothyra" spp.	Niko (2011)	Omi River	*Eostaffella-Millerella* zone	
				Endothyra sp. A	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Endothyra sp. B	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Endothyra sp. C	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	

Appendix 8. The occurrence list of foraminiferal fossils from the Carboniferous Omi Limestone. It includes fusulinida.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Foraminifera	Fusulinidia	Fusulinida	Endothyridae	*Endothyra* sp. D	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Endothyra sp. E	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Endothyranopsis crassa	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Endothyranopsis leticulata	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Endothyranopsis compressa	Nakazawa (1997)	Fukugakuchi; Hisgashiyama; Nishiyama; Omi River	*Mediocris breviscula* zone	
				Endothyranopsis cf. compressa	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Endothyranopsis spp.	Kano and Yoshida (1994)	Fukugakuchi	*Mediocris breviscula* zone	
				Eoendothyranopsis spp.	Ueno and Nakazawa (1993); Kano and Yoshida (1994)	Nishiyama	*Mediocris breviscula* zone	
				Haplophragmella ganelinae	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Haplophragmella fallax				
				Haplophragmella sp.	Niko (2011)	Omi River	*Eostaffella-Millerella* zone	
				Omphalotis? frequentata	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Omphalotis? sp.	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Planoendothyra spirilliniformis	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Planoendothyra aljutovica	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Planoendothyra sp.	Niko, 2011 Sci. Rep. Niigata Univ. (Geology)	Omi River	lower Eostaffella-Millerella Zone, whose age is the late Visean to Serpukhovian	
				Planoendotityra cf. *spirilliniformis*	Niko & Hasegawa, 2000	Higashiyama	late Bashkirian	
				Pojarkovella aff. *nibelis*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Pojarkovella sp. A	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Pojarkovella sp. B	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Pojarkovella spp.	Nakazawa (1997)	Fukugakuchi; Nishiyama; Higashiyama; Omi River	*Mediocris breviscula* zone; *E. mosquensis* zone	
				Spinothyra pauciseptata	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Zellerinella sp. A	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Zellerinella sp. B	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Zellerinella sp.C	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Zellerinella spp.	Nakazawa (1997)	Fukugakuchi; Nishiyama; Higashiyama; Omi River	*Mediocris breviscula* zone , *E. mosquensis* zone	

Appendix 9. The occurrence list of foraminiferal fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Foraminifera	Fusulinidia	Fusulinida	Fusulinidae	*Akiyoshiella ozawai*	Watanabe (1973); Nakazawa (1997); Hasegawa and Goto (1990)	Itagamine; Higashiyama; Nishiyiama; Fukugakuchi	*Akiyoshiella ozawai* zone; *Profusulinella* zone	
				Akiyoshiella toriyamai	Watanabe (1973); Nakazawa (1997)	Itagamine;Higashiyama; Nishiyama	*Akiyoshiella ozawai* zone, *Profusulinella* zone	
				Beedeina sp.	Nakazawa (1997); Hasegawa and Goto (1990)	Higashiyama; Nishiyama	*Beedeina* sp. zone; *Fusulina- Fusulinella* zone	
				Fusulinella biconica	Hayasaka (1924); Fujita (1958); Nakazawa (1997); Hasegawa and Goto (1990)	Higashiyama; Nishiyama; Shinetsu Chemical Industry; Gongen	*Fusulinella biconica* zone; *Fusulinella-Fusulina* zone	
				Fusulinella bocki	Kawada (1954); Fujita (1958); Nakazawa (1997); Hasegawa and Goto (1990)	southern Higashiyama Mine; Nishiyama Mine; Maikomidaira	C2 zone; *Fusulinella biconica* zone; *Fusulinella-Fusulina* zone	
				Fusulinella elegantula	Hasegawa and Goto (1990)	Higashiyama	*Fusulinella* zone	
				Fusulinella hayasakai	Watanabe (1973)	Itagamine	*Akiyoshiella ozawai* zone	
				Fusulinella itoi	Hasegawa and Goto (1990)	Higashiyama	*Fusulinella* zone	
				Fusulinella jamesensis	Watanabe (1973)	Itagamine	*Akiyoshiella ozawai* zone	
				Fusulinella minima				
				Fusulinella pigmae	Hasegawa and Goto (1990)	Higashiyama	*Fusulinella* zone	
				Fusulinella pseudobocki	Hasegawa and Goto (1990)	Higashiyama	*Fusulinella* zone	
				Fusulinella purchra	Watanabe (1973)	Itagamine	*Akiyoshiella ozawai* zone	
				Fusulinella simplicata	Hasegawa and Goto (1990)	Higashiyama	*Fusulinella* zone	
				Fusulinella cfr. *girty*	Kawada (1954)	Itagamine	C2 zone	
				Fusulinella n. sp.	Kawada (1954)	Maikomidaira	C2 zone	
				Profusulinella beppensis	Nakazawa (1997); Hasegawa and Goto (1990)	Fukugakuchi; Nishiyama; Higashiyama	*Profusulinella daiyamensis* Zone; *Profusulinella* Zone; *Akiyoshiella ozawai* zone	
				Profusulinella daiyamensis	Nakazawa (1997); Hasegawa and Goto (1990)	Fukugakuchi; Nishiyama; Higashiyama	*Profusulinella daiyamensis* zone; *Profusulinella* zone	
				Profusulinella omiensis	Watanabe (1973)	Itagamine	*Profusulinella omiensis- P. daiyamansis* zone	
				Profusulinella probiconica	Watanabe (1973)	Itagamine	*Akiyoshiella ozawai* zone	
				Profusulinella pseudorhomboides	Watanabe (1973)	Itagamine	*Akiyoshiella ozawai* zone	
				Profusulinella rhomboides	Nakazawa (1997)	Nishiyama; Higashiyama	*Profusulinella daiyamensis* Zone; *Profusulinella* Zone; *Akiyoshiella ozawai* zone	
				Profusulinella sp. A	Watanabe (1973)	Itagamine	*Profusulinella omiensis- P. daiyamansis* zone	
				Pseudofusulinella pulchra	Nakazawa (1997)	Nishiyama; Higashiyama	*Beedeina* sp. zone	
				Quasifusulina sp.	Endo (1952)	Utatonami	C3	
			Lasiodiscidae	*Eolasiodiscus* cf. *donbassicus*	Niko and Hasegawa (2000)	Higashiyama	late Bashkirian	
				Eolasiodiscus sp.	Kano and Yoshida (1994)	Fukugakuchi	*Eostaffella kanmerai* zone	
				Howchinia gibba	Ueno & Nakazawa 1993	Nishiyama	Late Vsean	
				Howchinia sp.	Ueno and Nakazawa (1993); Kano and Yoshida (1994)	Fukugakuchi; Nishiyama	Mediocris mediocris zone	
				Monotaxinoides sp.	Niko (2011)	Omi River	*Eostaffella-Millerella* zone	

Appendix 10. The occurrence list of foraminiferal fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Foraminifera	Fusulinidia	Fusulinida	Ozawainellidae	*Eostaffella ikensis*	Niko (2011)	Omi River	*Eostaffella-Millerella* zone	
				Eostaffella kanmerai	Kano and Yoshida (1994)	Fukugakuchi	*Eostaffella kanmerai* zone- *Eostaffella-Millerella* zone	
				Eostaffella mosquensis	Nakazawa (1997)	Fukugakuchi; Nishiyama	*Eostaffella mosquensis* zone	
				Eostaffella postmosquensis	Watanabe (1973); Niko (2011)	Itagamine; Omi River	*Pseudostaffella antiqua* zone; *Eostaffella-Millerella* zone, *Profusulinella daiyamensis* zone; *Profusulinella* zone	
				Ozawainella cfr. *angulata*	Kawada (1954)	Osawa	C3	
				Ozawainella vozhgalica	Watanabe (1973)	Itagamine	*Profusulinella omiensis- P. daiyamansis* zone	
				Ozawainella sp.	Hasegawa and Goto (1990)	Nishyama; Fukugakuchi	*Profusulinella* zone; *Fusulina- Fusulinella* zone	
				Plectostaffella (?) sp.	Niko (2011)	Omi River	*Eostaffella-Millerella* zone	
				Pseudoendothyra cf. *struvii*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Pseudoendothyra cfr. *Bona grandisa*	Hasegawa and Goto (1990)	Nishyama; Higashiyama; Fukugakuchi	Profusulinella zone; Bashkirian- earliest Moscovian	
				Pseudoendothyra sp.	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Mediocris breviscula	Nakazawa (1997), Yoshida et al. (1987); Niko and Hasegawa (2000); Ueno and Nakazawa (1993); Kano and Yoshida (1994)	Fukugakuchi; Nishiyama; Higashiyama; Omi River	*Mediocris breviscula* Zone; *Eostaffella-Millerella* Zone	
				Millerella marblensis	Nakazawa (1997)	Fukugakuchi; Nishiyama; Higashiyama	*Millerella marblensis* zone, *Eostaffella-Millerella* zone	
				Mediocris medicoris	Nakazawa (1997), Yoshida et al., 1987 Trans. Paleont. Soci. Japan. Ueno & Nakazawa 1993; Kano and Yoshida (1994)	Fukugakuchi; Nishiyama; Higashiyama; Omi River	*Mediocris breviscula* Zone; *Eostaffella-Millerella* Zone	
				Millerella sp.	Fujita (1958); Hasegawa and Goto (1990); Kano and Yoshida (1994); Nakazawa (1997); Niko and Hasegawa (2000)	Nishiyama Mine; Higashiyama Mine; Fukugakuchi; Omi River	*Eostaffella- Millerella* zone; *Profusulinella* zone; *Fusulinella* zone	
				Pseudostaffella antiqua	Kano and Yoshida (1994); Nakazawa (1997)	Fukugakuchi; Nishiyama; Higashiyama	*Pseudostaffella antiqua* zone; *Profusulinella daiyamensis* zone; *Profusulinella* zone	
				Pseudostaffella kanumai	Watanabe (1973)	Itagamine	*Profusulinella omiensis- P. daiyamansis* zone	
				Pseudostaffella minuta	Nakazawa (1997)	Fukugakuchi; Nishiyama; Higashiyama	*Pseudostaffella antiqua* zone, *Eostaffella-Millerella* zone	
			Pseudoammodiscidae	*Pseudoglomospira* sp.	Ueno and Nakazawa (1993)	Nishiyama	*Eostaffella kanmerai* zone- *Eostaffella-Millerella* zone	
				Pseudoammodiscus cf. *volgensis*	Ueno and Nakazawa (1993); Kano and Yoshida (1994)	Nishiyama; Fukugakuchi	Late Vsean	
				Pseudoammodiscus spp.	Kano and Yoshida (1994)	Fukugakuchi	*Eostaffella- Millerella* zone	

Appendix 11. The occurrence list of foraminiferal fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Foraminifera	Fusulinidia	Fusulinida	Palaeotextulariidae	*Climacammina procera*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Climacammina sp. A	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Climacammina sp. B	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Climacammina sp. C	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Climacammina sp.	Fujita (1958); Nakazawa (1997); Kano and Yoshida (1994)	Omi River; Fukugakuchi	*"Endothyra"* spp. Zone- *Triticites* zone	
				Cribrostomum spp.	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Cribrothyra omiensis	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Palaeotextularia ex gr. *longiseptata*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Palaeotextularia sp.	Niko (2011); Kano and Yoshida (1994)	Fukugakuchi	*Endothyra* zone- *Profusulinella antiqua* zone	
				Palaeotextularia sp. A	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Palaeotextularia sp. B	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
			Schubertellidae	*Eoschubertella mexicana*	Kawada (1954)	Onigahana	C3 zone	
				Eoschubertella sp.	Hasegawa and Goto (1990)	Nishyama; Higashiyama; Fukugakuchi	*Profusulinella* zone	
				Schubertella cf. *porrecta*	Niko and Hasegawa (2000)	Higashiyama	late Bashkirian	
				Schubertella n. sp.	Kawada (1954)	Onigahana	C3	
			Schwagerinidae	*Triticites skinneri*	Kawada (1954)	southern, central northern areas of Omi Limestone	C3 zone	
				Triticites cullomensis	Kawada (1954)	southern, central northern areas of Omi Limestone	C3 zone	
				Triticites kagaharensis	Kawada (1954)	Osawa	C3 zone	
				Triticites minimous	Endo 1952; Kawada (1954); Fujita (1958)	Shinetsu Chemical Industry; Onigahana	*Triticites* zone	
				Triticites milleri	Endo 1952; Kawada (1954); Fujita (1958)	Shinetsu Chemical Industry; Onigahana	*Triticites* zone	
				Triticites montiparus	Kawada (1954); Watanabe (1973)	central areas of Omi Limestone	C3 zone	
				Triticites simplex	Kawada (1954); Hasegawa and Goto (1990)	Shinetsu Chemical Industry; Omi River	*Triticites* zone	
				Triticites cfr. *springvillensis*	Kawada (1954)	Mizube	C3 zone	
				Triticites subventricosus	Kawada (1954)	Onigahana	C3 zone	
				Triticites cf. *kagaharensis*	Fujita (1958)	Shinetsu Chemical Industry	C3 zone; *Triticite* s zone	
				Triticites sp. A	Hasegawa and Goto (1990)	Shinetsu Chemical Industry	*Triticites* zone	
				Triticites n. sp.	Kawada (1954)	southern, central northern areas of Omi Limestone	C3 zone	
			Staffellidae	*Nankinella yokoyamai*	Watanabe (1973); Niko and Hasegawa (2000)	Itagamine: Higashiyama	*Profusulinella omiensis*- *P. daiyamansis* zone	
				Staffella akagoensis	Watanabe (1973)	Itagamine	*Akiyoshiella ozawai* zone	
				Staffella sp.	Hasegawa and Goto (1990); Kawada (1954)	Higashiyama; Omi River	*Fusulina*- *Fusulinella* zone	

Appendix 12. The occurrence list of foraminiferal fossils from the Carboniferous Omi Limestone.

	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Foraminifera	Fusulinidia	Fusulinida	Tetrataxidae	*Tetrataxis fortis*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis maxima	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis cfr. *maxima* var. *depressa*	Hayasaka (1924)	Omi River	uncertain	
				Tetrataxis conica	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis pressula	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis minima	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis bogushi	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis parviconica	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis serpuhkovensis	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis cf. *barkhatovae*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis sp.	Niko (2011); Yoshida et al. (1987); Fujita (1958)	Fukugakuchi; Omi River; Shinetsu Chemical Industry; Itagamine	*Eostaffella-Millerella* zone; *Fusulinella* zone	
				Tetrataxis sp. A	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tetrataxis sp. B	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Textralia spp.	Fujita (1958); Kano and Yoshida (1994)	Denka; Omi River; Uta; Fukugakuchi	Endothyra zone- Triticites zone	
			Tuberitinidae	*Eotuberitina reitlngerae*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Eotuberitina spp.	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Tuberitina sp.	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
			Valvulinellidae	*Valvulinella youngi*	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
				Valvulinella latissima	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
	Rotalidia	Lagenida	Nodosariidae	*Dentalina* sp.	Fujita (1958)	Omi River	*Fusulinella* zone	
				Nodosaria? sp.	Fujita (1958)	Omi River; Shinetsu Chemical Industry; Itagamine; Sarugababa; Uta	*Fusulinella* zone; *Triticites* zone	
	Textularidia	Astrorhizida	Ammodiscidae	*Ammovertella* sp.	Ueno and Nakazawa (1993)	Nishiyama	Late Vsean	
		Textulariida	Textulariidae	*Bigenerina* cfr. *elegans*	Hayasaka (1924); Fujita (1958); Hasegawa and Goto (1990)	Omi River	Moscovian-Artinskian	
			Textulariidae	*Bigenerina* sp.	Fujita (1958)	Itagamine; Omi River	Fusulinella zone; Triticites zone	

Appendix 13. The occurrence list of foraminiferal fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Arthropoda	Ostracoda	Halocyprida	Polycopidae	*Polycope* sp. A	This study	Nishiyama	Bashkirian	
				Polycope sp. B	This study	Nishiyama	Bashkirian	
		Palaeocopida	Kellettinidae	*Kellettina* cf. *robusta*	This study	Fukugakuchi	Bashkirian	
		Podocopida	Bairdiidae	*Bairdia* sp.	This study	Fukugakuchi	Bashkirian	
			Bairdiocyprididae	*Silenites* sp.	This study	Fukugakuchi	Bashkirian	
			Bythocyprididae	*Bythocypris* sp.	This study	Fukugakuchi	Bashkirian	
			Pachydomellidae	*Spinomicrocheilinella* sp.	This study	Fukugakuchi	Bashkirian	
			Incertae sedis	*Deloia* sp.	This study	Fukugakuchi	Bashkirian	
			indet.	gen. et sp. indet. A	This study	Fukugakuchi	Bashkirian	
			indet.	gen. et sp. indet. B	This study	Fukugakuchi	Bashkirian	
	Trilobita	Odontopleurida	Damesellidae	*Brachymetopus omiensis*	Kobayashi and Hamada (1980); Yokoi (2013)	uncertain	Carboniferous	
				Brachymetopus japonica	Endo and Matsumoto (1962)	Nishiyama	*Fusulinella* zone	
		Proetida	Phillipsiidae	*Cummingella imamurai*	Kobayashi and Hamada (1980)	uncertain	Carboniferous	
				Cummingella mesops	Kobayashi and Hamada (1980); Yokoi (2013)	uncertain	Carboniferous	
				Cummingella otai	Kobayashi and Hamada (1980)	uncertain	Carboniferous	
				Cummingella subtrigonalis	Kobayashi and Hamada (1980)	uncertain	Carboniferous	
				Cummingella sp.	FMM display	uncertain	Carboniferous	
			Proetidae	*Humilogriffithides taniguchii*	Endo and Matsumoto (1962)	Nishiyama	*Fusulinella* zone	
				Linguaphillipsia sp.	Kobayashi and Hamada (1980)	uncertain	Visean?	

Appendix 14. The occurrence list of arthropod fossils from the Carboniferous Omi Limestone. The high- lightened species are reported and described in this study.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Echinodermata	Blastoidea	Fissiculata	Phaenoschismatidae	*Nymphaeoblastus(?) sp.*	Yokoi (2013)	uncertain	Carboniferous	
	Crinoidea	Dendrocrinida	Erisocrinidae	*Akiyoshicrinus* sp.	FMM display	uncertain	Carboniferous	
		Hybocrinida	Hybocrinidae	gen et sp. indet	FMM display	uncertain	Carboniferous	
		Monobathrida	Paragaricocrinidae	gen et sp. indet	FMM display	Higashiyama Mine	Carboniferous	
			Periechocrinitidae	*Megistocrinus* sp.	Hayasaka (1924); Yokoi (2013)	uncertain	Carboniferous	
			Platycrinitidae	*Platyplateium* sp.	Yokoi (2013)	uncertain	Carboniferous	
		Sagenocrinida	Mespilocrinidae	*Mespilocrinus* sp.	FMM display	uncertain	Carboniferous	
			Dactylocrinidae	gen et sp. indet	FMM display	uncertain	Carboniferous	
		indet.	Acrocrinidae	*Acrocrinus* sp.	FMM display	uncertain	Carboniferous	
			Cromyocrinidae	*Goleocrinus* sp.	FMM display	Higashiyama Mine	Carboniferous	
				gen et sp. indet	FMM display	uncertain	Carboniferous	
	Echinoidea	indet.	indet.	gen. et ap. indet. A	this study	Fukugakuchi	Bashkirian	
				gen. et ap. indet. B	this study	Fukugakuchi	Bashkirian	
	Holothuroidea	Apodida	Theelidae	*Thalattocanthus consonus*	this study	Fukugakuchi	Bashkirian	
		Dactylochirotida	Priscopedatidae	*Clavallus* sp.	this study	Fukugakuchi	Bashkirian	
		Elasipoda	Protocaudinidae	*Microantyx botoni*	this study	Fukugakuchi	Bashkirian	
	Ophiuroidea	Oegophiurida	Furcasteridae	*Furcaster* sp.	this study	Fukugakuchi	Bashkirian	

Appendix 15. The occurrence list of echinoderm fossils from the Carboniferous Omi Limestone. The high- lightened species are reported and described in this study.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Bryozoa	Stenolaemata	Cryptostomida	Nikiforovellidae	*Streblotrypella ?* sp. indet.	Sakagami (1963)	Nishiyama, Omi River	C1 zone	
			Rhabdomesidae	*Rhabdomeson yabei*	Sakagami (1963)	Nishiyama	C1 zone	
			Rhomboporidae	*Rhombopora* sp.	Sakagami (1963)	Higashiyama	C1 zone	
			Streblascoporidae	*Streblascopora amabilis*	Sakagami (1963)	Nishiyama	C1 zone	*Ascopora* sp. of Fujita (1958)
				Streblascopora grossa	Sakagami (1963)	Nishiyama; Higashiyama	C1 zone	
		Cystoporida	Cystodictyonidae	*Fistulipora minima*	Hayasaka (1924)	uncertain	C1 zone	
				Fistulipora sp.	Sakagami (1962)	Nishiyama	C1 zone	
				Sulcoretepora complicata	Sakagami (1963)	Nishiyama	C1 zone	
				Sulcorctepora ? sp. indet.	Sakagami (1963)	Higashiyama	C1 zone	
			Fistuliporidae	*Cheilotrypa* sp.	Sakagami (1962)	Nishiyama	C1 zone	
				Fistulipora minima	Hayasaka (1924) Sakagami (1963)	Nishiyama	C1 zone	
				Fistulipora cf. *minima*	Fujita (1958)	Higashiyama	C1 zone	
			Hexagonellidae	*Hexagonella* sp.	Fujita (1958)	Nishiyama	*Fusulinella* zone	
				Prismopora nipponica	Sakagami (1962)	Nishiyama	C1 zone	
		Fenestrida	Acanthocladiidae	*Penniretepora* cf. *irregularis*	Sakagami (1963)	Nishiyama	C1 zone	
				Penniretepora higashiyamensis	Sakagami (1963)	Higashiyama	C1 zone	
				Penniretepora regularis	Sakagami (1963)	Nishiyama	C1 zone	
				Penniretepora sp.	Fujita(1958); Sakagami (1963)	Nishiyama	C1 zone	
				Thamniscus sp.	Fujita (1958)	Nishiyama	C1 zone	
			Fenestellidae	*Fenestella binodosa*	Sakagami (1962)	Nishiyama	C1 zone	
				Fenestella kawadae	Sakagami (1962)	Nishiyama	C1 zone	
				Fenestella cf. *triserialis*	Sakagami (1962)	Nishiyama	C1 zone	
				Fenestella sp.	Fujita (1958); Sakagami (1962)	eastern Uta	C1 zone	
				Moorephylloporina ? sp.	Fujita (1958)	Nishiyama	C1 zone	doubtful by Sakagami (1962)
				Protoretepora hayasakae	Hayasaka (1924); Fujita (1958); Sakagami (1962)	Nishiyama; eastern Uta	C1 zone	*Phyllopora* sp. of Hayasaka (1924) and Fujita (1958)
				Protoretepora sp.	Fujita 1958	Nishiyama	C1 zone	
			Polyporidae	*Polypora fujitae*	Sakagami (1963)	Nishiyama	C1 zone	
				Polypora indet. sp.	Hayasaka, 1924	Omi River	C1 zone	
		Trepostomatida	Stenoporidae	*Stenopora nishiyamensis*	Sakagami (1962)	Nishiyama	C1 zone	

Appendix 16. The occurrence list of bryozoan fossils from the Carboniferous Omi Limestone.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Conodonta	Conodonti	Ozarkodinida	Anchignathodontidae	*Hindeodus minutus*	Watanabe (1975); Igo and Koike (1964); this study	Nishiyama; Omi River	*Endotyra* zone; *Millerella* - coral brachiopod zone- *Id. sulcatus* zone	*Spathognathodus minutus* of Watanabe (1975)
				Subbryanthodus subaequalis	Watanabe (1975)	Omi River	*Endotyra* zone	*Ozarkodina subequalis* of Watanabe (1975)
			Cavusgnathidae	*Cavusgnathus unicornis*	Watanabe (1975)	Nishiyama	*Endotyra* zone	
				Cavusgnathus sp.	Watanabe (1975)	Nishiyama	*Endotyra* zone	
				Vogelgnathus campbelli	Watanabe (1975)	Nishiyama; Omi River	*Endotyra* zone	*Spathognathodus campbelli* of Watanabe (1975)
			Gnathodontidae	*Gnathodus bilineatus*	Watanabe (1975); Mizuno and Nakazawa (1993); Isomura (1996)	Fukugakuchi; Nishiyama; Omi River	*Endotyra* zone	
				Gnathodus cfr. *bilineatus*	Watanabe (1975)	Omi River	*Endotyra* zone	
				Gnathodus girty	Isomura (1996)	uncertain	upper Visean	
			Gondolellidae	*Mesogondolella clarki*	Isomura (1996); this study	Fukugakuchi; Nishiyama	*M. clarki* zone	
				Mesogondolella dentiseparata	Isomura (1996)	Uta River	Gzelian	
			Idiognathodontidae	*Declinognathodus noduliferous*	Igo and Koike (1964); Mizuno and Nakazawa (1993); Isomura (1996); this study	Fukugakuchi; Nishiyama	*Millerella* - coral brachiopod zone, D. noduliferus zone	*Streptognathodus japonicus, Gnathodus* sp. of Igo and Koike (1964)
				Declinognathodus praenoduliferous	this study	Fukugakuchi	D. noduliferus zone	
				Declinognathodus sp. A	this study	Omi River	Bashkirian- Moscovian	
				Declinognathodus sp. B	this study	Omi River	Bashkirian- Moscovian	
				Idiognathodus delicatus	this study	Fukugakuchi	*M. clarki* zone	
				Idiognathodus cf. *incurves*	this study	Nishiyama	*M. clarki* zone	
				Idiognathodus togashii	Igo and Koike (1964)	Nishiyama	*Millerella* - Coral Brachiopod Zone, Late Carbonifrous	maybe a juvinile elements of S. expansus
				Idiognathodus sp. A	this study	Nishiyama	Bashkirian- Moscovian	
				Idiognathodus sp. B	this study	Fukugakuchi	*S. expansus* zone	
				Idiognathoides corrugatus	this study	Fukugakuchi	*Id. sulcatus* zone- *S. expansus* zone	
				Idiognathoides macer	this study	Nishiyama	Bashkirian- Moscovian	
				Idiognathoides pacificus	Isomura (1996); this study	uncertain	*S. expansus zon* e; middle- upper Moscovian	
				Idiognathoides aff. *pacificus*	this study	Fukugakuchi	*Id. sulcatus* zone	
				Idiognathoides sinuatus	Igo and Koike (1964)	Nishiyama	*Millerella* - Coral Brachiopod Zone, Late Carbonifrous	

Appendix 17. The occurrence list of conodont fossils from the Carboniferous Omi Limestone. The high- lightened species are reported and described in this study.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Conodonta	Conodonti	Ozarkodinida	Idiognathodontidae	*Idiognathoides sulcatus*	Igo and Koike (1964); this study	Fukugakuchi; Nishiyama	*Millerella* - coral brachiopod zone, *Id. sulcatus* zone	*Gnathodus opimus* of Igo and Koike (1964)
				Neognathodus atokaensis	this study	Fukugakuchi; Nishiyama	*S. expansus* zone	
				Neognathodus symmetricus	Mizuno and Nakazawa (1993); this study	Fukugakuchi	Bashkirian- Moscovian	
				Neognathodus bassleri	Mizuno and Nakazawa (1993)	Fukugakuchi	Bashkirian	
				Neognathodus kanumai	this study	Fukugakuchi; Nishiyama	*S. expansus* zone	
				Neognathodus sp. A	this study	Nishiyama	*M. clarki* zone	
				Streptognathodus einori	this study	Fukugakuchi	*M. clarki* zone	
				Streptognathodus expansus	Isomura (1996); this study	Fukugakuchi; Nishiyama	*S. expansus* zone	
				Streptognathodus elegantulus	Isomura (1996)	uncertain	upper Moscovian- Kasimovian	
				Streptognathodus suberectus	this study	Fukugakuchi; Nishiyama	*S. expansus* zone- *M. clarki* zone	
				Streptognathodus cf. *suberectus*	this study	Nishiyama	*S. expansus* zone	
				Streptognathodus subsimplex	this study	Fukugakuchi	*S. expansus* zone	
			Spathognathodontidae	*Lochriea multinodosa*	Watanabe (1975)	Nishiyama; Omi River	*Endotyra* zoan, Lower Carboniferous	*Gnathodus nodosus* of Watanabe (1975)
				Lochriea commutata	Watanabe (1975); Mizuno and Nakazawa (1993)	Fukugakuchi; Nishiyama; Omi River	*Endotyra* zone *Millerella* - Coral Brachiopod zone	*Gnathodus commutatus* of Watanabe (1975
				Neolochriea glaber	this study	Fukugakuchi	*D. noduliferus* zone- *Id. sulcatus* zone	
			Sweetognathidae	*Diplognathodus? orphanus*	this study	Fukugakuchi	*S. expansus* zone	
			indet.	not Pa element	Igo and Koike (1964); Mizuno and Nakazawa (1993); Watanabe (1975); this study	Fukugakuchi; Nishiyama; Omi River	Visean- Bashkirian	*Hindeodella alatoides, Hindeodella segaformis, Neoprioniodus scitulus, N. loxus, Ozarkodina compressa,* of Watanabe (1975); *Spathognathodus echigoensis, Ozarkodina orientale, Euprioniodina dentata, Synprioniodina microdenta, Hindeodella sakagamii, H. paradelicatula, H. asiatica* of Igo and Koike (1964); *Paragnathus commutatus* of Mizuno and Nakazawa (1993)
		Prioniodinida	Prioniodinidae	*Kladoganathus* sp.	Watanabe (1975)	Nishiyama	*Endotyra* zone	*Magniratella* sp., Apatognathus? sp., gen. et sp. indet. of Watanabe (1975); *Lingonodina hanaii* of Igo and Koike (1964)
				Lonchodina? nipponica	Igo and Koike (1964)	Nishiyama	*Millerella* - Coral Brachiopod zone	*Roundya subacodus* of Igo and Koike (1964) are probably M element
				Lonchodina? sp.	Watanabe (1975)	Nishiyama	*Endotyra* zone	
				Idioprioniodus sp.	Igo and Koike (1964); this study	Nishiyama	*Millerella* - Coral Brachiopod zone	*Synprioniodina collinsoni* of Watanabe (1975)

Appendix 18. The occurrence list of conodont fossils from the Carboniferous Omi Limestone. The high- lightened species are reported and described in this study.

Phyllum	Class	Order/ Suborder	Family/ Superfamily	Scientific Name	Key Reference	Locality	Age	Note
Chordata	Actinopterygii	indet.	indet.	Actinopterygii indet. A	This study	Fukugakuchi; Nishiyama	Bashikirian-Moscovian	
				Actinopterygii indet. B	This study	Fukugakuchi	Bashikirian-Moscovian	
	Chondrichthyes	Bransonelliformes	incertae sedis	*Bransonella* sp.?	This study	Fukugakuchi	Bashikirian-Moscovian	
		Ctenacanthiformes	Ctenacanthidae	*Cladodus* sp.?	This study	Nishiyama	Bashikirian-Moscovian	
			indet.	Ctenacanthidae? gen. et sp. indet.	This study	Fukugakuchi	Bashikirian-Moscovian	
		Euselachii	Protacrodontidae	Protacrodontidae gen. et sp. indet.	This study	Fukugakuchi	Bashikirian-Moscovian	
		indet.	indet.	Gen et sp. indet. A	This study	Nishiyama	Bashikirian-Moscovian	
				Gen et sp. indet. B	This study	Omi River	Bashikirian-Moscovian	
Porifera	Calcarea	Inozoa	indet.	*Hikorocodium* sp.	Nakazawa (1997)	Higashiyama Mine	Beediana sp. zone	
		indet.	indet.	Calcarea indet.	This study	Fukugakuchi	Bashikirian-Moscovian	
				Calcaronea indet.	This study	Fukugakuchi	Bashikirian-Moscovian	
	Demospongia	indet.	indet.	Heteroscleromorpha indet.	This study	Fukugakuchi	Bashikirian-Moscovian	
	Sclerospongiae	indet.	indet.	*Chaetetes tangshanensis*	Rowett and Minato (1968)	Fukugakuchi	Lower Carboniferous	
				Cheatetes sp.	Nakazawa (1998)	Fukugakuchi; Nishiyama; Higashiyama	Bashikirian-Moscovian	
Chlorophyta	Ulvophyceae	Dasycladales	Polyphysaceae	*Anthracoporella spectabilis*	Endo (1952)	Utatonami	C3	
Cyanobacteria	indet	indet.	indet.	*Girvanella sp.*	Kano and Yoshida (1994); Nakazawa (1997)	Fukugakuchi	*Eostaffella-Millerella* Zone	
				Ortonella sp.	Nakazawa (1997)	Nishiyma	*Fusulinella biconica* zone	
Rhodophyta	indet.	indet.	indet.	*Komia* sp.	Yoshida and Okimura (1992); Kano and Yoshida (1994); Nakazawa (1997)	Fukugakuchi	*Eostaffella-Millerella* zone	
incertae sedis	Chitinozoa	Prosomatifera	indet.	Prosomatifera indet. A	This study	Fukugakuchi	Bashikirian-Moscovian	
				Prosomatifera indet. B	This study	Fukugakuchi	Bashikirian-Moscovian	
	indet.	indet.	indet.	Microproblematica A	This study	Fukugakuchi	Bashikirian-Moscovian	
				Microproblematica B	This study	Fukugakuchi	Bashikirian-Moscovian	
				Microproblematica C	This study	Fukugakuchi	Bashikirian-Moscovian	
				Microproblematica D	This study	Fukugakuchi	Bashikirian-Moscovian	
				Microproblematica E	This study	Fukugakuchi	Bashikirian-Moscovian	
				Microproblematica G	This study	Fukugakuchi	Bashikirian-Moscovian	
				Microproblematica I	This study	Nishiyama	Bashikirian-Moscovian	

Appendix 19. The occurrence list of other fossils from the Carboniferous Omi Limestone. The high- lightened species are reported and described in this study.

		weight (kg)	Hindeodus			Declinognathodus				Neol.	Idiognathodus					Idiognathoides					Mesogon.	Neognathodus				Streptognathodus					Dip?	Idiop.	others				
			cristulus	aff. cristulus	minutus	praenoduliferus	noduliferus	sp.A	sp.B	glaber	covadongae	delicatus	sinuousus	cf. incurves	sp.A	corrugatus	macer	pacificus	aff. pacificus	sulcatus	clarki	atokaensis	kanumai	symmetricus	sp. A	einori	expansus	suberectus	cf. suberectus	subsimplex	orphanus	sp.	Sa	Sb	Sc	M	Pb
Omi Riv. foat		3.2					3	1	1											2			1														
Nishiyama	NR-30	1.4																		1																	
	NR-26	1.9												1	3		1				1				1							1					
	NR-18	1.2																									1										
	NR-17	1.1																		1							1									1	
	NR-12	1.2					1													1															1		
	NR-7	0.9													1																						
	NR-5	1.1													4																						
	NR-1	2.1																									1										
	N210-7	0.5																																			
	N210-6	1.6																					1														
	N210-5	0.4																																			
	N210-4	2.5					4										3					1	1				2	2	1								
	N210-3	2.9					2													1							2	4							1		2
	N210-2	0.7																																			
	N210-1	1.3																																	2		
	NG-5	1.3					1																														
	NG-6	1.1					1																				1										
	NG-2	0.5																																			
	NG-1	0.7																																			

Appendix 20. The list of microfossils from the Nishiyama area and Omi River.

		Ostracoda										Actinopterygii			Chondrichthyes						
		Polycope A	Polycope B	Kellettina	Bairdia	Silenites	Bythocypris	Spinomicrocheilinella?	Deloia	indet. A	indet. B	indet A	indetB	scale	Protacrodontidae	Bransonella	Ctenacanthidae?	Cladodus	indet A	indet B	scale
Omi Riv. foat																				1	
Nishiyama	NR-30																				
	NR-26		1																		
	NR-18																				
	NR-17																				
	NR-12																				
	NR-7																	1			
	NR-5																				
	NR-1																				
	N210-7																				
	N210-6																				
	N210-5																				
	N210-4	2	1								1	3							1		
	N210-3	3	2									1									
	N210-2																				
	N210-1																				
	NG-5																				
	NG-6																				
	NG-2																				
	NG-1																				

Appendix 21. The list of microfossils from the Nishiyama area and Omi River.

		Mollusca								Echinoidea		Holothuroidea				Ophiuroidea	Porifera		
		Annuliconcha	Veneroida	Glabrocingulum	Mourlonia	Eotomariidae	Microdomatidae	Anomphalidae	Bellerophontidae	indet. A	indet. B	T. consonus	M. botoni	Clavallus	E. subhexagona	Furcaster	Calcarea	Calcaronea	Heteroscleromorpha
Omi Riv. foat		1		1	1	1	1	1											
Nishiyama	NR-30																		
	NR-26												1		1	2			
	NR-18																		
	NR-17																		
	NR-12																		
	NR-7																		
	NR-5																		
	NR-1																		
	N210-7																		
	N210-6																		
	N210-5																		
	N210-4												1						
	N210-3															1			
	N210-2																		
	N210-1																		
	NG-5																		
	NG-6																		
	NG-2																		
	NG-1																		

Appendix 22. The list of microfossils from the Nishiyama area and Omi River.

		Chitinozoa			Microproblematica							
		indet. A	indet. B	indet. C	A	B	C	D	E	F	G	H
Omi Riv. foat												
Nishiyama	NR-30											
	NR-26											
	NR-18											
	NR-17											
	NR-12											
	NR-7											
	NR-5											
	NR-1											
	N210-7											
	N210-6											
	N210-5											
	N210-4											
	N210-3											1
	N210-2											
	N210-1											
	NG-5											
	NG-6											
	NG-2											
	NG-1											

Appendix 23. The list of microfossils from the Nishiyama area and Omi River.

		weight (kg)	Hindeodus			Declinognathodus				Neol.	Idiognathodus					Idiognathoides					Mesogon.	Neognathodus				Streptognathodus					Dip?	Idiop.	others				
			cristulus	aff. cristulus	minutus	praenoduliferus	noduliferus	sp.A	sp.B	glaber	covadongae	delicatus	sinuousus	cf. incurves	sp.A	corrugatus	macer	pacificus	aff. pacificus	sulcatus	clarki	atokaensis	kanumai	symmetricus	sp. A	einori	expansus	suberectus	cf. suberectus	subsimplex	orphanus	sp.	Sa	Sb	Sc	M	Pb
Fukugakuchi	F-13	1.4									1																										
	F-12	1.1																		1																	
	F-11	1.5																																			
	F-10	1.8											1							2				1		1		1									
	Mk2-19	1.5									1									1	3																
	Mk2-18	0.5																																			
	Mk2-17	1.8										2									1						1										
	Mk2-16	0.5																																			
	Mk2-15	2.3			1							15								2	5																
	Mk2-9	0.3																																			
	Mk2-7	0.5																																			
	Mk2-4	1.1														1																					
	Mk2-2	0.3																																			
	Mk-40	1.3																1		1			1														
	Mk-39	1.4																		2							1										
	Mk-37	0.6																		1																	
	Mk-36	0.3																																			
	Mk-35	1.7																		2			2				1										
	Mk-34	2.2																5		4			6				1									1	1
	Mk-33	1.1					1													1			3														
	Mk-32	0.5																																			
	Mk-31	0.6																																			
	M-20	2.1					1																									1			1	1	2
	M-18	2.5					2													2												2			1		
	M-17	1.3																																			
	M-16	0.9																									1			1							
	M-15	0.4																																			
	M-14	2.6					1											1		3							1	2									1
	M-13	1.1																																			
	M-12	0.4																																			
	M-11	2.2																				1															
	M-10	0.7																																			
	M-9	1.1			1					1																											
	M-8	1.8			1																																
	M-7	0.5																																			1
	M-6	0.5																																			
	M-5	0.6																																			
	M-4	1.5					1			1						1				1																	
	M-3	1.6																																			
	M-2	2.1					2			1									1	1																	
	M-1	1.1								1														2													
	MF-4	1.4					2			1																											
	MF-1	5.1				1	1																														
	MF-2	0.5																																			
	MF-3	0.9																																			

Appendix 24. The list of microfossils from the Fukugakuchi area.

		Ostracoda										Actinopterygii			Chondrichthyes						
		Polycope A	Polycope B	Kellettina	Bairdia	Silenites	Bythocypris	Spinomicrocheilinella?	Deloia	indet. A	indet. B	indet A	indetB	scale	Protacrodontidae	Bransonella	Ctenacanthidae?	Cladodus	indet A	indet B	scale
Fukugakuchi	F-13											2	1		1	1					
	F-12																				
	F-11																				
	F-10																				
	Mk2-19																				
	Mk2-18																				
	Mk2-17																				
	Mk2-16																				
	Mk2-15																				
	Mk2-9																				
	Mk2-7																				
	Mk2-4																				
	Mk2-2																				
	Mk-40																				
	Mk-39																				
	Mk-37																				
	Mk-36																				
	Mk-35																				
	Mk-34																				
	Mk-33																				
	Mk-32																				
	Mk-31																				
	M-20		1																		
	M-18											1					1				
	M-17																				
	M-16																				
	M-15																				
	M-14																				
	M-13																				
	M-12																				
	M-11																				
	M-10																				
	M-9																				
	M-8																				
	M-7																				
	M-6																				
	M-5																				
	M-4																				
	M-3																				
	M-2			1	1	1	1	1	1	1											
	M-1																				
	MF-4																				
	MF-1											2									3
	MF-2																				
	MF-3																				

Appendix 25. The list of microfossils from the Fukugakuchi area.

		Mollusca								Echinoidea		Holothuroidea				Ophiuroidea	Porifera		
		Annuliconcha	Veneroida	Glabrocingulum	onia aff. hay	Eotomariidae	Microdomatidae	Anomphalidae	Bellerophontidae	indet. A	indet. B	T. consonus	M. botoni	Clavallus	E. subhexagona	Furcaster	Calcarea	Calcaronea	Heterosclеromorpha
Fukugakuchi	F-13															1			
	F-12																		
	F-11																		
	F-10																		
	Mk2-19																		
	Mk2-18																		
	Mk2-17																		
	Mk2-16																		
	Mk2-15																		
	Mk2-9																		
	Mk2-7																		
	Mk2-4																		
	Mk2-2																		
	Mk-40																		
	Mk-39																		
	Mk-37																		
	Mk-36																		
	Mk-35																		
	Mk-34																		
	Mk-33																		
	Mk-32																		
	Mk-31																		
	M-20												1				1	1	
	M-18		1							3						2			
	M-17																		
	M-16																		
	M-15																		
	M-14																		
	M-13																		
	M-12																		
	M-11																		
	M-10																		
	M-9																		
	M-8								1										
	M-7																		
	M-6																		
	M-5																		
	M-4																		
	M-3																		
	M-2																		
	M-1																		
	MF-4																		
	MF-1									6	1	1	8	1		3	1	3	3
	MF-2																		
	MF-3																		

Appendix 26. The list of microfossils from the Fukugakuchi area.

		Chitinozoa			Microproblematica							
		indet. A	indet. B	indet. C	A	B	C	D	E	F	G	H
Fukugakuchi	F-13											
	F-12											
	F-11											
	F-10											
	Mk2-19											
	Mk2-18											
	Mk2-17											
	Mk2-16											
	Mk2-15											
	Mk2-9											
	Mk2-7											
	Mk2-4											
	Mk2-2											
	Mk-40											
	Mk-39											
	Mk-37											
	Mk-36											
	Mk-35											
	Mk-34											
	Mk-33											
	Mk-32											
	Mk-31											
	M-20											
	M-18	1		1			3					
	M-17											
	M-16								4			
	M-15											
	M-14											
	M-13											
	M-12											
	M-11											
	M-10											
	M-9											
	M-8											
	M-7											
	M-6											
	M-5											
	M-4											
	M-3											
	M-2	1			1	1						
	M-1											
	MF-4											
	MF-1							11		1		
	MF-2											
	MF-3											

Appendix 27. The list of microfossils from the Fukugakuchi area.

		weight (kg)	Hindeodus			Declinognathodus				Neol.	Idiognathodus					Idiognathoides					Mesogon.	Neognathodus				Streptognathodus					Dip?	Idiop.	others				
			cristulus	aff. cristulus	minutus	praenoduliferus	noduliferus	sp.A	sp.B	glaber	covadongae	delicatus	sinuousus	cf. incurves	sp.A	corrugatus	macer	pacificus	aff. pacificus	sulcatus	clarki	atokaensis	kanumai	symmetricus	sp. A	einori	expansus	suberectus	cf. suberectus	subsimplex	orphanus	sp.	Sa	Sb	Sc	M	Pb
Maruyama	AI-13	0.9																																			
	AI-12	1.1									1																										1
	AI-10	1.3																																			
	AI-9	2.9									6									4																	
	AI-8	2.3									1																										
	AI-6	0.9																																			
	AI-5	0.7																																			
	AI-4	3.1	2		1															1											5			1	1	2	1
	AI-3	1.2																																			
	AI-2	3.1	1	2	2																										12				1	1	
	AI-1	2	2								1																										

Appendix 28. The list of microfossils from the Maruyama area, Akiyoshi Limestone.

		Ostracoda										Actinopterygii			Chondrichthyes						
		Polycope A	Polycope B	Kellettina	Bairdia	Silenites	Bythocypris	Spinomicrocheilinella?	Deloia	indet. A	indet. B	indet A	indetB	scale	Protacrodontidae	Bransonella	Ctenacanthidae?	Cladodus	indet A	indet B	scale
Maruyama	AI-13																				
	AI-12																				
	AI-10																				
	AI-9											4	2						1		4
	AI-8											1									
	AI-6																				
	AI-5																				
	AI-4																				
	AI-3																				
	AI-2												1	1							
	AI-1																				

Appendix 29. The list of microfossils from the Maruyama area, Akiyoshi Limestone.

		Mollusca								Echinoidea		Holothuroidea				Ophiuroidea	Porifera		
		Annuliconcha	Veneroida	Glabrocingulum	onia aff. hay	Eotomariidae	Microdomatidae	Anomphalidae	Bellerophontidae	indet. A	indet. B	T. consonus	M. botoni	Clavallus	E. subhexagona	Furcaster	Calcarea	Calcaronea	Heteroscleromorpha
Maruyama	AI-13																		
	AI-12																		
	AI-10																		
	AI-9															1			
	AI-8																		
	AI-6																		
	AI-5																		
	AI-4												1		1			1	
	AI-3																		
	AI-2												2			1		2	
	AI-1																		

Appendix 30. The list of microfossils from the Maruyama area, Akiyoshi Limestone.

		Chitinozoa			Microproblematica							
		indet. A	indet. B	indet. C	A	B	C	D	E	F	G	H
Maruyama	AI-13											
	AI-12											
	AI-10											
	AI-9		1								1	
	AI-8											
	AI-6											
	AI-5											
	AI-4											
	AI-3											
	AI-2											
	AI-1											

Appendix 31. The list of microfossils from the Maruyama area, Akiyoshi Limestone.