Radiolarian biostratigraphy and biogeography of the Middle Permian in East Asia

(東アジアにおけるペルム紀中世の放散虫生層序と生物地理)

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Contents

Abstract

The Permian Period, one of the most varied terms during the Earth history, is paleogeographically characterized by the presences of superoceans namely the Panthalassa and the Paleotethys. Additionally, the Permian is the term that a large amount of chert had accumulated. Hence, siliceous rocks as represented by cherts should provide some information of the Permian paleocean and thus the Permian Earth. Although some taxonomic paleobiogeography in Permian had been recognized, few studies have focused on Permian radiolarian paleobiogeography. It is effective for recognition of paleobiogeography and provincialism to compare radiolarian faunas among several geological bodies formed under different locations. I compared radiolarian assemblages that were collected from China and Japan.

I had researched the Liuhuang section in Chaohu, Anhui and the Gujingling section in Xiaodong, Guangxi in South China. The Liuhuang section comprises the Maokou, Gufeng, and Longtan formations. Radiolarian fossils abundantly occur from the Gufeng Formation. Gujingling section consists of the Bancheng Formation belonging to the Qinzhou allochthon. In addition to these, I had surveyed the Yoshii Group in the Yoshii area, Okayama, Japan.

Three radiolarian assemblage zones, namely *Pseudoalbaillella fusiformis*, *Pseudoalbaillella monacanthus*, and *Ruzhencevispongus uralicus*, were recognized from the Liuhuang section; I set up three assemblage zones, *Pseudoalbaillella fusiformis*, *Pseudoalbaillella monacanthus*, and *Follicucullus porrectus-F. scholasticus*, from the Gujingling section. Additionally, three radiolarian zones, *Albaillella sinuata*, *Pseudoalbaillella fusiformis*, and *Pseudoalbaillella monacanthus*, were recognized from the Yoshii Group.

The subsections 3–6 of the Gujingling section were morphologically and biogtratigraphically surveyed with specimens of *Pseudoalbaillella fusiformis*, *Pseudoalbaillella internata*, *Pseudoalbaillella monacanthus*, *Pseudoalbaillella fusiformis* m. S, *Pseudoalbaillella internata* m. S, and *Pseudoalbaillella monacanthus* m. S. Some characteristics of *Pseudoalbaillella internata* are intermediate between those of *Pseudoalbaillella fusiformis* and *Pseudoalbaillella monacanthus*. These characteristics suggest that *Pseudoalbaillella monacanthus* is direct descendant of *Pseudoalbaillella fusiformis* and *Pseudoalbaillella internata* is intermediate species between *Pseudoalbaillella fusiformis* and *Pseudoalbaillella monacanthus*. Changes of species occurrence frequency and horizons support the suggestions.

The Gufeng Formation in the Lower Yangtze region had been deposited in an outer

shelf environment under sulphate-reducing conditions and fronted the Paleotethys in the middle Permian on the basis of previous studies. Fossil compositions and petrological characteristics of the Gujingling section indicate that the Bancheng Formation was deposited in a basin deeper than 1000 m which was located at least a few hundred kilometers from the Yangtze block in the Middle Permian. The Akiyoshi terrane was deposited on an ocean floor that was located a few hundred kilometers from the Indo-China block in the Middle Permian on the basis of previous studies.

Quantitative analysis shows the following results. No *Pseudotormentus* was obtained from the Liuhuang section, while it abundantly occurred from the Gujingling section; *Longtanella* commonly occurred from the *Pseudoalbaillella fusiformis* Zone in the Liuhuang section, but no *Longtanella* occurred from the Gujingling section. *Quadriremis*, *Pseudoalbaillella*, and some taxa occurred from the both sections. *Pseudotormentus* and *Quadriremis* have similar forms and size, indicating that these species assumedly had been undergone similar taphonomy. That is, the ratios of these radiolarians may show more primary composition in the paleocean. The Liuhuang and Gujingling sections had been deposited in different oceans, suggesting that the faunal differences are caused by influences from the oceans.

As the result of the comparison based on reviews, the following characters were recognized. Some taxa, such as *Pseudoalbaillella*, *Hegleria*, Latentifistularia, and Entactinaria, commonly occur from all units. Meanwhile some of other taxa occur from limited units. *Longtanella* had commonly occurred from the Gufeng Formation, while it has never been observed from the accretionary complexes in Japan. *Pseudotormentus* had commonly occurred from the Qinzhou allochthon and the accretionary complexes in Japan however it had barely occurred from the Gufeng Formation. *Cauletella* had commonly occurred from the accretionary complexes in Japan, such as the Akiyoshi terrane and the Chichibu composite terrane, while it has never been observed from the Gufeng Formation and the Qinzhou allochthon. These results are consistent with the result of the quantitative analysis, implying that the radiolarian faunal differences between the Gufeng and Bancheng formations possibly represent wider distributed provinces.

In the Late Permian, *Pseudotormentus* has occurred mainly from the Panthalassa, while *Quadriremis* has occurred from both the Panthalassa and Paleotethys. These occurrences imply that radiolarian provincialism, uneven distribution of *Pseudotormentus*, had remained until the late Permian. Some recent radiolarians inhabit only the Pacific Ocean. *Pseudotormentus* may be the species characterized by inhabitation in large ocean like those.

Meanwhile, the Gufeng and Bancheng Formation had been deposited in different depth. Previous research of living and Quaternary radiolarians showed the radiolarian faunal differences by sea depth. These differences might indicate the paleo-depth distinctions.

1. Introduction

1.1. Paleocean in late Paleozoic

The late Paleozoic Era from the latest Carboniferous to Permian is one of the most variegated terms during the Earth History. Several events had happened during the term. The most severe mass extinction in the Phanerozoic occurred at the end of Permian (e.g., Sepkoski, 1984). Jin et al. (1994) and Stanley and Yang (1994) pointed out that the mass extinction consists of two independent extinction events. First and second extinction events are called the Guadalupian-Lopingian boundary event (GLB event) and the Permian-Triassic boundary event in a strict sense (PTB event), respectively. Several hypothesis to explain the cause and process of each extinction have been put forward, such as volcanism (Ranne and Basu, 1991), bolide impact (Becker et al., 2001), magnetic reversal (Haag and Heller, 1991), widespread regression (Erwin, 1993) and ocean anoxia (Wignall and Hallam, 1992; Hotinski et al., 2001). Marine sediments, especially pelagic deposits, recorded long-term marine oxygen depletion from Late Permian to middle Triassic, and this is called the super anoxia event (e.g., Isozaki, 1997). Multiple glaciations had waxed and waned across Gondwana from the late Carboniferous to middle Permian. This term is called the late Paleozoic Ice Age (e.g., Isbell et al., 2011). In late Middle Permian (= Capitanian), global cooling event, called the Kamura event, and high productivity are recorded in carbonate had been deposited low-latitude of the Panthalassa and Paleotethys (e.g., Isozaki et al., 2007, 2011). Soreghan et al. (2008) pointed out that huge eolian siltstone had accumulated during the late Paleozoic Ice Age, especially the Permian Period.

This term is paleogeographically characterized by the presences of superoceans namely the Panthalassa and the Paleotethys (e.g., Ross and Ross, 1990; Golonka and Ford, 2000). Therefore, it is important to obtain the information of the Panthalassa for revealing the Permian global environment. A large amount of chert had accumulated in the Panthalassa had waxed in the middle Permian, which is called the Permian Chert event (Murchey and Jones, 1992; Beauchamp and Baud, 2002). Hence, siliceous rocks as represented by cherts are one of the major components in the late Paleozoic, indicating that the information of those in the paleoceans should provide that of the Permian Earth.

Bio-provincialism is one of the important information of paleontology and paleoceanography. Some taxonomic provincialism in Permian had been recognized (e.g., fusulina: Kobayashi, 1997; conodont: Mei and Henderson, 2001; brachiopod: Shen et al., 2009). Mei and Henderson (2001) recognized the conodont provincialism and its change thorough the Permian. According to them, the provincialism appeared at the Artinskian (late Early Permian); it was established at the Kungurian (latest Early Permian).

1.2. Permian radiolaria

Radiolarians are planktonic protozoa (e.g., Anderson, 1983; De Wever et al., 2001). Radiolarians appeared early in the Cambrian (e.g., Brawn et al., 2007) and are widely distributed in shallow-to-open oceans at depths of up to 4,000 m in the modern ocean (e.g., Boltovskoy et al., 2010). Radiolarians are important fossils for determining geological age and for understanding oceanographic history. Although the Paleozoic and Mesozoic radiolarians had long been ignored, some researchers had found meaning of them with the developments of the observation and extraction methods in 1970's (e.g., Pessagno and Newport, 1972).

The late Paleozoic radiolarian occurrences had been reported from some countries, especially in last three decades (e.g., Ormiston and Babcock, 1979; Holdsworth and Jones, 1980; Kozur, 1980; Ishiga and Imoto, 1980; Sheng and Wang, 1985; De Wever et al., 1988; Adachi, 1988; Grapes et al., 1990; Sashida et al., 1993a, b; Takemura et al., 1998). Late Paleozoic radiolarian zones had been constructed mainly on the basis of Albaillellaria (e.g., China: Wang and Yang, 2011; Japan: Ishiga, 1986a, 1990; USA: Blome and Reed, 1992). Kuwahara (1997) showed lineage of Late Permian radiolarians and set the Upper Permian radiolarian lineage zones in detail. In contrast to the Upper Permian, Lower to Middle Permian lineages remain incompletely understood. Additionally, some points have yet to be elucidated fully, such as paleoecology, the utility as a facies fossil, and others.

In addition to these, few studies had focused on Permian radiolarian paleobiogeography, although that of some taxa had been well researched. Ishiga (1986b) suggested that the distinction of *Follicucullus* by lithofacies. According to him, *F. scholasticus* m. I occurred from bedded cherts, while *F. scholasticus* m. I, *F. bipartitus*, and *F. charveti* occurred from clastic rocks. Wang et al. (2006) correlated Upper Permian radiolarians from South China with those from other areas. They concluded that late Paleozoic radiolarian biogeography is characterized by probably a single Paleo-Tethys planktonic faunal realm.

1.3. Outline and aim of the doctoral program

As mentioned previously, several information of Permian radiolaria has yet to be elucidated fully, although they had comprised the essential components in the paleocean. I have surveyed geologically and extracted fossils, especially radiolarians. On the basis of these, I have discussed Permian radiolarians and paleoceanography, such as biostratigraphy, paleoecology (e.g., Appendix A), and morphology (e.g., Appendix B). Additionally, I have studied Mesozoic strata in Japan as an applicative research (e.g., Appendix C). In this thesis, I focus on paleobiogeography (Fig. 1).

Although some taxonomic provincialism in Permian had been recognized, few studies have focused on Permian radiolarian provincialism. It is effective for recognition of provincialism to compare radiolarian faunas among several geological bodies formed under different locations. Middle Permian sequences in Japan and China abundantly include radiolarian fossils (described in the chapter 2). In addition to this, the sequences in China had formed under hemipelagic to inshore and deeper to shallow sea whereas those within accretionary complexes in Japan had formed under pelagic and deep-sea. Hence, the radiolarian faunal comparison among these is effective for recognition of its provincialism. From these reasons, I compared radiolarian assemblages that were collected from China and Japan. This comparison is based on the data of previous studies, in addition to those from my samples. I then discuss about Middle Permian radiolarian provincialism on the basis of the comparison.

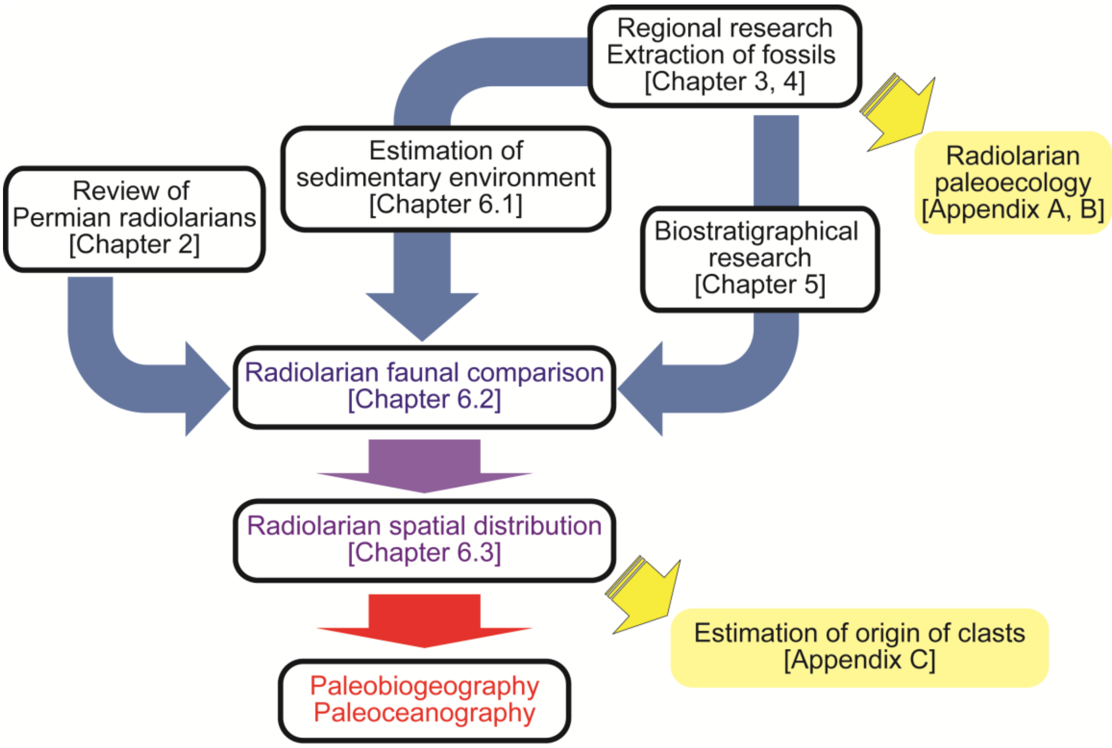


Figure 1. Flow of this thesis and doctoral research program.

2. Permian cherts

2.1. Permian Chert Event

A large amount of chert had accumulated during the late Paleozoic. The accumulation in the east Panthalassa had waxed in the middle Permian and it is called the Permian Chert event (Murchey and Jones, 1992; Beauchamp and Baud, 2002). Amounts of biogenesis cherts are influenced by siliceous organisms and ocean environments. Although Murchey and Jones (1992) pointed out that the scale and scope of the Permian Chert event differ among locations, the detailed distribution of the event in the west Panthalassa has not been made yet. The Permian and Jurassic accretionary complexes including upper Paleozoic cherts (Akiyoshi, Tamba-Mino-Ashio, and Chichibu composite terranes) are distributed in southwest Japan. The upper Paleozoic cherts in there are the most studied by applying radiolarian dating. I compile the occurrences of the cherts to clarify the detailed distribution of Permian cherts.

2.2. Radiolarian zone and age assignment

Upper Paleozoic radiolarian zones have been constructed in several areas (e.g., USA: Blome and Reed, 1995; China: Wang and Yang, 2011). In this chapter, I use radiolarian zones constructed in pelagic deposits in southwest Japan by Ishiga (1986a, 1990) and Kuwahara et al. (1998). The definitions from the *Pseudoalbaillella nodosa* Assemblage-Zone (A-zone) to the *Follicucullus monacanthus* Range-Zone (R-zone) are after Ishiga (1986a, 1990). I rename the *Pseudoalbaillella scalprata* m. *rhombothoracata* A-zone as the *Pseudoalbaillella rhombothoracata* A-zone on the basis of the re-description of *Pseudoalbaillella rhombothoracata* Ishiga and Imoto by Shimakawa and Yao (2006). The definitions from the *F. ventricosus-F. scholasticus* to *Neoalbaillella optima* assemblage-zones are after Kuwahara et al. (1998). Permian Epochs and Ages were defined by conodont, foraminifera, and ammonoid (e.g., Henderson et al., 2012). Hereinafter, I mention age assignments of each radiolarian zone on the basis of co-occurred other fossils and stratigraphic relation (Fig. 2).

Conodonts, *Idiognathodus delicatus* Gunnell, *I. sinuatus* Harris and Hollingsworth, *I. roundyi* Gunnell, and *Gondolella clarki* Koike occurred from a part of the *Pseudoalbaillella nodosa* A-zone (Ishiga, 1982). *Gondolella clarki* which has the shortest range among these conodont fossils occurred from Bashkrian and lower Moscovian (e.g., Wang and Qi, 2007). Hence, I provisionally define that the *Pseudoalbaillella nodosa* A-zone corresponds to the Moscovian. Although the lower limit of the *Pseudoalbaillella nodosa* A-zone likely reaches the Bashkrian, it is not shown in Fig. 2.

The *Pseudoalbaillella bulbosa* A-zone in southwest Japan yielded *Idiognathodus delicatus* and *Streptognathodus elongatus* Ellison (Ishiga, 1982). *Hindeodus expansa* (Perlmutte), *I. delicatus*, and *St. elongatus* occurred from the *Pseudoalbaillella u-forma* morphotype I A-zone (Ishiga, 1982; Ishiga et al., 1984). *Streptognathodus elongatus* occurred from the upper Gzhelian, Asselian, and lower Sakmarian (e.g., Kozur, 1995; Boardman II et al., 1998, 2009). In this chapter, the *Pseudoalbaillella bulbosa* and *Pseudoalbaillella u-forma* m. I assemblage-zones are temporally corresponded to the Kasimovian and Gzhelian, respectively.

Ishiga and Imoto (1980) found *Sweetognathus whitei* (Rhodes), which is characteristic species of the *Sw. whitei* zone (lower-middle Artinskian), from the Tajiridani section with *Pseudoalbaillella rhombothoracata*. *Pseudoalbaillella sakmarensis* Kozur described at the Sakmarian Stage in Cis-Urals (Kozur, 1981) occurred from the *Pseudoalbaillella lomentaria* R-zone to the lower part of the *Pseudoalbaillella rhombothoracata* A-zone (Ishiga, 1986a). Ishiga and Suzuki (1984) found *Hi. minutus* (Ellison) and *Deplognathodus* sp. cf. *D. nodosus* Igo with *Albaillella sinuata* Ishiga and Imoto. *Deplognathodus nodosus* is characteristic species of the *D. lnceolatus-D. nodosus* zone corresponding to the Leonardian (approximately corresponded to the Artinskian and Kungurian) (Igo, 1981). *Hindeodus minutus* occurred from the Asselian, Sakmarian and Artinskian (Kozur, 1995). From these occurrences, the *Pseudoalbaillella rhombothoracata* A-zone corresponds to the lower Sakmarian; the *Pseudoalbaillella lomentaria* R-zone corresponds to the upper Sakmarian to lower Artinskian; the *A. sinuata* R-zone corresponds to the upper Artinskian, in this chapter.

Zhang et al. (2010) showed that the FA of *Jinogondolella nankingensis gracilis* (Clark and Ethington), corresponding to the base of Roadian, coincides with the FA of *Pseudoalbaillella globosa*. Therefore, the base of the *Pseudoalbaillella globosa* A-zone places the base of the Roadian. The FA of *F. monacanthus* coincides with the FA of *J. aserrata* in the Gufeng Formation of the Luojiaba section in the Jianshi, west Hubei, China (unpublished data of Ma Qiangfen of China University of Geosciences, Wuhan). Kusunoki et al. (2004) found *F. monacanthus* Ishiga and Imoto and *Mesogondolella* sp. cf. *M. postserrata* (Behnken) (synonym of *J. postserrata*) which is characteristic species of the Capitanian (e.g., Henderson et al., 2012). Nishikane et al. (2011) concluded that the FA of *A. yamakitai* Kuwahara places below the Guadalupian-Lopingian transitional zone in the upper Capitanian. In this chapter, the *F. monacanthus* R-zone corresponds to the Wordian to the lower Capitanian; the *F. scholasticus-F. ventricosus* A-zones corresponds to the upper Capitanian excluding the uppermost Capitanian.

According to Xia et al. (2004), the boundary between the *N. ornithoformis* and *N. optima* assemblage-zones, defined by the FA of *A. lauta* Kuwahara, are placed in the *C. orientalist* zone; the base of the *N. ornithoformis* A-zone, defined by the FA of *A. protolevis* Kuwahara, are placed in the *C. asymmetrica* zone. The comparing the *F. charveti-A. yamakitai*, *N. ornithoformis*, and *N. optima* assemblage-zones to conodont zones are after the opinion from Xia et al. (2004) in this chapter.

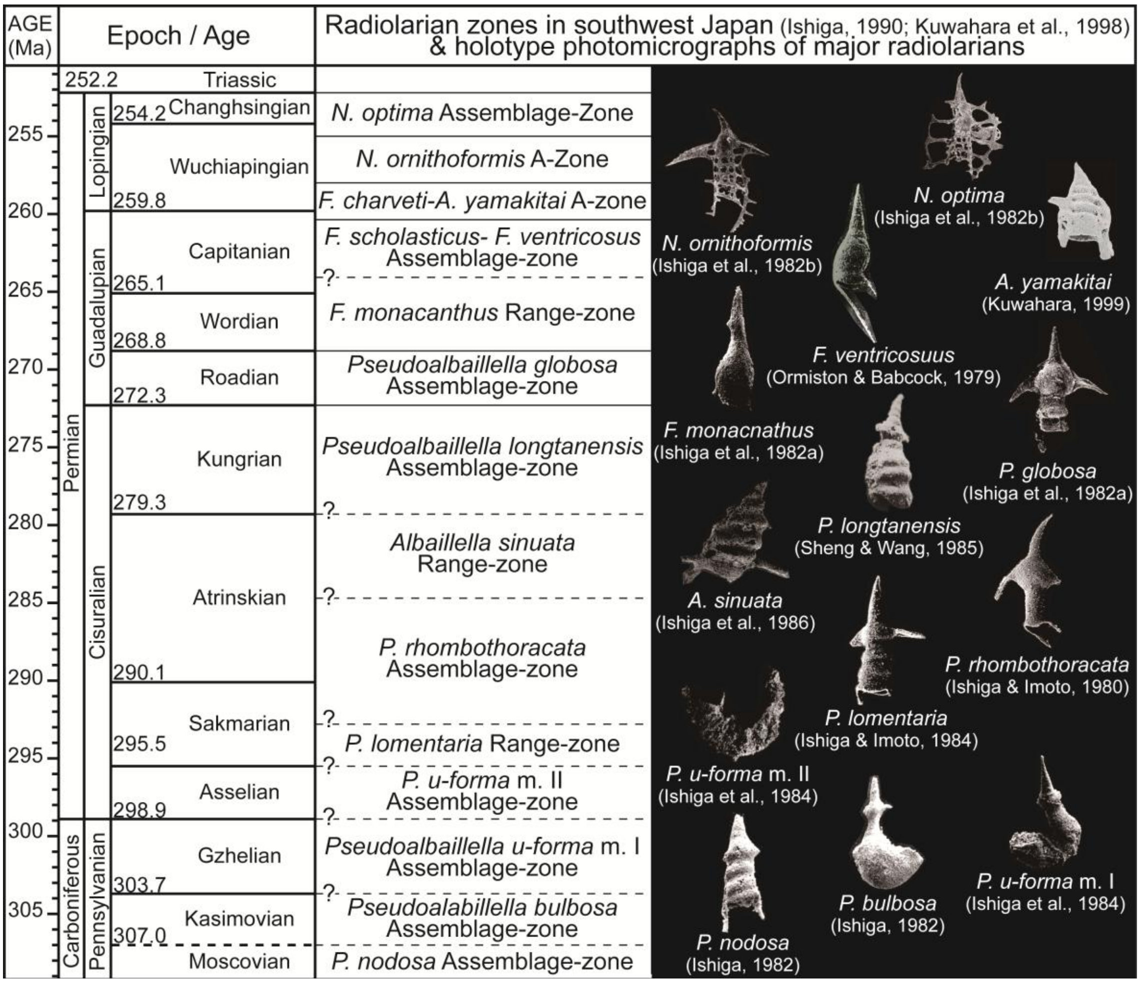


Figure 2. Late Paleozoic radiolarian zones.

2.3. Permian chert within accretionary complex in southwest Japan

The Permian accretionary complex (Akiyoshi terrane) and Jurassic accretionary complexes (Tamba-Mino-Ashio and Chichibu composite terranes) are distributed in southwest Japan (Ichikawa, 1990; Fig. 3.A). Some geological bodies of these terranes include upper Paleozoic radiolarian-bearing cherts. I mention radiolarian occurrence in each geological unit (Tables 1). The definitions, names, and distributions of each terrane are after Ichikawa (1990).

The Akiyoshi terrane, occupies the Inner Zone of southwest Japan, is a Permian accretionary complex. It consists mainly of oceanic basalts, pelagic carbonates, pelagic to hemipelagic siliceous rocks, and trench-fill terrigenous clastics (Kanmera et al., 1990). It had been located in the west Panthalassa during Late Carboniferous to Middle Permian, and then it accreted at an active margin in Middle to Upper Permian. Some researchers had observed chert-clastic sequences (CCSs: representing processes of oceanic plate movement from ocean ridge to active margin) from the Akiyoshi terrane (e.g., Ishiga et al., 1986; Naka et al., 1986; Uchiyama et al., 1986; Sano et al., 1987; Goto, 1988). Latest Carboniferous to Permian radiolarians had occurred mainly from the pelagic to hemipelagic siliceous rocks and terrigenous clastics. Eight geological bodies are dealt here.

The Tamba-Mino-Ashio terrane, occupies the Inner Zone of southwest Japan, is a Jurassic accretionary complex. The Permian sequence in the terrane consists mainly of oceanic basalts, pelagic carbonates, and pelagic siliceous rocks (e.g., Mizutani, 1990; Nakae, 2000). Latest Carboniferous to Permian radiolarians had been observed mainly from the pelagic siliceous rocks. It had been located in the central Panthalassa during Late Carboniferous to Permian. I deal with 17 geological bodies here.

The Chichibu composite terrane, occupies the Outer Zone of southwest Japan, is also a Jurassic accretionary complex. The Permian sequence of it is composed mainly of oceanic basalts, pelagic carbonates, and pelagic siliceous rocks (e.g., Matsuoka et al., 1998). Latest Carboniferous to Permian radiolarians had occurred mainly from the pelagic siliceous rocks. It had been located in the central Panthalassa during Late Carboniferous to Permian. There is an opinion that considers the Chichibu composite and Tamba-Mino-Ashio terranes as same unit before the late Mesozoic (e.g., Tazawa, 2004). I deal with 22 geological bodies of the Chichibu composite terrane.

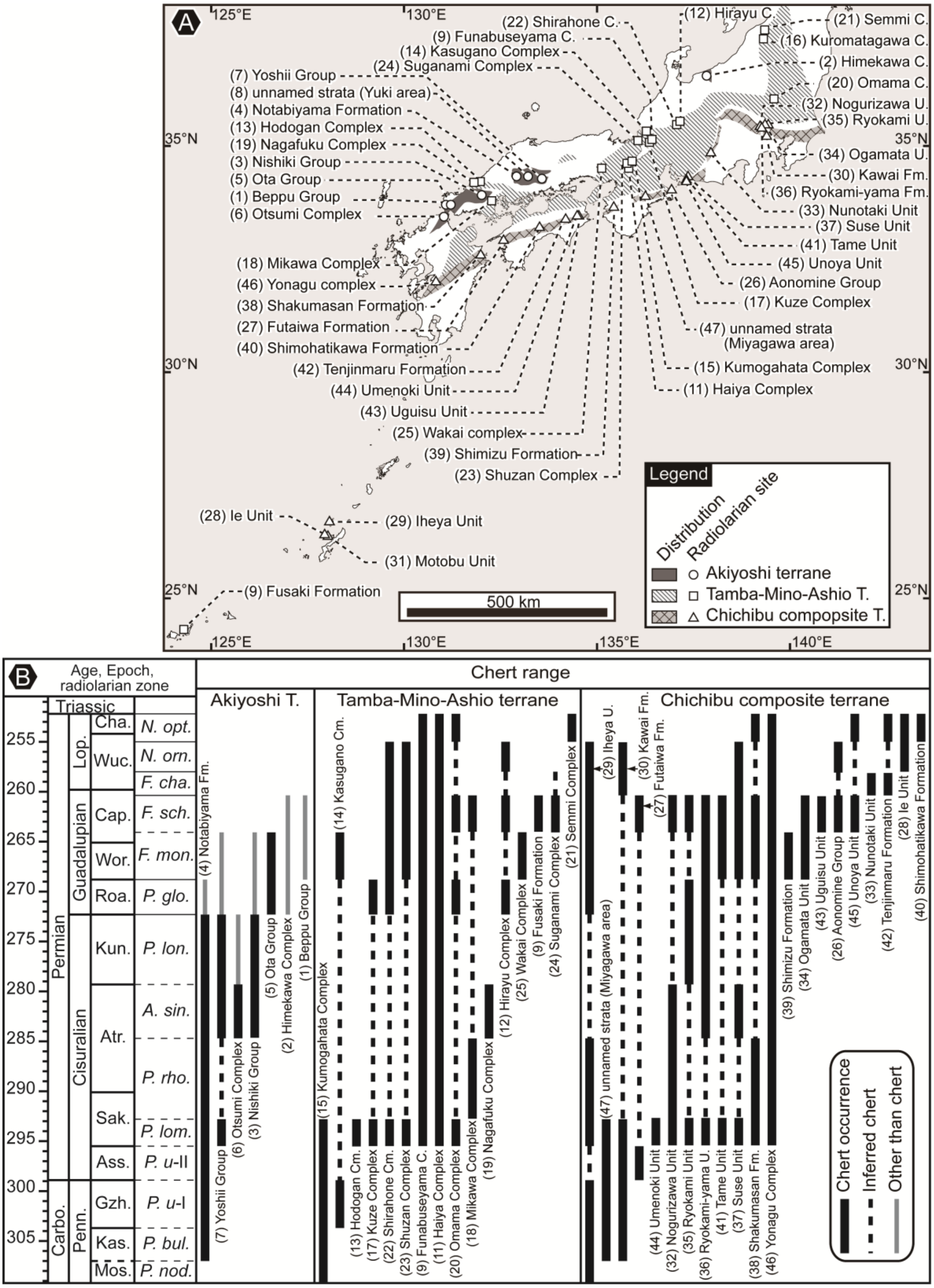


Figure 3. A: Distribution of Akiyoshi, Tamba-Mino-Ashio, and Chichibu composite terranes in southwest Japan (modified from Ichikawa, 1990), and localities of the compiled geological units. B: Chert occurrence ranges in late Paleozoic.

2.4. Chert occurrence biases during Permian

Figure 3.B shows chert ranges on the basis of radiolarian occurrences. The Akiyoshi terrane is characterized by a slightly-large amount of chert of the Lower Permian (the *A. sinuata* R-zone to the *Pseudoalbaillella longtanensis* A-zone). There is no radiolarian chert from the middle Middle to Upper Permian (the *F. monacanthus* R-zone to the *Neoalbaillella optima* A-zone) in the Akiyoshi terrane. The Tamba-Mino-Ashio terrane has the following characters: the cherts of the Upper Carboniferous to Lower Permian (the *Pseudoalbaillella nodosa* to *Pseudoalbaillella longtanensis* assemblage-zones) are a small amount excluding the middle Lower Permian cherts (the *Pseudoalbaillella lomentaria* R-zone); the Middle to Upper Permian cherts (the *Pseudoalbaillella globosa* to *Neoalbaillella optima* assemblage-zones) are a large amount. The Chichibu composite terrane is characterized by a small amount chert from the Upper Carboniferous to lower Middle Permian (the *Pseudoalbaillella nodosa* to *Pseudoalbaillella globosa* zones) excluding the middle Lower Permian cherts (the *Pseudoalbaillella lomentaria* R-zone), and large amount cherts from the middle Middle to Upper Permian (the *F. monacanthus* R-zone to the *Neoalbaillella optima* A-zone).

The Tamba-Mino-Ashio and Chichibu composite terranes have the following common characteristics: the Upper Carboniferous to the Lower Permian cherts are a small amount; the middle Middle to Upper Permian cherts are a large amount; the middle Lower Permian (the *Pseudoalbaillella lomentaria* R-zone) and upper Middle Permian (the *F. scholasticus-F. ventricosus* A-zone) cherts are remarkably large amount. In contrast the largest amount of cherts in the Akiyoshi terrane is the upper Lower Permian (the *Pseudoalbaillella longtanensis* A-zone).

Table 1. Radiolarian zone occurrence in each geological body.

Legend	
A	With photo
B	No photo
C	Only zone
D	Not from chert

Information of geological units				Radiolarian zone														
number	Terrane	Name	Area	*Neoalbaillella optima*	*Neoalbaillella ornithoformis*	*F. charveti-A. yamakitai*	*F. scholasticus-F. ventricosus*	*Follicucullus monacanthus*	*Pseudoalbaillella globosa*	*P. longtanensis*	*Albaillella sinuata*	*P. rhombothoracata*	*Pseudoalbaillella lomentaria*	*P. u-forma* m. II	*P. u-forma* m. I	*Pseudoalbaillella bulbosa*	*Pseudoalbaillella nodosa*	References
1	Akiyoshi	Beppu Group	Akiyoshi				D	D										Kametaka (2006)
2		Himekawa Cm.	Itoigawa				D	D	D									Tazawa et al. (1984); Kawai & Takeuchi (2001)
3		Nishiki Group	Muikaichi				D	D	D	A	A							naka & Ishiga (1985); Ishiga et al. (1986); Naka et al. (1986)
4		Notabiyama Fm.	Taishaku						D	B	B	B	B	B	B	B		Isozaki (1983, 1984); Goto (1988)
5		Ota Group	Akiyoshi					A	A									Fujii (1972); Sano et al. (1983); Uchiyama et al. (1986)
6		Otsumi Complex	Kiku Peninsula							D	B							Yanase & Isozaki (1993); Nakae et al. (1998)
7		Yoshii Group	Yoshii				D	D	D	B	B		B					Yoshimura (1961); Sano et al. (1987); Ito (2010MS)
8		unnamed strata [Yuki area]																Oho et al. (1985); Sada et al. (1985)
9	Tamba-Mino-Ashio	Funabuseyama Cm.	Funabuse-yama	A	A	A	A	A	A	A	A	A	A					Sano (1988); Nakae (2000)
10		Fusaki Formation	Ishigaki-jima				A											Isozaki & Nishimura (1989)
11		Haiya Complex	Kifuneyama	A	A	A	A	A	A	A	A	A	A					Ishiga and Imoto (1980); Kimura et al. (1998)
12		Hirayu Complex	Takayama-Kiso		A		A		A									Kojima (1982); Nakae (2000); Niwa et al. (2003)
13		Hodogan Cm.	Takayama-Kiso										B					Fukudomi (1990); Nakae (2000)
14		Kasugano Cm.	Nanjo				A	A							A			Hattori & Yoshimura (1982); Taga (1997);Nakae (2000)
15		Kumogahata Cm.	Ohmori										A	A	A	A	A	Ishiga et al. (1984); Imoto et al. (1998)
16		Kuromatagawa Cm.	Kuromata-gawa															Hara & Kashiwagi (2004); Matsumoto et al. (2001)
17		Kuze Complex	Mino						A				A					Saito (1989), Nakae (2000)
18		Mikawa Complex	Iwakuni				B					B						Takami & Itaya (1996); Nakae (2000)
19		Nagafuku Cm.	Iwakuni								B							Fukudomi (1990); Nakae (2000)
20		Omama Complex	Omama	B			B		B				B					Kamata (1997); Takayanagi et al. (2001)
21		Semmi Complex	Kambara	A														Uchino et al. (2010)
22		Shirahone Cm.	Hikagedaira		B	B	B	A	B				A					Adachi and Kojima (1983); Kojima (1984); Nakae (2000)
23		Shuzan Complex	Shizukawa		A	A	A	A					A					Kusunoki et al. (2004); Nakae (2000)
24		Suganami Complex	Yogo		B		A											Kurimoto et al. (1999); Nakae (2000)
25		Wakai Complex	Ikuno					A										Hori et al. (2004); Yoshikawa et al. (2005)
26	Chichibu composite	Aonomine Group	Toba		A		A											Ohba & Adachi (1995); Umeda (1995)
27		Futaiwa Formation	Mikame				B							B				Kashima (1986)
28		Ie Unit	Ie-jima	A	A													Shen et al. (1996)
29		Iheya Unit	Iheya-jima		B	B	A	B	B			A	A		A	B	B	Takami et al. (1999)
30		Kawai Formation	Itsukaichi		A	A							A	B	A	A		Saito (1984); Sashida (1995); Sashida & Tonishi (1985, 1986, 1988)
31		Motobu Unit	Motobu Penisula															Fujita (1989)
32		Noguizawa Unit	Ryokami-yama				C				C	C	C					Hisada et al. (1992)
33		Nunotaki Unit	Tohyama			A												Muramatsu (2001, 2006)
34		Ogamata Unit	Ryokami-yama				C	C										Hisada et al. (1992)
35		Ryokami Unit	Ryokami-yama				B		B	C			C					Hisada et al. (1992); Hara et al. (2010)
36		Ryokami-yama U.	Ryokami-yama				C	C	C	C	C		C					Hisada et al. (1992)
37		Suse Unit	Toyohashi		A	A	A	A			A		A					Hori (2004a, b); Nakashima et al. (2008)
38		Shakumasan Fm.	Saiki	A			A	A				A	A					Sato et al. (1982); Yoshida & Murata (1985)
39		Shimizu Fm.	Saiki					A										Kurimoto (1986)
40		Shimohachikawa Fm.	Ino	A														Yamakita (1988); Kuwahara & Yamakita (2001)
41		Tame Unit	Toyohashi				A	A					A					Niwa & Otsuka (2001); Hori (2004a); Nakashima et al. (2008)
42		Tenjinmaru Fm.	Tenjinmaru	A		A												Yamakita (1988); Kuwahara & Yamakita (2001)
43		Uguisu Unit	Kamikatsu				A											Suazuki & Itaya (1994)
44		Umenoki Unit	Kamikatsu										B					Suazuki & Itaya (1994)
45		Unoya Unit	Toyohashi	A			A											Hori (2004a);Nakashima et al. (2008)
46		Yonagu Complex	Kuma	A	A	A	A	A	A	A	A	A	A					Nishizono et al. (1982); Nishizono (1996)
47		unnamed strata [Miyagawa area]											A	A	A	A		Kuwahara (1992)

3. Geological setting and lithology

3.1. Liuhuang section in Chaohu (Gufeng Formation)

3.1.1. Outline of the Gufeng Formation

The Gufeng Formation was originally named as “the Gufeng Zhen Limestone” at Hujia Village of Gufeng, Anhui Province by Liang and Li in 1924 (re-quoted from Bureau of Geology and Mineral Resources of Anhui Province, 1997). The original definition is as follows. “It is characterized by black carbonate shales and silica-rich carbonates, which are lithostratigraphically-located between the Qixia and Longtan formations. Basal black shales include abundant fossils typified by ammonite and brachiopod”. Bureau of Geology and Mineral Resources of Anhui Province (1997) redefined the Gufeng Formation as follows. “It is characterized by black or gray-yellow thin-bedded siliceous rocks, siliceous shales, siltstones, carbonous shales, and manganese shales, which are lithostratigraphically-located between the Qixia and Longtan formations. Basal shales include manganese and phosphate nodules. Several fossils (e.g., ammonoids, brachiopods, bivalves, and radiolarians) occur from it.” In this thesis, I use the designation of the Gufeng Formation because its character and distribution are valid. The definition is basically after from Bureau of Geology and Mineral Resources of Anhui Province (1997).

The Gufeng Formation is distributed in South China (e.g., Yang and Feng, 1997; Xia and Zhang, 1998). The lower reaches of the Yangtze River is called the Lower Yangtze region. The Gufeng Formation in the Lower Yangtze region is distributed in north Zhejiang, south Jiangsu, and south Anhui. Bureau of Geology and Mineral Resources in each province in China had compiled regional geology in each province (e.g., Bureau of Geology and Mineral Resources of Anhui Province, 1997). According to them, the Gufeng Formation in Anhui is summarized as follows. The Gufeng Formation conformably contacts with the underlying Qixia and overlying Longtan formations. The Wuxue Formation conformably overlies the Gufeng Formation in some areas. The total thickness of the Gufeng Formation is relatively-unvaried and the average is approximately 25 m; the thinnest one is 10 m; the thickest one is 107 m. Some researchers had studied continuously the Anmenkou section at Chaohu (e.g., Nagai et al., 1998; Kametaka et al., 2002, 2005, 2009; Takebe et al., 2007). Kametaka et al. (2002) divided the Gufeng Formation of the Anmenkou section into two members: the Phosphate Nodule-bearing Mudstone Member (PNMM) and the Siliceous Rock

Member (SRM) in ascending order. The former (ca. 4 m in total thickness) consists of mudstones including abundant phosphate nodules; the latter (ca. 25 m) is composed mainly of alternations of black cherts, mudstones, and siliceous mudstones, with minor tuffaceous mudstone and porous chert beds. In the Anmenkou section, the Gufeng Formation disconformably contacts with the underlying Qixia Formation and is overlied by the Yinping Formation.

3.1.2. Liuhuang section

The Liuhuang section (31°37'04.36"N, 117°48'30.69"E) is situated 5 km northwest of Chaohu, Anhui Province, China (Fig. 4.C). The section outcrops at an east slope of a hill just west of Liuhuang Village. The Anmenkou section is located just southwest of the Liuhuang section. The Maokou, Gufeng, and Longtan formations are exposed in the Liuhuang section. The Maokou Formation composed of white limestone with some brachiopods and fusulinids conformably underlies the Gufeng Formation. The Gufeng

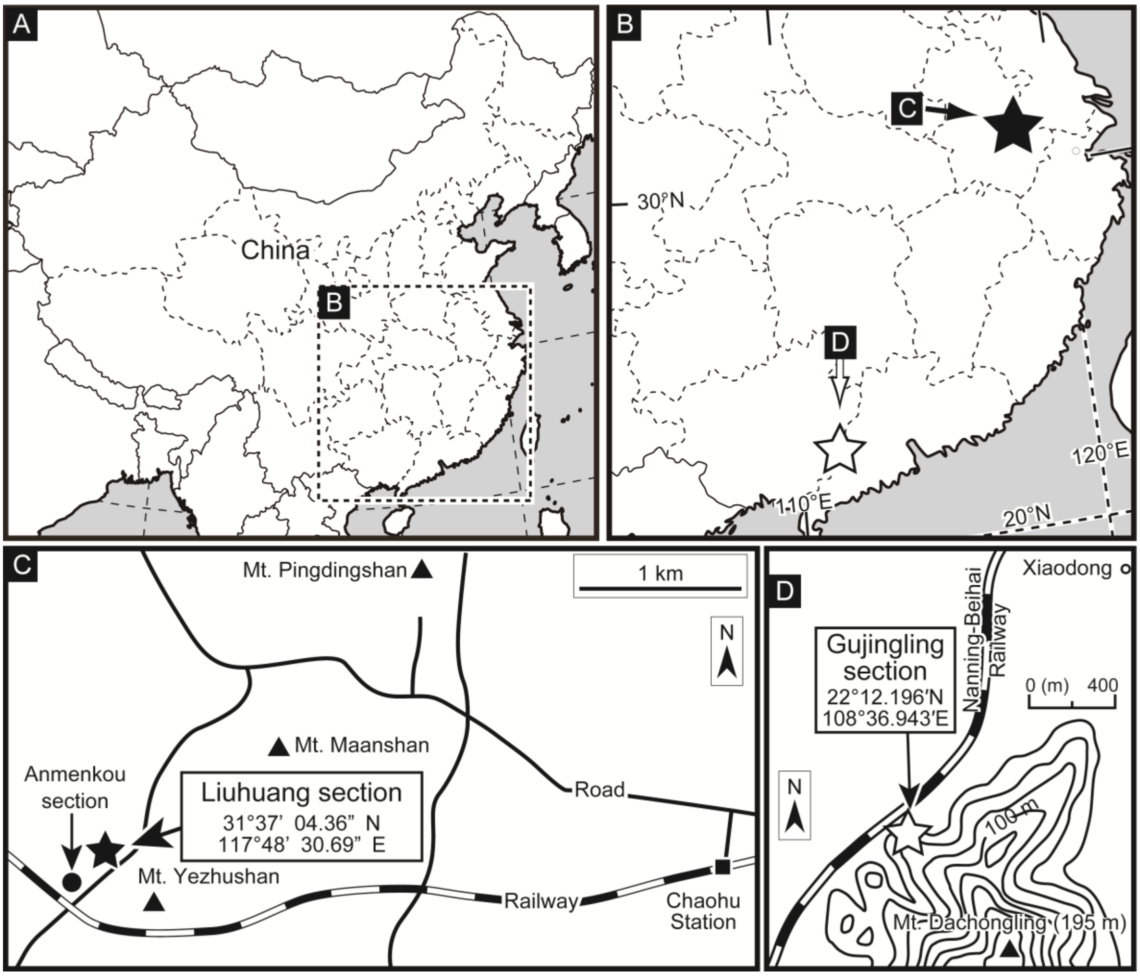


Figure 4. Index map of the Liuhuang section.

Formation consists mainly of cherts, siliceous mudstones, mudstones, and phosphate-nodule-bearing mudstones, and a small amount of limestones, argillutites, tuffaceous mudstones, and sandstones. The Longtan Formation consisting of sandstones and mudstones with coal beds conformably overlies the Gufeng Formation. These strata approximately strike N50°E and dip 60°NW with some small folds. These strata are overturned on the basis of the typical Permian stratigraphic sequence in this area (Fig. 5). I divided the Gufeng Formation in this section into 12 subsections. The features of each subsection are as follows in ascending order (numbers in parenthesis indicate the thickness of each subsection: Fig. 6); subsection 1: mudstones including phosphate nodules, with ammonoids and bivalves (330 cm); subsection 2: middle-thick alternations of black cherts and siliceous mudstones, interbedding dark-brown mudstones (160 cm); subsection 3: dark-brown mudstones interbedding black cherts (42 cm); subsection 4: thin bedded cherts interbedding mudstones (210 cm); subsection 5: gray porous cherts interbedding mudstones (40 cm); subsection 6: black cherts interbedding mudstones (160 cm); subsection 7: alternations of mudstones and cherts (40 cm); subsection 8: alternations of cherts and mudstones (75 cm); subsection 9: thin bedded black cherts interbedding mudstones (145 cm); subsection 10: alternations of siliceous mudstones and mudstones (165 cm); subsection 11: mudstones interbedding cherts and siliceous mudstones (550 cm); subsection 12: mudstone interbedding siliceous mudstones (510 cm).

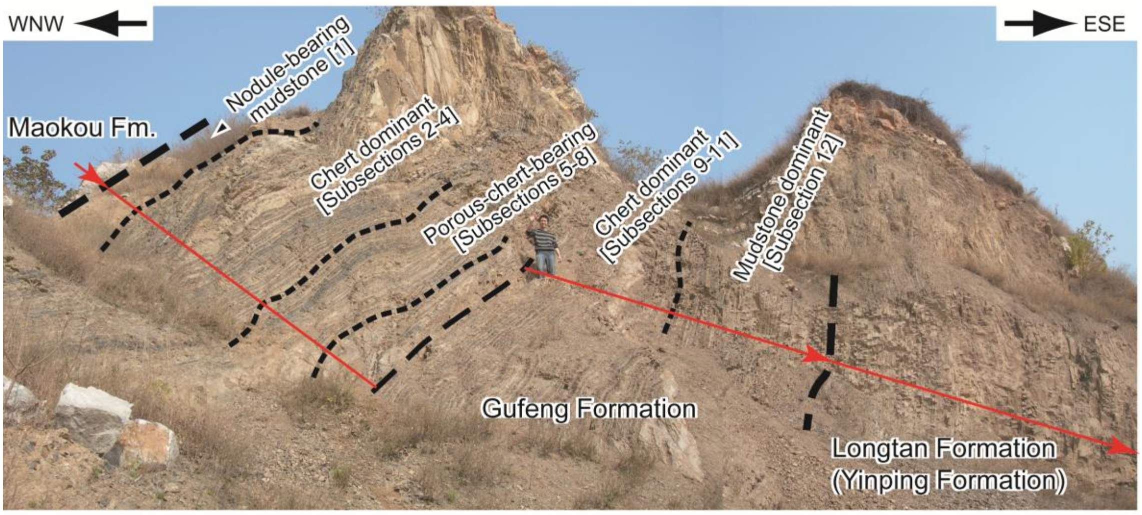


Figure 5. Field occurrence of the Liuhuang section.

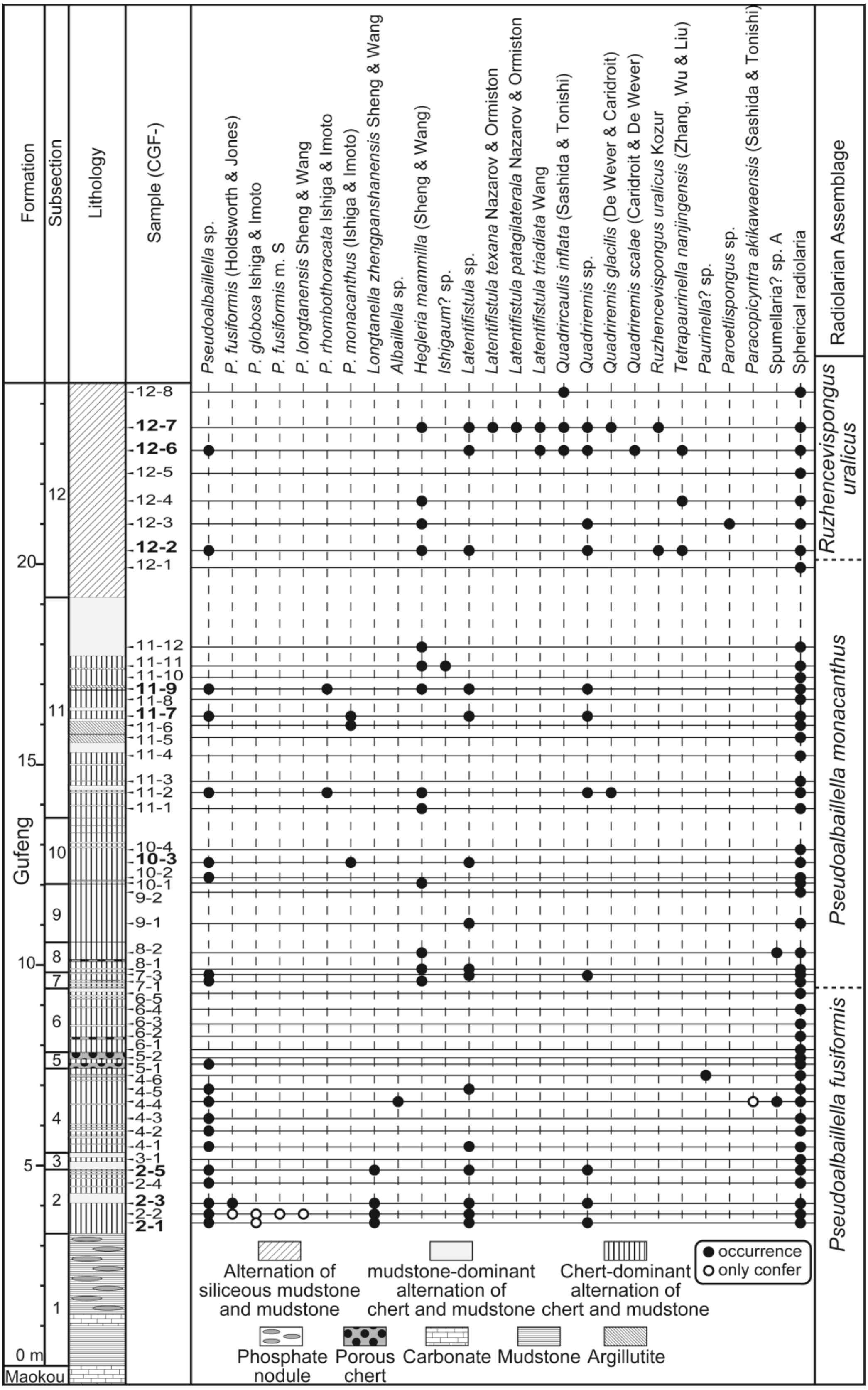


Figure 6. Columnar section and radiolarian distribution of the Liuhuang section.

3.2. Gujingling section in Xiaodong (Bancheng Formation)

3.2.1. Bancheng Formation

The Ordovician to Upper Permian siliceous rock strata are distributed in the Qinzhou basin, South China (Wang et al., 1998b; Wang and Jin, 2000). Defined by gray-yellow or brown-gray thin-bedded siliceous-rocks, muddy siliceous-rocks, siliceous-shales and mudstones, the Bancheng Formation is lithostratigraphically located between the Devonian-Carboniferous Shijia and Upper Permian Pengjiu formations (Bureau of Geology and Mineral Resources of Guangxi Autonomous Region, 1997). It conformably overlies the former and unconformably underlies the acidic lava of the latter. In addition to radiolaria and sponge, several fossils such as conodonts, brachiopods and bivalves have been observed in this formation (e.g., Wang et al., 1998a; Bureau of Geology and Mineral Resources of Guangxi Autonomous Region, 1997; Zhang et al., 2010).

Wang et al. (1995) deduced the paleoenvironment of the Bancheng Formation from geochemical data of cherts in the Qinzhou area. On the basis of the abundant siliceous fossils and absence of intense Ce anomaly, they concluded that the cherts were deposited under a deep or bathyal sea with minor contribution of hydrothermal activity. Wang and Jin (2000) determined from the lack of clastic influx that the Qinzhou allochthon was located hundreds of kilometers east of the South China Block, which supplied the clastic debris.

3.2.2. Gujingling section

The Gujingling section (22°12.196’ N, 108°36.943’ E), situated 2 km southwest of Xiaodong, Guangxi Zhuang Autonomous Region, China (Fig. 4.D), outcrops along the south side of the Nanning-Beihai railway. These strata approximately strike N-S and dip 70°W. This section belongs to the Bancheng Formation and is composed of red-to-yellow-red cherts and yellow-to-yellow-brown siliceous siltstones (Fig. 7). Microscope observation revealed that these siliceous siltstones consist of scattered subrounded quartz and siliceous microfossils such as radiolaria and sponges with clay materials (Figs. 8.A, 8.C, 8.D). In addition, these siltstones contain silt-sized quartz and no sand-sized materials. Microscope observation revealed that the cherts in the Gujingling section consist mainly of cryptocrystalline quartz and siliceous microfossils with a few clay minerals (Fig. 8.B).

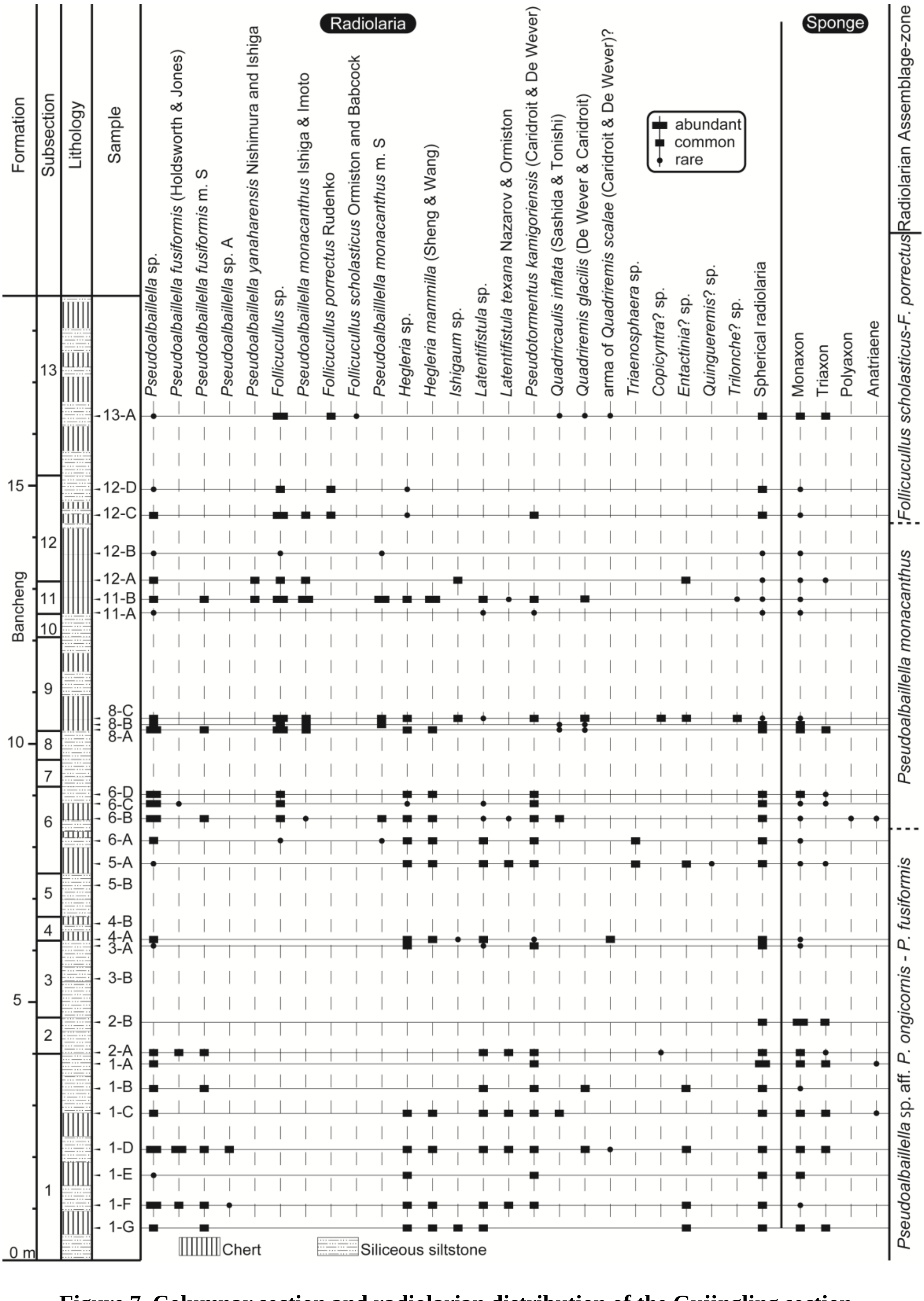


Figure 7. Columnar section and radiolarian distribution of the Gujingling section.

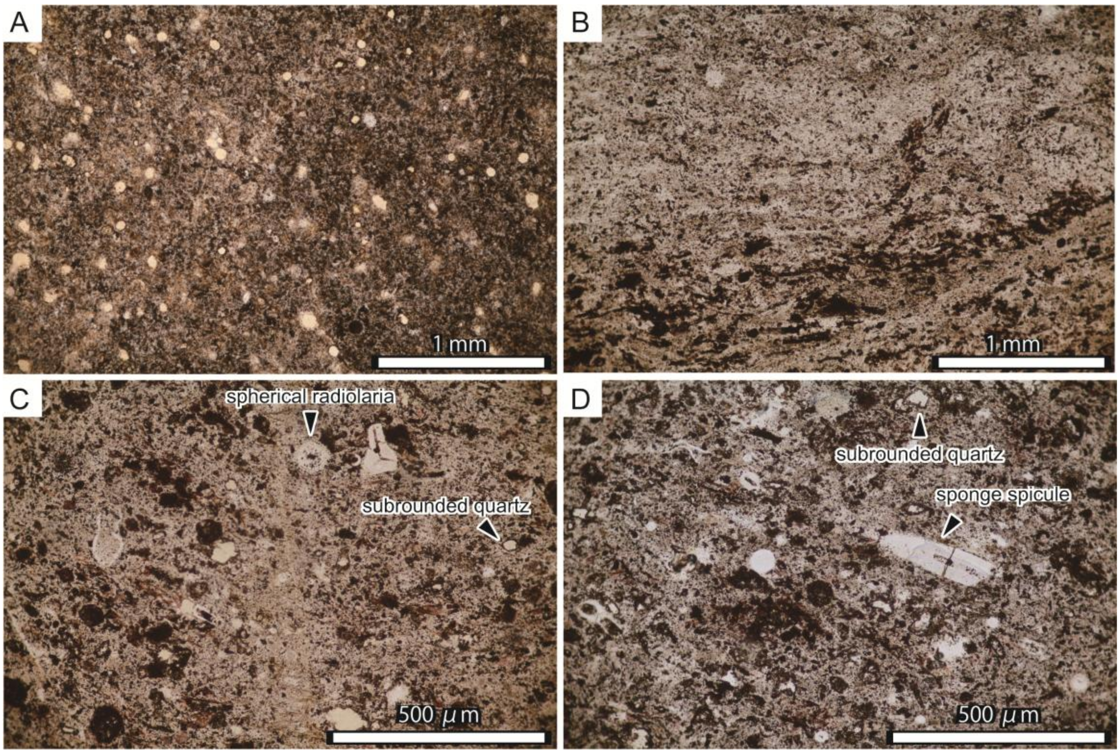


Figure 8. Thin section photomicrographs of siliceous rocks from the Gujingling section. (A) Siliceous siltstone (sample 5-B); scattered subrounded quartz and siliceous microfossils (white color) such as radiolarians and sponges with clay materials; plain light. (B) Chert (sample 4-B); cryptocrystalline quartz and siliceous microfossils (white color) with a few clay minerals; plain light. (C) Spherical radiolaria and subrounded quartz within clay materials in siliceous siltstone (sample 3-B); plain light. (D) Sponge spicules and subrounded quartz within clay materials in siliceous siltstone (sample 3-B); plain light.

3.3. Yoshii Group

3.3.1. Akiyoshi terrane

The Akiyoshi terrane is Permian accretionary complex that is distributed in southwest Japan (Fig. 9.A). The Akiyoshi terrane is characterized by large calcareous rock masses and surrounding non-calcareous rocks, such as cherts, siliceous mudstone, mudstone, and sandstone (Kanmera et al., 1990). The latter constitutes chert-clastic sequences (CCSs) ranging from the late Carboniferous to middle Permian. Sano and Kanmera (1988) concluded that the calcareous and non-calcareous rocks are heterotopic facies that had deposited on and around an oceanic seamount in an open-ocean floor.

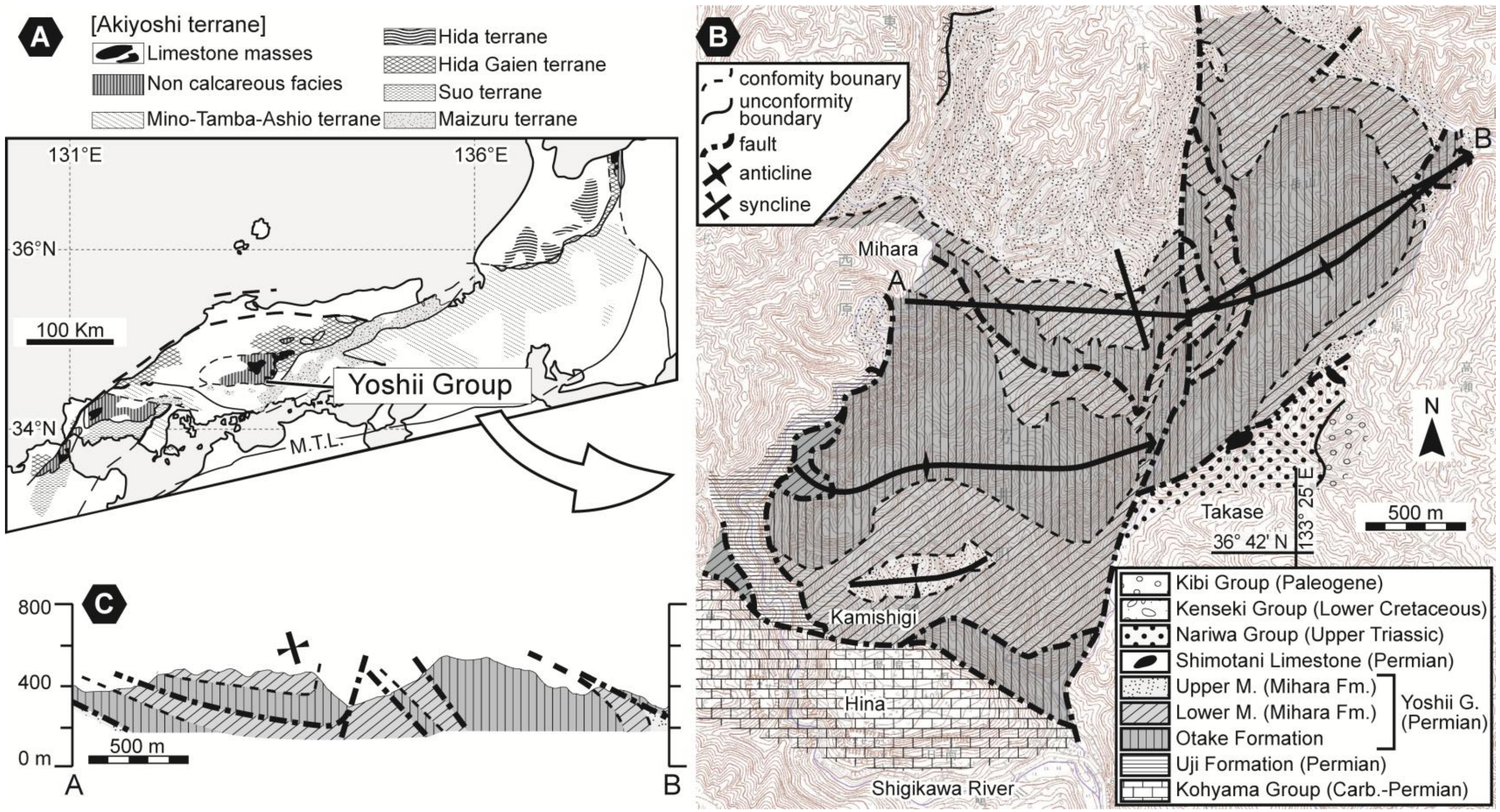


Figure 9. A: Simplified geologic map of the Inner Zone of southwest Japan (modified from Kanmera et al., 1990). B: Geological map in the Yoshii area. C: Cross section in the Yoshii area. B and C are modified from Ito (2010MS).

3.3.2. Yoshii Group

The Yoshii Group belonging to the Akiyoshi terrene is distributed in the Yoshii area, west Okayama Prefecture. Kobayashi et al. (1938) firstly showed the geological outline of the Yoshii area including this study area. They considered that the Paleozoic in the Yoshii area as the Chichibu Paleozoic strata consisting of the following ascending strata: the Chert, Alternation of sandstone and slate, and Limestone. Yoshimura (1961) named the Chert and Sandstone-slate formations sensu Nakano (1952) the Yoshii Group. He divided the Yoshii Group into the Otake and Mihara formations in ascending order. The Otake Formation consists mainly of chert; the Mihara Formation is composed mainly of clastics. Sano et al. (1987) divided the Yoshii Group into the Chert, Siliceous mudstone, and Sandstone-shale formations. It consists of Lower to Middle Permian CCS (Sano et al., 1987).

I have surveyed the Yoshii area and drawn the geological map (Figs. 9.B, 9.C, 10). The following strata are exposed in the Yoshii area: the Uji Formation and the Kohyama, Yoshii, Nariwa, Kenseki, and Kibi groups. The Permian Uji Formation and Carboniferous-Permian Kohyama Group belong to the Akiyoshi terrane in addition to the Yoshii Group. The Uji Formation consists mainly of muddy rocks such as mudstone, alternations of sandstone and mudstone, and clast-bearing mudstone; the Kohyama Group is composed mainly of limestone with minor chert and siliceous limestone. The upper Triassic Nariwa Group is distributed in the southeast part of the study area. Although no contact between the Nariwa and Yoshii groups were observed in the study area, their distributions indicate vertical boundary strike NE-SW. Oto (1985) observed unconformable boundary between the Nariwa Group and Paleozoic in the Shimotani and Shida areas, located east of the study area. Paleozoic and Mesozoic strata in the study area unconformable underlay the Lower Cretaceous Kenseki and Paleogene Kibi groups.

I divide the Yoshii Group into the Otake and Mihara Formation in ascending order. The Otake Formation consists of cherts; the Mihara Formation is composed mainly of clastic rocks. The Mihara Formation is subdivided into the Lower and Upper members. The Lower Member consists mainly of siliceous mudstone and tuff; the Upper Member is composed mainly of mudstone and sandstone. The Yoshii Group constitutes CCS. Ito and Matsuoka (2009) observed an imbricate structure that CCSs repeat from the Yoshii Group in the Otake area (= western part of the Yoshii area) (Fig. 9.C).

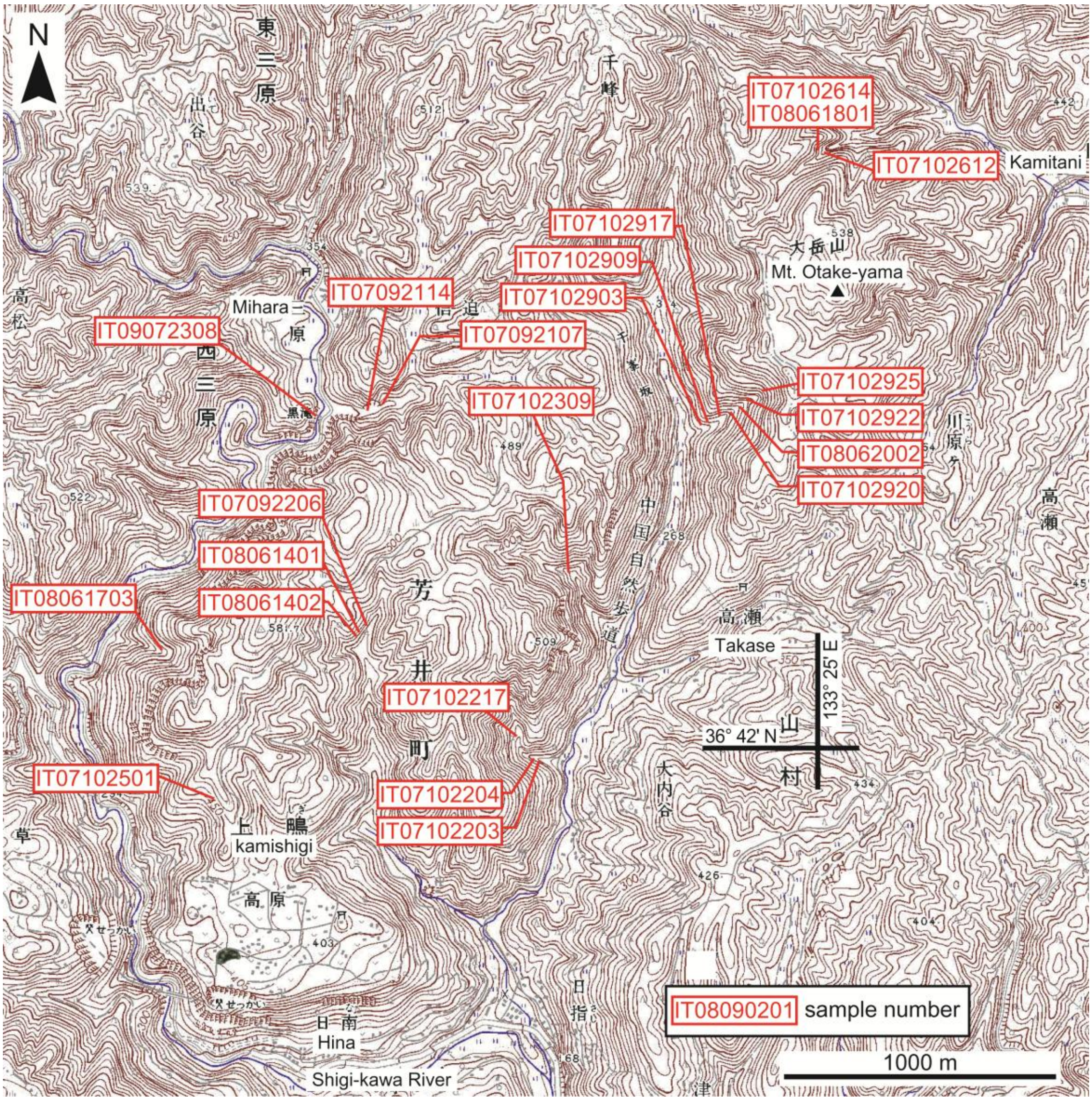


Figure 10. Sample localities in the Yoshii area.

4. Fossil occurrences

4.1. Materials and methods

I collected 49 samples from the Gufeng Formation in the Liuhuang section and 26 samples from the Bancheng Formation in the Gujingling section (Figs. 6, 7). The samples were crushed and soaked in an approximately 3% hydrofluoric acid (HF) solution for 24 hours at room temperature. The HF solutions were removed and the containers holding the etched samples were subsequently refilled with a fresh HF solution. Adequate residues were then collected through a sieve with a mesh diameter of 0.054 mm. Some of well-preserved radiolarians in the residues were mounted on stubs and photographed with a scanning electronic microscope. Selected fossil photomicrographs are shown in Figs. 11–14.

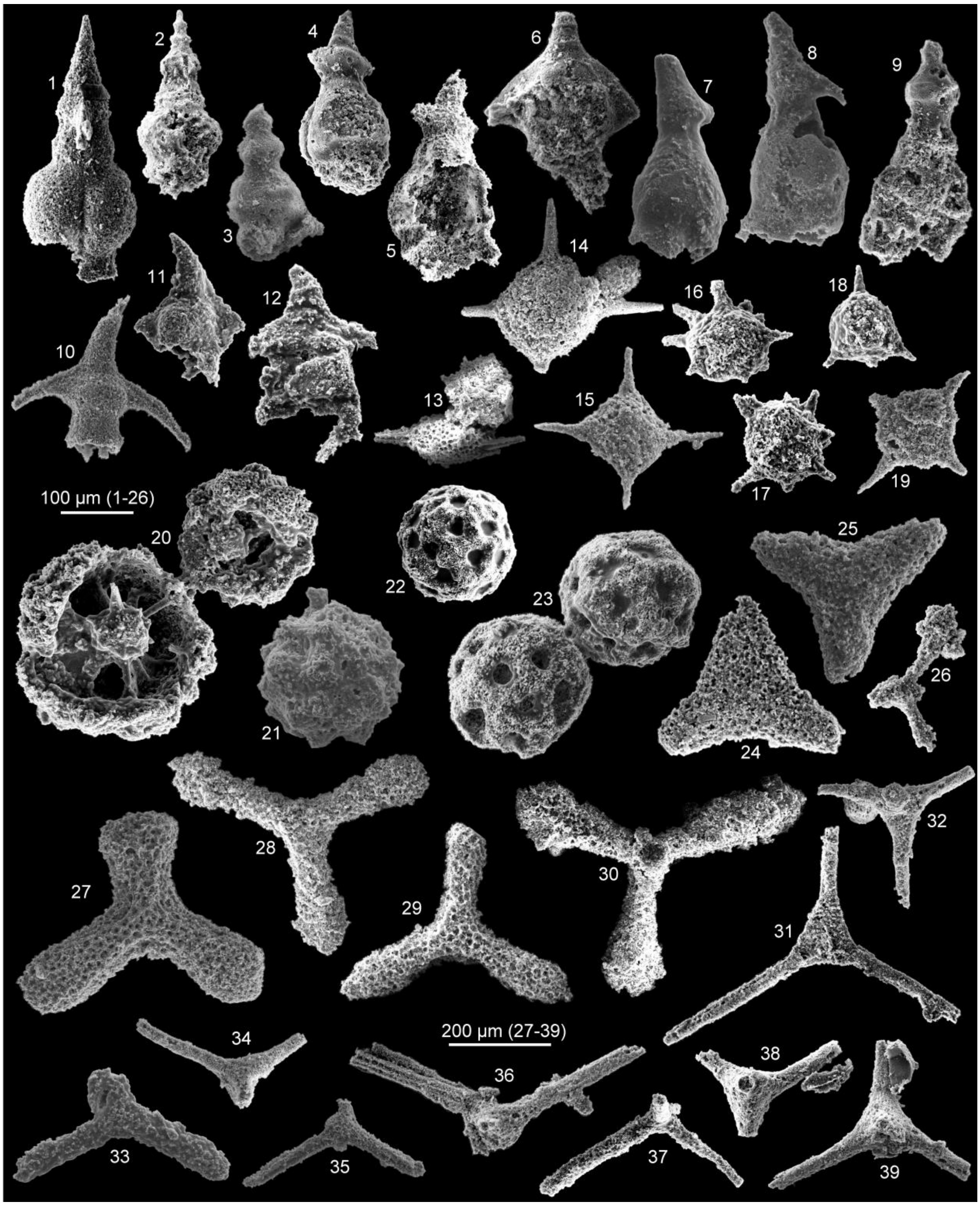
Among the collected samples from the Liuhuang and Gujingling sections, 18 samples including better preserved radiolarians underwent the above processes from soak of samples for collection of residues again. The residues were enclosed within one or several prepared slides with a mounting medium (Entellan new) per one sample. Quantities of the following suprageneric radiolarians in each slide were counted under a transmitted light microscope: albaillellarians, spherical radiolarians (involve spumellarians and entactinarians), and stauraxon radiolarians. In addition to suprageneric radiolarians, we focused on the following generic radiolarians, *Pseudotormentus* and *Quadriremis*, and *Longtanella* and *Pseudoalbaillella*. Quantities of these genera in each slide were also counted under the transmitted light microscope. The result of counts is shown in Table 2.

I had collected 175 samples from siliceous rocks of the Yoshii Group in the Yoshii area. These samples also underwent the HF treatment as mentioned above. However, the HF concentration is approximately 5%. These works includes the results of my master thesis. Selected radiolarian photomicrographs are reprinted in Figs. 15, 16.

4.2. Liuhuang section in Chaohu (Gufeng Formation)

Radiolarian preservation was poor to moderate. Some samples from the lower part of the Liuhuang section are moderately preserved, while most samples from the upper part are poorly preserved.

Several researchers had reported radiolarian occurrences from the Gufeng Formation in the Lower Yangtze region (e.g., Sheng and Wang, 1985; Kametaka et al., 2009). Most researchers since Wang and Qi (1995) had divided the Gufeng Formation into three radiolarian assemblage-zones. I also recognized three radiolarian assemblages in the Liuhuang section in the following ascending order: *Pseudoalbaillella fusiformis*, *Pseudoalbaillella monacanthus*, and *Ruzhencevispongus uralicus* (Fig. 7).



The characteristic species of the *Pseudoalbaillella fusiformis* assemblage are *Pseudoalbaillella fusiformis* (Holdsworth and Jones) and *Longtanella zhengpanshanensis* Sheng and Wang. This assemblage corresponds to those of the *Pseudoalbaillella globosa* Assemblage-Zone of Wang et al. (1997) and Ishiga (1986a, 1990), and the *Pseudoalbaillella longtanensis*-*P. fusiformis* Assemblage-Zone of Kametaka et al. (2009).

The characteristic species of the *Pseudoalbaillella monacanthus* assemblage are *Pseudoalbaillella monacanthus* (Ishiga and Imoto) and *Hegleria mammilla* Shang and Wang. This assemblage corresponds to those of the *F. monacanthus* Assemblage-Zone of Wang et al. (1994) and Kametaka et al. (2009), and the *F. monacanthus* Range-Zone of Ishiga (1986, 1990).

The characteristic species of the *R. uralicus* assemblage are *R. uralicus* Kozur, *Tetrapaurinella nanjingensis* (Zhang, Wu, and Li), *Latentifistula triadiata* Wang, *Quadricaulis inflata* (Sashida and Tonishi) and *He. mammilla*. This assemblage corresponds to those of the *F. scholasticus*-*F. ventricosus* Interval-Zone of Wang et al. (1994), the *F. scholasticus* m. I Assemblage-Zone of Ishiga (1986a, 1990), and the *F. scholasticus*-*R. uralicus* Assemblage-Zone of Kametaka et al. (2009).

Figure 11. Photomicrographs of radiolarians from the Liuhuang section. 1–3: *Longtanella zhengpanshanensis* Sheng and Wang; 4, 5: *Pseudoalbaillella fusiformis* (Holdsworth and Jones); 6: *Pseudoalbaillella* sp. cf. *P. globosa* Ishiga and Imoto; 7, 8; *Pseudoalbaillella monacanthus* (Ishiga and Imoto); 9: *Pseudoalbaillella longtanensis* Sheng and Wang; 10: *Pseudoalbaillella fusiformis* m. S; *Pseudoalbaillella scalprata* (Holdsworth and Jones); 12: *Albaillella* sp.; 13: *Paroetlispongus* sp.; 14, 15, 19: *Tetrapaurinella nanjingensis* (Zhang, Wu and Liu); 16, 17: *Paracopicyntra* sp. cf. *P. akikawaensis* (Sashida and Tonishi); 18: *Paurinella*? sp.; 20, 21: *Hegleria mammilla* (Sheng and Wang); 22, 23: Spumellaria? sp. A; 24, 25: *Ruzhencevispongus uralicus* Kozur; 26: *Ishigaum*? sp.; 27: *Latentifistula texana* Nazarov and Ormiston; 28, 29: *Latentifistula patagilaterala* Nazarov and Ormiston; 30: *Latentifistula* sp.; 31, 32: *Latentifistula triadiata* Wang; 33: *Latentifistula*? sp.; 34: *Quadriremis scalae* (Caridroit and De Wever); 35, 36: *Quadriremis glacilis* (De Wever and Caridroit); 37: *Quadriremis* sp.; 38: 13, 14: *Quadricaulis inflata* (Sashida and Tonishi). Sample numbers: 1, 2, 4, 5, 10, 12: CGF-2-3; 3: CGF-2-5; 6, 9: CGF-2-2; 7, 8: CGF-10-3; 11: CGF-11-9; 13: CGF-12-3; 14, 15, 24, 28–31, 36, 38, 39: CGF-12-7; 16, 17: CGF-4-4;19, 32, 34: CGF-12-6; 18: CGF-4-6; 22: CGF-4-4; 23: CGF-8-2; 20: CGF-10-1; 21: CGF-7-1; 25: CGF-12-2; 26: CGF-11-11; 27: CGF-8-1; 33: CGF-4-5; 35: CGF-11-2; 37: CGF-2-1

The counts showed the following results (Table 2). Albaillellarians and spherical radiolarians more commonly occurred than stauraxon radiolarians from the lower Liuhuang section (CGF-2-1, CGF-2-3, and CGF-2-5; *Pseudoalbaillella fusiformis* assemblage). Spherical radiolarians are extremely dominant in the middle Liuhuang section (CGF-10-3, CGF-11-7, CGF-11-9, and CGF-12-2; *Pseudoalbaillella monacanthus* assemblage). In the upper Liuhuang section (CGF-12-6 and CGF-12-7; *R. uralicus* assemblage), spherical radiolarians and latentifistularians are dominant. *Longtanella* occurred from only the lower Liuhuang section (CGF-2-1, CGF-2-3, and CGF-2-5; *Pseudoalbaillella fusiformis* assemblage). The Liuhuang section commonly yielded *Quadriremis*, while no *Pseudotormentus* were obtained.

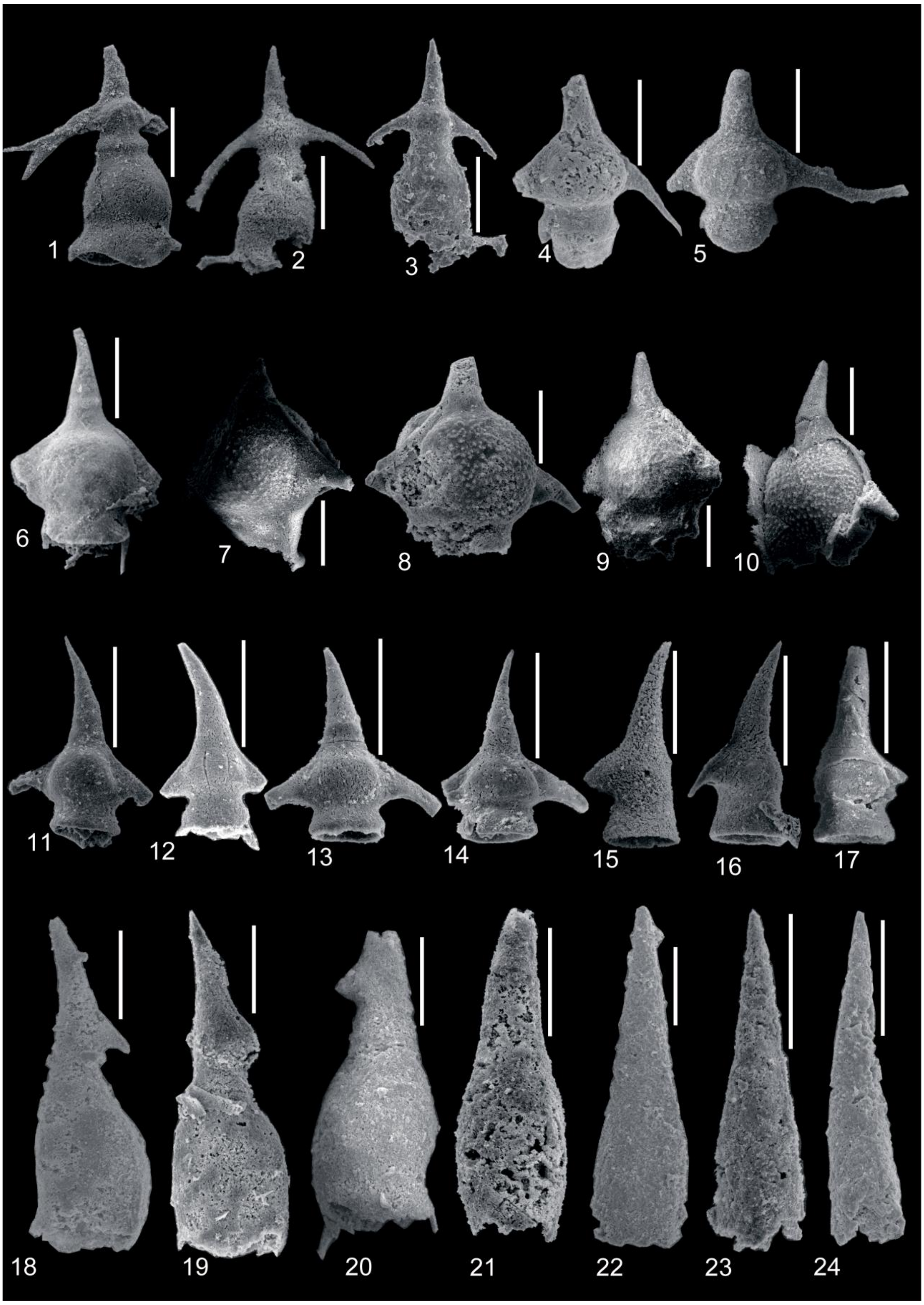
4.3. Gujingling section in Xiaodong (Bancheng Formation)

Radiolarians were generally more abundant than sponge spicules in all samples except sample 2-B; their preservation varied from good to slightly-poor.

Three successive radiolarian assemblage-zones were recognized in the Gujingling section in the following ascending order: *Pseudoalbaillella fusiformis*, *Pseudoalbaillella monacanthus*, and *Follicucullus scholasticus-Follicucullus porrectus*.

The *Pseudoalbaillella fusiformis* A-zone comprises the lower part of the Gujingling section (GJL 1-G to 6-A). The characteristic species of this zone are *Pseudoalbaillella fusiformis*, *Pseudoalbaillella* sp. A, *He. mammilla*, *Latentifistula texana* Nazarov and Ormiston, *Pseudotormentus kamigoriensis* (Caridroit and De Wever), and *Quadriremis glacilis*. The *Pseudoalbaillella fusiformis* A-zone corresponds to the *Pseudoalbaillella globosa* A-zone from the pelagic cherts of southwest Japan (Ishiga, 1986a, 1990) and the oceanic facies of South China (Wang and Yang, 2011) in addition to the *Pseudoalbaillella longtanensis-Pseudoalbaillella fusiformis* A-zone from the outer shelf facies of the Yangtze region in South China (Kametaka et al., 2009).

Figure 12. Radiolarian fossils from the Gujingling section. 1–3: *Pseudoalbaillella fusiformis* (Holdsworth and Jones); 4, 5: *Pseudoalbaillella yanaharensis* Nishimura and Ishiga; 6–10: *Pseudoalbaillella* sp. A; 12-14: *Pseudoalbaillella fusiformis* m. S; 15–17: *Pseudoalbaillella monacanthus* m. S; 18–20: *Pseudoalbaillella monacanthus* Ishiga and Imoto; 21–23: *Follicucullus porrectus* Rudenko; 24: *F. scholasticus* Ormiston and Babcock. Sample numbers: 1–3, 6–11: 1-D; 4, 5, 19, 20: 11-B; 12: 2-A; 13: 1-F; 14: 1-D; 15, 16: 8-C; 17: 6-A; 18: 12-A; 21: 12-C; 22: 12-D; 23, 24: 13-A. Scale bar: 100 µm.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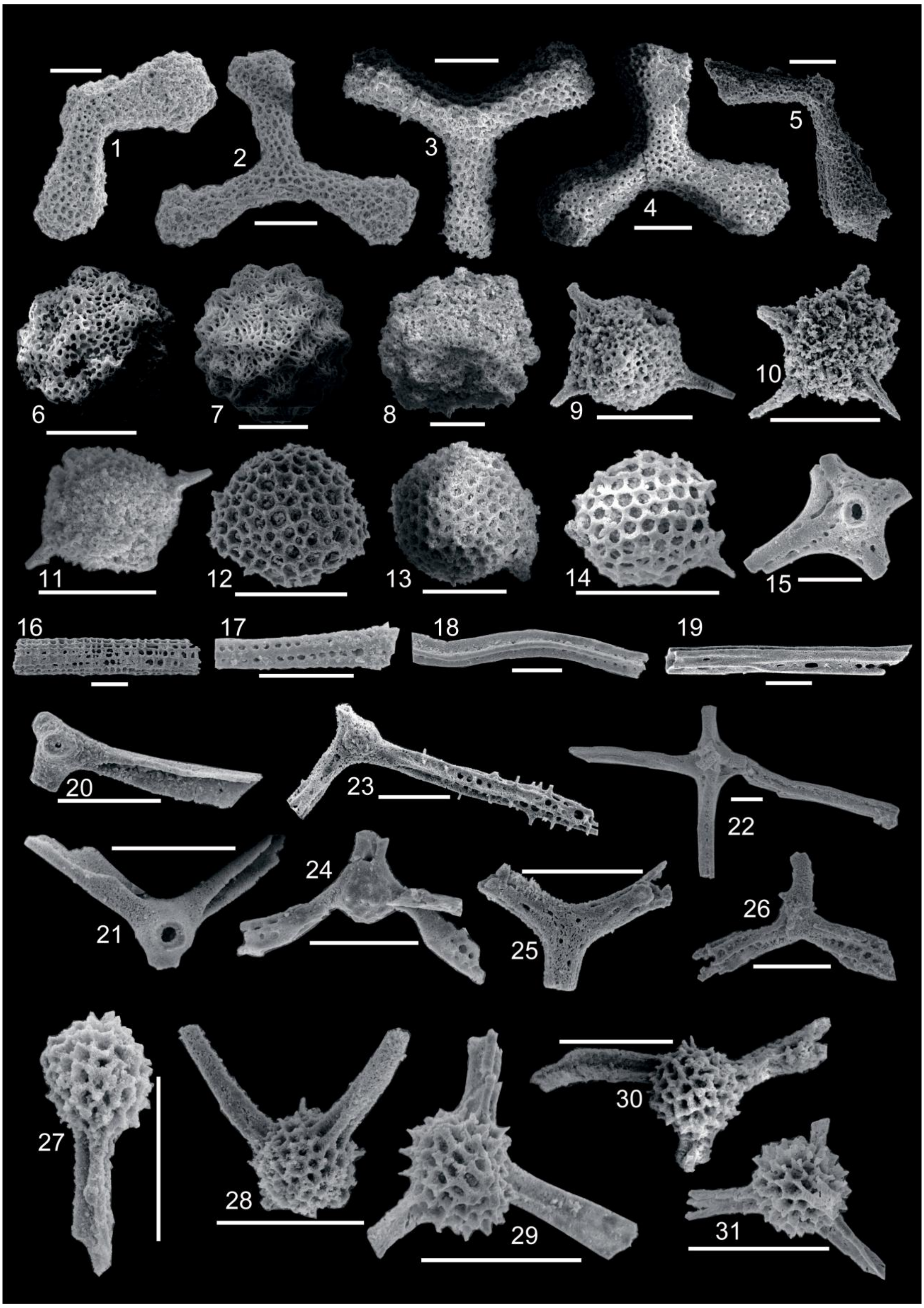
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The *Pseudoalbaillella monacanthus* A-zone is situated in the middle part of the Gujingling section (GJL 6-B to 12-B). The characteristic species of this zone are *Pseudoalbaillella monacanthus*, *Pseudoalbaillella yanaharensis* Nishimura and Ishiga, *He. mammilla*, *Pseudotormentus kamigoriensis*, and *Quadriremis glacilis*. The *Pseudoalbaillella monacanthus* A-zone corresponds to the *Follicucullus monacanthus* R-zone from the pelagic cherts of southwest Japan (Ishiga, 1986a, 1990), the *Follicucullus monacanthus* Interval-Zone (I-zone) from the oceanic facies of South China (Wang and Yang, 2011) and the *Follicucullus monacanthus* A-zone from the outer shelf facies of the Yangtze region in South China (Kametaka et al., 2009).

The *F. scholasticus-F. porrectus* A-zone is located in the upper part of the Gujingling section (GJL 12-G to 13-A). The characteristic species of this zone are *Follicucullus porrectus* Rudenko, *Follicucullus scholasticus* Ormiston and Babcock, *Follicucullus monacanthus*, and *Pseudotormentus kamigoriensis*. The *F. porrectus* A-zone corresponds to the *Follicucullus scholasticus-Follicucullus ventricosus* A-zone from the pelagic cherts of southwest Japan (Kuwahara et al., 1998) and the oceanic facies of South China (Wang and Yang, 2011). This zone is also correlated with the *F. scholasticus-R. uralicus* A-zone from the outer shelf facies of the Yangtze region in South China (Kametaka et al., 2009).

The faunas of sponge spicules were generally composed of abundant monaxons and common triaxons with rare anatriaene and very rare polyaxons.

Figure 13. Radiolarian fossils from the Gujingling section. 1–4: *Latentifistula texana* Nazarov and Ormiston; 5: *Latentifistula* sp. cf. *L. texana* Nazarov and Ormiston; 6, 7: *Hegleria mammilla*; 8: *He.* sp.; 9-11: *Copicyntra*? sp.; 12–14: *Trilonche*? sp.; 15–17: *Quadricaulis inflata* (Sashida and Tonishi); 18, 19: *Quadriremis scalae* (Caridroit and De Wever); 20, 21: *Quadriremis glacilis* (De Wever and Caridroit); 22, 23: *Pseudotormentus kamigoriensis* Caridroit and De Wever; 24: *Quinqueremis*? sp.; 25, 26: *Ishigaum* sp.; 27, 28: *Entactinia*? sp.; 29–31: *Triaenosphaera* sp. Sample numbers: 1, 7, 15: 1-C; 2, 22, 26, 29: 5-A; 3: 11-B; 4, 30: 1-F; 5, 6, 14, 16, 19, 21, 23: 1-D; 8: 12-C; 9, 10, 12, 13, 28: 8-C; 11: 2-A; 17, 27: 1-B; 18: 4-A; 20: 6-C; 24: 6-C; 25: 13-A; 31: 6-A. Scale bar: 100 µm.

Figure 14. Sponge spicules from the Gujingling section. 1–7: monaxon; 8, 10: bended monaxon or rhabdostyle; 9: acanthostyle; 11–15: triaxon; 16: polyaxon; 17, 18: anatriaene. Sample numbers: 1: 6-C; 2: 12-D; 3, 7, 9, 10, 12: 1-G; 4: 2-A; 5, 17: 10-C; 6: 11-B; 8: 4-A; 11: 13-A; 13: 5-A; 14, 15: 1-D; 16: 6-A; 18: 1-A. Scale bar: 100 µm.

4.4. Yoshii Group

Radiolarian preservations were generally poor. Among the collected samples, eight samples included better preserved radiolarians (Fig. 10).

Lower to Middle Permian radiolarians had occurred from the Yoshii Group (Sada et al., 1985, 1992; Sano et al., 1987). I observed Early to Middle Permian radiolarians of the *Albaillella sinuata* R-zone of Ishiga (1986a, 1990) and the *Pseudoalbaillella fusiformis* and *Pseudoalbaillella monacanthus* zones from the Yoshii Group (Figs. 15, 16).

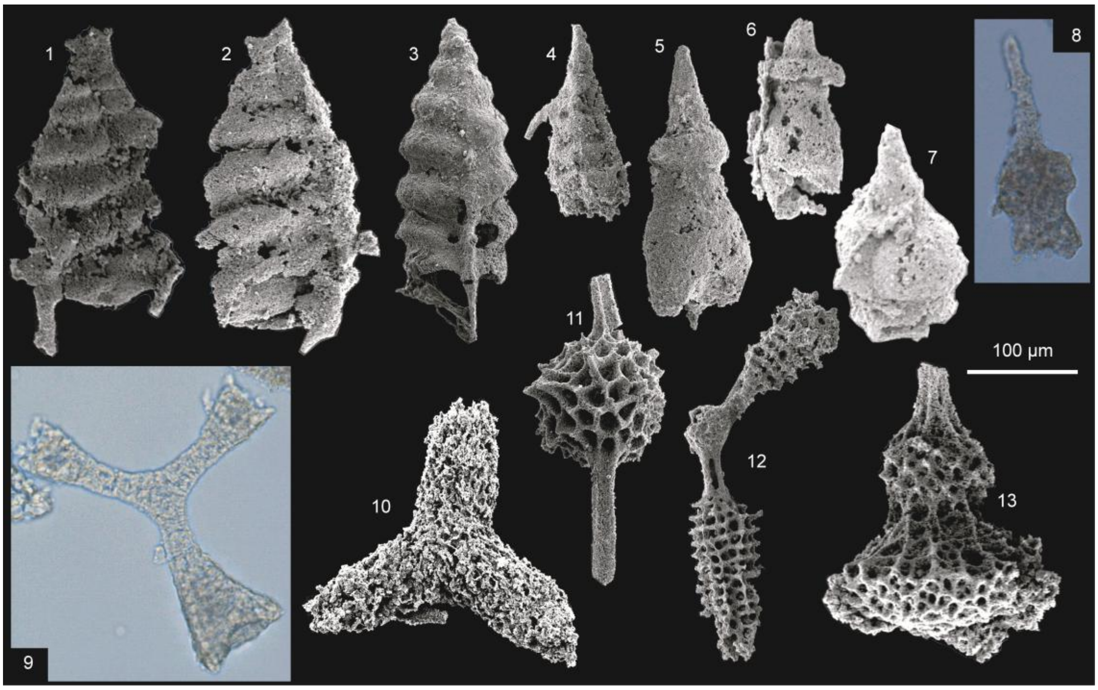

Figure 15. Photomicrographs of Permian radiolarians from the Yoshii Group in the Otake-yama area (east part of the Yoshii area) (re-printed from Ito, 2010MS). 1, 2: sample IT08062002; 3, 10, 11–13: sample IT07102614; 4: sample IT07102903; 5–9: sample IT07102909. 1–3: *Albaillella sinuata* Ishiga and Imoto; 4: *Pseudoalbaillella*? sp.; 6, 7: *Pseudoalbaillella fusiformis* (Holdsworth and Jones); 7: *Pseudoalbaillella* sp. cf. *P. globosa* Ishiga and Imoto; 8: *Pseudoalbaillella fusiformis* m. S; 9: *Cauletella* sp.; 10: *Entactinia* sp.; 11: *Latentifistula* sp.; 12: *Latentibifistula* sp.; 13: *Pseudotormentus* sp.; 14: Latentifistulidae? gen. et sp. indet.

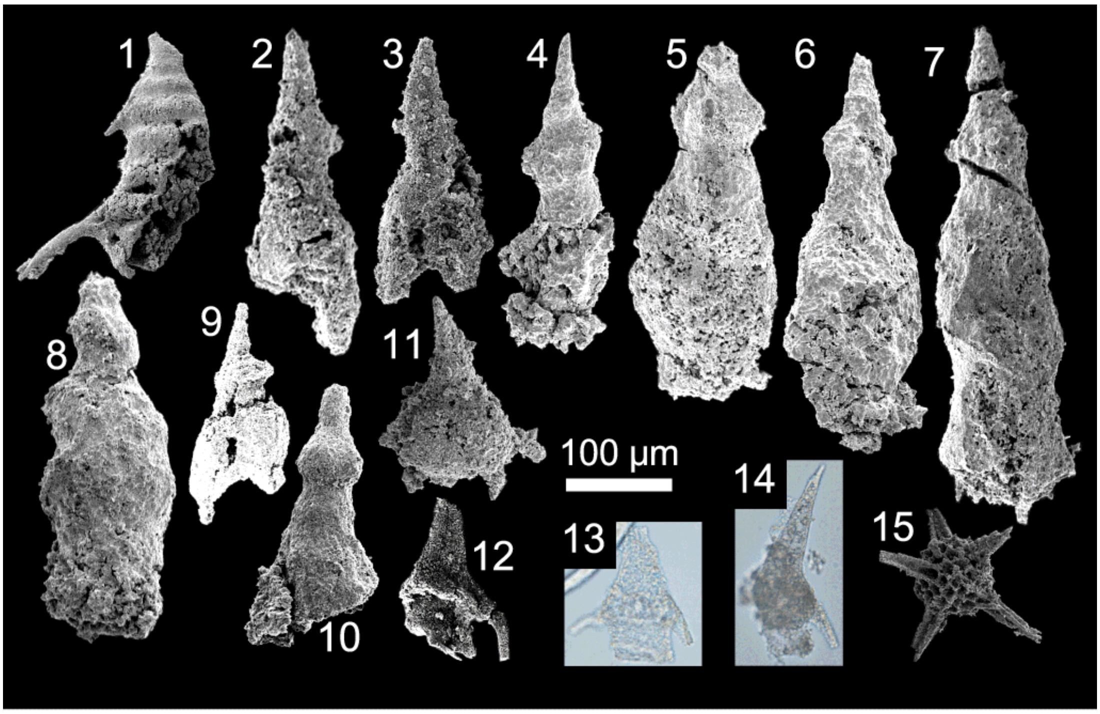

Figure 16. Photomicrographs of Permian radiolarians from the Yoshii Group in the Mihara area (west part of the Yoshii area) (re-printed from Ito, 2010MS). 1, 15: sample IT08061401; 2–3, 11: sample IT07102203; 4–8: sample IT09072308; 9–10: IT07102501; 12–14: IT08061703. 1: *Albaillella sinuata* Ishiga and Imoto; 2: *Pseudoalbaillella monacanthus* (Ishiga and Imoto); 3: *Pseudoalbaillella* sp. cf. *P. monacanthus*; 4: *Pseudoalbaillella*? *fusiformis* (Holdsworth and Jones); 6-10: *Pseudoalbaillella* sp. cf. *P. fusiformis*; 11: *Pseudoalbaillella* sp. cf. *P. globosa* Ishiga and Imoto; 12–14: *Pseudoalbaillella* sp. A; 15: *Entactinia* (?) sp.

Table 2. Count of radiolarian composition of selected samples from the Gujingling and Gujingling sections.

Section	Sample number	Radiolarian zone	Spuragenetic composition: Albaillellarians	Spuragenetic composition: Spherical radiolarians (entactinarians+spumellarians)	Spuragenetic composition: Stauraxon radiolarians	*Longtanella* group	*Pseudoalbaillella* group	*Quadriremis* group	*Pseudotormentus* group	**QPE (*Pseudotormentus* / *Quadriremis* Number)**
Liuhuang	CGF-12-7	*Ruzhencevispongus uralicus*	0	34	30	0	0	6	0	0.0
	CGF-12-6	*Ruzhencevispongus uralicus*	6	64	20	0	2	6	0	0.0
	CGF-12-2	*Ruzhencevispongus uralicus*	2	242	36	0	0	10	0	0.0
	CGF-11-9	*Pseudoalbaillella monacanthus*	3	83	4	0	0	18	0	0.0
	CGF-11-7	*Pseudoalbaillella monacanthus*	16	61	4	0	16	20	0	0.0
	CGF-10-3	*Pseudoalbaillella monacanthus*	6	113	3	0	6	14	0	0.0
	CGF-2-5	*Pseudoalbaillella fusiformis*	20	24	5	12	8	22	0	0.0
	CGF-2-3	*Pseudoalbaillella fusiformis*	36	43	12	20	16	6	0	0.0
	CGF-2-1	*Pseudoalbaillella fusiformis*	25	24	8	16	9	4	0	0.0
Gujingling	GJL-13-A	*Follicucullus porrectus-F. scholasticus*	50	36	20	0	4	4	16	80.0
	GJL-12-D	*Follicucullus porrectus-F. scholasticus*	24	44	16	0	2	2	8	80.0
	GJL-12-C	*Follicucullus porrectus-F. scholasticus*	28	48	70	0	16	4	50	92.6
	GJL-11-B	*Pseudoalbaillella monacanthus*	12	10	24	0	12	2	15	88.2
	GJL-8-C	*Pseudoalbaillella monacanthus*	15	11	21	0	15	3	14	82.4
	GJL-6-B	*Pseudoalbaillella monacanthus*	24	13	33	0	24	4	26	86.7
	GJL-2-A	*Pseudoalbaillella fusiformis*	7	15	13	0	7	2	10	83.3
	GJL-1-D	*Pseudoalbaillella fusiformis*	14	26	20	0	14	2	12	85.7
	GJL-1-F	*Pseudoalbaillella fusiformis*	16	18	18	0	16	4	12	75.0

5. Radiolarian biostratigraphy

5.1. Materials and methods

For the biostratigraphical and morphological research, I used 50 samples collected from the subsections 3–6 of the Gujingling section (Fig. 17). The samples underwent same treatment as mentioned the previous chapter. Selected radiolarian photomicrographs are shown in Figs. 18, 19.

Well-preserved specimens that have observable apical cone, pseudoabdomen, and wings were used for a measurement. The following parameters were measured under a transmitted light microscope (Fig. 20.A): HT: height of the total length of specimens from the top of an apical cone to the base of a pseudoabdomen; HU: height of the upper part from the top of an apical cone to the crotch of wings; HL: height of the lower part from the crotch of wings to the base of a pseudoabdomen. The data with the measurements are shown in Figs. 20.B, 20.C. Quantities of *Pseudoalbaillella* in each slide were counted under the transmitted light microscope. Unidentifiable specimens that have broken wing(s) were counted as *Pseudoalbaillella* sp. Table 3 shows the quantities of *Pseudoalbaillella* from the subsections 3-6.

5.2. Systematic paleontology

The terminologies of *Pseudoalbaillella* described in this paper are shown in Figs. 18, 20. An end of an apical cone is ascribed as the top of a specimen; a base of a pseudoabdomen is ascribed as the bottom of a specimen. The concave side of turned apical cone is ascribed as ventral side; the convex side is ascribed as dorsal side.

Subclass RADIOLARIA Müller, 1858
Superorder POLYCYSTINA Ehrenberg, 1838, emend. Riedel, 1967
Order ALBAILLELLA Deflandre, 1953
Family FOLLICUCULLIDAE Ormiston and Babcock, 1979
Genus *Pseudoalbaillella* Holdsworth and Jones, 1980
Type species: *Pseudoalbaillella scalprata* Holdsworth and Jones, 1980

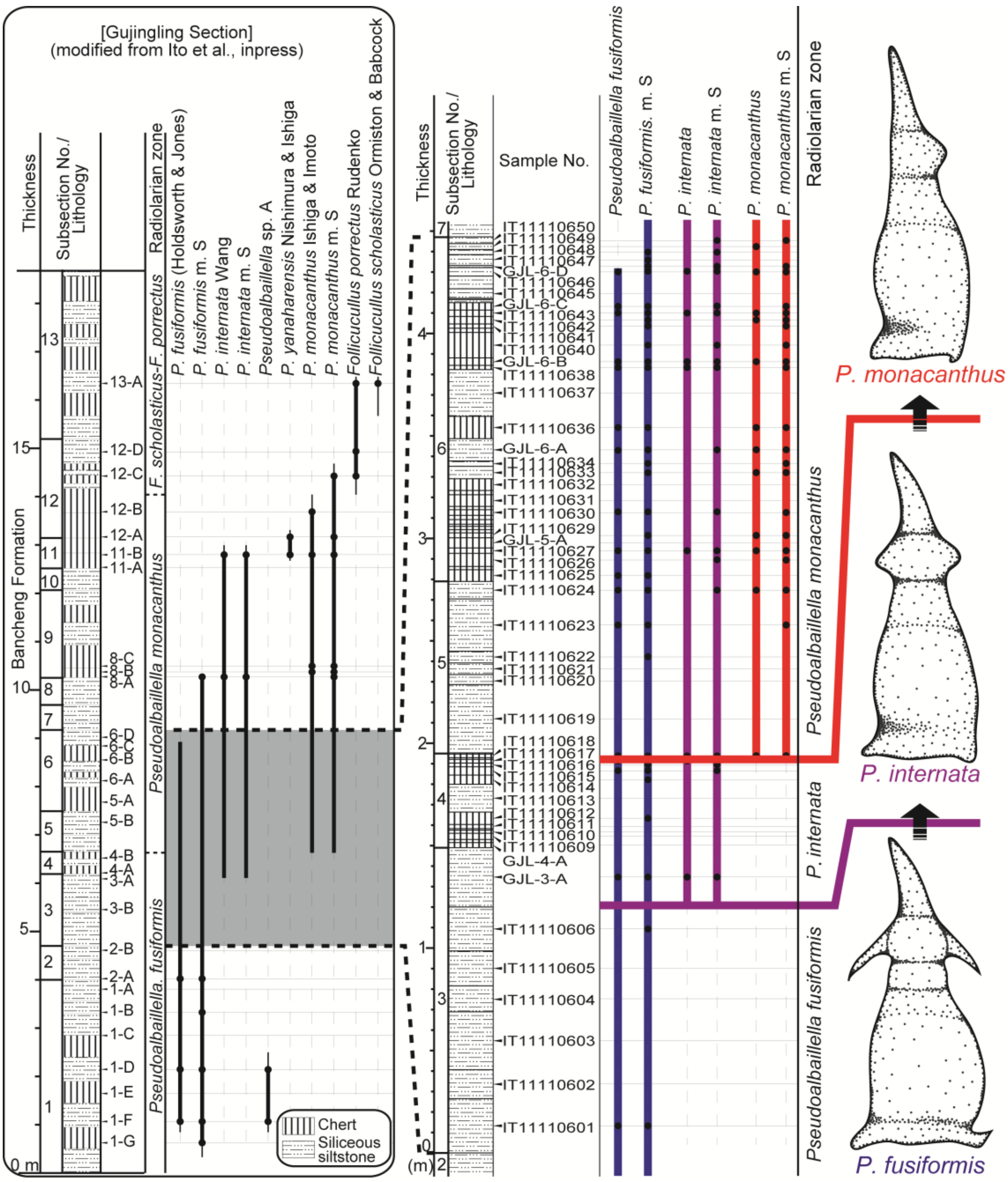

Figure 17. Detailed columnar section and Follicucullidae distribution of the Gujingling section.

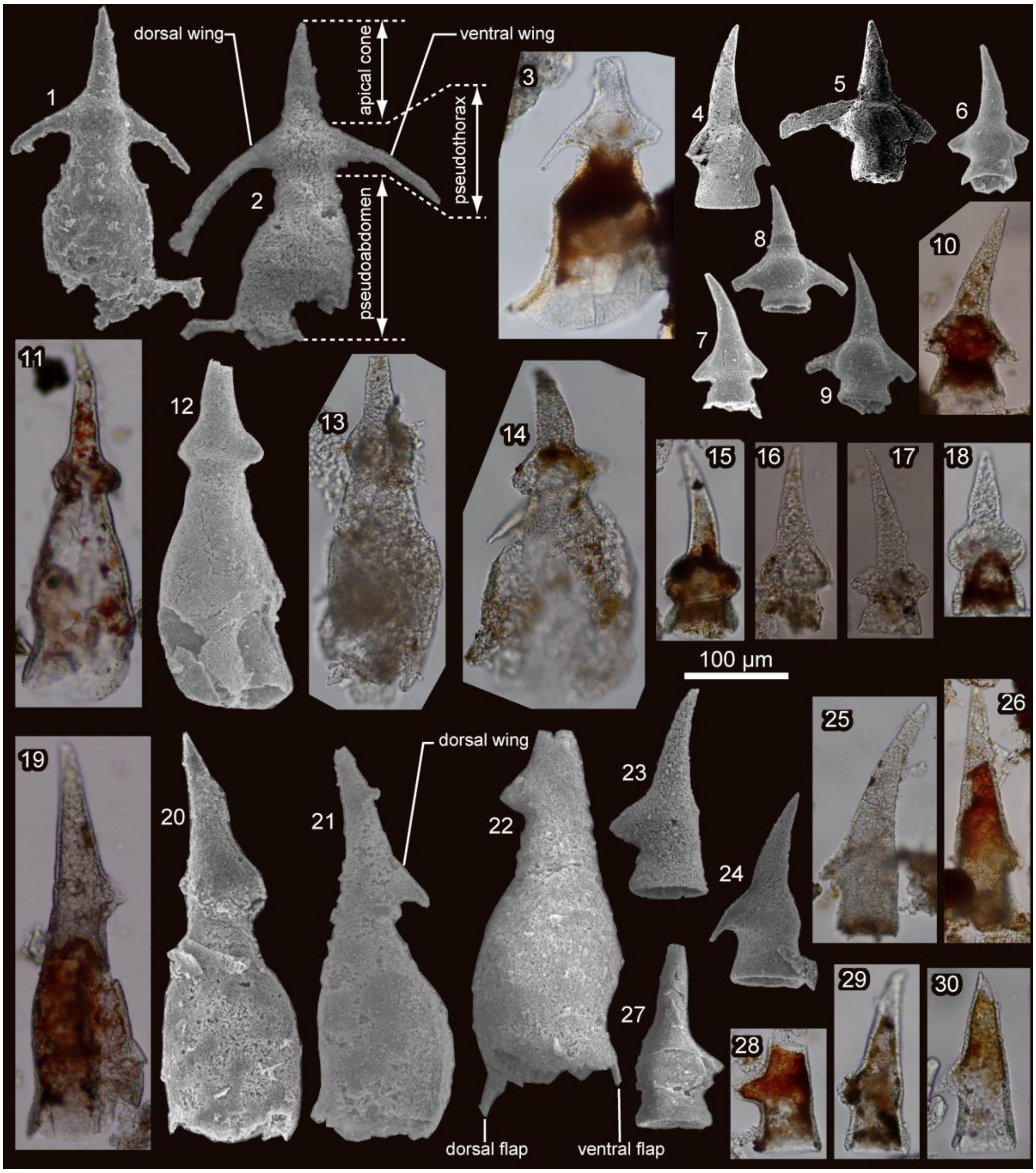

Figure 18. ***Pseudoalbaillella*** **from the Gujingling section. 1–3:** ***Pseudoalbaillella fusiformis*** **(Holdsworth and Jones, 1980); 4–10:** ***P. fusiformis*** **morphotype S; 11–14:** ***P. internata*** **Wang, 2012; 15-18:** ***P. internata*** **m. S; 19–22:** ***P. monacanthus*** **(Ishiga and Imoto, 1982); 23–30:** ***P. monacanthus*** **m. S. Sample numbers: 1, 2, 9: GJL-1-D; 3: IT11110601; 4: IT11110618; 5: IT11110624; 6, 13: GJL-6-B; 7: GJL-2-A; 8: GJL-1-F; 10, 26: IT11110643; 11: IT11110617; 12: GJL-8-A; 13: IT11110639; 14: IT11110638; 15: IT11110617; 16: IT11110616; 17: IT11110640; 18: IT11110626; 19: IT11110646; 20, 22: GJL-11-B; 21: GJL-12-A; 23, 24: GJL-8-C; 25: IT11110627; 27: GJL-6-A; 28: IT11110628; 29: IT11110623; 30: IT11110636.**

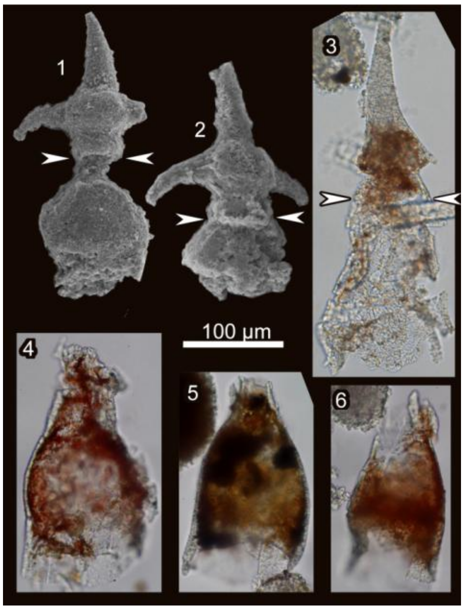

Figure 19. Half-broken *Pseudoalbaillella* from the Gujingling section. 1–3: Half-broken *P. fusiformis*; 4: pseudoabdomen of *P. internata*?; 5: pseudoabdomen of *P. fusiformis*?; 6: pseudoabdomen of *P. monacanthus*? Sample numbers: 1, 2: GJL-1-F; 3, 6: IT11110618; 4: IT11110623; 5: IT11110646.

***Pseudoalbaillella fusiformis* (Holdsworth and Jones, 1980)**

Figs. 18.1–18.3, 19.1–19.3

1980 *Parafollicucullus fusiformis* Holdsworth and Jones - Holdsworth and Jones, p. 284, fig. 1.D.

1982b *Pseudoalbaillella fusiformis* (Holsworth and Jones) - Ishiga et al., pl. 4, fig. 10.

1985 *Pseudoalbaillella nanjingensis* (Shang and Wang) - Sheng and Wang, pl. 1, figs. 1-4, 7.

Diagnosis: *Pseudoalbaillella* with apical cone without segmentation, small pseudothorax with blade-like wings extending downward, and inflated and weakly segmented pseudoabdomen.

Description: Shell consists of apical cone, pseudothorax with wings, and pseudoabdomen. There are no pore and ornament on exterior surface of the shell. An apical cone without segmentation is straight or slightly curves to the ventral side. A pseudothorax is small and globular, with ventral and dorsal wings. Wings are symmetrical and blade-like. Wings curve downward in an arc. Well-preserved specimens have wings longer than 200 μm (Fig. 18.2). The base of wings is platy and triangular. A pseudoabdomen is composed of three segments. The first segment (upper part of pseudoabdomen) is cylindrical and slightly expands downward. The second segment (middle part of pseudoabdomen) is longer than the first segment and inflated. The dorsal side of the second segment is more strongly-inflated than the ventral side (Fig. 18.2). The third segment is skirt-like, and apertural margin is flared (Fig. 18.3). Most of obtained specimens from the Gujingling section have the poorly-preserved third segment. Lateral spine straightly extends from apertural margin of the dorsal side (Figs. 18.1, 18.2).

Measurements: Four specimens were measured. The HT ranges from 216 µm to 299 µm; average of the HT is 269 µm. The HU ranges from 112 µm to 160 µm; average of the HU is 134 µm. The HL ranges from 104 µm to 147 µm; average of the HL is 134 µm.

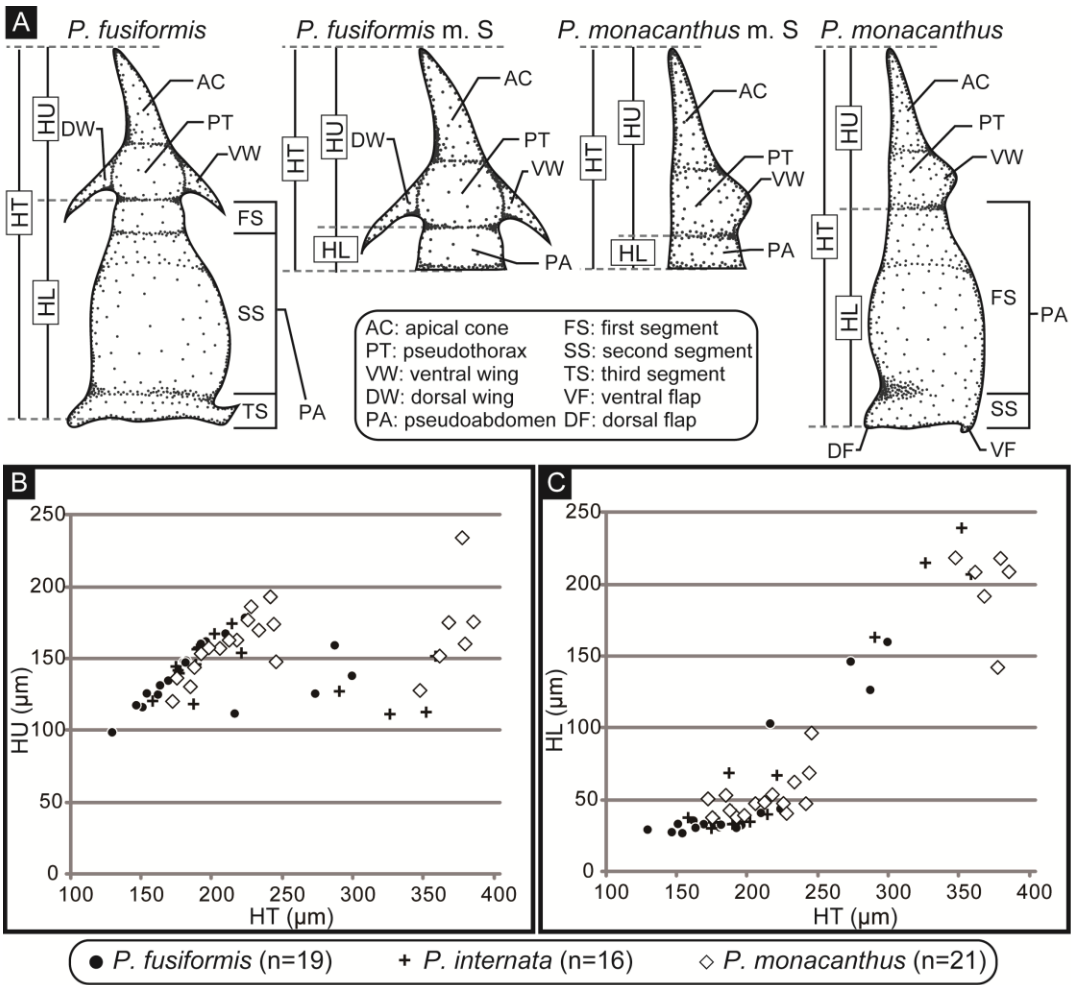

Figure 20. A: Terminologies and measured parameters of *P. fusiformis* and *P. monacanthus*; B: Scatter diagram of HU and HT of *Pseudoalbaillella* from the subsections 3–6 of the Gujingling section; C: Scatter diagram of HL and HT of *Pseudoalbaillella* from the subsections 3–6 of the Gujingling section.

Occurrences: This species occurred from the lower part of the Gujingling section (GJL-1-F to IT11110646: Fig. 17). The quantitative ratio of *Pseudoalbaillella fusiformis* to the total of *Pseudoalbaillella* decreases upward (Table 3). This species has occurred from Japan (e.g., Ishiga et al., 1982b), South China (e.g., Kametaka et al., 2009), and U.S.A. (e.g., Holdsworth and Jones, 1980).

Range: Late Cisuralian (Early Permian) to Guadalupian (Middle Permian). *Pseudoalbaillella fusiformis* is characteristic species of the *Pseudoalbaillella globosa* A-zone in southwest Japan (Ishiga, 1986a) and diagnostic species of the *Pseudoalbaillella longtanensis*- *Pseudoalbaillella fusiformis* A-zone in South China (Kametaka et al., 2009; Wang et al., 2012). It has occurred from the upper *Pseudoalbaillella longtanensis* A-zone to the *F. monacanthus* R-zone in southwest Japan (Ishiga, 1986a, 1990) and from the *Albaillella xiaodongensis* to *F. monacanthus* zones in South China (Wang et al., 1994). Kuwahara and Yao (1998) found *Pseudoalbaillella fusiformis* from the *Neoalbaillella grypa* to *N. optima* zones (Lopingian: Upper Permian) in southwest Japan.

Comparison: This species differs from *Pseudoalbaillella internata* in having blade-like wings extending downward. *Pseudoalbaillella fusiformis* in the Gujingling section in the Xiaodong area has unclearer segmented pseudoabdomen than the holotype from Alaska (Holdsworth and Jones, 1980). *Pseudoalbaillella fusiformis* from the Yanahara area in southwest Japan (Nishimura and Ishiga, 1987) has long wings connecting with long flaps. However, no specimen has connected-wing with flap from the Gujingling section.

***Pseudoalbaillella fusiformis* morphotype S**

Figs. 18.4–18.10

1982 *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga, Kito et Imoto - Ishiga et al., pl. 2, figs. 1-7.

Diagnosis: *Pseudoalbaillella* with apical cone without segmentation, small pseudothorax with blade-like wings extending downward and short pseudoabdomen.

Description: Shell consists of apical cone, pseudothorax with wings, and pseudoabdomen. There are no pore and ornament on exterior surface of the shell. An apical cone without segmentation is straight or slightly curves to the ventral side. A pseudothorax is small and globular with ventral and dorsal wings. Wings are symmetrical and blade-like. Wings curve downward. The base of wings is platy and triangular. A pseudoabdomen is cylindrical and slightly expands downward. Apertural margin of the pseudoabdomen is ring-like and horizontal (Figs. 18.4, 18.8).

Measurements: Fifteen specimens were measured. The HT ranges from 129 µm to 223 µm; average of the HT is 174 µm. The HU ranges from 99 µm to 179 µm; average of the HU is 141 µm. The HL ranges from 30 µm to 44 µm; average of the HL is 33 µm.

Occurrences: This species occurred from the lower part of the Gujingling section (GJL-1-G to GJL-8-A: Fig. 17). The quantitative ratio of *Pseudoalbaillella fusiformis* m. S to the total of *Pseudoalbaillella* decreases upward (Table 3). This species has occurred from Japan (e.g., Ishiga et al., 1982b), South China (e.g., Wang et al., 2012), and U.S.A. (e.g., Blome and Reed, 1992).

Range: Late Cisuralian (Early Permian) to Guadalupian (Middle Permian). It has occurred from the *Pseudoalbaillella longtanensis* A-zone to the *F. monacanthus* R-zone in southwest Japan (Ishiga, 1986a, 1990) and from the *A. sinuata* to *F. monacanthus* zones in South China (Wang et al., 1994).

Comparison: This species differs from *Pseudoalbaillella internata* m. S in having blade-like wings extending downward.

Discussion: The upper half of some species of *Pseudoalbaillella*, such as *Pseudoalbaillella longtanensis* Sheng and Wang and *Pseudoalbaillella ishigai* Wang, is similar to *Pseudoalbaillella* sp. aff. *P. longicornis* sensu Ishiga et al. (1982b) in size and shape. Ishiga et al. (1982b) showed that occurrence ranges of these species of *Pseudoalbaillella* overlap those of *Pseudoalbaillella* sp. aff. *P. longicornis*. These indicate that some of *Pseudoalbaillella* derived from other *Pseudoalbaillella* than *Pseudoalbaillella fusiformis*. On the other hand, *Pseudoalbaillella fusiformis* m. S from the Gujingling section is similar to the upper half of *Pseudoalbaillella fusiformis* in shape and has blade-like wings (Fig. 18). Well-preserved specimens of *Pseudoalbaillella fusiformis* have long wings joining with spines to form framework structure (Nishimura and Ishiga, 1987). The HU of most specimens of *Pseudoalbaillella fusiformis* m. S falls within the range from 100 µm to 200 µm which is approximately same as that of *Pseudoalbaillella fusiformis* (Fig. 21.B). These similarities of shape and size suggest that *Pseudoalbaillella fusiformis* m. S. from the Gujingling section is the upper half of *Pseudoalbaillella fusiformis*. The occurrences of half-broken specimens of *Pseudoalbaillella fusiformis* (Figs. 19.1–19.3) support this interpretation.

Pseudoalbaillella internata **Wang, 2012**

Figs. 18.11–18.14

1982b *Pseudoalbaillella fusiformis* (Holdsworth and Jones) – Ishiga et al., pl. 4, fig. 12.

2012 *Pseudoalbaillella internata* Wang – Wang et al., pl. 16, fig. 29-32, pl. 17, figs.

15, 18, 19.

Diagnosis: *Pseudoalbaillella* with apical cone without segmentation, small pseudothorax with small wenny wings, and inflated and slightly segmented pseudoabdomen.

Description: Shell consists of apical cone, pseudothorax with wings, and pseudoabdomen. There are no pore and ornament on exterior surface of the shell. An apical cone without segmentation is straight or slightly curves to the ventral side. A pseudothorax is small and globular with ventral and dorsal wings. Wings are symmetrical extending from ventral and dorsal sides. Wings are wenny forming triangular with rounded end (Fig. 18.12) or hemicycle (Fig. 18.11). Some specimens have wings barely trail down (Fig. 18.12). Most specimens have the unclear borders between a pseudothorax and wings, being formed spheroid (Fig. 18.11). Two segments are observable in pseudoabdomen. The first segment (upper two-thirds or more of pseudoabdomen) is barrel-shaped and downwardly-inflated. The dorsal side of the first segment is more strongly-inflated than the ventral side (Figs. 18.11, 18.12); the ventral side of the bottom of the first segment is constricted. The border between the first and second segments of dorsal side is unclear and seems to be successive without any sections, while that of ventral side is clear by the constriction (Figs. 18.11, 18.12). The second segment (lowermost part of pseudoabdomen) is deflated and shorter than the first segment, and apertural margin is flared (Figs. 18.11, 18.14). No flap and spine at the bottom of pseudoabdomen was observed from the specimens from the Gujingling section.

Measurements: Four specimens were measured. The HT ranges from 290 μm to 359 μm; average of the HT is 332 μm. The HU ranges from 111 μm to 152 μm; average of the HU is 126 μm. The HL ranges from 163 μm to 239 μm; average of the HT is 206 μm.

Occurrences: This species occurred from the middle part of the Gujingling section (GJL-3-A to GJL-11-B: Fig. 17). The quantity of *Pseudoalbaillella internata* is less than *Pseudoalbaillella fusiformis* and *Pseudoalbaillella monacanthus* in most horizons (Table 3). This species has occurred from Japan (e.g., Ishiga et al., 1982b) and South China (e.g., Wang et al., 2012).

Range: Guadalupian (Middle Permian). *Pseudoalbaillella internata* has occurred from the *Pseudoalbaillella globosa* and *F. monacanthus* zones in South China (Wang et al., 2012).

Comparison: This species differs from *Pseudoalbaillella fusiformis* in having the following characters: small and wenny wings that are not like blade, pseudoabdomen composed of two segments, the longer HT and HL in general, and clearer constriction in the ventral side of a pseudoabdomen.

Discussion: Wang et al. (2012) considered this species as an intermediate species between *Pseudoalbaillella fusiformis* and *Pseudoalbaillella monacanthus*. Some characteristics of *Pseudoalbaillella internata* such as small asymmetrical wings and the constricted pseudoabdomen in ventral side are intermediate, corresponding with the consideration.

***Pseudoalbaillella internata* morphotype S**

Figs. 18.15–18.18

Diagnosis: *Pseudoalbaillella* with apical cone without segmentation, small pseudothorax with small wenny wings, and short pseudoabdomen.

Description: Shell consists of apical cone, pseudothorax with wings, and pseudoabdomen. There are no pore and ornament on exterior surface of the shell. An apical cone without segmentation is straight or slightly curves to the ventral side. A pseudothorax is small and globular with ventral and dorsal wings. Wings are symmetrical extending from ventral and dorsal sides. Wings are wenny forming triangular with rounded end (Fig. 18.17) or hemicycle (Figs. 18.15, 18.18). The borders between a pseudothorax and wings are unclear, forming spheroid (Figs. 18.15, 18.18). A pseudoabdomen is cylindrical and slightly expands downward. Apertural margin of the pseudoabdomen is ring-like (Figs. 18.15, 18.18).

Measurements: Twelve specimens were measured. The HT ranges from 158 μm to 221 μm; average of the HT is 189 μm. The HU ranges from 118 μm to 174 μm; average of the HU is 148 μm. The HL ranges from 30 μm to 69 μm; average of the HL is 41 μm.

Occurrences: This species occurred from the middle part of the Gujingling section (GJL-3-A to GJL-11-B: Fig. 17). The quantity of *Pseudoalbaillella internata* m. S is less than *Pseudoalbaillella fusiformis* m. S and *Pseudoalbaillella monacanthus* m. S in most horizons (Table 3). This species has occurred from Japan (e.g., Ishiga et al., 1982b) and South China (e.g., Wang et al., 2012).

Range: Guadalupian (Middle Permian). *Pseudoalbaillella internata* has occurred from the *Pseudoalbaillella fusiformis* and *F. monacanthus* zones in South China.

Comparison: This species differs from *Pseudoalbaillella fusiformis* m. S in having small and wenny wings that are not like blade.

Discussion: *Pseudoalbaillella internata* m. S is similar to the upper half of *Pseudoalbaillella internata* in shape (Fig. 18). The HU of most specimens of *Pseudoalbaillella internata* m. S falls within the range from 100 μm to 200 μm which is approximately same as that of *Pseudoalbaillella internata* (Fig. 20.B). These similarities of shape and size suggest that the upper half of *Pseudoalbaillella internata* is *Pseudoalbaillella internata* m. S. The first appearances of *Pseudoalbaillella internata* and *Pseudoalbaillella internata* m. S are the same horizon (GJL-3-A: Fig. 17).

***Pseudoalbaillella monacanthus* (Ishiga and Imoto, 1982)**

Figs. 18.19–18.22

1980 *Follicucullus* sp. A - Ishiga and Imoto, pl. 4, figs. 11-15.

1982b *Follicucullus monacanthus* Ishiga and Imoto – Ishiga et al., pl. 4, figs. 15-17, 21-23.

2011 *Pseudoalbaillella monacanthus* (Ishiga and Imoto) – Wang and Yang, p. 138, figs. 4v, 4w.

Diagnosis: *Pseudoalbaillella* with apical cone without segmentation, small pseudothorax with a dorsal wing, and pseudoabdomen.

Description: Shell consists of apical cone, pseudothorax with a dorsal wing, and pseudoabdomen. There are no pore and ornament on exterior surface of the shell. An apical cone without segmentation is straight or slightly curves to the ventral side. A pseudothorax is small with a dorsal wing. The dorsal wing is wenny forming triangular with rounded end (Fig. 18.22) or hemicycle (Fig. 18.20). Some specimens have wings barely curve downward (Fig. 18.21). Most specimens have the unclear borders between a pseudothorax and dorsal wing. The ventral side of pseudothorax is slightly wenny in a few specimens (Fig. 18.20). Two segments are observable in pseudoabdomen. The first segment (upper two-thirds or more of pseudoabdomen) is barrel-shaped and downwardly-inflated. The dorsal side of the first segment is more strongly inflated than the ventral side (Figs. 18.19, 18.21, 18.22); the ventral side of the bottom of the first segment is constricted. The border between the first and second segments of dorsal side is unclear and seems to be successive without any sections, while that of ventral side is clear by the constriction (Figs. 18.19, 18.21, 18.22). The second segment (lowermost part of pseudoabdomen) is deflated and shorter than the first segments. Short flaps are spine-like extending downward from apertural margin of the dorsal and ventral sides (Fig. 18.22). However, most specimens from the Gujingling section lose flaps.

Measurements: Six specimens were measured. The HT ranges from 347 μm to 385 μm; average of the HT is 370 μm. The HU ranges from 128 μm to 234 μm; average of the HU is 171 μm. The HL ranges from 143 μm to 219 μm; average of the HL is 198 μm.

Occurrences: This species occurred from the middle to upper parts of the

Gujingling section (IT11110618 to GJL-12-B: Fig. 17). The quantitative ratio of *Pseudoalbaillella monacanthus* to the total of *Pseudoalbaillella* increases upward (Table 3). This species has occurred from Japan (e.g., Ishiga et al., 1982b), South China (e.g., Kametaka et al., 2009), and U.S.A. (Holdsworth and Jones, 1980; Blome and Reed, 1992), and Thailand (Sashida et al., 1993a).

Range: Guadalupian (Middle Permian). *Pseudoalbaillella monacanthus* is diagnostic species of the *F. monacanthus* Zone in southwest Japan (Ishiga, 1986a) and South China (Wang et al., 1994; Kametaka et al., 2009; Wang et al., 2012). Kuwahara and Yao (1998) found *Pseudoalbaillella monacanthus* from the *Neoalbaillella grypa* to *N. optima* zones (Lopingian: Upper Permian).

Comparison: This species differs from *Pseudoalbaillella fusiformis* and *Pseudoalbaillella internata* in having no ventral wing. This species has longer HL and clearer constriction in the ventral side of pseudoabdomen than those of *Pseudoalbaillella fusiformis*.

Discussion: Ishiga et al. (1982b) placed *Pseudoalbaillella fusiformis* under the genus *Follicucullus*. Most researchers had then followed them. Wang et al. (2012) reassigned this species to genus *Pseudoalbaillella* based on the evolution from *Pseudoalbaillella fusiformis* to *Pseudoalbaillella monacanthus*. *Follicucullus* was proposed by Ormiston and Babcock (1979). The major diagnosis is as follows: shell inperforate, apical portion conical, beneath which is a weakly inflated to subspherical region shapely demarked from skirt-like expansion of apertural region. Whereas the major diagnosis of *Pseudoalbaillella* proposed by Holdsworth and Jones (1980) is as follows: bilaterally symmetrical, imperforate, siliceous shells of unknown internal structure showing major division into apical cone, more or less swollen, winged “pseudothorax,” and “pseudoabdomen.” On the basis of these quotations, one of the most important criteria is division of a shell and presence or absence of wing. The shells of *Follicucullus* is divided into apical portion and weakly inflated to subspherical region, while those of *Pseudoalbaillella* are divided into apical cone, winged pseudothorax, and pseudoabdomen. Moreover, wing is undescribed in the diagnosis of *Follicucullus* whereas *Pseudoalbaillella* diagnostically has winged pseudothorax. I recognized that the shell of *Pseudoalbaillella monacanthus* is divided into apical cone, pseudothorax, and pseudoabdomen. Additionally, pseudothorax of *Pseudoalbaillella monacanthus* is winged. I therefore placed *Pseudoalbaillella monacanthus* under genus *Pseudoalbaillella* here.

Pseudoalbaillella monacanthus **morphotype S**

Figs. 18.23–18.30

1982b *Follicucullus* sp. B – Ishiga et al., pl. 4, figs. 18-20

1995 *Albaillella* sp. – Wang, pl. 1, fig. 9.

2009 *Follicucullus* sp. cf. *F. monacanthus* Ishiga and Imoto: Kametaka et al., p. 116, figs. 6.24 and 6.25.

Diagnosis: *Pseudoalbaillella* with apical cone without segmentation, small pseudothorax with a dorsal wing, and short pseudoabdomen.

Description: Shell consists of apical cone, pseudothorax with a dorsal wing, and pseudoabdomen. There are no pore and ornament on exterior surface of the shell. An apical cone without segmentation is straight or slightly curves to the ventral side. A pseudothorax is small with a dorsal wing. The dorsal wing is wenny forming triangular with rounded end (Fig. 18.23) or hemicycle (Fig. 18.28). Some specimens have wings barely curve downward (Fig. 19.24). Most specimens have the unclear borders between a pseudothorax and wings. The ventral side of pseudothorax is slightly wenny in a few specimens (Fig. 18.24). A pseudoabdomen is cylindrical and slightly expands downward. Apertural margin of the pseudoabdomen is ring-like (Figs. 18.23, 18.28).

Measurements: Fifteen specimens were measured. The HT ranges from 172 μm to 245 μm; average of the HT is 211 μm. The HU ranges from 121 μm to 193 μm; average of the HU is 159 μm. The HL ranges from 38 μm to 97 μm; average of the HL is 52 μm.

Occurrences: This species occurred from the middle to upper parts of the Gujingling section (IT11110618 to GJL-12-C: Fig. 2). The quantitative ratio of *Pseudoalbaillella monacanthus* m. S to the total of *Pseudoalbaillella* increases upward (Table 3). This species has occurred from Japan (e.g., Ishiga et al., 1982b) and South China (e.g., Kametaka et al., 2009).

Range: Guadalupian (Middle Permian). *Pseudoalbaillella monacanthus* m. S has occurred from the *F. monacanthus* zones in southwest Japan (Ishiga et al., 1982b) and South China (Kametaka et al., 2009).

Comparison: This species differs from *Pseudoalbaillella fusiformis* m. S and *Pseudoalbaillella internata* m. S in having no ventral wing.

Discussion: *Pseudoalbaillella monacanthus* m. S is similar to the upper half of *Pseudoalbaillella monacanthus* in shape (Fig. 18). The HU of most specimens of *Pseudoalbaillella monacanthus* m. S falls within the range from 100 μm to 200 μm which is approximately same as that of *Pseudoalbaillella monacanthus* (Fig. 20.B). These similarities of shape and size suggest that the upper half of *Pseudoalbaillella monacanthus* is *Pseudoalbaillella monacanthus* m. S. The first appearances of

Pseudoalbaillella monacanthus and *Pseudoalbaillella monacanthus* m. S are the same horizon (IT11110618: Fig. 17). Previous studies had reported co-occurrences of *Pseudoalbaillella monacanthus* and *Pseudoalbaillella monacanthus* m. S (e.g., Ishiga et al., 1982b, 1986; Kametaka et al., 2009).

5.3. Radiolarian lineage

As mentioned in the discussion of *Pseudoalbaillella internata*, some characteristics of *Pseudoalbaillella internata* (e.g., small asymmetrical wings and the constricted pseudoabdomen in ventral side) are intermediate between those of *Pseudoalbaillella fusiformis* and *Pseudoalbaillella monacanthus*. This characteristic suggests that *Pseudoalbaillella monacanthus* is direct descendant of *Pseudoalbaillella fusiformis*. The occurrence change of these species supports this suggestion (Fig. 17; Table 3).

Additionally, the morphological similarities suggest that the upper half of *Pseudoalbaillella fusiformis*, *Pseudoalbaillella internata*, and *Pseudoalbaillella monacanthus* are the same as *Pseudoalbaillella fusiformis* m. S., *Pseudoalbaillella internata* m. S., and *Pseudoalbaillella monacanthus* m. S., respectively. This suggestion indicates that these short morphotypes are also useful as an index.

Table 3. Occurrence list of *Pseudoalbaillella* from the subsections 4-6 of the Gujingling section.

Bed	Lithology	Fossil preservation	*Pseudoalbaillella* sp.	*Pseudoalbaillella fusiformis* (Holdsworth & Jones)	*P. fusiformis* m. S	*Pseudoalbaillella internata* Wang	*P. internata* m. S	*Pseudoalbaillella monacanthus* Ishiga & Imoto	*P. monacanthus* m. S
IT11110650	sl	×	6				1		5
IT11110649	sl	△	5					1	1
IT11110648	sl	×	5		1		1		1
IT11110647	sl	×	3		1				2
GJL-6-D	sl	△	8		3		2		5
IT11110646	sl	○	16	1	8	1	3	3	19
IT11110645	sl	×	4						2
GJL-6-C	ch	△	9	1	4		4		7
IT11110643	ch	△	4	2	2	1	2	1	7
IT11110642	ch	△	6		2			1	4
IT11110641	ch	△	7		2				6
IT11110640	ch	△	7		2		3		3
GJL-6-B	ch	○	7	1	2	1	4	2	5
IT11110638	ch	△	10	2	3	2	2		5
IT11110637	sl	×							
IT11110636	ch	△	7	1	2			2	8
GJL-6-A	sl	△	10	1	2		1	1	7
IT11110634	sl	△	7		2				7
IT11110633	sl	△	8		3			1	6
IT11110632	ch	×							
IT11110631	ch	×	7						2
IT11110630	ch	×	4	1	1		1		3
IT11110629	ch	△	6		2			1	7
GJL-5-A	ch	×	6						
IT11110627	ch	○	29	2	10	2	5	2	30
IT11110626	ch	×	4				1		3

Bed	Lithology	Fossil preservation	*Pseudoalbaillella* sp.	*Pseudoalbaillella fusiformis* (Holdsworth & Jones)	*P. fusiformis* m. S	*Pseudoalbaillella internata* Wang	*P. internata* m. S	*Pseudoalbaillella monacanthus* Ishiga & Imoto	*P. monacanthus* m. S
IT11110625	ch	×	8	1	3				3
IT11110624	sl	○	41	1	12		9	1	20
IT11110623	sl	○	19	1	8				17
IT11110622	sl	×	3		1				
IT11110621	sl	×	1						
IT11110620	sl	×	3						
IT11110619	sl	△	2						
IT11110618	ch	△	41	3	10	2	10	2	15
IT11110617	ch	○	67	5	29	1	12		
IT11110616	ch	△	9		1		3		
IT11110615	ch	△	14	1	9		2		
IT11110614	ch	△	11		2				
IT11110613	sl	×	2						
IT11110612	ch	×	4		1				
IT11110611	ch	×	5						
IT11110610	ch	×	7						
IT11110609	ch	△	2						
GJL-4-A	ch	△	2		2				
GJL-3-A	sl	△	8	1	2	1	2		
IT11110606	sl	○	19		4				
IT11110605	sl	△	2						
IT11110604	sl	△							
IT11110603	sl	×	2						
IT11110602	sl	×							
IT11110601	sl	△	2	1	1				

ch: chert; sl: siliceous siltstone

○: good; △: moderate; ×: bad

specimen quantity: 1~9 10~

6. Discussion

6.1. Sedimentary environment of the geological units

Permian radiolarian-bearing strata are distributed in several areas. Firstly, I mention sedimentary environment (e.g., paleolocation and redox condition) which are dealt with for radiolarian faunal comparison on the basis of the previous studies and the result of this study.

6.1.1. The Gufeng Formation

The Yangtze block (=South China block), sedimentary place of the Gufeng Formation, had been located in equatorial area in Middle Permian (Golonka and Ford, 2000: Fig. 21). The Yangtze block rotated clockwise by the collision with the Indo-China block (=North China block) at the Jurassic (e.g., Zhao and Coe, 1987; Gilder and Courtillot, 1997). The Gufeng Formation in the Lower Yangtze region had fronted the Paleotethys in the middle Permian. Kametaka et al. (2009) concluded that the radiolarian chert of the Gufeng Formation was deposited in an outer shelf environment under sulphate-reducing conditions. In this thesis, I obey these opinions.

6.1.2. The Bancheng Formation

Wang et al. (1995) deduced that the cherts of the Bancheng Formation were

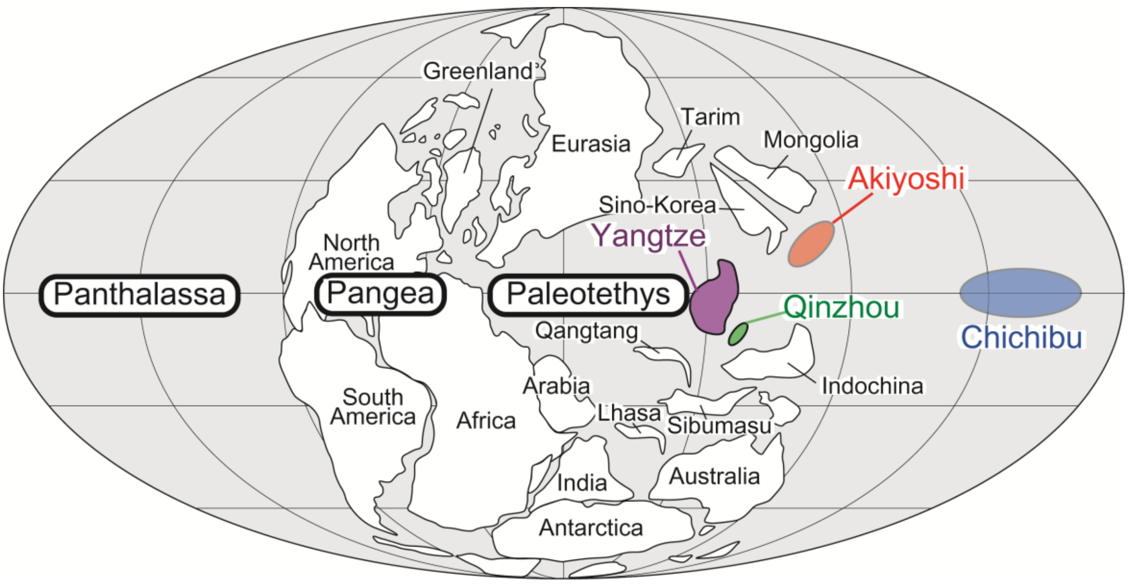

Figure 21. Paleogeography in middle Permian (modified from Tazawa, 2004).

deposited under a deep or bathyal sea with minor contribution of hydrothermal activity on the basis of the abundant siliceous fossils and absence of intense Ce anomaly. Wang and Jin (2000) determined from the lack of clastic influx that the Qinzhou allochthon was located hundreds of kilometers east of the South China Block, which supplied the clastic debris.

The proportion of siliceous microfossils from the Gujingling section is generally characterized by the dominance of radiolaria. The radiolarian assemblages of the section commonly consist of abundant Albaillellaria and spherical radiolaria with minor Latentifistularia and Entactinaria. The sponge spicules from the Gujingling section are composed of abundant monaxons and common triaxons with rare anatriaene and very rare polyaxons. The triaxons originate from hexactinellids; anatriaene originates from demosponges (Murchey, 2004). Hence, the sponge fauna consists mainly of hexactinellids with minor demosponges.

Murchey (2004) investigated the relationship between the fauna and proportion of siliceous microfossils from the siliceous rocks and divided the Phosphoria basin of western USA into the Eastern, Central and Western belts. The results showed that the fauna and proportion of radiolarians and sponges are well correlated with water depth. Beds in the Eastern belt deposited in a shallow basin are characterized by a high proportion of sponge spicules to radiolaria and dominant demosponge-derived sponge spicules such as rhax and strongyle. In contrast, the deeper Western belt shows a low ratio of sponge spicules to radiolarians and dominant hexactinellid-derived sponge spicules such as triaxons. The Central belt exhibits intermediate features between the Eastern and Western belts. The Bancheng Formation in the Gujingling section resembles the cherts and siliceous mudstones from the Western belt with characteristic low proportions of sponge spicules and dominant hexactinellid-derived sponge spicules. On the basis of the paleobathymetric model of spicule population in Murchey (2004), the minimum inferred paleobathymetric range of the Gujingling section is approximately 1000 m.

Wang and Jin (2000) speculated that the Qinzhou allochthon including the Bancheng Formation was located hundreds of kilometers east of the South China Block until the Guadalupian because its lithofacies do not include clastic rocks of continental origin. The siliceous siltstones from the Gujingling section are characterized by an inclusion of silt-sized quartz and no inclusion of sand-sized materials. The latter characteristic suggests that the Gujingling section was not formed near a continent. Silt-sized quartz grains can move several thousand kilometers as eolian dust in a Cenozoic ocean. Okamoto et al. (2002) discovered quartz from the Pleistocene deep-sea sediment core in the Hess Rise in the central North Pacific. They compared the grain size distribution of quartz from the core with that from the Chinese Loess Plateau. They concluded that the quartz moved as eolian dust from the Chinese Loess Plateau positioned several thousand kilometers from the core. Therefore, the silt-sized quartz in the section may originate from a continent as eolian dust. These results suggest that the Bancheng Formation in the Gujingling section was located at least a few hundred kilometers from the South China Block in the Middle Permian, which supports the speculation of Wang and Jin (2000).

In summary, the Bancheng Formation in the Gujingling section was deposited in a basin deeper than 1000 m which was located at least a few hundred kilometers from the Yangtze block in the Middle Permian.

6.1.3. Yoshii Group

The accretion cite of the Akiyoshi terrane has been debated for years. Kobayashi (1999) speculated that it was accreted at the east margin of the Yangtze block o the basis of foraminiferan fauna. Meanwhile, Tazawa et al. (2009) concluded that it was accreted at the east margin of the Indo-China block that is based on brachiopod fauna. In this thesis, I obey the opinion of Tazawa et al. (2009). The youngest radiolarians from muddy rocks of the Akiyoshi terrane were the *Pseudoalbaillella longtanensis* to *F. scholasticus-F. ventricosus* assemblage-zones (Fig. 3.B). In general, age of muddy rocks in CCS border on that just before accretion. Therefore, the Akiyoshi terrane was assumedly accreted in middle Middle to early Late Permian. In the modern ocean, plate velocity is generally several cm/year (e.g., Crough, 1983). Hence, the Akiyoshi terrane was located a few hundred kilometers from the Indo-China block in the Middle Permian.

Sano and Kanmera (1988) concluded that radiolarian-bearing cherts of the Akiyoshi terrane were deposited on an ocean floor. I have never observed clastics from cherts of the Yoshii Group, supporting this conclusion.

6.2. Radiolarian faunal comparison

6.2.1. Comparison between the Gufeng and Bancheng formations

As mentioned in the previous chapter, I recognized the *Pseudoalbaillella fusiformis-Pseudoalbaillella monacanthus* lineage. Additionally, the upper Gufeng Formation corresponding to the *F. scholasticus-F. ventricosus* zone are characterized by lower diversity and poorer preservation than the lower Gufeng Formation that corresponds to *Pseudoalbaillella fusiformis* Zone (e.g., Kametaka et al., 2009; chapter 4.1). Therefore, I use the uppermost part of the *Pseudoalbaillella fusiformis* Zone for the quantitatively comparison in this chapter (Fig. 22).

The differences of radiolarian occurrences between the Liuhuang and Gujingling sections are as follows. *Longtanella* commonly occurred from the Gufeng Formation of the Liuhuang section, while no *Longtanella* occurred from the Bancheng Formation. In contrast, no *Pseudotormentus* were obtained from the Gufeng Formation; that abundantly occurred from the Bancheng Formation.

Matsuoka (2000) proposed VEN (*Vallupus* (V) / *Eucyrtidiellum* (E) Number = V/(V+E)×100) as one of paleoceanographic parameter which indicates a tropical environment. I use the same idea to show the ratio of *Quadriremis* and *Pseudotormentus*. I propose PQN (*Pseudotormentus* (P) / *Quadriremis* (Q) Number = P/(P+Q)×100). The PQEs of all analyzed samples from the Liuhuang section are 0. The PQEs of all analyzed samples from the Gujingling section are 75 to 93. The Gujingling section showed a significantly lower QPE than the Liuhuang section (Table 2).

Age		Radiolarian zone (Ishiga, 1986, 1990)	Liuhuang section (Gufeng Fm.)	Gujingling section (Bancheng Fm.)
Permian	Lopingia	*N. optima*		
		N. ornithoformis		
		F. charveti- A. yamakitai		
	Guadalupian	*F. ventrocosus- F. scholasticus*	*R. uralicus*	*F. porrectus*
		F. monacanthus	*Pseudoalbaillella monacanthus*	*Pseudoalbaillella monacanthus*
		P. globosa	*Pseudoalbaillella fusiformis*	*Pseudoalbaillella fusiformis*
	Cisralian	*P. longtanensis*		
		A. sinuata		
		P. rhombothoracata		
		P. lomentaria		
		P. u-forma m. II		

Figure 22. Radiolarian biostratigraphical correlation between the Liuhuang and Gujingling sections.

6.2.2. Morphological characteristics of Pseudotormentus and Quadriremis

Quadriremis Nazarov and Ormiston, 1985 is defined by the following diagnosis: "Latentifistulidae with internal framework forming a nonporous sphere with four hollow rays. Three rays usually emerging from sphere at 120' with fourth ray perpendicular to that grouping. Internal framework enclosed in platy, platy- latticed or, rarely, a spongy shell. Terminal spines connected with rays of internal framework by thin rods" (Nazarov and Ormiston, 1985). O'Dogherty (2009) regarded *Nazarovella* De Wever and Caridroit, 1984 and *Raciditor* Sugiyama, 2000 as a synonym of *Quadriremis*. *Pseudotormentus* De Wever and Caridroit, 1984 is defined by the following diagnosis: "Latentifistulidae with three coplanar rays. The rays are made up of single hollow tubes proximally; distally, they are surrounded by a meshwork. This meshwork is built with 6–8 longitudinal beams joined by transverse bars. This meshwork evokes that of Hagiastridae" (Caridroit and De Wever, 1986: original description was written by French in De Wever and Caridroit (1984)).

Pseudotormentus and *Quadriremis* have similar forms and size. Although *Quadriremis* has four rays, fourth ray is short and extend perpendicularly to other three rays. These similarities indicate that these species assumedly had been undergone similar taphonomy. In other words, the ratios of these radiolarians may show more primary composition in the paleocean.

6.3. Radiolarian distribution in paleocean

6.3.1. Provincial boundary

The quantitative comparison shows that the ratio of *Pseudotormentus* and *Quadriremis* characterize radiolarian componential differences between the Liuhuang and Gujingling section. Additionally, the ratio of *Longtanella* and *Pseudoalbaillella* also characterize the radiolarian componential differences in the upper *Pseudoalbaillella fusiformis* Zone between the Liuhuang and Gujingling section. It is thought that the faunal differences occurred as a result of various factors overlapping. In the Middle Permian, the Gufeng Formation had been deposited on the Yangtze block and located in the east end of the Paleotethys; the Bancheng Formation had been deposited on ocean floor positioned at least a few hundred kilometers from the Yangtze block and placed in the west end of the Panthalassa (Fig. 21: chapter 6.1).

The Liuhuang and Gujingling sections had been deposited in different oceans, suggesting that the faunal differences are caused by influences from the oceans. In this case, the faunal difference naturally indicates that a boundary or transitional zones among the influential oceanic basins was located between the Gufeng and Bancheng formations (Fig. 23). This indication implies the radiolarian faunal differences between the Gufeng and Bancheng formations may represent wider distributed provinces, such as the Panthalassa and Paleotethys provinces.

6.3.2. Radiolarian componential comparison in middle Permian

I compare the radiolarian components among several geological units on the basis of previous occurrence reports in addition to the quantitative comparison. As the result of the comparison, I recognized the following characters (Fig. 24). Some taxa, such as *Pseudoalbaillella*, *Hegleria*, Latentifistularia, and Entactinaria, commonly occur from all units. Meanwhile some of other taxa occur from limited units. *Longtanella* had commonly occurred from the Gufeng Formation in the Yangtze region (e.g., this study; Sheng and Wang, 1985) whereas it has never been observed from the accretionary complexes in Japan. *Pseudotormentus* had commonly occurred from the Qinzhou allochthon (this study) and the accretionary complexes in Japan (e.g., Ishiga et al., 1986; Hori, 2004b). However it had barely occurred from the Gufeng Formation (Kametaka et al., 2009). *Cauletella* had commonly occurred from the accretionary complexes in Japan, such as the Akiyoshi terrane (e.g., this study; Ishiga et al., 1986) and the Chichibu composite terrane (e.g., Hori, 2004b), while it has never been observed from the Gufeng Formation and the Qinzhou allochthon.

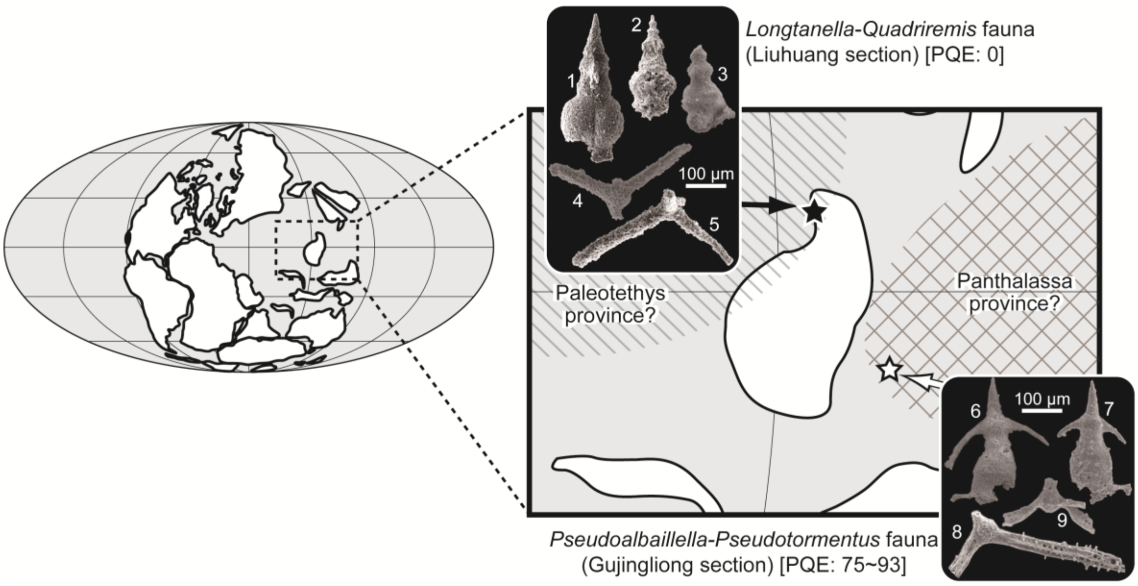

Figure 23. Suggested radiolarian paleobiogeography in the early Middle Permian (*Pseudoalbaillella fusiformis* Zone).

These results are consistent with the result of the quantitative analysis. Moreover, these results support the above mentioned implication that the radiolarian faunal differences between the Gufeng and Bancheng formations may represent wider distributed provinces.

According to Mei and Henderson (2001), the conodont provincialism had been established from the Kungurian (middle Lower Permian) to the end of Permian. The result of this study indicates that the radiolarian provincialism had been also established at least in the Middle Permian. Mei and Henderson (2001) pointed out the provincial reduction from Middle to Late Permian caused by global environmental change. Shen et al. (2009) showed the provincial reduction of brachiopod from Middle to Late Permian. They speculated that the global regression at the end-Guadalupian caused the reduction of brachiopod provincialism.

Some researchers have recognized provincial change in Permian of several taxa. These taxa, such as brachiopod and fusulina, are not holoplanktonic but radiolaria is. The present study showed middle Permian radiolarian provincialism. Further studies which focus on late Permian radiolarian provincialism and comparison among them should contribute to clarifying Permian environmental change.

6.3.3. Radiolarian componential comparison in late Permian

Late Permian radiolarians have occurred from several areas. Although *Quadriremis* has occurred from the uppermost Permian in the Yangtze block which had fronted Paleotethys, *Pseudotormentus* has not occurred from there (e.g., Feng et al., 2007; He et al., 2007, 2008, 2011). *Pseudotormentus* has occurred from the Tamba-Mino-Ashio terrane (e.g., Kuwahara and Yao, 1998). Sashida and Salyapongse (2002) reported

	radiolarian taxa	Yangtze platform (Gufeng Fm.)	Qingzhou block (Bancheng Fm.)	Akiyoshi terrane (e.g. Yoshii Gr.)	Chichibu C. T. &Tamba-Mino-Ashio terrane
Pseudoalbaillella fusiformis	*Pseudoalbaillella*	common	common	common	common
	Hegleria	common	common	common	common
	Longtanella	common	rare	-	-
	Pseudotormentus	rare	common	common	common
	Cauletella	-	-	common	common
	Latentifistularia	common	common	common	common
	Entactinaria	common	common	common	common

Figure 24. Componential comparison of radiolarian faunas.

Quadriremis with *F. porrectus* from Thailand; Sashida et al. (2000a, b) had found *Quadriremis* from the *Neoalbaillella optima* Zone in Thailand. These radiolarian-bearing strata in Thailand had been deposited in pelagic to hemi-pelagic basins in the Paleotethys (Sashida and Salyapongse, 2002). Sashida et al. (1995) found *Quadriremis* and *Pseudotormentus* from the *Neoalbaillella ornithoformis* Zone in Malaysia. However, the specimen described as *Pseudotormentus* sp. (Fig. 11.14 in Sashida et al., 1995) is poorly preserved and characteristic structure cannot be observed. Blome and Reed (1995) reported *Quadriremis* and *Pseudotormentus* from the *Neoalbaillella ornithoformis* Zone in U.S.A. The compiled map is shown in Fig. 25. These occurrences imply that radiolarian provincialism had remained until late Permian.

Middle Permian radiolarians have also occurred from other strata that had been deposited in the central to east Paleotethys, such as Thailand (e.g., Sashida et al., 1993a, b; Sashida and Salyapongse, 2002), Malaysia (e.g., Sashida et al., 1995), and Oman (De Wever et al., 1988). Further studies which focus on the above mentioned key radiolarians from these strata should provide surer grounds.

6.3.4. Cause for the radiolarian componential differences

As mentioned above, various factors, such as ocean area and water-depth, overlap and cause a faunal difference. The distribution of *Pseudotormentus* and *Quadriremis* in late Permian seems to be controlled by the differences of the oceanic basins, Panthalassa

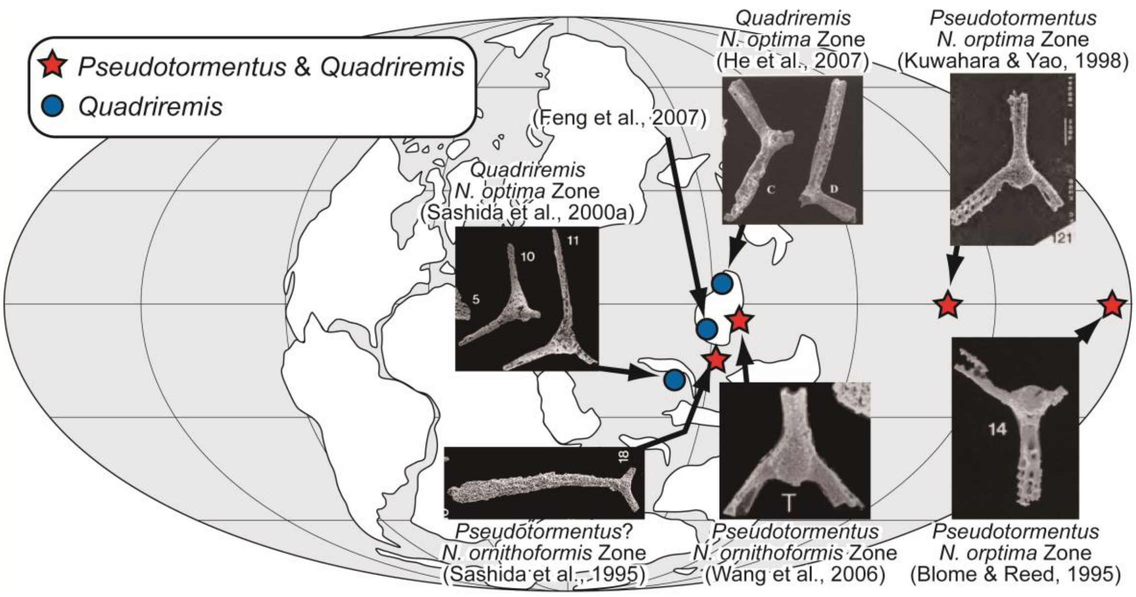

Figure 25. Occurrences of *Pseudotormentus* and *Quadriremis* in the Late Permian.

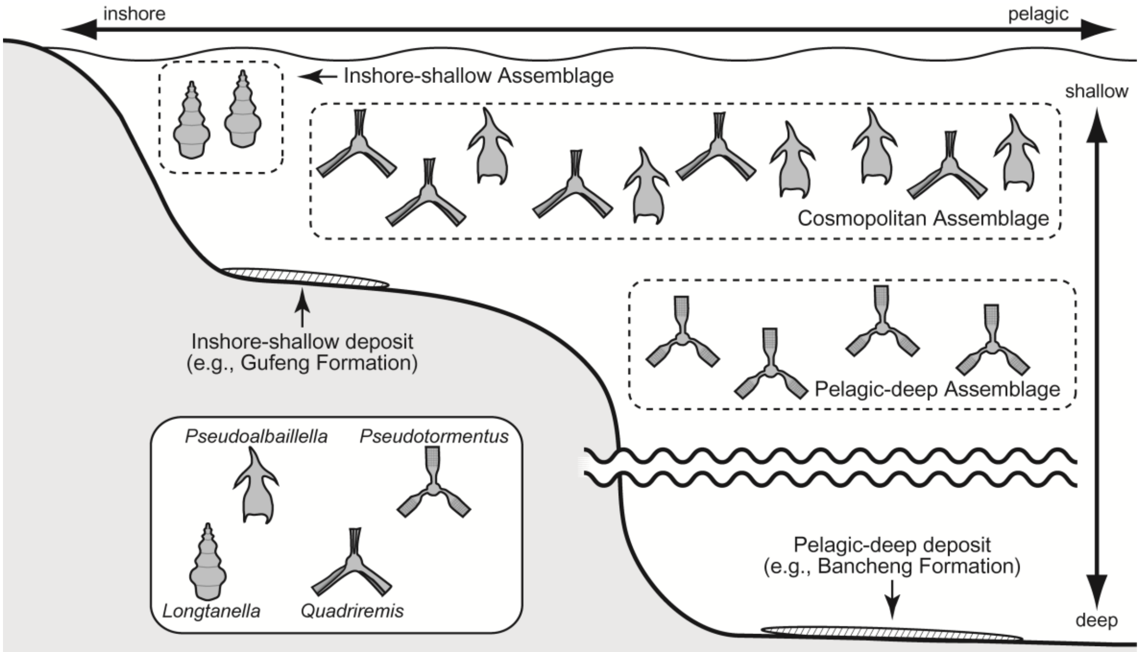

Figure 26. Simplified model of radiolarian distribution in the early Middle Permian (*Pseudoalbaillella fusiformis* Zone) paleocean.

and Paleotethys. Boltovskoy et al. (2010) compiled the recent radiolarian distribution data from plankton and sediment trap samples. Some radiolarians (e.g., *Pterocanium korotnevi* Dogiel; *Haeckeliella macrodoras* (Haeckel)) inhabit only the Pacific Ocean based on their data. *Pseudotormentus* may be the species characterized by inhabitation in large ocean like these species.

Meanwhile, their sedimentary environments have different depth (chapter 6.1). Some researchers had examined the utility of Permian radiolaria as an indicator of paleo-depth (e.g., Kozur, 1993; Kuwahara, 1999). However, they used higher taxonomic composition for the examinations. Itaki (2003) discovered shallow and deep assemblages from living radiolarians and fossil ones in Quaternary in the Japan Sea. According to his data, higher taxonomic composition does not always indicate paleo-depth. However, some species show habitat separation by depth. In the present study, I recognized lower taxonomic componential differences between the Liuhuang and Gujingling sections. These differences might indicate the paleo-depth distinctions (Fig. 26).

6.3.5. Applicative research on post-Permian strata

Mesozoic and Cenozoic strata that include Permian-radiolarian-bearing-clasts are distributed in Japan (e.g., Kashiwagi, 2012; Ito et al., 2012). Radiolarians from clasts should provide the information of the denudation and exhumation histories of a geologic unit which supplied those clasts (Appendix C). In this thesis, I showed Permian radiolarian faunal differences among geological units. These differences likely contribute to clarifying their origin. Future studies of Permian radiolarians from those clasts might provide a better understanding of the late Mesozoic tectonic frame in East Asia.

7. Conclusion

1. Late Paleozoic chert within Permian and Jurassic accretionary complexes in southwest Japan (Akiyoshi, Tamba-Mino-Ashio, and Chichibu composite terranes) has the following occurrence biases. The Upper Carboniferous to the Lower Permian cherts are small amount in the Tamba-Mino-Ashio and Chichibu composite terranes, while the middle Middle to Upper Permian cherts are large amount. The largest amount of cherts in the Akiyoshi terrane is the upper Lower Permian.
2. Three radiolarian assemblages, namely *Pseudoalbaillella fusiformis*, *Pseudoalbaillella monacanthus*, and *Ruzhencevispongus uralicus*, were recognized at the Gufeng Formation in the Liuhuang section. Three assemblage zones, namely *Pseudoalbaillella fusiformis*, *Pseudoalbaillella monacanthus*, and *Follicucullus porrectus-F. scholasticus*, were recognized at the Bancheng Formation of the Gujingling section, in Xiaodong, China. Three radiolarian zones, *Albaillella sinuata*, *Pseudoalbaillella globosa*, and *Pseudoalbaillella monacanthus*, were recognized in the Yoshii Group in the Yoshii area, southwest Japan.
4. The *Pseudoalbaillella fusiformis-Pseudoalbaillella monacanthus* lineage was recognized at the subsections 3–6 of the Gujingling section on the basis of morphological characteristics and occurrence change.
5. Fossil compositions and petrological characteristics of the Gujingling section indicate that the Bancheng Formation was deposited in a basin deeper than 1000 m which was located at least a few hundred kilometers from the Yangtze block in the Middle Permian.
6. Quantitative analysis shows the following results. No *Pseudotormentus* was obtained from the Liuhuang section, while it abundantly occurred from the Gujingling section; *Longtanella* commonly occurred from the *Pseudoalbaillella fusiformis* Zone in the Liuhuang section, but no *Longtanella* occurred from the Gujingling section. *Quadriremis*, *Pseudoalbaillella*, and some taxa occurred from the both sections.
7. *Pseudotormentus* and *Quadriremis* have similar forms and size. This indicates that these species assumedly had been undergone similar taphonomy. In other words, the ratios of these radiolarians may show more primary composition in the paleocean.
8. The Liuhuang and Gujingling sections had been deposited in different oceans. This suggests that the faunal differences are caused by influences from the oceans.
9. The comparison based on reviews showed the following characters. Although some taxa commonly occur from all units, some of other taxa occur from limited units.

Longtanella had commonly occurred from the Gufeng Formation, while it has never been observed from the accretionary complexes in Japan. *Pseudotormentus* had commonly occurred from the Qinzhou allochthon and the accretionary complexes in Japan however it had barely occurred from the Gufeng Formation. *Cauletella* had commonly occurred from the accretionary complexes in Japan, such as the Akiyoshi terrane and the Chichibu composite terrane, while it has never been observed from the Gufeng Formation and the Qinzhou allochthon.

9. The results from the reviews are consistent with the result of the quantitative analysis and imply that the radiolarian faunal differences between the Gufeng and Bancheng formations possibly represent wider distributed provinces.
10. *Pseudotormentus* has occurred mainly from the Panthalassa, while *Quadriremis* has occurred from both the Panthalassa and Paleotethys in the Late Permian. These occurrences imply that radiolarian provincialism, uneven distribution of *Pseudotormentus*, had remained until the late Permian.
11. The Gufeng and Bancheng Formation had been deposited in different depth, indicating the possibility that the faunal difference was caused by paleo-depth distinctions.

8. Acknowledgements

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Appendix A: Permian colonial radiolarians from South China and their phylogeny

Abstract

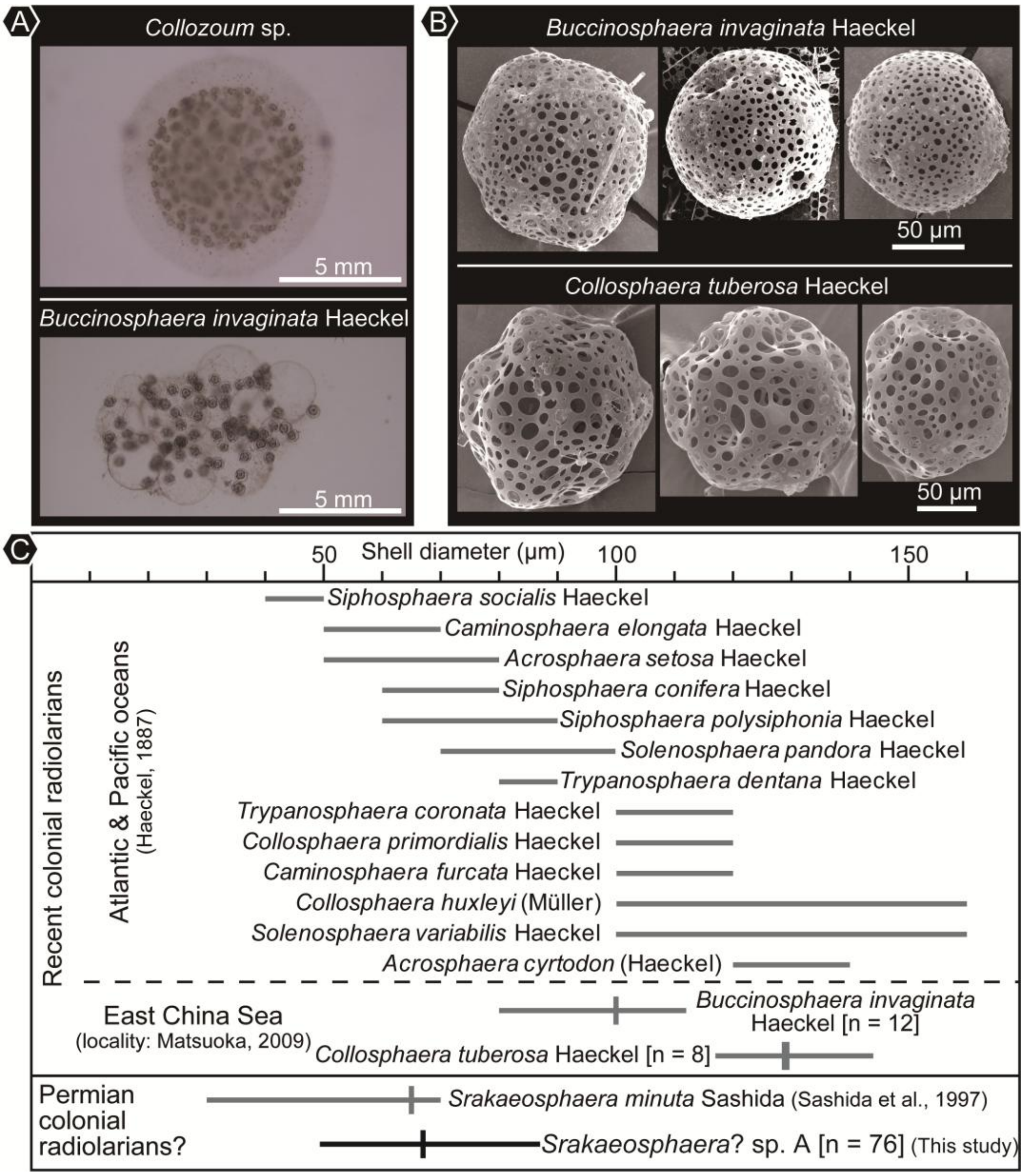
***Srakaeosphaera*? sp. A, discovered from the Upper Permian of the Yutouling section in the Xiaodong area, Guangxi Zhuang Autonomous Region, South China, is characterized by small spherical shells with porous surfaces. The shells are morphologically similar to those of recent colonial radiolarians. Additionally, the shells of *Srakaeosphaera*? sp. A are combined to form aggregations. The morphological similarities and formation of aggregations suggest that this species is a colonial radiolarian. However, this species is ca. 200 myr older than previous occurrences of evident colonial radiolarians from the Eocene. It is believed that colonial radiolarians live exclusively on symbiotic algae, based on previous observations of living examples. Therefore, it is plausible to suggest that *Srakaeosphaera*? sp. A has symbionts, which would indicate that the origin of symbiont-bearing radiolarians dates back to at least the Permian. On this basis, we suggest that this is the oldest known example of symbiont-bearing radiolarians.**

1. Introduction

Radiolarians, a type of marine amoeboid protozoa, have colonial and solitary mode of life. Recent colonial radiolarians are characterized by possession of a gelatinous mass with numerous cells (Fig. A-1.A). Family Collozoidae Haeckel has no shell or scattered spicules in a gelatinous sheath, while Family Collosphaeridae Müller has shells characterized by a single-layered thin-walled structure, spherical or oval–spherical shape, and porous surface (e.g., Haeckel, 1887; Anderson et al., 2002) (Fig. A-1.B). Most recent colonial radiolarians have shells smaller than 150 μm in diameter (Fig. A-1.C).

Living colonial radiolarians have symbiotic algae and inhabit shallow water in oligotrophic open oceans (e.g., Swanberg, 1983; Boltovskoy et al., 2010; Suzuki et al., 2012); therefore, colonial radiolarians, which employ symbiotic strategies, presumably play fundamental roles in marine ecosystems. However, there has been little discussion to date of colonial and symbiont-bearing radiolarians in the fossil record. Although Cenozoic colonial radiolarian fossils have been reported by several researchers (e.g., Holdsworth and Harker, 1975; Knoll and Johnson, 1975; Goll, 1980), there has been only one report of pre-Cenozoic colonial radiolarians in the fossil record: Sashida et al. (1994) highlighted the possibility that small spherical radiolarians (described as *Srakaeosphaera minuta* Sashida by Sashida et al., 1997) from the Permian are colonial.

Here, we report *Srakaeosphaera*? sp. A from the Upper Permian of the Yutouling section in the Xiaodong area, Guangxi Zhuang Autonomous Region, South China. This species is characterized by small spherical shells with porous surfaces, similar to features noted in recent colonial radiolarians. Moreover, these shells are combined to form aggregations. The morphological similarities and the formation of aggregations suggest that this species is a colonial radiolarian. Therefore, we here discuss the phylogeny of colonial radiolarians and the origin of symbionts in radiolarians.



2. Study section

The Ordovician to Upper Permian radiolarian-bearing siliceous rock strata included in the Qinzhou allochthon are distributed throughout the Qinzhou basin, South China (Wang and Jin, 2000) (Fig. A-2.A, B). Previously, Permian radiolarians have been shown to occur in this area (e.g., Wang et al., 2006, 2012). The Yutouling section (22°11.961′ N, 108°36.929′ E), situated 2 km southwest of Xiaodong in Guangxi Zhuang Autonomous Region, China, outcrops along the southeast side of the Nanning–Beihai railway (Fig. A-2.C). This section is composed primarily of red to yellow-red silty cherts with minor tuff, tuffaceous siltstone, and siltstone (Fig. A-2.D).

We collected 103 siliceous rock samples from the section. Some albaillellarians that are characteristic species of the Lopingian (Upper Permian), such as *Albaillella cavitata* Kuwahara and *Albaillella protolevis* Kuwahara, occur in the section. The lower part of the section corresponds to the *Follicucullus charveti*–*Albaillella yamakitai* Assemblage Zone in southwest Japan (Kuwahara et al., 1998); the upper part of the section corresponds to the *Neoalbaillella ornithoformis* Assemblage Zone. *Srakaeosphaera*? sp. A which is studied in this paper was obtained from one horizon (sample YTL-3-2) of the *Follicucullus charveti*–*Albaillella yamakitai* Assemblage Zone and four horizons (samples YTL-4-2, YTL-5-10, YTL-5-14, YTL-6-7) of the *Neoalbaillella ornithoformis* Assemblage Zone.

Figure A-1. A: Photomicrographs of colonies of *Collozoum* sp. (sample 20040429) and *Buccinosphaera invaginata* Haeckel (sample 20020310) collected using a 44-µm opening plankton net from a research vessel at a site about 3 km south of the Sesoko Station in Motobu Town, Okinawa, Japan (detailed localities and collection methods are the same as those of Matsuoka, 2009). B: Photomicrographs of individual shells of *Buccinosphaera invaginata* and *Collosphaera tuberosa* (Haeckel) from sample 20041104_11Sesoko. C: distributions of shell diameter of major recent colonial radiolarians, *Srakaeosphaera minuta* Sashida, and *Srakaeosphaera*? sp. A. The diameters of *Buccinosphaera invaginata* and *Collosphaera tuberosa* are based on specimens of sample 20041104_11Sesoko. Those of other recent colonial radiolarians are after Haeckel (1887); the diameter of *Srakaeosphaera minuta* is after Sashida et al. (1997), and that of *Srakaeosphaera*? sp. A is based on specimens from the Yutouling section of this study.

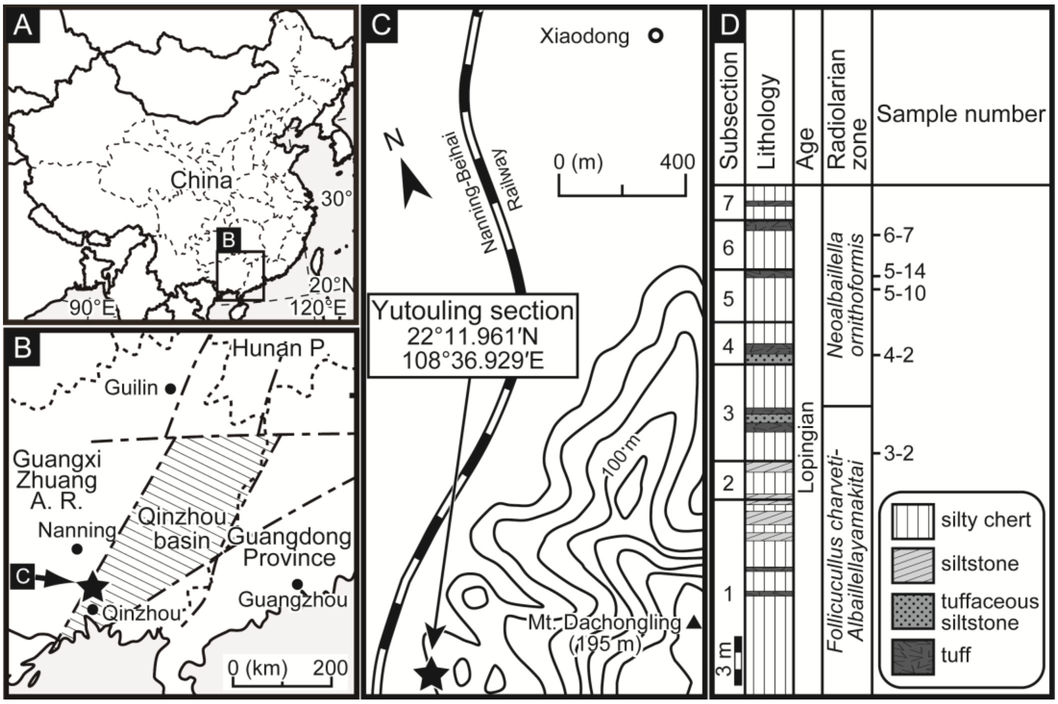


Figure A-2. Index map and columnar section of the Yutouling section.

3. Description of radiolarians and morphological comparison

Shells of *Srakaeosphaera*? sp. A are spherical and have porous surfaces (Figs. A-3.1, A-3.2 and A-3.4–A-3.6). The shells are 49 μm to 87 μm in diameter, based on the measurement of 17 specimens (four isolated shells and 72 shells included in 13 aggregations); the average diameter is 67 μm. Although *Srakaeosphaera minuta*, the type species of the genus, has a multilayered concentric shell (Sashida et al., 1997), no inner structure of *Srakaeosphaera*? sp. A is observable. Combined shells of *Srakaeosphaera*? sp. A form an aggregation composed shells of approximately the same size (Figs. A-3.6–A-3.14). Spherical to oval–spherical aggregations consist of more than 10 shells (Figs. A-3.7, A-3.9, and A-3.15). Combined shells lie in a single stratum on the surface of a hollow aggregation (Fig. A-3.15). Some broken aggregations and shells separated from aggregations are observed (Figs. A-3.3, A-3.8, and A-3.10–A-3.14).

Recent shell-bearing colonial radiolarians (Family Collosphaeridae) exhibit the following shell morphological characteristics: single-layered, thin-walled, spherical or oval–spherical, and latticed (e.g., Anderson et al., 2002), such as *Buccinosphaera invaginata* Haeckel and *Collosphaera tuberosa* (Haeckel) (Fig. A-1.B). Although the distribution of shell diameters of recent colonial radiolarians differs by species, most are smaller than 150 µm (Fig. A-1.C). We measured shell diameters of *Buccinosphaera invaginata* and *Collosphaera tuberosa* in our samples collected using a 44-µm opening plankton net from a research vessel at a site about 3 km south of the Sesoko Station in Motobu Town, Okinawa, Japan (detailed localities and collection methods are the same as those of Matsuoka, 2009). The shells of *Buccinosphaera invaginata* in our samples range from 80 µm to 112 µm in diameter; the average diameter is 100 µm. The shells of *Collosphaera tuberosa* from our samples range from 117 µm to 144 µm in diameter; the average diameter is 129 µm.

The following morphological characteristics of *Srakaeosphaera*? sp. A are similar to those of some recent colonial radiolarians: small spherical shells with porous surfaces. Meanwhile, although no inner structure of *Srakaeosphaera*? sp. A is observable, recent colonial radiolarians exhibit single-layered and thin-walled shells. The shells of *Srakaeosphaera*? sp. A are combined by direct contact, but recent colonial radiolarians tend not to exhibit combined shells by direct contact, instead existing as scattered shells in a gelatinous mass.

However, some recent spherical radiolarians have been shown to form combined shells (e.g., Haeckel, 1887; Itaki and Bjørklund, 2007). Itaki and Bjørklund (2007) concluded that combined radiolarians, such as *Actinomma leptoderma* (Jørgensen), formed as a result of reproduction by binary fission. These combined shells were reported to consist of only two or three individuals; however, aggregations of *Srakaeosphaera*? sp. A consist of more than 10 shells. Furthermore, the combined shells are of various sizes (Itaki and Bjørklund, 2007), while aggregations of *Srakaeosphaera*? sp. A are composed of shells of approximately the same size. Therefore, the aggregations of *Srakaeosphaera*? sp. A reported here are dissimilar enough that they are unlikely to have formed by binary fission.

4. Discussions

Few previous studies have discussed colonial radiolarians in the fossil record, particularly those from pre-Cenozoic sediments. However, Cenozoic colonial radiolarians that are connected phylogenetically to recent species have been reported from Eocene and younger sediments (e.g., Holdsworth and Harker, 1975; Knoll and Johnson, 1975; Goll, 1980). Sashida et al. (1994) discovered *Srakaeosphaera minuta* (described formally in Sashida et al., 1997), characterized by small spherical shells, in

Permian bedded cherts in the Sra Kaeo area, eastern Thailand. They highlighted the possibility that the species was a colonial radiolarian on the basis of its similarities to recent radiolarians in terms of shape and size. As shown in this study, *Srakaeosphaera*? sp. A forms aggregations consisting of several combined shells. The formation of aggregations, in addition to morphological similarities, strongly suggests that this species is a colonial radiolarian. This discovery extends the evident colonial radiolarian record into the Late Permian, that is, ca. 200 myr further back than the occurrences described in previous studies (Fig. A-4).

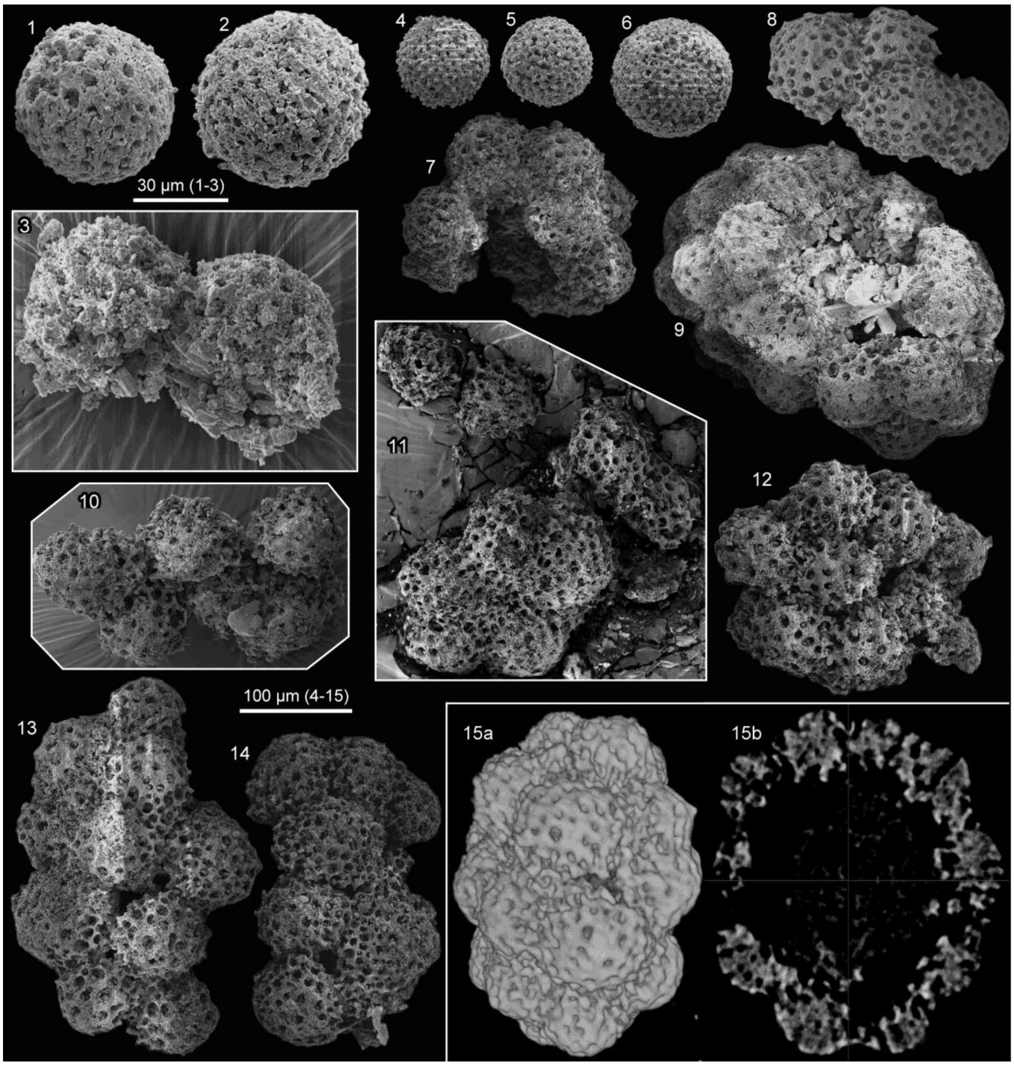


Figure A-3. Photomicrographs from scanning electron microscopy and three-dimensional computer graphics based on computed tomographic scan data of *Srakaeosphaera*? sp. A. 1–6: YTL-3-02; 7–15: YTL-4-02. 1, 2, 4–6: isolated shell. 3: combined shells by direct contact. 7, 9, 12: an aggregation of shells. 8, 10, 11, 13, 14: broken aggregation and shells separated from an aggregation. 15: outer shape (a) and inside view (b) of oval–spherical hollow aggregation from 3D data.

Recently, several researchers have discussed radiolarian evolution with respect to molecular phylogeny (e.g., Kunitomo et al., 2006; Ishitani et al., 2012). Kunitomo et al. (2006) showed that recent colonial radiolarians and nassellarians form a clade and deduced that they diverged between the Jurassic and Eocene. Meanwhile, the results of this study indicate the presence of Permian colonial radiolarians; this is inconsistent with the evolution described by Kunitomo et al. (2006). This inconsistency suggests that *Srakaeosphaera*? sp. A is not in the recent colonial radiolarian lineage but in another lineage. Some recent colonial radiolarians form colonies consisting of cells placed in one single stratum on the surface (e.g., *Sphaerozoum alveolatum* Haeckel; Haeckel, 1887), resembling aggregations of *Srakaeosphaera*? sp. A. However, these recent colonial radiolarians do not possess shells. The aggregations characterized by combined shells in a single stratum may represent the characteristic feature of this Permian lineage. To date, no Mesozoic colonial radiolarian fossil occurrences have been reported, but small spherical radiolarian assemblages have been found in the lowermost Triassic sediments (Kuwahara et al., 2010; Sano et al., 2012) and the Sphaeroids Zone has been delineated (Yao and Kuwahara, 1997; Yao, 2009). It may be that these also represent a colonial radiolarian lineage that is disconnected from the recent one.

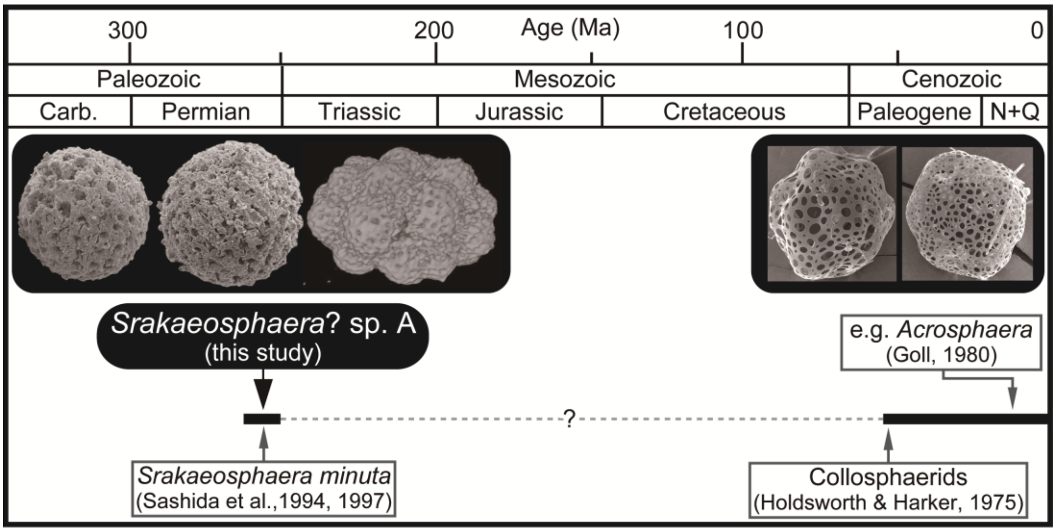


Figure A-4. Major occurrences of colonial radiolarians in the fossil record.

Matsuoka (2007) found a relationship between feeding behavior and shell morphology based on observation of living radiolarians, concluding that recent colonial radiolarians live exclusively on symbiotic algae because these radiolarians always contain symbionts in their colonies and their feeding behavior has never been observed. Recent colonial radiolarians have been shown to inhabit shallow water in oligotrophic open oceans (Swanberg, 1983; Boltovskoy et al., 2010; Suzuki et al., 2012). If *Srakaeosphaera*? sp. A is a colonial radiolarian, it too must presumably have symbionts. If this presumption holds true, it indicates that the origin of symbiont-bearing radiolarians dates back to at least the Permian. In contrast to radiolarians, previous researchers have noted symbiosis in Paleozoic larger benthic foraminiferans (e.g., BouDagher-Fadel, 2008; Vachard et al., 2010). It is believed that these larger foraminiferans housing symbionts had evolved around the middle to late Carboniferous (Vachard et al., 2004). However, no symbiont-bearing plankton has been reported from Paleozoic, although planktonic foraminiferans having symbionts occurred from the Mesozoic (e.g., Bornemann and Norris, 2007). Our presumption implies that symbiosis in both planktonic and benthic microorganisms had already established in the Permian paleocean.

5. Conclusions

Srakaeosphaera? sp. A is characterized by small spherical shells with porous surfaces that are morphologically similar to recent colonial radiolarian shells. Moreover, the shells of *Srakaeosphaera*? sp. A are combined to form aggregations. The morphological similarities and the formation of aggregations suggests that this species is a colonial radiolarian, that is, ca. 200 myr older than previous occurrences of evident colonial radiolarians from the Eocene. On the basis of previous observations of living examples, it is believed that colonial radiolarians live exclusively on symbiotic algae. Therefore, it is plausible to suggest that *Srakaeosphaera*? sp. A had symbionts, which would indicate that the origin of symbiont-bearing radiolarians dates back to at least the Permian.

In general, it is difficult to recognize symbionts in the fossil record. Here we have shown the origin of symbiosis in radiolarians on the basis of a comparison between living and fossil radiolarians. These kinds of the information are important in assessing conditions of paleocean, such as productivity and diversity. We expect that future comparative research will contribute to more detailed reconstruction of paleoceans based on the fossil record.

Appendix B: Swollen type of *Albaillella sinuata* (Early Permian radiolaria) from a chert boulder in Ie-jima Island, Okinawa Prefecture, Japan

Abstract

Early Permian radiolarians were occurred from a chert boulder within Pleistocene limestones in Ie-jima Island, Okinawa Prefecture, Japan. The upper and lower parts of the chert boulder are corresponded to the *Pseudoalbaillella rhombothoracata* Assemblage-Zone and the *Albaillella sinuata* Range-Zone in southwest Japan, respectively. Swollen type of *Albaillella sinuata* Ishiga and Watase are commonly occurred from one bed of the upper part. The ratios of typical swollen type and intermediate forms to the total population of *Albaillella sinuata* from the horizon are 27.1% and 13.6%, respectively. The morphological distribution of the species from the sample is characterized by the common occurrences of typical normal and swollen types with a few intermediate forms. The occurrence of swollen type of *Albaillella sinuata* has distributional differences among areas, like other Albaillellaria species.

1. Introduction

Albaillellaria (including *Albaillella* Deflandre, *Pseudoalbaillella* Holdsworth and Jones, *Follicucullus* Ormiston and Babcock and *Neoalbaillella* Takemura and Nakaseko) is a major index order among late Paleozoic radiolarians. Most of Upper Paleozoic radiolarian zones have been constructed on the basis of Albaillellaria occurrence (e.g., Ishiga, 1986a, 1990; Blome and Reed, 1995; Kuwahara et al., 1998; De Wever et al., 2001; Wang and Yang, 2011). Ishiga (1991) pointed out the dimorphism of Albaillellaria, divided into normal type and swollen type. The latter is characterized by having a strongly-swollen apical cone, pseudoabdomen or shell body as its name suggests. Ishiga (1991) examined the ratio of swollen and normal types with Permian Albaillellaria (*Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga and Imoto, *Pseudoalbaillella ornata* Ishiga and Imoto, *Pseudoalbaillella sakmarensis* (Kozur), *Pseudoalbaillella elongata* Ishiga and Imoto, *Pseudoalbaillella rhombothoracata* Ishiga, *Albaillella asymmetrica* Ishiga and Imoto, and *Neoalbaillella ornithoformis* Takemura and Nakaseko). He showed that the ratios of swollen type are different among these species. Wu et al. (2010) described swollen type of *Neoalbaillella* as a new species for a practical usage. There had been few illustrated specimens in literatures to show morphological variations of swollen type.

We obtained Early Permian radiolarian fossils from a chert boulder in Ie-jima Island, Okinawa Prefecture, Japan. Swollen type of *A. sinuata* Ishiga and Watase was commonly occurred from one bed of the boulder. Although the locality of the radiolarian occurrence in this study is probably the same as that in Ujiie and Ohba (1991), there were only two illustrated specimens of swollen type. Additionally, they did not describe it as swollen type of *A. sinuata* but as gen. et sp. indet. Xia and Zhang (1998) found swollen type of *A. sinuata* from the Gufeng Formation in South China. They described it as *A.* sp. aff. *A. sinuata*. In this chapter, we describe normal and swollen types of *A. sinuata* with photomicrographs to show its morphological distribution.

2. Geological setting

Ie-jima Island is situated about 9 km northwest of the Motobu Peninsula of Okinawa Island, Okinawa Prefecture, Japan (Fig. B-1). Most areas of Ie-jima Island are covered by Pleistocene limestones belonging to the Ryukyu Group except for Paleozoic-Mesozoic basement rocks exposed around the Mt. Gusuku-yama (Nakae et al., 2010). The Mt. Gusuku-yama, located at the center of Ie-jima Island, is composed of cherts ranging from the Late Permian to Late Jurassic in age (Shen et al., 1996). There are some red chert clasts at Waji in the north margin of Ie-jima Island (Fig. 1). Permian radiolarian occurrences had been reported from Waji (Ujiie and Ohba, 1991; Shen et al., 1996). Ujiie and Ohba (1991) recognized *A. sinuata*, *A.* sp., *Pseudoalbaillella* sp., *Follicucullus monacanthus* Ishiga and Imoto, *F. scholasticus* Ormiston and Babcock, *Latentifistula patagilaterala* Nazarov and Ormiston, *Hegleria* sp., *Quadriremis* sp. and gen. et sp. indet. (=swollen type of *A. sinuata*). Shen et al. (1996) found *A. triangularis* Ishiga, Kito and Imoto, *Entactinia modesta* Sashida and Tonishi, *Heiloentactinia* sp. and *Palaeoscenidium* sp. from some red cherts at Waji.

Red cherts at Waji are exposed as clasts within Pleistocene limestones belonging to the Ryukyu Group (Fig. B-2). The chert clasts in the conglomerates are scattered in the limestones (Figs. B-2.A, B-2.B). These clasts are not rounded but are irregular in shape. The rims of the chert clasts are intricately-shaped (Fig. B-2.C). The chert clasts vary in size ranging from several mm to about 6 m in diameter. We named the chert sequence in the biggest chert boulder in Waji as the Waji section (Fig. B-2.D). The Waji section is

480 cm in total thickness. The section consists of red cherts with intercalated claystone. The red cherts are well-bedded; few chert beds are amalgamated. The thicknesses in each bed of the red cherts are 4 mm to 115 mm; those of the intercalated claystone are 2 mm to 64 mm. The thickest part, where three beds are amalgamated, is 142 mm.

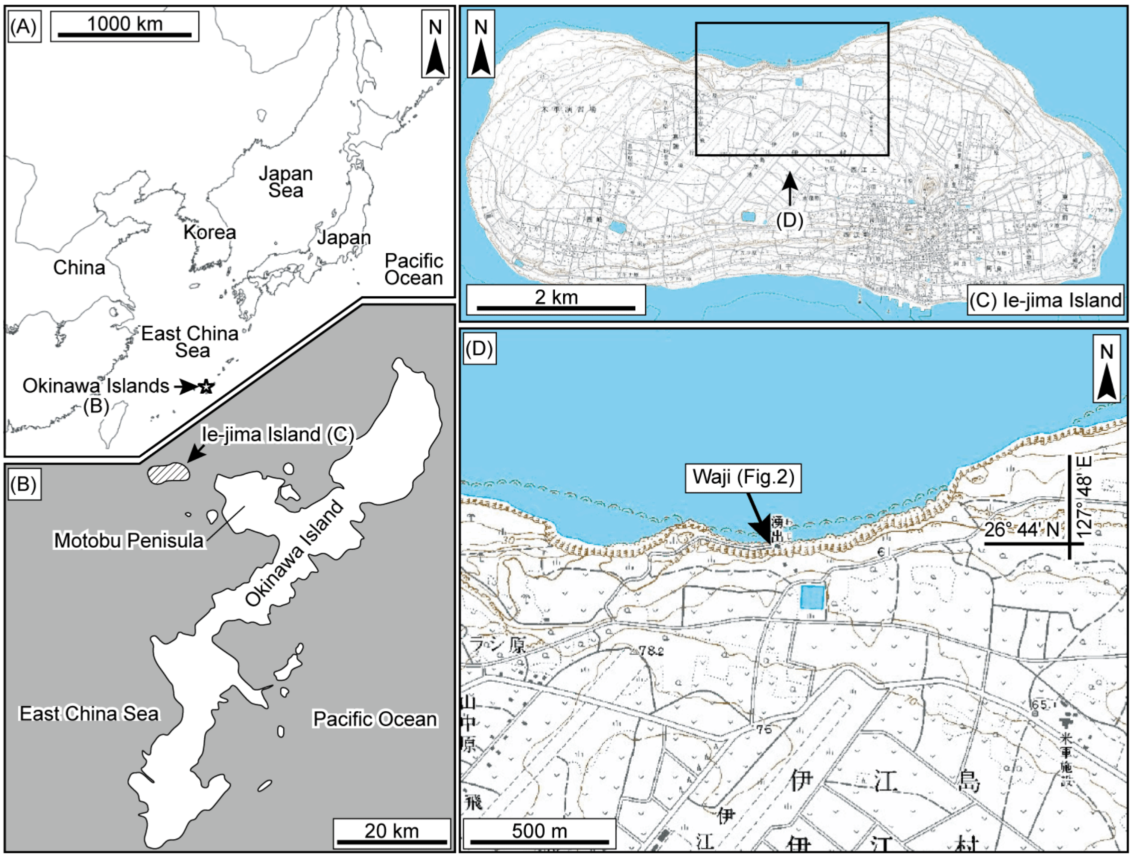


Figure B-1. Index map of Waji in Ie-jima Island, Okinawa prefecture, Japan. Maps C and D are from 1:50,000 topographic map "Ie-jima" published by Geospatial Information Authority of Japan.

3. Materials and Methods

Seven samples were collected from the Waji section. The samples were crushed, about 1 cm on a side, and fragments were soaked in an HF solution (about 5%) for 24 hours at room temperature. The used HF solutions were cleared out. The containers holding the etched samples were subsequently refilled with a new HF solution. After that, adequate residues were collected through a sieve with a mesh diameter of 0.054 mm and dried for examination under a binocular microscope. The well-preserved radiolarians were later mounted on stubs and photographed with a scanning electronic microscope (SEM) for more detailed observations.

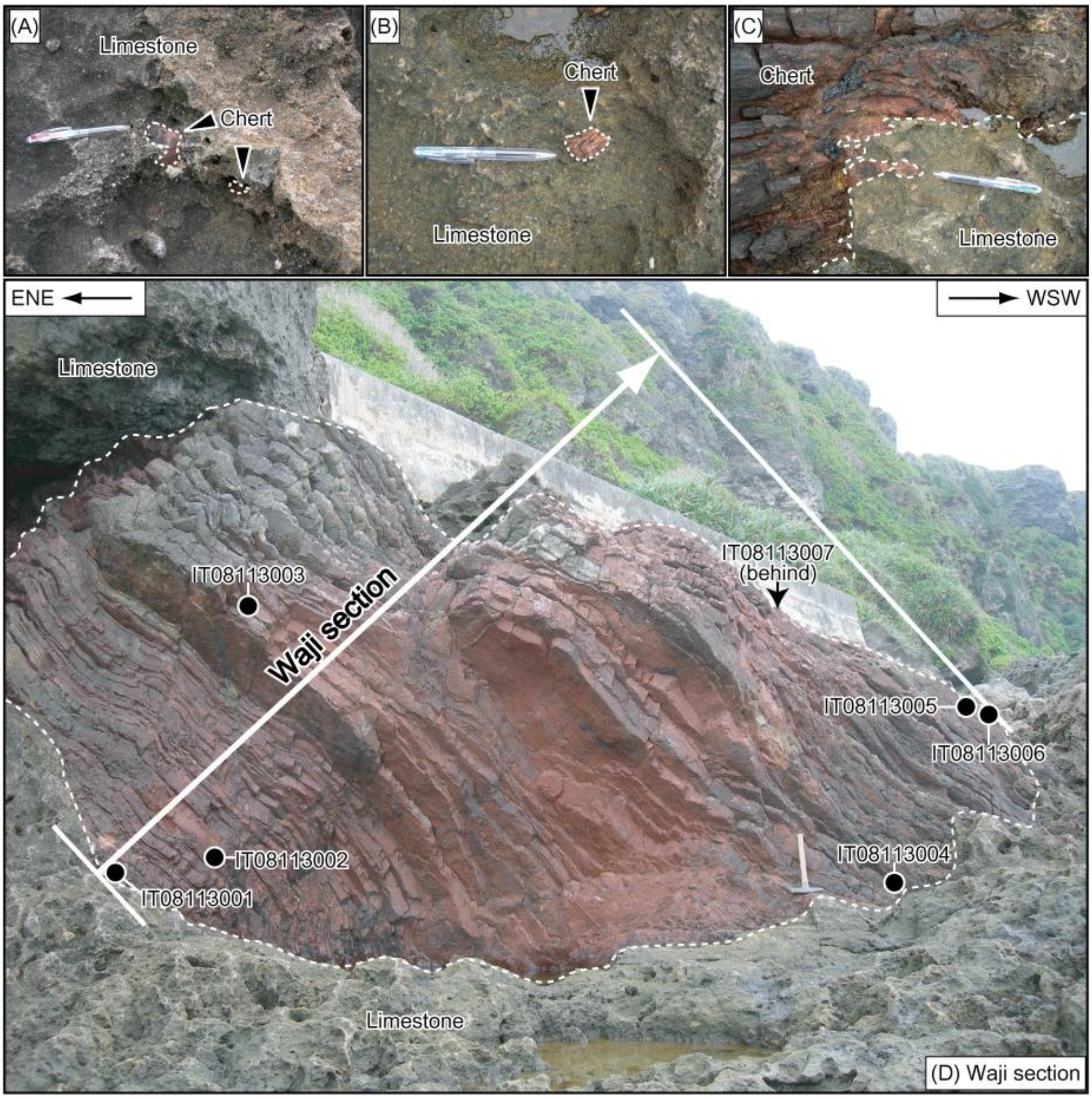


Figure B-2. Exposures of cherts in the Waji area. A, B: chert pebble in limestone. C: boundary between chert boulder and limestone matrix. D: overall view at Waji.

4. Radiolarian assemblages

Figure B-3 shows the radiolarian distribution in the Waji section. Photomicrographs of selected specimens are shown in Figs. B-4 and B-5. We divided the section into the upper and lower parts on the basis of radiolarian assemblages. The radiolarian assemblage of the lower part consists of *Pseudoalbaillella postscalprata* Ishiga, *A. asymmetrica*, *A.* sp., *L.* sp., *Hegleria mammilla* (Sheng and Wang), *Pseudotormentus kamigoriensis* (Caridroit and De Wever), *Triaenosphaera* sp., *Entactinia itsukaichiensis*

Sashida and Tonishi, and *Entactinia*? sp. The lower part corresponds to the *Pseudoalbaillella scalprata* m. *rhombothoracata* Assemblage-Zone in southwest Japan of Ishiga (1986a, 1990). We rename this *Pseudoalbaillella scalprata* m. *rhombothoracata* Assemblage-Zone as the *Pseudoalbaillella rhombothoracata* Assemblage-Zone according to re-description of *Pseudoalbaillella rhombothoracata* by Shimakawa and Yao (2006). The radiolarian assemblage of the upper part is composed of *A. sinuata*, swollen type of *A. sinuata*, *A.* sp., *Pseudoalbaillella longtanensis* (Sheng and Wang), *L. texana* Nazarov and Ormiston, *L.* sp., *Hegleria mammilla*, *Quadricaulis inflata* (Sashida and Tonishi), *Pseudotormentus kamigoriensis*, *T.* sp., *E. itsukaichiensis*, and *Entactinia*? sp. The upper part corresponds to the *Albaillella sinuata* Range-Zone in southwest Japan of Ishiga (1986a, 1990).

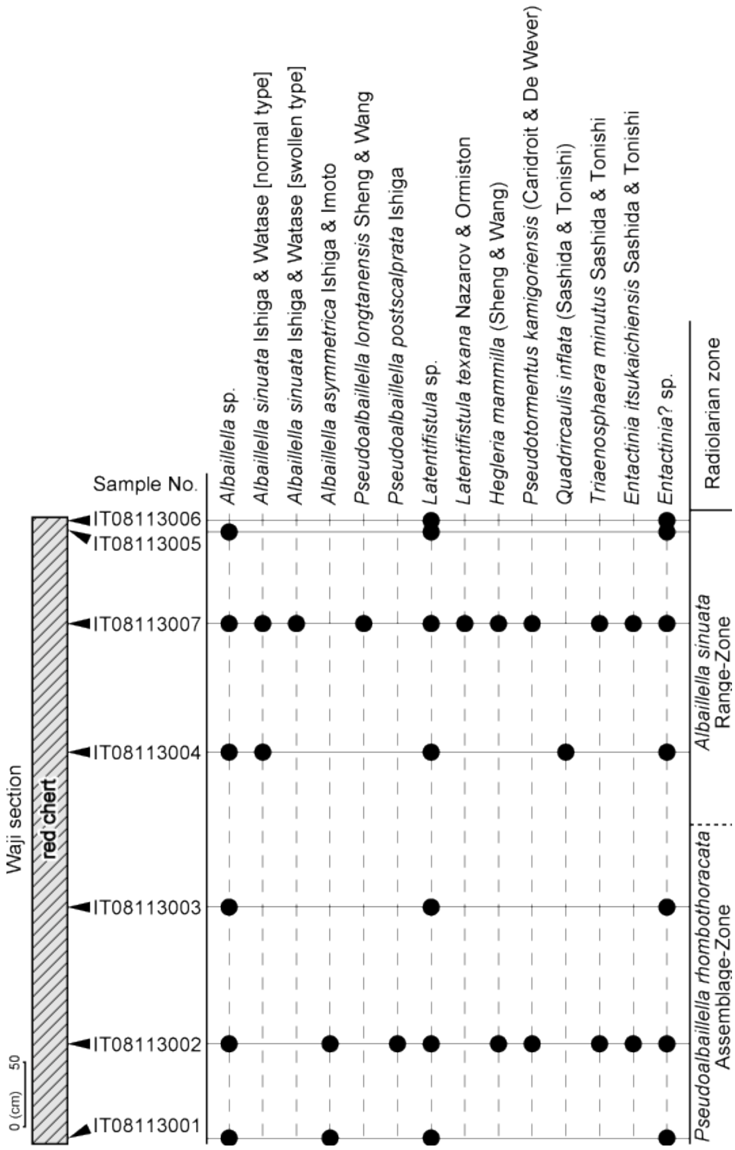


Figure B-3. Lithological columnar section and radiolarian distribution in the Waji section.

White part: chert bed; black part: intercalated claystone.

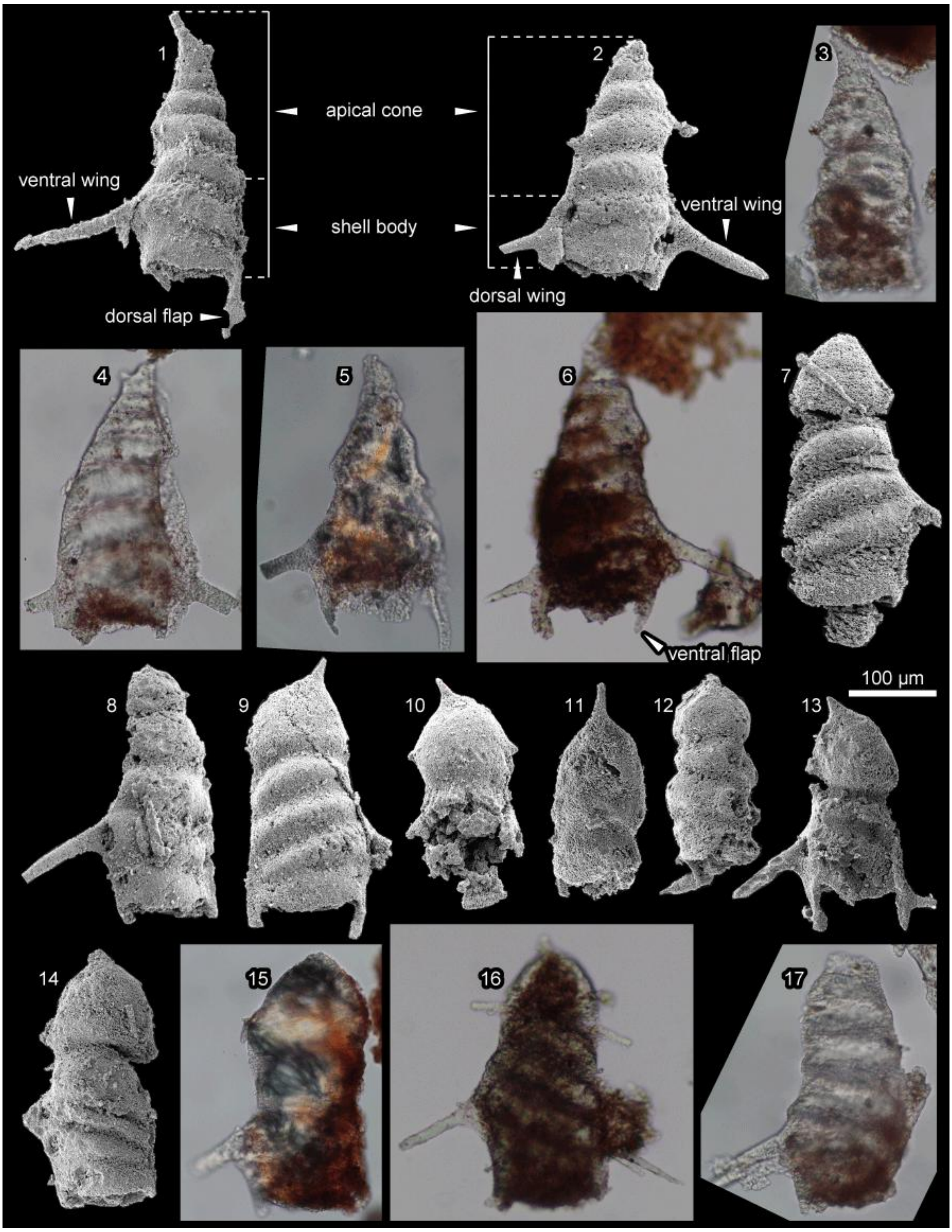


Figure B-4. Photomicrographs of normal and swollen types of *Albaillella sinuata* Ishiga and Watase from the red chert (IT08113007) of the Waji section. 1–6: normal type of *A. sinuata*; 8, 17; Intermediate form between normal and swollen types of *A. sinuata*; 7, 9–16: swollen type of *A. sinuata*.

5. Systematic paleontology

In this chapter, we deal only normal and swollen types of *A. sinuata* among radiolarian assemblages of the present study. Swollen type of *A. sinuata* was commonly occurred from the sample IT08113007. Swollen type of Albaillellaria without *A. sinuata* was not yielded from the sample. No swollen type Albaillellaria is found in other samples.

Subclass RADIOLARIA Müller, 1858
Superorder POLYCYSTINA Ehrenberg, 1838, emend. Riedel, 1967
Order ALBAILLELLA Deflandre, 1953
Family ALBAILLELLIDAE Deflandre 1952, sensu emend. Holdsworth, 1977
Genus *Albaillella* Deflandre 1952, sensu emend. Holdsworth, 1966
Type species: *Albaillella paradoxa* Deflandre, 1952

***Albaillella sinuata* Ishiga & Watase 1986**

Figs. B-4.1–B-4.6
Albaillella sp. D. Ishiga et al., 1982b, p. 54, pl. 4, figs. 1–3, 5–7.
Albaillella sp. D. Ishiga et al., 1982c, p. 24, pl. 1, figs. 17, 18.
Albaillella sp. D. Ishiga and Suzuki, 1984, p. 67, pl. 1, figs. 1–7, 11.
Albaillella sp. A. Yamamoto, 1985, p. 370, pl. 1, fig. 1.
Albaillella sinuata Ishiga and Watase n. sp. Ishiga et al., 1986, p. 49, pl. 1, figs. 1–8.
Albaillella sinuata Ishiga and Watase. Sano, 1988, p. 711, pl. 2, fig. 5.
Albaillella sinuata Ishiga and Imoto. Ishiga, 1990, p. 293, pl. 1, fig. 15.
Albaillella sinuata Ishiga and Watase. Ujiie and Ohba, 1991, p. 51, pl. 2, figs. 7, 8.
Albaillella sinuata Ishiga and Watase. Blome and Reed, 1992, p. 363, figs. 9.7, 9.8.
Albaillella sinuata Ishiga and Watase. Sashida et al., 1993b, p. 105, fig. 6.7.
Albaillella sinuata Ishiga and Watase. Takemura and Yamakita, 1993, p. 49, pl. 1, fig. 7.
Albaillella sinuata Ishiga and Watase. Kuwahara and Yao, 1998, p. 42, pl. 1, fig. 6.
Pseudoalbaillella sinuata Ishiga and Watase. Sashida et al., 1998, p. 21, fig. 11.19. (written as *Albaillella sinuata* Ishiga and Watase in the text)
Albaillella sinuata Ishiga and Watase. Kuwahara, 1997, p. 70, pl. 1, fig. 8.
Albaillella sinuata Ishiga and Watase. Xia and Zhang, 1998, p. 198, pl. 1, figs. 2, 4.

Albaillella sinuata Ishiga and Watase. Wang et al., 1998b, p. 369, pl. 3, fig. 1.

Albaillella sinuata Ishiga and Watase. Hori, 2004b, p. 300, pl. 4, figs. 16–23, 27–29.

Albaillella sinuata Ishiga, Kito and Imoto. Mitsumura and Kamata, 2009, p. 568, pl. 3, fig. 3.

Albaillella sinuata Ishiga and Watase. Wang and Yang, 2011, p. 138, figs. 4.E, 4.F.

Materials: Thirty-five specimens were collected from sample IT08113007 and 25 specimens were examined by a SEM or an optical microscope. Six specimens were illustrated in this paper.

Remarks: Shell, which consists of apical-cone and shell-body, is conical and inclines toward the ventral side. Shell surface is obliquely traversed by six or more bands. Rod-like wings extend from dorsal and ventral sides of shell body. Both wings are slightly curving downward. Flaps extend from dorsal and ventral sides of the base of shell body. Both flaps are slightly curving medial ward of the shell. Morphological comparisons between normal and swollen types of *A. sinuata* will be mentioned later.

Occurrences: Normal type of *A. sinuata* was abundantly occurred from the upper part of the Waji section. This species had been occurred from the Lower-Middle Permian in Japan, U.S.A., South China and Thailand. Normal type of *A. sinuata* had been also occurred from Late Permian radiolarian assemblage in southwest Japan (Takemura and Yamakita, 1993; Kuwahara, 1997). However, Takemura and Yamakita (1993) considered it as a reworked fossil by reason that there are few species in it.

Swollen type of *Albaillella sinuata* Ishiga & Watase 1986

figs. 4.7–4.17

Albaillella sp. D. Ishiga et al., 1982b, p. 54, pl. 4, fig. 4.

Gen. et sp. indet. Ujiie and Ohba, 1991, p. 55, pl. 4, figs. 9–10.

Albaillella sinuata Ishiga and Watase. Xia and Zhang, 1998, p. 198, pl. 1, figs. 1, 3.

Albaillella sp. aff. *A. sinuata* Ishiga and Watase. Xia and Zhang, 1998, p. 198, pl. 1, figs. 5-7.

Albaillella sinuata Ishiga andWatase. Zhang et al., 2010, p. 144, fig. 5.R.

Materials: Sixteen strongly-inflated specimens of swollen type were collected from sample IT08113007 and 15 specimens of them were examined by a SEM or an optical microscope. Eight weakly-inflated specimens of swollen type were collected and examined by a SEM or an optical microscope from the sample IT08113007. Eleven specimens of swollen type were illustrated in this paper.

Remarks: Shell is conical with swollen apical cone or cylinder-like form. Shell surface is obliquely traversed by five or less bands; bands in middle-upper parts of apical cone are unobservable in strongly-inflated specimens (e.g., Figs. B-4.10, B-4.11). Rod-like wings extend from dorsal and ventral sides of shell body. Both wings are slightly curving downward. Flaps extend from dorsal and ventral sides of the base of shell body. Both flaps are slightly curving medial ward of the shell. There is no broad difference in total length of its shell between normal and swollen types. An inflated part of all swollen type specimens is situated above than its wings. Specimens of swollen type vary from weakly (e.g., Figs. B-4.8, B-4.17) to strongly (e.g., Fig. B-4.10) in swollenness.

Occurrences: Swollen type of *A. sinuata* was commonly occurred from one horizon of the Waji section (sample IT08113007). Swollen type of *A. sinuata* had been also occurred from the Lower-Middle Permian in the Tamba area of southwest Japan and the Xiaodong area of South China.

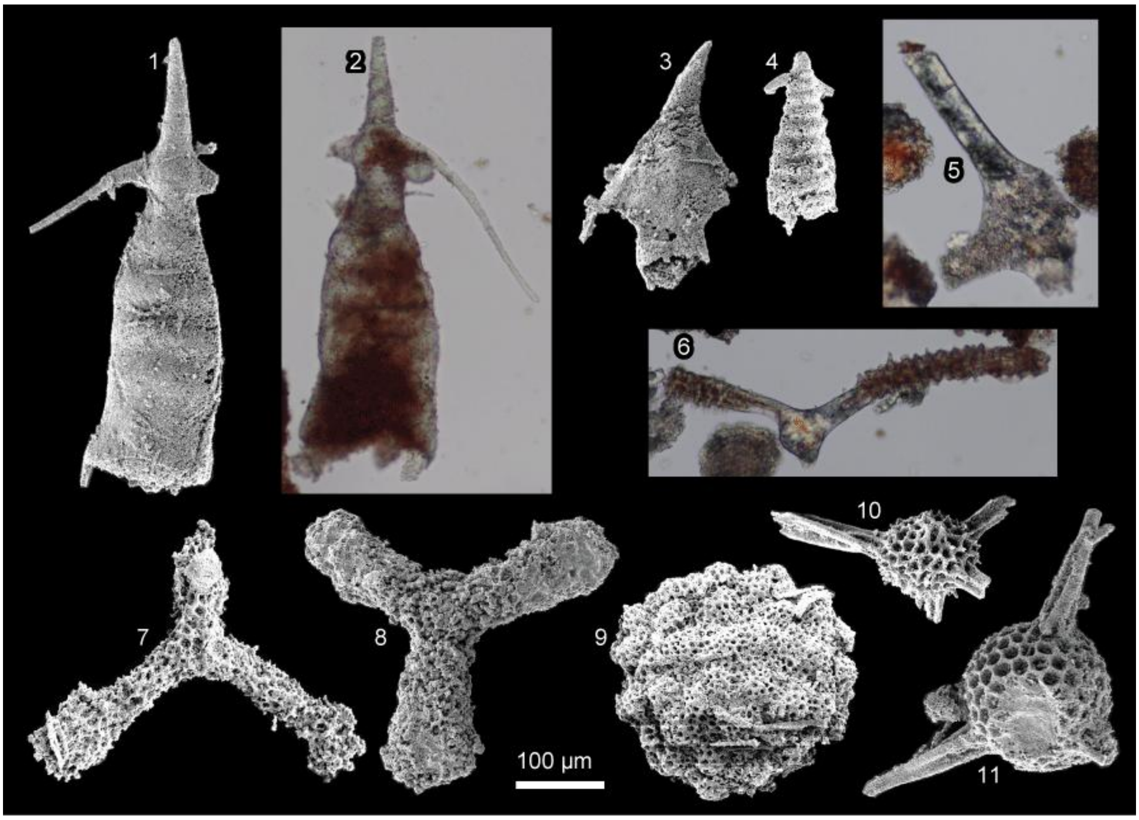


Figure B-5. Photomicrographs of Early Permian radiolarians from cherts in the Waji section. 1, 2: *Pseudoalbaillella longtanensis* Sheng and Wang; 3: *Pseudoalbaillella postscalprata* Ishiga; 4: *Albaillella asymmetrica* Ishiga and Imoto; 5: *Quadricaulis inflata* (Sashida and Tonishi); 6: *Pseudotormentus kamigoriensis* (Caridroit and De Wever); 7: *Latentifistula texana* Nazarov and Ormiston; 8: *Latentifistula* sp.; 9: *Hegleria mammilla* (Sheng and Wang); 10: *Entactinia itsukaichiensis* Sashida and Tonishi; 11: *Triaenosphaera* sp. 1, 2, 7, 8,

10, 11: IT08113007; 3, 4, 9: IT08113002; 5: IT08113004; 6: IT08113003.

6. Discussion

The ratios of each type to the total number of *A. sinuata* from sample IT08113007 are as follows: non-inflated specimens (typical normal type): 59.3%; weakly-inflated specimens (intermediate forms between normal and swollen types): 13.6%; strongly-inflated specimens (typical swollen type): 27.1%. This indicates that normal type specimens are more abundant than that of swollen type. In addition, intermediate forms are less abundant than those of both typical types. Ishiga (1991) examined the ratios between normal and swollen types in several species of *Pseudoalbaillella* and *Neoalbaillella*. According to him, the ratios of swollen type to total number of those species are not more than 10%. However, the ratio of swollen type of *A. sinuata* of sample IT08113007 in the Waji section is over 40%.

The occurrence of strongly-inflated specimens of *A. sinuata* is confined to few areas. Although weakly-inflated specimen were occurred from the Tamba area (Ishiga et al., 1982b, pl. 4, fig. 4.), strongly-inflated specimens have never been reported yet. The specimens of swollen type in the Waji section are morphologically similar to those from the Gufeng Formation in the Xiaodong area (Xia and Zhang, 1998). Meanwhile, swollen type specimens of *P. globosa* Ishiga and Imoto (described as morphotype of *P. globosa* in the original paper) were also occurred from the Xiaodong area; no swollen types were occurred from Waji except for *A. sinuata*.

The occurrence of swollen type significantly differs depending on species and among areas (Ishiga, 1991). The present study indicates that swollen type of *A. sinuata* also has distributional differences among areas. These differences perhaps reflect any environmental distinction. Meanwhile, swollen type has morphological features differing from each holotype. Therefore, it seems that few swollen type specimens had been used in figures in literatures. It is necessary to show illustrated specimens for elucidating the accurate distribution.

Appendix C: Reconstruction of an oceanic plate sequence supplied radiolarian-bearing clasts with the Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan

Abstract

The Tetori Group ranging from Middle Jurassic to Lower Cretaceous interbeds conglomerates including radiolarian-bearing clasts at several horizons. Mesozoic radiolarian fossils were obtained with observation of etched surfaces from clasts within conglomerates of the Mizukamidani Formation of the Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan. Middle-Late Triassic (TR2C to TR5A zones: middle Anisian to middle Carnian) radiolarians occurred from a chert pebble; Middle Jurassic (JR4 zone: Bajocian to early Bathonian) radiolarians occurred from a siliceous mudstone pebble. The reconstructed oceanic plate sequence from these consists of Middle-Upper Triassic chert, Middle Jurassic siliceous mudstone, Jurassic chert, Triassic chert, and Jurassic siliceous mudstone. Middle Jurassic (JR4) siliceous mudstones had occurred from some strata of the Jurassic accretionary complexes in East Asia (e.g. Russian, Japan, and Philippines). Hence the clasts from this study should be originated from some of these geological bodies or corresponding ones. In regard to the provenance of the Tetori Group, a review of radiolarian-bearing clasts in the Tetori Group shows the following characters: most of radiolarian-bearing clasts are derived from the Tamba-Mino-Ashio terrane; there are a few clasts originated from the Akiyoshi terrane or the Hida Gaien belt. An observation of etched surfaces with hydrofluoric-acid is one of the effective methods to elucidate relationships between rock facies of clasts and occurred radiolarians from the clasts. The observational method should provide the information of the denudation and exhumation histories of the Jurassic accretionary complexes.

1. Introduction

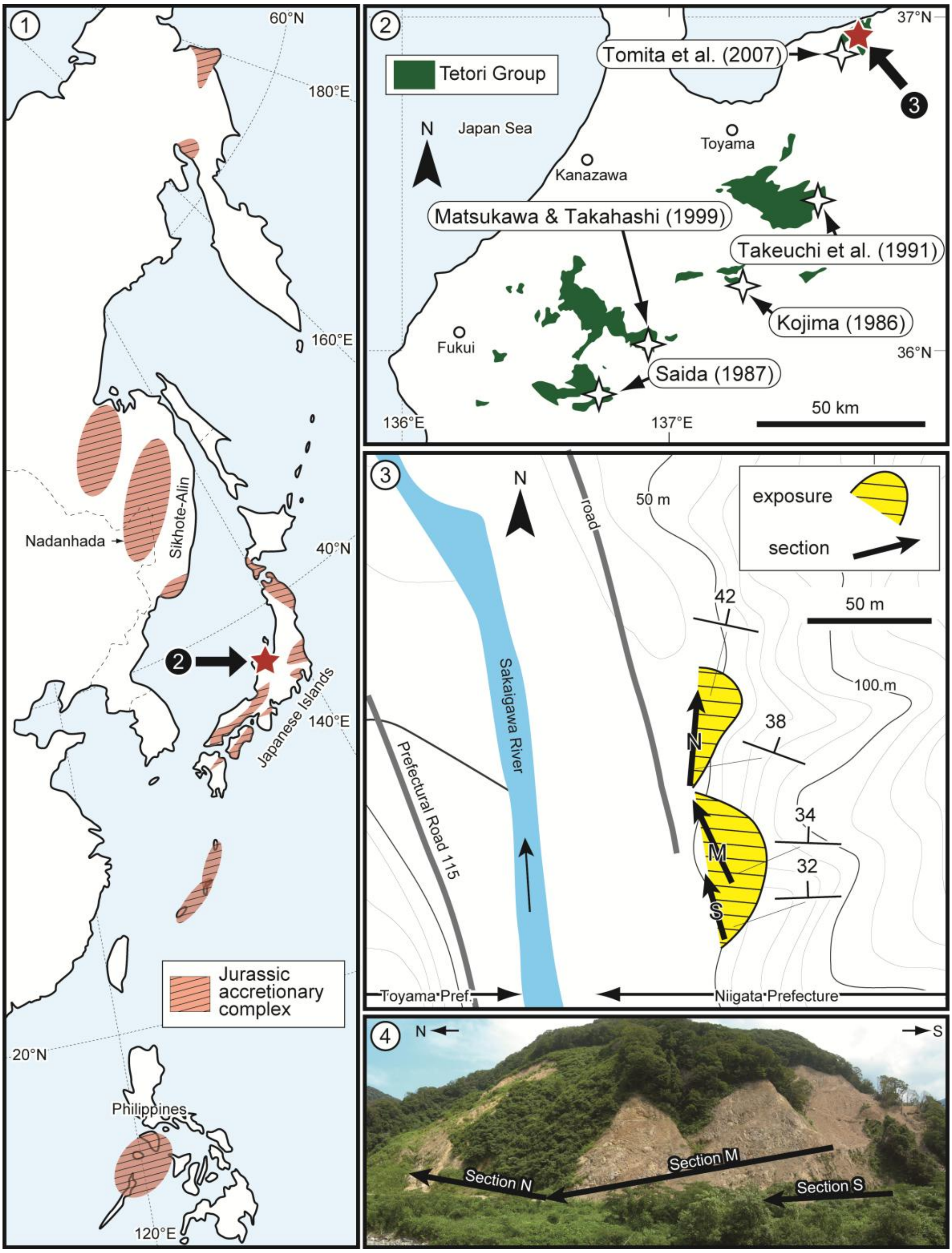
The Middle Jurassic to Lower Cretaceous Tetori Group is one of the major Mesozoic megafossil-bearing strata in East Asia as represented by occurrences of dinosaurs (e.g., Fujita, 2003). The Tetori Group, distributed in the Hokuriku district, central Japan (Fig. C-1.2), is characterized by marine and terrestrial deposits consisting mainly of clastics such as sandstone and conglomerate (e.g., Matsukawa et al., 2003). Clastic rock facies and compositions provide the information of their provenance. Takeuchi et al. (1991) investigated the clastic components of the Tetori Group in the Kurobegawa area, and showed that those differ by members. Takeuchi and Takizawa (1991) discussed tectonic histories of provenances of the Tetori group on the basis of the clastic componential differences. Ages of clasts basing radiolarians also provide some useful information for speculating those provenances. Fujita (2002) quantitatively analyzed clastic components from the Tetori Group in the Kuzuryu area. He then observed that the components had changed upward as follows: granite-dominant, chert-dominant, and orthoquartzite-dominant.

Some radiolarian fossils had been yielded from siliceous rock clasts within conglomerates of the Tetori Group (described in the next chapter). Takeuchi et al. (1991) presumed that these clasts were derived from the Hida Gaien belt and the Mino terrane. Meanwhile, few papers had identified the detailed-ages of clasts within conglomerates of the Tetori Group. Hence, it has not yet led to suggest some specific geological bodies among the belts and terranes.

It is important to elucidate relationships between rock facies of clasts and occurred radiolarians from it for deducing the origin of those radiolarian-bearing clasts. An observation of etched surfaces with hydrofluoric-acid (HF) is one of the effective methods for that. Takeuchi et al. (1991) observed etched surfaces of clasts from the Tetori Group, however they made no detailed mention of the method.

The Niigata University's research group have investigated the Mizukamidani Formation of the Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan, and briefly-reported about lithology and geological structure (Sakai et al., 2012), and radiolarians from conglomerates (Ito et al. 2012). I obtained radiolarian fossils from siliceous rock clasts within conglomerates of the Mizukamidani Formation with observation of etched surfaces. In this paper, I show HF-treatment processes of the conglomerates for the observational methods, and report radiolarian occurrences from those. I identify its age and reconstruct the original oceanic plate sequence. I then discuss about geological bodies that supplied radiolarian-bearing clasts during the sedimentation of the Mizukamidani Formation on the basis of the radiolarian age and its rock facies.

Figure C-1. Distributions of Jurassic accretionary complexes in East Asia modified from Kojima and Kametaka (2000). 2: Distributions of the Tetori Group (after Maeda, 1961) and radiolarian fossil localities in previous studies. 3: A route map of the study sections 4: Distant view of the study sections from the left bank.



1
60°N
180°E
160°E
40°N
140°E
20°N
120°E
Nadanhada
Sikhote-Alin
Japanese Islands
Philippines
Jurassic accretionary complex
2
37°N
36°N
136°E
137°E
Tetori Group
N
Japan Sea
Toyama
Kanazawa
Fukui
Tomita et al. (2007)
Matsukawa & Takahashi (1999)
Takeuchi et al. (1991)
Kojima (1986)
Saida (1987)
50 km
3
N
road
50 m
100 m
exposure
section
42
38
34
32
Sakaigawa River
Prefectural Road 115
Toyama Pref.
Niigata Prefecture
4
N
S
Section N
Section M
Section S

2. Radiolarian occurrences from clasts within conglomerates of the Tetori G.

There had been some radiolarian occurrence reports from conglomerates of the Tetori Group since 1980's. I review those reports in this chapter and summarized in Table C-1. Although some taxonomic names of those radiolarians have been hitherto revised, I used the names and styles in the original papers.

Saida (1987) obtained Triassic and Jurassic radiolarians such as *Triassocampe*(?) sp. and *Tricolocapsa*(?) cf. *fusiformis* Yao from conglomerates of the uppermost Itoshiro Subgroup or Akaiwa Subgroup in the uppermost reaches of the Kuzuryugawa River, Fukui Prefecture. *Triassocampe*(?) sp. occurred from a chert pebble in the same area. He indicated that radiolarian-bearing cherts and siliceous mudstones had exposed during the sedimentation of the strata. Fujita (2002) considered the radiolarian-yielding strata of Saida (1987) as a part of the Kamihanbara Formation of the Itoshiro Subgroup. Takeuchi et al. (1991) observed residues from conglomerates and etched surfaces of those conglomerates from the Tetori Group in the upper reaches of the Kurobegawa River, Toyama Prefecture. They found Permian shales, Triassic chert, conglomerate including Permian and Triassic radiolarians, and conglomerate yielding Jurassic radiolarians. They observed Permian radiolarians such as *Pseudoalbaillella* sp. from a shale pebble with thin-section. They presumed the origins of these clasts within conglomerates as follows: Permian shales were derived from the Hida Gaien belt; conglomerates including Triassic and Jurassic radiolarians were derived from the Mino terrane in the broad sense (inc. the Tamba, Mino, Ashio, Nadanhada, and Western Silhote-Alin belts). They concluded that the Mino terrane, a Jurassic accretionary complex, had exposed during the sedimentation of the uppermost Akaiwa Subgroup because the radiolarian-bearing conglomerates are interbedded above the uppermost Akaiwa Subgroup. Matsukawa and Takahashi (1999) reported Permian or Triassic radiolarian fossils from chert clasts of the Otaniyama Formation of the Tetori Group in the upper reaches of the Shokawa River, Gifu Prefecture. They pointed out that the Mino terrane sensu Takeuchi et al. (1991) had exposed earlier than the age presumed by Takeuchi et al. (1991). Tomita et al. (2007) obtained radiolarians from clasts within conglomerates of the Mizukamidani and Kurobishiyama formations in the northeast part of Toyama Prefecture. Permian radiolarians such as *Follicucullus porrectus* Rudenko and *Pseudoalbaillella* sp. cf. *P. fusiformis* (Holdsworth and Jones) occurred from a mudstone clast of the Mizukamidani Formation; Permian radiolarians (e.g. *Pseudoalbaillella* sp. cf. *P. fusiformis*) and Triassic radiolarians (e.g. *Pseudostylosphaera japonica* Nakaseko and Nishimura) from chert clasts of the lower

Kurobishiyama Formation. They pointed out that the supplies of accretionary complex-derived clasts differed by location and times on the basis of their and previous studies.

The Yokoo conglomerate, characterized by abundant chert clasts, is distributed in the Yokoo area, Nyukawa Village, Gifu Prefecture. Some researchers have considered the Yokoo conglomerate as a component of the Tetori Group (e.g., Nozawa et al., 1975). Kojima (1986) obtained Permian radiolarians from two chert pebbles within the Yokoo conglomerate. One chert clast includes *Albaillella levis* Ishiga, Kito and Imoto which is a Late Permian radiolaria; another chert clast includes *F. scholasticus* Ormiston and Babcock and *F. ventricosus* Ormiston and Babcock which are Middle Permian radiolarians.

3. Geological settings of the Mizukamidani Formation

The Tetori Group is representative sediment from the Middle Jurassic to Early Cretaceous in the Inner Zone of the Southwest Japan. It is divided into three following subgroups in ascending order: Kuzuryu, Itoshiro, and Akaiwa (Fig. C-2). The Kuzuryu Subgroup consists of marine to brackish strata with ammonoids; the Itoshiro Subgroup is composed mainly of brackish to terrestrial strata and characterized by flood plain deposits; the Akaiwa Subgroup consists mainly of brackish to terrestrial strata and is characterized by coarse-grained sandstone formed on braided stream (Isaji, 2010). There have been several opinions about the stratigraphic correlation of the Tetori Group because of under-abundant occurrences of index fossils and lithostratigraphic variance between localities.

The Itoigawa area is located at the west-end of Niigata Prefecture, near the border between Niigata and Toyama prefectures (Fig. C-1). The Mesozoic sequences in this area are composed of the Jurassic Kuruma Group and the Tetori Group. The Tetori Group of this area consists of the Mizukamidani, Kurobishiyama, and Shiritakayama formations (e.g., Tomita et al., 2006). The Mizukamidani Formation (Kobayashi et al,. 1957) consists mainly of poorly-sorted conglomerates and sandstone. Carbides and plant-fossil-fragments commonly occur from the Mizukamidani Formation, while other fossils have barely occurred. Although the Mizukamidani Formation had been formerly considered as the uppermost part of the Kuruma Group (e.g., Kobayashi et al., 1957; Goto, 1983), it has been corresponded to the Akaiwa Subgroup in recent decades (e.g., Shiraishi, 1992; Tomita et al., 2006).

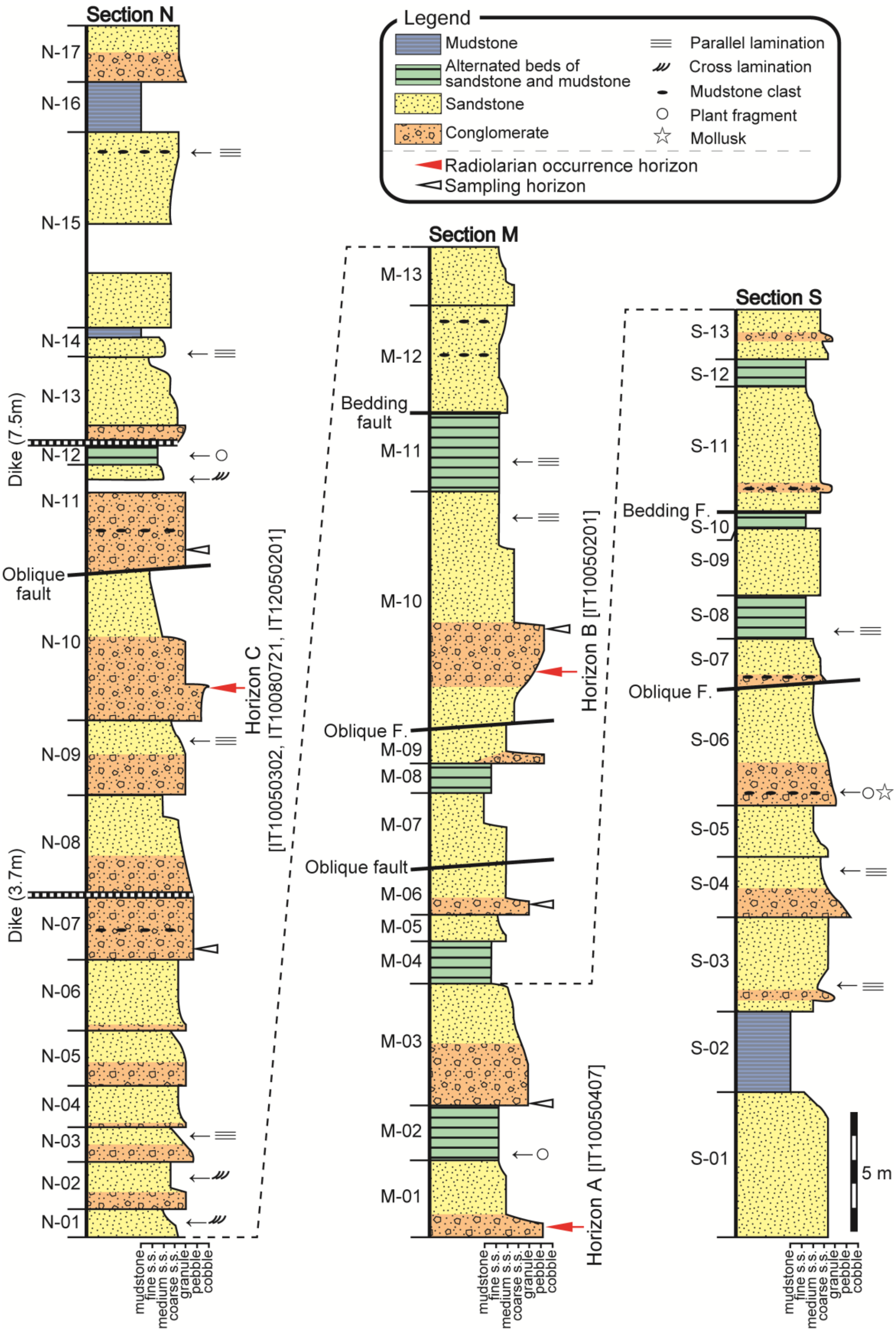


Figure C-2. Columnar sections of the Mizukamidani Formation in this study.

The study sections (36°57.556′ N, 137°39.152′ E) outcrop along the right bank of the Sakaigawa River (Figs. C-1.3, C-1.4). I sectioned three columns, northward-namely S, M, and N (Fig. C-2). The uppermost part of the Section S (S-11 to S-13) and the lowermost part of the Section M (M-01 to M-03) are same horizons. The sections M and N are successive. These strata approximately strike N80° W and dip 35° N. There are some oblique and bedding faults in the sections. The sections are composed mainly of feldspathic-arenite and conglomerates including abundant orthoquartzite and chert pebbles, with common mudstone beds and mud clasts. Fining-upward cycles are repeated in the sections. Carbides commonly occur from the sections; plant-fossil-fragments occurred from several horizons; trace fossils are observed in mudstone clasts. Sakai et al. (2012) found a molluscan fossil from a mudstone clast in the lower S-06 as a first report of mollusks from the Mizukamidani Formation.

4. Materials and methods

4.1. Sampling horizons

I collected some samples from five horizons of the Section M and three horizons of the Section N (Fig. C-2). I sampled those mainly from clast-supported conglomerates. Radiolarian fossils occurred from clasts within conglomerates in three horizons (A, B, and C). In this chapter, I describe the horizons yielding radiolarians.

4.1.1. Horizon A

The Horizon A is situated in a white conglomerate layer in the lowermost M-01. The conglomerate layer varies in thickness and the thickest part is 1 m. Clasts are dominantly chert (white, black, dark-gray, and red colored) pebbles and minor tuff, dark-gray siliceous mudstone, bright-gray sandstone, and orthoquartzite pebbles, with bright-gray very-coarse-grained sandstone matrixes. Clasts are sub-angular to sub-rounded, poorly-sorted, and matrix-supported. There are closed-spaced mudstone clasts. Clasts are typically 2 cm in diameter; the largest clasts are approximately 4 cm in long-axis diameter.

One conglomerate sample (IT10050407) that includes a radiolarian-bearing clast was collected from the Horizon A in the lower part of the conglomerate layer. Clasts of the sample are partially clast-supported; the clasts are dominantly bright-gray and black chert (1 to 2 cm in diameter).

4.1.2. Horizon B

The Horizon B is situated in a brown conglomerate layer (2.7 m in thickness) in the lower M-10. Clasts are dominantly chert (white, black, dark-gray, and red) and orthoquartzite pebbles, and minor tuff, dark-gray siliceous mudstone, bright-gray sandstone, andesite, and granite pebbles, with bright-gray coarse-grained sandstone matrixes. Clasts are sub-rounded to rounded, poorly-sorted, and clast-supported. Clasts are typically 3 cm in diameter; the largest clasts are approximately 12 cm in long-axis diameter.

I collected one conglomerate sample (IT10050201) that includes a radiolarian-bearing clast from the Horizon B in the lower part of the conglomerate layer. Clasts in this sample are clast-supported; the clasts are dominantly gray chert (2 to 4 cm in diameter) and orthoquartzite (4 to 6 cm).

4.1.3. Horizon C

The Horizon C is situated in a brown conglomerate layer (3.4 m) in the lower N-10. Clasts are dominantly chert (black, dark-gray, and gray) and orthoquartzite pebbles, and minor black siliceous mudstone, fine-grained sandstone, and granite pebbles, with bright-gray very-coarse-grained sandstone matrixes. Clasts are sub-rounded to rounded, poorly-sorted, and clast-supported. Clasts are typically 2 cm in diameter; the largest clasts are approximately 10 cm in long-axis diameter.

Three conglomerate samples (IT10050302, IT12050102, and IT10080721) that include radiolarian-bearing clasts were collected from the Horizon C in the middle part of the conglomerate layer. Clasts of these samples are clast-supported; clasts are relatively-dominantly chert (1 to 4 cm in diameter) and siliceous mudstone (2 cm).

4.2 HF-treatment and observation of etched surfaces

The samples were cut in hand-size with rock cutter. The cut samples were soaked in an approximately 5% hydrofluoric acid (HF) solution for one day at room temperature. The HF solution was removed and the etched sample was subsequently refilled with fresh water. The water was removed and the etched sample was dried naturally.

Surfaces of the etched samples without evaporated were photographed with a scanning electron microscope (SEM). I observed the etched surfaces and evaluated the following contents: fossil identifications, dominances of fossil (inc. bioclast) and matrix, fossil components, fossil distributional biases, and fossil directions. The dominances of fossil and matrix were evaluated by dominant and supporting fossil. The fossil components were evaluated by amounts of Nassellaria, spherical-radiolaria, and spicules. Spicules are generally derived from sponge or radiolarian skeletons, but there were no discriminative characteristics under this observation with a SEM. Hence, I make no mention of sources of each spicule. The fossil distributional biases were evaluated by that there are differences of the ratios and fossil components by site or not. The fossil directions were evaluated by that fossils having a long-axis (e.g. Nassellaria and spicule) carry a sense of direction or not.

5. Results

I observed etched surfaces and obtained radiolarian fossils from five clasts within the samples from the horizons. Selected photomicrographs of the etched surfaces are shown in Fig. C-3; those of radiolarian fossils are shown in Fig. C-4. I describe the results of the observation, the occurred radiolarians and their ages.

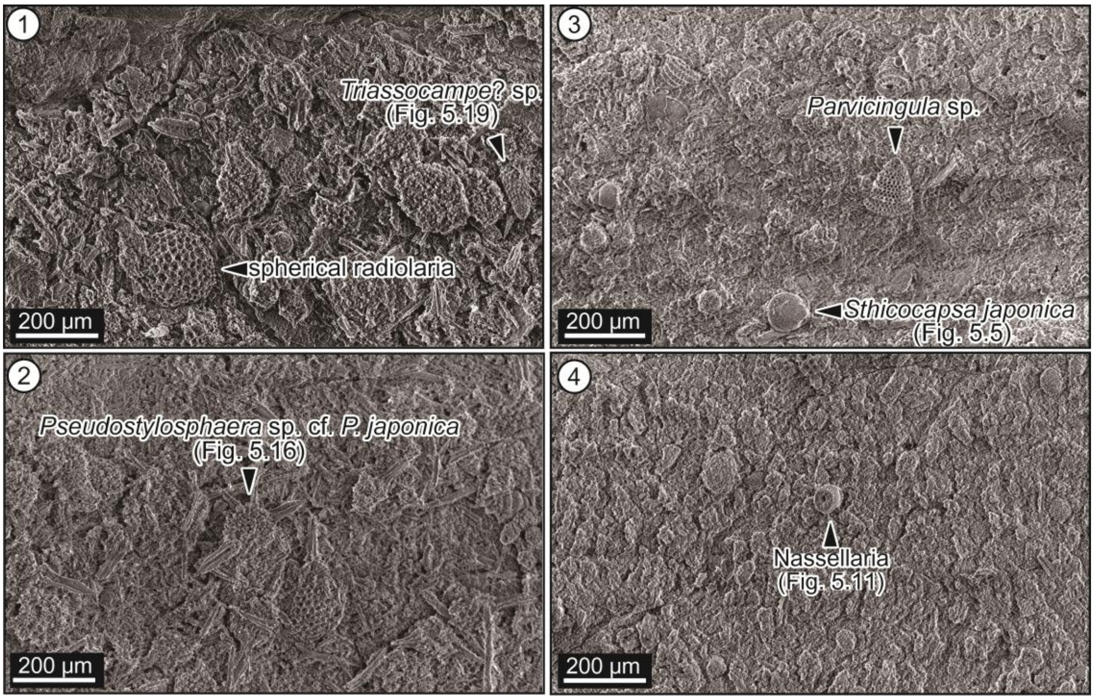


Figure C-3. Etched surfaces of siliceous rock pebbles within the Mizukamidani Formation in the study sections. 1: sample IT10050407-1 (chert: Horizon A); 2: sample IT10050201-1 (chert: Horizon B); 3: sample IT12050102-1 (siliceous mudstone: Horizon C); 4: sample IT10080721-1 (siliceous mudstone: Horizon C).

5.1 Fossil occurrences

5.1.1. Horizon A

An etched surface of a chert pebble (IT10050407-1) is dominantly spherical radiolarians and spicules, and fossil-supported (Fig. C-3.1). The fossil distributional biases and the fossil directions are not observed.

Triassocampe? sp. (Fig. C-4.19) occurred from the chert pebble. This radiolaria occurs from Triassic sequences, indicating that the sample is Triassic chert.

5.1.2. Horizon B

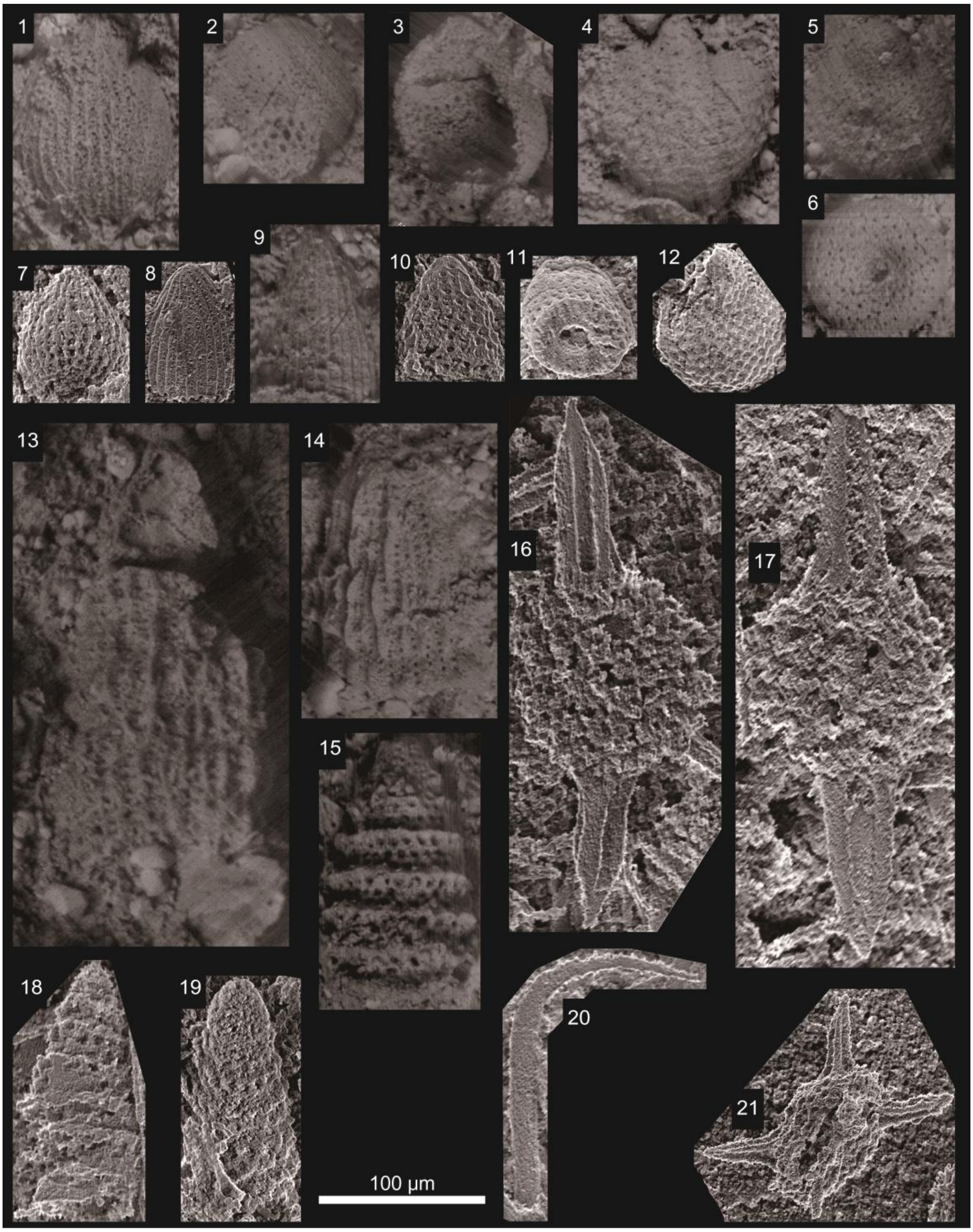
An etched surface of a chert pebble (IT10050201-1) is dominantly spherical radiolarians and spicules, with minor Nassellaria. It is fossil-supported (Fig. C-3.2). A little fossil distributional bias is observed. The fossil directions are not observed.

The chert pebble yielded *Pseudostylosphaera* sp. cf. *P. japonica* (Figs 4.16, 4.17), spine A2 of Sugiyama (1997) (Fig. C-4.20) and *Triassocampe*? sp. (Fig. C-4.18). *Pseudostylosphaera japonica* occurred from the TR2B (lower Anisian) to TR5A (middle Carnian) zones; spine A2 occurred from the TR2C (middle Anisian) to TR5B (middle Carnian) zones (Sugiyama, 1997). Hence the chert corresponds to any horizon from the TR2C to TR5A zones (middle Anisian to middle Carnian).

5.1.3. Horizon C

Etched surfaces of two chert pebbles (IT10050302-1 and IT10050302-2) are dominantly spherical radiolarians and spicules, with minor Nassellaria. It is fossil-supported. A little fossil distributional bias is observed. The fossil directions are not observed.

Figure C-4. Photomicrographs of radiolarian fossils from clasts within the Mizukamidani Formation in the study sections. 1–3: *Striatojaponocapsa plicarum* (Yao); 4–6: *Sthichocapsa japonica* Yao; 7–9: *Archaeodictyomitra* sp.; 10, 11: Nassellaria; 12: close-end Nassellaria; 13, 14: *Hsuum* sp.; 15: *Parvicingula* sp.; 16, 17: *Pseudostylosphaera* sp. cf. *P. japonica* Nakaseko and Nishimura; 18, 19: *Triassocampe*? sp.; 20: spine A2 of Suigiyama (1997); 21: spherical radiolaria? with four spines. Sample numbers: 1–6, 9, 13–15: IT12050102-1 (siliceous mudstone: Horizon C): 16–18, 20: IT10050201-1 (chert: Horizon B); 19: IT10050407-1 (chert: Horizon A); 7: IT10050302-1 (chert: Horizon C); 8, 10–12: IT10080721-1 (siliceous mudstone: Horizon C); 21: IT10050302-2 (chert: Horizon C).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An etched surface of one siliceous mudstone pebbles (IT12050102-1) is dominantly closed-end and multi-segmented Nassellaria, and slightly-matrix-supported (Fig. C-3.3). The fossil distributional biases and the fossil directions are not observed. An etched surface of another siliceous mudstone pebbles (IT10080721-1) is dominantly matrix and matrix-supported with scattered fossils (Fig. C-3.4). Nassellaria is dominant; spherical radiolaria is a few; no spicule is observed. The fossil distributional biases and the fossil directions are not observed.

Closed-end Nassellaria (Fig. C-4.7) was obtained from the chert pebble (IT10050302-1). Closed-end Nassellaria abundantly occurs from Jurassic sequences, indicating that probably the sample is Jurassic chert. Spherical? radiolaria with four spines (Fig. C-4.21) occurred from the chert pebble (IT10050302-2) of the Horizon C. The following radiolarians occurred from the siliceous mudstone pebble (IT12050102-1): *Striatojaponocapsa plicarum* (Yao) (Figs C-4.1–C-4.3), *Sthichocapsa japonica* Yao (Figs. C-4.4–C-4.6), *Archaeodictyomitra* sp. (Fig. C-4.9), *Hsuum* sp. (Figs. C-4.13, C-4.14), and *Parvicingula* sp. (Fig. C-4.15). This radiolarian assemblage corresponds to that of the JR4 Zone (Bajocian to lower Bathonian) of Matsuoka (1995).

Archaeodictyomitra sp. (Fig. C-4.8) and closed-end Nassellaria (Fig. C-4.12) were gained from the siliceous mudstone pebble (IT10080721-1). This radiolarian assemblage corresponds to that of the Jurassic therefore it is Jurassic siliceous mudstone.

5.2. Characteristics of etched surfaces

General characters of each rock facies of clasts as far as the etched surface observation of this study are summarized as follows.

The etched surfaces of chert clasts are dominantly fossils and fossil-supported (Figs. C-3.1, C-3.2). Triassic cherts commonly include spicules; Jurassic cherts barely include those. Meanwhile Triassic cherts include no closed-end Nassellaria but Jurassic cherts commonly include those. Multi-segmented Nassellaria commonly occurs from both cherts. There is a little fossil distributional bias. The fossil directions are not observed.

The etched surfaces of siliceous mudstone clasts are dominantly matrixes and matrix-supported (Figs. C-3.3, C-3.4). Closed-end and multi-segmented Nassellaria commonly occurs, while spicules barely occur. The fossil distributional biases and the fossil directions are not observed.

6. Discussion

6.1. Reconstruction of an oceanic plate sequence

In this chapter, I reconstruct an oceanic plate sequence of the geological body that supplied the sedimentary spaces of the Tetori Group in the Itoigawa area with radiolarian-bearing clasts. The following radiolarian-bearing clasts were recognized from the study sections: Middle-Upper Triassic (TR2C to TR5A: middle Anisian to middle Carnian) chert, Middle Jurassic (JR4: Bajocian to lower Bathonian) siliceous mudstone, Jurassic chert, Triassic chert, and Jurassic siliceous mudstone. Figure C-5 shows the reconstructed column of the Mizukamidani Formation of the section on the basis of these radiolarian ages. This componential characteristic conforms to that of Jurassic accretionary complexes in East Asia.

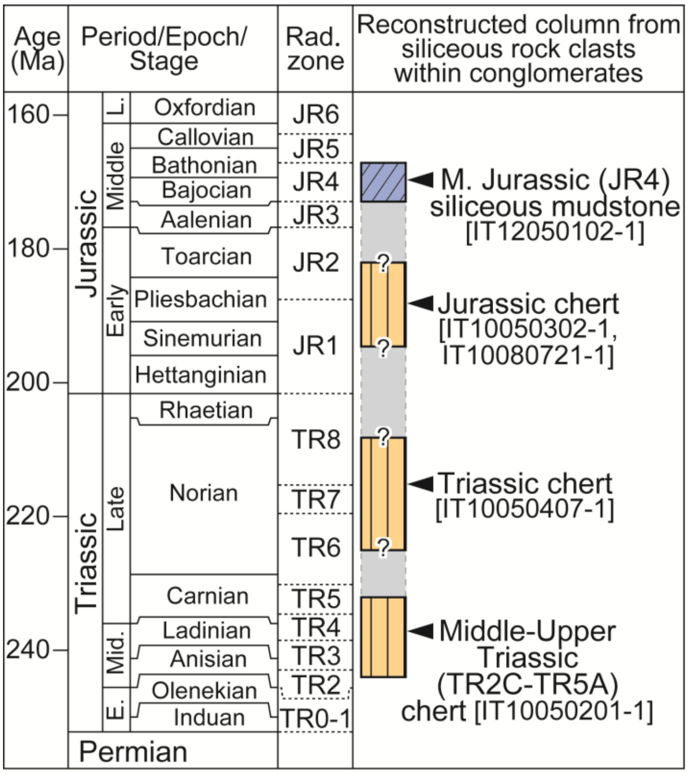

Figure C-5. A reconstructed column from radiolarian-bearing clasts in the Mizukamidani Formation in the study sections. Radiolarian zones and its age assignment are after Matsuoka (1995) and Sugiyama (1997).

Jurassic accretionary complexes are widely distributed in East Asia (Kojima and Kametaka, 2000; Nakae, 2000) (Fig. C-1.1). Siliceous mudstones within the Jurassic accretionary complexes vary in age from the lower Lower Jurassic (JR1: Hettangian to middle Pliensbachian) strata (e.g., Kasugano complex: Hattori and Yoshimura, 1982; Nakae, 2000) to the uppermost Jurassic to lower Lower Cretaceous (KR1: uppermost Tithonian to middle Valanginian) strata (e.g., Kashiwagi unit: Matsuoka, 1996; Matsuoka et al., 1998). Middle Jurassic (JR4) siliceous mudstones had occurred from some geologic bodies of the Jurassic accretionary complexes (e.g., Khabarovsk complex in Russian: Kojima et al., 1991; Togano unit in Japan: Matsuoka, 1984; Northern Busuanga belt in Philippines: Zamoras and Matsuoka, 2001). Hence the clasts from this study should be originated from some of these geological bodies or corresponding ones.

6.2. Origins of radiolarian-bearing clasts in previous studies

I discuss the origins of radiolarian-bearing clasts of the Tetori Group in the previous studies in this chapter. Table C-1 shows the origins in each samples of the Tetori Group in this and previous studies. The definitions of the Akiyoshi and Maizuru terranes are after Ichikawa (1990); that of the Hida Gaien belt is after Tsukada et al., (2004). Although that of the Tamba-Mino-Ashio terrane are essentially based on Ichikawa (1990), it includes Jurassic accretionary complexes in other countries in East Asia (e.g., Russian, China, and Philippines) which is considerate as extension of the Tamba-Mino-Ashio terrane (Kojima and Kametaka, 2000). I do not discuss the origins of radiolarians from residues derived from conglomerates because it is unable to identify rock facies of radiolarian-bearing clast. Although it is unclear that the Yokoo conglomerate belongs to the Tetori Group, I deal with it in this chapter.

There had been many occurrence reports of the clasts which were probably derived from the Tamba-Mino-Ashio terrane. Triassic chert clasts (e.g., 1298 of Saida, 1987; part of Yr 64: Takeuchi et al., 1991) were originated from the Tamba-Mino-Ashio terrane. Kojima (1986) found the Permian chert clast (JMP959) including *F. scholasticus* and *F. ventricosus* which is characteristic species of the upper Middle Permian (*F. scholasticus-F. ventricosus* Assemblage-Zone: Kuwahara et al., 1998), and the Permian chert clast (JMP882) including *Albaillella levis* occurred from the Upper Permian (*Neoalbaillella ornithoformis* Assemblage-Zone: Ishiga et al., 1982a; Kuwahara et al., 1998). The Akiyoshi terrane also contains Permian cherts, but the youngest Permian chert of the terrane corresponds to the lower Middle Permian

(*Pseudoalbaillella globosa* Assemblage-Zone: Ishiga et al., 1986; Sano et al., 1987; Goto, 1988). Hence the Permian cherts of Kojima (1986) also were derived from the Tamba-Mino-Ashio terrane.

Permian radiolarian occurrences had been reported from mudstone clasts also (Takeuchi et al., 1991; Tomita et al., 2007). Takeuchi et al. (1991) considered that the Permian mudstone clast (Yr103) including *F.* sp. cf. *F. scholasticus* morphotype II Ishiga was originated from the Hida Gaien belt. *Follicucullus porrectus* which co-occurred with *F. scholasticus* morphotype II (=*F. ventricosus*) occurred from a tuff of the Hida Gaien belt (Takeuchi et al., 2004). Meanwhile there are mudstones including *F. scholasticus* in the Akiyoshi terrane (e.g., Ishiga et al., 1986; Sano et al., 1987) and the Maizuru terrane (e.g., Nishimura and Ishiga, 1987; Ishiga et al., 1988). Therefore the mudstone clasts of Takeuchi et al. (1991) and Tomita et al. (2007) were perhaps originated from the Akiyoshi or Maizuru terranes.

Tomita et al. (2007) reported the Permian chert clast which includes *Pseudoalbaillella* sp. cf. *P. fusiformis* and *Pseudoalbaillella* sp. aff. *P. longicornis* Ishiga and Imoto. These species commonly occurred from the Middle Permian (*Pseudoalbaillella globosa* Assemblage-Zone: e.g., Ishiga, 1986a). These radiolarians had occurred from the Akiyoshi and Tamba-Mino-Ashio terranes (e.g., Ishiga et al., 1982b; Sano et al., 1987), indicating that these were derived from the either terranes.

In summary, the radiolarian-bearing conglomerates of the Tetori Group consist mainly of the Tamba-Mino-Ashio terrane-derived clasts whereas a few clasts were originated from the Akiyoshi terrane or the Hida Gaien belt.

7. Conclusions

Mesozoic radiolarians were occurred from siliceous rock pebbles of the Mizukamidani Formation of the Tetori Group in the Itoigawa area, Niigata Prefecture, central Japan. On the basis of these radiolarian occurrences, the radiolarian-bearing clasts of the section consist of Middle-Upper Triassic (TR2C to TR5A: middle Anisian to middle Carnian) chert, Middle Jurassic (JR4: Bajocian to lower Bathonian) siliceous mudstone, Jurassic chert, Triassic chert, and Jurassic siliceous mudstone. This componential characteristic conforms to that of Jurassic accretionary complexes in East Asia. The origins of radiolarian-bearing clasts of the Tetori Group are summarized as follows basing the previous studies. The radiolarian-bearing conglomerates are composed mainly of Jurassic accretionary complex-derived clasts; a few clasts were derived from the Akiyoshi terrane or the Hida Gaien belt.

In previous studies, few reports had shown the detailed-age of accretionary complexes that supplied the accommodation spaces of the Tetori Group with radiolarian-bearing clasts. The result of this study showed it for the first time. Takeuchi et al. (1991) and Takeuchi and Takizawa (1991) had pointed out the provenance of the Tetori Group had differed from age to age. Further studies of radiolarian-bearing clasts within conglomerates of whole of the Tetori Group should provide the information of the denudation and exhumation histories of the Jurassic accretionary complexes. Matsukawa and Fukui (2009) discussed late Mesozoic marine transgression and regression in East Asia on the basis of the molluscan faunal change of the late Mesozoic strata in Heilongjiang Province of China and the Tetori Group. The histories of the Jurassic accretionary complexes derived from the further studies also might provide a better understanding of the late Mesozoic tectonic frame in East Asia.

Table C-1. List of radiolarian occurrences from conglomerates of the Tetori Group in the present and previous studies.

Area (reference)	Sub Group	Formation / Member	Rock facies of sample (sample number)	Observation	Major fossil occurrence	Age	Origin
Lower reaches of the Sakaigawa River, Niigata Prefecture (This study)	Akaiwa Subgroup	Mizukamidani Formation	chert (IT10050407-1: Horizon A)	etched surface	*Triassocampe* ? sp.	Triassic	Tamba-Mino-Ashio
			chert (IT10050201-1: Horizon B)	etched surface	*Pseudostylosphaera* sp. cf. *P. japonica*, spine A2 of Sugiyama (1997), *Triassocampe* ? sp.	Mid.-Upp. Triassic (TR2C-TR5A)	Tamba-Mino-Ashio
			chert (IT10050302-1: Horizon C)	etched surface	*Archaeodictyomitra* sp.	Jurassic	Tamba-Mino-Ashio
			chert (IT10050302-2: Horizon C)	etched surface	spherical radiolaria? with four spines	?	?
			siliceous mudstone (IT12050102-1: Horizon C)	etched surface	*Striatojaponocapsa plicarum*, *Sthichocapsa japonica*, *Archaeodictyomitra* sp., *Hsuum* sp., *Parvicingula* sp.	Middle Jurassic (JR4)	Tamba-Mino-Ashio
			siliceous mudstone (IT10080721-1: Horizon C)	etched surface	*Archaeodictyomitra* sp., closed-end Nasselaria	Jurassic	Tamba-Mino-Ashio
Uppermost reaches of the Kuzuryugawa River, Fukui Prefecture (Saida, 1987)	Itoshiro Subgroup / Kamihanbara Formation (Fujita, 2002)		conglomerate (1256)	residue	*Tricolocapsa* (?) cf. *fusiformis*, *Parahsuum* sp., *Triassocampe* (?) sp.,	Triassic and Jurassic (mixed)	-
			chert (1298)	residue	*Triassocampe* (?) sp., *Archaeospongoprunum* sp.,	Triassic	Tamba-Mino-Ashio
			siliceous shale	residue	*Triassocampe* (?) sp., Jurassic radiolaria	Triassic and Jurassic (mixed)	?
Upper reaches of the Kurobegawa River, Toyama Prefecture (Takeuchi et al., 1991)	Akaiwa Subgroup	Minamimatadani Conglomerate Member	shale (Yr103)	residue	*Follicucullus* sp. cf. *F. scholasticus* morphotype II	Permian	Akiyoshi, Maizuru, or Hida Gaien
			shale (Mt907)	thin section	*Pseudoalbaillella* sp., Albaillellaria	Permian	Akiyoshi, Maizuru, or Hida Gaien
		Yakushizawa-migimata Conglomerate Member	conglomerate (Yr64)	residue	*F.* sp. cf. *F. scholasticus* m. I, *Triassocampe deweveri*, *Pseudostylosphaera* sp. cf. *P. occostyla*	Permian and Triassic (mixed)	-
			chert (part of Yr64)	etched surface	*Triassocampe* sp., *Pseudostylosphaera* sp.	Triassic	Tamba-Mino-Ashio
			conglomerate (Mt722)	residue	*Hsuum* sp., Nassellaria	Jurassic	-
Upp. reaches, Shokawa Riv., Gifu Prf. (Matsukawa & Takahashi, 1999)	Itoshiro Subgroup / Otaniyama Formation		chert	?	?	Permian or Triassic	?
Northeast part of Toyama Prefecture (Tomita et al., 2007)	Akaiwa S.	Upper Part of the Mizukamidani Fm.	mudstone	?	*Follicucullus porrectus, Pseudoalbaillella* cf. *fusiformis*	Permian	Akiyoshi, Maizuru, or Hida Gaien
		Lower part of the Kurobishiyama Formation	chert	?	*Pseudoalbaillella* sp. cf. *P. fusiformis, Pseudoalbaillella* sp. aff. *P. longicornis*	Permian	Akiyoshi or Tamba-Mino-Ashio
			chert	?	*Pseudostylosphaera japonica, Triassocampe* sp.	Triassic	Tamba-Mino-Ashio
Yokoo area, Nyukawa, Gifu Prf. (Kojima, 1986)	Itoshiro Subgroup? (Nozawa et al., 1975)		chert (JMP882)	residue?	*Albaillella levis*, *Follicucullus* sp.	Permian	Tamba-Mino-Ashio
			chert (JMP959)	residue?	*F. ventricosus*, *F. scholasticus*, *F. monacanthus*	Permian	Tamba-Mino-Ashio

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Translation list

1. English-Japanese

Akiyoshi	秋吉
Aonomine	青峰
Ashio	足尾
Beppu	別府
Chichibu	秩父
Funabuseyama	舟伏山
Fusaki	富崎
Futaiwa	双岩
Haiya	灰屋
Hikagedaira	日影平
Himekawa	姫川
Hirayu	平湯
Hodogan	程岩
Ie	伊江
Iheya	伊平屋
Ikuno	生野
Ino	伊野
Ishigaki	石垣
Itsukaichi	五日市
Itoigawa	糸魚川
Iwakuni	岩国
Kambara	蒲原
Kamikatsu	上勝
Kasugano	春日野
Kawai	川井
Kifuneyama	貴船山
Kiku	企救
Kuma	球磨
Kumogahata	雲ヶ畑
Kuromatagawa	黒又川
Kuze	久瀬
Mikame	三瓶
Mikawa	美川
Mino	美濃
Miyagawa	宮川
Motobu	本部
Muikaichi	六日市
Nagafuku	長福
Nanjo	南条
Nishiki	錦
Nogurizawa	野栗沢
Notabiyama	野旅山
Nunotaki	布滝
Ogamata	大ガマタ
Omama	大間々
Oomori	大森
Ota	大田
Otsumi	大積
Ryokami	両神
Ryokami-yama	両神山
Saiki	佐伯
Semmi	仙見
Shakumasan	尺間山
Shimizu	清水
Shimohachikawa	下八川
Shirahone	白骨
Shizukawa	志津川
Shuzan	周山
Suganami	菅並
Suze	嵩山
Taishaku	帝釈
Takayama-Kiso	高山木曽

Tame ________ 多米	Umenoki ________ 梅木
Tamba ________ 丹波	Unoya ________ 雲谷
Tenjinmaru ________ 天神丸	Wakai ________ 若井
Toba ________ 鳥羽	Yogo ________ 余呉
Tohyama ________ 遠山	Yonagu ________ 与奈久
Toyohashi ________ 豊橋	Yoshii ________ 芳井
Uguisu ________ 鶯	Yuki ________ 油木

2. English-Chinese

Anhui ________ 安徽	Longtan ________ 龙潭
Anmenkou ________ 庵门口	Maokou ________ 茅口
Bancheng ________ 板城	Pengjiu ________ 彭久
Gufeng ________ 孤峰	Qinzhou ________ 钦州
Dalong ________ 大隆	Qixia ________ 栖霞
Guangxi ________ 广西	Shijia ________ 石夹
Gujingling ________ 古井岭	Wuxue ________ 武穴
Hubei ________ 湖北	Xiaodong ________ 小董
Jiangsu ________ 江苏	Yinping ________ 阴平
Jiangxi ________ 江西	Yangtze ________ 扬子
Liuhuang ________ 刘黄	Zhejiang ________ 浙江