Permian–Cretaceous radiolarians from Ie Island, Okinawa Prefecture, Japan

Tsuyoshi ITO* and Atsushi MATSUOKA**

Abstract

Ie Island in northwestern Okinawa Prefecture, Japan, mainly comprises of basement rocks (Gusukuyama Formation of the Southern Chichibu terrane) and the overlying Pleistocene Ryukyu Group. The bedded cherts of the Gusukuyama Formation in Mt. Gusuku in the central part of Ie Island have yielded radiolarians ranging from the *Neoalbaillella optima* Zone (Changhsingian, Lopingian, Permian) to the *Kilinora spiralis* Zone (JR6: Oxfordian, Upper Jurassic). Siliceous mudstones in the southern flank of Mt. Gusuku have yielded radiolarians of the *Pseudodictyomitra carpatica* Zone (KR1: uppermost Jurassic–lowermost Cretaceous). This age difference is assumed to indicate the presence of a thrust between Mt. Gusuku and the southern flank of the mountain. Red chert clasts are contained in the Pleistocene Ryukyu Group at Waji on the north coast of Ie Island, and Permian radiolarians have been obtained from chert clasts. In addition, a red bedded chert boulder at Waji yielded Cisuralian (Early Permian) radiolarians including dimorphic pair of *Albaillella sinuata* Ishiga and Watase.

Key words: Permian, Triassic, Jurassic, Cretaceous, radiolaria, dimorphism, accretionary complex, chert, Southern Chichibu terrane, Ryukyu Arc

* Stratigraphy and Tectonics Research Group, Research Institute of Geology and Geoinformation, Geological Survey of Japan, AIST, Tsukuba 305-8567, Japan

** Department of Geology, Faculty of Science, Niigata University, Niigata 950-2181, Japan
Corresponding author: T. Ito,
ito-t@aist.go.jp

(Manuscript received 21 July, 2017; accepted 10 August, 2017)

Introduction

The Japanese Islands, located near a subduction zone in East Asia, mainly comprise accretionary complexes (Isozaki et al., 2010). Jurassic and Cretaceous accretionary complexes are distributed over the northwestern part of the Okinawa Islands (Nakae et al., 2010) (Fig. 1B). Konishi (1963) determined that the Jurassic accretionary complexes are an extension of the Southern Chichibu terrane. Oceanic rocks and terrigenous clastics of the Jurassic accretionary complexes are exposed mainly in Ie, Iheya, and Izena Islands and on the Motobu Peninsula (Fujita, 1989; Takami et al., 1999).

Ie Island is located to the northwest of the Motobu Peninsula of Okinawa Island and most of its area is covered with Pleistocene limestones. However, Mt. Gusuku exposed in the central part of the island is composed of Permian–Jurassic radiolarian-bearing bedded cherts (Ujiié and Oba, 1991a; Matsuoka et al., 1996; Shen et al., 1996). In addition, latest Jurassic–earliest Cretaceous radiolarian assemblages have occurred in siliceous mudstones on the southern flank of Mt. Gusuku, and chert clasts occurring within Pleistocene

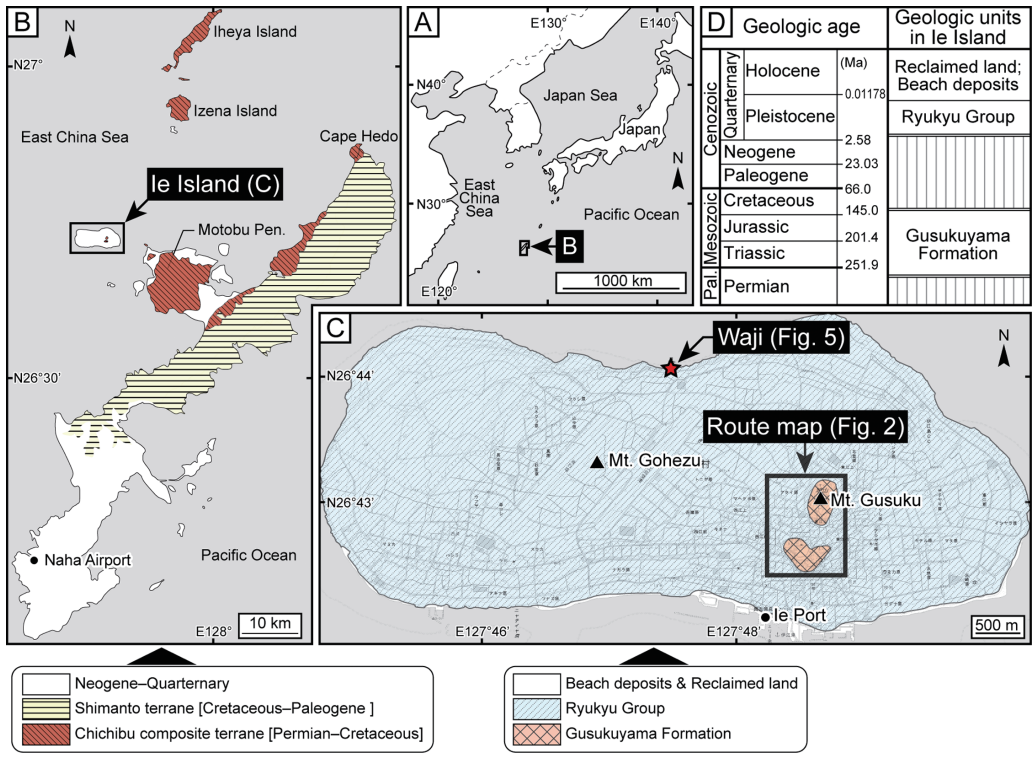

Fig. 1. Geologic maps of the Okinawa Islands and Ie Island and summary of geology of Ie Island. Geologic map of Okinawa Islands is after Nakae et al. (2010). Distribution of the Gusukuyama Formation in Mt. Gohezu is unshown because its distribution is narrow. Base map is from 1:50,000 topographic map "Ie-jima" published by Geospatial Information Authority of Japan. Numerical ages of the summary of geology are after Ogg et al. (2016).

limestones at Waji on the northern coast of the island have yielded Permian radiolarian assemblages (Ujiié and Oba, 1991a; Ito and Matsuoka, 2015). These include dimorphic pairs of the Albaillellaria (Ujiié and Oba, 1991a; Ito and Matsuoka, 2015) that have rarely been reported worldwide.

This article introduces the geologic outline of Ie Island and the radiolarian occurrences within two places, i.e., Mt. Gusuku and Waji.

Geologic outline

Ie Island is located approximately 9 km off northwest of the Motobu Peninsula. It is a small gourd-shaped island with a circumference of approximately 22 km. The northern coast of the island is topographically characterized by terrace plains with steep escarpments, while the southern area is low-pitched (Kinoshita, 2013).

The Ryukyu Group on Ie Island mainly comprises basal conglomerates, calcareous sandstones, and coral limestones in ascending order (Kinoshita, 2013), where limestones belonging to the Pleistocene Ryukyu Group cover most of the island (Fig. 1C). On the basis of boring data (Okinawa General Bureau, 1983) and rock exposure at Waji, the maximal thickness of the Ryukyu Group in Ie Island is known to be thicker than 50 m (Fujishiro, 1995). Basement rocks are exposed only around Mts. Gusuku and Gohezu. Limestones are slightly exposed around Mt. Gohezu whereas Mt. Gusuku is composed of bedded cherts. Outcrops comprising bedded cherts, siliceous mudstones, and sandstones are scattered in the south of Mt. Gusuku. Hashimoto et al. (1976) named the basement rocks around Mt. Gusuku the "Shiroyama Formation," although detailed characteristics were not described. Fujita (1989) then defined the Gusukuyama Formation as an equivalent of the pre-defined Shiroyama Formation. Fujita (1989) also named the basement rocks around Mt. Gohezu as the "Ie Formation," representing an extension of the Maedake, Iheya, and Izena formations in Iheya and Izena Islands, although the detailed characteristics were not described. Takami et al. (1999) proposed the unit division of accretionary complexes in Ie, Iheya, and Izena Islands and the Motobu Peninsula; according to this division, the basement rocks around Mt. Gusuku and Cape Bisezaki (the northwest end of the Motobu Peninsula) belong to the Ie unit. However, Nakae et al. (2010) followed the division of Fujita (1989) and named the basement rocks around Mt. Gusuku as the "Gusuykuyama Formation." Furthermore, Osozawa and Watanabe (2011) proposed the Ie Complex, which is distributed over both Mts. Gusuku and Gohezu, Cape Bisezaki, and the northeastern coast of Ie Island. The present study follows the description defined by Fujita (1989) and Nakae et al. (2010) in which the basement rocks in Ie Island are known as the Gusukuyama Formation. A geological summary of Ie Island is shown in Fig. 1D.

Bedded cherts are exposed at Waji on the north coast of Ie Island. Some researchers

have considered these cherts to be basement rocks (Ujiié and Hashimoto, 1983; Ujiié and Oba, 1991a; Shen et al., 1996; Takami et al., 1999). However, Osozawa and Watanabe (2011) and Ito and Matsuoka (2015) indicated that the cherts are contained as clasts within the Ryukyu Group at Waji but not basement rocks.

Stop descriptions

STOP 1. Mt. Gusuku

Mountain Gusuku is also known as "Tacchu" and is located in the central part of Ie Island. This mountain comprises bedded cherts, which generally strike W–E and dip 30° to 40° N, although several small folds are also recognized within the cherts. Limestones are exposed near stairs just south of the mountain (Fig. 2).

Permian, Triassic, and Jurassic radiolarians have been found to occur in the bedded cherts of Mt. Gusuku (Ujiié and Hashimoto, 1983; Fujita, 1989; Ujiié and Oba, 1991a, 1991b; Suzuki, 1992; Shen et al., 1996). *Neoalbaillella optima* Ishiga, Kito, and Imoto was obtained from chert near the start point of a climbing route for Mt. Gusuku (Shen et al., 1996), but the outcrop is currently covered by concrete (Fig. 2). *Neoalbaillella optima* is the diagnosed species from the *N. optima* Assemblage-Zone of the Changhsingian, Lopingian, upper Permian (Kuwahara et al., 1998). Although Triassic radiolarians were extracted, the occurrences were rare relative to the Jurassic radiolarian occurrences. For example, Ujiié and Oba (1991a) reported only one occurrence site of Triassic radiolarians; Shen et al. (1996) reported the Triassic radiolarian occurrences including *Palaeosaturnalis triassicus* (Kozur and Mostler) from three localities. *Palaeosaturnalis triassicus* ranges from the middle Carnian to the middle Norian (Dumitrica et al., 2010). In addition, Shen et al (1996) discovered *Kilinora spiralis* (Matsuoka), which is the diagnosis species of the *K. spiralis* Zone (JR6) of the Oxfordian, Upper Jurassic (Matsuoka, 1995), in the bedded cherts near the crest of Mt. Gusuku (Fig. 2).

In the south of the Mt. Gusuku, cherts and siliceous mudstones had been exposed near the Ie Junior High School, but most of these outcrops have now disappeared owing to land development. However, prior to the development, some researchers collected rock samples from the outcrops and conducted radiolarian preparation treatments (Ujiié and Hashimoto, 1983; Fujita, 1989; Ujiié and Oba, 1991b; Suzuki, 1992; Shen et al., 1996). The radiolarian age of the siliceous mudstones has been assigned as Tithonian–Berriasian by the researchers.

In this respect, Fig. 3 shows radiolarian photomicrographs from a siliceous mudstone sample that was collected at the northwest of Ie Junior High School in 1992 by A. Matsuoka. This radiolarian assemblage can be correlated to the *Pseudodictyomitra carpatica* Zone (KR1) of the Tithonian–Berriasian, uppermost Jurassic–lowermost Cretaceous (Matsuoka, 1995). The radiolarian age is thus consistent with the results of the above-mentioned previous studies.

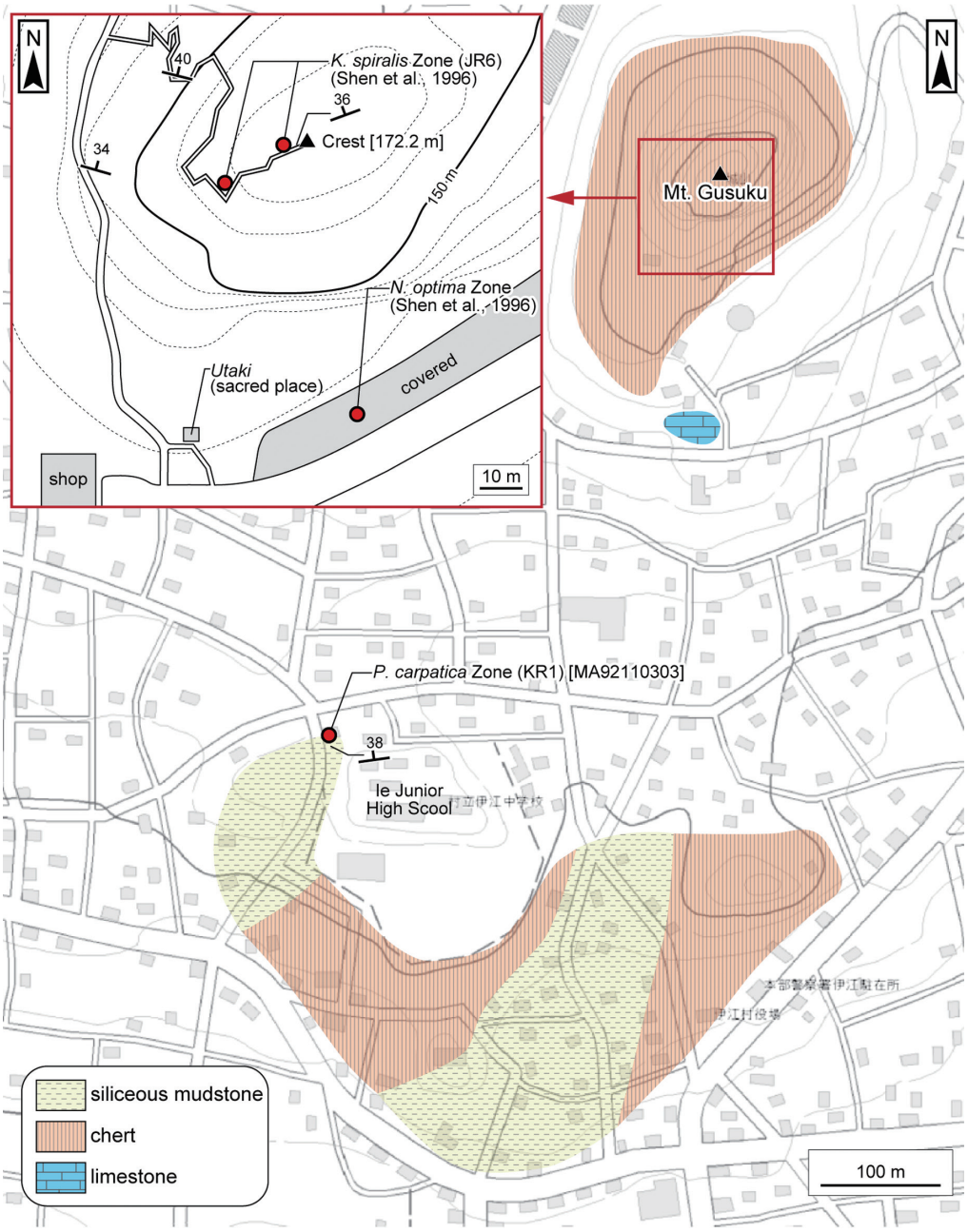

Fig. 2. Route map around Mt. Gusuku. Rock distribution around the Ie Junior High School is mainly based on Shen et al. (1996). Base map is from 1:50,000 topographic map "Ie-jima" published by Geospatial Information Authority of Japan.

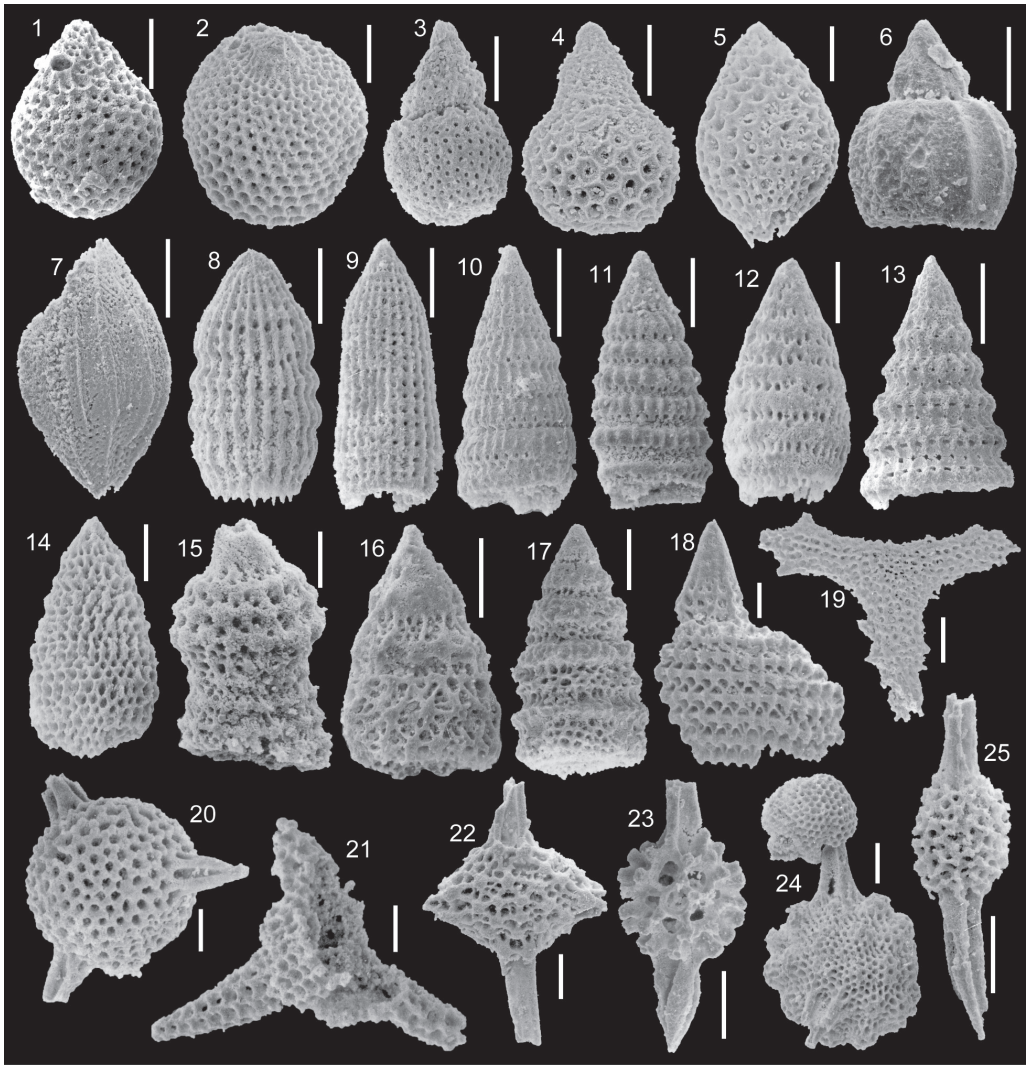

Fig. 3. Photomicrographs of radiolarian tests from MA92110303 collected at the west of the Ie Junior High School. **1:** *Zhamoidellum ovum* Dumitrica; **2:** *Cryptamphorella* sp.; **3:** *Hiscocapsa* sp.; **4:** *Hiscocapsa acuta* Hull; **5:** *Stichocapsa*(?) sp. aff. *S.*(?) *pulchella* (Rüst); **6:** *Eucyrtidiellum pyramis* (Aita); **7:** *Protunuma japonicus* Matsuoka and Yao; **8:** *Archaeodictyomitra minoensis* (Mizutani); **9:** *Archaeodictyomitra excellens* (Tan Sin Hok); **10:** *Loopus primitivus* (Matsuoka and Yao); **11:** *Pseudodictyomitra carpatica* (Lozyniak); **12:** *Loopus nudus* (Schaaf); **13:** *Praecaneta*(?) sp.; **14:** *Parvicingula*(?) sp.; **15:** *Ristola cretacea* (Baumgartner); **16:** *Xitus* sp.; **17:** *Cinguloturris carpatica* Dumitrica.; **18:** *Mirifusus dianae* (Karrer); **19:** *Paronaella*(?) *tubulata* Steiger; **20:** *Triactoma* sp.; **21:** *Podocapsa amphitreptera* Foreman; **22:** *Emiluvia* sp. cf. *E. chica* Foreman; **23:** *Pantanellium* sp.; **24:** *Acastea* sp.; **25:** *Archaeospongoprunum* sp. All scale bars are 50 μm.

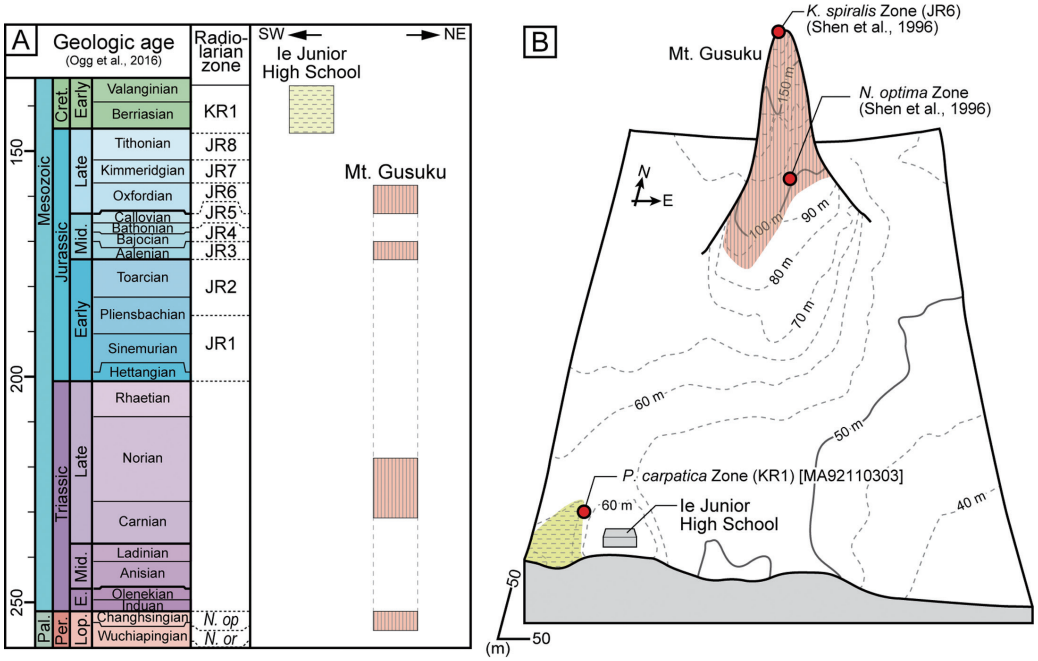

Fig. 4. Columnar and simplified three-dimensional graphic which show rock facies and age of the Gusukuyama Formation around Mt. Gusuku. Pal.: Paleozoic; Per.: Permian; Cret.: Cretaceous; E.: Early; Mid.: Middle.

On the basis of previous data and results of this present study (Fig. 4A), the bedded cherts at Mt. Gusuku range from the Changhsingian (Lopingian, upper Permian) to the Oxfordian (Upper Jurassic), whereas the siliceous mudstones near Ie Junior High School correspond to the Tithonian–Berriasian (uppermost Jurassic–lowermost Cretaceous). This implies that the younger siliceous mudstones near the Ie Junior High School are structurally located in a lower position than the older cherts at Mt. Gusuku (Fig. 4D). On the basis of this age difference, Shen et al. (1996) assumed the presence of a north-dipping thrust between these rocks and implied that the thrust represents an off-scrape accretionary process. However, as previously noted, the occurrence sites of Triassic radiolarians at Mt. Gusuku are a few relative to those of Jurassic radiolarians. If Mt. Gusuku is composed of a continuous succession of bedded cherts then this occurrence seems rather considerably uneven. It may imply the presence of other large faults within Mt. Gusuku.

STOP 2. Waji

Pleistocene limestones of the Ryukyu Group are well-exposed along the north coast of Ie Island. Red chert clasts, which vary in size ranging from several millimeters to approximately 6 m in diameter, are included within the limestones at Waji (Fig. 5). Ito and Matsuoka (2015) named the chert sequence (4.8 m in total thickness) found in the biggest

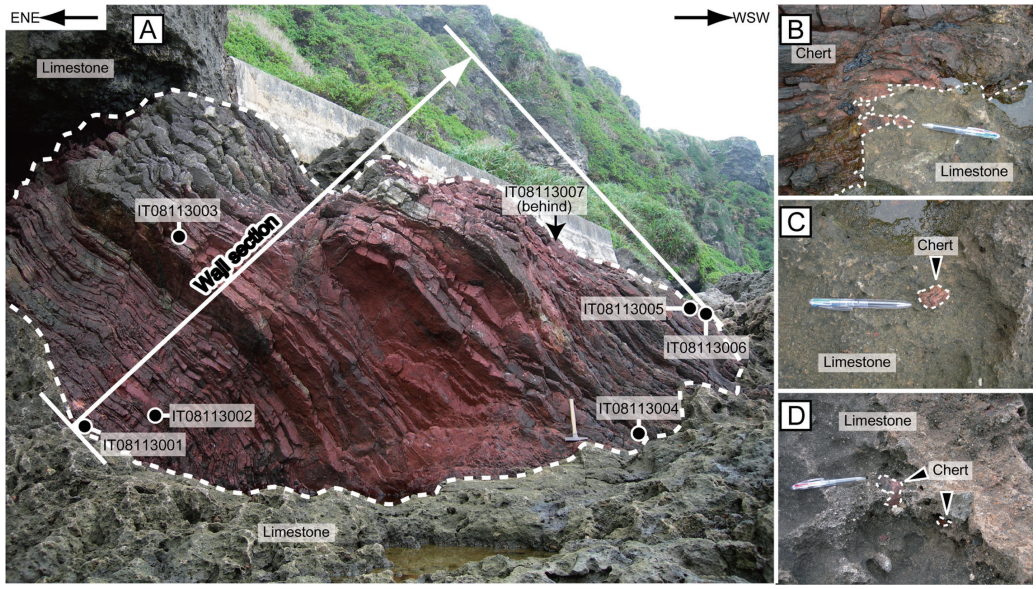

Fig. 5. Exposures of red cherts at Waji (after Ito and Matsuoka, 2015). **A:** Overall view of the Waji section; **B:** Boundary between chert boulder and limestone matrix; **C, D:** chert pebbles within limestone.

chert boulder at Waji the "Waji section" (Figs. 5A, 6A).

Permian radiolarians have been noted to occur in red cherts at Waji (Ujiié and Oba, 1991a; Shen et al., 1996; Ito and Matsuoka, 2015). Ujiié and Oba (1991a) reported Cisuralian (Early Permian) radiolarians such as *Albaillella sinuata* Ishiga and Watase and Capitanian (Guadalupian, Middle Permian) radiolarians such as *Pseudoalbaillella monacanthus* Ishiga and Imoto and *Follicucullus scholasticus* Ormiston and Babcock. Shen et al. (1996) obtained Changhsingian radiolarians such as *Albaillella triangularis* Ishiga, Kito, and Imoto. Ito and Matsuoka (2015) extracted Cisuralian radiolarians such as *A. sinuata* and *Pseudoalbaillella ishigai* Wang from the Waji section (Fig. 6).

Furthermore, Ujiié and Oba (1991a) and Ito and Matsuoka (2015) showed dimorphic pairs of the Order Albaillellaria. Ishiga (1991) had previously proposed and described that some taxa of the Albaillellaria are dimorphic represented by normal and swollen types. As the name suggests, swollen type specimens have a more swollen apical portion compared to normal type specimens (Fig. 6B). Ishiga (1991) also suggested the possibility that this dimorphism is caused by alternating generations, which is known in some living foraminifers (e.g., Leutenegger, 1977; Goldstein, 1999). Furthermore, the swollen type specimens have been recognized in some genera of the Albaillellidae and Follicucullidae (Table 1). The swollen type specimens are generally characterized by their rare occurrence and low population (2.1%–9.5%: Ishiga, 1991). However, the occurrence ratio of swollen type specimens of *A. sinuata* from one horizon in the Waji section is 27.1% (Ito and Matsuoka, 2015).

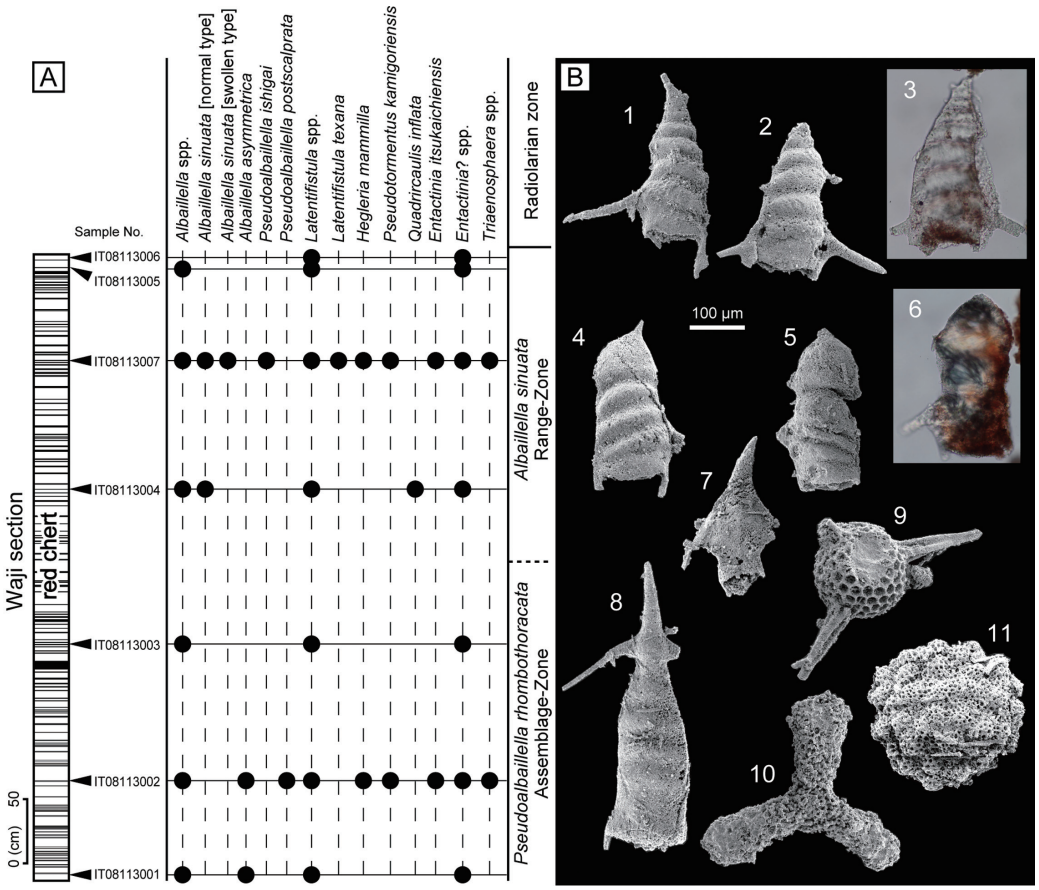

Fig. 6. Columnar of the Waji section and photomicrographs of major radiolarians obtained from the Waji section (modified from Ito and Matsuoka, 2015). **1–3:** Normal type of *Albaillella sinuata* Ishiga and Imoto; **4–6:** swollen type of *A. sinuata*; **7:** *Pseudoalbaillella postscalprata* Ishiga; **8:** *Pseudoalbaillella ishigai* Wang; **9:** *Triaenosphaera* sp.; **10:** *Latentifistula texana* Nazarov and Ormiston; **11:** *Hegleria mammilla* (Sheng and Wang). 1–6, 8–10: IT08113007; 7, 11: IT08113002.

Table 1. Illustrated Permian albaillellarian specimens of swollen-type in major previous studies.

Family	Genus	Species	Reference with plate and/or figure number	Age and locality	Original description
Albaillellidae Deflandre	*Albaillella* Deflandre	*A. sinuata* Ishiga and Watase	pl. 4, fig. 4, Ishiga et al., 1982a	Artinskian (Cisuralian), Tamba, Japan	*A.* sp. D
			pl. 4, figs. 9–10, Ujiié and Oba, 1991a	Artinskian (Cisuralian), Okinawa, Japan	Gen. et sp. indet.
			pl. 1, figs. 5–7, Xia and Zhang, 1998	Artinskian (Cisuralian), Guangxi, China	*A.* sp. aff. *A. sinuata*
			fig. 6.2, Zhang et al., 2002	Artinskian (Cisuralian), Guangxi, China	*A.* sp. aff. *A. sinuata*
			figs. 4.7–4.17, Ito and Matsuoka, 2015	Artinskian (Cisuralian), Okinawa, Japan	Swollen type of *A. sinuata*
		A. asymmetrica Ishiga and Imoto	pl. 3, figs. 10, 11, Ishiga et al., 1982a	Artinskian (Cisuralian), Tamba, Japan	*A. asymmetrica*
	Neoalbaillella Takemura and Nakaseko*	*N. optima* Ishiga, Kito and Imoto	pl. 1, fig. 32, Kuwahara and Yao, 1998	Changhsingian (Lopingian), Mino, Japan	*N.* sp. B
			pl. 1, fig. 5, Sashida et al., 2000	Changhsingian (Lopingian), Klaeng, Thailand	*N.*? sp.
			pl. 1fig. 12, Zhu et al., 2006	Changhsingian (Lopingian), N. Tibet, China	*N.* sp.
			fig. 3.10, Wu and Feng, 2008	Changhsingian (Lopingian), Guangxi, China	*N.* sp. A
			figs. 8.11–8.17, Wu et al., 2010	Changhsingian (Lopingian), Guangxi, China	*N. camarata* Wu and Feng
		N. pseudogrypa Sashida and Tonishi	pl. 1, fig. 12, Takemura et al., 2009	Changhsingian (Lopingian), Shikoku, Japan	Swollen type of *N. pseudogrypa*
		Neoalbaillella sp.**	pl. 34, figs. 2, 3, Takemura and Nakaseko, 1981	Changhsingian (Lopingian), Tamba, Japan	*N.* sp. A
			pl. 1, fig. 31, Kuwahara and Yao, 1998	Changhsingian (Lopingian), Mino, Japan	*N.* sp. A
			figs. 6.13–6.15, Jin et al., 2007	Changhsingian (Lopingian), Guangxi, China	*N.* sp. 1 and *N.* sp. 2
			figs. 8.18–8.21, 8.23, Wu et al., 2010	Changhsingian (Lopingian), Guangxi, China	*N. cephalota* Wu and Feng
Follicucullidae Ormiston and Babcock	*Pseudoalbaillella* Holdsworth and Jones***	*P. lomentaria* Ishiga and Imoto	pl. 2, figs. 14, 15, Ishiga and Imoto, 1980	Sakmarian (Cisuralian), Tamba, Japan	*P. lomentaria*
		P. sakmarensis Kozur	pl. 3, fig. 2, Ishiga and Imoto, 1980	Sakmarian (Cisuralian), Tamba, Japan	*P.* sp. A
		P. simplex Ishiga and Imoto or short form of *Pseudoalbaillella* species	pl. 1, fig. 19, Ishiga et al., 1984	Asselian? (Cisuralian), Tamba, Japan	*P. simplex*
		P. anfractus (Nazarov and Rudenko)	pl. 2, figs. 1–16, Panasenko and Rudenko, 1987	Sakmarian (Cisuralian), South Ural	*Haplodiacanthus anfractus*
		Short form of *P. fusiformis* (Holdsworth and Jones) sensu Ito et al., 2015	pl. 2, figs. 5, 7, Ishiga et al., 1982a	Roadian (Guadalupian), Tamba, Japan	*P.* sp. aff. *P. longicornis* Ishiga and Imoto
		P. ornata Ishiga and Imoto	pl. 1, figs. 2–4, Ishiga, 1991	Sakmarian (Cisuralian), Tamba, Japan	Swollen-type of *P. ornata*
		P. globosa Ishiga and Imoto	pl. 3, figs. 11, 12, Xia and Zhang, 1998	Roadian (Guadalupian), Guangxi, China	*P. globosa* m. II
	Follicucullus Ormiston and Babcock	*F. porrectus* Rudenko	pl. 3, fig. 2, Ujiié and Oba, 1991a	Capitanian (Guadalupian), Okinawa, Japan	*F. scholasticus* Ormiston and Babcock

* Ishiga (1991) noted the presence of swollen-type of *N. ornithoformis* Takemura and Nakaseko and *N. gracilis* Takemura and Nakaseko in the text. ** These specimens lack their pseudoabdomen and/or wings, so that their corresponding species are indeterminable. *** Ishiga (1991) noted the presence of swollen-type of *P. elongata* Ishiga and Imoto in the text.

Acknowledgements

We are grateful to Prof. Yoshiaki Aita (Utsunomiya University) for careful review and helpful comments which improved the manuscript.

References

Dumitrica, P., Tekin, U. K. and Bedi, Y., 2010, Eptingiacea and Saturnaliacea (Radiolaria) from the middle Carnian of Turkey and some late Ladinian to early Norian samples from Oman and Alaska. *Paläontologische Zeitschrift*, **84**, 259–292.

Fujishiro, N., 1995, The coral assemblages and developmental history of the Pleistocene coral reef of Ie Island, Okinawa Prefecture. *102nd Ann. Meet. Geol. Soc. Japan, Abstr.*, 190 (in Japanese).

Fujita, H., 1989, Stratigraphy and geologic structure of the pre-Neogene strata in the central Ryukyu Islands. *Jour. Sci. Hiroshima Univ. Ser. C*, **9**, 237–284.

Goldstein, S. T., 1999, Foraminifera: A biological overview. *In* Sen Gupta, B. K., ed., *Modern Foraminifera*. Kluwer Academic Publishers, pp. 50–68.

Hashimoto, S., Yoshida, K., Minoura, K. and Nakagawa, H., 1976, Geology of the northern part of Okinawa-jima – A preliminary report, Part I. *Geol. Study Ryukyu Isls.*, **1**, 9–20 (in Japanese).

Ishiga, H., 1991, "Dimorphic pairs" of Albaillellaria (Late Paleozoic Radiolaria), Japan. *Mem. Fac. Sci., Shimane Univ.*, **25**, 119–129.

Ishiga, H. and Imoto, N., 1980, Some Permian radiolarians in the Tamba District, southwest Japan. *Earth Sci. (Chikyu Kagaku)*, **34**, 333–345.

Ishiga, H., Imoto, N., Yoshida, M. and Tanabe, T., 1984, Early Permian radiolarians from the Tamba belt, Southwest Japan. *Earth Sci. (Chikyu Kagaku)*, **38**, 44–52.

Ishiga, H., Kito, T. and Imoto, N., 1982a, Middle Permian radiolarian assemblages in the Tamba district and an adjacent area, southwest Japan. *Earth Sci. (Chikyu Kagaku)*, **36**, 272–281.

Ishiga, H., Kito, T. and Imoto, N., 1982b, Permian radiolarian biostratigraphy. *News Osaka Micropaleontol. (NOM), Spec. Vol.*, no. 5, 17–26 (in Japanese with English abstract).

Isozaki, Y., Aoki, K., Nakama, T. and Yanai, S., 2010, New insight into a subduction-related orogen: A reappraisal of the geotectonic framework and evolution of the Japanese Islands. *Gondwana Res.*, **18**, 82–105.

Ito, T., Feng, Q. L. and Matsuoka, A., 2015, Taxonomic significance of short forms of middle Permian *Pseudoalbaillella* Holdsworth and Jones, 1980 (Follicucullidae: Radiolaria). *Rev. Micropaléont.*, **58**, 3–12.

Ito, T. and Matsuoka, A., 2015, Swollen type of *Albaillella sinuata* Ishiga and Watase (Permian radiolaria) from a chert boulder in Ie-jima Island, Okinawa Prefecture, Japan. *News Osaka Micropaleontol. (NOM), Spec. Vol.*, no. 15, 207–217.

Jin, Y. X., Feng, Q. L., Meng, Y. Y., He, Q. H. and Gu, S. Z., 2007, Albaillellidae (Radiolaria) from the Latest Permian in Southern Guangxi, China. *Jour. Paleont.*, **81**, 9–18.

Kinoshita, N., 2013, Studies on the Nagarabaru-Higashi shellmound: Iejima, Okinawa, during the 5th century through first half of 7th century. *Rep. Grant-in-Aid Sci. Res. (A) 2009~2012, Japan,* 392p. (in Japanese).

Konishi, K., 1963, Pre-Miocene basement complex of Okinawa and tectonic belt of the Ryukyu Islands. *Sci. Rep. Kanazawa Univ.*, **8**, 569–602.

Kuwahara, K. and Yao, A., 1998, Diversity of Late Permian radiolarian assemblages. *News Osaka Micropaleont. (NOM), Spec. Vol.*, no. 11, 33–46 (in Japanese with English abstract).

Kuwahara, K., Yao, A. and Yamakita, S., 1998, Reexamination of Upper Permian radiolarian biostratigraphy. *Earth Sci. (Chikyu Kagaku)*, **52**, 391–404.

Leutenegger, S., 1977, Reproductive cycles of larger foraminifera and depth distribution of generations. *Utrecht Micropaleont. Bull.*, **15**, 27–34.

Matsuoka, A., 1995, Jurassic and Lower Cretaceous radiolarian zonation in Japan and the western Pacific.

Island Arc, **4**, 140–153.

Matsuoka, A., Aita, Y., Munasri, Wakita, K., Shen, G., Ujiié, H., Sashida, K., Vishnevskaya, V., Bragin, N. and Cordey, F., 1996, Mesozoic radiolarians and radiolarian-bearing sequences in the circum-Pacific regions: A report of the symposium 'Radiolarians and Orogenic Belts'. *Island Arc,* **5**, 203–213.

Nakae, S., Kaneko, N., Miyazaki, K., Ohno, T. and Komazawa, M., 2010, *Geological Map of Japan 1:200,000, Yaron Jima and Naha*. Geological Survey of Japan, AIST (in Japanese with English abstract).

Ogg, J. G., Ogg, G. M. and Gradstein, F. M., 2016, A *Concise Geologic Time Scale 2016*. Elsevier, Amsterdam, 234p.

Okinawa General Bureau, 1983, *Ground water of Okinawa Prefecture: hydrogeological map of Okinawa Prefecture**. 95p. (in Japanese). *The title was translated by the authors.

Osozawa, S. and Watanabe, Y., 2011, *Geology of Nago and Yambaru District*. Nago Museum, 209p. (in Japanese with English abstract).

Panasenko, E. S. and Rudenko, B. S., 1987, Systematic significance of some morphologic feature of Albaillellidae (Paleozoic). *Paleont. Jour*., 13–21 (in Russian).

Sashida, K., Salyapongse, S. and Nakornsri, N., 2000, Latest Permian radiolarian fauna from Klaeng, eastern Thailand. *Micropaleontology*, **46**, 245–263.

Shen, G. P., Ujiié, H. and Sashida, K., 1996, Off-scraped Permian–Jurassic bedded chert thrust on Jurassic–early Cretaceous accretionary prism: Radiolarian evidence from Ie Island, central Ryukyu Island Arc. *Island Arc*, **5**, 156–165.

Suzuki, H., 1992, Mesozoic radiolarian fauna from the Ie Island, Okinawa Prefecture. *99th Ann. Meet. Geol. Soc. Japan, Abstr*., 124 (in Japanese).

Takami, M., Takemura, R., Nishimura, Y. and Kojima, T., 1999, Reconstruction of oceanic plate stratigraphies and unit division of Jurassic–Early Cretaceous accretionary complexes in the Okinawa Islands, central Ryukyu Island Arc. *Jour. Geol. Soc. Japan*, **105**, 866–880 (in Japanese with English abstract).

Takemura, A. and Nakaseko, K., 1981, A new Permian radiolarian genus from the Tamba Belt, Southwest Japan. *Trans. Proceed. Palaeont. Soc. Japan, New Ser*., no. 124, 208–214.

Takemura, A., Ueshima, S., Miyake, A., Takemura, S. and Yamakita, S., 2009, Late Permian radiolarian fauna from a phosphatic nodule in Northern Chichibu Belt, Shikoku, Southwest Japan. *News Osaka Micropaleontol. (NOM), Spec. Vol.*, no. 14, 583–594 (in Japanese with English abstract).

Ujiié, H. and Hashimoto, Y., 1983, Geology and radiolarian fossils of the inner "Motobu Belt" in the Okinawa-jima region. *Earth Monthly (Gekkan Chikyu)*, **5**, 706–712 (in Japanese).

Ujiié, H. and Oba, T., 1991a, Geology and Permo–Jurassic radiolaria of the Iheya zone, innermost belt of the Okinawa Island Region, Middle Ryukyu Island Arc, Japan. Part 1. Geology and Permian radiolaria. *Bull. Coll. Sci., Univ. Ryukyus*, no. 51, 35–55.

Ujiié, H. and Oba, T., 1991b, Geology and Permo–Jurassic radiolaria of the Iheya zone, innermost belt of the Okinawa Island Region, Middle Ryukyu Island Arc, Japan. Part 2. Mesozoic radiolaria and geological structure. *Bull. Coll. Sci., Univ. Ryukyus*, no. 52, 53–89.

Wu, J. and Feng, Q. L., 2008, Late Changhsingian radiolarian biostratigraphy from Guangxi, South China and its correlation to conodonts. *Sci. China Ser. D: Earth Sci*., **51**, 1601–1610.

Wu, J., Feng, Q. L., Gui, B. W. and Liu, G. C., 2010, Some new radiolarian species and genus from Upper Permian in Guangxi Province, South China. *Jour. Paleont*., **84**, 879–894.

Xia, W. C. and Zhang, N., 1998, Early to Middle Permian radiolarians from the Kuhfeng Formation in southeastern Guangxi, South China. *Earth Sci. (Chikyu Kagaku)*, **52**, 188–202.

Zhang, N., Xia, W. C. and Shao, J., 2002. Radiolarian successional sequences and rare earth element variations in Late Paleozoic chert sequences of South China: An integrated approach for study of the evolution of paleo-ocean basins. *Geomicrobiol. Jour*., **19**, 439–460.

Zhu, T. X., Zhang, Q. Y., Dong, H., Wang, Y. J., Yu, Y. S. and Feng, X. T., 2006., Discovery of the Late Devonian and Late Permian radiolarian cherts in tectonic mélanges in the Cêdo Caka area, Shuanghu, northern Tibet, China. *Geol. Bull. China*, **25**, 1413–1418 (in Chinese with English abstract).