GUADALUPIAN AND LOPINGIAN (MIDDLE AND LATE PERMIAN) RADIOLARIANS FROM CHERT BLOCKS WITHIN CONGLOMERATE OF THE MINO BELT, SOUTHWEST JAPAN

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ABSTRACT

Capitanian (late Guadalupian, Middle Permian) and Changhsingian (late Lopingian, Late Permian) radiolarians were obtained from chert blocks within the conglomerates of the Kamiaso Complex of the Mino Belt in Awano, Gifu Prefecture, central Japan. The former contains 15 species assigned to 10 genera with 4 undetermined species, and the latter contains 5 species assigned to 11 genera with 9 undetermined species. The chert blocks were presumably derived from an accretionary complex prior to accretion on the oceanic plate.

INTRODUCTION

Jurassic accretionary complexes (ACs) are widely exposed in Southwest Japan and their oceanic plate stratigraphy (OPS) has been reconstructed (e.g., Isozaki et al., 1990; Matsuda and Isozaki, 1991; Nakae, 2000; Wakita and Metcalfe, 2005). Presently, based on numerous studies on radiolarians and conodonts, the ages of each lithology in the OPS of the Jurassic ACs have been determined (Matsuoka et al., 1998; Nakae, 2000; Kojima et al., 2016). The typical OPS of Jurassic ACs is composed of Carboniferous-Permian ocean-ridge basalt, Carboniferous-Permian pelagic carbonate, Carboniferous-Jurassic pelagic chert with the uppermost Permian-Lower Triassic siliceous claystone, Jurassic hemipelagic siliceous mudstone, and trench-fill mudstone and sandstone (Wakita and Metcalfe, 2005).

Conglomerate overlying the sandstone in the OPS is known to be found in some geological units of the Jurassic ACs, such as Kamiaso Conglomerate (Adachi, 1971), Sakahogi Conglomerate (Kondo and Adachi, 1975), Wadano Conglomerate (Kanuma, 1956), Kawachidani Conglomerate (Adachi and Wakita, 1979), Kanmuriyama Conglomerate (Hattori et al., 1985), Sawando Conglomerate (Tanaka et al., 1952), and Bansho Conglomerate (Otsuka, 1985). In contrast to numerous studies on siliceous and muddy rocks (chert, siliceous mudstone, and mudstone), few radiolarian studies have been conducted on blocks within conglomerate in the OPS.

Ito et al. (2016b) preliminarily reported on Guadalupian and Lopingian (Middle and Late Permian) radiolarians from chert blocks in the distributional area of conglomerate layers of the Kamiaso Complex of the Mino Belt. In this study, we report a radiolarian assemblage with spicule assemblages from Permian chert blocks based on re-investigation. On that basis, the origin of the chert blocks has been discussed.

GEOLOGICAL SETTING

The Mino Belt (with the Tamba and Ashio belts) contains the Jurassic ACs of the Inner Zone of Southwest Japan (Fig. 1a). According to Nakae (2000), those in the Mino area comprises seven geologic units, i.e., the Sakamototoge, Samondake, Funafuseyama, Kuze, Nabi, Kamiaso, and Kanayama complexes. The Kamiaso Complex (Wakita, 1988; Nakae, 2000) is considered in this study. The complex is characterized by repeats of coherent sequences of the lowermost Triassic siliceous claystone, Triassic-Middle Jurassic chert, Middle Jurassic siliceous mudstone and mudstone, and overlying sandstone with conglomerates (Wakita, 1988; Nakae, 2000). These lithologies present chert-clastic sequences of upper OPS.

The abundance of conglomerates is one of the major characteristics of the Kamiaso Complex. The Kamiaso, Wadano, and Sakahogi conglomerates are well known. The conglomerate layers of the Kamiaso Complex are stratigraphically located in the uppermost part of the repeated sequences. The conglomerate of the Kamiaso Complex contains several lithoclasts of large blocks such as limestone, chert, and basalt (Fig. 1b).

The sampling localities in this study were located in southern Awano, near the Tsubogawa River (Fig. 1c). We collected eight chert samples from two chert blocks: seven from the riverside (Fig. 2) and one from the roadside chert blocks. The riverside chert block is a dark gray-red bedded chert of approximately 5 m in total thickness, and the block contains a layer of sample KY2014061103 of Ito et al. (2016b). The roadside chert block was a dark-gray massive chert, and sample KY2014061107 from Ito et al. (2016b) was collected from the block. These chert blocks are located in the distributional area of the conglomerate of the Kamiaso Complex; therefore, they are large, intercalated blocks within thick conglomerate layers.

MICROFOSSIL OCCURRENCES AND AGE ASSIGNMENTS

Methods for microfossil extraction

The samples were treated as follows: they were crushed into fragments of approximately 1 cm and soaked in a 3%

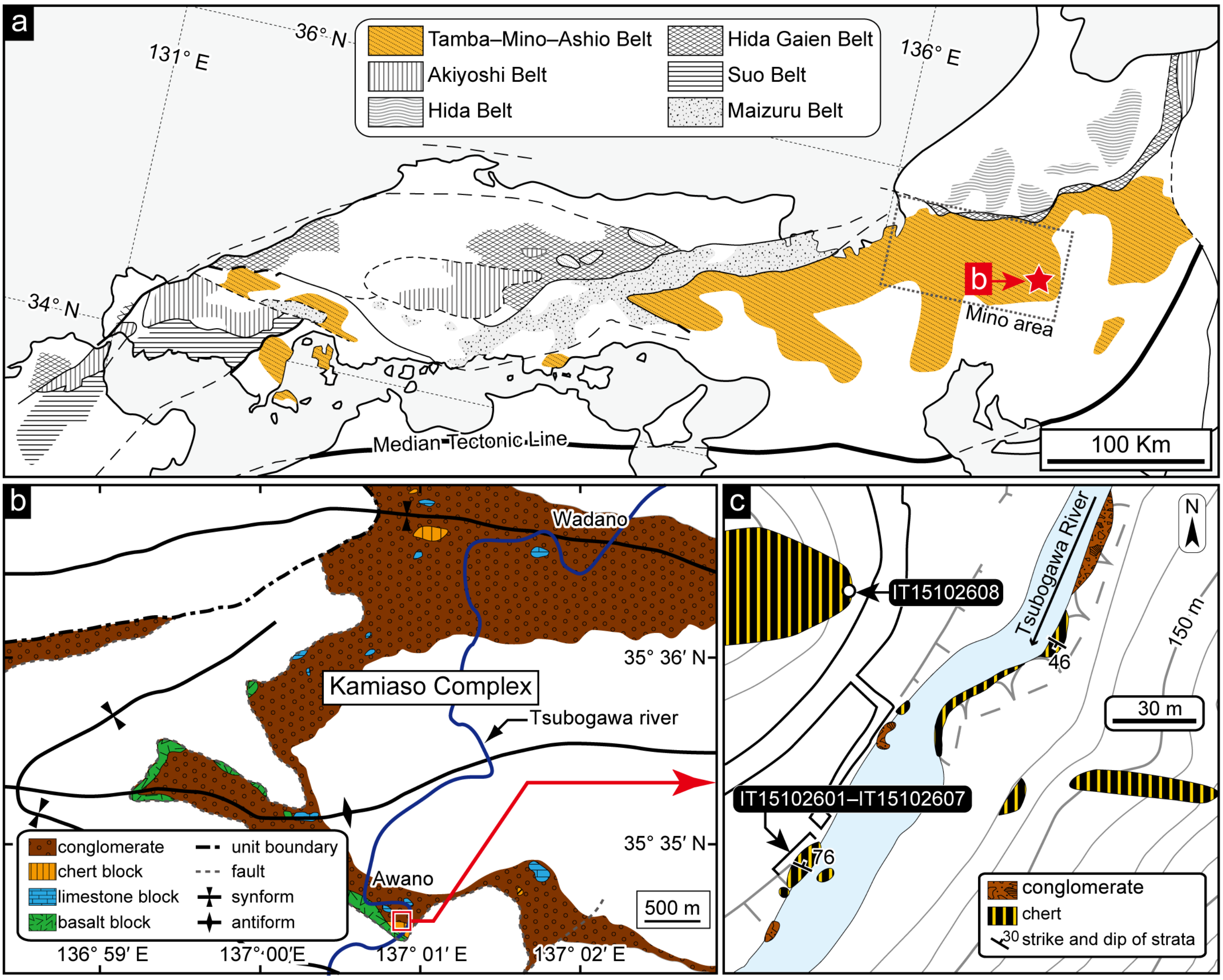

Fig. 1 - Index map of the study area. a) Simplified geologic map of the Inner Zone of Southwest Japan (modified from Kanmera et al., 1990). Dashed lines indicate presumed or concealed boundaries of the belts. b) Distribution of conglomerate with blocks around the Tsubogawa River, Gifu Prefecture, Japan (modified from Ito et al., 2016b). c) Traverse map of the sampling sites (modified from Ito et al., 2016b). The reader is referred to the PDF online for a colour version.

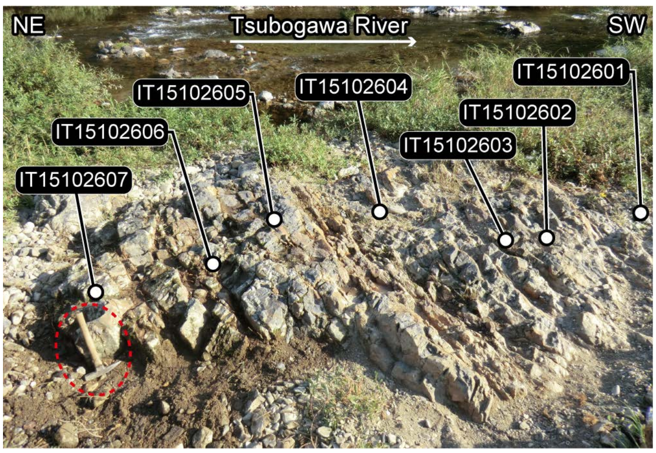

Fig. 2 - Chert block exposed in riverside of the Tsubogawa River. A red circle indicates a hammer as scale (length: ca. 35 cm).

hydrofluoric acid (HF) solution for 24 h at room temperature (ca. 20-30°C). The HF solution was removed, and the containers with the etched samples were refilled with fresh HF solution. This process was repeated three times. Some of the residues were enclosed within the prepared slides with mounting medium (Entellan New) and photographed using a transmitted light microscope. Adequate residues were collected through a sieve with a mesh diameter of 0.054 mm and dried for examination under a binocular microscope. Well-preserved specimens were mounted on stubs and photographed using a scanning electron microscope for a more detailed observation.

The occurrence ratios and extracted radiolarians and spicules for each sample are shown in Fig. 3. The taxonomy of most radiolarians was based on Noble et al. (2017), whereas that of Albaillellaria was based on Xiao et al. (2020; 2021) and Ito and Suzuki (2022). The terminology for the spicules was based on the work of Boury-Esnault

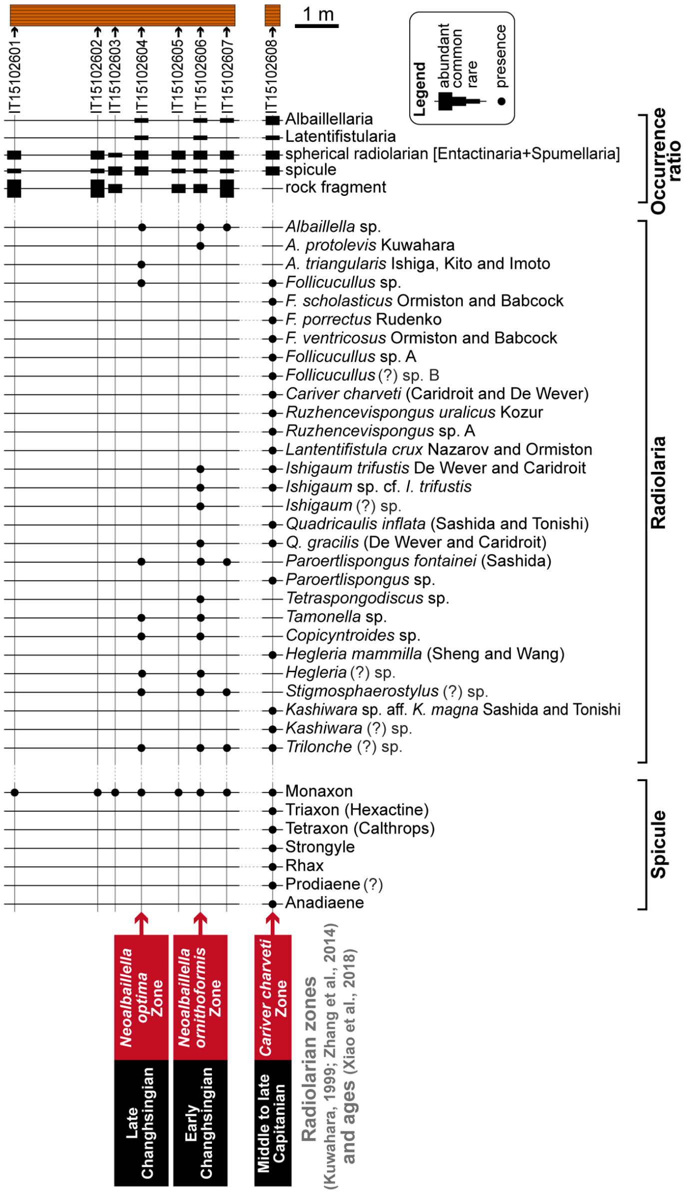

Fig. 3 - Occurrence ratio and extracted species of radiolarians and spicules from chert blocks of the Kamiaso Complex.

and Rützler (1997). Photomicrographs of the transmitted light microscopy and SEM images of Albaillellaria are shown in Fig. 4, those of Latentifistularia in Fig. 5, those of Entactinaria and Spumellaria in Fig. 6, and those of the spicules in Fig. 7.

Radiolarian occurrences

Sample (IT15020608) from the roadside chert block (Fig. 1c) yielded common specimens of Albaillellaria and spherical radiolarians (Entactinaria and possibly Spumellaria) with rare specimens of Latentifistularia. We identified 15 species that were assigned to 10 genera of radiolarians with 4 undetermined species (Figs. 3-6). Ito et al. (2017) reported a bi-apical *Follicucullus*, which is a possible malformed individual of *Follicucullus porrectus* Rudenko, from this sample. *Follicucullus* sp. A has a club-shaped swollen apical cone that differs from previously known species.

Samples (IT15020601-IT15020607) from the riverside chert block (Figs. 1c, 2) yielded the orders Albaillellaria and Latentifistularia and spherical radiolarians (Entactinaria and possibly Spumellaria). Albaillellaria were detected in three samples; however, they were rare. Spherical radiolarians were observed in all samples. Latentifistularia were rarely detected in either sample. We identified 5 species that were assigned to 11 genera of radiolarians with 9 undetermined species (Figs. 3-6).

Spicule occurrences

Sample (IT15020608) from the roadside chert block yielded common spicules. Several types of spicules, such as monaxon, triaxon, tetraxon, strongyle, rhax, prodiaene?, and anadiaene (Fig. 7), were observed. Except for possible monaxon, triaxon (hexactine) is common, whereas polyaxon is not observed. Based on the investigation by Murchey (2004), the occurrence of anadiaene and hexactine with no protriaene or anatriaene indicates that they originated from the sponge Hexactinellida. Meanwhile, as Ito et al. (2016c) pointed out, we need to be careful whether Murchey's investigation can be applied directly because it is based on recent sponges.

Samples (IT15020601-IT15020607) from the riverside chert block yielded common spicules. In contrast to the sample from the roadside chert block, the samples from the riverside block yielded only monaxon. Owing to the lack of diversity of spicule type, the origin of the block is unknown.

Age assignment

Sample (IT15020608) of the roadside block yielded *Cariver charveti* (Caridroit and De Wever) (Fig. 4q), *Follicucullus porrectus* Rudenko (Fig. 4d-h, l-n, w), *Follicucullus scholasticus* Ormiston and Babcock (Fig. 4i, k), and *Follicucullus ventricosus* Ormiston and Babcock (Fig. 4o, p). Based on the co-occurrence of these species, the sample can be correlated to the *Cariver charveti* Zone (=*Follicucullus charveti* Zone of Zhang et al., 2014; Fig. 3) indicating the late Capitanian, late Guadalupian, Middle Permian in age.

Among the riverside block samples, IT15102604 and IT15102606 yielded *Albaillella triangularis* Ishiga, Kito and Imoto (Fig. 4b) and *Albaillella protolevis* Kuwahara (Fig. 4c), respectively. According to the detailed work on Late Permian *Albaillella* lineage by Kuwahara (1999), the first appearance horizon of *Albaillella protolevis* is the base of the *Neoalbaillella ornithoformis* Zone and its occurrence range reaches *Neoalbaillella optima* Zone; the first appearance horizon of *Albaillella triangularis* is the base of the *Neoalbaillella optima* Zone. Based on this, samples IT15102604 and IT15102606 were tentatively correlated with the *Neoalbaillella optima* (late Changhsingian) and *Neoalbaillella ornithoformis* (early Changhsingian) zones, respectively (Fig. 3). Both zones indicate the Changhsingian, late Lopingian, Late Permian in age (Xiao et al., 2018).

IMPLICATIONS FOR ORIGIN OF THE CHERT BLOCKS

From the perspective of radiolarian assemblages, the samples analyzed in this study were characterized by the absence of the genus *Pseudotormentus* De Wever and Caridroit and presence of *Quadricaulis* Caridroit and De Wever. The former genus has been identified in several geological units of

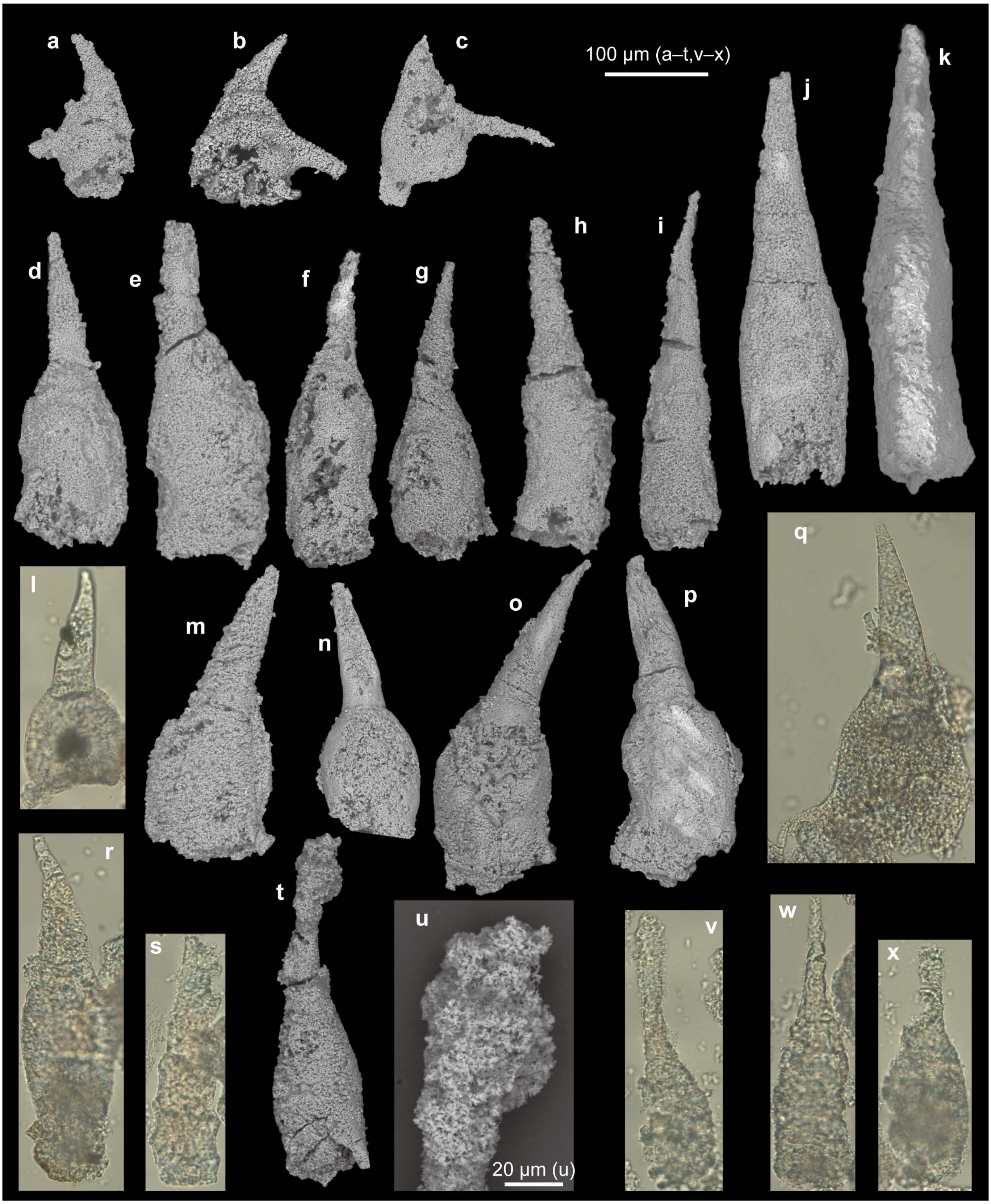

Fig. 4 - Photomicrographs and SEM images of the Albaillellaria from the chert blocks of the Kamiaso Complex. a) *Albaillella* sp., IT15102606. b) *Albaillella triangularis* Ishiga, Kito and Imoto, IT15102604. c) *Albaillella protolevis* Kuwahara, IT15102606. d-h, l-n, w) *Follicucullus porrectus* Rudenko, IT15102608. i, k) *Follicucullus scholasticus* Ormiston and Babcock, IT15102608. j, r) intermediate form of *F. porrectus* and *F. scholasticus*, IT15102608. o, p) *Follicucullus ventricosus* Ormiston and Babcock, IT15102608. q) *Cariver charveti* (Caridroit and De Wever), IT15102608. s) *Follicucullus* (?) sp. B, IT15102608. t, v, x) *Follicucullus* sp. A, IT15102608. u) Enlarged image of apical cone of t.

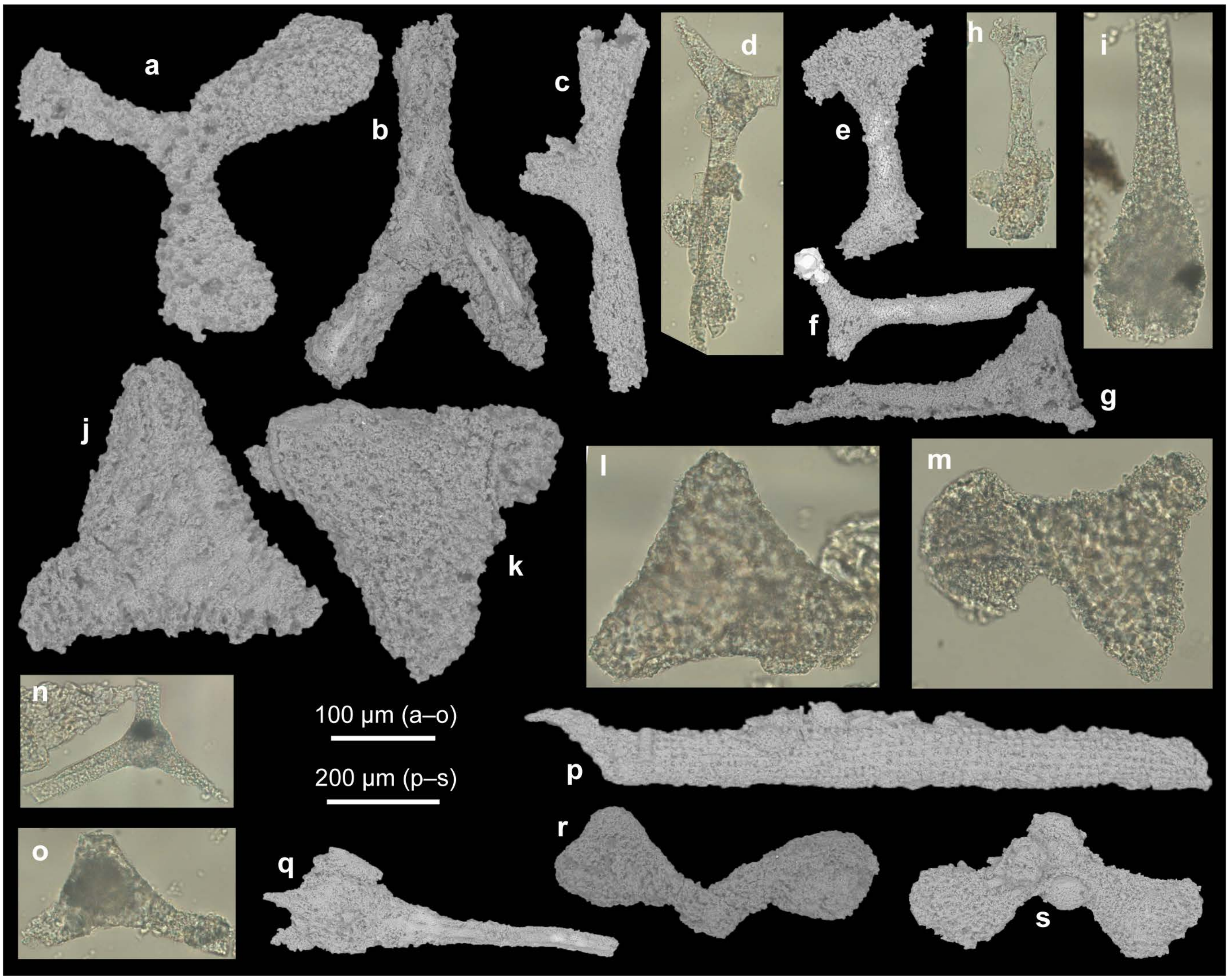

Fig. 5 - Photomicrographs and SEM images of the Latentifistularia from the chert blocks of the Kamiaso Complex. a, b, r, s) *Latentifistula crux* Nazarov and Ormiston, IT15102608. c, e) *Ishigaum trifustis* De Wever and Caridroit, IT15102606. d, h) *Ishigaum* sp. cf. *I. trifustis* De Wever and Caridroit, IT15102608. f) *Ishigaum* sp. cf. *I. trifustis* De Wever and Caridroit, IT15102606. i) *Ishigaum* (?) sp., IT15102606. g, o, p) *Quadricaulis inflata* (Sashida and Tonishi), IT15102608. j-l) *Ruzhencevispongus uralicus* Kozur, IT15102608. m) *Ruzhencevispongus* sp. A, IT15102608. a, q) *Quadricaulis gracilis* (De Wever and Caridroit), IT15102608. n) *Quadricaulis gracilis* (De Wever and Caridroit), IT15102608.

the Japanese Islands (Ito et al., 2016a), and Ito et al. (2016a; 2020) considered it as the facies genus of Panthalassa with using comparison of both *Pseudotormentus* and *Quadricaulis* (originally *Quadriremis* in Ito et al., 2016a). Thus, the radiolarian assemblage seems to differ from the previously reported Permian assemblages of the Japanese Islands.

There are three possible origins of gravel within the OPS: (i) an on-land geological body (i.e., from normal strata on land), (ii) an accretionary complex (AC) after accretion, and (iii) an AC before accretion. In cases (i) and (ii), the chert blocks were transported over long distance and crushed to reduce the size. The chert blocks considered in this study were enormous; therefore, they were unlikely to have been transported over long distances. Furthermore, as mentioned above, the radiolarian assemblage seems to differ from already known assemblages reported from currently exposed geological units, including (i) an on-land geologic body and (ii) an AC after accretion. Therefore, case (iii) is the most plausible among the possible origins (Fig. 8).

The mechanism through which blocks are supplied from the pre-accretionary oceanic plate is known to be the development of normal faults in the outer ridge (Kanamori, 1977; Carminati et al., 2014). At the early subduction stage, the subduction angle of the slab was low and compressive stresses acted on the oceanic plate. As the stage advances, the subduction angle of the slab becomes steeper, and tensile stresses act on the oceanic plate to form a normal fault. Particularly, the formation of normal faults in the oceanic plate is considered to have occurred at a relatively late stage of slab subduction (Kanamori, 1977). Numerical simulations have recently evaluated the effects of plate age and subduction velocity on the plate subduction angle. Naliboff et al. (2013) identified the age of the plate as one of the factors in the formation of normal faults.

The Izanagi Plate, the plate of the Jurassic accretionary complexes (ACs), was formed in the Devonian and accreted mainly in the Early to Late Jurassic age (Wakita and Metcalfe, 2005). The conglomerate layers within the oceanic plate stratigraphy (OPS) of the Jurassic ACs are found in younger

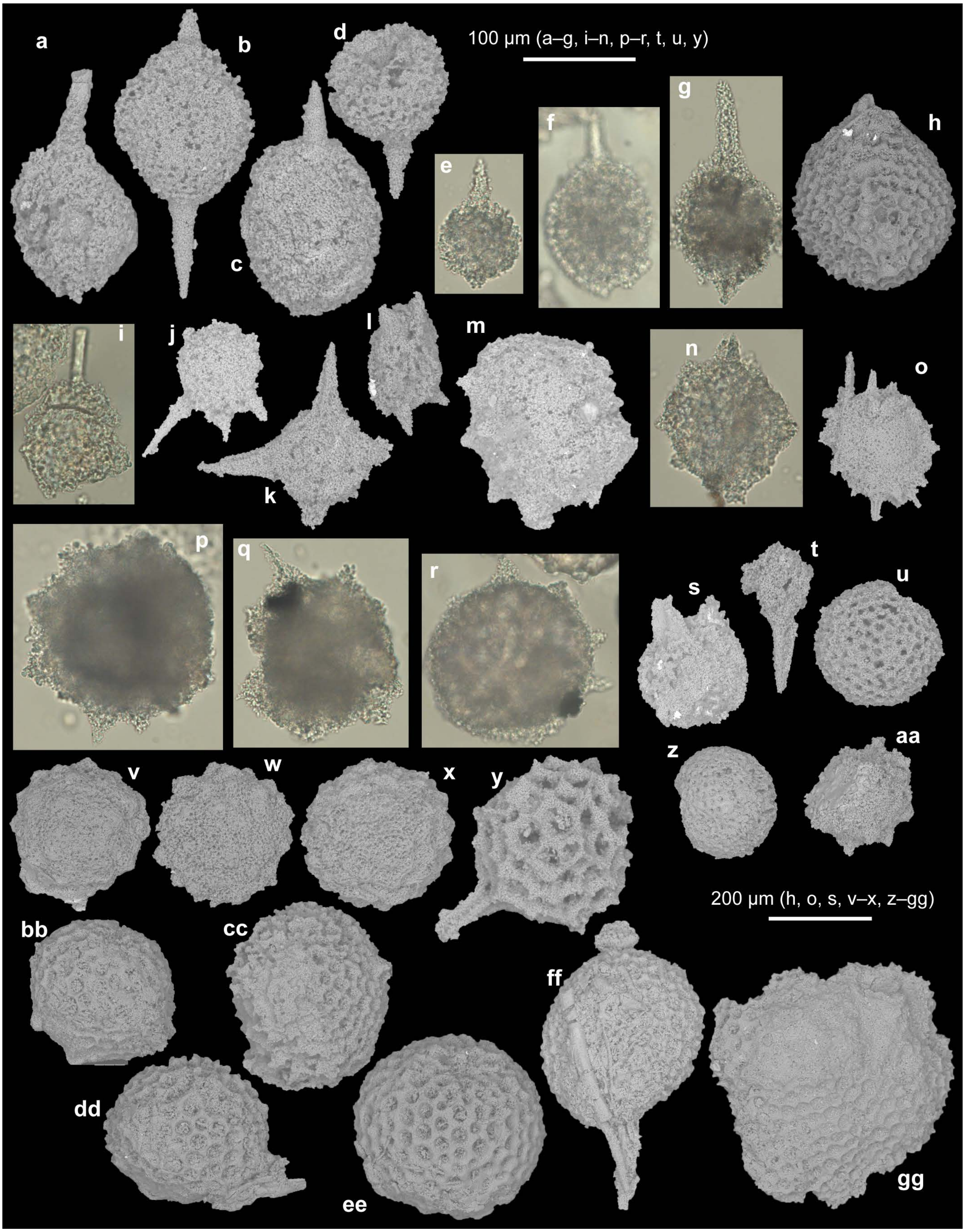

Fig. 6 - Photomicrographs and SEM images of the Entactinaria and Spumellaria from the chert blocks of the Kamiaso Complex. a-d) *Paroertlispongus fontainei* (Sashida), IT15102606. e, g) *Paroertlispongus fontainei* (Sashida), IT15102604. f) *Paroertlispongus fontainei* (Sashida), IT15102607. i) *Paroertlispongus* sp., IT15102608. k, t) *Tetraspongodiscus* sp., IT15102606. j) *Tamonella* sp. IT15102604. l) *Tamonella* sp. IT15102606. m, n) *Copicyntroides* sp., IT15102604. o-r) *Copicyntroides* sp., IT15102606. s) *Stigmosphaerostylus* (?) sp., IT15102604. y) *Stigmosphaerostylus* (?) sp., IT15102606. h, u, cc, ff) *Trilonche* (?) sp., IT15102608. z) *Trilonche* (?) sp., IT15102606. v-x) *Hegleria mammilla* (Sheng and Wang), IT15102608. aa) *Hegleria* (?) sp., IT15102606. bb, dd, ee) *Kashiwara* sp. aff. *K. magna* Sashida and Tonishi, IT15102608. gg) *Kashiwara* (?) sp., IT15102608.

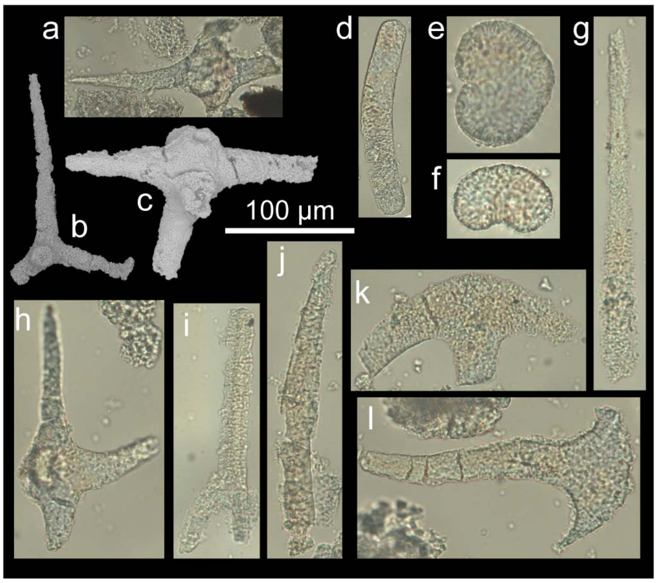

Fig. 7 - Photomicrographs and SEM images of spicules from the chert blocks of the Kamiaso Complex. a, c, h) Triaxon (Hexactine). b) Tetraxon (Calthrops). d) Strongyle. e, f) Rhax. g, j) Monaxon. i) Prodiaene (?). k, l) Anadiaene. All specimens were obtained from IT15102608.

geological units among the Jurassic ACs, such as Kamiaso, Sakahogi, and Wadano conglomerates of the Kamiaso Complex, Kawachidani Conglomerate of the Samondake Complex, Kanmuriyama Conglomerate of the Imajo Complex and Sawando and Bansho conglomerates of the Sawando Complex. Based on the compilation by Nakae (2000), the accretion age of these complexes containing conglomerate approximates the Middle-Late Jurassic. This may indicate the history of the Izanagi Plate with changes in subduction angles. Meanwhile, it has been noted that the age of the plate does not necessarily coincide with the subduction angle of the slab (Masson, 1991). Further studies of the aforementioned conglomerate within the OPS in several areas are necessary to clarify the history of the Izanagi Plate.

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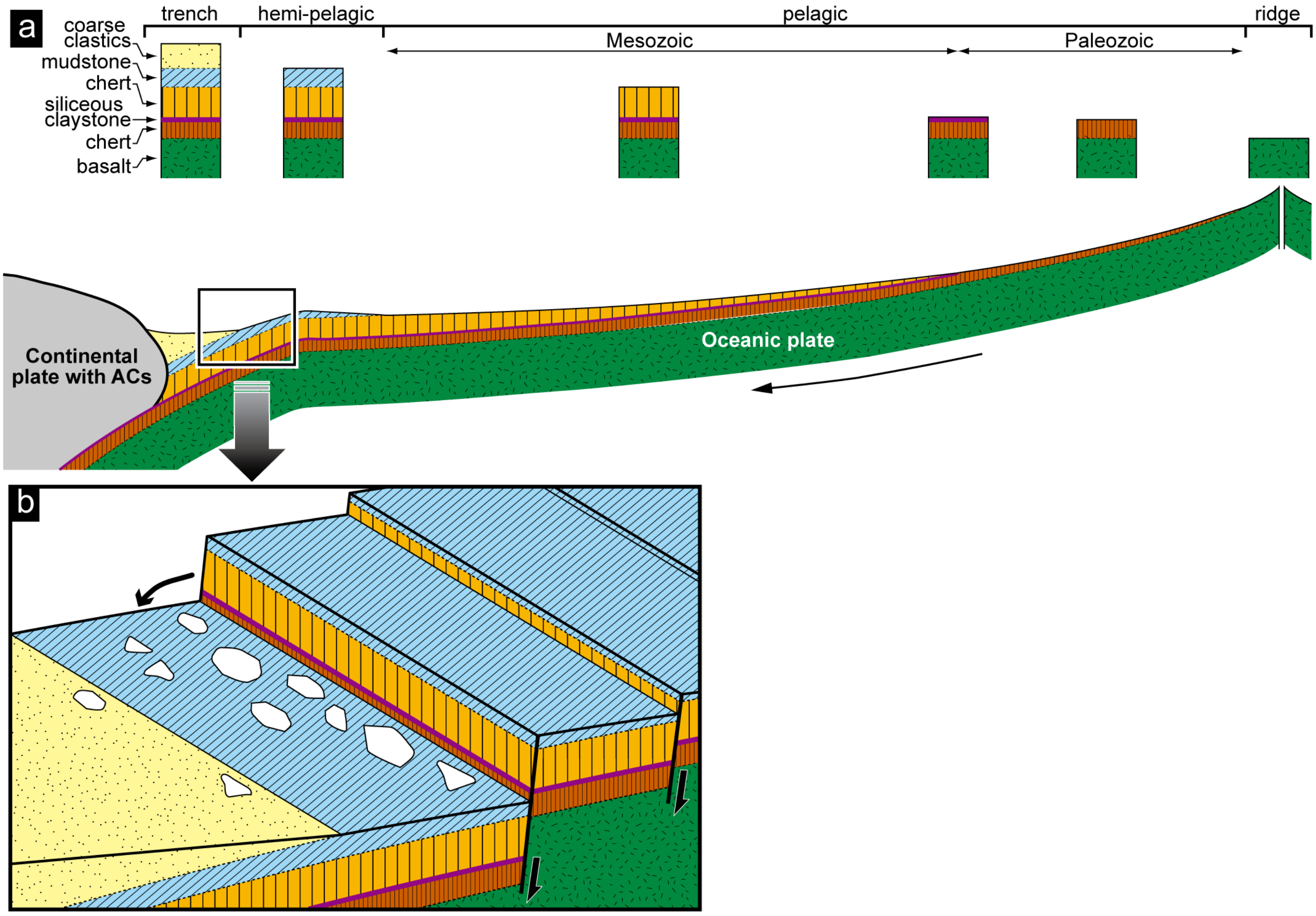

Fig. 8 - Simplified scheme of oceanic plate stratigraphy (OPS) and oceanic plate on the oceanward trench. a) Typical OPS formed by the movement of oceanic plates (based on some previous studies, such as Matsuda and Isozaki, 1991; Wakita and Metcalfe, 2005 and Ito, 2022). Carbonate rocks are not shown in the OPS, but they generally accumulate on basaltic seamounts. b) Possible origin of the chert blocks from an accretionary complex before accretion. White parts indicate blocks within conglomerate. The reader is referred to the PDF online for a colour version.

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