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Article

Middle Jurassic radiolarians from the ammonite bearing Toyora Group, Yamaguchi Prefecture, Southwest Japan

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Abstract: The Toyora Group is one of the typical Lower to Middle Jurassic strata in Japan that is distributed throughout Yamaguchi Prefecture, Southwest Japan. It yields abundant ammonoids. Although, microfossils, such as radiolarians, have not been previously reported from the group, radiolarian fossils are first discovered at seven localities from the uppermost Toyora Group. Those correspond to the *Transhsuum hisuikyoense* and *Striatojaponocapsa plicarum* zones and are determined to be from Aalenian to Bathonian in age. These radiolarian age determinations are a little older than those determined using ammonoids and inoceramids. According to previous studies, the assignment age of the first appearance of *Stj. plicarum* is only estimated to be near the Aalenian–Bajocian boundary. To discuss this issue, further study is required to correct the fossil data such as the Aalenian ammonoids that occur in the intervals of ammonoid and radiolarian localities.

Keywords: radiolaria, ammonoid, Jurassic, Toyora Group, Utano Formation, Yamaguchi Prefecture, Southwest Japan

1. Introduction

In Japan, most Jurassic strata are within accretionary complexes resulting from Mesozoic oceanic plate subduction. These strata are composed of various mixed rocks, such as oceanic plate-fragments, pelagic sediments and trench-filled clastic materials derived from the continent. The so-called shallow marine sediments are deposited on a continental shelf or in forearc basins composed of the accretionary strata. These shallow marine sediments overlie the accretionary strata on faulted or unconformable contacts. Before the rapid progress of research on the Jurassic accretionary complexes during the 1980s, these were a focus of stratigraphic research because of their abundant megafossils resulting from their comparatively limited mixing and weak deformation.

The geology of Southwest Japan is divided into the Inner (north) and Outer (south) zones by a major fault, the Median Tectonic Line, which formed in the Cretaceous. The Jurassic accretionary complexes are widely distributed in both zones.

The Lower to Middle Jurassic Toyora Group is one of the typical strata distributed in Yamaguchi Prefecture in the Inner Zone of Southwest Japan (Fig. 1). The Toyora Group comprises stratified clastic rocks, namely, sandstones and mudstones, with a small amount of conglomerates. They are deposited under shallow marine to brackish water conditions based on their sedimentary facies features and fossil associations, including characteristic black shale that indicates anoxic sedimentary conditions.

Various fossils, mainly ammonoids, bivalves, gastropods and plants, have been reported from the Toyora Group. As this area is a type locality of the Early to Middle Jurassic ammonoid biostratigraphy in Japan, these ammonoids have been studied in detail since the early twentieth century. However, research on fossil radiolarians from the Paleozoic and Mesozoic in Japan started during the late 1970s when samples of radiolarians were collected and analyzed from the accretionary complexes. Sedimentary rocks in Mesozoic accretionary complexes of Japan that yield megafossils are very rare. This study aims to find radiolarians in the shallow marine sediments, such as the Toyora Group, for correlation with geologic ages assigned from ammonoids. Radiolarians from the Torinosu Group and its equivalent beds in the Outer Zone of Southwest Japan were the focus of previous studies on Mesozoic

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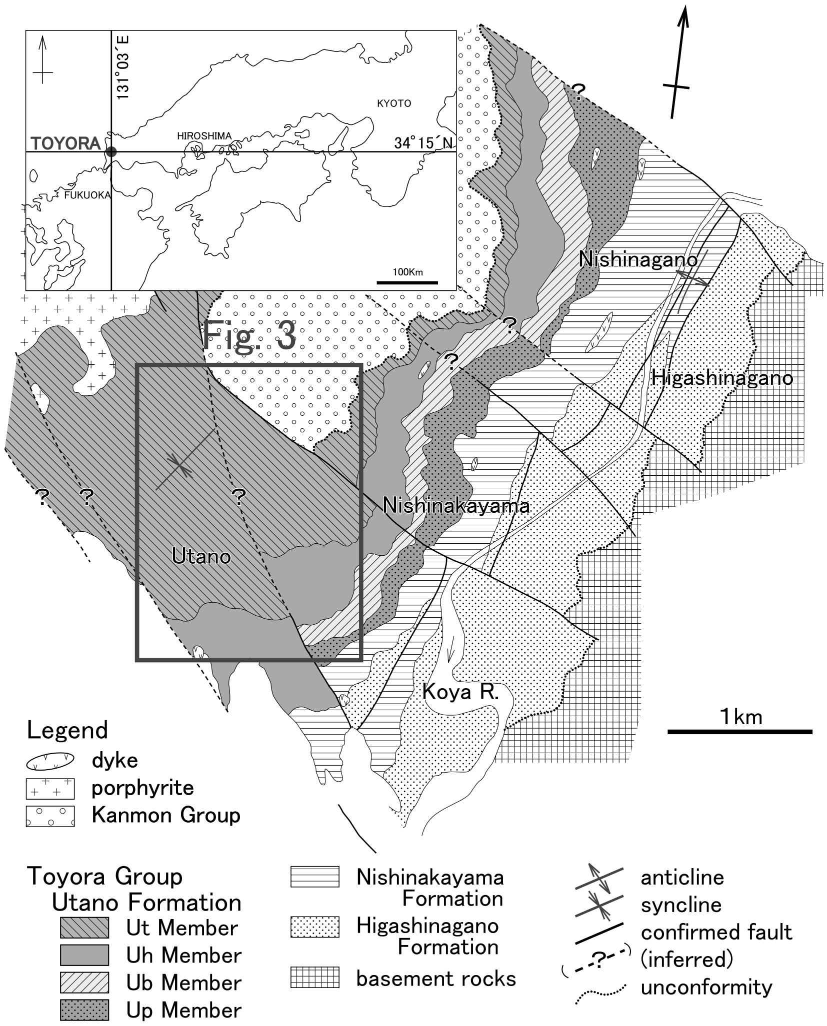

Fig. 1 Geological map of the Toyora Group around the Utano area, Yamaguchi Prefecture (modified from Hirano, 1971)

radiolarians (Matsumoto and Nishizono, 1985, Kozai *et al.*, 2006). Recently, Jurassic radiolarians were reported from shallow marine sediments of the Tetori Group on the Japan Sea side. On the basis of ammonoid biostratigraphy, radiolarians from this group are assigned to the Middle and Upper Jurassic (Callovian to Tithonian) (Hirasawa *et al.*, 2010). Sano and Kashiwagi (2015) explained that the high component ratio of Spumellaria (73–92 %) shows the Boreal element. This study, for the first time, describes radiolarians from the Toyora Group and the assignment of their geologic age and successfully correlates the geologic ages of the radiolarian biostratigraphy of the Middle Jurassic in Japan with the ammonoid one.

2. Geologic overview of the Toyora Group

Geological studies of the Toyora Group started with Yokoyama (1902) and Kobayashi (1926). Yokoyama (1902) described Jurassic ammonoids, while Kobayashi (1926) described inoceramids with lithostratigraphic notes. Toriyama (1938) showed the basic lithostratigraphic framework of the group. In the current study, the geologic overview is described on the basis of the studies by Hirano (1971, 1973a, b) who established the lithostratigraphy and ammonoid biostratigraphy of the northern distribution area of the Toyora Group. Based on his research, distribution area of the Toyora Group is divided into the northern and southern areas by the Kikugawa Fault. The effect of a granitic rock intrusion is comparatively very weak in the northern area of this group. Nakada and Matsuoka (2009, 2011) established a detailed ammonoid biostratigraphy of the Nishinakayama Formation of the group and discussed the exact stratigraphic location of the Pliensbachian–Toarcian boundary in this formation.

2. 1 Lithostratigraphy

The Toyora Group, comprising the Higashinagano, Nishinakayama, and Utano formations in ascending order, has a total thickness of 1800 m (Fig. 2). The Higashinagano Formation is 400 m in thickness and unconformably overlies the Sangun metamorphic rocks. It is composed of basal conglomerate, coarse sandstone, fine sandstone,

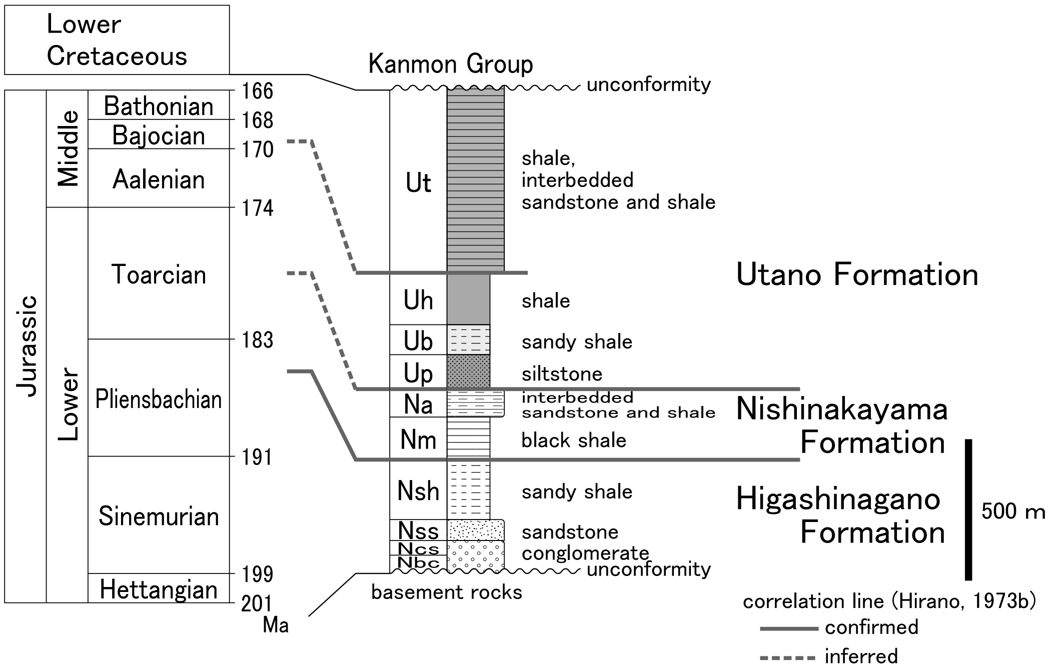

Fig. 2 Modified lithological succession and geologic age of the Toyora Group in the type locality after Hirano (1971, 1973a, b). Numerical ages are referred to the international chronostratigraphic chert ver. 2020/01 (Cohen *et al.*, 2013: updated in 2020). Abbreviations Nbc, Ncs, Nss and Nsh stand for the lower, middle, upper and uppermost members of the Higashinagano Formation; Nm and Na for the lower and upper members of the Nishinakayama Formation; Up, Ub, Uh and Ut for the lower, middle, upper and uppermost members of the Utano Formation.

and sandy shale in ascending order. This formation has been determined as a transgressive deposit because of its fining-upward sedimentary sequence. The Higashinagano Formation is subdivided into four members: the lower, middle, upper, and uppermost (abbreviated as the Nbc, Ncs, Nss and Nsh in Hirano, 1971, respectively) in ascending order. The Nishinakayama Formation is 250 m in thickness and is mainly composed of black shale, interbedding sandstone at its upper part. The black shale is recognized as the facies deposited under stagnant anoxic conditions because of the presence of sedimentary pyrite (Shikama and Hirano, 1970). This facies indicative of the shelf deposits records the early Toarcian oceanic anoxic event (Izumi *et al.*, 2012). The Nishinakayama Formation is divided into two members: the lower and upper (the Nm and Na, respectively) in ascending order. The Utano Formation is 1100 m in thickness and comprises silty shale, sandy shale, and interbedded sandstone and shale. In addition, the uppermost part of this formation has not been delimited because of a covering of the Lower Cretaceous Kanmon Group. The Utano Formation is recognized as a regressive sequence from its coarsening-upward sedimentation and is divided into four members: the lower, middle, upper, and uppermost (the Up, Ub, Uh, and Ut, respectivey) in ascending order. At the Utano Dam locality, the maximum thickness of the uppermost member (Ut) is 650 m.

2. 2 Biostratigraphy and geologic age based on megafossils

In studying the radiolarian assignment ages, it is effective to establish the biostratigraphy and geological age of each formation or member by the described megafossils, mainly ammonite (Fig. 2, Hirano, 1971, 1973a, b). Ammonoids are rarely found in the Higashinagano Formation but are abundant in the Nishinakayama Formation. The uppermost member of the Utano Formation (Ut) frequently yields ammonoids. Ammonoids have not been recognized in the lower member (Nbc) of the Higashinagano Formation. Abundant fossils, such as ammonoids, bivalves, gastropods, brachiopods, and corals, occur in the middle member (Ncs) of the Higashinagano Formation. The geologic age of Ncs is correlated with the early Sinemurian based on the occurrence of *Arietites* sp. That of the upper member (Nss), depending on its location, is correlated with the late Sinemurian to the Pliensbachian based on the age of Ncs in the northern area and the occurrences of the Pliensbachian ammonoid (*Amaltheus* cf. *stokes* (Sowerby) and *Arieticeras* aff. *apertum* Monestier) in the southern area. Based on the ages of Nss and the base of the Nishinakayama Formation above this member, the geological age of the uppermost member (Nsh) also depends on its location and is correlated with the latest Sinemurian to upper Pliensbachian.

Ammonoid fauna from the Nishinakayama Formation have been grouped into three zones: the *Fontanelliceras* *fontanellense*, *Protogrammoceras nipponicum*, and *Dactylioceras helianthoides*, in ascending order, and the lower (Nm) and upper (Na) members of the Nishinakayama Formation are assigned to the upper Pliensbachian to lower Toarcian and lower Toarcian, respectively (Hirano, 1973a, b). Furthermore, Nakada and Matsuoka (2011) established four ammonoid zones in Nm and correlated these with European zonations: the *Canavaria japonica*, *Paltarpites paltus*, *Dactylioceras helianthoides*, and *Harpoceras inouyei* zones in ascending order.

In the Utano Formation, the lower (Up) and middle (Ub) members are correlated with the upper Toarcian given the occurrences of *Grammoceras* and *Phymatoceras* in abundance in the Up and *Phymatoceras* sp. in the Ub. In this formation, the upper member (Uh) yields ammonoids such as *Planammatoceras* cf. *kitakamiensis* Buckman, *Dumortieria*? sp. and *Calliphylloceras* sp. These are assigned to the uppermost Toarcian to partially lower Bajocian. The uppermost member (Ut) is correlated with the Bathonian because of the occurrence of *Harpophylloceras* sp. and *Inoceramus utanoensis* (Hirano, 1973b). Based on the assigned age of the megafossils, the border between the Uh and Ut is in the lower Bajocian to Bathonian with a concordant stratigraphic contact.

2. 3 Pliensbachian–Toarcian boundary

Tanabe (1991) demonstrated that bituminous mudstones result from the deposition of marine sediments during anoxic events, which have occurred worldwide, based on the geochemical and sedimentological data and the extremely rare occurrence of benthic fossils. Nakada and Matsuoka (2011) determined that the Pliensbachian–Toarcian boundary is at the base of the *Paltarpites paltus* Zone based on the four established ammonoid zones and the lower member of the Nishinakayama Formation (Nm), which are correlated in detail with European zones.

3. Lithostratigraphy of the sampling section study route

Radiolarians were found from seven samples collected from the Utano B, C2, and D1 routes belonging to the Uh and Ut that crop out in the Utano Valley (along the current Utano Dam), where the thickest sequence of the Utano Formation is throughout distributed (Hirano, 1971). Hirano (1973a, b) has described ammonoids from the Utano A and D2 routes of this study (Fig. 3).

Utano A route

Along the Utano A route, the 400-m-thick Ut of the Utano Formation is exposed and mainly comprises interbedded sandstone and shale (Fig. 4). Sandy shale varying from 20 to 30 m in thickness occurs at three stratigraphic horizons. *Holcophylloceras* sp. described by Hirano (1973b: locality 59) occurs in the shale above the thick sandstone bed in the upper part of this route.

Utano B route

The lower part of the Utano B route (Fig. 4) is composed of the 150-m-thick massive sandy shale of the Uh of the Utano Formation. The upper part of this route consists of the interbedded sandstone and shale of the Ut of the Utano Formation with sandy shale; these are repeated every tens of meters. Their total thickness is 400 m. Tuffaceous shales are infrequently intercalated within the upper part of the strata. Radiolarian samples UT-4, UT-5, and UT-6 were collected from three horizons in the upper half of the Ut.

Utano C1 and C2 routes

The thickness and sedimentary facies of the Uh and Ut of the Utano Formation along the Utano C1 and C2 (C2n and C2s) routes are similar to those of the Utano B route (Fig. 4). The Ut is overlain unconformably by the Cretaceous Kanmon Group at the stratigraphic top of the Utano C2s route. A radiolarian sample UT-7 was collected at the horizon 70 m beneath this unconformity.

Utano D1 and D2 routes

The lower part of the Utano D1 and D2 routes comprises the 250-m-thick sandy shale of the Uh of the Utano Formation. The upper 200 m part consists of the interbedded sandstone, shale, and sandy shale of the Ut (Fig. 4). These lithologies are repeated every tens of meters. In the Utano D1 route, a radiolarian sample UT-1 was collected from the Uh, and samples UT-2 and UT-3 were collected from the middle part of the Ut. Hirano (1973a) reported ammonoids (*Dumortieria*? sp.) from shale in the lower part of the Uh in the Utano D2 route.

4. Radiolarian assemblages and age assignment

Seven radiolarian samples were collected from the studied route. Radiolarians from four samples (UT-1, UT-2, UT-5 and UT-7) were identified, whereas those from the other three samples could not be identified because of poor preservation. Age assignments of these identified radiolarians are mainly discussed on the basis of the radiolarian zonations of Nishizono *et al.* (1997) and Matsuoka (1995).

4. 1 Radiolarian assemblages

The locality and radiolarian assemblage of each sample are shown as follows.

Sample UT-1

Locality: Utano D1 route (sandy shale of the Uh).
Assemblage: Despite abundant Nassellaria and the poor preservation of the test surfaces in this sample, only *Praeparvicingula*? sp. A can be identified (Fig. 5m).

Sample UT-2

Locality: Utano D1 route (sandy shale of the Ut).
Assemblage: Abundant Spumellaria and Nassellaria are included in the sample; however, these are poorly preserved on the test surface. The following radiolarians were identified (Fig. 5b, e, j): *Canutus* sp., *Parahsuum* sp., and *Transhsuum* aff. *hisuikyoense*.

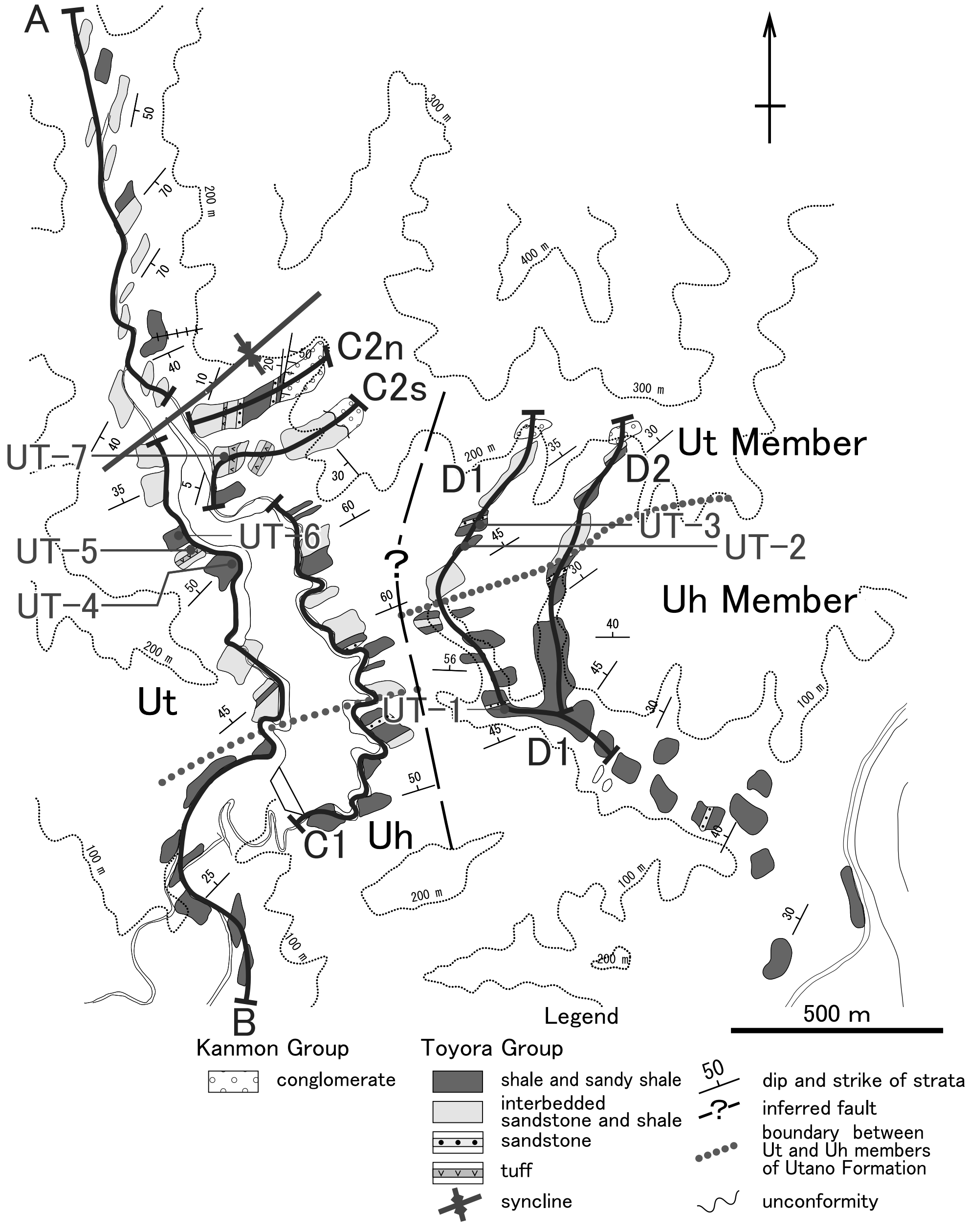

Fig. 3 Locality map for radiolarians and surveyed routes of Utano A, B, C1, C2, D1 and D2. UT-1 to Ut-7 are the locations of radiolarian occurrence.

Sample UT-3
Locality: Utano D1 route (sandy shale of the Ut located immediately above UT-2).
Assemblage: Despite the presence of abundant Nassellaria, no radiolarian species is identified because of their poor preservation on the test surfaces.

Sample UT-4
Locality: Utano B route (sandy shale of the Ut).
Assemblage: Despite abundant Nassellaria in the sample, no radiolarian species is identified due to their poor preservation on the test surfaces.

Sample UT-5
Locality: Utano B route (shale of the Ut).
Assemblage: Despite poor preservation, the following radiolarian species are identified (Fig. 5a, d, f, i, l, n–o, s, x–y): *Archicapsa pachyderma*, *Spongocapsula* sp. A, *Parahsuum* ? *hiconocosta*, *Transhsuum* aff. *brevicostatum*, *Praeparvicingula aculeata*, *Wrangellium* aff. *burnsensis*, *Droltus hecatensis*, *Unuma typicus*, *Stichocapsa convexa* and *Stichocapsa magnipora*.

Sample UT-6
Locality: Utano B route (sandy shale of the Ut)

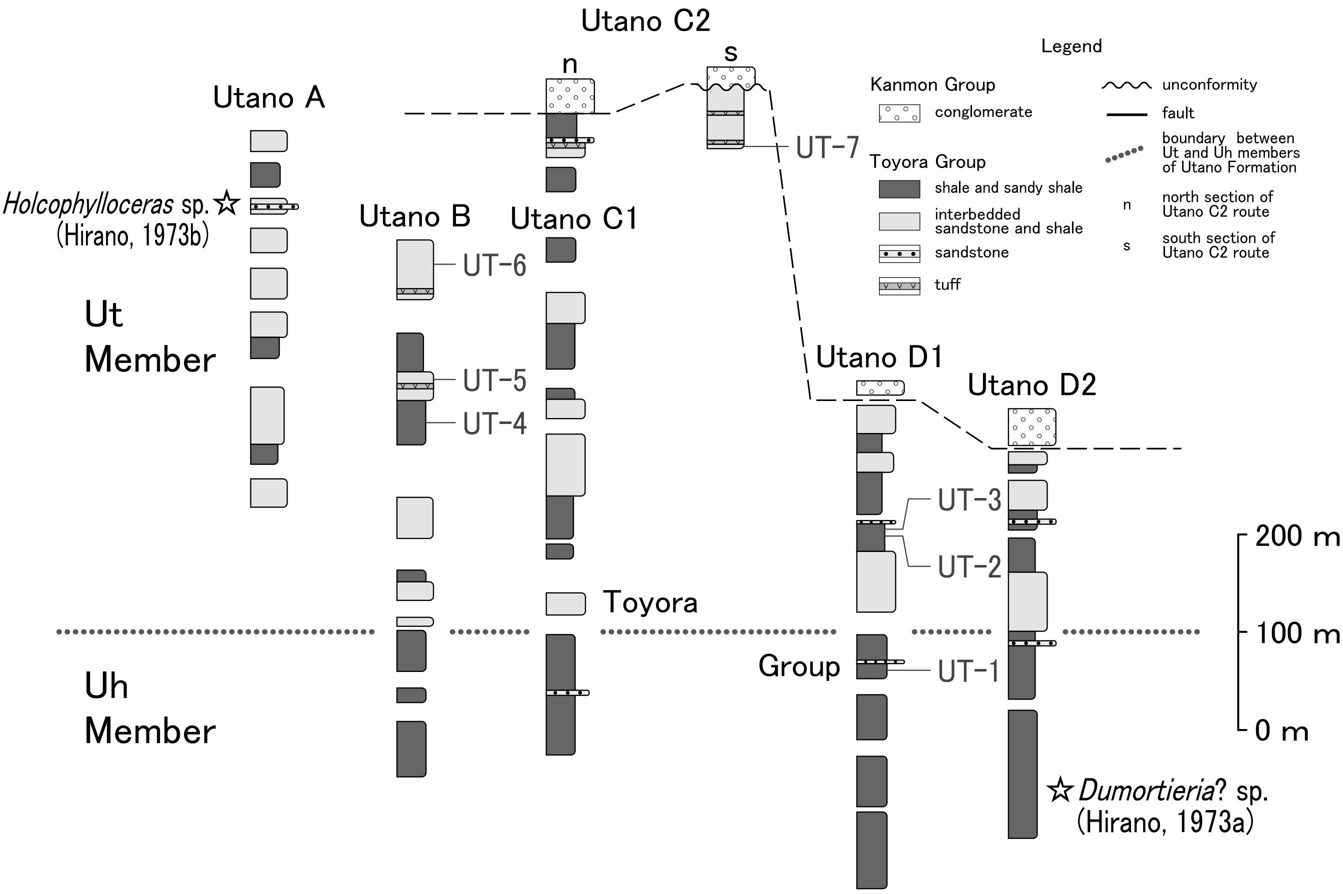

Fig. 4 Columnar sections of Utano A, B, C1, C2, D1 and D2 routes.

Assemblage: Despite the inclusion of radiolarians, no specimens is identified due to their poor preservation on the test surfaces.

Sample UT-7
Locality: Utano C2 route (nodule in the sandy shale of the Ut)
Assemblage: Well-preserved Nassellaria are included (Figs. 5c, g–h, k, p–r, t–w, z). The following radiolarians are identified: *Archicapsa pachyderma*, *Spongocapsula* aff. *krahsteinensis*, *Transhsuum maxwelli*, *Archaeodictyomitra* sp. H in Nishizono 1996, *Triversus hungaricus*, *Unuma latusicostatus*, *Unuma typicus*, *Podobursa nodosa*, *Striatojaponocapsa plicarum*, *Tricolocapsa undulata*, and *Eucyrtidiellum unumaense*.

4. 2 Correlation with radiolarian zonation and age assignment

According to Nishizono *et al.* (1997), the co-occurrence of *Archicapsa pachyderma*, *Stichocapsa convexa*, and *Striatojaponocapsa plicarum* in UT-7 collected from the Ut indicates the *Stj*. *plicarum* Zone (Nishizono *et al.*, 1997). UT-5 was collected from the stratigraphic level 240 m beneath sample UT-7 in the Ut. An assemblage with a co-occurrence of *A. pachyderma*, *Parahsuum*? *hiconocosta*, *Unuma typicus*, and *Stichocapsa convexa* but no *Str. plicarum* occurred in UT-5, which was correlated with the *Transhsuum hisuikyoense* Zone (Nishizono *et al.*, 1997). This correlation does not contradict the assemblage of the *Th. hisuikyoense* Zone of sample UT-2, which is in the lower part of the Ut. The *Th. hisuikyoense* and *Stj. plicarum* zones are assigned to the Aalenian and Bajocian to Bathonian, respectively (Nishizono *et al.*, 1997). Therefore, it is estimated that the boundary between the two zones is in the middle part of the Ut, which is 360 m above the Uh–Ut boundary at the stratigraphic level between the samples UT-5 and UT-7 (Fig. 6).

According to Matsuoka (1995), the co-occurrence of *Stj. plicarum* and *Eucyrtidiellum unumaense*, as seen in UT-7, correlates with the *Stj. plicarum* and *Stj. conexa* zones (Matsuoka, 1995; Matsuoka and Ito, 2019). However, the co-occurrence of *Stj. plicarum*, *Unuma typicus*, *Unuma latusicostatus*, *Stichocapsa convexa*, and *Eucyrtidiellum unumaense* but no *Stj conexa* shows that the radiolarians from UT-7 could be correlated with the *Stj. plicarum* Zone. Furthermore, the radiolaria in UT-5 could be correlated with the *Laxtorum*? *jurassicum* Zone (Matsuoka, 1995) because the co-occurrence of *A. pachyderma*, *Unuma typicus*, and *Stichocapsa convexa* but no *Stj. plicarum* is found in UT-5. Matsuoka (1995) correlated the *L.*?

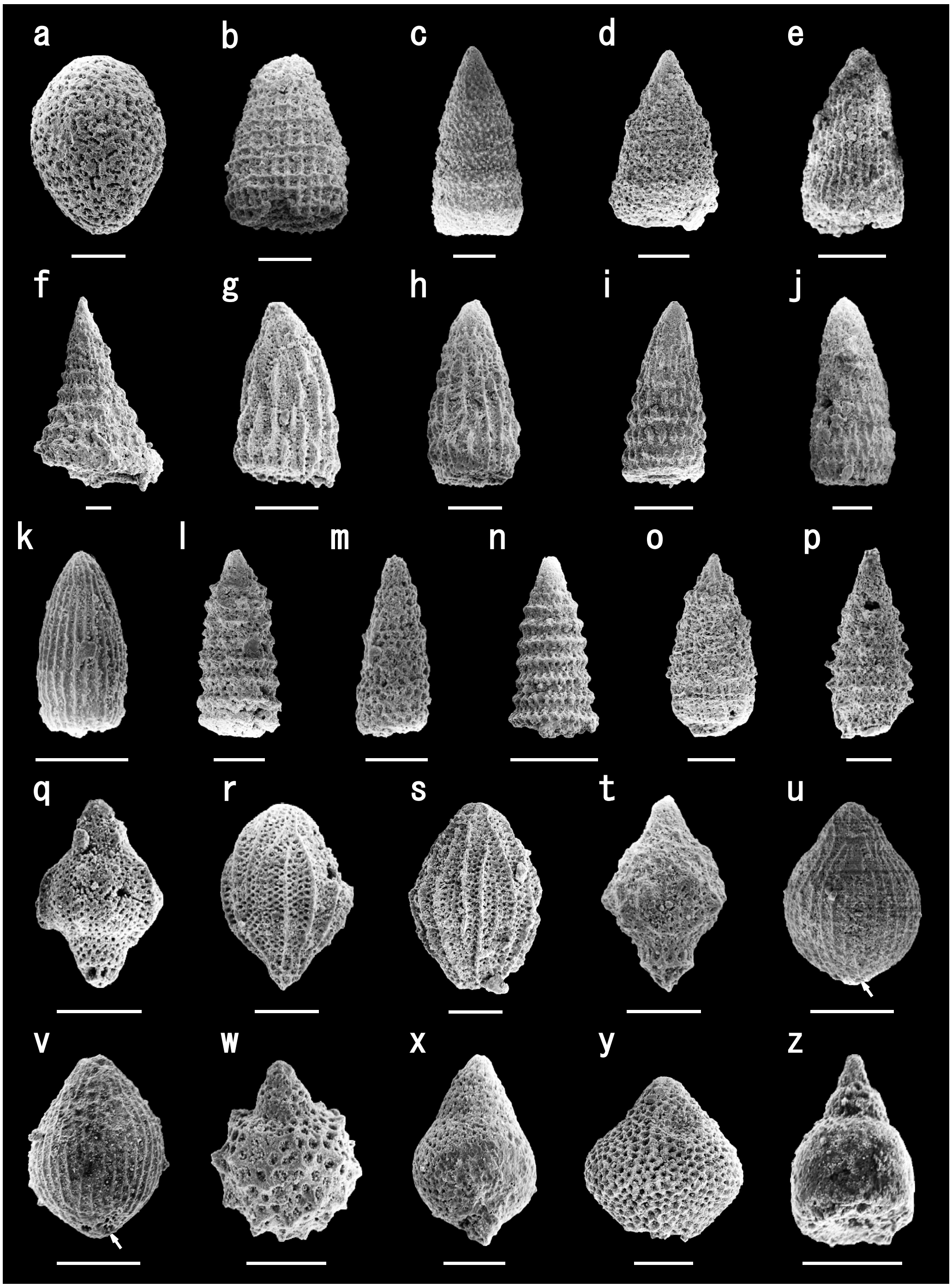

Fig. 5 SEM (Scanning Electron Microscope) photos of radiolarian.
a: *Archicapsa pachyderma* (Tan) (locality; UT-5). b: *Canutus* sp. (locality; UT-2). c: *Spongocapsula* aff. *S. krahsteinensis* Suzuki and Gawlick (UT-7). d: *Spongocapsula* sp. A (locality; UT-5). e: *Parahsuum* sp. (locality; UT-2). f: *Parahsuum*? *hiconocosta* Baumgartner and De Wever (locality; UT-5). g, h: *Transhsuum maxwelli* (Pessagno) (locality; UT-7). i: *Transhsuum* aff. *brevicostatum* (Ozvoldova) (locality; UT-5). j: *Transhsuum* aff. *hisuikyoense* (Isozaki and Matsuda) (locality; UT-2). k: *Archaeodictyomitra* sp. H in Nishizono (1996) (locality; UT-7). l: *Praeparvicingula aculeata* (Carter) (locality; UT-5). m: *Praeparvicingula*? sp. A (locality; UT-1). n: *Wrangellium* aff. *burnsensis* (Pessagno and Whalen) (locality; UT-5). o: *Droltus hecatensis* Pessagno and Whalen (locality; UT-5). p: *Triversus hungaricus* (Kozur) (locality; UT-7). q: *Unuma latusicostatus* (Aita) (locality; UT-7). r: *Unuma typicus* Ichikawa and Yao (locality; UT-7). s: *Unuma typicus* Ichikawa and Yao (locality; UT-5). t: *Podobursa nodosa* (Chiari, Marucucci and Prela) (locality; UT-7). u, v: *Striatojaponocapsa plicarum* (Yao) (locality; UT-7). Arrows of u and v show the circular area. w: *Tricolocapsa undulata* (Heitzer) (locality; UT-7). x: *Stichocapsa convexa* Yao (locality; UT-5). y: *Stichocapsa magnipora* Chiari, Marucci and Prela (locality; UT-5). z: *Eucyrtidiellum unumaense* (Yao) (locality; UT-7). All scale bars indicate 50 μm.

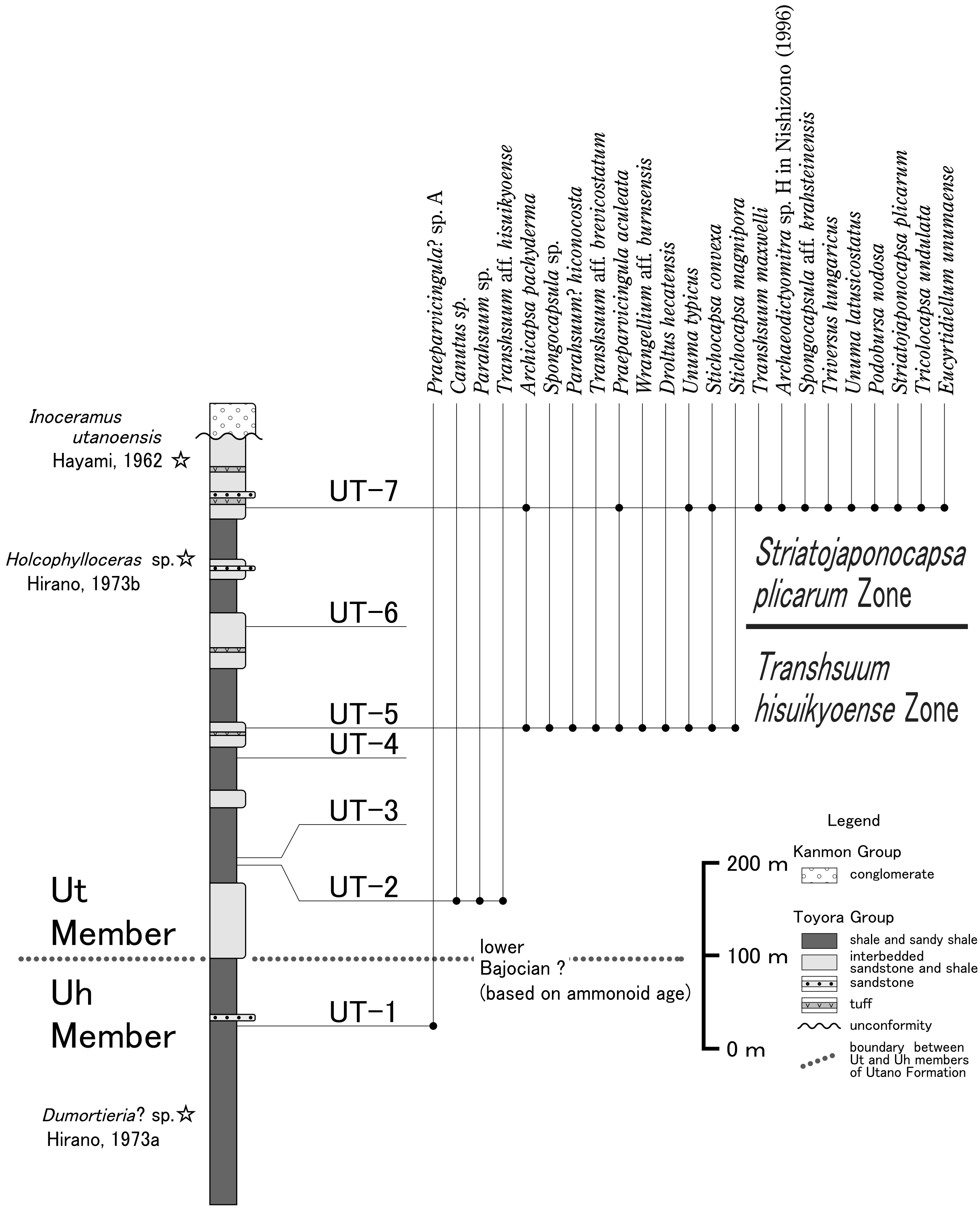

Fig. 6 Biostratigraphic distribution of radiolarian species in the Utano sections, the Toyora Group.

jurassicum and *Stj. plicarum* zones with the Aalenian and Bajocian to early Bathonian, respectively. Therefore, the geological ages assigned by radiolarians indicate that the boundary between the *Th. hisuikyoense* and *Stj. plicarum* zones (Nishizono *et al.*, 1997) is in the middle part of the Ut, which is the border of the Aalenian and Bajocian.

4. 3 Correlation between radiolarian and macrofossil age assignments

Find-spots of ammonoid are close to the two radiolarian sampling sites. *Dumortieria*? sp. occurs in the lower part of the upper member (Uh) in the Utano D2 route (Figs. 4 and 6), which is correlated with 280 m below UT-2; it is assigned to the Toarcian Stage of the Lower Jurassic (Hirano, 1973a). Hirano (1973b) showed that the Uh is assigned to the horizon ranging from the uppermost Toarcian to the Bajocian (mainly Aalenian) on the basis of an ammonoid *Planammatoceras* cf. *kitakamiensis* in the Uh, occurred outside of the study area. The stratigraphic level of *Holcophylloceras* sp. (Hirano, 1973b: locality 59) is 180 m above UT-5 and 60 m below UT-7 (Figs. 4 and 6), which is the upper part of the Ut in the Utano A route. The genus *Holcophylloceras* ranges in age from the Bajocian to the Aptian in the Early Cretaceous (Sandoval *et al.*, 2001, Majidifard, 2003). Furthermore, Hayami (1962) showed that *Inoceramus utanoensis* (Kobayashi), which occurred in the Ut, is very similar to *I. kystatymensis* as reported from the Bathonian in the Lena River, Russia (Koschelkina, 1963; Hirano, 1973b). This indicates that the uppermost member (Ut) includes at least the Bajocian to Bathonian in the Middle Jurassic.

Previous studies have shown the Aalenian–Bajocian boundary is in the Ut based on radiolarians (e.g. Matsuoka, 1995; Nishizono *et al.*, 1997) and in the upper part of the Uh based on ammonoids (Hirano, 1973b). The difference in the stratigraphic interval of the two ammonoid localities is 580 m, while that of the radiolarian localities (UT-5: Aalenian and UT-7: Bajocian) is 240 m (Fig. 6).

The assigned ages of ammonoids from the Utano Formation, indicate that the first appearance age of *Striatojaponocapsa plicarum* could be redefined from the Aalenian to the early Bajocian. According to Nishizono *et al.* (1997), *Stj. plicarum* first appeared in the lower Bajocian based on calibration by ammonoids occurring in the Kitakami Mountains, Tohoku district, central Kyushu district and Canada. Matsuoka (1995) showed that *Stj. Plicarum* appeared in the Bajocian based on the correlation data by ammonoids occurring in Spain, Italy and Japan. Furthermore, Baumgartner *et al.* (1995) set the range of *Stj. plicarum plicarum* from the upper Bajocian to the lower Bathonian (UA Zones 4 and 5). However, in previous studies (Matsuoka, 1995; Nishizono *et al.*, 1997), the first appearance age of *Stj. plicarum* could not be established for the assigned ages of ammonoid and was only estimated to be around the Aalenian/Bajocian boundary.

Considering this difference, further study is required to collect fossil data such as the Aalenian ammonoids from these intervals.

5. Conclusions

Radiolarian fossils were first discovered from the Lower to Middle Jurassic Toyora Group containing abundant ammonoids. The radiolarian fossils, found in seven localities from the uppermost Toyora Group, are assigned to the Aalenian–Bathonian based on the presence of ammonoids and inoceramids. According to Nishizono *et al.* (1997), these radiolarian assemblages are correlated to the *Transhsuum hisuikyoense* and *Striatojaponocapsa plicarum* zones which have been assigned to the Aalenian and Bajocian to lower Bathonian, respectively. Although the upper–uppermost member (Uh–Ut) boundary of the Utano Formation was correlated with the lower Bajocian based on megafossils (Hirano, 1973b), it should be assigned to the Aalenian based on the radiolarian zonation. The stratigraphic intervals of the two ammonoid localities and that of the radiolarian localities (UT-5: Aalenian and UT-7: Bajocian) are 580 m and 240 m, respectively. According to previous studies, the first appearance of *Stj. plicarum* could not be calibrated to the ammonoid assignment ages and is only estimated to be near the Aalenian/Bajocian boundary. To discuss this issue, further study is required to correct the fossil data such as the Aalenian ammonoid occurring in these intervals.

6. Systematic Paleontology

The familial classification system basically follows Takemura (1986), Suzuki *et al.* (2002), Suzuki and Gawlick (2003, 2009). The classification for genera *Archicapsa* and *Canutus* are based on Haeckel (1881), Pessagno and Whalen (1982), respectively.

Subclass **RADIOLARIA** Müller, 1858

Order **NASSELLARIA** Ehrenberg, 1875

Family **SETHOCAPSIDAE** Haeckel, 1881

Genus ***Archicapsa*** Rüst, 1885

Archicapsa pachyderma (Tan, 1927)
(UT-5, Fig. 5a)
1986 *Archicapsa pachyderma* (Tan) – Matsuoka and Yao, pl. 1, fig. 5.
1990 *Archicapsa pachyderma* (Tan) – Yao, pl. 2, fig. 15.
1990 *Archicapsa pachyderma* (Tan) – Hori, fig. 9.44.
1996 *Archicapsa pachyderma* (Tan) – Nishizono, pl. 12, fig. 4.
Remarks: Test is ellipsoidal with a spherical apical part and slightly pointed aperture side.
Range: This species occurs from the *Droltus*? sp. A–*Hsuum*? sp. G to *Striatojaponocapsa plicarum* zones in Outer zone of Southwest Japan (Nishizono, 1996).

Family **CANUTIDAE** Pessagno and Whalen, 1982

Genus ***Canutus*** Pessagno and Whalen, 1982

***Canutus* sp.**
(UT-2, Fig. 5b)
Remarks: Test is short, inflated and conical. Test surface consists of square symmetrical pore frames with nodes. In present specimen, the two or three layered structure and apical part are unclear due to poor preservation.

Family **THEOPERIDAE** Haeckel 1881;

emend. Takemura, 1986

Genus ***Spongocapsula*** Pessagno, 1977

Spongocapsula* sp. aff. *S. krahsteinensis Suzuki and Gawlick in Gawlick *et al.* (2004)
(UT-7, Fig. 5c)
1996 *Spongocapsula*? sp. – Nishizono, pl. 27, fig. 11.
aff. 2004 *Spongocapsula krahsteinensis* n. sp.– Gawlick *et al.*, p. 313–315, abb. 4.7–4.10.
Remarks: Test is short, inflated and spindle-shaped. Gawlick *et al.* (2004) regarded that underneath the microgranular outer layer of this species is spongy test. This specimen has a resemble test of *S. krahsteinensis*.
Range: late Bajocian to Callovian (Gawlick *et al.*, 2004)

***Spongocapsula* sp. A**
(UT-5, Fig. 5d)
Remarks: Test is conical shaped increasing slowly in height and moderately rapidly in width proximally, gradually decreasing in width distally. Cephalis and thorax are imperforate.

Genus ***Parahsuum*** Yao, 1982

***Parahsuum* sp.**
(UT-2, Fig. 5e)
Remarks: Test is conical and lacking ornamentation at cephalis, thorax and abdomen due to poor preservation of this sample. In a side view, sixteen edged costae are visible on post-abdominal chambers. Single row of square pore frames is arranged with circular, primary pores between costae.

Parahsuum*? *hiconocosta Baumgartner and De Wever in Baumgartner *et al.* (1995)
(UT-5, Fig. 5f)
1985 *Andromeda*? sp. – De Wever *et al.*, pl. 1, figs. 12, 13, 16.
1995 *Parahsuum*? *hiconocosta* n. sp. – Baumgartner *et al.*, p. 378, pl. 3011, figs. 1 (H) –6.
1996 *Andromeda* sp. B – Nishizono, pl. 26, fig. 18.
Remarks: Test is elongated conical form with concave and wedge-shaped outline in lateral view. Segments are well marked by a nodose circumferential ridge. The present species has rectangular and elevated vertical pore-frames with a protruding nodose as characteristic structures of this species.
Range: This species occurs from the *Transhsuum hisuikyoense* Zone in Outer zone of Southwest Japan (Nishizono, 1996). UA Zones 2–4, late Aalenian–late Bajocian (Baumgartner *et al.*, 1995)

Genus ***Transhsuum*** Takemura, 1986

Transhsuum maxwelli (Pessagno, 1977)
(UT-7, Fig. 5g, h)
1977 *Hsuum maxwelli* n. sp. – Pessagno, p.81, pl. 7, figs. 14–16.
1995 *Transhsuum maxwelli* group (Pessagno) – Baumgartner *et al.*, p. 582, pl. 3180, figs. 4, 5.
1997 *Hsuum maxwelli* Pessagno – Nishizono *et al.*, pl. III, fig. 10.
2009 *Hsuum maxwelli* Pessagno – Suzuki and Gawlick, p. 168, fig. 5.7.
Remarks: Test is conical. Cephalis is perforate without long and massive apical horn. The specimen shown in Fig. 5h has the test of increasing rapidly in width. Short, massive and discontinuous costae are distributed on a test.
Range: UA Zones 3–10, early–middle Bajocian to late Oxfordian–early Kimmeridgian. (Baumgartner *et al.*, 1995). The first appearance of *Transhsuum maxwelli* group is located in the upper part of *Striatojaponocapsa plicarum* Zone in Outer zone of Southwest Japan (Matsuoka, 1995: Bajocian to middle Bathonian).

Transhsuum* sp. aff. *T. brevicostatum (Ozvoldova, 1975)
(UT-5, Fig. 5i)
aff. 1975 *Lithostrobus brevicostatus* n. sp. – Ozvoldova, p. 84, pl. 102, fig. 1.
aff. 1979 *Lithostrobus brevicostatus* Ozvoldova – Ozvoldova, p. 259, pl. 5, fig. 2.
aff. 1995 *Transhsuum brevicostatum* group (Ozvoldova) –Baumgartner *et al.*, p. 578, pl. 3181, figs. 2, 4.
aff. 1996 *Hsuum brevicostatum* Ozvoldova – Nishizono, pl. 21, figs. 8, 9.
Remarks: Test is conical. Post-abdominal segments have short longitudinal ribs. The specimen shown in Fig. 5i could not be identified as *Transhsuum brevicostatum* because two longitudinal lines of pores are unclear due to poor preservation. *Th. brevicostatum* (Ozvoldova) is rare in the *Striatojaponocapsa plicarum* Zone after Nishizono (1996).
Range: UA Zones 3–11, early–middle Bajocian to late Kimmeridgian–early Tithonian. (Baumgartner *et al.*, 1995).

Transhsuum* sp. aff. *T. hisuikyoense (Isozaki and Matsuda 1985)
(UT-2, Fig. 5j)
Measurements (in μm): height 200, maximum width 100.
Remarks: General form and surface ornamentations of post-abdominal segments are very similar to *Hsuum hisuikyoense* Isozaki and Matsuda, 1985. However, details of apical part are unclear due to poor preservation.
Range: UA Zones 2–4, late Aalenian–late Bajocian (Baumgartner *et al.*, 1995).

Genus ***Archaeodictyomitra*** Pessagno, 1976

***Archaeodictyomitra* sp. H** in Nishizono, 1996
(UT-7, Fig. 5k)
1982 *Archaeodictyomitra* sp. A – Pessagno and Whalen,

p. 117, pl. 8, fig. 10.
1996 *Archaeodictyomitra* sp. H – Nishizono, pl. 24, fig. 4.

Remarks: This species has rounded test apically and constricted distally. Twelve costae are visible on post-abdominal chambers in a side view. This species occurs from the *Striatojaponocapsa plicarum* Zone in Outer zone of Southwest Japan (Nishizono, 1996).

Genus ***Praeparvicingula*** Pessagno, Blome and Hull in Pessagno *et al.*, 1993

Praeparvicingula aculeata (Carter in Carter *et al.*, 1988)
(UT-5, Fig. 5l)

1988 *Parvicingula aculeata* n. sp. – Carter *et al.*, p. 54–55, pl. 18, figs. 1, 2, 7.
1997 *Parvicingula dhimenaensis dhimenaensis* Baumgartner – Yao, pl. 13, fig. 625.

Remarks: Test is subcylindrical and maintaining same width of post-abdominal chamber. Cephalis and thorax are sparsely perforate without horn. Post-abdominal chambers has three lateral rows of pore frames between ridges. Those are depressed in central row. Sharp pointed nodes are clear, that separate the abdomen and first few post-abdominal chambers. The narrow tube is lacking on the final post-abdominal chamber. Goričan *et al.* (2006) clasified *Parvicingula aculeata* Carter to genus *Praepalvicingula* on the basis of the above test structures.
Range: middle Toarcian–Early Bajocian (Carter *et al.*, 1988) (no-data earlier than middle Toarcian in Carter *et al.*, 1988)

***Praeparvicingula*? sp. A.**
(UT-1, Fig. 5m)
Remarks: Test is subcylindrical with dome-shaped cephalis. Horn and terminal tube are unknown due to poor preservation. The present specimen is different from *Praeparvicingula tlellensis* Carter in having the non-parallel pore alignment to circumferential ridges.

Family **Amphipyndacidae** Riedel, 1967

Genus ***Wrangellium*** Pessagno and Whalen, 1982

Wrangellium* sp. aff. *W. burnsensis (Pessagno and Whalen, 1982)
(UT-5, Fig. 5n)

1988 *Parvicingula* sp. aff. *P. burnsensis* (Pessagno and Whalen) – Carter *et al.*, p. 55, pl. 18, figs. 10, 15.

Remarks: Test is characterized by having nodose circumferential ridges with H-linked structures. The specimen identified as *P.* aff. *burnsensis* Pessagno and Whalen (pl 18, figs 10 and 15 of Carter *et al.*, 1988) is considered to be classified as genus *Wrangellium* in having circumferential ridges with H-linked structures.
Range: middle Toarcian to early Bajocian (Carter *et al.*, 1988)

Genus ***Droltus*** Pessagno and Whalen, 1982

Droltus hecatensis Pessagno and Whalen, 1982
(UT-5, Fig. 5o)

1982 *Droltus hecatensis* n. sp. – Pessagno and Whalen, p. 121, pl. 1, figs. 12, 13, pl. 4, figs. 1, 2, 6, 10.
1998 *Droltus hecatensis* Pessagno and Whalen – Carter *et al.*, p. 63, pl. 15, fig.14.
2002 *Droltus hecatensis* Pessagno and Whalen – Suzuki *et al.*, 2002. p. 181–182, figs. 8G, 8H, 8L–8M.
2003 *Droltus hecatensis* Pessagno and Whalen – Suzuki and Gawlick, p. 191–192, fig. 6.72.
2009 *Droltus hecatensis* Pessagno and Whalen – Suzuki and Gawlick, p. 177, figs. 6.50A, 6.50B.

Remarks: Apical horn is ornamented with thick blades. Abdomen and several post-abdominal chambers have irregularly sized and shaped polygonal pore frames with solid small spines in somewhere. In lower one third, test consists of three longitudinal rows of pores between every adjacent pairs of costae.
Range: *Droltus hecatensis* occurs commonly in Lower Jurassic of west coast of Canada (Carter *et al.*, 1998) and Peru (Suzuki *et al.*, 2002). Suzuki and Gawlick (2003, 2009) described this species from the Callovian to Oxfordian in the Northern Calcareous Alps.

Genus ***Triversus*** Takemura, 1986

Triversus hungaricus (Kozur, 1985)
(UT-7, Fig. 5p)

1984 *Parvicingula dhimenaensis* n. sp. – Baumgartner, p. 778, pl. 7, fig. 4.
1985 *Eoxitus hungaricus* n. sp. – Kozur, p. 216, figs. 1a, 1b, 1d, 1e.
1995 *Parvicingula dhimenaensis* Baumgartner ssp. A – Baumgartner *et al.*, p. 406, pl. 4071, figs. 1–4.
1996 *Parvicingula dhimenaensis* Baumgartner – Nishizono, pl. 25, figs. 11–13.
2003 *Triversus hungaricus* (Kozur) – Suzuki and Gawlick, p. 195–196, fig. 6.58–6.60.
2009 *Triversus hungaricus* (Kozur) – Suzuki and Gawlick, p. 170, fig. 5.14; figs. 6.6A, 6.6B, 6.7, 6.8.

Remarks: Test has an elongated cephalis and is spindle-shaped with pronounced spines on circumferential ridges.
Range: UA Zones 3–8, early–middle Bajocian to middle Callovian (Baumgartner *et al.*, 1995).

Genus ***Unuma*** Ichikawa and Yao, 1976

Unuma latusicostatus (Aita, 1987)
(UT-7, Fig. 5q)

1987 *Tricolocapsa latusicostata* n. sp. – Aita, p. 76, pl. 4, figs. 7a–8b; pl. 10, figs. 8, 9.
1995 *Unuma latusicostatus* (Aita) – Baumgartner *et al.*, p. 622, pl. 4058, figs. 1, 4.
1996 *Tricolocapsa latusicostata* (Aita) – Nishizono, pl. 13, fig. 11.

Remarks: The present specimen has seven longitudinal plicae in a half side view, and four longitudinal rows of pores between neighboring plicae. No nodes or spines on the plicae.
Range: UA Zones 2–5, late Aalenian to latest Bajocian–early Bathonian (Baumgartner *et al,* 1995).

Unuma typicus Ichikawa and Yao, 1976
(UT-7, Fig. 5r; UT-5, Fig. 5s)
1976 *Unuma typicus* n. sp. – Ichikawa and Yao, p. 112, pl. 1, figs. 1–3.
1996 *Unuma typicus* Ichikawa and Yao – Nishizono, pl. 18, figs. 15, 16.
Remarks: The specimen shown in Fig. 5r (UT-7) has nine longitudinal plicae in a half side view, and four longitudinal rows of pores between neighboring plicae without spines. The specimen shown in Fig. 5s (UT-5) is very similar to *Unuma typicus* Ichikawa and Yao. Probably, this will be an immature (variation) specimen or basal appendage has been broken.
Range: This species occurs from the *Hsuum hisuikyoense* to *Striatojaponocapsa plicarum* zones in Outer zone of Southwest Japan (Nishizono, 1996). UA Zones 3–4, early–middle Bajocian to late Bathonian (Baumgartner *et al.*, 1995).

Genus ***Podobursa*** Wisniowski 1889; emend. Foreman, 1973

Podobursa nodosa (Chiari, Marucucci and Prela, 2002)
(UT-7, Fig. 5t)
2002 *Williriedellum nodosum* n. sp. – Chiari *et al.*, p. 84, pl. 5, figs. 15–19.
2009 *Podobursa nodosa* (Chiari, Marucucci and Prela) – Suzuki and Gawlick, p. 178, figs. 5.20, 5.21.
Remarks: Cephalis and thorax are conical. Abdomen is large globose with nodes surrounded by irregular pores. Final segment terminates in a prolonged tube with elongate pores and solid pore flames.
Range: UA Zone 5, latest Bajocian to early Bathonian (Chiari *et al,* 2002).

Family ***Arcanicapsidae*** Takemura, 1986

Genus ***Striatojaponocapsa*** Kozur, 1984

Striatojaponocapsa plicarum (Yao, 1979)
(UT-7, Fig. 5u, v)
1979 *Tricolocapsa plicarum* n. sp. –Yao, p. 32, pl. 4, figs. 1–11.
1984 *Striatojaponocapsa plicarum* (Yao) – Kozur, p. 56, pl. 7, fig. 3
1996 *Tricolocapsa plicarum* Yao – Nishizono, pl. 13, figs. 14–16.
2007 *Striatojaponocapsa plicarum* (Yao) – Hatakeda *et al.*, p. 16, pl. 1, figs. 1–10
2009 *Striatojaponocapsa plicarum* (Yao) – Suzuki and Gawlick, p. 182, figs. 5.39A, 5.39B.
Measurements (in μm): Fig. 5u; height 92, width 80, width of basal appendage 30, Fig. 5v; height 95 (broken cephalis), width 75, width of basal appendage 28.
Remarks: Abdomen is spherical with eighteen longitudinal plicae along an equator in a side view. One row of small pores are arranged in neighboring two longitudinal plicae. The basal appendage of the specimen shown in Fig. 5u is small with unclear circular area. In the specimen of the shown in Fig. 5v, circular area without surrounding ridges (Hatakeda *et al.*, 2007) is wider than that of the specimen shown in Fig. 5u.
Range: *Stj. plicarum* with small appendage (30 to 35 μm) occurs in near the last horizon of this species (Hatakeda *et al.*, 2007). UA Zones 4–5, late Bajocian to latest Bajocian–early Bathonian (Baumgartner *et al.*, 1995). This species occurs from the *Striatojaponocapsa plicarum* to *Cinguloturris carpatica* zones in Outer zone of Southwest Japan (Nishizono, 1996).

Genus ***Tricolocapsa*** Haeckel, 1881

Tricolocapsa undulata (Heitzer, 1930)
(UT-7, Fig. 5w)
1930 *Lithobotrys undulata* n. sp. – Heitzer, p.390, pl. 28, fig. 22.
1987 *Sethocapsa funatoensis* n. sp. – Aita, p. 73, pl. 2, figs. 6a–11; pl. 7, figs. 14, 15.
1993 *Tricolocapsa undulata* (Heitzer) – Ozvoldova and Faupl, pl. 3, fig. 12.
1996 *Sethocapsa funatoensis* Aita – Nishizono, pl. 16, figs. 5, 6.
2003 *Tricolocapsa undulata* (Heitzer) – Suzuki and Gawlick, p. 210, fig. 5.41; fig. 6.39.
2009 *Tricolocapsa undulata* (Heitzer) – Suzuki and Gawlick, p. 183, figs. 5.44A, 5.44B, 5.45A, 5.45B; figs. 6.18A, 6.18B, 6.19A, 6.19B.
Remarks: This species was described by Aita (1987) as *Sethocapsa funatoensis*. This species differs from *Sethoc. yahazuensis* by having rather spinose or pointed nodes on the last segment (Aita, 1987). Suzuki and Gawlick (2003) regarded these two species as younger synonyms of *Lithobotrys undulata* Heitzer.
Range: This species occurs from the *Striatojaponocapsa plicarum* to *Stylocapsa*? *spiralis* zones in the Outer zone of Southwest Japan (Nishizono, 1996).

Genus ***Stichocapsa*** Haeckel, 1881

Stichocapsa convexa Yao, 1979
(UT-5, Fig. 5x)
1979 *Stichocapsa convexa* n. sp. – Yao, p. 35, pl. 5, figs. 14–16; pl. 6, figs. 1–7.
1986 *Stichocapsa convexa* Yao – Takemura, p. 55, pl. 7, figs. 9, 10.
1996 *Stichocapsa convexa* Yao – Nishizono, pl. 14, fig. 13.
Remarks: Test consists of four segments, conical at upper

half. Forth segment is a truncated sphere with small aperture.
Range: This species occurs mainly from middle of the *Transhsuum hisuikyoense* to the uppermost of the *Striatojaponocapsa plicarum* zones in the Outer zone of Southwest Japan (Nishizono 1996).

Stichocapsa magnipora Chiari, Marucci and Prela, 2002
(UT-5, Fig. 5y)
2002 *Stichocapsa magnipora* – Chiari *et al.*, p. 76–77, pl. 3, figs. 13–17.
Remarks: Last segment is inflated with flattened base and aperture. Test has a large depression between the third chamber and the final one. Size of pores is smaller than holotype.
Range: UA Zones 4–7, late Bajocian to late Bathonian–early Callovian. (Chiari *et al.*, 2002).

Family **EUCYRTIDIELLIDAE** Takemura, 1986

Genus ***Eucyrtidiellum*** Baumgartner, 1984

Eucyrtidiellum unumaense (Yao, 1979)
(UT-7, Fig. 5z)
1979 *Eucyrtidium*? *unumaensis* n. sp. – Yao, p. 39, pl. 9, figs. 1–11.
1984 *Eucyrtidiellum putsulatum* Yao – Baumgartner, p. 765, pl. 4, figs. 4, 5.
1986 *Monosera unumaensis* (Yao) – Takemura and Nakaseko, p. 1022, figs. 4.1–4.9.
1990 *Eucyrtidiellum unumaense* (Yao) – Nagai and Mizutani, p. 597, figs. 4.6, 4.7.
1995 *Eucyrtidiellum unumaense putsulatum* Baumgartner – Baumgartner *et al.*, p. 220, pl. 3013, figs. 1, 2.
Remarks: Shell of four segments. Cephalis with a horn where the root remains. Thorax nodose with the sutural pores at distal part. Most of the abdomen is not preserved. However, the part of it with nodes in proximal portion. The fourth segment is lost due to poor preservation. These features show that this specimen similar to *Eucyrtidiellum unumaense putsulatum* Baumgartner *et al.*, 1995.
Range: UA Zones 3–8, early–middle Bajocian to middle Callovian – early Oxfordian (Baumgartner *et al.*, 1995).

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References

Aita, Y. (1987) Middle Jurassic to Lower Cretaceous radiolarian biostratigraphy of Shikoku with reference to selected sections Lombardy basin and Sicily. *Science Reports of the Tohoku university, Second Series (Geology)*, **58**, 1–91.

Baumgartner, P. O. (1984) A Middle Jurassic–Early Cretaceous low latitude radiolarian zonation based on unitary association and age of Tethyan radiolarites. *Eclogae Geologicae Helvetiae*, **77**, 729–837.

Baumgartner, P. O., O' Dogherty, L., Goričan S., Dumitrica-Jud, R., Dumitrica, P., Pillevuit, A., Urquhart, E., Matsuoka, A., Danellian, T., Bartolini, A., Carter, E. S., De Wever P., Kito, N., Marcucci, M. and Steiger, T. (1995) Radiolarian catalogue and systematics of Middle Jurassic to Early Cretaceous Tethyan genera and species. *Memoires de Geologie (Lausanne)*, no. 23, 37–685.

Carter, E. S., Cameron, B. E. B. and Smith, P. L. (1988) Lower and Middle Jurassic radiolarian biostratigraphy and systematic paleontology, Queen Charlotte Islands, British Columbia. *Geological Survey of Canada Bulletin*, **386**, 1–109.

Carter E. S., Whalen, P. A. and Guex, J. (1998) Biochronology and paleontology of Lower Jurassic (Hettangian and Sinemurian) radiolarians, Queen Charlotte Island, British Columbia. *Geological Survey of Canada Bulletin*, **496**, 1–161.

Chiari, M., Marcucci, M. and Prela, M. (2002) New species of Jurassic radiolarians in the sedimentary cover of ophiolites in Mirdita area, Albania. *Micropaleontology*, **48**, 61–87.

Cohen, K. M., Harper, D. A., Gibbard, P. L. and Fan, J. -X. (2013) International Chronostratigraphic Chart. *Episodes*, **36**, 199–204 (updated in 2020, https://stratigraphy.org/icschart/ChronostratChart2020-01.pdf, Accessed: 2020-01-23).

De Wever, P., Duée, G. and El Kadiri, K. (1985) Les sériesstratigraphiques des klippes de Chrafate (Rif septentrional, Maroc). *Bulletin de la Sociéte Géologique de France, série 8*, **1**, 363–379 (in French with English abstract).

Ehrenberg, C. G. (1875) Fortsetzung der mikrogeologischen Studien als Gesammt-Uebersicht der mikroskopischen Paläontologie gleichartig analysirter Gebirgsarten der Erde, mit specieller Rücksicht auf den Polycystinen-Mergel von Barbados. *Abhandlungen der Königlichen Preussichen Akademie der Wissenschaften zu Berlin*, **1875**, 1–225 (in German).

Forman, H. P. (1973) Radiolaria from DSDP Leg 20, *In* Heezen, C., MacGregor, D., Forman, P., Hekel, H., Hesse, R., Hoskins, A., Okada, H. and Ruef, H. eds., *Initial Reports of the Deep See Drilling Project.*, **20**, 249–305.

Gawlick, H., Schlagintweit, F., Ebli, O. and Suzuki, H. (2004) Die Plassen-Formation (Kimmeridgium) des

Krahstein (Steirisches Salzkammergut, Österreich) und ihre Unterlagerung: neue Daten zur Fazies, Biostratigraphie und Sedimentologie. *Zentralblatt für Geologie und Paläontologie*, **2003**, 295–334 (in German with English abstract).

Goričan, Š., Carter, E. S., Dumitrica, P., Whalen, P., Hori, R., De Wever, P., O'Dogherty, L., Matsuoka, A. and Guex, J. (2006) *Catalogue and systematics of Pliensbachian, Toarcian and Aalenian radiolarian genera and species*. Založba ZRC Publishing, SAZU, Ljubljana, 1–446.

Hatakeda, K., Suzuki, N. and Matsuoka, A. (2007) Quantitative morphological analyses and evolutionary history of the Middle Jurassic polycystine radiolarian genus *Striatojaponocapsa* Kozur. *Marine Micropaleontology*, **63**, 39–56.

Haeckel, H. (1881) Entwurf eines Radiolarien-Systems auf Grund von Studien der Challenger-Radiolarien. *Jenaische Zeitschrift für Naturwissenschaft*, **15**, 418–472 (in German).

Hayami, I. (1962) Jurassic pelecypod fauna in Japan with special reference to their stratigraphical provinces. *Journal of Geological Society of Japan*, **68**, 96–108 (in Japanese with English abstract).

Heitzer, I. (1930) Die Radiolarienfauna der mitteljurassischen kieselmergel im Sonnwendgebirge. *Jahrebuch der Geologischen Bundesanstalt*, **80**, 381–406 (in German).

Hirano, H. (1971) Biostratigraphic study of the Jurassic Toyora Group part 1. *Memoirs of the Faculty of Science, Kyushu University. Series D, Geology*, **21**, 93–128.

Hirano, H. (1973a) Biostratigraphic study of the Jurassic Toyora Group part 2. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **89**, 1–14.

Hirano, H. (1973b) Biostratigraphic study of the Jurassic Toyora Group part 3. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **90**, 45–71.

Hirasawa, S., Kashiwagi, K. and Fujita, M. (2010) Marine strata and dinosaur footprints of the Upper Jurassic to Lower Cretaceous Tetori Group, Toyama Prefecture. *Journal of Geological Society of Japan*, **116**, Supplement, 103–121 (in Japanese).

Hori, R. (1990) Lower Jurassic radiolarian zones of Japan. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **159**, 562–586.

Ichikawa, K. and Yao, A. (1976) Two new genera of Mesozoic cyrtoid radiolarians from Japan. *In* Takayanagi, Y. and Saito, T. eds., *Progress in micropaleontology, special publication*, Micropaleontology Press, 110–117.

Isozaki, Y. and Matsuda, T. (1985) Early Jurassic radiolarians from bedded chert in Kamiaso, Mino Belt, central japan. *Earth Science (Journal of the Association for the Geological Collaboration in Japan)*, **39**, 429–442.

Izumi, K., Miyaji, T. and Tanabe, K. (2012) Early Toarcian (Early Jurassic) oceanic anoxic event recorded in the shelf deposits in the northwestern Panthalassa: evidence from the Nishinakayama Formation in the Toyora area, west Japan. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **315–316**, 100–108.

Kobayashi, T. (1926) Note on the Mesozoic formations in prov. Nagato. *Journal of Geological Society of Japan*, **33**, 1–19.

Koschelkina, Z. V. (1963) Stratigraphy and bivalve mollusks of the Jurassic deposits of Viluysk syncline and near Verhojansk foredeep. *Transactions of the Northeast, Integrated Research Institute, Siberian Branch of the USSR Academy of Sciences*, **5**, 1–219 (in Russian).

Kozai, T., Ishida, K. and Kondo, Y. (2006) Jurassic–Cretaceous boundary and Cretaceous formations in the Tosayamada–Birafu area, Kochi Prefecture. *Journal of Geological Society of Japan*, **112**, Supplement, 89–99 (in Japanese).

Kozur, H. (1984) New radiolarian taxa from the Triassic and Jurassic. *Geologisch-Paläontlogische Mitteilungen Innsbruck*, **13**, 49–88.

Kozur, H. (1985) The radiolarian genus Eoxitus n. gen. from the *Unuma echinathus* Zone (Bajocian) of the northern Hungary. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, series B*, **88**, 211–220.

Majidifard, M. (2003) Biostratigraphy, lithostratigraphy, ammonite taxonomy and microfacies analysis of the Middle and Upper Jurassic of northeastern Iran. *Dissertation zur Erlangung des Naturwissenschaftlichen Doktorgrades Der Bayerischen Julius-Maximilians-Universität Würzburg*, **2003**, 1–201.

Matsuoka, A. (1995) Jurassic and Lower Cretaceous radiolarian zonation in Japan and in the western Pacific. *The Island Arc*, **4**, 140–153.

Matsuoka, A. and Yao, A. (1986) A newly proposed radiolarian zonation for the Jurassic of Japan. *Marine Micropaleontology*, **11**, 91–105.

Matsuoka, A. and Ito, T. (2019) Updated radiolarian zonation for the Jurassic in Japan and the western Pacific. *Science Reports of Niigata University (Geology)*, **34**, 49–57.

Matsumoto, T. and Nishizono, Y. (1985) *Decipia* from the Ebirase Formation of Kyushu. *Journal of Geolological Society of Japan*, **91**, 421–423 (in Japanese).

Müller, J. (1858) Einige neue bei St. Tropezam Mittelmeer beobachetete Polycystinen und Acanthometren. *Königlich-Preußische Akademie der Wissenschaften zu Berlin, Monatsberichte*, Jahrgang **1858**, 154–155 (in German).

Nakada, K and Matsuoka, A. (2009) On the Pliensbachian/Toarcian boundary in the Lower Jurassic Toyora Group in southwest Japan. *Volumina Jurassica*, **7**, 47–54.

Nakada, K. and Matsuoka, A. (2011) International correlation on the Pliensbachian/Toarcian (Lower Jurassic) ammonoid biostratigraphy of the Nishinakayama Formation in the Toyora Group, Southwest Japan. *Newsletter on Stratigraphy*, **44**, 89–111.

Nagai, H. and Mizutani, S. (1990) Jurassic *Eucyrtidiellum* (radiolaria) in the Mino terrane. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **159**, 587–602.

Nishizono, Y. (1996) Mesozoic convergent process of the Southern Chichibu Terrane in West Kyushu, Japan, on the basis of Triassic to Early Cretaceous radiolarian biostratigraphy. *Kumamoto Journal of Science, Earth Sciences*, **14**, 45–226 (in Japanese with English abstract).

Nishizono, Y., Sato, T. and Murata, M. (1997) A revised Jurassic radiolarian zonation for the South Belt of the Chichibu terrane, western Kyushu, Southwest Japan. *Marine Micropaleontology*, **30**, 117–138.

Ozvoldova, L. (1975) Upper Jurassic radiolarians from the Kisuca Series in the Klippen Belt. *Západné karpaty, Séria Paleontologia*, **1**, 73–86.

Ozvoldova, L. (1979) Radiolarian assemblage of radiolarian cherts of Podbiel locality (Slovakia). *Casopis pro Mineralogii a Geologii*, **24**, 249–261.

Ozvoldova, L. and Faupl, P., (1993) Radiolarien aus kieseligen Schichtgliedern des Juras der Grestener und Ybbsitzer Klippenzone (Ostalpen, Niedrösterreich). *Jahrbuch der Geologischen Bundesanstalt*, **136**, 479–494 (in German with English abstract).

Pessagno, E. A. (1976) Radiolarian zonation and stratigraphy of the Upper Cretaceous portion of the Great Valley Sequence, California Coast Ranges. *Micropaleontology Special Publication*, **2**, 1–95.

Pessagno, E. A. (1977) Upper Jurassic radiolarian biostratigraphy of the California Coast Ranges. *Micropaleontology*, **23**, 56–113.

Pessagno, E. A. and Whalen, A. P. (1982) Lower and Middle Jurassic radiolaria (multicyrtid Nassellariina) from California, east-central Oregon and the Queen Charlotte Islands, B.C. *Micropaleontology*, **28**, 111–169.

Pessagno, E. A., Blome, C. D., Hull, D. M. and Six, W. M. (1993) Jurassic radiolaria from the Josephine ophiolite and overlying strata, Smith River subterrane (Klamath Mountains), northwestern California and southwestern Oregon. *Micropaleontology*, **39**, 93–166.

Riedel, R. (1967) Some new families of radiolaria. *Proceedings of the Geological Society of London*, **1640**, 148–149.

Rüst, D. (1885) Beiträge zur Kenntniss der fossilen Radiolarien aus Gesteinen des Jura. *Palaeontographica*, **31**, 269–321 (in German).

Sandoval, J., O' Dogherty, L. and Guex, J. (2001) Evolutionary rates of Jurassic ammonites in relation to sea-level fluctuations. *Palaios*, **16**, 311–335.

Sano, K. and Kashiwagi, K. (2015) The comparison of Middle to Late Jurassic, shallow-marine radiolarian assemblages between the Inner and Outer zones of Southwest Japan. *Proceedings of 164th Regular Meeting of Palaeontological Society of Japan*, 48 (in Japanese).

Shikama, T. and Hirano, H. (1970) On the mode of occurrence of ammonites in the Nishinakayama Formation, Toyora Group. *Science Reports of Yokohama National University, Section 2*, **16**, 61–71.

Suzuki, H. and Gawlick, H. (2003) Biostratigraphie und Taxonomie der Radiolarien aus den Kieselsedimenten der Blaa Alm und nördlich des Loser (Nördliche Kalkalpen, Callovium-Oxfordium). *Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten Österreichs*, **46**, 137–228 (in German with English abstract).

Suzuki, H. and Gawlick, H. (2009) Jurassic radiolarians from cherty limestones below the Hallstatt salt mine (Northern Calcareous Alps, Austria). *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, **251**, 155–197.

Suzuki, H., Prinz, P. and Schmidt-Effing, R. (2002) Radiolarien aus dem Grenzbereich Hettangum/ Sinemurium von Nordperu. *Paläontologische Zeitschrift*, **76**, 163–187 (in German with English abstract).

Tan, S. H. (1927) Over de samenstelling en het ontstaan van krijten mergel-gesteenten van de Molukken. *Jaarboek van het Mijinwezen in Nederlandsch Oost-Indië*, **55**, 5–165 (in Dutch).

Takemura, A. (1986) Classification of Jurassic Nassellarians (radiolaria). *Palaeontographica, Abteilung A: Palazoologie- Stratigrahie*, **195**, 29–74.

Takemura, A. and Nakaseko, K. (1986) The cephalic skeletal structure of Jurassic "*Eucyrtidium*" (radiolaria). *Journal of Paleontology*, **60**, 1016–1024.

Tanabe, K. (1991) Early Jurassic macrofauna of the oxygen-depleted epicontinental marine basin in the Toyora area West Japan. *Saito Ho-on Kai Special Publication*, no. 3, 147–161.

Toriyama, R. (1938) Geology of the Toyora Group in the Toyora Country, Yamaguchi Prefecture. *Journal of Geological Society of Japan*, **45**, 247–258 (in Japanese).

Wisniowski, T. (1889) Beitrag zur Kenntniss der Mikrofauna aus den oberjurassischen Feuersteinknollen der Umgegend von Krakau. *Jahrbuch der Kaiseriche-Königlichen Geologischen Reichsanstalt*, **38**, 657–702 (in German).

Yao, A. (1979) Radiolarian fauna from the Mino Belt in the northern part of the Inuyama area, central Japan. Part 2: Nassellaria 1. *Journal of Geosciences, Osaka City University*, **22**, 21–72.

Yao, A. (1982) Middle Triassic to Early Jurassic radiolarians from the Inuyama area, central Japan. *Journal of Geosciences, Osaka City University*, **25**,

53–70.
Yao, A. (1990) Triassic and Jurassic radiolarians. *Pre-Cretaceous terranes of Japan*, Publication of IGCP Project no. 224, Osaka, 329–345.
Yao, A. (1997) Faunal change of Early–Middle Jurassic radiolarians. *News of Osaka Micropaleontologist, Special Volume*, no. 10, 155–182 (in Japanese with English abstract).
Yokoyama, M. (1902) Jurassic ammonites from Echizen and Nagato. *Journal of the College of Science, Imperial University of Tokyo,* **14**, 1–17.

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西南日本，山口県に分布するアンモナイトを含む豊浦層群から産出した放散虫

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要　旨

豊浦層群は西南日本山口県に分布する日本における下部－中部ジュラ系模式地の一つであり，アンモナイト化石を多産する．しかし，放散虫のような微化石の報告は今まで知られていない．豊浦層群最上部 7 か所から *Transhsuum hisuikyoense* 帯および *Striatojaponocapsa plicarum* 帯の放散虫を見出した．これらの放散虫は，中期ジュラ紀 Aalenian から Bathonian を指示すると考えられる．この放散虫指示年代は，アンモナイトやイノセラムスで決定された地質年代よりもやや古い．先行研究によれば *Stj. plicarum* の初出現年代は，Aalenian と Bajocian の境界付近と推定されているにすぎない．この課題を検討するためには，アンモナイトと放散虫の産出間隙から Aalenian を指示するアンモナイトのような化石資料のさらなる蓄積が必要である．