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 Transhshuum 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
radiolarians (Matsumoto and Nishizono, 1985, Kozai et al., 2006). Recently, Jurassic radiolarians were reported from shallow marine sediments of the Totori 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,
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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
Corrected Proof

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Harpoceras inouyei zones in ascending order. Paltarpites paltus these with European zonations: the Canavaria japonica established four ammonoid zones in Nm and correlated 1973a, b). Furthermore, Nakada and Matsuoka (2011) lower Toarcian and lower Toarcian, respectively (Hirano, 1973a, b). Furthermore, Nakada and Matsuoka (2011) determined that the Pliensbachian–Toarcian boundary is at the base of the Pliensbachian Toarcian boundary is at the base of the

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 Calliphyloceras 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, e1j): Canutus sp., Parahsuum sp., and Transhsuum aff. hisuikyoense.
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)
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 hisuikyoensis Zone (Nishizono et al., 1997). This correlation does not contradict the assemblage of the Th. hisuikyoensis Zone of sample UT-2, which is in the lower part of the Ut. The Th. hisuikyoensis 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.?
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Fig. 5  SEM (Scanning Electron Microscope) photos of radiolarian.
a: Archicapsa pachyderma (Tan) (locality; UT-5).  b: Canatus 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. hisiukyoense (Isozaki and Matsuda) (locality; UT-2).  k: Archaeodictyomitra sp. H in Nishizono (1996) (locality; UT-7).  l: Prae-parvicingula audeleata (Carter) (locality; UT-5).  m: Prae-parvicingula? 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 latucostatus (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, Marucci and Prela) (locality; UT-7).  u, v: Striatojaponocapsa plicarum (Yao) (locality; UT-7).  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.
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
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(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 Bathanian in the Lena River, Russia (Koschelkina, 1963; Hirano, 1973b). This indicates that the uppermost member (Ut) includes at least the Bajocian to Bathanian 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 hisuiykoense 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;
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. 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. A – Pessagno and Whalen, 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).
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**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 *Striatopajonocapsa 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. 5i)

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 have 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. Gorican et al. (2006) classified *Parvicingula aculeata* Carter to genus *Praeparvicingula* on the basis of the above test structures.

**Range:** middle Toarcian–Early Bajocian (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 thellensis* 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. 6.5A, 6.5B.

**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 *Exoities 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* range 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 *Williriedellium 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
Middle Jurassic radiolarians from the ammonite bearing Toyora Group, Yamaguchi Prefecture, Southwest Japan (NISHIZONO and YONEMITSU)

Eucyrtidiellum unumaense (Yao, 1979)

- UT-7, Fig. 5z

Range: UA Zones 4–7, late Bajocian to late Bathonian–
holotype.

Remarks: This species occurs mainly from middle of the Transshuum 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–
half. Forth segment is a truncated sphere with small aperture.

Family EUCYRTIDIELLIDAE Takemura, 1986

Genus Eucyrtidiellum Baumgartner, 1984

Eucyrtidiellum unumaense (Yao, 1979)

(UT-7, Fig. 5z)

1979 Eucyrtidiellum? 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 sutral pores at distal part. Most of the abdomen is not preserved. However, the part of it with nodes in proximal portion.

Range: UA Zones 3–8, early–middle Bajocian to middle Callovian – early Oxfordian (Baumgartner et al., 1995).

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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

西園 幸久・米光 功雄

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Transshuam hisukyoense 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隔から 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。

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