Revised radiolarian zonation of the Upper Cretaceous Izumi inter-arc basin (SW Japan)

Révision des zones à radiolaires des séries du Crétacé supérieur du bassin inter-arc d'Izumi (sud-ouest du Japon)

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Abstract

The radiolarian zonation of the Izumi Group is revised for an integrated biostratigraphy across the Campanian / Maastrichtian boundary, together with the ammonite occurrence, fission track and magnetostratigraphic calibration of the acidic tuff key beds. The significance of direct correlation in the same sections, between macro- and micro-fossils (i.e. between relatively near-shore nektonic and turbiditic planktonic- fauna) is discussed in relation to the litho- and bio-facies of the Izumi group. Late Cretaceous paleoceanographic changes inferred from the studied radiolarian fauna represent a regional marker event for the chronostratigraphic correlation of continental shelf to turbidite deep-sea sequences which accumulated on a mid latitudinal margin facing towards the NW paleo-Pacific. The proposed Campanian / Maastrichtian boundary is at the limit between *Pachydiscus awajiensis* and *Nostoceras hetonaiense* ammonite zones. **This boundary corresponds to the radiolarian last occurrence** of *Amphipyndax pseudoconulus* (= *A. enesseffi*), *Archaeodictyomitra sliteri, Dictyomitra formosa, D. koslovae and* ***Rhopalosyringium magnificum*** at the top of the *Myllocercion acineton* **Assemblage Zone (uppermost Campanian), and the first occurrence of** *Clathrocyclas gravis and Dorcadospyris* sp. A, **at** the base of the ***Maastrichtian Clathrocyclas gravis*** **Assemblage** Zone. *The new data settle partly a* chronostratigraphic discrepancy between radiolarian and ammonite zonations in the Izumi Group, which was pointed out previously by Ishida et al. (2010).

Keywords: Late Cretaceous; ammonite; radiolaria; zonal correlation; Izumi Group; Japan.

Résumé

Ayant pour but la biostratigraphie intégrée à travers la limite Campanien /

Maastrichtien, la corrélation directe entre zones à radiolaires et celles à ammonites du groupe d' Izumi fut ré-examinée et révisée, en tenant compte de la calibration géochronologique à l' aide de *traces de fission* et de la magnétostratigraphie des niveaux marqueurs de cinérites. L' importance d' une telle corrélation directe sur les mêmes coupes entre macro- et micro-fossiles (soit entre du necton relativement littoral et du plancton de mer ouverte) est discutée en relation avec les litho- et bio-faciès du groupe d' IzumiDes changements paléocéanographiques du Crétacé supérieur, déduits de la faune des radiolaires représentent un événement marqueur régional de corrélations chrono-stratigraphiques entre le faciès de plateau continental et celui de bassin, pour les séries sédimentaires accumulées sur une marge des moyennes latitudes ouverte vers l' océan paléo- Pacifique nord occidental. La limite Campanien / Maastrichtien proposée se situe entre les zones à *Pachydiscus awajiensis* et *Nostoceras hetonaiense* des Ammoniites. **Cette limite correspond à la dernière occurrence (**LO) des **radiolaires** *Amphipyndax pseudoconulus* (= *A. enesseffi*), *Archaeodictyomitra sliteli, Dictyomitra formosa, D. koslovae et* ***Rhopalosyringium magnificum*** au sommet de la zone à *Myllocercion acineton* **(Campanien sommital), et à la première occurrence (FO) des espèces** *Clathrocyclas gravis et Dorcadospyris* sp. à **la** base de **la zone** à ***Clathrocyclas gravis*** du ***Maastrichtien.*** *Nos nouvelles données résoluent partiellement le problème du* décalage chronostratigraphique entre les zones à radiolaraires et celles à ammonites, mis en évidence précédemment par Ishida et al. *(*2010).

Mots clé: Crétacé supérieur ; ammonites ; radiolares; corrélation des biozones; groupe d'Izumi ; Japon

1. Introduction

The Izumi Group (Harada, 1890) is composed of Upper Cretaceous inter-arc basin deposits that crop out along the northern side of the Median Tectonic Line (ex. Takahashi and Yamasaki, 1991). It is one of the most important sedimentary sequences for direct correlation of radiolarian and ammonite biostratigraphy in Japan and the NW Pacific region (Fig. 1). The distribution of both ammonites and radiolarians is generally facies-controlled, as ammonites were dominantly near-shore dwellers, while radiolarians occur in relatively pelagic marine facies.

Following the first global radiolarian biostratigraphic compilations for the Late Cretaceous (e.g. Pessagno, 1976; Sanfilippo and Riedel, 1985), Suyari and Hashimoto (1985) initially reported the occurrence of Campanian radiolarians in the Izumi Group. Yamasaki (1987) first studied the radiolarian zonations of the Group (Fig. 9), while Hollis and Kimura (2001) reviewed the Campanian and Maastrichtian radiolarian zonations in Japan. The radiolarian zonation of the Izumi Group was discussed based on the occurrence of *Amphipyndax pseudoconulus, A. tylotus, Dictyomitra koslovae, D. formosa and Pseudotheocampe abschnitta (Yamasaki, 1987; Ishida and Hashimoto, 1998; Tanaka and Yamasaki, 2000; Hashimoto et al., 2001).*

According to recent reports (Hashimoto and Ishida, 1997; Hashimoto et al., 2001; Hollis and Kimura, 2001), the Campanian to Maastrichtian assignment that can be made based on radiolarians is relatively younger than the one suggested by ammonites. To improve the chronological accuracy, direct correlation of ammonite and radiolarian zonations in the same stratigraphic succession is necessary. Reviewing the distribution of radiolarians and ammonites in the Izumi Group, the Campanian / Maastrichtian chronostratigraphic boundary was tentatively drawn between the *Pachydiscus awajiensis* Zone and *Nostoceras hetonaiense* Zone (Morozumi, 1985). On the other hand, *Pravitoceras sigmoidale*, a very short-range zonal index of the later Campanian, occurs in the *Inoceramus shikotanensis* Zone of the Hakobuchi Formation in Hokkaido (Matsunaga et al., 2008), alike its occurrence in the Izumi Group. We hope to provide a much more precise biostratigraphic correlation between the Yezo Group and the Izumi Group.

We here provide a revised scheme of radiolarian zones for the Izumi Group (Fig. 8) and their correlation with the ammonite zones in Japan (Fig. 9), based on research on the Izumi Group and the Ezo Supergroup (after Morozumi, 1985; Toshimitsu et al., 1995; Matsunaga et al., 2008; Shigeta et al., 2010).

Fig. 1.

2. Regional setting

2.1. Geological outline

The Izumi Group overlies unconformably the Upper Cretaceous Ryoke volcano-plutonic series (ca. 100 - 80 Ma) in Shikoku, Awaji Island the Izumi Mountains. It consists of continental shelf and deep-sea turbidite deposits. The continental shelf facies is subdivided into a Northern and a Southern Shelf facies (Figs. 2 - 4), which is characterized by ammonite and inoceramid bearing argillitic facies above a basal conglomerate.

The deep-sea turbidite facies, here called the Central Turbidite Facies, is characterized by turbiditic successions in which fine sediments yield radiolarians. The total thickness of the Central Turbidite Facies reaches ca. 60 km, however the maximum thickness of the individual formations is only few kilometers in a single area (Fig. 5), because the depocenter of the turbidite facies shifted from the west to the east during the deposition of turbidites (Yamasaki, 1986). Seismo-geologic studies (Itoh et al., 1996) established that the depth of the Central Turbidite Facies (reflection of unconformable boundary of theIzumi Group and the Ryoke Granites) is 5.5 km below the ground in the mid-Asan Mountains area (ex. sections of Takikubo and Horita formations in Fig. 5). Therefeore, the 60 km-thick sequence mentioned above represents a stacking of an east to west prograding turbidite fan, and not a vertical thickness. Inter-fingering of the two lithofacies is well monitored by acidic tuff intercalations, as key beds. The succession and its lateral extension are well traceable, because the Izumi Group forms eastward plunging synclinal structures.

Fig. 2.

Fig. 3.

Fig. 4.

Fig. 5.

2.2. Lithostratigraphy of the Izumi Group

Many researchers have surveyed the lithostratigraphy of the Izumi Group (Nakagawa, 1961; Suyari, 1966, 1973; Miyata et al., 1993; Noda et al., 2010). The Northern Shelf and Central Turbidite Facies are well correlated by many acidic tuff intercalations. Tuff beds T1 to T24 are indicated as key beds in Figs. 2 – 5.

2.2.1. Northern Shelf Facies

The Northern Shelf Facies extends along the northern margin of the Group. The facies is composed of basal conglomerate, arkosic sandstone and thick argillaceous beds with tuffaceous intercalations. The basal conglomerateoverlies unconformably the Upper Cretaceous Ryoke Granites and volcano-plutonics. The arkosic sandstone yields brackish and shallow-marine mollusks (Ichikawa and Maeda, 1963), whereas the successive argillaceous beds with ammonites and inoceramids are suggestive of outer-shelf deposits (Yamasaki, 1986). The Northern Shelf Facies is subdivided into the Kussaki, Shiroyama, Hiketa, Seidan, and Mutsuo formations that appear in this order from west to the east (Matsumoto and Morozumi, 1980; Morozumi, 1985; Itihara et al., 1986, Yamasaki, 1986; Miyata et al., 1993; Noda et al., 2010). The Kussaki Formation (Noda et al., 2010) occurs in central Shikoku. The Shiroyama and Hiketa formations, which represent a contemporaneous heterotopic relation (Yamasaki, 1986), are distributed in Eastern Shikoku, and the Seidan Formation (Ichikawa, 1961) is found on the Awaji Island. The Mutsuo Formation was subdivided into the basal Kasayama Conglomerate, Azenotani Mudstone and Takihata Alternation members (Itihara et al., 1986). They show contemporaneous heterotopic relations and are distributed in the Izumi Mountains. In the eastern part, the Azenotani Mudstone Member is replaced by the Takihata Alternation Member, which is composed of alternating conglomerate, sandstone and mudstone (Fig. 5).

2.2.2. Central Turbidite Facies

The Central Turbidite Facies deposits comprise dominantly alternating beds of sandstone and mudstone with many acidic tuff intercalations. It was lithostratigraphically subdivided into the Yamanouchi, Matsusegawa, Isoura, Niihama, Kan-onji, Takikubo, Horita, Higaidani, Bandodani, Anaga, Kita-ama, Nada, Tomogashima, Kada, Shindachi, Iwade and Kokawa formations, in ascending order and from west to the east. The Yamanouchi and Matsusegawa formations (Okamura et al., 1984) occur in western Shikoku. The Isoura and Niihama formations (Noda et al., 2010) occur in central Shikoku. The Kan-onji Formation in central Shikoku derives from "the Kan-onji Super Formation" of Nakagawa (1961). The Takikubo, Horita, Higaidani and Bandodani formations occur successively in eastern Shikoku (Yamasaki, 1986). The Anaga, Kita-ama and Nada formations successively appear in the southern Awaji Island（Ichikawa, 1961). The Tomogashima Formation is distributed in the Tomogashima Island, while the Kada, Shindachi, Iwade and Kokawa formations are in the Izumi Mountains successively (Miyata et al., 1993).

2.2.3. Southern Shelf Facies

The Southern Shelf Facies has a limited extension, adjacent to and south of the Central Turbidite Facies. The independent Shimonada Formation (Morozumi, 1985) extends along the southern margin of the Awaji Island, and is fault-bounded with the Central Turbidite Facies. The Nate Formation (Miyata et al., 1993) consists of argillites and conglomerates along the Southern foot of the Izumi Mountains.

3. Material and methods

The Izumi Group is one of the best studied sections for biostratigraphic correlation, composed of the ammonite-yielding northern- and southern shelf- facies and the radiolarian-yielding central turbidite- facies. This is due to the mapping and detailed lithostratigraphic correlation of these three facies by many researchers (ex. Nakagawa, 1961; Suyari, 1966, 1973; Miyata et al., 1993; Noda et al., 2010). The acidic tuff beds that are intercalated in the turbidites are useful key beds for litholostratigraphic correlations (Figs. 2 – 5). In addition to lithostratigraphy, biostratigraphic research on radiolarians (Yamasaki, 1986; Hashimoto and Ishida, 1997; Hashimoto et al., 2001; Hollis and Kimura, 2001) and ammonites (Matsumoto and Morozumi, 1980; Morozumi, 1985; Shigeta et al., 2010) has allowed to make substantial progress in understanding the chronology of the entire Izumi Group. To improve the chronological accuracy, we studied the direct correlation of ammonite and radiolarian zonations within the entire Izumi Group, compiling all available biostratigraphic and lithostratigraphic data in the Izumi Group.

4. Ammonite zonation in the Izumi Group

The Campanian–Maastrichtian ammonite zonation of the Izumi Group was subdivided into the following ten zones based on Morozumi (1985) and Shigeta et al. (2010) (Fig. 6):

***Sphenoceramus schmidti* Zone:** In t**he lower part of the Kussaki Formation,** *S. schmidti* is associated with *Gaudryceras striatum* (Locs. A1–A3 in Fig. 2: Noda and Tashiro, 1973). *Bevahites* aff. *lapparenti* occurs together with *S.* cf. *schmidti* in the upper horizon (Loc. A4: Matsumoto and Obata, 1963).

***Metaplacenticeras subtilistriatum* Zone**: **The lower part of the Hiketa Formation** (Locs. A5–A7 in Fig. 3: Bando and Hashimoto, 1984) **yields** *M. subtilistriatum* (Bando and Hashimoto, 1984; Morozumi, 1985).

***Baculites kotanii* Zone: The middle part of the Hiketa Formation** (Locs. A8, A9 in Fig. 3: Matsumoto at al., 1980) corresponds to the *B. kotanii* Zone (Morozumi, 1985).

Didymoceras sp. Zone: The upper part of the Hiketa Formation and the Higaidani Formation yield *Didymoceras sp***.** (Loc. A10: Nishiyama et al., 2009; A11: Morozumi, 1985; A12: Nakagawa, 1960; Fig. 3).

***Didymoceras awajiense* Zone:** *Patagiosites laevis* and *Gaudryceras* aff. *striatum occur in the D. awajiense Zone* (Morozumi, 1985). **The upper part of the Higaidani Formation (**Locs. A13–A15: Morozumi, 1985; Locs. A16, A17: Bando and Hashimoto, 1984) **and the lower part of the Seidan Formation** (Loc. A18: Morozumi, 1985) **belong to this zone.**

***Pravitoceras sigmoidale* Zone: The highest occurrence of** *P. sigmoidale* lies in the **upper part of the Bandodani Formation (**Locs. A19 – A23: Bando and Hashimoto, 1984; Loc. A26: Morozumi and Tsujino, 2003) and the upper part of the Seidan Formation (Locs. A24, A25: Morozumi, 1985) of the western block.

Pachydiscus awajiensis Zone: *P. awajiensis* occurs in a single horizon **of the Seidan Formation (**Loc. A28)**, the Anaga Formation (**Loc. A27) **and the lower part of the Kita-ama Formation** (Morozumi, 1985)**.**

***Nostoceras hetonaiense* Zone:** *N. hetonaiense* occurs in the upper part of the Kita-ama Formation *(Locs. A29*, A30: Fig. 3*) together with Baculites inornatus, Inoceramus (Endocostea) shikotanensis* and "*Anisomyon*" *problematicus* (Morozumi, 1985).

Gaudryceras izumiense Zone: *G. izumiense occurs in the middle part of the* Azenotani Mudstone Member of the Shindachi Formation in the Izumi Mountains (Locs. A31, A32: Matsumoto and Morozumi, 1980; Fig. 4). According to Shigeta *et al*. (2010), the lower part of the ***G. izumiense Zone partly overlaps with the upper part of the N. hetonaiense Zone.***

***Pachydiscus* aff. *subcompressus* Zone:** *P.* aff. *subcompressus occurs in* the Shimonada Formation (Loc. A33: Matsumoto and Morozumi, 1980; Fig. 3), in association with *Anagaudryceras matsumotoi, Zelandites* cf. *varuna and G. makarovense*. The same faunal association was reported from the uppermost part of the Yezo Group (Ando *et al*., 2001) and from the Senpohshi Formation of the Nemuro Group (Naruse e*t al*, 2000; Nifuku *et al*., 2009) in Hokkaido, as well as from Sakhalin (Shigeta and Maeda, 2005).

Fig. 6.

5. Revised radiolarian zonation in the Izumi Group

The biostratigraphic revision of this study is based on 103 local faunas that we obtained from the Izumi Group. Among them, we selected 36 local faunas for this study (Fig. 7). Based on the first occurrence (FO) and last occurrence (LO) of some marker species, the following 8 radiolarian assemblage zones and interval zones are distinguished. A compilation of the age range of index radiolarian species is given in Fig. 8; radiolarians from the Izumi Group are shown in Plates 1 and 2.

Fig. 7.

Fig. 8.

Plate 1.

Plate 2.

Fig. 9.

5.1. Dictyomitra koslovae Zone

Base: Apparent FO of *Stichomitra compsa.*

Top: FO of *Amphipyndax pseudoconulus, Amphipyndax tylotus and Pseudotheocampe abschnitta*.

Associate species: *Alievium gallowayi, Amphipyndax conicus, Amphipyndax* aff.

pseudoconulus, Amphipyndax stocki, Archaeodictyomitra sliteri, Archaeodictyomitra simplex, Artostrobium urna, *Cornutella californica, Cryptamphorella sphaerica, Dictyomitra andersoni, Dictyomitra densicostata, Dictyomitra formosa, Dictyomitra koslovae and D.* aff. *koslovae, Dictyomitra multicostata, Lithomelissa amazon, Mita regina, Orbiculiforma renillaeformis, Pseudoaulophacus floresensis, Pseudoaulophacus lenticulatus, Rhopalosyringium magnificum, Stichomitra asymbatos, Stichomitra campi, Stichomitra livermorensis and Theocampe apicata*.

Occurrence: Locs. R1 – R3 (Fig. 2; Yamanouchi Formation), Loc. R4 **(Fig. 2;** Niihama Formation), Loc. R5 (Fig.2; Kan-onji Formation).

Age: upper Lower Campanian. The Ammonite species *Gaudryceras striatum* occurs together with the inoceramid species *Sphenoceramus schmidti* in the lower part of this zone (Locs. A1 – A3). *Bevahites* aff. *lapparenti* occurs together with *S.* cf. *schmidti* in the upper part of this zone (Loc. A4).

5.2. Archaeodictyomitra lamellicostata Zone

Base: FO of *Amphipyndax pseudoconulus, Amphipyndax tylotus, and Pseudotheocampe abschnitta*.

Top: FO of *Clathrocyclas tintinnaeformis, and Cryptamphorella conara.*

Associate species: *A. lamellicostata, A.* aff. *pseudoconulus, Amphipyndax stocki, Archaeodictyomitra sliteri, Archaeodictyomitra simplex, Alievium gallowayi, Amphipyndax conicus, Archaeospongoprunum hueyi, Cornutella californica, Dictyomitra andersoni, Dictyomitra multicostata, Cryptamphorella sphaerica, Dictyomitra densicostata, Dictyomitra formosa, Dictyomitra koslovae, D.* aff. *koslovae, Orbiculiforma renillaeformis, Pseudoaulophacus floresensis, Pseudoaulophacus* *lenticulatus, Rhopalosyringium magnificum, Stichomitra asymbatos, Stichomitra campi, Stichomitra compsa and Stichomitra livermorensis.*

Occurrence: Locs. R6, R7 (Fig**. 2 and 3;** Kan-onji Formation), Locs. R8 – R11 (Fi**g. 3;** Horita Formation), Locs. R12 and R13 (Fig. 3; Higaidani Formation).

Age: lower Upper Campanian. The Ammonite species *Metaplacenticeras subtilistriatum* occurs in the upper part of this zone (Loc. A5 – A7), ***Baculites kotanii*** (Locs. A8, A9) and *Didymoceras sp***.** (Locs. A10 – A12) *also* occur in this zone.

5.3. Clathrocyclas tintinnaeformis Zone

Base: *FO of C. tintinnaeformis* and *Cryptamphorella conara*

Top: FO of *Stichomitra cechena and Archaeodictyomitra* sp. A.

Associate species: *Amphipyndax conicus, Amphipyndax pseudoconulus, Amphipyndax tylotus, Amphipyndax stocki, Archaeodictyomitra lamellicostata, Archaeodictyomitra sliteri, Archaeodictyomitra simplex, Archaeospongoprunum hueyi, Cornutella californica, Dictyomitra andersoni, Dictyomitra densicostata, Dictyomitra koslovae, Dictyomitra formosa, Dictyomitra multicostata, Dictyomitra rhadina, Lithocampe wharanui, Lithomelissa amazon, Orbiculiforma renillaeformis, Pseudoaulophacus lenticulatus, Pseudotheocampe abschnitta, Stichomitra asymbatos, Stichomitra campi, Stichomitra livermorensis and Stylotrochus polygonatus.*

Occurrence: Locs. R14 – R18 (Fig. 3; Higaidani Formation).

Age: upper Upper Campanian. The Ammonites species *Patagiosites laevis*, *Gaudryceras* aff. *striatum and Didymoceras awajiense* **(**Locs. A13 – A18) occur in this zone.

5.4. Stichomitra cechena Zone

The assemblage zone defined by the occurrence of *S. cechena and Archaeodictyomitra* sp. A.

Top: *FO of Myllocercion acineton, Theocampe daseia and Lithomelissa heros.*

Associate species: *Allievium gallowayi, Amphipyndax pseudoconulus, A.* aff. *pseudoconulus, Amphipyndax stocki, Amphipyndax tylotus, Archaeodictyomitra lamellicostata, Archaeodictyomitra simplex, Archaeodictyomitra sliteri, Archaeospongoprunum hueyi, Cryptamphorella sphaerica, Dictyomitra andersoni, Dictyomitra densicostata, Dictyomitra formosa, Dictyomitra koslovae, D.* aff. *koslovae, Dictyomitra multicostata, Dictyomitra rhadina, Pseudotheocampe abschnitta, Stichomitra asymbatos, Stichomitra carnegiense and Theocampe apicata.*

Occurrence: Locs. R19 and R20 (Fig. 3; Bandodani Formation).

Age: upper Upper Campanian. The Ammonite species *Pravitoceras sigmoidale* **(**Locs. A19 - A26) and *Solenoceras* (*S.*) cf. *taxanum occur in the uppermost argillite bed of the zone.*

5.5. Myllocercion acineton Zone

Base: FO of *M. acineton, Theocampe daseia and Lithomelissa heros.*

Top: LO of *Amphipyndax pseudoconulus, and* FO *of Clathrocyclas gravis and Dorcadospyris* sp. A.

Associate species: ***Acidnomelos proapteron****, Afens liriodes, Amphipyndax aff. pseudoconulus, Amphipyndax tylotus, Amphipyndax stocki, Archaeodictyomitra lamellicostata, Archaeodictyomitra sliteri, Archaeodictyomitra* sp. A, *Archaeospongoprunum hueyi, Cornutella californica, Cryptamphorella sphaerica, Dictyomitra andersoni, Dictyomitra densicostata, Dictyomitra formosa, Dictyomitra koslovae, D.* aff. *koslovae, Dictyomitra multicostata, Dictyomitra rhadina, Lithomelissa amazon, Mita regina, Orbiculiforma renillaeformis, Phormostrichoartus? strongi, Pseudotheocampe abschnitta, Rhopalosyringium magnificum, Stichomitra carnegiense, Stichomitra cathara, Stichomitra cechena, Stichomitra asymbatos, Stichomitra campi, Stichomitra livermorensis, Stylotrochus polygonatus, Theocampe apicata and Theocapsomma comys.*

Occurrence: Locs. R21 – R23 (Fig. 3; Bandodani Formation), Locs. R24 – R27 (Fig. 3; Anaga Formation).

Age: uppermost Upper Campanian. The Ammonite species *Pachydiscus awajiensis* occurs in **part of** this zone **(**Locs. A27, A28).

5.6. Clathrocyclas gravis Zone

Assemblage zone defined by the occurrence of *C. gravis and Dorcadospyris* sp. A

Top: FO of *Stichomitra asymmetra* and *Stichomitra* sp. A.

Associate species: *Afens liriodes, Alievium gallowayi, Amphipyndax conicus, Amphipyndax ellipticus, Amphipyndax tylotus, Archaeodictyomitra lamellicostata, Archaeospongoprunum hueyi, Cryptamphorella sphaerica, Dictyomitra andersoni, Dictyomitra densicostata, Dictyomitra multicostata, Mita regina, Myllocercion acineton, Stichomitra carnegiense, Stichomitra cechena, Stichomitra asymbatos, Stichomitra campi and Theocapsomma comys.*

Occurrence: Loc. R28 (Fig. 3; Kita-ama Formation) and Locs. R29 and R30 (Fig. 3; Nada Formation).

Age: lowermost Lower Maastrichtian. Ammonite *Nostoceras hetonaiense* occur in this zone (Loc. A29, A30). *Baculites inornatus, Inoceramus (Endocostea) shikotanensis* and “*Anisomyon*” *problematicus* are also reported from this zone.

5.7. Stichomitra asymmetra Zone

Base: FO of *S. asymmetra and Stichomitra* sp. A.

Top: FO of *Cryptocarpium*? cf. *ornatum and Stichomitra sp. B.*

Associate species: *Afens liriodes, Amphipyndax conicus, Amphipyndax tylotus, Amphipyndax stocki, Archaeodictyomitra lamellicostata, Archaeospongoprunum hueyi, Clathrocyclas gravis, Clathrocyclas hyronia, Clathrocyclas tintinnaeformis, Cornutella californica, Cryptamphorella sphaerica, Dictyomitra andersoni, Dictyomitra densicostata, Dictyomitra multicostata, Dictyomitra rhadina, Dorcadospyris* sp. A, *Mita regina, Myllocercion acineton, Orbiculiforma renillaeformis, Patellula euessceei, Phormostrichoartus? strongi, Pseudoaulophacus floresensis, Pseudoaulophacus paragueraensis, Pseudotheocampe abschnitta, Stichomitra carnegiense, Stichomitra cathara, Stichomitra asymbatos, Stichomitra campi, Stichomitra livermorensis and Theocapsomma comys.*

Occurrence: Locs. R31, R32 (Fig. 3; Kada Formation), Loc. R33 (Fig. 3; Shindachi Formation).

Age: upper Lower Maastrichtian. The Ammonite species *Gaudryceras izumiense occurs in the middle part of the* Azenotani Mudstone Member in the Izumi Mountains (Locs. A32 and A33: Matsumoto and Morozumi, 1980; Fig. 4). On the other hand, a single specimen of *G. izumiense*, which Morozumi (1985) reported from a floated nodule of the Shimonada Formation (Loc. A31) on Awaji Island, was recently re-identified as

Gaudryceras makarovense by Maeda et al. (2005).

5.8. Cryptocarpium? cf. ornatum Zone

Base: FO of *C.*? cf. *ornatum and Stichomitra sp. B.*

Top: *LO of Allievium murphyi.*
Associate species: *Afens liriodes, Allievium murphyi, Amphipyndax stocki, Amphipyndax tylotus, Archaeodictyomitra lamellicostata, Archaeodictyomitra rigida, Archaeospongoprunum hueyi, Cryptamphorella conara, Dictyomitra andersoni, Dictyomitra multicostata, Dictyomitra rhadina, Dorcadospyris* sp. A, *Lithocampe wharanui, Mita regina, Orbiculiforma sacramentoensis, Patellula verteroensis, Parvicuspis schastaensis, Phaseliforma concensis, Pseudoaulophacus floresensis, Sphaerostylus hastate, Stichomitra asymbatos, Stichomitra asymmetra, Stichomitra campi, Stichomitra granulate and Stichomitra sp. A.*

Occurrence: Loc. R34 (Fig. 3: Iwade Formation), Locs. R35, R36 (Fig. 3; Kokawa Formation)

Age: Upper Maastrichtian. The Ammonite species *Pachydiscus* aff. *subcompressus occurs* together with *Anagaudryceras matsumotoi, Zelandites* cf. *varuna and Gaudryceras makarovense* (Loc. A34).

6. Discussion

6.1. Chronology of the radiolarian zonation

Kodama (1990) recognized magnetostratigraphic Chron 32r in the Izumi Group that he regarded as Upper Campanian (Fig. 5: Kodama et al., 2002). Kodama (1990) further correlated a horizon in the lower part of the ***Dictyomitra koslovae*** **Zone around** Loc. R3 (Fig. 2) to the Chron 33r, while he regarded the normal anomaly above radiolarian Loc. R3 horizon as the beginning of the polarity Chron 33 (Middle Campanian – lowest Maastrichtian). Consequently, the lower part of the Izumi Group is assigned to the lowest Campanian.

The fission track age of the acidic tuff bed T2 (Fig. 2) that lies above the radiolarian Loc. R4 is 79±2.2 Ma (Noda et al., 2010).The Loc. R28 horizon in the radiolarian ***Clathrocyclas gravis*** **Zone** (Fig. 3: in eastern Awaji Island) was correlated to the magnetostratigraphic Subchron 32.1r in Chron 32.2 of earliest Maastrichtian age (**Kodama, 1990). The age determination coincides with that of the ammonite species *Nostoceras hetonaiense.***

Regarding the ***Stichomitra asymmetra*** **Zone of the Izumi Group of the Izumi Mountains, the fission track age of acidic tuff bed T18, above radiolarian Loc. R32, is** 76.5±3.8 Ma, while that of bed T19 is 72.1±4.1 Ma (**Miyata et al., 1993)**. In the ***Cryptocarpium*? cf. *ornatum* Zone, acidic tuff bed T22, situated above the radiolarian Loc. R34, is dates as** 73.1±3.8 Ma, while the bed T23, situated above the **radiolarian** Loc.R35 is dates as 72.2±3.9 Ma (Fig. 5).

The question of fluctuation of fission track ages ranging from Middle – Late Campanian to Middle Maastrichtian remains, as the present biostratigraphy of the Izumi Group seems more accurate than the fission track dating. An integrated total understanding should, therefore be formulated. *While Pachydiscus* aff. *subcompressus has not yet been reported from the Izumi Mountain region, the radiolarian fauna from the* Loc. R34 horizon (Fig. 4), situated in the ***C.*? cf. *ornatum* Zone, is the same as that from the**

Loc. R35 horizon that is 700 m above the ammonite *Gaudryceras izumiense horizon in the radiolarian* ***Stichomitra asymmetra*** **Zone.** *The radiolarian fauna of C.? cf. ornatum Zone includes the Maastrichtian –Paleocene indices of C.? cf. ornatum and Dorcadospyris* sp. A that has not appeared in the *S. asymmetra* Zone.

A further reason is the presence of the ammonite *P.* aff. *subcompressus Zone that shows the faunal affinity with that of the Yezo Group. Therefore, the upper Maastrichtian P.* aff. *subcompressus Zone above the* ***G. izumiense*** *Zone should be expected to be present in the Izumi Mountains. W*e thus estimate that the radiolarian *C.? cf. ornatum Zone corresponds to the lower part of the ammonite P.* aff. *subcompressus Zone, while a detailed faunal record at the top of the C.? cf. ornatum Zone remains still unclear due to the rarity of the fauna.*

The Campanian / Maastrichtian boundary was set at the border between the ammonite *Pachydiscus awajiensis* Zone and *N. hetonaiense* Zone, and the radiolarian *Myllocercion acineton* **Zone and *Clathrocyclas gravis* Zone** (Fig. 5)**.** The LO of *Amphipyndax pseudoconulus* (= *A. enesseffi*), *Dictyomitra formosa* and *D. koslovae* as well as *Rhopalosyringium magnificum* ***and*** *Archaeodictyomitra sliteri* (Fig. 8) was proven to be the top of *M. acineton* **Zone (uppermost Campanian). As a result, the top of** *Pseudotheocampe abschnitta* (PA) Assemblage Zone (Yamasaki, 1987) might be settled at the latest Campanian (Fig. 9).

From a chronological view-point, Ishida et al. (2010) suggested that around the Campanian / Maastrichtian boundary the ammonite zones are relatively older than the radiolarian ones. We mark the importance of their co-occurrence and stratigraphic intercalation within the same basin, and propose that the radiolarian zonal boundary of *M. acineton* Zone / *C. gravis* Zone is correlative with the ammonite zonal boundary of

N. hetonaiense Zone / ***P. awajiensis* Zone** that was proposed to be the Campanian / Maastrichtian boundary in the Izumi Group.

The confirmed ranges of the selected radiolarian species in the Izumi Group and Shimanto Supergroup (Fig. 8) represent the vertical faunal transition in the Upper Cretaceous mid-latitudinal inter-arc basin to the trench-slope facies that was facing towards the NW Pacific. This may partly settle the chronostratigraphic discrepancy between the radiolarian and ammonite zones in the Izumi Group, as pointed out in Ishida et al. (2010).

6.2. Paleoceanographic inferences

Takahashi and Ishii (1993) indicated that, due to currents, their *Amphipyndax tylotus* Zone in the Izumi Group includes a mixed radiolarian fauna of both boreal (high latitude) and warm (low latitude) current affinities, respectively. The former consists of the association of *Stichomitra livermorensis*, *Lithomelissa* sp. and *Theocampe altamontensis,* while the latter is characterized by *Amphipyndax enesseffi (= A. pseudoconulus)*, *Pseudotheocampe abschinitta*, *Archaeodictyomitra lamellicostata* and *Myllocercion acineton*.

In our study, the lower and upper zones (*Stichomitra compsa* Zone and *Clathrocyclas gravis Zone to Cryptocarpium? cf. ornatum Zone*) are dominated by species considered as having a warm current affinity, whereas assemblages of the middle zones (*A. lamellicostata* Zone to *Clathrocyclas tintinnaeformis* Zone) are characterized by a mixture of species considered as having both boreal and warm current affinities. Especially, the radiolarian fauna of the *Stichomitra cechen*a and *M. acineton* Zones (correlative with the ammonite *Pravitoceras sigmoidale* Zone and *Pachydiscus* *awajiensis* Zone) contain species of boreal affinity, best *represented by the dominance of Lithomelissa* sp.

Based on our overview of the Upper Cretaceous Izumi inter-arc basin to the Shimanto trench slope facing towards the paleo-Pacific along the Yangtze continental eastern margin, Ishida et al. (2010) pointed out a faunal turnover at the *M. acineton* / *C. gravis* zonal boundary. This turnover is substantiated by the LO of *S. compsa*, *Stichomitra manifesta*, *Alievium praegallowayi*, *Archaeospongoprunum nishiyamae*, *Dictyomitra densicostata* and *Dictyomitra. multicostata*. Subsequently, the faunal change *between the C. gravis Zone and the Stichomitra asymmetra Zone* represents the radiolarian faunal recovery by the warmer current affinities. The change is remarkable between the *M. acineton* Zone and *C. gravis* Zone in the Izumi Group, marked by LO of *A. pseudoconulus, Archaeodictyomitra sliteri, Dictyomitra formosa, D. koslovae and Rhopalosyringium magnificum*, and the FO *of C. gravis and Dorcadospyris* sp. A. Conclusively, the ocean climatic change inferred from this radiolarian faunal transition will be useful for much more precise chronological correlation around the Campanian / Maastrichtian boundary.

7. Conclusion

The radiolarian zones in the Izumi Group across the Campanian / Maastrichtian boundary was revised and correlated with the ammonite zones, based on the compilation of their occurrences, lithostratigraphic correlation, in addition to the verification of fission track dating of the key acidic tuff beds and the magnetostratigraphic data. The significance of the direct correlation in the same stratigraphic entity was discussed for unified global correlation of different taxa in relation with the litho- and biofacies properties of the Izumi Group. The Late Cretaceous oceanographic changes changes, as inferred from the radiolarian fauna, merits consideration of marker events in chronostratigraphic correlation of middle latitude continental shelf to turbidite basin facies facing the NW paleo-Pacific.

The Campanian / Maastrichtian boundary might be set at the limit between the ammonite *Pachydiscus awajiensis* Zone and *Nostoceras hetonaiense* Zone, and between the radiolarian *Myllocercion acineton* **Zone and *Clathrocyclas gravis* Zone in this paper.** The LO of the *Amphipyndax pseudoconulus* (= *A. enesseffi*), was proven to be the top of *Myllocercion acineton* **Zone (uppermost Campanian).** *Inoceramus shikotanensis* as the index of the *I. shikotanensis* Zone in the Yezo Group was proven to occur in the *Pravitoceras sigmoidal*e Zone of the upper Campanian. The chronostratigraphic lag between radiolarian and ammonite zonations in the Izumi Group is verified and partly settled.

8. Taxonomy

All radiolarian species identified on the studied section of the Izumi Group are listed in Fig. 7 and illustrated in Plates 1 and 2. A brief synonymy list allows to understand the species concept followed in this study.

***Acidnomelos proapteron* Foreman, 1978**

(Plate 2; Fig. 24)

1978 *Acidnomelos proapteron* nov. sp. - Foreman, p. 749, pl. 5, fig. 13.

***Afens liriodes* Riedel and Sanfilippo, 1974**

(Plate 2; Fig. 23)

1974 *Afens liriodes* nov. sp. - Riedel and Sanfilippo, p. 775, pl. 11, fig. 11, pl. 13, figs. 14-16.

1985 *Afens liriodes* Riedel and Sanfilippo - Riedel and Sanfilippo, p. 624, fig. 13.3a- c.

1998 *Afens liriodes* Riedel and Sanfilippo - Ishida and Hashimoto, pl. 2, fig. 19.

***Alievium gallowayi* (White, 1928)**

(Plate 2; Fig. 25)

1928 *Baculogypsina* ? *gallowayi* nov. sp. - White, p.305, pl. 41, figs. 9, 10.

1972 *Alievium gallowayi* (White) - Pessagno, p. 299, pl. 25, figs. 4- 6.

1976 *Alievium gallowayi* (White) - Pessagno, p. 7, pl. 8, figs. 13, 14, pl. 9, fig. 1.

1982 *Alievium gallowayi* (White) - Taketani, p. 50, pl. 10, fig. 7.

1997 *Alievium gallowayi* (White) - Hashimoto and Ishida, pl. 3, fig. 21.

1998 *Alievium gallowayi* (White) - Ishida and Hashimoto, pl. 2, fig. 22.

***Amphipyndax conicus* Nakaseko and Nishimura, 1981**

(Plate 1; Fig. 17)

1981 *Amphipyndax conicus* nov. sp. - Nakaseko and Nishimura, p. 143, pl. 12, figs. 1, 2.

1986 *Amphipyndax conicus* Nakaseko and Nishimura - Suyari, pl. 3, fig. 2, pl. 9, fig. 4.

1997 *Amphipyndax conicus* Nakaseko and Nishimura - Hashimoto and Ishida, pl. 2, fig. 11.

1998 *Amphipyndax conicus* Nakaseko and Nishimura - Ishida and Hashimoto, pl. 1, fig.

19.

***Amphipyndax pseudoconulus* (Pessagno, 1963)**

(Plate 1; fig. 7)

1963 *Lithostrobus pseudoconulus* nov. sp. - Pessagno, p. 210, pl. 1, fig. 8, pl. 5, figs. 6, 8.

1966 *Amphipyndax enesseffi* nov. sp. - Foreman, p. 356, text-figs. 10, 11.

1981 *Amphipyndax enesseffi* Foreman - Nakaseko and Nishimura, p. 144, pl.17, fig. 14.

1982 *Amphipyndax pseudoconulus* (Pessagno) - Empson-Morin, p. 510, pl. 1, 5a- d, 6, 7a- c, pl. 2, figs. 1- 4, 5, 9, 10, 12.

1985 *Amphipyndax pseudoconulus* (Pessagno) - Sanfilippo and Riedel, p. 596, figs. 7.1a- c.

1987 *Amphipyndax enesseffi* Foreman - Yamasaki, pl. 1, fig. 1.

1998 *Amphipyndax pseudoconulus* (Pessagno) - Ishida and Hashimoto, pl. 1, fig .15.

***Amphipyndax* aff. *pseudoconulus* (Pessagno), 1982**

(Plate 1; fig. 8)

aff. 1982 *Amphipyndax pseudoconulus* (Pessagno) - Empson-Morin, p. 510, pl. 1, 5a- d, 6, 7a- c, pl. 2, figs. 1- 4, 5, 9, 10, 12.

1997 *Amphipyndax* aff. *enesseffi* Foreman - Yamasaki, pl. 1, figs. 7, 8.

Remarks: This species is distinguished from *A. pseudoconulus* by less development of diagonal ridges on the segment.

***Amphipyndax stocki* (Campbell and Clark), 1968**

(Plate 1; Fig. 10)

1944 *Stichocapsa*? *stocki* nov. sp. - Campbell and Clark p. 44, pl. 8, figs. 31, 33.

1968 *Amphipyndax stocki* (Campbell and Clark) - Foreman, p. 78, 79, pl.8, figs. 12a, b.

1981 *Amphipyndax stocki* (Campbell and Clark) - Nakaseko and Nishimura, p. 145, pl. 12, fig. 5.

1987 *Amphipyndax stocki* (Campbell and Clark) - Yamasaki, pl. 1, fig. 6.

1997 *Amphipyndax stocki* (Campbell and Clark) - Hashimoto and Ishida, pl. 2, fig. 17.

***Amphipyndax tylotus* Foreman, 1978**

(Plate 1; Fig. 9)

1978 *Amphipyndax tylotus* nov. sp. - Foreman, p. 745, p. 4, figs. 1, 2.

1981 *Amphipyndax tylotus* Foreman - Nakaseko and Nishimura, pl. 17, fig. 13.

1982 *Amphipyndax tylotus* Foreman- Empson-Morin, p. 512, pl. 3, fig, 5.

1985 *Amphipyndax tylotus* Foreman - Sanfilippo and Riedel, p. 598, figs. 7.2a, b.

1987 *Amphipyndax tylotus* Foreman - Yamasaki, pl. 1, fig. 3.

1993 *Amphipyndax tylotus* Foreman - Takahashi and Ishii, pl. 4, fig. 18.

***Amphipyndax* aff. *tylotus* Foreman, 1978**

aff. 1978 *Amphipyndax tylotus* nov. sp. - Foreman, p. 745, p. 4, figs. 1, 2.

1987 *Amphipyndax* aff. *tylotus* Foreman - Yamasaki, pl. 1, fig. 9, 10.

***Archaeodictyomitra lamellicostata* (Foreman), 1985**

(Plate 2; Fig. 6)

1968 *Dictyomitra lamellicostata* nov. sp. - Foreman, p. 65, pl. 7, figs. 8a, b.

1995 *Dictyomitra lamellicostata* Foreman - Takahashi and Ishii, pl. 4, fig. 13.

1985 *Archaeodictyomitra lamellicostata* (Foreman) - Sanfilippo and Riedel, p. 599, figs. 7.5a - d.

1997 *Archaeodictyomitra lamellicostata* (Foreman) - Hashimoto and Ishida, pl. 3, fig. 15.

1998 *Archaeodictyomitra lamellicostata* (Foreman) - Ishida and Hashimoto, pl. 2, fig. 1.

***Archaeodictyomitra simplex* Pessagno, 1977**

(Plate 1; Fig. 2)

1977 *Archaeodictyomitra simplex* nov. sp. - Pessagno, p. 43, pl. 6, fig. 15.

1981 *Archaeodictyomitra simplex* Pessagno - Nakaseko and Nishimura, pl. 6, fig. 10, pl. 15, fig. 5.

1987 *Archaeodictyomitra simplex* Pessagno - Yamasaki, pl. 1, fig. 12.

***Archaeodictyomitra sliteri* Pessagno, 1977**

(Plate 2; Fig. 5)

1977 *Archaeodictyomitra sliteri* nov. sp. - Pessagno, p. 43, pl. 6, fig. 3, 4, 22, 23, 27.

1985 *Archaeodictyomitra sliteri* Pessagno - Suyari and Hashimoto, pl. 5, fig. 4, 5.

1986 *Archaeodictyomitra sliteri* Pessagno - Suyari, pl. 2, fig. 7, pl. 4, fig. 13.

1995 *Archaeodictyomitra sliteri* Pessagno - Takahashi and Ishii, pl. 3, fig. 20.

1997 *Archaeodictyomitra sliteri* Pessagno - Hashimoto and Ishida, pl. 1, fig. 6.

***Archaeodictyomitra* sp. A**

(Plate 1; Fig. 1)

1986 *Archaeodictyomitra* sp. B - Suyari, pl. 18, fig. 12, 13.

Remarks: This species is identical to *Archaeodictyomitra* sp. B in Suyari (1986) with a slender test with eleven to twelve straight costae in half hemisphere.

***Archaeospongoprunum hueyi* Pessagno, 1973**

(Plate 1; Fig. 18)

1973 *Archaeospongoprunum hueyi* nov. sp. - Pessagno, p.61, pl.13, fig. 1.

1976 *Archaeospongoprunum hueyi* Pessagno - p. 33, pl. 11, figs. 5.

1992 *Archaeospongoprunum hueyi* Pessagno - Okamura, pl.34, figs. 5, 18.

1997 *Archaeospongoprunum hueyi* Pessagno - Hashimoto and Ishida, pl. 3, fig. 25.

***Artostrobium urna* Foreman, 1971**

1971 *Artostrobium urna* nov. sp. - Foreman, p. 1677, pl. 4, figs. 1, 2.

1982 *Artostrobium urna* Foreman - Taketani, p. 53, pl. 2, fig. 12, pl. 10, fig. 17.

1987 *Artostrobium urna* Foreman - Yamasaki, pl.2, fig. 16.

1998 *Artostrobium urna* Foreman - Ishida and Hashimoto, pl. 1, fig. 21.

***Clathrocyclas gravis* Vishnevskaya, 1986**

(Plate 2; Fig. 19)

1986 *Clathrocyclas*? *gravis* nov. sp. - Vishnevskaya, p. 148, pl. 3, fig. 2.

1995 *Clathrocyclas*? *gravis* Vishnevskaya - Takahashi and Ishii, pl. 4, fig. 25.

2001 *Clathrocyclas gravis* Vishnevskaya - Hollis and Kimura, p. 247.

***Clathrocyclas tintinnaeformis* Campbell and Clark, 1944**

(Plate 2; Fig. 18)

1944 *Clathrocyclas tintinnaeformis* nov. sp. - Campbell and Clark, p. 31, pl. 7, fig. 52.

***Clathrocyclas hyronia* Foreman, 1968**

(Plate 2; Fig. 17)

1968 *Clathrocyclas*? *hyronia* nov. sp. - Foreman, p. 47, pl. 5, figs. 1a, b.

1992 *Clathrocyclas hyronia* Foreman - IWATA et al., pl. 3, fig. 1.

1997 *Clathrocyclas hyronia* Foreman - Hashimoto and Ishida, pl. 3, fig. 19.

***Cornutella californica* Campbell and Clark, 1944**

(Plate 1, Fig. 21)

1944 *Cornutella californica* nov. sp. - Campbell and Clark, p. 22, pl. 7, fig. 33, 34, 42, 43.

1968 *Cornutella californica* Campbell and Clark - Foreman, p. 21, pl. 3, fig. 1a- c.

1973 *Cornutella californica* Campbell and Clark - Dumitrica, p. 788, pl. 10, fig. 1.

1982 *Cornutella californica* Campbell and Clark - Taketani, p. 65, pl. 6, fig. 6a, b, 7, pl. 13, fig. 7, 8.

1986 *Cornutella californica* Campbell and Clark - Iwata and Tajika, pl. 3, fig. 6.

1995 *Cornutella californica* Campbell and Clark - Takahashi and Ishii, pl. 4, fig. 17.

1997 *Cornutella californica* Campbell and Clark - Hollis, p.71. pl. 17, figs. 13- 15.

***Cryptamphorella sphaerica* (White), 1970**

(Plate 1, Fig. 26)

1928 *Baculogypsina*? *sphaerica* nov. sp. - White, 1928, p. 306, pl. 41, figs. 12-13.

1963 *Holocryptocapsa*? *sphaerica* (White) - Pessagno, p. 206, pl. 1, fig. 3, pl. 5, figs. 1, 2.

1970 *Cryptamphorella sphaerica* (White) - Dumitrica, p. 38, pl. 12, figs. 73a- 77c, pl. 20, fig. 133a, b.

1998 *Cryptamphorella sphaerica* (White) - Ishida and Hashimoto, pl. 2, fig. 17.

***Cryptocarpium*? cf. *ornatum* (Ehrenberg), 1997**

(Plate 2; Fig. 16)

cf. 1874 *Cryptoprora ornata* nov. sp. - Ehrenberg, p. 222.

cf. 1876 *Cryptoprora ornata* Ehrenberg - Ehrenberg, pl. 5, fig. 8.

1973 *Cryptoprora* cf. *ornata* Ehrenberg - Dumitrica, p. 789, pl. 9, fig. 1.

1997 *Cryptocarpium*? cf. *ornatum* (Ehrenberg) - Hollis, pl. 15, fig. 4.

***Dictyomitra andersoni* (Campbell and Clark), 1968**

(Plate 1; Fig. 4)

1944 *Lithocampe* (*Lithocampanula*) *andersoni* nov. sp. - Campbell and Clark, p.42, pl. 8, fig. 25.

1968 *Dictyomitra andersoni* (Campbell and Clark) - Foreman, p. 68, pl. 7, figs. 6a- d.

1995 *Dictyomitra andersoni* (Campbell and Clark) - Takahashi and Ishii, pl. 4, fig. 14.

1987 *Dictyomitra tiara* Campbell and Clark - Yamasaki, pl. 1, fig. 18.

1997 *Dictyomitra tiara* Campbell and Clark - Hashimoto and Ishida, pl. 2, fig. 2, 20.

***Dictyomitra densicostata* Pessagno, 1976**

(Plate 1; Fig. 6)

1976 *Dictyomitra densicostata* nov. sp. Pessagno, p. 51, pl. 14, figs. 10- 14.

1997 *Dictyomitra densicostata* Pessagno - Hashimoto and Ishida, pl. 2, fig. 4, pl. 3, fig. 10.

1998 *Dictyomitra densicostata* Pessagno - Ishida and Hashimoto, pl. 1, fig. 22.

Remarks: This species is distinguished from *D. rhadina* by having relatively strong segment-stricture with a transverse row of pores in the post abdominal chamber of the former. More than twelve costae in half hemisphere.

***Dictyomitra formosa* Squinabol, 1904**

(Plate 2; Fig. 2)

1904 *Dictyomitra formosa* nov. sp. - Squinabol, p. 232, pl. 10, fig. 4.

1975 *Dictyomitra duodecimcostata* (Squinabol) - Foreman, p. 614, pl. 1G, figs. 8.

1976 *Dictyomitra formosa* Squinabol - Pessagno, p. 51, pl. 8, figs. 10-12.

1986 *Dictyomitra duodecimcostata* (Squinabol) - Suyari, pl. 8, figs. 1- 6, figs. 1, 2, pl.11, fig. 1, pl.12, figs. 10, pl. 14, 1, 2,10, 11, pl. 15, figs. 1- 3.

1987 *Dictyomitra duodecimcostata* (Squinabol) - Yamasaki, pl.1, fig.20.

1992 *Dictyomitra formosa* Squinabol - Iwata et al., pl. 5, fig. 5.

1994 *Dictyomitra formosa* Squinabol - O’Dogherty, p. 80, pl. 4, figs. 8-12.

1995 *Dictyomitra formosa* Squinabol - Takahashi and Ishii, pl. 4, fig. 1.

1997 *Dictyomitra formosa* Squinabol - Hashimoto and Ishida, pl. 1, figs. 10, pl. 2, figs. 14- 15.

1998 *Dictyomitra formosa* Squinabol - Ishida and Hashimoto, pl. 1, figs. 23, 24.

Remarks: This species is characterized by having clearly crenulated high costae with a stronger segmental constriction than *Dictyomitra multicostata*.

***Dictyomitra koslovae* Foreman, 1975**

(Plate 1; Fig. 3)

1975 *Dictyomitra koslovae* nov. sp. - Foreman, p. 614, pl.7, fig. 4.

1985 *Dictyomitra koslovae* Foreman - Sanfilippo and Riedel, p. 599, figs. 4a - b, d, e.

1987 *Dictyomitra koslovae* Foreman - Yamasaki, pl. 1, fig. 22.

1995 *Dictyomitra koslovae* Foreman - Takahashi and Ishii, pl. 4, fig. 2.

1997 *Dictyomitra koslovae* Foreman - Hashimoto and Ishida, pl. 2, fig. 3.

***Dictyomitra* aff. *koslovae* Foreman, 1975**

(Plate 2; Fig. 4)

aff. 1975 *Dictyomitra koslovae* nov. sp. - Foreman, p. 614, pl.7, fig. 4.

1986 *Dictyomitra* aff. *koslovae* Foreman - Suyari, pl. 20, figs. 5 - 8.

1987 *Dictyomitra* aff. *koslovae* Foreman - Yamasaki, pl. 1, figs. 23, 24.

1995 *Dictyomitra* aff. *koslovae* Foreman - Takahashi and Ishii, pl. 4, figs. 3, 4.

1997 *Dictyomitra* aff. *koslovae* Foreman - Hashimoto and Ishida, pl. 3, fig. 5.

***Dictyomitra multicostata* Zittel, 1876**

(Plate 1; Fig. 5)

1876 *Dictyomitra multicostata* nov. sp. - Zittel, p. 81, pl. 2, figs. 2, 4.

1968 *Dictyomitra multicostata* Zittel - Foreman, pl. 64, pl. 7, figs. 4a, b.

1976 *Dictyomitra multicostata* Zittel - Pessagno, p. 52, pl. 14, figs. 4- 9.

1986 *Dictyomitra multicostata* Zittel - Suyari, pl. 8, fig. 8.

1997 *Dictyomitra multicostata* Zittel - Hashimoto and Ishida, pl. 2, fig. 1.

1998 *Dictyomitra multicostata* Zittel - Ishida and Hashimoto, pl. 1, fig. 18.

***Dictyomitra rhadina* Foreman, 1968**

(Plate 2; Fig. 1)

1968 *Dictyomitra rhadina* nov. sp. - Foreman, p. 66, pl. 7, figs. 5a, b.

Remarks: This species is characterized by having slender cylindrical test with a weaker crenulated outline than *D. densicostata.*

***Dorcadospyris* sp. A**

(Plate 2; Fig. 26)

1997 *Dorcadospyris* aff. *confluens* (Ehrenberg) - Hollis, pl. 22, fig. 13.

1998 *Dorcadospyris* sp. - Hatenashi Research Group, pl. 2, fig. 6.

Remarks: This species, identified above, is characterized by less developed foot spines and having more number of pores on cupola than the original species. Even the preservation of feet is not sufficient, we regarded this form as *Dorcadospyris* as we remarked in the text.

***Lithocampe wharanui* Hollis, 1997**

(Plate 1; Fig. 16)

1997 *Lithocampe wharanui* nov. sp. - Hollis, p. 76, pl. 18, figs. 8- 10.

***Lithomelissa amazon* Foreman, 1968**

(Plate 1; Fig. 20)

1968 *Lithomelissa*? *amazon* nov. sp. - Foreman, p. 26, pl. 4, figs. 1a, b.

1987 *Bisphaerocephalina*? *amazan* (Foreman) - Yamasaki, pl. 2, fig. 1.

1997 *Bisphaerocephalina*? *amazan* (Foreman) - Hashimoto and Ishida, pl. 3, fig. 4.

2001 *Lithomelissa amazon* Foreman - Hollis and Kimura, p. 250.

Lithomelissa heros **Campbell and Clark, 2001**

(Plate 1; Fig. 19)

1944 *Lithomelissa* (*Micromelissa*) *heros* nov. sp. - Campbell and Clark, p. 25, pl. 7, fig. 23.

1968 ? *Lithomelissa heros* Campbell and Clark- Foreman, p. 25, pl. 3. figs. 5a, b, text fig. 1, fig. 7.

1987 *Bisphaerocephalina*? *heros* (Campbell and Clark) - Yamasaki, pl. 2, fig. 2.

2001 *Lithomelissa heros* Campbell and Clark - Hollis and Kimura, p.250.

Mita regina **(Campbell and Clark), 1982**

(Plate 1; Fig. 12)

1944 *Lithomitra* (*Lithomitrissa*) *regina* nov. sp. - Campbell and Clark, p. 41, pl. 8, figs. 30, 38, 40.

1976 *Archaeodictyomitra*? *regina* (Campbell and Clark) - Pessagno, p. 49, pl. 14, figs. 1-3.

1986 *Archaeodictyomitra*? *regina* (Campbell and Clark) - Teraoka and Kurimoto, pl. 7, fig. 12.

1982 *Mita regina* (Campbell and Clark) - Taketani, p. 60, pl. 5, figs. 3a, b, pl. 12, fig. 2.

1995 *Mita regina* (Campbell and Clark) - Takahashi and Ishii, pl. 4, fig. 28.

1997 *Mita regina* (Campbell and Clark) - Hollis, p. 70, pl. 17, figs. 1- 4, 10.

***Myllocercion acineton* Foreman, 1968**

(Plate 2; Fig. 15)

1968 *Myllocercion acineton* nov. sp. - Foreman, p. 37, pl. 5, fig. 11a – c.

1995 *Myllocercion acineton* Foreman - Takahashi and Ishii, pl. 4, fig. 23.

1997 *Myllocercion acineton* Foreman - Hollis, p. 62, pl. 14, figs. 7 - 11.

1997 *Myllocercion acineton* Foreman - Hashimoto and Ishida, pl. 3, fig. 23.

1998 *Myllocercion acineton* Foreman - Ishida and Hashimoto, pl. 2, fig. 13.

***Orbiculiforma renillaeformis* (Campbell and Clark), 1975**

(Plate 1; Fig. 25)

1944 *Spongodiscus renillaeformis* nov. sp. - Campbell and Clark, p.18, pl. 6, fig. 5, 6, 8, 10.

1975 *Orbiculiforma renillaeformis* (Campbell and Clark) - Pessagno, p. 1014, pl. 1, fig. 7.

1976 *Orbiculiforma renillaeformis* (Campbell and Clark) - Pessagno, p. 36, pl. 11, fig. 11.

1991 *Orbiculiforma renillaeformis* (Campbell and Clark) - Hollis, p. 86, pl. 7, fig. 1- 3.

1997 *Orbiculiforma renillaeformis* (Campbell and Clark) - Hollis, pl. 9, fig. 4- 7.

***Phormostrichoartus*? *strongi* Hollis, 1997**

(Plate 2; Fig. 20)

1997 *Phormostrichoartus*? *strongi* nov. sp. - Hollis, p. 59, pl. 13, fig. 1-5.

***Pseudoaulophacus floresensis* Pessagno, 1963**

(Plate 1, Fig. 24)

1963 *Pseudoaulophacus floresensis* nov. sp. - Pessagno, p. 200, pl. 2, figs. 2 - 5, pl. 4, fig. 6, pl. 7, figs. 1, 5.

1976 *Pseudoaulophacus floresensis* Pessagno - Pessagno, p. 28, pl. 9, figs. 11, 12.

1982 *Pseudoaulophacus floresensis* Pessagno - Taketani, p. 51, pl. 10, fig. 11.

1985 *Pseudoaulophacus floresensis* Pessagno - Sanfilippo and Riedel, p. 595, figs. 6.3a, b.

1987 *Pseudoaulophacus floresensis* Pessagno - Yamasaki, pl. 2, fig. 21.

1995 *Pseudoaulophacus floresensis* Pessagno - Takahashi and Ishii, pl.4, fig. 11.

***Pseudoaulophacus lenticulatus* (White), 1963**

(Plate 1; Fig. 23)

1928 *Baculogysina*? *lenticulata* nov. sp. - White, p. 306, pl. 41, figs. 9, 11.

1963 *Pseudoaulophacus lenticulatus* (White) - Pessagno, p. 202, pl. 2, fig. 8.

1972 *Pseudoaulophacus lenticulatus* (White) - Pessagno, p. 306, pl. 29, fig. 4, 6.

1982 *Pseudoaulophacus lenticulatus* (White) - Taketani, p. 51, pl. 10, fig. 11.

1985 *Pseudoaulophacus lenticulatus* (White) - Sanfilippo and Riedel, p.596, figs. 6a, b.

1987 *Pseudoaulophacus lenticulatus* (White) - Yamasaki, pl. 2, fig. 22.

1997 *Pseudoaulophacus lenticulatus* (White) - Hashimoto and Ishida, pl. 2, fig. 10.

***Pseudotheocampe abschnitta* Empson-Morin, 1981**

(Plate 2; Fig. 12)

1981 *Pseudotheocampe abschnitta* nov. sp. - Empson-Morin, p. 64, pl. 5, figs. 1a - 3d.

1987 *Pseudotheocampe abschnitta* Empson-Morin - Yamasaki, pl.2, fig. 4.

1995 *Theocampe abschnitta* (Empson-Morin) - Takahashi and Ishii, pl. 4, fig. 22.

1997 *Pseudotheocampe abschnitta* Empson-Morin - Hashimoto and Ishida, pl. 3, fig. 16.

1998 *Pseudotheocampe abschnitta* Empson-Morin - Ishida and Hashimoto, pl. 2, fig. 14.

Rhopalosyringium magnificum **Campbell and Clark, 1944**

(Plate 1; Fig. 14)

1944 *Rhopalosyringium magnificum* nov. sp. - Campbell and Clark, p. 30, pl. 7, figs. 16, 17.

1968 *Rhopalosyringium magnificum* Campbell and Clark - Foreman, p. 55, pl. 6, figs. 7a-b.

1981 *Rhopalosyringium magnificum* Campbell and Clark - Empson-Morin, p. 265, pl. 8, figs. 1a - d.

1997 *Rhopalosyringium magnificum* Campbell and Clark - Hashimoto and Ishida, pl. 3, fig. 20.

Stichomitra asymbatos **Foreman, 1968**

(Plate 1; Fig. 22)

1968 *Stichomitra asymbatos* nov. sp. - Foreman, p. 73, pl. 8, figs. 10a- c.

1982 *Stichomitra asymbatos* Foreman - Taketani, p. 54, pl. 4, fig. 13; pl. 11, figs. 3, 4.

1987 *Stichomitra asymbatos* Foreman - Yamasaki, pl. 1, fig. 15.

1995 *Stichomitra asymbatos* Foreman - Takahashi and Ishii, pl. 3, fig. 24.

1997 *Stichomitra asymbatos* Foreman - Hashimoto and Ishida, pl. 3, fig. 17.

1998 *Stichomitra asymbatos* Foreman - Ishida and Hashimoto, pl. 2, fig. 4.

Stichomitra asymmetra **Foreman, 1978**

(Plate 2; Fig. 3)

1977 *Stichomitra asymmetra* nov. sp. - Foreman, pl. 1, fig. 10.

1978 *Stichomitra asymmetra* Foreman - p. 748, pl. 5, fig. 2.

1997 *Stichomitra asymmetra* Foreman - Keller et al., pl. 1, fig. 16, pl. 3, figs. 9- 12.

Stichomitra campi **(Campbell and Clark), 1968**

(Plate 1; Fig. 11)

1944 *Cyrtocapsa* (*Cyrtocapsoma*) *campi* nov. sp. - Campbell and Clark, p. 8, figs. 14, 15, 17, 20.

1968 *Stichomitra*? *campi* (Campbell and Clark) - Foreman, p. 75, pl. 8, figs. 3a - c.

1987 *Stichomitra campi* (Campbell and Clark) - Yamasaki, pl. 2, fig. 7.

1997 *Stichomitra campi* (Campbell and Clark) - Hashimoto and Ishida, pl. 2, fig. 18.

Stichomitra carnegiense **(Campbell and Clark), 1997**

(Plate 2; Fig. 10)

1944 *Eucyrtidium carnegiense* nov. sp. - Campbell and Clark, p. 42, pl. 8, figs. 36, 37.

1985 *Eucyrtidium carnegiense* Campbell and Clark - Suyari and Hashimoto, pl. 6, figs. 7-8.

1997 *Stichomitra carnegiense* (Campbell and Clark) - Hollis, p. 78, pl. 19, figs. 7- 12.

***Stichomitra cathara* Foreman, 1968**

1968 *Stichomitra cathara* nov. sp. - Foreman, p. 71, pl. 8, fig. 9.

1991 *Stichomitra cathara* Foreman - Ling, p. 320, pl. 2, fig. 10.

***Stichomitra cechena* Foreman, 1968**

(Plate 2; Fig. 11)

1968 *Stichomitra cechena* nov. sp. - Foreman, p. 77, pl. 8, fig. 1.

***Stichomitra compsa* Foreman, 1968**

(Plate 1; Fig. 13)

1968 *Stichomitra compsa* nov. sp. - Foreman, p. 72, pl. 8, figs. 8a, b

1973 *Stichomitra compsa* Foreman - Dumitrica, p. 789, pl. 1, fig. 4, pl. 8, figs. 8a - b.

1998 *Stichomitra compsa* Foreman - Ishida and Hashimoto, pl. 2, fig. 6.

***Stichomitra livermorensis* (Campbell and Clark), 1968**

(Plate 1; Fig. 15)

1944 *Artocapsa livermorensis* nov. sp. - Campbell and Clark, p. 45, pl. 8, figs. 10, 19, 21, 27.

1968 *Stichomitra*? *livermorensis* (Campbell and Clark) - Foreman, p. 76, pl. 8, figs. 2a, b.

1987 *Stichomitra livermorensis* (Campbell and Clark) - Yamasaki, pl. 2, fig. 6.

1997 *Stichomitra livermorensis* (Campbell and Clark) - Hashimoto and Ishida, pl. 3, fig. 3.

***Stichomitra* sp. A**

(Plate 2; Fig. 1)

1972 *Stichocapsa* sp., - Petrushevskaya and Kozlova, pl. 8, fig. 6, 7.

Remarks: Comparing with *S. asymbatos*, this species has more smooth tests with weak apical horn. The test outline is not crenulated than *S. carnegiense*.

***Stichomitra* sp. B**

(Plate 2; Fig. 8)

1977 *Stichomitra* sp. - Foreman, pl. 1, fig.11.

1994 *Stichomitra* sp. - Spörli and Aita, pl. 3, fig. 9.

Remarks: This species, identified by Foreman (1977), is characterized by small apical horn and relatively large pores on test with moderate collar stricture. The thorax and the successive chambers are recognized by clear segmentation.

***Stylotrochus polygonatus* Campbell and Clark, 1944**

(Plate 2; Fig. 22)

1944 *Stylotrochus polygonatus* nov. sp. - Campbell and Clark, p. 19, pl. 5, figs. 2, 10, 11.

1972 *Stylotrochus*? *polygonatus* Campbell and Clark - Petrushevskaya and Kozlova, p. 528, pl. 4, fig.10.

***Theocampe apicata* Foreman, 1971**

(Plate 2; Fig. 21)

1971 *Theocampe apicata* nov. sp. - Foreman, p. 1679, pl. 4, fig. 6; 1978, p. 745, pl. 5, figs. 21, 22, 28.

1985 *Theocampe apicata* Foreman - Sanfilippo and Riedel, p. 604, figs. 9, 2a - c.

1987 *Theocampe apicata* Foreman - Yamasaki, pl. 2, fig. 9.

***Theocampe bassilis* Foreman, 1968**

(Plate 2; Fig. 9)

1968 *Theocampe bassilis* nov. sp. - Foreman, p. 50, pl. 6, fig. 10.

***Theocapsomma comys* Foreman, 1968**

(Plate 2; Fig. 13)

1968 *Theocapsomma comys* nov. sp. - Foreman, p. 29, pl. 4, figs. 2a - c.

1985 *Theocapsomma comys* Foreman - Sanfilippo and Riedel, p. 623, fig. 14.4a - d.

***Theocampe daseia* Foreman, 1968**

(Plate 2; Fig. 14)

1968 *Theocampe daseia* nov. sp. - Foreman, p. 48, pl. 6, figs. 9a – b.

1997 *Theocampe daseia* Foreman - Hashimoto and Ishida, pl. 3, fig. 14.

Acknowledgments

We greatly thank Dr. Yoshiro Morozumi, Ex-Director Chairman of the Tokushima Prefectural Museum, and Professor Jiro Takahashi of the Ehime University for reading of the manuscript and for useful suggestions. Sincere thanks are due to Dr. Hirsch Francis, Ex-Guest Professor of the Kyoto University Museum for valuable comments.

Thanks are extended to Dr. Yoshiaki Aita and two anonymous reviewers for their critical reading of the manuscript. We are also grateful to Dr. Luis O'Dogherty of the University of Cadiz, Dr. Taniel Danelian of the Lille University, Dr. Atsushi Takemura of the Hyogo University of Education, and the commission members of the InterRad 13th at Cadiz, who invited us to present this study.

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Captions

Fig. 1. Geographic distribution of the Izumi Group. MTL: Median Tectonic Line.

Fig. 2. Geological map of the Izumi Group in Western Shikoku (After Editorial Board of Shikoku Engineering Geological map, 1998) with radiolarian and ammonite localities. 1: Basal conglomerate and arkosic sandstone; 2: Sandstone and alternations of sandstone and mudstone; 3: Alternations of sandstone and mudstone in equal proportion; 4: Mudstone and alternations of sandstone and mudstone with dominance of mudstone; 5: Acidic tuff; 6: Radiolarian locality; 7: Ammonite and inoceramid locality, A1- A3 (Noda and Tashiro, 1973), A4 (Matsumoto and Obata, 1963).

Fig. 3. Geological map of the Izumi Group in the Asan Mountains and Awaji Island (After Editorial Board of Shikoku Engineering Geological map, 1998) with radiolarian and ammonite localities. 1: Basal conglomerate and arkosic sandstone; 2: Sandstone and alternations of sandstone and mudstone; 3: Alternations of sandstone and mudstone in equal proportion; 4: Mudstone and alternations of sandstone and mudstone with dominance of mudstone; 5: Acidic tuff; 6: Radiolarian locality; 7: Ammonite locality, A8-A9 (Matsumoto at al., 1980), A5-A7, A16-A17 , A19-A22 (Bando and Hashimoto, 1984), A10 (Nishiyama et al., 2009), A12 (Nakagawa, 1960), A11, A13-A15, A18, A24-A25, A27-A30, A33 (Morozumi, 1985), A26 (Morozumi and Tsujino, 2003).

Fig. 4. Geological map of the Izumi Group in the Izumi Mountains (After Kurimoto et al., 1998) with radiolarian and ammonite localities.1: Basal conglomerate and arkosic sandstone; 2: Sandstone and alternations of sandstone and mudstone; 3: Alternations of sandstone and mudstone in equal proportion; 4: Mudstone and alternations of sandstone and mudstone with dominance of mudstone; 5: Acidic tuff; 6: Radiolarian locality; 7: Ammonite locality, A31, A32 (Matsumoto and Morozumi, 1980).

Fig. 5. Lithostratigraphic correlation of the Northern Shelf-, Central Turbidite- and Southern Shelf facies of the Izumi Group with radiolarian and ammonite zonations, magnetostratigraphic Chron and fission-track ages. The ages (Ma) were followed after Ogg and Hinnov (2012). A: ammonite and inoceramid horizons; R: Radiolarian horizons; F.: Formation; C. M: Conglomerate Member; M. M.: Mudstone Member; A. M.; Alternation Member; ※: Inoceramid Zone.

Fig. 6. Campanian-Maastrichtian ammonite and inoceramid zonations of the Izumi Group and NW Pacific region. ※: Inoceramid Zone

Fig. 7. Radiolarian occurrences in the Izumi Group. Locality numbers correspond to those in Figs. 2 - 5. ***Dk: Dictyomitra koslovae* Zone; Al:** *Archaeodictyomitra lamellicostata Zone;* **Ct: *Clathrocyclas tintinnaeformis* Zone; Sc: *Stichomitra cechena* Zone; Ma:** *Myllocercion acineton* **Zone; Cg: *Clathrocyclas gravis* Zone; Sa: *Stichomitra asymmetra* Zone; Co: *Cryptocarpium*? cf. *ornatum* Zone.**

Fig. 8. Compilation of the age range of index radiolarian species. Ranges were compiled after Campbell and Clark (1944), Dumitrica (1970), Foreman (1968), Pessagno (1976), Foreman (1978), Empson-Morin (1981), Taketani (1982; 1995), Okamura et al. (1984), Sanfilippo and Riedel (1985), Suyari and Hashimoto (1985), Vishnevskaya (1986), Iwata and Tajika (1986), Yamasaki (1987), Iwata et al. (1992), Takahashi and Ishii (1993), Hashimoto and Ishida (1997), Ishida and Hashimoto (1998), Hashimoto et al. (2001), Hollis and Kimura (2001), O' Dogherty et al. (2009), Ishida et al. (2010) and Noda et al. (2010).

Fig. 9. Radiolarian zonation as revised in this study and its correlation with previous radiolarian zonations.

Plate 1. Radiolarians from the Izumi Group (Part 1).

Scale bar =100 μm; A: 18; B: 4, 6, 8 - 11, 14 - 17, 19, 20, 22-26; C: 5, 1 - 3, 5, 7, 12, 13, 21.

Fig. 1. *Archaeodictyomitra sp. A: Myllocercion acineton Zone, Loc. R23;* ***Fig. 2.*** *Archaeodictyomitra simplex Pessagno: Archaeodictyomitra lamellicostata Zone, Loc. R10;* ***Fig. 3.*** *Dictyomitra koslovae Foreman: Stichomitra cechena Zone, Loc. R19;* ***Fig. 4.*** *Dictyomitra andersoni (Campbell and Clark): Clathrocyclas tintinnaeformis Zone, Loc. R17;* ***Fig. 5.*** *Dictyomitra multicostata Zittel: Archaeodictyomitra lamellicostata Zone, Loc. R12;* ***Fig. 6.*** *Dictyomitra densicostata Pessagno: Clathrocyclas tintinnaeformis Zone, Loc. R17;* ***Fig. 7****. Amphipyndax pseudoconulus (Pessagno): Myllocercion acineton Zone, Loc. R23;* ***Fig. 8.*** *Amphipyndax aff. pseudoconulus (Pessagno): Myllocercion acineton Zone, Loc. R23;* ***Fig. 9.*** *Amphipyndax tylotus Foreman: Stichomitra asymmetra Zone, Loc.R31;* ***Fig. 10.*** *Amphipyndax stocki (Campbell and Clark): Archaeodictyomitra lamellicostata Zone, Loc.R10;* ***Fig. 11.*** *Stichomitra campi (Campbell and Clark): Archaeodictyomitra lamellicostata Zone, Loc. R1;* ***Fig. 12.*** *Mita regina (Campbell and Clark): Clathrocyclas gravis Zone, Loc. R28;* ***Fig.* 13.** *Stichomitra compsa Foreman: Archaeodictyomitra lamellicostata Zone, Loc. R8;* ***Fig. 14.*** *Rhopalosyringium magnificum Campbell and Clark: Myllocercion acineton Zone, Loc. R23;* ***Fig. 15.*** *Stichomitra livermorensis (Campbell and Clark): Dictyomitra koslovae Zone, Loc. R3;* ***Fig. 16.*** *Lithocampe wharanui Hollis: Clathrocyclas tintinnaeformis Zone, Loc. R15;* ***Fig. 17.*** *Amphipyndax conicus Nakaseko and Nishimura: Archaeodictyomitra lamellicostata Zone, Loc. R12;* ***Fig. 18.*** *Archaeospongoprunum hueyi Pessagno: Myllocercion acineton Zone, Loc. R23;* ***Fig. 19.*** *Lithomelissa heros Campbell and Clark: Myllocercion acineton Zone, Loc. R21;* ***Fig. 20.*** *Lithomelissa amazon Foreman: Myllocercion acineton Zone, Loc. R21;* ***Fig. 21.*** *Cornutella californica Campbell and Clark: Stichomitra asymmetra Zone, Loc. R32,*

Fig. 22. *Stichomitra asymbatos Foreman: Stichomitra asymmetra Zone, Loc. R29;* ***Fig. 23.*** *Pseudoaulophacus lenticulatus (White): Dictyomitra koslovae Zone, Loc.1;* ***Fig. 24.*** *Pseudoaulophacus floresensis Pessagno: Cryptocarpium? cf. ornatum Zone, Loc. R34;* ***Fig. 25.*** *Orbiculiforma renillaeformis (Campbell and Clark): Archaeodictyomitra lamellicostata Zone, Loc. R9;* ***Fig. 26.*** *Cryptamphorella sphaerica (White): Stichomitra asymmetra Zone, Loc. R31.*

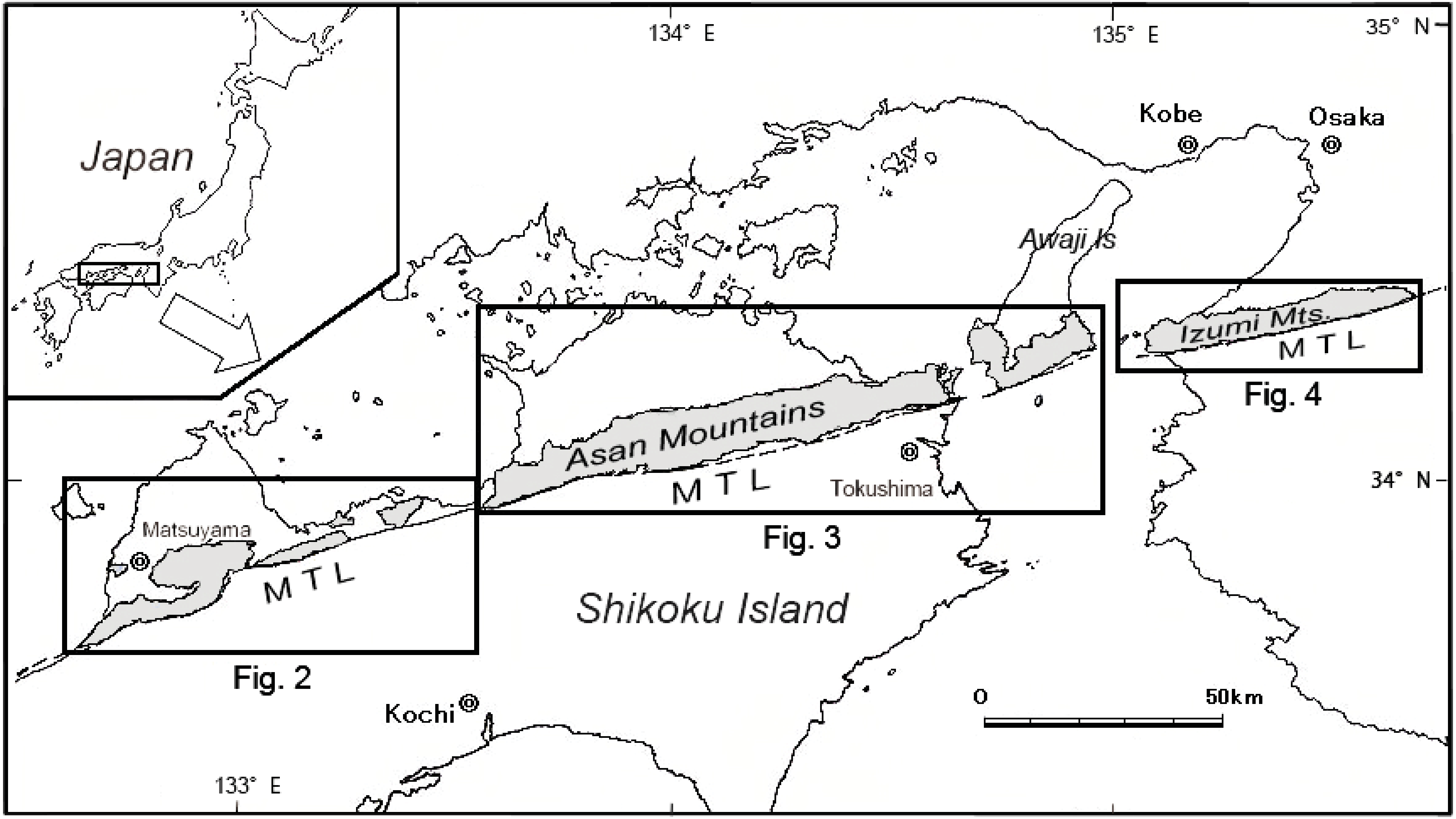
Plate 2. Radiolarians from the Izumi Group (Part 2).

Scale bar =100 μm; A: 23; B: 1, 2 – 4, 7, 10, 22, 25; C: 8, 11, 17 – 20, 26; D: 5, 6, 9, 12 – 16, 21, 24.

Fig. 1. *Dictyomitra rhadina Foreman: Archaeodictyomitra lamellicostata Zone, Loc. R10;* ***Fig. 2.*** *Dictyomitra formosa Squinabol: Stichomitra cechena Zone, Loc. R19;* ***Fig. 3.*** *Stichomitra asymmetra Foreman: Stichomitra asymmetra Zone, Loc. R32;* ***Fig. 4.*** *Dictyomitra aff. koslovae Foreman: Myllocercion acineton Zone, Loc. R20;* ***Fig. 5.*** *Archaeodictyomitra sliteri Pessagno: Archaeodictyomitra lamellicostata Zone, Loc. R7;* ***Fig. 6.*** *Archaeodictyomitra lamellicostata (Foreman): Stichomitra asymmetra Zone, Loc.R31;* ***Fig. 7.*** *Stichomitra sp. A: Stichomitra asymmetra Zone, Loc. R31;* ***Fig. 8.*** *Stichomitra sp. B: Cryptocarpium? cf. ornatum Zone, Loc. R34;* ***Fig. 9.*** *Theocampe bassilis Foreman: Myllocercion acineton Zone, Loc. R21;* ***Fig. 10.*** *Stichomitra carnegiensis (Campbell and Clark): Stichomitra asymmetra Zone, Loc. R31;* ***Fig. 11.*** *Stichomitra cechena Foreman: Archaeodictyomitra lamellicostata Zone, Loc. R19;* ***Fig. 12.*** *Pseudotheocampe abschnitta Empson-Morin: Myllocercion acineton Zone, Loc.23;* ***Fig. 13.*** *Theocapsomma comys Foreman: Stichomitra asymmetra Zone, Loc. 32;* ***Fig. 14.*** *Theocampe daseia Foreman: Myllocercion acineton Zone, Loc. R21;* ***Fig. 15.***

Myllocercion acineton Foreman: Clathrocyclas gravis Zone, Loc. R28; **Fig. 16.** *Cryptocarpium? cf. ornatum (Ehrenberg): Cryptocarpium? cf. ornatum Zone, Loc. R34;* **Fig. 17.** *Clathrocyclas hyronia Foreman: Myllocercion acineton Zone, Loc.23;* **Fig. 18.** *Clathrocyclas tintinnaeformis Campbell and Clark: Clathrocyclas tintinnaeformis Zone, Loc. R15;* **Fig. 19.** *Clathrocyclas gravis Vishnevskaya: Clathrocyclas gravis Zone, Loc. R28;* **Fig. 20.** *Phormostrichoartus? strongi Hollis: Myllocercion acineton Zone, Loc. R23;* **Fig. 21.** *Theocampe apicata Foreman: Myllocercion acineton Zone, Loc. R21;* **Fig. 22.** *Stylotrochus polygonatus Campbell and Clark: Archaeodictyomitra lamellicostata Zone, Loc. R12;* **Fig. 23.** *Afens liriodes Riedel and Sanfilippo: Stichomitra asymmetra Zone, Loc. R32;* **Fig. 24.** *Acidnomelos proapteron Foreman: Myllocercion acineton Zone, Loc.23;* **Fig. 25.** *Allievium gallowayi (White): Archaeodictyomitra lamellicostata Zone, Loc. R10;* **Fig. 26.** *Dorcadospyris sp. A: Clathrocyclas gravis Zone, Loc. R30.*

Fig. 1



134° E
135° E
35° N
Japan
Kobe
Osaka
Awaji Is
Izumi Mts.
M T L
Fig. 4
Asan Mountains
M T L
Tokushima
Fig. 3
34° N
Matsuyama
M T L
Fig. 2
Shikoku Island
Kochi
0
50km
133° E

Fig. 2

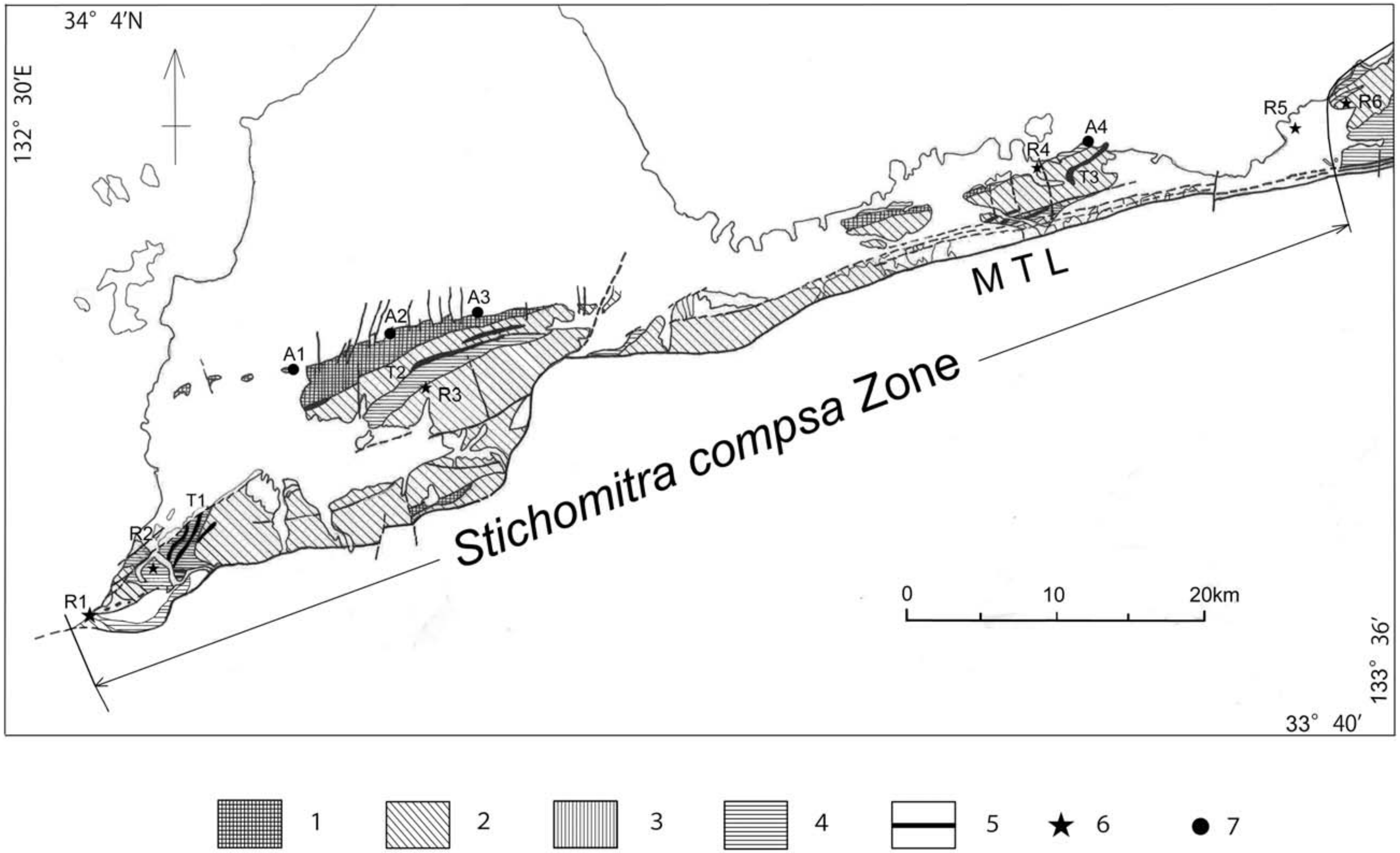

34° 4′N
132° 30′E
A1
A2
A3
A4
T1
T2
T3
R1
R2
R3
R4
R5
R6
M T L
Stichomitra compsa Zone
0
10
20km
133° 36′
33° 40′
1
2
3
4
5
6
7

Fig. 3

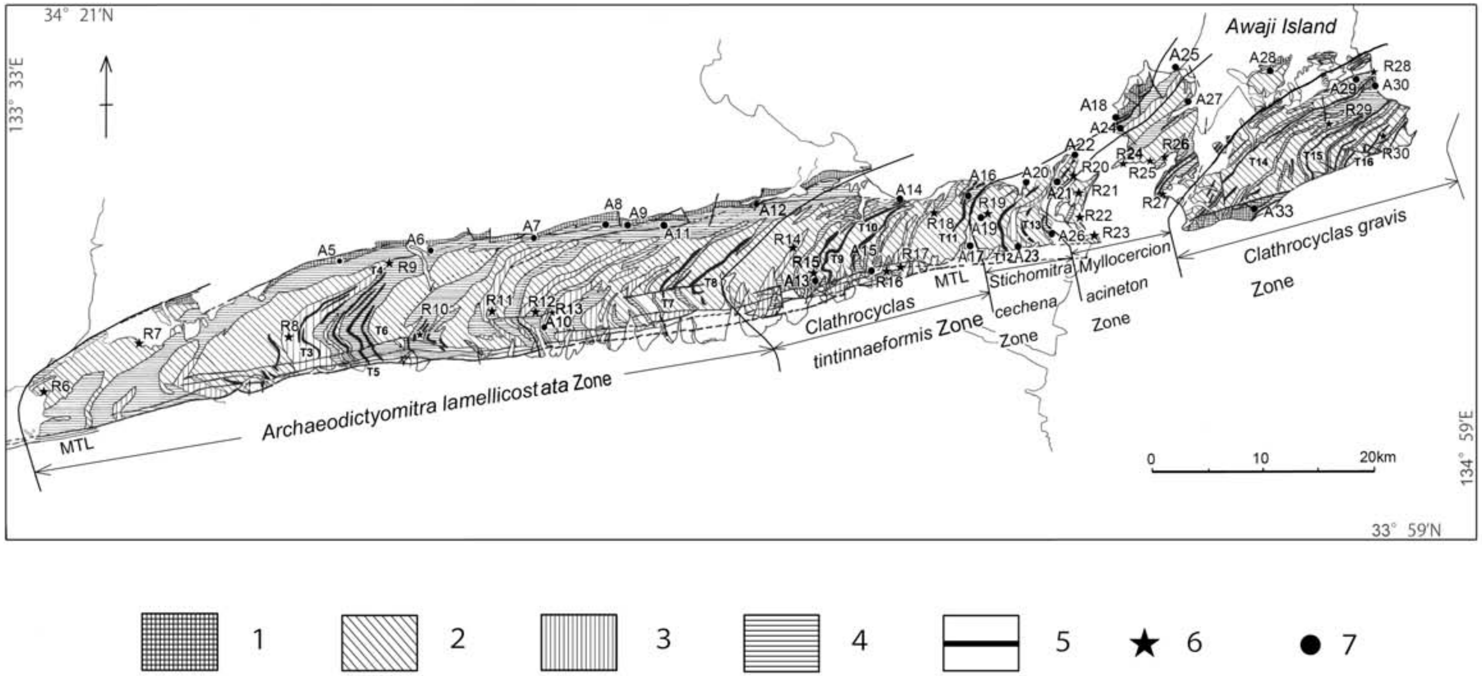

34° 21'N
133° 33'E
Awaji Island
Archaeodictyomitra lamellicostata Zone
Clathrocyclas tintinnaeformis Zone
Stichomitra cechena Zone
Myllocercion acineton Zone
Clathrocyclas gravis Zone
MTL
0 10 20km
134° 59'E
33° 59'N
1 2 3 4 5 6 7

Fig. 4

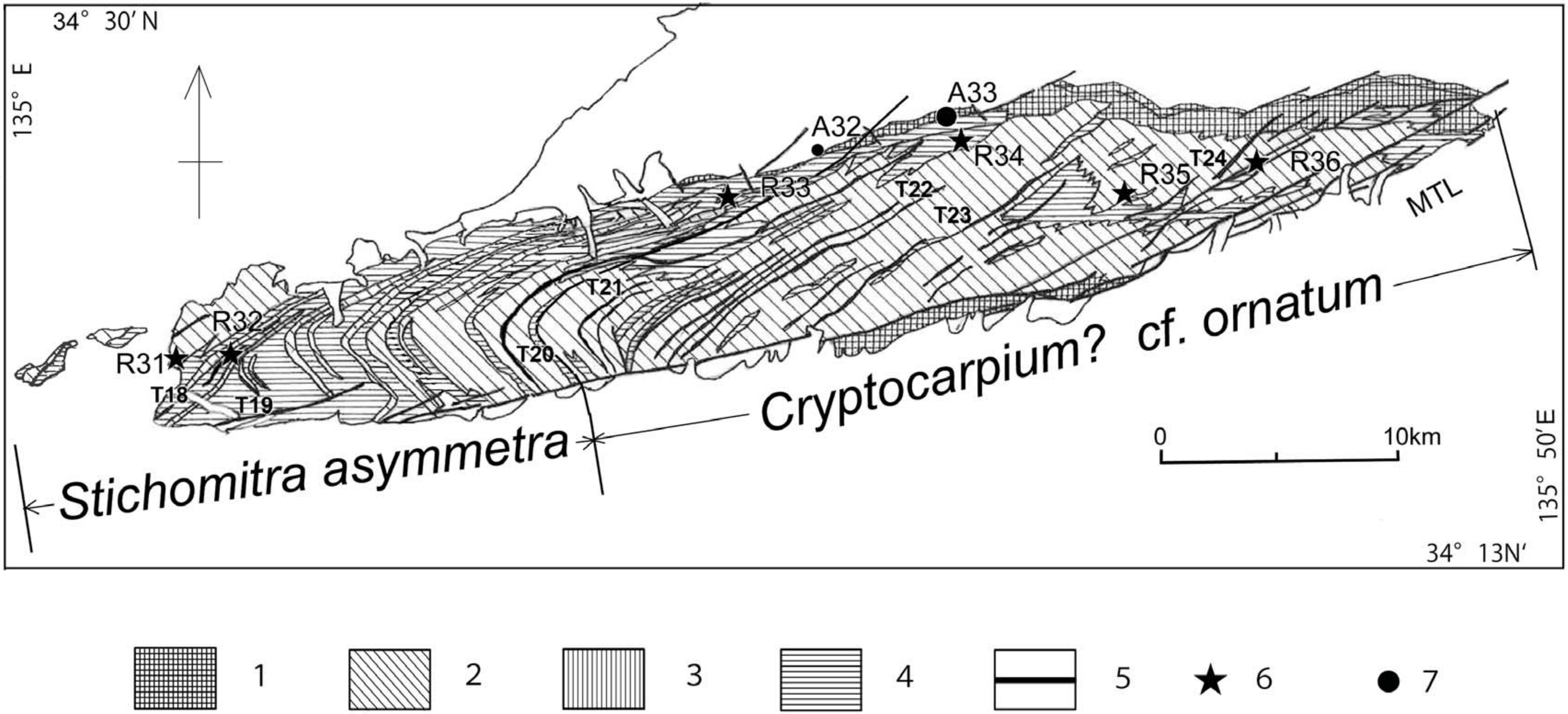
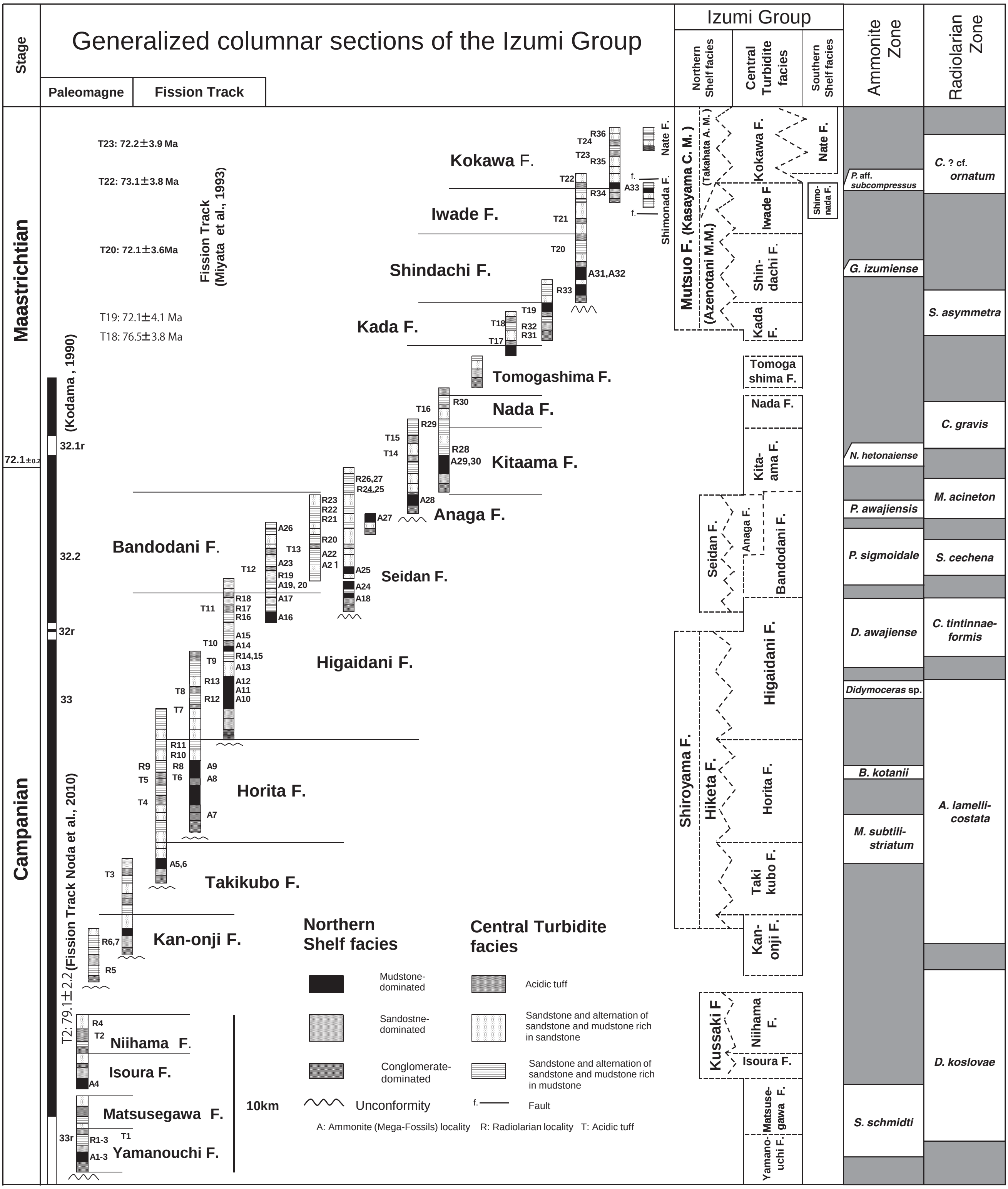

34° 30′ N
135° E
A33
A32
R34
R33
R35
T24
R36
T22
T23
MTL
T21
R32
R31
T20
T18
T19
Cryptocarpium? cf. ornatum
Stichomitra asymmetra
0
10km
135° 50′ E
34° 13N′
1
2
3
4
5
6
7

Fig. 5



Generalized columnar sections of the Izumi Group
Stage
Paleomagne
Fission Track
Izumi Group
Northern Shelf facies
Central Turbidite facies
Southern Shelf facies
Ammonite Zone
Radiolarian Zone
Maastrichtian
Campanian
72.1±0.2
T23: 72.2±3.9 Ma
T22: 73.1±3.8 Ma
T20: 72.1±3.6Ma
T19: 72.1±4.1 Ma
T18: 76.5±3.8 Ma
Fission Track (Miyata et al., 1993)
(Kodama , 1990)
32.1r
32.2
32r
33
33r
T2: 79.1±2.2 (Fission Track Noda et al., 2010)
Kokawa F.
Iwade F.
Shindachi F.
Kada F.
Tomogashima F.
Nada F.
Kitaama F.
Anaga F.
Bandodani F.
Seidan F.
Higaidani F.
Horita F.
Takikubo F.
Kan-onji F.
Niihama F.
Isoura F.
Matsusegawa F.
Yamanouchi F.
10km
Nate F.
Shimonada F.
Mutsuo F. (Kasayama C. M.)
(Takahata A. M.)
(Azenotani M.M.)
Shimo-nada F.
Tomoga shima F.
Shiroyama F.
Hiketa F.
Kussaki F
Isoura F.
Matsuse-gawa F.
Yamano-uchi F.
P. aff. subcompressus
G. izumiense
N. hetonaiense
P. awajiensis
P. sigmoidale
D. awajiense
Didymoceras sp.
B. kotanii
M. subtili-striatum
S. schmidti
C. ? cf. ornatum
S. asymmetra
C. gravis
M. acineton
S. cechena
C. tintinnae-formis
A. lamelli-costata
D. koslovae
Northern Shelf facies
Central Turbidite facies
Mudstone-dominated
Sandostne-dominated
Conglomerate-dominated
Unconformity
Acidic tuff
Sandstone and alternation of sandstone and mudstone rich in sandstone
Sandstone and alternation of sandstone and mudstone rich in mudstone
Fault
A: Ammonite (Mega-Fossils) locality R: Radiolarian locality T: Acidic tuff

Fig. 6

STAGE				NW Pacific Region (Toshimitsu et al., 1995)				Izumi Group
Ma		Substage		Ammonite Zone: Desmoceratacease		Ammonite Zone: Selected associate	Inoceramid Zone	Ammonite Zone (Morozumi, 1985; Shigeta et al., 2010)
66.0	Maastrichtian	Upper	K6b2	*Pachydiscus* (*P.*) *flexuosus*		*Gaudryceras hamanakense*	"*Inoceramus*" *awajiensis*	*Pachydiscus* aff. *subcompressus*
	Maastrichtian	Upper	K6b2	*Pachydiscus* (*P.*) *flexuosus*	*Pachydiscus* (*N.*) *gracilis*	*Gaudryceras izumiense*	*Sphenoceramus hetonaianus*	(gray)
	Maastrichtian	Lower	K6b1	*Pachydiscus* (*P.*) *kobayashii*	*Pachydiscus* (*N.*) *gracilis*	*Gaudryceras izumiense*	*Sphenoceramus hetonaianus*	*Gaudryceras izumiense*
	Maastrichtian	Lower	K6b1	*Pachydiscus* (*Neodesmoceras*) *japonicus*		*Nostoceras hetonaiense*	*Inoceramus* (*Endocostea*) *shikotanensis*	*Nostoceras hetonaiense*
72.1 ±0.2	Campanian	Upper	Kb6a4	*Pachydiscus* (*P.*) *awajiensis*	*Desmophylites diphylloides*	*Pravitoceras sigmoidale*	*Inoceramus* (*Endocostea*) aff. *balticus*	*Pachydiscus awajiensis*
	Campanian	Upper	Kb6a4	*Pachydiscus* (*P.*) *awajiensis*	*Desmophylites diphylloides*	*Pravitoceras sigmoidale*	*Inoceramus* (*Endocostea*) aff. *balticus*	*Pravitoceras sigmoidale*
	Campanian	Upper	Kb6a4	*Patagiosites laevis*	*Desmophylites diphylloides*	*Didymoceras awajiense*	*Inoceramus* (*Endocostea*) aff. *balticus*	*Didymoceras awajiense*
	Campanian	Upper	Kb6a4	*Patagiosites laevis*	*Desmophylites diphylloides*	*Didymoceras awajiense*	*Inoceramus* (*Endocostea*) aff. *balticus*	*Didymoceras* sp.
	Campanian	Upper	Kb6a4	*Patagiosites laevis*	*Desmophylites diphylloides*	*Didymoceras awajiense*	*Inoceramus* (*Endocostea*) aff. *balticus*	*Baculites kotanii*
	Campanian	Upper	Kb6a3	*Anapachydiscus facicostatus*	*Desmophylites diphylloides*	*Metaplacenticeras substilistriatum* — *Hoplitoplacenticeras monju*	*Mytiloides shimanukii*	*Metaplacenticeras subtilistriatum*
	Campanian	Lower	Kb6a2	*Canadoceras kossmati*	*Desmophylites diphylloides*	*Delawarella* sp.	*Sphenoceramus schmidti* — *Sphenoceramus orientalis* — *Inoceramus* (*P.*) *chicoensis*	※*Sphenoceramus schmidti*
	Campanian	Lower	Kb6a1	*Anapachydiscus naumanni*	*Desmophylites diphylloides*	*Plesiotexanites shiloensis* — *Menabites mazenoti* — *Submortoniceras* cf. *condamyi*	*Sphenoceramus schmidti* — *Sphenoceramus orientalis* — *Inoceramus* (*P.*) *chicoensis*	※*Sphenoceramus schmidti*
83.6 ±0.2	Campanian	Lower	K5b2	*Anapachydiscus naumanni*	*Desmophylites diphylloides*	*Plesiotexanites shiloensis* — *Menabites mazenoti* — *Submortoniceras* cf. *condamyi*	*Inoceramus* (*Platyceramus*) *japonicus*	(gray)

Fig. 7

Radiolarian Zone	Dk					Al								Ct					Sc		Ma							Cg			Sa			Co		
Specific Name ＼ Locality Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Amphipyndax stocki (Campbell & Clark)	●		●	●	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●		●	●	●	●	●			●	●	●		●		●
Archaeodictyomitra simplex Pessagno	●		●	●	●			●		●				●					●			●		●	●											
Dictyomitra formosa Squinabol	●	●	●	●	●	●	●						●	●	●				●						●											
Dictyomitra multicostata Zittel	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●		●		●		●			●		●	●	●		●		●
Pseudoaulophacus floresensis Pessagno	●	●	●	●	●				●												●										●			●		
Stichomitra asymbatos Foreman	●		●	●	●	●			●		●	●	●		●	●			●	●		●						●	●	●	●			●		●
Stich omitra campi (Campbell & Clark)	●		●	●			●		●	●	●	●		●	●			●										●			●					●
Stichomitra compsa Foreman	●	●	●					●	●																											
Stichomitra livermorensis (Campbell & Clark)	●	●	●					●	●	●	●						●				●										●					
Alievium gallowayi (White)	●								●	●			●							●			●					●								
Orbiculiforma renillaeformis (Campbell & Clark)	●								●			●			●					●										●	●					
Amphipyndax conicus Nakaseko & Nishimura	●								●			●			●								●								●	●		●		
Archaeospongoprunum salumi Pessagno		●	●			●			●	●		●			●			●					●		●											
Dictyomitra koslovae Foreman		●	●	●	●	●	●		●		●		●	●	●				●				●													
Amphipyndax aff. *tylotus* Foreman			●	●			●		●	●	●										●							●			●			●		●
Amphipyndax aff. *pseudoconulus* (Pessagno)			●	●	●	●													●		●		●		●	●										
Archaeospongoprunum stocktonensis Pessagno			●								●		●	●											●					●						
Artostrobium urna Foreman			●	●																																
Cornutella californica Campbell & Clark			●	●	●				●				●	●				●					●	●			●				●	●				
Cryptamphorella macropora Dumitrica			●	●							●										●		●								●	●		●		●
Dictyomitra andersoni (Campbell & Clark)			●	●	●				●	●		●				●	●	●	●		●	●	●		●			●		●				●		
Dictyomitra densicostata Pessagno			●			●	●	●				●	●		●		●		●				●		●	●				●	●	●				
Lithomelissa amazon Foreman			●		●										●			●			●	●	●			●		●								
Mita regina (Campbell & Clark)			●																				●					●		●						●
Praestylospaera hastata (Campbell & Clark)			●					●			●		●	●																●	●	●				
Archaeodictyomitra sliteri Pessagno			●					●									●					●	●													
Rhopalosyringium magnificum Campbell & Clark			●						●		●	●									●		●		●	●	●									
Dictyomitra aff. *koslovae* Foreman				●	●	●							●							●							●	●								
Amphipyndax ellipticus Nakseko & Nishimura				●	●	●		●					●	●		●							●					●			●	●		●		
Conocaryomma dauerhafta Empson-Morin				●																			●		●											
Diacanthocapsa cf. *ancus* (Foreman)				●		●			●	●	●	●		●				●																		
Diacanthocapsa ovoidea Dumitrica				●	●										●						●															
Pseudoaulophacus paraqueraensis Pessagno				●									●																			●				
Theocampe apicata Foreman					●																●		●					●								
Cryptamphorella sphaerica (White)					●			●											●				●			●		●		●	●					●
Pseudoaulophacus lenticulatus (White)					●				●		●						●																			
Diacanthocapsa acuminata Dumitrica					●	●						●					●								●											
Amphipyndax pseudoconulus (Pessagno)						●	●				●	●	●					●	●			●	●	●	●	●	●									
Amphipyndax tylotus Foreman						●	●	●	●		●	●	●	●	●		●	●	●	●	●	●	●		●	●	●	●		●	●	●		●		
Pseudotheocampe abschnitta Empson-Morin						●	●						●							●	●		●		●			●		●						
Archaeodictyomitra lamellicostata (Foreman)							●		●	●		●			●	●			●	●		●	●								●	●		●		
Afens liriodes Riedel & Sanfilippo									●												●		●							●	●			●		●
Archaeospongoprunum hueyi Pessagno									●			●	●	●		●			●		●	●	●		●			●					●	●		
Dictyomitra rhadina Foreman										●	●						●						●								●			●		
Theocapsoma comys Foreman										●											●						●			●						
Lithocampe wharanui Hollis												●			●	●																		●		
Stichomitra cathara Foreman												●											●								●					
Stylotrochus polygonatus Campbell & Clark												●		●									●					●								
Coniforma antiochensis Pessagno													●					●			●		●													
Clathrocyclas tintinnaeformis Campbell & Clark														●																	●					
Cryptamphorella conara Foreman														●	●	●					●		●						●	●	●		●	●		
Phormostrichoartus? strongi Hollis																●							●							●	●					
Stichomitra carnegiense (Campbell & Clark)																	●		●		●		●					●			●					
Stichomitra cechena Foreman																			●		●		●					●								
Archaeodictyomitra sp. A																			●	●			●	●				●								
Alievium murphi Pessagno																				●			●													●
Lithomelissa heros Campbell & Clark																					●		●		●			●								
Theocampe daseia (Foreman)																					●		●					●								
Myllocercion acineton Foreman																					●							●		●						
Amphipyndax alamedaensis (Campbell & Clark)																					●		●								●					
Clathrocyclas hyronia Foreman																							●		●											
Theocampe bassilis Foreman																							●													
Acidnomelos proapterm Foreman																							●													
Clathrocyclas gravis Vishnevskaya																												●		●	●		●			
Dorcadospyris sp. A																												●		●				●		●
Foremania schona Empson-Morin																														●						
Stylosphaera cf. *hastata* (Campbell & Clark)																														●						
Theocampe ruekena Empson-Morin																														●						
Stichomitra asymmetra Foreman																															●	●		●		●
Parvicuspis schastaensis Pessagno																															●				●	
Patellula euessceei Empson-Morin																															●					
Clathrocyclas hyronia Foreman																															●					
Clathrocyclas sp. A																															●		●		●	
Sphaerostylus hastata Campbell & Clark																															●			●		
Archaeodictyomitra rigida Pessagno																															●			●		●
Stichomitra sp. A																															●					●
Stylloshaera pusilla Campbell & Clark																																●				
Patellura verteroensis (Pessagno)																																●			●	
Cryptocarpium? cf. *ornatum* (Ehrenberg)																																		●	●	
Phaseliforma concensis (Lioman)																																		●		
Stichomitra sp. B																																		●		●
Clathrocyclas aff. *australis* Hollis																																		●		
Orbiculiforma sacramentoensis (Campbell & Clark)																																				●
Theocampe? sp.																																		●		
Amphiternis? sp.																																		●		●
Eucyrtidium? sp.																																				●
Spyrids gen. et sp. indet.																																				●
Gen.sp.indet.																																				●

Fig. 8

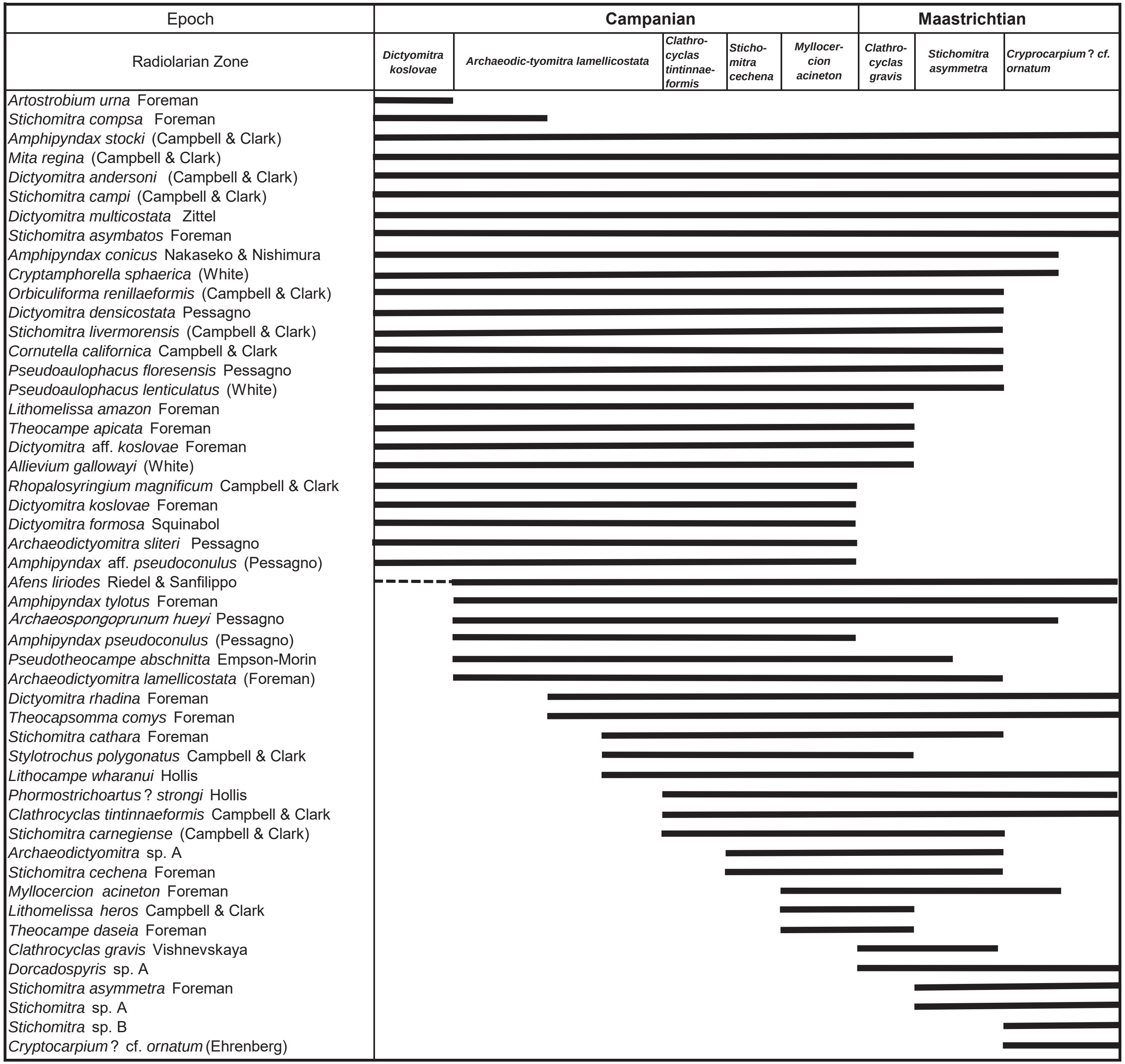

Epoch
Campanian
Maastrichtian
Radiolarian Zone
Dictyomitra koslovae
Archaeodic-tyomitra lamellicostata
Clathro-cyclas tintinnae-formis
Sticho-mitra cechena
Myllocer-cion acineton
Clathro-cyclas gravis
Stichomitra asymmetra
Cryprocarpium ? cf. ornatum
Artostrobium urna Foreman
Stichomitra compsa Foreman
Amphipyndax stocki (Campbell & Clark)
Mita regina (Campbell & Clark)
Dictyomitra andersoni (Campbell & Clark)
Stichomitra campi (Campbell & Clark)
Dictyomitra multicostata Zittel
Stichomitra asymbatos Foreman
Amphipyndax conicus Nakaseko & Nishimura
Cryptamphorella sphaerica (White)
Orbiculiforma renillaeformis (Campbell & Clark)
Dictyomitra densicostata Pessagno
Stichomitra livermorensis (Campbell & Clark)
Cornutella californica Campbell & Clark
Pseudoaulophacus floresensis Pessagno
Pseudoaulophacus lenticulatus (White)
Lithomelissa amazon Foreman
Theocampe apicata Foreman
Dictyomitra aff. koslovae Foreman
Allievium gallowayi (White)
Rhopalosyringium magnificum Campbell & Clark
Dictyomitra koslovae Foreman
Dictyomitra formosa Squinabol
Archaeodictyomitra sliteri Pessagno
Amphipyndax aff. pseudoconulus (Pessagno)
Afens liriodes Riedel & Sanfilippo
Amphipyndax tylotus Foreman
Archaeospongoprunum hueyi Pessagno
Amphipyndax pseudoconulus (Pessagno)
Pseudotheocampe abschnitta Empson-Morin
Archaeodictyomitra lamellicostata (Foreman)
Dictyomitra rhadina Foreman
Theocapsomma comys Foreman
Stichomitra cathara Foreman
Stylotrochus polygonatus Campbell & Clark
Lithocampe wharanui Hollis
Phormostrichoartus ? strongi Hollis
Clathrocyclas tintinnaeformis Campbell & Clark
Stichomitra carnegiense (Campbell & Clark)
Archaeodictyomitra sp. A
Stichomitra cechena Foreman
Myllocercion acineton Foreman
Lithomelissa heros Campbell & Clark
Theocampe daseia Foreman
Clathrocyclas gravis Vishnevskaya
Dorcadospyris sp. A
Stichomitra asymmetra Foreman
Stichomitra sp. A
Stichomitra sp. B
Cryptocarpium ? cf. ornatum (Ehrenberg)

Fig. 9

<table>
<tr><th>Stage</th><th>UAZ (O'Dogherty et al., 2009)</th><th>This paper</th><th>Pessagno (1976)</th><th>Sanfillippo & Riedel (1985)</th><th>Yamasaki (1987)</th><th>Hashimoto & Ishida (1997)</th><th>Hollis & Kimura (2001)</th></tr>
<tr><td rowspan="5">Maastrichtian</td><td rowspan="3">66</td><td></td><td rowspan="5">Orbiculiforma renillaeformis</td><td rowspan="10">Amphipyndax tylotus</td><td rowspan="4"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td rowspan="2">Cryptocarpium? cf. ornatum</td></tr>
<tr><td rowspan="2">Amphipyndax tylotus Subzone 2</td><td rowspan="2">Clathrocyclas? gravis</td></tr>
<tr><td rowspan="2">65</td><td>Stichomitra asymmetra</td></tr>
<tr><td>Clathrocyclas gravis</td><td rowspan="2">Pseudotheocampe abschnitta</td><td>Amphipyndax tylotus Subzone 1</td><td>Pseudotheocampe abschnitta</td></tr>
<tr><td rowspan="6">Campanian</td><td rowspan="5">64</td><td>Myllocercion acineton</td><td rowspan="2">Patylibracchium dickinsoni</td><td rowspan="4">Amphipyndax pseudoconulus Subzone 2</td><td rowspan="5">Amphipyndax pseudoconulus</td></tr>
<tr><td>Stichomitra cechena</td><td rowspan="4">Amphipyndax tylotus</td></tr>
<tr><td>Clathrocyclas tintinnaeformis</td><td rowspan="4">Crucella espartoensis</td></tr>
<tr><td rowspan="2">Archaeodictyomitra lamellicostata</td></tr>
<tr><td>Amphipyndax pseudoconulus Subzone 1</td></tr>
<tr><td>63</td><td>Dictyomitra koslovae</td><td>Amphipyndax pseudoconulus</td><td>Dictyomitra koslovae</td><td>Stichomitra compsa</td><td>Dictyomitra koslovae</td></tr>
</table>

Plate 1

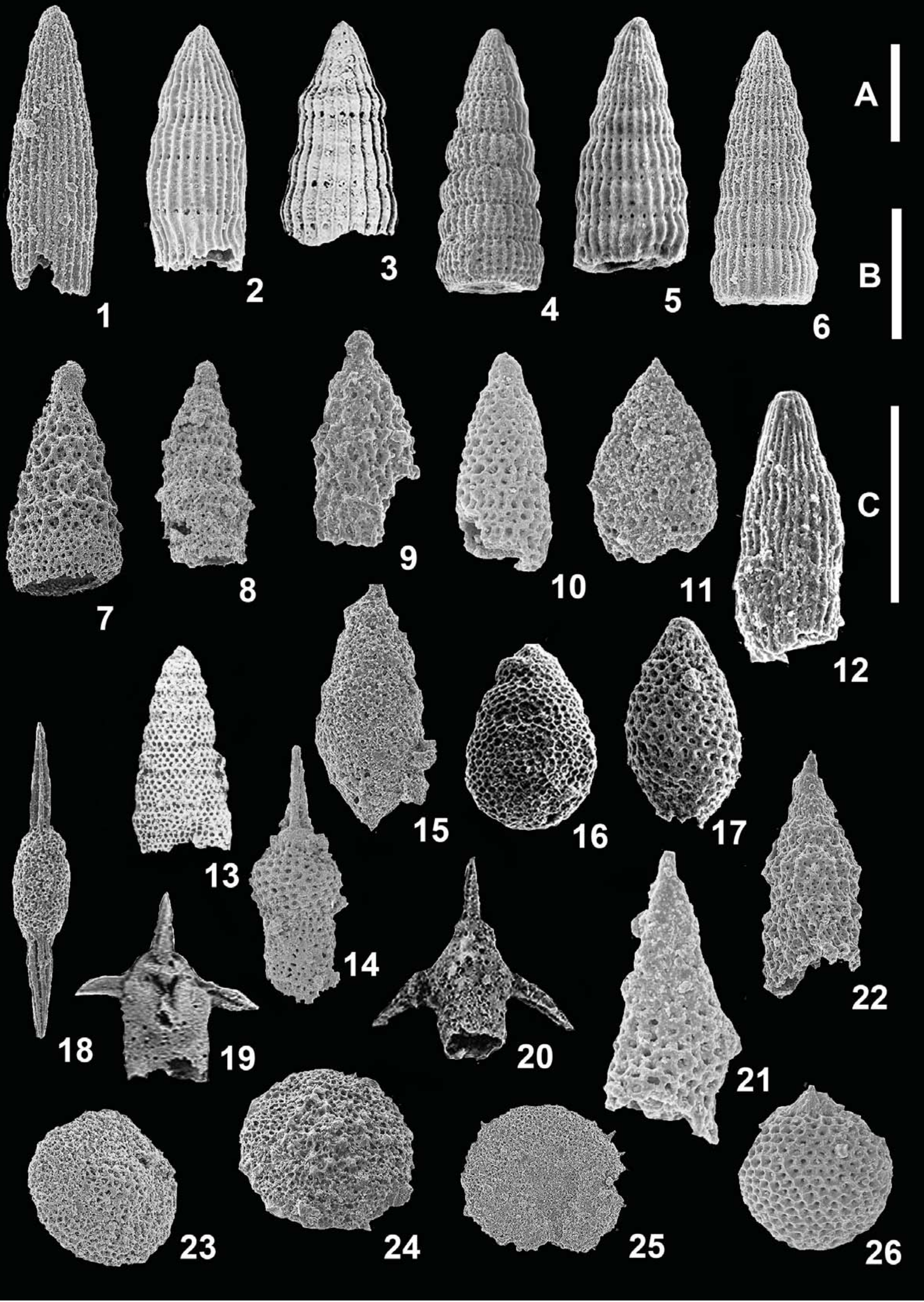


Plate 2