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doi:10.2517/2019PR017

The first report on Early Cretaceous Radiolaria from Myanmar

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Received xxxx, 2019; Revised manuscript accepted xxxx, 2018/03/24

Abstract

An Early Cretaceous radiolarian fauna is found from the Tagaung Taung area, central Myanmar. The fauna consists of the following species: *Acanthocircus dicranacanthos* (Squinabol), *Stylosphaera squinaboli* Tan Sin Hok, *Hiscocapsa* cf. *subcrassitestata* (Aita), *Svinitzium* cf. *depressum* (Baumgartner), *Thanarla brouweri* (Tan Sin Hok), *Archaeodictyomitra mitra* Dumitrica, *Archaeodictyomitra apiarium* (Rüst), *Archaeodictyomitra vulgaris* Pessagno, *Hemicryptocapsa* cf. *pseudopilula* Tan Sin Hok, *Hemicryptocapsa capita* Tan Sin Hok, *Holocryptocapsa hindei* Tan Sin Hok and *Cryptamphorella challengeri* Schaaf. These species indicate clearly an Early Cretaceous age (Hauterivian), and therefore this is the first report on Cretaceous radiolarians from Myanmar.

Key words: Cretaceous, Myanmar, Ngapyawdaw Chaung Formation, Radiolaria, Tagaung Taung

Introduction

Fossil polycystine radiolarians, which have SiO_2 skeleton/test, are the main constituents of radiolarian chert in the Phanerozoic. In Myanmar several chert sequences are known, however, no fossil radiolarians have been reported directly from chert of the basement rocks, although Suzuki *et al*. (2004) have extracted Jurassic radiolarians from chert pebbles contained in a conglomerate of the Eocene Pondaung Formation. The ages of the chert sequences are important to reconstruct oceanic plate stratigraphy that explains geotectonic development of ocean floor. From a red claystone of the Ngapyawdaw Chaung Formation of Myanmar, Maung Maung *et al*. (2011) have already reported a latest Jurassic radiolarian fauna, but there is no radiolarian report from chert of Myanmar basement rocks. Because this is the first report on fossil radiolarians from Mesozoic chert in Myanmar, we describe them in detail and its plate tectonic significance is discussed.

Geologic setting

The study area is located 10 km northeast of Tagaung town, which is on the left bank of the River Ayeyarwaddy (Figure 1). The area is called the Tagaung Taung area. The study area is geotectonically situated in the western edge of the Shan-Tennasserim massif. The area is, however, covered/surrounded by Cenozoic sediments, showing the feature of the Inner-Burman Tertiary Basin (Bender, 1983), which stretches in the west of the River Ayeyarwaddy.

A comprehensive account on detailed geology and mineralisation of the Tagaung Taung area has come out by the second author (La Ja). He distinguishes six stratigraphic units in the Tagaung Taung area: ultrabasic rocks, schists of the Ngapyawdaw Chaung Formation, Ngapyawdaw Chaung Formation, Baingbin Conglomerate, Male Formation and Khuntu Chaung Fanglomerate (Figure 2).

The bedded chert of the Ngapyawdaw Chaung Formation in the Tagaung Taung area (That-tu bedded chert; samples C and D; described herein) is brick-red in colour, highly contorted in nature, and shows no associated basaltic rocks. Although radiolarian tests are contained in the That-tu bedded chert, the geologic age and description of radiolarians from it have not yet been presented. This study provides them for the first time. The previous age of the That-tu bedded chert was assigned as Cretaceous, examined by the second author, La Ja in 1980s, on the basis of his previous findings of foraminifers from limestone intercalations. This foraminifer assemblage consists of

Orbitolina kurdica Henson, 1948, *Orbitolina* cf. *concava* Lamarck, 1816, *Oligostegina* sp. and *Dictyoconus* sp., assumed to be of an Albian to Cenomanian age. In terms of today's Cretaceous biostratigraphy of foraminifers, it should be reexamined because of mixing of species indicating different ages (personal communication with Felix Schlagintweit in Munich).

Material and method

Chert samples named C and D were collected from the That-tu bedded chert of the Ngapyawdaw Chaung Formation in the Tagaung Taung area (Figure 2). Because samples C and D were collected from a same horizon, we treat here as one combined sample.

Chert samples C and D were etched by 3–5% hydrofluoric acid for 2 to 22 hours in several times in the laboratory of Osaka City University, Japan. Etched residues were put through sieves between 36 and 200 meshes, and washed by water. Residues were observed under a binocular to pick up radiolarian tests with a tiny brush. Radiolarian tests were put on a cylindrical metal stub to make a preparation for scanning electron microscope. Observations were made with a scanning electron microscope of Kyoto University Museum (GEOL JSM-6060) and with that of Otani University (TECHNEX Mighty-8DX).

Radiolarian fauna and its age

Radiolarians extracted from samples C and D of the That-tu bedded chert are depicted in figure 3 as scanning electron micrographs. Identified species are as follows: *Acanthocircus dicranacanthos* (Squinabol, 1914), *Stylosphaera squinaboli* Tan Sin Hok, 1927, *Hiscocapsa* cf. *subcrassitestata* (Aita, 1986), *Svinitzium* cf. *depressum* (Baumgartner, 1984), *Thanarla brouweri* (Tan Sin Hok, 1927), *Archaeodictyomitra mitra* Dumitrica, 1997, *Archaeodictyomitra apiarium* (Rüst, 1885), *Archaeodictyomitra* cf. *apiarium* (Rüst, 1885), *Archaeodictyomitra vulgaris* Pessagno, 1977, *Hemicryptocapsa* cf. *pseudopilula* Tan Sin Hok, 1927, *Hemicryptocapsa capita* Tan Sin Hok, 1927, *Holocryptocapsa hindei* Tan Sin Hok, 1927, *Cryptamphorella challengeri* Schaaf, 1981 and *Dictyomitra* sp.

To determine the geologic age, such species as *Holocryptocapsa hindei*, *Hemicryptocapsa capita*, *Acanthocircus dicranacanthos* and *Svinitzium depressum* are important (Figure 4). The stratigraphic range of *Holocryptocapsa hindei* is referred to as Barremian to middle Aptian after the zonation of O'Dogherty (1994). The radiolarian stratigraphic chart of O'Dogherty (1994), however, begins with the Barremian, so that we should pay attention to the first appearance horizon of *Holocryptocapsa hindei*. Its stratigraphic range can go down at least to Hauterivian (personal communication from Luis O'Dogherty). From the Şahvelet area of northeast Turkey, Robertson *et al*. (2013) reported radiolarian assemblage including *Holocryptocapsa hindei* together with *Mirifusus dianae* Karrer. They dated their sample E2-86 as Hauterivian, which marks the last occurrence horizon of *Mirifusus dianae* (Baumgartner *et al*., 1995a). The first appearance horizon of *Holocryptocapsa hindei*, therefore, can be within the Hauterivian.

The stratigraphic range of *Hemicryptocapsa capita* starts from the Berriasian (Matsuoka, 1989, 1992; Taketani, 2013) and ends in the Barremian (Goričan, 1994). *Acanthocircus dicranacanthos* occurs in the Upper Jurassic and ends its occurrence within the upper Barremian (Schaaf, 1981; Goričan, 1994). Therefore, *Hemicryptocapsa capita* and *Acanthocircus dicranacanthos* restrict the upper limit of the horizon of the samples C and D to the upper Barremian.

Svinitzium depressum appears in the Tithonian (e.g. Steiger, 1992), and its stratigraphic range extends into the earliest Hauterivian (U. A. zone 18 of Baumgartner *et al*., 1995a; as *Wrangellium depressum*). Although our specimen is ill-preserved and identified with cf. (Figure 3.2), it can restrict the upper limit of the samples.

Above mentioned four species assign the age range of the fauna to the Hauterivian to Barremian without doubt, and possibly to early Hauterivian. Such *Archaeodictyomitra* species as *A. vulgaris*, *A. apiarium* and *A. mitra* occur commonly in the Lower Cretaceous strata. The last occurrence horizon of *Stylosphaera squinaboli* lies in the lower Aptian (Schaaf, 1981 as *Sphaerostylus lanceola*), and that of *Archaeodictyomitra apiarium* in the upper Barremian/lower Aptian (Baumgartner *et al*., 1995a).

The here described radiolarian fauna indicates an Early Cretaceous age (Hauterivian or Barremian) undoubtedly, and it restricts to Hauterivian possibly. This age is older than that of the foraminifer assemblage reported from the intercalations of the That-tu bedded chert (assumed as Albian to Cenomanian).

Systematic palaeontology

Subclass Radiolaria Müller, 1858

Order Polycistida Ehrenberg, 1838, emend. Riedel, 1967

Suborder Nassellaria Ehrenberg, 1875

Remarks.—Family classification of the suborder Nassellaria is to be based on the cephalic skeletal elements, because they make the fundamental structure of the nassellarians (Takemura, 1986).

Family Theoperidae Haeckel, 1881, emend. Takemura, 1986

Remarks.—The cephalic skeletal elements of the family Theoperidae are composed of a median bar, an apical spine, a vertical spine, a dorsal spine, two lateral spines and two secondary lateral spines. Distinct arches do not exist except collar ring.

Genus ***Archaeodictyomitra*** Pessagno, 1976

Type species.—*Archaeodictyomitra squinaboli* Pessagno, 1976.

Archaeodictyomitra mitra Dumitrica, 1997

Figures 3.4, 3.9

Archaeodictyomitra mitra Dumitrica in Dumitrica *et al.*, 1997, p. 40, pl. 7, figs. 8, 13–15, 19–23; Suzuki *et al.*, 2001, fig. 6.7; Suzuki and Gawlick, 2003, p. 179, fig. 6.19.

Remarks.—This species possesses a short conical test with seven to eight longitudinal plicae on a side view. Distal part of test is sometimes constricted (Figure 3.4).

Archaeodictyomitra apiarium (Rüst, 1885)

Figure 3.5

Lithocampe apiarium Rüst, 1885, p. 314, pl. 39, fig. 8.

Archaeodictyomitra apiara (Rüst, 1885). Pessagno, 1977b, p. 41, pl. 6, figs. 6, 14.

Archaeodictyomitra apiarium (Rüst, 1885). Kocher, 1981, p. 56, pl. 12, fig. 13; Goričan, 1994, p. 61, pl. 20, figs. 5, 6, 12, 17, 18; Baumgartner *et al*., 1995b, p. 98, pl. 3263, figs. 1–7; Dumitrica *et al*., 1997, p. 38, pl. 7, fig. 7; Krische *et al*., 2013, pl. 2, fig. 4.

Remarks.—Our specimen has a shorter test than typical examples of this species. Cylindrical postabdominal portion allows to identify *Archaeodictyomitra apiarium*.

Archaeodictyomitra aff. ***apiarium*** (Rüst, 1885)

Figure 3.3

Remarks.—Depicted specimen has a weak constriction at the middle of the test. This feature is one of the characters of *Archaeodictyomitra apiarium*. However, the specimen has a conical test rather than cylindrical, so that it can be differentiated from typical *A. apiarium*.

Archaeodictyomitra vulgaris Pessagno, 1977

Figure 3.6

Archaeodictyomitra vulgaris Pessagno, 1977b, p. 44, pl. 6, fig. 15.

Remarks.—Number of longitudinal plicae is six on a side view of our specimen, which is smaller than that of *Archaeodictyomitra apiarium*.

Genus ***Dictyomitra*** Zittel, 1876

Type species.—*Dictyomitra multicostata* Zittel, 1876 (subsequently designated by Campbell, 1954).

Dictyomitra sp.

Figure 3.11

Remarks.—The figured specimen shows close affinity with *Dictyomitra pseudoscalaris* Tan Sin Hok, 1927, *Dictyomitra formosa* Squinabol, 1904 or *Archaeodictyomitra coniforma* Dumitrica, 1997. Because of its bad preservation it cannot be identified with specific name.

Genus ***Thanarla*** Pessagno, 1977

Type species.—*Phormocyrtis veneta* Squinabol, 1903.

Thanarla brouweri (Tan Sin Hok, 1927)

Figure 3.13

Eucyrtidium Brouweri Tan Sin Hok, 1927, p. 57, pl. 11, figs. 89–91, 93.

Thanarla brouweri (Tan Sin Hok, 1927). Nakaseko and Nishimura, 1981, p. 162, pl. 6, fig. 14, pl. 7, figs. 1, 2, pl. 15, fig. 13; O'Dogherty, 1994, p. 86, pl. 5, figs. 1–12; Suzuki *et al*., 2002, p. 57, fig. 4.6.

Remarks.—Our specimen has a wide conical test with longitudinal plicae that can be counted eight on a side view. A line of pores is arranged between plicae.

Genus ***Svinitzium*** Dumitrica, 1997

Type species.—*Pseudodictyomitra depressa* Baumgartner, 1984.

Svinitzium cf. ***depressum*** (Baumgartner, 1984)

Figure 3.2

cf. *Pseudodictyomitra depressa* Baumgartner, 1984, p. 782, pl. 8, figs. 2, 7, 8, 11.

cf. *Svinitzium depressum* (Baumgartner, 1984). Dumitrica *et al*., 1997, p. 53, pl. 11, figs. 11, 17.

Remarks.—Although the depicted specimen is poorly preserved, whole test morphology, conspicuous circumferential ridges with nodes and pore arrangement make the comparison with *Svinitzium depressum* possible.

Family Arcanicapsidae Takemura, 1986

Remarks.—The cephalic skeletal elements of the family Arcanicapsidae are a median bar (MB), an apical spine (A), a vertical spine (V), a dorsal spine (D) and two lateral spines (L). Two secondary lateral spines (l) are not seen as separated spicules, but they seem to be buried in a part of a collar ring, which is composed of two secondary lateral spines (l) and arches connecting vertical-lateral (VL) and lateral-secondary lateral spines (Ll). It looks a cross shape surrounded by a circle from basal view (Takemura, 1986).

Genus ***Hiscocapsa*** O'Dogherty, 1994

Type species.—*Cyrtocapsa grutterinki* Tan Sin Hok, 1927.

Remarks.—O'Dogherty (1994) defined the genus as follows: “Nassellaria possessing three or four chambers, and having a large, globose, open terminal chamber without tube or spine.” This definition is applicable to the four-chambered nassellarians having a globose fourth chamber with a wide opened base. If a specimen has a closed fourth chamber, it has to be assigned to *Tetracapsa* Haeckel, 1881 or *Crococapsa* O'Dogherty *et al*., 2017.

Hiscocapsa cf. ***subcrassitestata*** (Aita, 1986)

Figure 3.1

cf. *Sethocapsa subcrassitestata* Aita in Aita and Okada, 1986, p. 118, pl. 4, figs. 14–16, pl. 7, fig. 6a–c.

Remarks.—Our specimen is composed of four segments, and a row of large pores is arranged between abdomen and fourth segments. These features indicate a close relationship with *Sethocapsa subcrassitestata* Aita, 1986. According to the description by Aita in Aita and Okada (1986), *S. subcrassitestata* has no aperture at its base, although he showed no pictures of closed base. A specimen of Aita (pl. 4, fig. 15 in Aita and Okada, 1986), however, shows flattened base that could be a sign of possessing a basal aperture. Although our specimen is partly broken, its base seems to be opened widely. Thus, the specimen is set in the genus *Hiscocapsa*.

Family Williriedellidae Dumitrica, 1970

Remarks.—The cephalic skeletal structure of the family Williriedellidae resembles that of the family Arcanicapsidae, i.e. a cross is set in the collar ring. Williriedellidae differ from Arcanicapsidae by the depressed cephalo-thorax into the abdomen.

Genus ***Hemicryptocapsa*** Tan Sin Hok, 1927

Type species.—*Hemicryptocapsa capita* Tan Sin Hok, 1927 (subsequently designated by Campbell, 1954).
Remarks.—*Hemicryptocapsa* has a three-chambered test with a large ball-formed abdomen. It differs from *Cryptamphorella* by having a constricted anti-apical aperture.

Hemicryptocapsa capita Tan Sin Hok, 1927
Figure 3.12
Hemicryptocapsa capita Tan Sin Hok, 1927, p. 50, pl. 9, fig. 69; Taketani, 2013, pl. 5, figs. 8, 9.
Remarks.—Our specimen has a cap-shaped appendage with larger pores. This character is conspicuous of this species.

Hemicryptocapsa cf. ***pseudopilula*** Tan Sin Hok, 1927
Figure 3.10
cf. *Hemicryptocapsa pseudopilula* Tan Sin Hok, 1927, p. 51, pl. 9, fig. 67; Schaaf, 1981, p. 434, pl. 2, fig. 5a, b.
Remarks.—Our specimen has a lager cone-shaped cephalo-thorax than that of SEM image by Schaaf (1981: pl. 2, fig. 5a).

Genus ***Cryptamphorella*** Dumitrica, 1970

Type species.—*Hemicryptocapsa conara* Foreman, 1968.
Remarks.—*Cryptamphorella* has a three-chambered test with a large globose abdomen. It differs from *Hemicryptocapsa* by lacking an anti-apical aperture.

Cryptamphorella challengeri Schaaf, 1981

Figures 3.16

Cryptamphorella challengeri Schaaf, 1981, p. 433, pl. 9, figs. 6a, b.

Remarks.—Morphology of our specimen is almost concordant with the description of Schaaf (1981). Depicted specimen shows distinct collar- and lumbar-strictures. Figure 3.16b shows no aperture on the base of abdomen.

Genus ***Holocryptocapsa*** Tan Sin Hok, 1927

Type species.—*Holocryptocapsa fallax* Tan Sin Hok, 1927 (subsequently designated by Campbell, 1954).

Holocryptocapsa hindei Tan Sin Hok, 1927

Figures 3.14, 3.15

Holocryptocapsa hindei Tan Sin Hok, 1927, p. 52, pl. 10, fig. 75; Schaaf, 1981, p. 435, pl. 9, fig. 4a, b, 14; O'Dogherty, 1994, p. 212, pl. 35, figs. 9–17.

Remarks.—Tan Sin Hok (1927) mentioned characteristic feature of this species as follows: "Schaal onregelmatig bolvormig met afgeplatte basis (Test irregular ball-form with flattened base)." Specimens figured here show such flattened abdominal base with a centred small aperture. *Holocryptocapsa hindei* differs from *Holocryptocapsa fallax* Tan Sin Hok, 1927 (non *Holocryptocapsa fallax* in sense of O'Dogherty, 1994 [= *Stylocryptocapsa fallax* Tan Sin Hok, 1927) in the presence of flattened base of abdomen. On the other hand, *Holocryptocapsa fallax* possesses more spherical test without flattened base.

Suborder Spumellaria Ehrenberg, 1875

Family Actinommidae Haeckel, 1862

Remarks.—Here we use the family Actinommidae in a broad sense, which is a part of the superfamily Actinommacea Haeckel, 1862 emend. Kozur and Moslter (1979).

Genus ***Stylosphaera*** Ehrenberg, 1847

Stylosphaera Ehrenberg, 1847, p. 54; Haeckel, 1887, p. 133; Frizzell and Middour, 1951, p. 14; Kozur and Mostler, 1979, p. 16.

Sphaerostylus Haeckel, 1881, p. 451; Foreman, 1973, p. 258; Sanfilippo and Riedel, 1985, p. 588; Suzuki and Gawlick, 2003, p. 165. [junior homonym of the insect genus *Sphaerostylus* Chaudoir, 1848 of Carabidae.]

Pantanellium Pessagno, 1977a, p. 78.

Type species.—*Stylosphaera hispida* Ehrenberg, 1854 (Subsequently designated by Frizzell and Middour, 1951).

Remarks.—Ehrenberg (1847) established the genus *Stylosphaera* as follows: "Tests nucleate and subglobose, the young included by the adults (involute). Nuclei radiate. Two opposite spiny radii from center" (originally written in Latin; its translation in Foreman and Riedel, 1972). This definition dose not involved the length of two spines. Subsequently, Haeckel (1881) established the new genus *Sphaerostylus* that has two spines unequal long. At this time *Stylosphaera* was practically emended as having two spines almost same long. After the Haeckelian taxonomy was established, Mesozoic forms having two latticed spheres with two polar spines were attributed to *Stylosphaera* or *Sphaerostylus* for a long time. In 1977 a new genus *Pantanellium* was introduced by Pessagno for these forms. His argument to establish new genus is as follows: "Unfortunately, the single illustration and the description of the type species of *Sphaerostylus* (i. e. *Sphaerostylus zitteli* Rüst) are exceedingly poor and of virtually no use to any worker hoping to make a definitive identification. …… therefore, that the name *Sphaerostylus* be considered a nomen dubium." Pessagno's assertion of the establishment *Pantanellium* lacks its grounds, because the genus established before 1931 did not have to designate its type species (ICZN Article 67.4.1: Ride *et al*. eds., 2000). Thus the genus *Sphaerostylus* should not be *nomen dubium*, and *Pantanellium* is a younger synonym of the genus *Sphaerostylus* Haeckel, 1881 (Suzuki and Gawlick, 2003). However, the genus name *Sphaerostylus* has been already occupied by a genus name of the family Carabidae (insect). If protists that do not use photosynthesis should be under the rules of ICZN (International Code of Zoological Nomenclature), *Sphaerostylus* is a junior homonym of *Sphaerostylus* Chaudoir, 1848. As reasons mentioned above, the genus *Stylosphaera* Ehrenberg, 1847 has priority and is here used excluding the criterion of spine length.

Stylosphaera squinaboli Tan Sin Hok, 1927

Figure 3.8

Stylosphaera squinaboli Tan Sin Hok, 1927, p. 35, pl. 6, fig. 9a–d.

Sphaerostylus lanceola (Parona, 1890). Tumanda, 1989, p. 35, pl. 1, fig. 1.

Pantanellium squinaboli (Tan Sin Hok, 1927). Nakaseko and Nishimura, 1981, p. 156, pl. 1, figs. 1, 10; Baumgartner *et al.*, 1995b, p. 372, pl. 5607, figs. 1–7.

Pantanellium squinaboli squinaboli (Tan Sin Hok, 1927). Baumgartner, 1992, p. 322, pl. 8, figs. 2–3.

Pantanellium corriganensis Pessagno, 1977, p. 33, pl. 1, figs. 5, 6; Steiger, 1992, p. 26, pl. 1, figs. 5, 6.

Remarks.—Our specimen exhibits ten pores of latticed sphere in a side view. The number of pores is clearly reduced in comparison with that of Jurassic form, e.g. *Stylosphaera lanceola* Parona, 1890 (fifteen to nineteen pores in a side view; Suzuki and Gawlick, 2003; Suzuki and Kuwahara, 2005).

Family Saturnalidae Deflandre, 1953

Genus ***Acanthocircus*** Squinabol, 1903, emend. Donofrio and Mostler, 1978

Type species.—*Acanthocircus irregularis* Squinabol, 1903 (Subsequently designated by Campbell, 1954).

Acanthocircus dicranacanthos (Squinabol, 1914)

Figure 3.7

Saturnalis dicranacanthos Squinabol, 1914, p. 289, pl. 22, fig. 4–7, pl. 23, fig. 8, p. 290, fig. 1.

Acanthocircus dicranacanthos (Squinabol, 1914). Foreman, 1975, p. 610, pl. 2D, figs. 5, 6; Pessagno, 1977a, p. 73, pl. 3, fig. 5.

Remarks.—Our specimen shows a part of the ring, having a bifurcated spine with a triangular lateral node.

Plate tectonic implication

Above mentioned radiolarian fauna indicates clearly an Early Cretaceous age. This means that the That-tu bedded chert of the Ngapyawdaw Chaung Formation was originally deposited on the Tethys ocean in sensu lato. According to the plate tectonic evolution of Myanmar demonstrated by Mitchell (1989), a middle Early Cretaceous ocean (ocean III) existed between the Lhasa Block and Mount Victoria Land. The ocean III was finally subducted under the Lhasa Block from south to north. The That-tu bedded chert was deposited on the ocean III with ophiolitic rocks, which was originally located south of the Lhasa Block. Mitchell (1989) inferred that the extension of the Lhasa Block in Tibet stretches underneath the Shan-Thai Block of Myanmar, and a part of ophiolite with Early Cretaceous chert are now exposed between the Shan-Tennasserim massif and Inner-Burman Tertiary Basin. One of the present authors, La Ja, has already confirmed the occurrence of mid-Cretaceous foraminifers from the intercalations of the That-tu bedded chert. Here described radiolarian fauna of Hauterivian age widens the age of the That-tu bedded chert that proves the existence of the ocean III of Mitchell (1989) from Hauterivian to Albian–Cenomanian time.

Conclusions

1. An Early Cretaceous radiolarian fauna is found from the That-tu bedded chert of the Tagaung Taung area, central Myanmar.
2. The geologic age of the fauna is estimated by the occurrence of *Holocryptocapsa hindei* (Hauterivian to middle Aptian), *Svinitzium depressum* (Tithonian to earliest Hauterivian), *Hemicryptocapsa capita* (Berriasian to Barremian) and *Acanthocircus dicranacanthos* (Jurassic to Barremian), indicating an age of early Hauterivian (Early Cretaceous).
3. This is the first report on the Early Cretaceous radiolarians from Myanmar as well as the first radiolarian age determination of chert within the basement rocks in Myanmar.
4. The That-tu bedded chert was deposited on the ocean III of Mitchell (1989) in Early Cretaceous time, which existed between the Lhasa Block and Mount Victoria Land.

Acknowledgement

The authors are thankful to Masanaru Takai (Primate Research Institute of Kyoto University) and Zin Maung Maung Thein (Magway University) for their suggestions for the palaeontological research in Myanmar. They also thank Terufumi Ohno (Kyoto University Museum) for his kind offer of using a scanning electron microscope of Kyoto University Museum. The authors express special thanks to Luis O'Dogherty for his discussion of radiolarian dating during the INTERRAD XV conference in Niigata, Japan, and to Špela Goričan and Yojiro Taketani for their fruitful comments during the review of this manuscript. The authors thank Felix Schlagintweit for his comments on Cretaceous foraminifers from the That-tu bedded chert. A part of this study has been already presented in the 2006 annual meeting of the Palaeontological Society of Japan in Matsue, the 15th Meeting of the International Association of Radiolarists in 2017 in Niigata, and the Inaugural Conference on Applied Earth Sciences in Myanmar and Neighboring Regions (MAESA 2017) in Yangon. The authors are also grateful for many discussions during these conferences. The part of this study is financially supported by the research funds of Otani University and Grant-in-Aid for Scientific Research on Innovative Areas from JSPS (Japan Society for the Promotion of Science) (KAKENHI Grant Number JP26106005).

References

Aita, Y. and Okada, H., 1986: Radiolarians and calcareous nannofossils from the uppermost Jurassic and Lower Cretaceous strata of Japan and Tethyan regions. *Micropaleontology*, vol. 32, p. 97–128.

Baumgartner, P. O., 1984: A Middle Jurassic-Early Cretaceous low-latitude radiolarian zonation based on Unitary Associations and age of Tethyan radiolarites. *Eclogae geologicae Helvetiae*, vol. 77, p. 729–837.

Baumgartner, P. O., 1992: Lower Cretaceous radiolarian biostratigraphy and biogeography off Northwestern Australia (ODP Sites 765 and 766 and DSDP Site 261), Argo Abyssal Plain and Lower Exmouth Plateau. *Proceedings of the Ocean Drilling Program*, *Scientific Results*, vol. 123, p. 299–342.

Baumgartner, P. O., Bartolini, A., Carter, E. S., Conti, M., Cortese, G., Danelian, T., De Wever, P., Dumitrica, P., Dumitrica-Jud, R., Goričan, Š., Guex, J., Hull, D. M., Kito, N., Marcucci, M., Matsuoka, A., Murchey, B., O'Dogherty, L., Savary, J., Vishnevskaya, V., Widz, D. and Yao, A., 1995a: Middle Jurassic to Early Cretaceous radiolarian biochronology of Tethys based on Unitary Associations. *Mémoires de Géologie* (*Lausanne*), no. 23, p. 1013–1048.

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

Bender, F., 1983: *Geology of Burma*. 293 p., Gebrüder Borntraeger, Berlin–Stuttgart.

Campbell, A. S., 1954: Radiolaria. *In*, Moore, R. C. *ed*., *Treatise on Invertebrate Paleontology Part D*, p. 11–163. Geological Society of America and University of Kansas Press, Lawrence.

Chaudoir, M. de., 1848: Mémoire sur la famille des carabiques. Première partie. *Bulletin de la Société Impériale des Naturalistes de Moscou*, vol. 21, p. 3–134.

Deflandre, G., 1953: Radiolaires fossiles. *In*, Grassé, P. P. *ed*., *Traite de Zoologie t. 1 fasc. 2*, p. 389–436. Masson, Paris.

Donofrio, D. A. and Mostler, H., 1978: Zur Verbreitung der Saturnalidae (Radiolaria) im Mesozoikum der nördlichen Kalkalpen und Südalpen. *Geologisch-Paläontologische Mitteilungen Innsbruck*, vol. 7, p. 1–55.

Dumitrica, P., 1970: Cryptocephalic and cryptothoracic Nassellaria in some Mesozoic deposits of Romania. *Revue Roumaine de Géologie*, *Géophysique et Géographie*, *Série de Géologie*, vol. 14, p. 45–124.

Dumitrica, P., Immenhauser, A. and Dumitrica-Jud, R., 1997: Mesozoic radiolarian biostratigraphy from Masirah ophiolite, Sultanate of Oman. Part I: Middle Triassic, uppermost Jurassic and Lower Cretaceous Spumellarians and Multisegmented Nassellarians. *Bulletin of the National Museum of National Science*, vol. 9, p. 1–106.

Ehrenberg, C. G., 1838: Über die Bildung der Kreidefelsen und des Kreidemergels durch unsichtbare Organismen. *Abhandlungen der königlichen Akademie der Wissenschaften in Berlin*, Bd. 1838, p. 59–147, pls. 1–4, 1 table.

Ehrenberg, C. G., 1847: Über eine halibiolitische, von Herrn R. Schomburgk entdeckte, vorherrschend aus mikroskopischen Polycystinen gebildete, Gebirgsmasse von Barbados. *Bericht der königlichen preussischen Akademie der Wissenschaften zu Berlin*, Jahre 1846, p. 382–385.

Ehrenberg, C. G., 1854: *Mikrogeologie*, 374 p., 41 pls. Voss, Leipzig.

Ehrenberg, C. G., 1875: Fortsetzung der mikrogeologischen Studien als Gesammt-Uebersicht der mikroskopischen Paläontologie gleichartig analysirter Gebirgsarten der Erde, mit specieller Rücksicht auf den Polycystinen-Mergel von Barbados. *Physikalische Abhandlungen der königlichen Akademie der Wissenschaften zu Berlin*, Bd. 1875, p. 1–225, pls. 221–230, Tabellen-Anhänge.

Foreman, H. P., 1968: Upper Maestrichtian Radiolaria of California. *Special Papers in Palaeontology*, vol. 3, p. 1–82.

Foreman, H. P., 1973: Radiolaria from DSDP Leg 20. *Initial Reports of the Deep Sea Drilling Project*, vol. 20, p. 249–305.

Foreman, H. P., 1975: Radiolaria from the North Pacific, Deep Sea Drilling Project, Leg 32. *Initial Report of the Deep Sea Drilling Project*, vol. 32, p. 579–676.

Foreman, H. P. and Riedel, W. R., 1972: *Catalogue of polycystine radiolaria*, vol. 1, part 2. American Museum of Natural History, New York.

Frizzell, D. L. and Middour, E. S., 1951: Paleocene radiolaria from southeastern Missouri. *University of Missouri*, *School of Mines and Metallurgy*, *Bulletin*, *Technical Series*, no. 77, 1–41.

Goričan, Š., 1994: Jurassic and Cretaceous radiolarian biostratigraphy and sedimentary evolution of the Budava Zone (Dinarides, Montenegro). *Mémoires de Géologie* (*Lausanne*), no. 18, p. 1–177.

Haeckel, E., 1862: *Die Radiolarien* (*Rhizopoda Radiaria*), 572 p., 35 pls. Georg Reimer, Berlin.

Haeckel, E., 1881: Entwurf eines Radiolarien-Systems auf Grund von Studien der Challenger-Radiolarien. *Jenaische Zeitschrift für Naturwissenschaft*, Bd. 15, p. 418–472.

Haeckel, E., 1887: Report on the radiolaria collected by H. M. S. Challenger during the years 1873–1876. *Report of the scientific results of the voyage of H.M.S. Challenger during the years 1873–76*, *Zoology*, vol. 18, CLXXXVIII+1803 p., 140 pls., Her Majesty's Government, London.

Henson, F. R. S., 1948: *Larger imperforate foraminifera of south-western Asia* (*Families Lituolidae, Orbitolinidae and Meandropsinidae*). British Museum (Natural History), London.

Kocher, R. N., 1981: Biochronostratigraphische Untersuchungen oberjurassischer Radiolarienführender Gesteine, insbesondere der Südalpen. *Mitteilungen aus dem* *geologischen Institut der Eidgenossische Technischen Hochschule und der Universität Zürich*, *Neue Folge*, Bd. 234, p. 1–184.

Kozur, H. and Mostler, H., 1979: Beiträge zur Erforschung der mesozoischen Radiolarien. Teil III: Die Oberfamilien Actinommacea HAECKEL 1862 emend., Artscacea HAECKEL 1882, Multiarcusellacea nov. der Spumellaria und triassische Nassellaria. *Geologisch-Paläontologische Mitteilungen Innsbruck*, Bd. 9, p. 1–132.

Krische, O., Suzuki, H. and Gawlick, H.-J., 2013: Mikrofazies und Radiolarienfauna der *Saccocoma*-Kalke in der westlichen Weitenau (Hochreith Einheit) [Nördlichen Kalkalpen, Salzburg]: Neue Daten zur Platznahme der Alpinen Haselgebirge Mélange. *Jahrbuch der Geologischen Bundesanstalt*, Bd. 153, p. 75–96.

Lamarck, J. B., 1816: *Histoire naturelle des animaux sans vertèbres*. *volume 2*. 568 p., Verdière, Paris.

Matsuoka, A., 1989: Radiolarian fossils from the Koyamada Formation (lowest Cretaceous) of the Somanakamura Group, northeast Japan. *Fossils* (*Palaeontological Society of Japan*), no. 46, 11–16. (*in Japanese with English abstract*)

Matsuoka, A., 1992: Jurassic and Early Cretaceous radiolarians from Leg 129, Sites 800 and 801, western Pacific Ocean. *Proceedings of the Ocean Drilling Program, Scientific Results*, vol. 129, p. 203–220.

Maung Maung, Aung Naing Thu and Suzuki, H., 2011: Latest Jurassic radiolarian fauna from the Chinghkran area, Myitkyina township, Kachin state, northern Myanmar. *Journal of the Myanmar Academy of Arts and Sciences*, vol. 9, p. 1–11.

Mitchel, A. H. G., 1989: The Shan plateau and western Burma: Mesozoic-Cenozoic plate boundaries and correlation with Tibet. *In*, Sengör, A. M. C. *ed*., *Tectonic Evolution of the Tethyan Region*., p. 567–583. Kluwer Academic Publishers, Dordrecht.

Müller, J., 1858: Über die Thalassicollen, Polycystinen und Acanthometren des Mittelmeeres. *Abhandlungen der königlichen Akademie der Wissenschaften in Berlin*, Bd. 1858, p. 1–62, pls. 61–11.

Nakaseko, K. and Nishimura, A., 1981: Upper Jurassic and Cretaceous radiolaria from the Shimanto Group in Southwest Japan. *Science Reports*, *College of General Education*, *Osaka University*, vol. 30, p. 133–203.

O'Dogherty, L., 1994: Biochronology and Paleontology of Mid-Cretaceous radiolarians from Northern Appennines (Italy) and Betic Cordillera. *Mémoires de Géologie* (*Lausanne*), no. 21, p. 1–413, pls. 1–74.

O'Dogherty, L., Goričan, Š. and Gawlick, H.-J., 2017: Middle and Late Jurassic radiolarians from the Neotethys suture in the Eastern Alps. *Journal of Paleontology*, vol. 91, p. 25–72.

Parona, C. F., 1890: Radiolarie nei noduli selciosi del calcare giurese di Cittiglio presso Laverno. *Bollettino della Società Geologica Italiana*, vol. 9, p. 132–175.

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

Pessagno, E. A. Jr., 1977a: Upper Jurassic radiolaria and radiolarian biostratigraphy of the California Coast Ranges. *Micropaleontology*, vol. 23, p. 56–113.

Pessagno, E. A. Jr., 1977b: Lower Cretaceous radiolarian biostratigraphy of the Great Valley Sequence and Franciscan complex, California Coast Ranges. *Cushman Foundation for Foraminiferal Research*, *Special Publication*, vol. 15, p. 1–87.

Ride, W. D. L., Cogger, H. G., Dupuis, C., Kraus, O., Minelli, A., Thompson, F. C. and Tubbs, P. K. *eds*., 2000: *International Code of Zoological Nomenclature*, *fourth edition*. XXIX+306 p., International Trust for Zoological Nomenclature, London.

Riedel, W. R., 1967: Protozoa Subclass Radiolaria. *In*, Harland, W. B. *et al. eds*., *The Fossil Record*., p. 291–298. Geological Society of London, London.

Robertson, A., Parlak, O., Ustaömer, T., Taslı, K., İnan, N., Dumitrica, P. and Karaoğlan, F., 2013: Subduction, ophiolite genesis and collision history of Tethys adjacent to the Eurasian continental margin: new evidence from the Eastern Pontides, Turkey. *Geodinamica Acta*, vol. 26, p. 230–293.

Rüst, D., 1885: Beiträge zur Kenntniss der fossilien Radiolarien aus Gesteinen des Jura. *Palaeontographica*, Bd. 31, p. 269–321, pls. 226–245.

Sanfilippo, A. and Riedel, W. R., 1985: Cretaceous radiolaria. *In*, Bolli, H. M., Saunders, J. B. and Perch-Nielsen, K. *eds*., *Plankton Stratigraphy*, vol. 2, p. 573–630. Cambridge University Press, Cambridge.

Schaaf, A., 1981: Late Early Cretaceous Radiolaria from Deep Sea Drilling Project Leg 62. *Initial Report of the Deep Sea Drilling Project*, vol. 62, p. 419–470.

Squinabol, S., 1903: Le Radiolarie dei Noduli selciosi nella Scaglia degli Euganei. *Rivista Italiana di Paleontologia*, vol. 9, p. 105–144, pls. 108–110.

Squinabol, S., 1904: Radiolarie cretacee degli Euganei. *Atti e Memorie della R. Accademia di Scienze Lettere ed Arti in Padova, Nuova. Serie*, vol. 20, p. 171–240, pls. 1–10.

Squinabol, S., 1914: Contributo alla conoscenza dei Radiolarii fossili del Veneto. *Memorie dell'Istituo Geologico della Reale Universita di Padova*, vol. 2, p. 249–306, pls. 220–224.

Steiger, T., 1992: Systematik, Stratigraphie und Palökologie der Radiolarien des Oberjura-Unterkreide-Grenzbereiches im Osterhorn-Trolikum (Nördliche Kalkalpen, Salzburg und Bayern). *Zitteliana*, Bd. 19, p. 3–132, pls. 1–27.

Suzuki, H. and Gawlick, H.-J., 2003: Biostratigraphie und Taxonomie der Radiolarien aus den Kieselsedimenten der Blaa Alm und nördlich des Loser (Nördliche Kalkalpen, Callovium-Oxfordium). *Mitteilungen der Gesellschaft der Geologie und Bergbaustudenten in Österreich*, Bd. 46, p. 137–228.

Suzuki, H. and Kuwahara, K., 2005: Systematische Beschreibung jurassischer Radiolarien und Schwammnadeln aus dem Gebiet Takagamine (Stadt Kyoto, Japan). *Nature and its Environment*, vol. 7, p. 37-–81. (*in Japanese with German and English abstracts*)

Suzuki, H., Maung Maung, Aye Ko Aung and Takai, M., 2004: Jurassic radiolaria from chert pebbles of the Eocene Pondaung Formation, central Myanmar. *Neues Jahrbuch für Geologie und Paläontologie, Abhandlungen*, Bd. 231, p. 369–393.

Suzuki, H., Wegerer, E. and Gawlick, H.-J., 2001: Zur Radiolarienstratigraphie im Unter-Callovium in den Nördlichen Kalkalpen - das Klauskogelbachprofil westlich von Hallstatt (Österreich). *Zentralblatt für Geologie und Paläontologie, Teil 1*, Bd. 2000, p. 167–184.

Suzuki, H., Yamaguchi, M. and Setoguchi, T., 2002: Cretaceous radiolaria from chert pebbles of the Miocene Honda Group of Huila, central Colombia. *Neues Jahrbuch für Geologie und Paläontologie, Monatshefte*, Bd. 2002, p. 48–64.

Takemura, A., 1986: Classification of Jurassic Nassellarians (Radiolaria). *Palaeontographica, Abteilung A*, Bd. 195, p. 29–74, pls. 21–12.

Taketani, Y., 2013: Lowermost Cretaceous radiolarian assemblage from the Koyamada Formation of the Somanakamura Group, Northeast Japan. *Bulletin of the Fukushima Museum*, no. 27, p. 1–24. (*in Japanese with English abstract*)

Tan Sin Hok, 1927: Over de samenstelling en het ontstaan van krijt- en mergel-gesteenten van de Molukken. *Jaarboek van het Mijnwezen in Nederlandsch Oost-Indië*, bd. 55, p. 5–165, pls. 161–116.

Tumanda, F. P., 1989: Cretaceous radiolarian biostratigraphy in the Esashi Mountain area, Northern Hokkaido, Japan. *Science Reports of the Institute of Geoscience, University of Tsukuba*, *Section B*, vol. 10, p. 1–44, pls. 1–10.

Zittel, K. A., 1876: Ueber einige fossile Radiolarien aus der norddeutschen Kreide. *Zeitschrift der deutschen geologischen Gesellschaft*, Bd. 28, p. 75–86, Taf. 72.

Captions of figures

Figure 1. Location map of the Tagaung Taung area, Myanmar.

Figure 2. Geologic map of the Tagaung Taung area.

Figure 3. Scanning electron micrographs of Early Cretaceous radiolarians from the That-tu bedded chert. 50 µm scale bar is applied to all pictures. **1,** *Hiscocapsa* cf. *subcrassitestata* (Aita, 1986); **2,** *Svinitzium* cf. *depressum* (Baumgartner, 1984); **3,** *Archaeodictyomitra* aff. *apiarium* (Rüst, 1885); **4,** *Archaeodictyomitra mitra* Dumitrica, 1997; **5,** *Archaeodictyomitra apiarium* (Rüst, 1885); **6,** *Archaeodictyomitra vulgaris* Pessagno, 1977; **7,** *Acanthocircus dicranacanthos* (Squinabol, 1914); **8,** *Stylosphaera squinaboli* Tan Sin Hok, 1927; **9,** *Archaeodictyomitra mitra* Dumitrica, 1997; **10,** *Hemicryptocapsa* cf. *pseudopilula* Tan Sin Hok, 1927; **11,** *Dictyomitra* sp.; **12,** *Hemicryptocapsa capita* Tan Sin Hok, 1927; **13,** *Thanarla brouweri* (Tan Sin Hok, 1927); **14,** *Holocryptocapsa hindei* Tan Sin Hok, 1927; **a,** side view; **b,** basal view; **15,** *Holocryptocapsa hindei* Tan Sin Hok, 1927; **a,** side view; **b,** oblique basal view; **16,** *Cryptamphorella challengeri* Schaaf, 1981; **a,** side view; **b,** oblique basal view.

Figure 4. Stratigraphic distribution of selected radiolarian species found from the Tagaung Taung area, Myanmar.

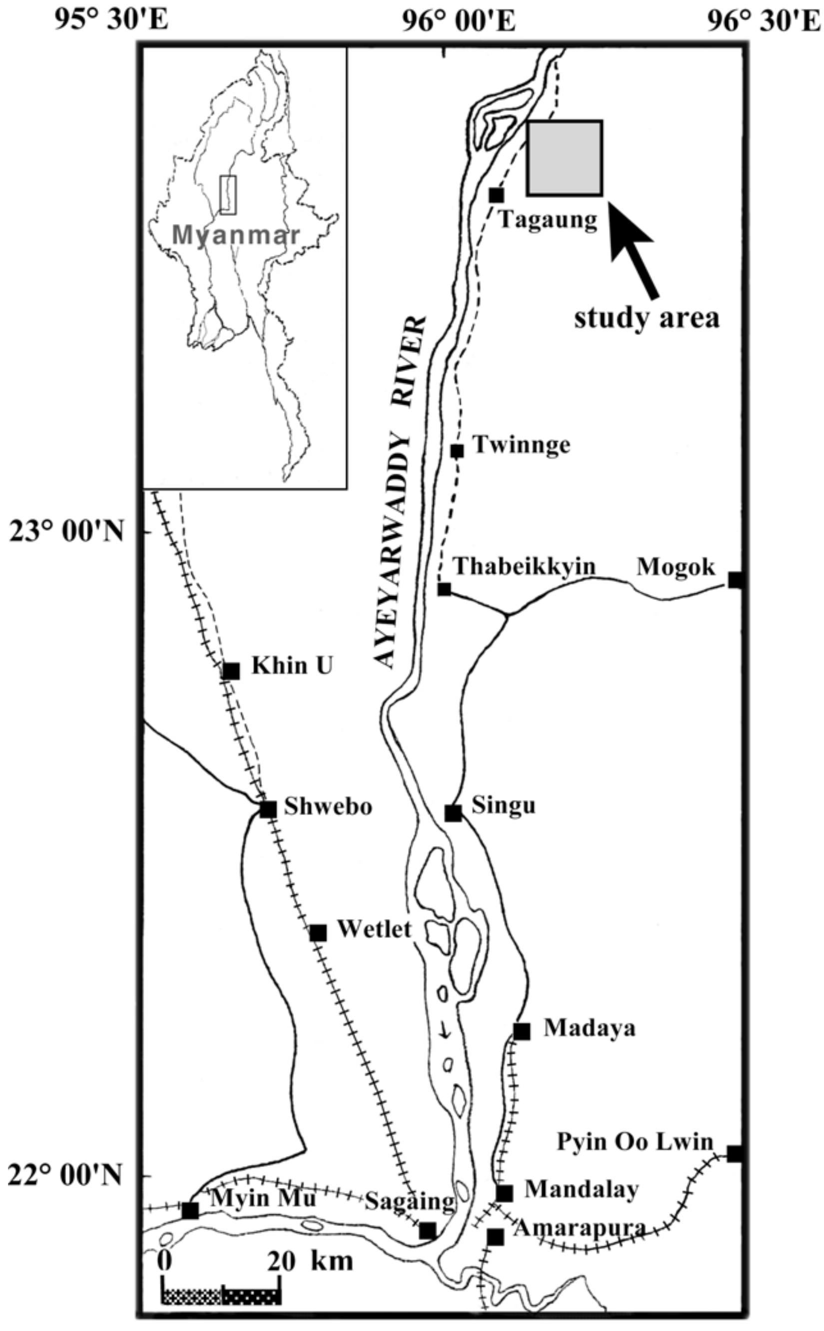


Figure 1 (Suzuki, La, Maung, Aung & Kuwahara)

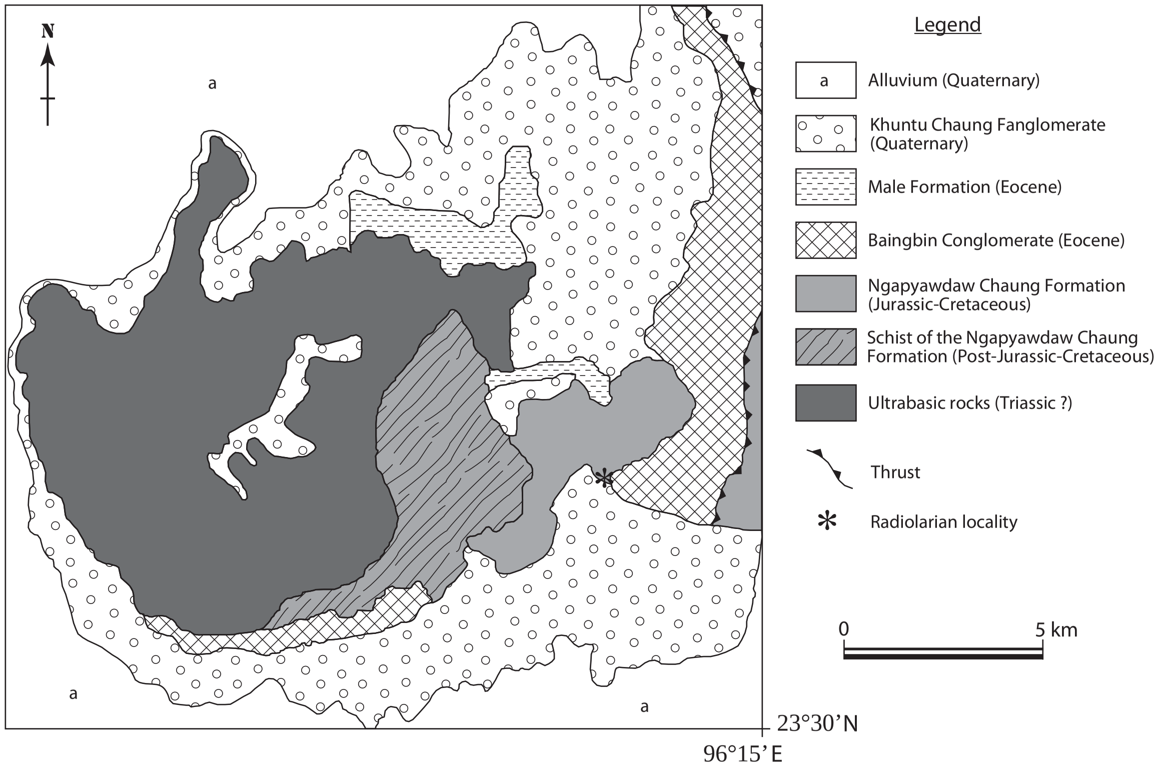
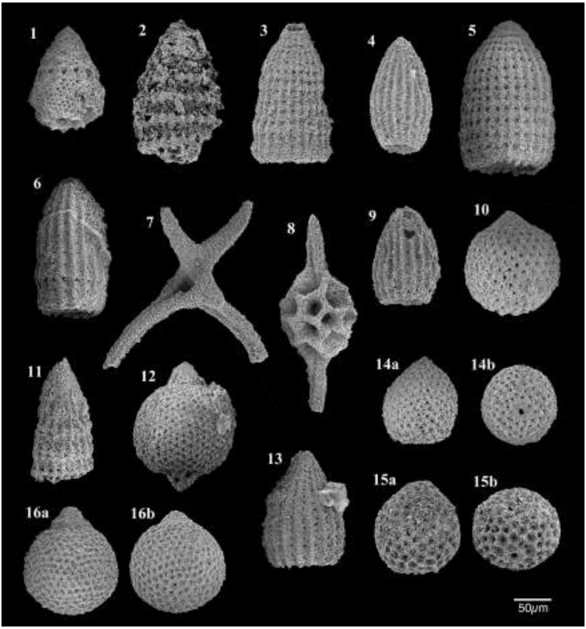


Figure 2 (Suzuki, La, Maung, Aung & Kuwahara)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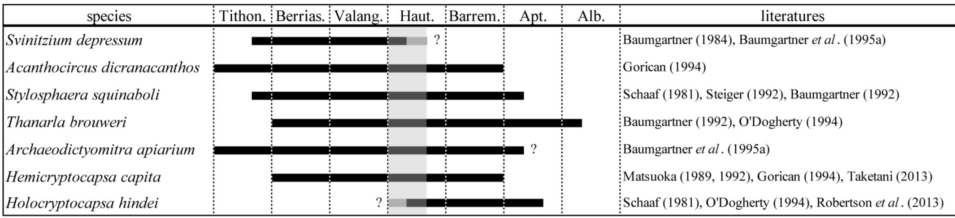

Suzuki et al. Figure 4