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Tethyan and non-Tethyan Early Cretaceous radiolarian faunas from West Timor, Indonesia: Paleogeographic and tectonic significance

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Abstract

Abundant and well-preserved Early Cretaceous radiolarians were recovered from calcilutites and shales of the Nakfunu Formation, Kolbano area, southern West Timor. The Cretaceous to Pliocene sedimentary rocks of the Kolbano area are an accretionary complex stacked at the leading edge of the Banda Islands arc. Radiolarian faunas of the Nakfunu Formation are characterized by the presence of unknown taxa elsewhere except its similarity with those of samples from the ODP Leg 123 Cores 765, regarded as non-Tethyan faunas. Four radiolarian assemblages have been discriminated, which indicate the range of Berriasian to early Aptian with a trend from non-Tethyan to Tethyan deposits in progressively younger strata. Stratigraphically, however, these strata are not in ascending order. The formation was imbricated, which was shown by frequent and random repetition of radiolarian assemblages in the strata. We believe that the faunas were derived from the southern paleolatitude origin generated by the influx of circumantarctic current. During the arc-continent collision commenced in the early Pliocene, the sequences were frontally accreted at the subduction zone. This findings may provide new insights to reveal the paleogeographic and tectonic significance of the island that has a long standing controversy, i.e. the original (pre deformational) location of the various stratigraphic units now present on Timor.

Keywords: Cretaceous, Non-Tethyan, Radiolaria, Tethyan, Timor Island

Introduction

The island of Timor (Fig. 1), situated in the southern Banda Arc in eastern Indonesia forms part of arc-continent collision zone between the northwestern Australian continental margin and the Banda Islands arc. The rock assemblages now present in Timor are composed of Permian to Quaternary deep- and shallow-marine sediments, metamorphic rocks and dismembered ophiolite. The close proximity of a great variety of rocks of widely different affinities and ages, makes the geology of the island rather complicated. For those, lithotectonic elements in Timor have frequently been described in terms of autochthonous, parautochthonous and allochthonous depending on their inferred origin with respect to the Australian continental margin (Audley-Charles, 1968, 1986; Carter et al., 1976; Barber et al., 1977). Parautochthonous unit formed Australian continental shelf deposits (Permian to Lower Pliocene); while allochthonous unit made up of ophiolitic, metamorphic and sedimentary rocks (Permian to Lower Pliocene) rest on the parautochthonous unit. Autochthonous unit (Miocene to Pliocene) is 'post deformational' sequences overlying deformed Miocene and older sequences. There are some confusions, however, of the usage of these terms even among these authors as to the original (pre-deformation) location of the various stratigraphic units on Timor (Charlton et al., 1991). Moreover, disagreement also has been rising on the style of deformation of the island. Three principal structural models have been proposed for Timor in extremely different way are regarded as:

1. Imbricate Model (e.g. Fitch and Hamilton, 1974; Hamilton, 1979). Timor is interpreted as an accumulation of chaotic material imbricated at the hanging wall of a subduction zone and essentially forms a large accretionary prism.
2. Overthrust Model (e.g., Carter et al., 1976; Barber et al., 1977; Barber, 1979; Audley-Charles,1986). Timor is regarded as a number of "Asian" allochthounous overthrusted on "Australian" parautocthonous.
3. Rebound Model (Chamalaum and Grady, 1978). This model suggests that the Australian continental margin entered a subduction zone in the vicinity of

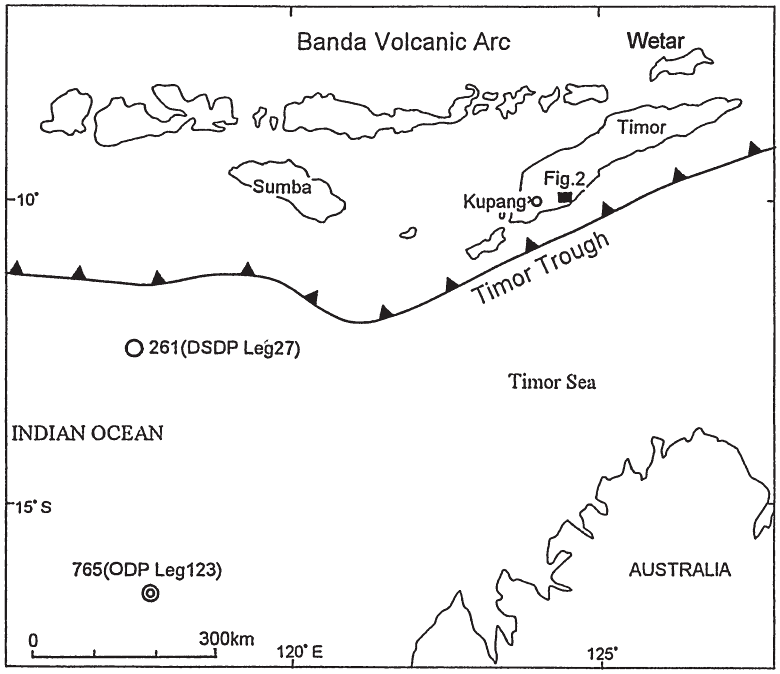

Figure 1. Map showing the tectonic setting around Timor Island and study area.

the Wetar Strait. Subsequently, the oceanic lithosphere detached from the continental part, resulting in the uplift of Timor by isostatic rebound controlled by step faults.

The Kolbano unit (Barber et al., 1977) is one of the key elements of tectonic evolution for Timor, from which we recovered abundant and well-preserved radiolarians. These data are used to reapply the paleogeographic and tectonic evolution of the island. The imbricated sequence of Cretaceous to Pliocene of the Kolbano unit is generally thought as an accretionary complex related to the subduction at the Timor Trough, but not chaotic mélange (e.g., Hamilton, 1979). Charlton (1989) mentioned that the Kolbano unit and the directly underlying sequences are not allochthonous as previously quoted by Barber et al. (1977). According to Charlton (1989), the Kolbano unit and the direct underlying sequences are thought essentially to be parautochthonous. They formed two distinct mega-sequences. The first is Permian to Jurassic shallow marine sediments (the "underplated" parautochthonous). The second is the overlying Kolbano unit which frontally accreted to the collision complex, or this is reffered to as the post-155 Ma rift mega-sequence (Audley-Charles, 2011). These Australian continental margin deposits entered to the Banda subduction zone commenced in the Early Pliocene (Carter et al., 1976; Audley-Charles, 1986; 2011).

The Nakfunu Formation

The Nakfunu Formation (Rosidi et al., 1979) which appears to be correlated with the Wai Bua Formation of Audley-Charles (1968) in East Timor (now Timor Leste), is a basal part of the Kolbano Unit. To the south, the formation is succeeded by Campanian-Lower Oligocene Borolalo/Ofu Formations and the lower Miocene-lower Pliocene Batuputih Formation (Charlton and Suharsono, 1990; Charlton and Wall, 1994). The Nakfunu Formation is well exposed in the headwater of the Noil Tuke River and also crops out along the road near Nunleo and near Tumu to Kolbano (Fig. 2).

The Nakfunu Formation consists of predominantly of moderate orange pink (10R 7/4) to pale reddish brown (10R 5/4) calcilutites and shales of deep marine deposits. The typical layer of centimeter to decimeter scale of the strata are occasionally intervening by massive (40-100cm) thick light brownish gray (5YR 6/1) shales. Although the bedding plane dips generally northwest, the attitudes of the strata are obscure. This is due to highly complicated folding and faulting, and the lack of identifiable sedimentary structure. These homoclinal sequences are frequently sliced by reverse faults. The formation is estimated to have the thickness of about 600 meter (Rosidi et al., 1979). Because of the intense structural disruption, Chalrton and Suharsono (1990) estimated that the lithostratigarphy of the Nakfunu Formation consists of six stratigraphic sequences. Sawyer et al. (1993) subdivided

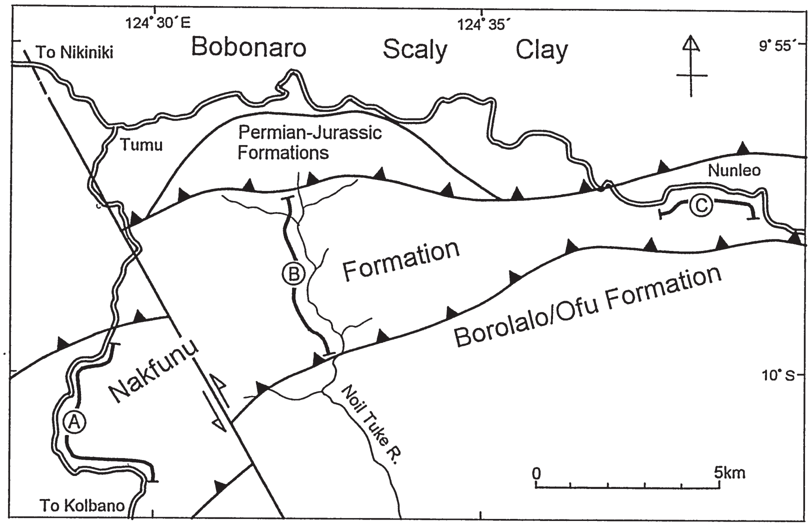

Figure 2. Simplified geologic map showing the study sections. Basic map is modified from Rosidi et al. (1979).

the formation into the Oinlasi and Tuke Members based on color character, and they assigned the formation within two age ranges; Berriasian to Aptian and Hauterivian to Aptian.

Radiolarian faunas

The occurrence of radiolarians in Timor was first reported by Hinde (1908). Since then, few accounts of radiolarian occurrence have been reported by Audley-Charles (1968), Rosidi et al. (1979), and Harsolumakso et al. (1995). The study emphasized on Triassic Radiolaria in Timor was made by Sashida et al. (1996, 1999). Martini et al. (2000) showed the occurrence of rich Late Triassic fossil faunas including radiolarians, palynomorphs, ammonites and conodonts from West Timor. In Timor Leste, Middle Jurassic Radiolaria from a siliceous argillite block in a structural mélange was presented by Haig and Bandini (2013).

In the present study, we recovered well-preserved radiolarian specimens from the Nakfunu Formation extracted by using standard hydrofluoric acid method (Pessagno and Newport, 1972). The Nakfunu Formation is reported to contain radiolarians of Albian age (Rosidi et al., 1979). Charlton and Wall (1994) complied those ages and extended it up to early Eocene by their planktonic foraminiferal zone. Harsolumakso et al. (1995) briefly reported Tithonian to Hauterivian radiolarians in their Unit F, the equivalent of the Nakfunu Formation. We reinterpret the age of the formation on the basis of more than 150 radiolarian species including age controlled species from radiolarian zonations elsewhere of previous authors (Foreman, 1973, 1975; Pessagno, 1977; Baumgartner, 1984; Sanfilippo and Riedel, 1985; Schaaf, 1981, 1984; Jud, 1994; and others).

Many taxa that have been reported from Rotti Island (Tan, 1927), located on the west of Timor Island are also found in the Nakfunu Formation. These radiolarians are similar with those of samples from Hole 765, the ODP Leg 123 Northwest Coast Australia regarded as non-Tethyan species (Baumgartner, 1992, 1993). According to Baumgartner (1993), the attributed "Tethyan" is used for taxa that are common in the Alpin-Mediterranean, Central Atlantic, Central Pacific, and Japanese samples and supposed to be as a low paleolatitude origin. Conversely, the attributed "non-Tethyan" is assigned to taxa which have never been documented from the low-paleolatitude belt.

We discriminate four radiolarian assemblages based on distinct faunal association found in each sample. Some of the non-Tethyan species tentatively are assigned under the genera *Parvicingula*, *Cyrtocapsa*, *Eusyringium*, and indeterminable taxa.

Assemblage 1 is represented by a non-Tethyan radiolarians (25 to 33 % of the total number of discriminated radiolarian specimens) with several certain Tethyan species (67 to 75 %). Non-Tethyan radiolarians are as follows; *Parvicingula* sp. C, *P.* sp. I, *Eucyringium*? sp. C., *Cyrtocapsa*? sp. E, *C.*? sp. D, *Lithocampe pseudochrysalis* Tan, Nassellaria gen. et sp. indet. B, Nassellaria gen. et sp. indet. C, Nassellaria gen. et sp. indet D, and others. The Tethyan taxa is characterized by the presence of *Acaeniotyle dentata* Baumgartner, *Hsuum feliformis* Jud, *Emiluvia chica decussata* Steiger, *Pantanellium squinaboli* (Tan), *Podocapsa amphitreptera* Foreman, *Podobursa triacantha* (Fischli), and others. This assemblage is assigned within the Berriasian to early Valanginian interval based on the Tethyan radiolarians.

Assembalge 2 is radiolarian association which is dominated by Tethyan species (95 %) with less non-Tethyan faunas (5 %). Non-Tethyan radiolarians are characterized by several unidentified species belonging to the genera *Cyrtocapsa*, *Eucyringium*, and others. The key species of Tethyan taxa includes *Archaeodictyomitra apiarium* (Rüst), *A. lacrimula* (Foreman), *Cecrops septemporatus* (Parona), *Eucyrtis columbaria* Renz, *Parvicingula boesii* (Parona), *P. usotanensis* Tumanda, *Pseudodictyomitra carpatica* (Lozyniak), *P. lilyae* (Tan), *Sethocapsa leiostraca* Foreman, *S. trachiostraca* Foreman, *S. uterculus* (Parona), *Wrangellium puga* (Schaaf) and *Xitus spicularius* (Aliev), and others indicating an interval of late Valanginian to early Barremian.

Assemblage 3 is radiolarian association occupied by whole Tethyan species. These radiolarians are identical with the Tethyan species of Assemblage 2. In other words, Assemblage 3 is radiolarian fauna in Assemblage 2 with lack of non-Tethyan species. Consequently, we assigned the late Valanginian to early Barremian age for this assemblage.

Assemblage 4 is the youngest one obtained from samples that contain whole Tethyan species such as *Dicroa periosa* Foreman, *Dictyomitra pseudoscalaris* (Tan), *Sethocapsa orca* Foreman, *S. simplex* Taketani, *Stichomitra asymbatos* Foreman, *S.*? *euganea* (Squinabol), and others. The age of those index taxa is within the early Aptian.

Radiolarian assemblages in each section

After all radiolarian-bearing samples from the Nakfunu Formation were examined, sampling points were marked on the map by the symbols 1, 2, 3, and 4 which refer to Assemblages 1, 2, 3, and 4, respectively (Fig. 3). The assemblages show random repetition in all sections. Followings are the account of radiolarian assemblages in each section.

Kolbano section (Fig. 3A)

Twenty-four of 64 samples from this section yielded Early Cretaceous radiolarians. The outcrops are spotted along the road from Tumu to Kolbano within 9 to 17 km. The Berriasian to early Valanginian Assemblage 1 was discriminated in samples KL:7, 8, 9, 10, 11, 15, 17, and 38. To the north, Assemblages 2, 3, and 4 are found in random repetition. Due to the soil cover, the relationship between strata of different radiolarian assemblages was not observed.

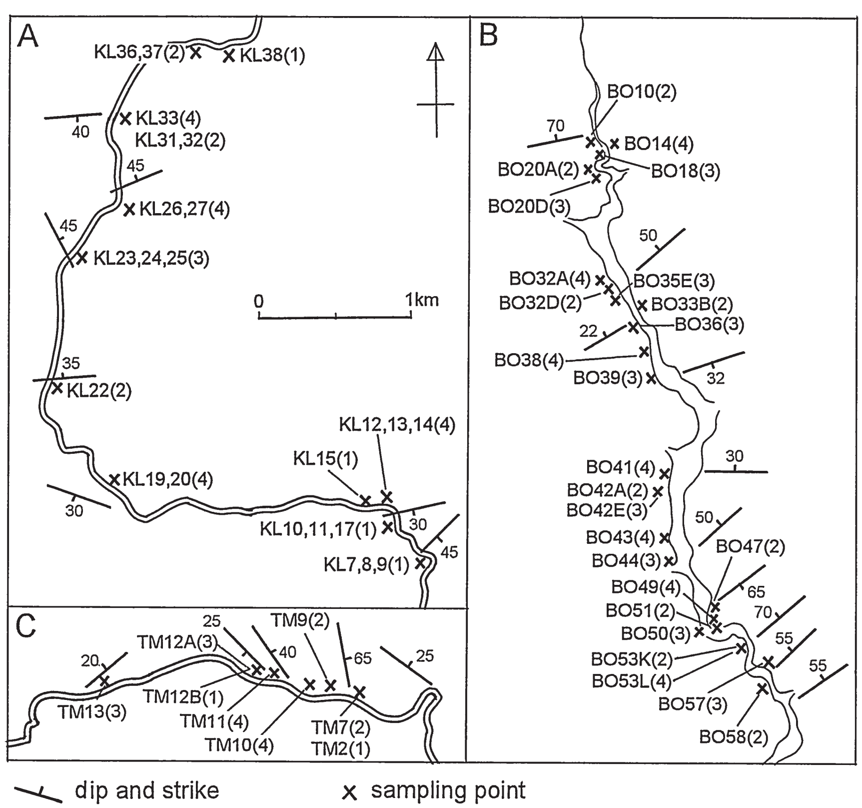

Figure 3. Rout map showing the sampling points along the Kolbano (A), Noil Tuke (B), and Nunleo Sections (C). Numbers in a parenthesis indicate the assemblage number.

Noil Tuke Section (Fig. 3B)

Among 150 samples collected along the Noil Tuke River, 23 samples yielded moderately to well-preserved radiolarians. Three radiolarian assemblages were discriminated from these samples, Assemblages 2, 3, and 4. Although the best exposures crop out along the Noil Tuke River, however, Assemblage 1 was not found along this section. At the sampling point BO-53, located at 124°32' 39" E and 9°54' 16" S, we observed the relationship between strata containing radiolarians of Assemblages 2 (sample BO-53K) and 4 (sample BO-53L) (Fig. 4). Northwest-dipping exposure of about 50 meter formed "inverse" strata. The strata including radiolarians of Assemblage 2 (late Valanginian-early Barremian) rest over the strata of Assemblage 4 (early Aptian) by a reverse fault.

Nunleo Section (Fig. 3C)

Radiolarian-bearing rocks are exposed near Nunleo Village along the road from Oinlasi to Tanjung Menu. Four radiolarian assemblages were discriminated from 7 of 27 samples collected. The strata bearing radiolarians of Assemblage 1 are found in two separate localities, samples TM2 and TM12B. The relationship between the strata bearing different radiolarian assemblages were not able to observe due to soil cover.

Discussion

The Nakfunu Formation is characterized by highly complicated folding and faulting and the lack of identifiable sedimentary structure, which preclude detailed stratigraphic investigation. We have attempted to settle the radiolarian biostratigraphy of the Nakfunu Formation to elucidate the structural development of Timor Island.

Biogeographically, radiolarian contents in the Nakfunu Formation are noteworthy. Several key species, for examples, *Mirifusus mediodilatatus* Rüst group, *Dibolachras tythopora* Foraman and *Crolanium pythiae* Schaaf, which are representatives of low latitude fauna of the interval of Tithonian to Valanginian, late Valanginian to Hauterivian, and Barremian, respectively, however, did not occur in the Nakfunu Formation. The taxa belonging to the genera *Obesacapsula* and *Mirifusus* are also absent in the study area. The absence of these radiolarians suggests that the Nakfunu Formation may have been deposited in the different oceanic current systems or in geographically different environmental basin with the formers.

Baumgartner (1992) presented Early Cretaceous radiolarian assemblages of the ODP Leg 123 off Northwestern Australia. The biogeography of those Neocomian radiolarians (Baumgartner, 1992), nanno fossils (Mutterlose, 1992) and benthic foraminifers (Holbourn and Kaminski, 1995) of the ODP Leg 123 consistently suggests as southern paleolatitude origin. As mentioned by Baumgartner (1992, 1993), the opening of a seaway between India and Australia-Antarctica during the Berriasian connected the circumantarctic area with the Argo Basin, which resulted in the influx of circumantarctic current and brought cold-water radiolarians. In this paper, we interpret the circumantarctic current continued to flow through the depositional location of the Nakfunu Formation. It is because the non-Tethyan fauna in Assemblage 1 of the Nakfunu Formation is correlative to those of Core ODP Leg 123-765-59R to -57R of Baumgartner (1992). During the Berriasian to early Valanginian interval, the sediments of the Nakfunu Formation situated at the nearly same paleolatitude position with those of site 765 and Site 766 to receive strong influx of non-Tethyan faunas. This position may be about 40°S in paleogeographic reconstruction (Ogg et al., 1992)

In the late Valanginian-early Barremian interval, the influx of circumantarctic current coincides with a rapid spreading of the Indo-Australian plate during the opening of Indian Ocean. The seafloor spreading in Argo Abyssal Plain (the incipient Indian Ocean) has already started since 155 Ma (Ludden, Gradstein, et al., 1990). The motion of the Indo-Australian plate conveyed the pre-defor-

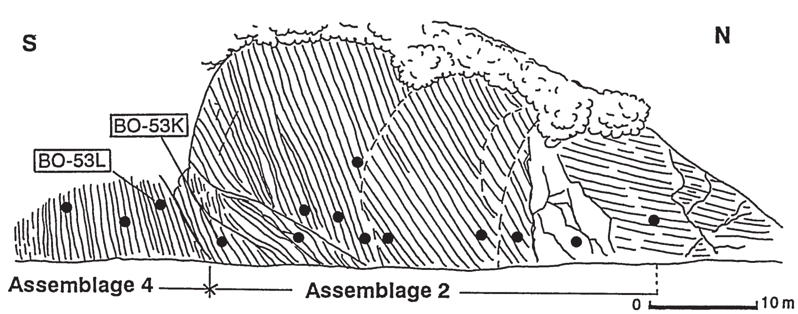

Figure 4. Outcrop sketch at the sampling point BO-53, showing the relationship of bedded shale containing radiolarians of Assemblage 2 (BO-53K) and Assemblage 4 (BO-53L). Other black dots are the location of supplementary samples.

mation of the Nakfunu Formation to the north direction. This made the latitude position of the Nakfunu Formation to be lower than Site 765. Hence, the influx of circumantarctic current with cold-water radiolarians could not fully succeed to reach the temperate area (lower paleolatitude), at which the warm water radiolarians had higher chance to fertilize, die and accumulate there. These accounts are confirmed by the diversity of Tethayn taxa which occur at localities of the ODP 123 and the Nakfunu Formation with refer to Jud (1994). Among 178 Tethyan taxa described by Jud (1994) from the Western Tethys, only 27 species could be identified at Site 765 (Baumgartner, 1993). These Tethyan species are less than those of the Nakfunu Formation, that we found at least 52 species. As a result, during the late Valanginian to early Barremian interval, two types of assemblages were occurred in the Nakfunu Formation, Assemblages 2 and 3. Assemblage 2 as dominant Tethyan taxa associated with non-Tethyan taxa and Assemblage 3 for wholly Tethyan taxa. Assemblage 2 corresponds to Cores ODP Leg 123-765-56R to -53R.

The last stage was of early Aptian or within the late Barremian to late Aptian interval, when the latitude position of those of the Nakfunu Formation is thought to be far lower and within the area with warm water oceanic system, the 'sterile' area for cold water radiolarians. Radiolarians of this age in the Nakfunu Formation are grouped into Assemblage 4.

The absence of non-Tethyan faunas at Site 261 of Renz (1974) was concluded by Baumgartner (1993) as having a more distance from the Argo Basin. The occurrence of non-Tethyan radiolarians in the Nakfunu Formation, Timor, which have more distant position from Site 261, suggests that distant position is not the primary, but rather by the geometry of the basin. Cold-water radiolarians carried by circumantarctic current (Baumgartner, 1993) into Argo Basin were upwelled along the margin up to the depositional location of the Nakfunu Formation.

Wensink et al. (1987) estimated the deposition of the Nakfunu Formation was at about 20°S. Based on their locality map (p. 92) of the Noil Tuke River, the sediments are unlikely of the sequence of the Nakufunu Formation. These samples is light gray silicified calcilutite and devoid of radiolarians. This exposures are about 30 meter

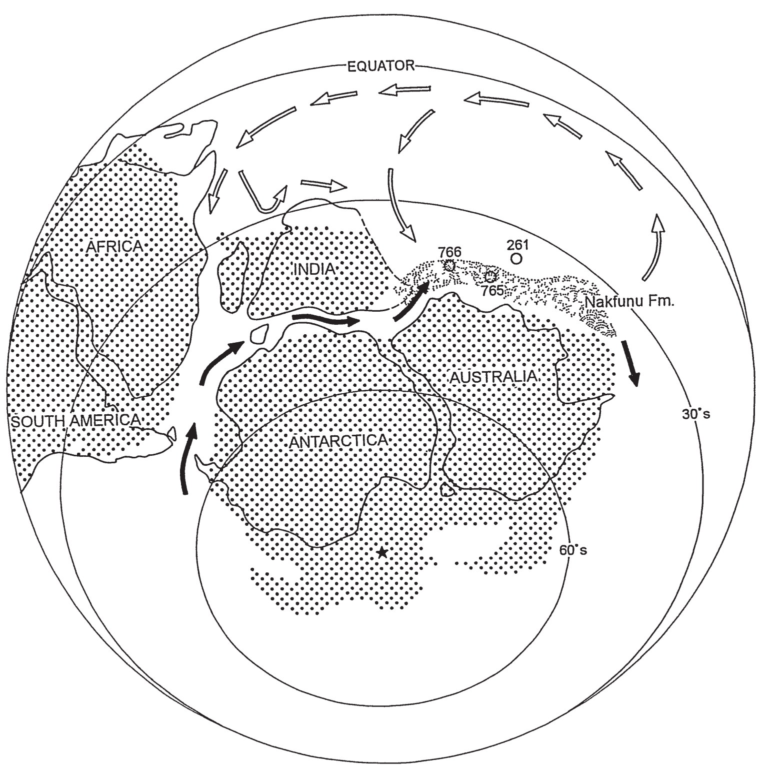

Figure 5. Paleogeographic map of southern hemisphere during the Early Cretaceous (modified from Powell et al., 1988; paleolatitude data from Ogg et al., 1992). The location of ODP Sites 765 and 766, DSDP Site 261 and Nakfunu Formation are indicated approximately. Radiolarian faunas in the Nakfunu Formation are interpreted to derive from both circumantarctic cold-water faunas (black arrow) and warm-water faunas (open arrow).

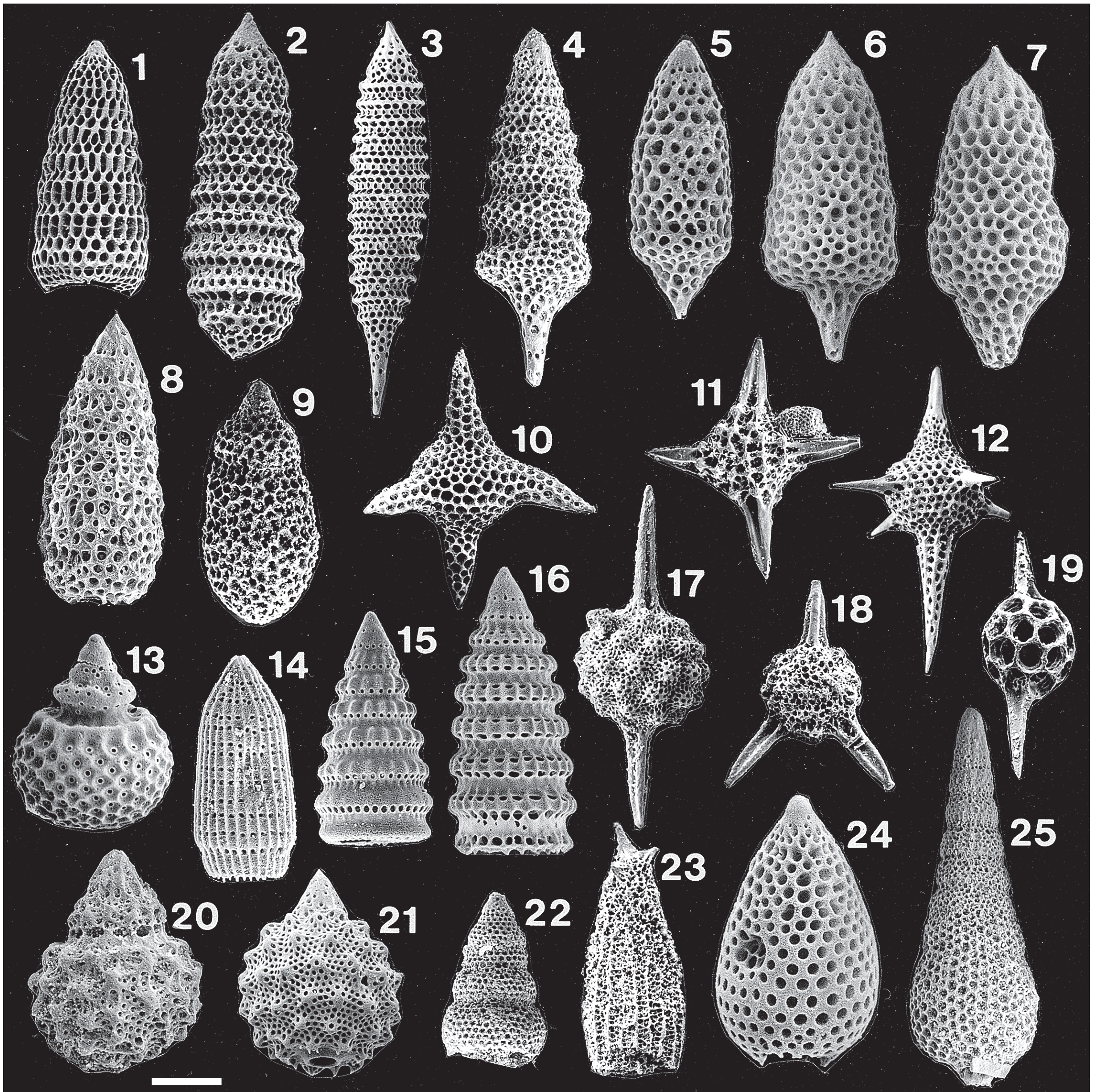

Figure 6. Radiolarians from the Nakfunu Formation. **1.** Nassellaria gen. et sp. indet. 2, Sample KL-17/1564, Scale = 100 µm, **2.** *Parvicingula* sp. C, Sample KL-17/1565, Scale = 150 µm, **3.** *Parvicingula* sp. I, Sample KL-17/9009, Scale = 100 µm, **4.** Nassellaria gen. et indet. 13, Sample KL-17/1561, Scale = 150 µm, **5.** *Eucyringium* ? sp. C, Sample BO-53A/1202, Scale = 150 µm, **6.** *Cyrtocapsa* ? sp. E, Sample BO-53A/1205, Scale = 150 µm, **7.** *Cyrtocapsa* ? sp. D, Sample BO-53A/1204, Scale = 150 µm, **8.** Nassellaria gen. et sp. indet. 9, Sample KL-15/1041, Scale = 150 µm, **9.** *Lithocampe pseudochrysalis* Tan Sin Hok, Sample TM-2/2367, Scale = 150 µm, **10.** *Podocapsa amphitreptera* Foreman, Sample KL-17/2566, Scale = 75 µm, **11.** *Emiluvia tectadecussata* Steiger, Sample KL-17/2564, Scale = 75 µm, **12.** *Podobursa triacantha* (Fischli), Sample KL-17/2562, Scale = 75 µm, **13.** *Sethocapsa uterculus* (Parona), Sample BO-18C/1706, Scale = 100 µm, **14.** *Archaeodictyomitra excellens* (Tan), Sample 53B/1308, Scale = 150 µm, **15.** *Pseudodictyomtira lilyae* (Tan), Sample BO-57A/1069, Scale = 150 µm, **16.** *Wrangellium puga* (Schaaf), Sample BO-57/A1070, Scale = 150 µm, **17.** *Acaeniotyle umbilicata* (Rüst), Sample TM-2/2375, Scale = 100 µm, **18.** *Acaeniotyle diaphorogona* Foreman, Sample KL-17/2574, Scale = 75 µm, **19.** *Pantanellium squinaboli* (Tan), Sample KL-117/2533, Scale = 150 µm, **20.** *Sethocapsa* sp. aff. *S. kaminogoensis* Aita, Sample 1744, Scale = 150 µm, **21.** *Cyrtocapsa* ? *grutterinki* (Tan), Sample BO-57A/1162, Scale = 150 µm, **22.** *Stichomitra communis* Squinabol, Sample BO-49A/1964, Scale = 100 µm, **23.** *Hsuum feliformis* Jud, sample KL-17/2453, Scale = 100 µm, **24.** *Stichocapsa pulchela* (Rüst), Sample KL-17/1122, Scale = 100 µm, **25.** *Stichomitra* ? *euganea* (Squinabol), Sample BO-53L/1608, Scale = 110 µm.

thick with dipping gently exposed downward of the river's confluent (near the positon 124° 32' 12''E and 9°53' 07''S). We suggest that these exposures are typical of the overlying Ofu Formation. If the latitude 20°S as estimated by Wensink et al. (1987) is accepted, it may be best for the younger Ofu Formation. The Ofu Formation exposed at the Noil Tuke River is in contact with the Nakfunu Formation either unconformable or by sinistral wrench fault.

In the Nakfunu Formation, the continuous succession of the strata is not found. This is shown by the presence of certain radiolarian assemblages. The random repetition of the strata in the study sections are detected by the presence of distinct four radiolarian assemblages. The repetition of the strata may be due to the imbrication (Barber et al., 1977). The Nakfunu Formation is suggested to be deposited in the northern margin of Australian continental slope. During the northward motion of the Australian continent, radiolarians were precipitated in the sediments through Berriasian to Aptian. As the Australian continental margin arrived at the collision zone commenced in the early Pliocene (Carter et al., 1976; Audley-Charles, 1986, 2011), the Nakfunu Formation were frontally accreted to the collision complex to form the parautochthonous of Timor, or as part of the younger, post-155 Ma rift mega-sequence (Audley-Charles, 2011).The underlying sequences, Permian to Jurassic formations of the continental shelf sediment were underplated as suggested by Charlton (1989).

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