

## Calcareous Nannoplankton (marine algae) Analysis in Subsurface Sediments of Andaman Sea

### *Analisis Nannoplankton Gampingan (algae laut) dalam Sedimen bawah permukaan di Laut Andaman*

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**ABSTRACT:** Andaman Sea in the Indo-Pacific Warm Pool (IPWP) is influenced by Indo-Australia monsoon winds. Marine sediment cores in this area, BS36 (06°55'50.8"N; 96°07'28.51"E; Water depth 1147.1 meters) were acquired by Geomarin III research vessel and analysed its morphology for nannoplankton occurrences. Results from qualitative identification on marine sediment core in Andaman Sea obtained 11 genus of nannoplankton marine algae in this area. Dominated genus discovered in this site is *Gephyrocapsa*, *Emiliana*, and *Helicosphaera*. Although this research is qualitative and preliminary study phase; however, this reference of modern nannoplankton taxonomy and features using Scanning Electron Microscope (SEM) would enhance marine algae biodiversity along Andaman Sea of Indonesian waters

**Keywords:** Nannoplankton, morphology, sediment core, taxonomy, Andaman Sea

**ABSTRAK :** Kawasan Laut Andaman terletak di wilayah kolam panas Indo-Pasifik sangat dipengaruhi oleh angin musim Indo-Australia. Contoh inti sedimen laut di wilayah BS 36 (06°55'50.8" Utara; 96°7'28.51" Timur; kedalaman laut 1147,1 meter) diambil menggunakan wahana kapal riset Geomarin III dan dianalisis morfologi nanoplankton yang ditemukan di wilayah ini. Hasil dari pemerian kualitatif dari contoh sedimen inti di Laut Andaman menghasilkan 11 genus nanoplankton sebagai alga laut yang dapat ditemukan pada lokasi ini. Genus yang sangat menonjol di satu lokasi titik pengambilan contoh sedimen inti yaitu *Gephyrocapsa*, *Emiliana*, dan *Helicosphaera*. Meskipun kajian ini masih bersifat kualitatif dan tahap studi awal; namun acuan tentang taksonomi nanoplankton modern dan kenampakan dari Scanning Electron Microscope (SEM) akan memperkaya biodiversitas alga laut di sepanjang Laut Andaman dari perairan Indonesia.

**Kata Kunci:** Nanoplankton, morfologi, contoh sedimen inti, taksonomi, Laut Andaman

## INTRODUCTION

Calcareous nannoplankton is a major component of oceanic phytoplankton with ranging size between 0.25 and 30  $\mu\text{m}$ . This calcareous nannoplankton belongs to the kingdom Protista, in the phylum Haptophyta (Hay et al., 1967). The evolution pattern of this group of marine organisms and its present-day distribution all over the marine world are extremely useful in various research domains, as: marine biology, marine geology, biogeochemistry and palaeontology. Since its discovery, the calcareous nannoplankton proved important for to hydrocarbon (Hay et al., 1967), global climate change (Sprengel et al., 2002; Bolliet et al., 2011), and biostratigraphy (Hendrizan et al., 2014).

In addition, modern productivity of calcareous nannoplankton is important to global climate change, especially genus *Emiliana* and *Florisphaera* (Bolliet et al., 2011). Blooming of *Emiliana huxleyi* is very useful to reduce carbon cycle from Atmosphere into the ocean (Riebesell et al., 2000; Delille et al., 2005). Calcareous nannoplankton at Andaman Sea, especially at Indonesian territory would be convincing to explore further due to limited study occur in this area. Andaman Sea is areas with sediment source originated from Himalayan mountain derived rivers, such as Irawady, Salween, and Sittang rivers (Awasthi et al., 2014). This Andaman Sea regarded as Mergui-North Sumatran Basin, which is bounded by convergence of Mergui Ridge with continental crust of Sunda Craton to the

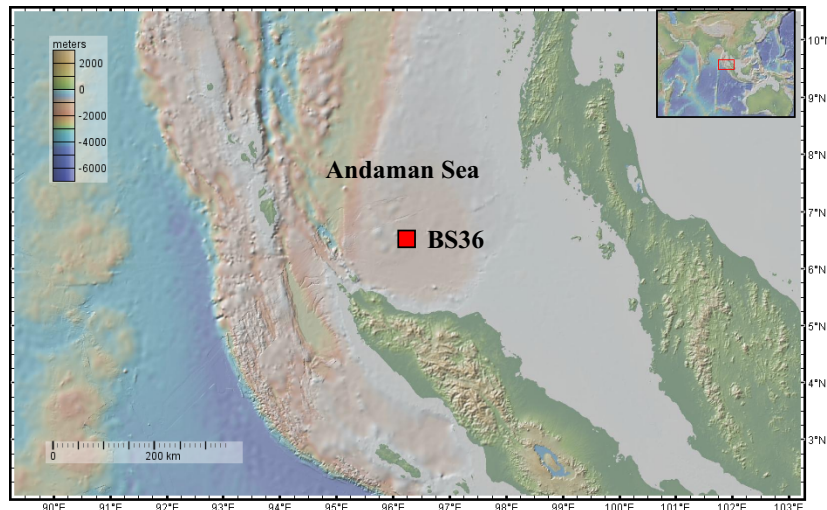


Figure 1. Study area of sediment BS36 in Andaman Sea. Map is yielded from geomapp application (<http://geomapp.org>); red square shows core location.

north, Asahan Arch to the east, Barisan Mountain to the south, and the Mergui ridge to the west (Tapponier et al., 1982).

Limited references occurred on coccolith that can be used for modern nannoplankton study in the Andaman Sea region. The latest publication on such areas from nannotax web is a study of morphometric changes of the genus *Gephyrocapsa* from two decades ago (Matsuoka and Okada, 1990). Preliminary study based on qualitative calcareous nannoplankton would be not applied to predict paleoproductivity condition in the Andaman Sea. However, this study is more concerned on taxonomic evidence based on calcareous nannoplankton assemblage in BS 36 (Andaman Sea) core site. Simple microscope is not enough to observe nannoplankton characteristics (Perch-Nielsen, 1985), instead SEM images that were used for studying characteristics of Andaman Sea nannoplankton. The objective of this study is to provide recent documentation of calcareous nannoplankton of Andaman Seas (Figure 1). It is based on identification of physical characteristics of coccolith assemblage.

## STUDY AREA

Tectonic setting of Andaman Sea considered as a back-arc basin, initially formed in Late Cretaceous by crustal extension of Sundaland (Tapponier et al., 1982; Hall, 2002). Collision of India with Asia initiated extrusion of Indochina causing clockwise rotation-oblique subduction-NWSE wrench faults systems and associated transtensional basins at the Andaman Sea (Tapponier et al., 1982). The sediments deposited in the west-central Andaman Sea probably until this BS36 site

location are derived from the Irrawaddy catchment, western slopes of the Andaman Islands, and catchments of the Salween and Sittang, and the Bengal shelf, with the first two sources contributing 30–60% of the material (Awasthi et al., 2014).

Andaman Sea is parts of the Indo Pacific Warm Pool (IPWP) with the sea surface temperature (SST) higher than 28 C. The climate in this region is affected by Australia-Indonesia monsoon (Tapper, 2002; Qu and Meyers, 2005; Kida and Richards, 2009; Mohtadi et al., 2011). Southeast monsoon in Andaman Sea, particularly between June-September, is characterized by upwelling activity that reduces sea surface temperatures by 1-2 C and

increases the number of chlorophyll (Mohtadi et al., 2011). Northwest monsoon occurring between December – March in the area is characterized by an increase in the rainfall intensity, stable sea surface temperatures and low chlorophyll concentration throughout the eastern part of the Indian Ocean

## METHODS

This study used marine sediment core, BS 36 (6°55'50.8"N; 96°7'28.51"E; length: 380 cm; water depth 1147.1 m) in Andaman Sea. Based on megascopic description, BS36 composes of clay and silt with darker color at the bottom than the upper part and Foraminifera sand was observed between 332 and 350 cm (Figure 2). The sediment color is getting darker into the bottom part of core BS36 in Andaman Sea and some foraminifera and pteropod shell existed along the core.

Calcareous nannoplankton analysis is collected on certain layer of BS 36 marine sediment cores. Nannoplankton is identified using Quanta 200 Environmental Scanning Electron Microscope (ESEM) at Laboratory of First Institute of Oceanography (FIO) of the State Oceanic Administration (SOA) in Qingdao, China, using 15,000 to 40,000 magnifications. Sediment samples are selected from clay residues and mounted on SEM stubs. The samples then coated with gold spray to avoid light dispersion using BALTEC SCD 005 sputter coater for 5 – 10 minutes. Determinations of nannoplankton genus are carried out using Perch-Nielsen, (1985).

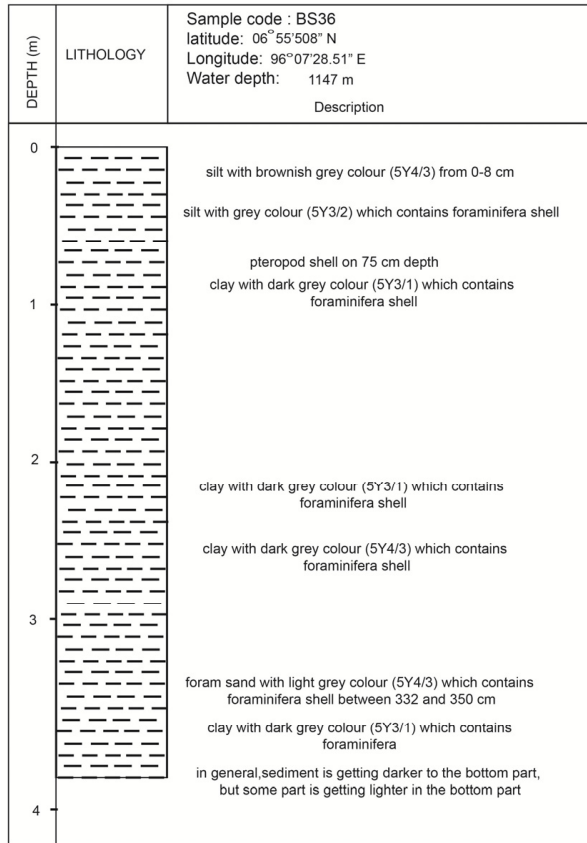


Figure 2. The description of sediment core BS36 in Andaman Sea. Color description used image column of Munsell color chart.

## RESULT

Samples from Andaman Sea contain 11 nannoplankton genus. All genus have uniform size between 2.5–5µm. The 11 genus are:

- 1) *Syracosphaera*, 2) *Helicosphaera*, 3) *Gephyrocapsa*, 4) *Calciosolenia*, 5) *Discosphaera*, 6) *Reticulofenestra*, 7) *Umbilicosphaera*, 8) *Florisphaera*, 9) *Emiliana*, 10) *Craticulithus*, 11) *Calcidiscus*.

Eleven genus nannoplankton occur in Andaman Sea (Table 1,2). Nannoplankton in core BS36 at Andaman Sea show some genus such as *Rhabdosphaera*, *Coccolithus*, *Calciosolenia*, and *Craticulithus* does not exist at the lower part of core started from 190 to 340 cm (Table 1, 2). *Gephyrocapsa*, *Emiliana*, and *Helicosphaera* dominated in the entire core length, number of that genus is 42%, 16%, and 11% respectively. Other genus except those 3 dominated genus are numbered between 1 and 5 % from total number of nannoplankton assemblage at the Andaman Sea.

## DISCUSSIONS

### Taxonomy of nannoplankton genus from Andaman Sea

Detailed taxonomy and characteristics of nannoplankton assemblages from Andaman Sea is explained below:

#### 1. Genus *Syracosphaera* (Figure 3A,C, O)

*Caneosphaera* Gaarder in Gaarder & Heimdal, 1977

*Gaarderia* Kleijne, 1993

**Description:** *Syracosphaera* has two flanges that look like placolith

**Locality in the core BS36:** This genus of *Syracosphaera* at Andaman Sea occurred in 4 samples, intermittent occurrence down the core.

**Remarks:** Proximal coccolith of *Syracosphaera* is characterized by a central wall and three shields (Perch-Nielsen, 1985).

Distribution: -

#### 2. Genus *Helicosphaera* (Figure 3B,I, Q)

*Helicosphaera* Kamptner, 1954

**Description:** *Helicosphaera* is a bolt-like coccolith and its sub-genus can be identified by the presence/

Table 1. List of nannoplankton assemblage at core BS36

Nannoplankton/ Depth (cm)	0	10	25	35	45	55	65	85	100	115	130	150	165	175	190
<i>Emiliana</i>				1		1	2	1				2	1		
<i>Gephyrocapsa</i>	3	1	1		1	2	1		7	1	3	1			1
<i>Helicosphaera</i>		2									1		1	1	
<i>Craticulithus</i>					2	1									
<i>Calciosolenia</i>								1			1		1		
<i>Calcidiscus</i>											1				
<i>Reticulofenestra</i>	1					1									
<i>Florisphaera</i>										1					
<i>Discosphaera</i>								1							
<i>Syracosphaera</i>	1										2				
<i>Umbilicosphaera</i>															

Table 2. Other list of nannoplankton assemblage at core BS36

Nannoplankton/ Depth (cm)	220	235	250	265	280	300	320	330	340
<i>Emiliana</i>			1	1		1			
<i>Gephyrocapsa</i>	1		1	3		1	1		
<i>Helicosphaera</i>		1			1		1		
<i>Craticulithus</i>									
<i>Calciosolenia</i>									
<i>Calcidiscus</i>									
<i>Reticulofenestra</i>					1		1	1	
<i>Florisphaera</i>									
<i>Discosphaera</i>									
<i>Syracosphaera</i>		1							1
<i>Umbilicosphaera</i>				1			1		

absence of separate bars, bar orientations and flange shape

**Locality in core BS36:** Occurred in 7 samples, intermittent in the upper part of the core.

**Remarks:** *Helicosphaera* species can be distinguished by their outline, by the presence or absence, shape and size of the terminal flange, or by details of the fine structure and/or angle of the central bridge (Perch-Nielsen, 1985).

**Distribution:** *Helicosphaera* spp. occurred in high nutrient condition of well-mixed upper water column at South Atlantic and Southern Ocean (Boeckel et al., 2006). *Helicosphaera* seem most commonly and consistently in hemipelagic sediments and are not found in pelagic sediments; they are restricted to or seem to prefer upwelling areas (Perch-Nielsen, 1985).

### 3. Genus *Gephyrocapsa* (Figure 3D,G,K)

*Gephyrocapsa* Kamptner, 1943

**Description:** *Gephyrocapsa* is found to have a distinctive bridge in the middle that characterized this genus. Such slits are also found in species of *Gephyrocapsa*.

**Locality in core BS36:** This genus is the most common genus at Andaman Sea, which occurred along the core until 320 cm.

**Remarks:** Two species of *Gephyrocapsa* are commonly used for biostratigraphic purpose: *G. caribbeanica* with First Occurrence (FO)/ (base CN13b) and *Gephyrocapsa oceanica* appears in base CN14 (Perch-Nielsen, 1985).

**Distribution:** *Gephyrocapsa* have dominated in the Atlantic Ocean, with the exception of tropical areas where various other species reach high abundances (McIntyre & Bé, 1967; Okada & Honjo, 1973).

Species of *Gephyrocapsa* included *Gephyrocapsa oceanica* dominating the flora in marginal seas along the western Pacific (Okada, 1983).

### 4. Genus *Calciosolenia* (Figure 3E)

*Anoplosolenia* Deflandre, 1952;

*Scapholithus* Deflandre 1954

**Description:** *Calciosolenia* is a coccosphere with trapezoid muralith and longitudinal bars in central area.

**Locality in core BS36:** *Calciosolenia* was distributed in 2 samples of 85 and 130 cm.

**Remarks:** Coccosphere with rhombic muraliths (scapholiths); monomorphic or dimorphic is placed in a separate genus (Deflandre, 1952; 1954). However, the coccolith structure of the two species is identical and their affinity is not in dispute (Young et al., 2003); therefore these two species of monomorphic and dimorphic scapholiths are included into one genus of *Calciosolenia*.

**Distribution:** Specimen of *Calciosolenia* was found off North Carolina coast in a water depth below 75 m (Marshall, 1969).

### 5. Genus *Discosphaera* (Figure 3F, S)

*Discosphaera* Haeckel, 1894

**Description:** trumpet-like spines, where the coccolith bases are broadly elliptical, with normal rhabdosphaeraceae-type rim, radial and lamellar cycles

**Locality in core BS36:** *Discosphaera* occurred in a sample of 85 cm

**Remarks:** -

**Distribution:** -

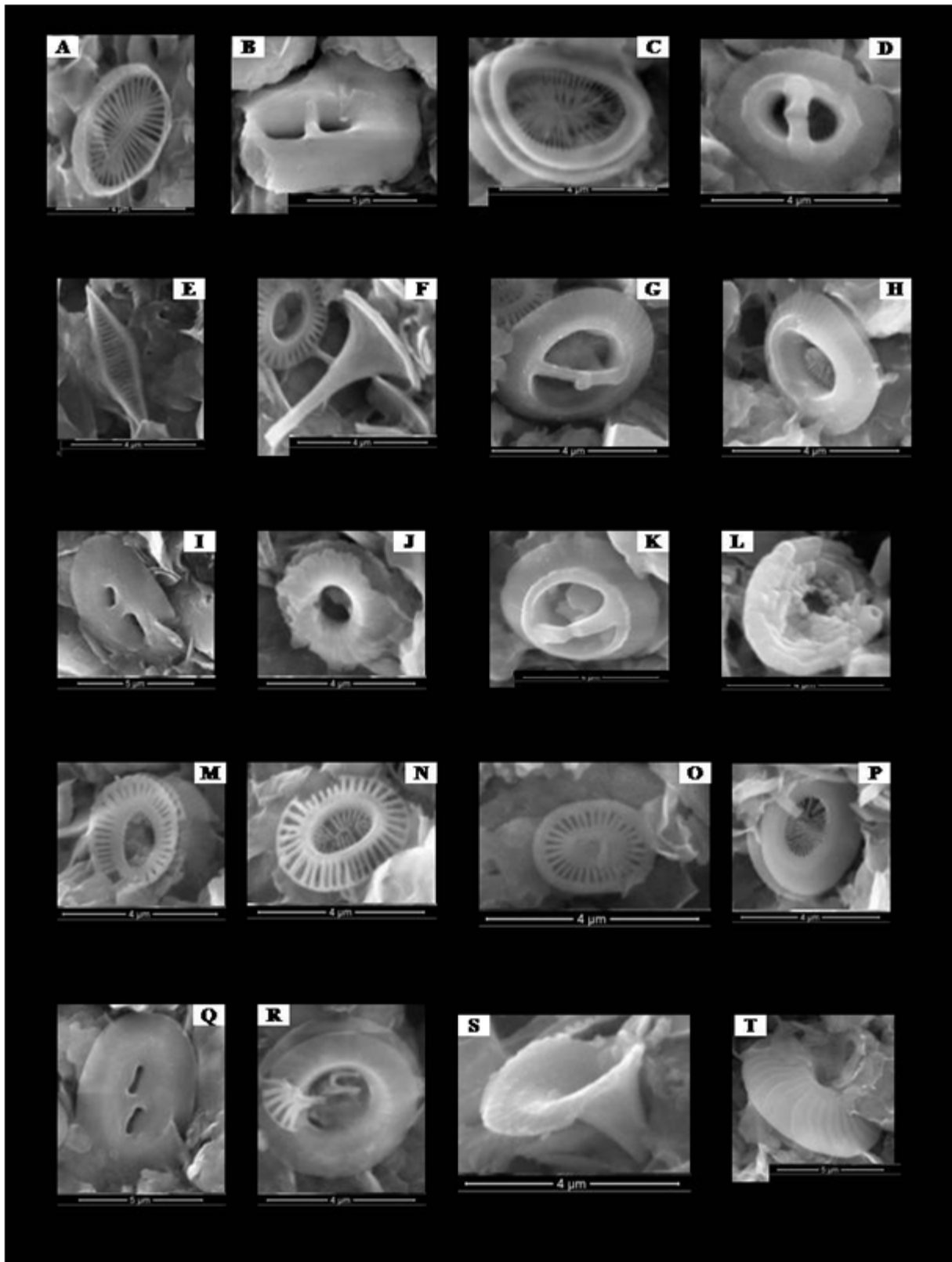


Figure 3. Nannoplankton collection from SEM images which found in Andaman Sea. A, C, O. *Syracosphaera*; B, I, Q. *Helicosphaera*; D, G, K. *Gephyrocapsa*; E. *Calciosolenia*; F, S. *Discosphaera*; H. *Reticulofenestra*; J, R. *Umbilicosphaera*; L. *Florisphaera*; M, N. *Emiliana*; P. *Craticullithus*; T. *Calcidiscus*



6. Genus *Reticulofenestra* (Figure 3H)

*Reticulofenestra* Hay, Mohler & Wade, 1966

**Description:** Coccoliths with a circular to elliptical outline, central-area open or closed; central area grill delicate, but quite often preserved.

**Locality in core BS36:** *Reticulofenestra* was discovered at 5 samples at the upper part and the bottom part of the core.

**Remarks:** Typical *Reticulofenestra* with a relatively wide central area spanned by a net disappear in Early Oligocene (Perch-Nielsen, 1985). The species within *Reticulofenestra* are distinguished by the overall size and by relative size of the central opening, as well as by the relative width of the wall (Perch-Nielsen, 1985). the genus *Crenolithus* has often been used as a synonym of small *Reticulofenestra* in modern and Quaternary studies (Young et al., 2003).

**Distribution:** -

7. Genus *Umbilicosphaera* (Figure 3J,R)

*Geminolithella* Backman, 1980;

*Cycloplacolithella* Haq, 1980

**Description:** *Umbilicosphaera* is a round shaped with small opening in the central part (1/3 or less of coccolith diameter).

**Locality in the core BS36:** This genus occurred only at the bottom part of the core

**Remarks:** -

**Distribution:** -

8. Genus *Florisphaera* (Figure 3L)

*Florisphaera* Okada & Honjo, 1973

**Description:** *Florisphaera* is formed from several coccolith plates arranged in a rectangle structure with zig-zag form in the shorter side.

**Locality in core BS36 :** This genus is only found at a sample of 115 cm

**Remarks:** -

**Distribution:** *Florisphaera* species especially *Florisphaera profunda* was found in the Atlantic and the Pacific tropical to transitional watermasses (Okada & Bukry, 1977 in Perch-Nielsen, 1985)

9. Genus *Emiliana* (Figure 3M, N)

*Emiliana* Hay & Mohler, in Hay et al., 1967

**Description:** the coccolith with T/I shape or slits occur between all distal shields, however it is not always in proximal shield, the size of *Emiliana* is very small between 2 and 4 µm.

**Locality in core BS36:** one of dominant genus occurred in 9 samples between depths of 35 and 300 cm.

**Remarks:** *Emiliana* is differentiated with *Pseudoemiliana* by occurrences of slits on the distal shield; *Pseudoemiliana* has only slits between some of the shield elements rather than T- or I-shaped elements (Perch-Nielsen, 1985). *Emiliana* in these study areas shows several types of slits dispersion with I- and T-shaped in the distal shield; some specimen has a close gap of slit features.

**Distribution:** *Emiliana* were found in the Capricorn basin in areas of a water depth above 40 m and dominated the assemblage to more than 95% in areas between the coast and 60 km offshore (Heckel, 1973).

10. Genus *Craticullithus* (Figure 3P)

*Craticullithus* Brown, 2010

**Description:** *Craticullithus* is a placolith that is characterized by wide central extensive central area with mesh-like structure.

**Locality in core BS36:** this genus occurred only in 2 samples at the upper part of the core.

**Remarks:** this genus is a Rare specimen, spherical, and monomorphic coccospheres (Gibbs et al., 2014)

**Distribution:** -

11. Genus *Calcidiscus* (Figure 3T)

*Calcidiscus* Kamptner, 1950

**Description:** *Calcidiscus* is characterized by circular or sub-circular; central area closed or with narrow opening.

**Locality in core BS36:** *Calcidiscus* only found at 1 sample of 130 cm.

**Remarks:** Coccoliths have circular to sub-circular outline. Proximal shield is characterized by birefringent, distal shield non-birefringent with curved sutures, and shields easily separated.

**Distribution:** *Calcidiscus* is cosmopolitan coccolithopore (Renaud et al., 2002). Specific species of *Calcidiscus* live in the coastal areas of Lisbon bay (Silva et al., 2009).

## CONCLUSION

Qualitative identification of sediment core at Andaman Sea yields 11 nannoplankton genus based on taxonomy and detailed morphological description of the marine algae, especially calcareous nannoplankton using Scanning Electron Microscope (SEM) images.

Our finding shows the importance of SEM images in nannofossil study. Nannofossils that are commonly found in Andaman Sea are *Gephyrocapsa*, *Emiliana*, and *Helicosphaera*. Those dominant nannoplankton shows several features of *Gephyrocapsa*, *Emiliana*, and *Helicosphaera* appear at Andaman Sea.

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## REFERENCES

- Awasthi, N., J. S. Ray, A. K. Singh, S. T. Band, and V. K. Rai. 2014, Provenance of the Late Quaternary sediments in the Andaman Sea: Implications for monsoon variability and ocean circulation, *Geochem. Geophys. Geosyst.*, 15, 3890–3906, doi:10.1002/2014GC005462.
- Backman, J. 1980. Miocene-Pliocene nannofossils and sedimentation rates in the Hatton-Rockall Basin, NE Atlantic Ocean. *Stockholm Contributions in Geology*, 36: 1-91.
- Boeckel B., Karl-Heinz Baumann, Rüdiger Henrich, Hanno Kinkel. 2006. Coccolith distribution patterns in South Atlantic and Southern Ocean surface sediments in relation to environmental gradients. *Deep Sea Research Part I: Oceanographic Research Papers*, Volume 53, Issue 6, June 2006, Pages 1073–109
- Bolliet, T., A. Holbourn, W. Kuhnt, C. Laj, C. Kissel, L. Beaufort, M. Kienast, N. Andersen, D. Garbe-Schönberg, 2011. Mindanao dome variability over the last 160 kyr: Episodic glacial cooling of the West Pacific Warm Pool. *Paleoceanography*, Vol. 26, PA1208, doi: 10.1029/2010PA001966.
- Bown, Paul R., Samantha J. Gibbs, Rosie Sheward, Sarah O’dea and David Higgins. 2014. Searching for cells: the potential of fossil coccospheres in coccolithophore research. *Coccolithophore 2014 workshop volume*
- Brown, P.R. 2010. Calcareous nannofossils from the Paleocene/Eocene Thermal Maximum interval of southern Tanzania (TDP Site 14). *Journal of Nannoplankton Research*, 31: 11-38.
- Deflandre, G. & Fert, C. 1954. Observations sur les coccolithophoridés actuels et fossiles en microscopie ordinaire et électronique. *Annales de Paléontologie*, 40: 115-176.
- Deflandre, G. 1952. Classe des Coccolithophoridés. (Coccolithophoridae. Lohmann, 1902). In: Grassé, P.P. (Editor), *Traite de Zoologie*. Masson, Paris, pp. 439-470.
- Delille, B., et al. (2005), Response of primary production and calcification to changes of pCO<sub>2</sub> during experimental blooms of the coccolithophorid *Emiliana huxleyi*, *Global Biogeochem. Cycles*, 19, GB2023, doi:10.1029/2004GB002318.
- Du, Y., T. Qu, and G. Meyers. 2008. Interannual Variability of Sea Surface Temperature off Java and Sumatra in a Global GCM, *J. Clim.*, 21(11), 2451–2465, doi:10.1175/2007JCLI1753.1.
- Gaarder, K.R. & Heimdal, B.R. 1977. A revision of the genus *Syracosphaera* Lohmann (Coccolithineae). "Meteor" *Forschungsergebnisse. Reihe D, Biologie*, 24: 54-71.
- Haq, B.U., 1980. Biogeographic history of Miocene calcareous nannoplankton and paleoceanography of the Atlantic Ocean. *Micropaleontology*, 26(4): 414-443.
- Hall, R. 2002. Cenozoic geological and plate tectonic evolution of SE Asia and the SW Pacific: computer-based reconstructions, model and animations. *Journal of Asian Earth Sciences*, Volume 20, Issue 4, April 2002, Pages 353–431
- Hay, W.W., Mohler, H.P., Roth, P.H., Schmidt, R.R. & Boudreaux, J.E. 1967. Calcareous nannoplankton zonation of the Cenozoic of the Gulf Coast and Caribbean-Antillean area, and transoceanic correlation. *Transactions of the Gulf Coast Association of Geological Societies*, 17: 428-480.
- Hay, W. W., Mohler, H. P. & Wade, M. 1966. Calcareous Nannoplankton from Nal'chik (Northwestern Caucasus). -- *Ecol. geol. Helv.*, 59, 1, p. 379-399.
- Heckel, H., 1973. Late Oligocene to Recent nannoplankton from the Capricorn Basin, Great Barrier Reef area. *Geol. Surv. Q+ Publ.* 359, *Palaeontol. Pap.* 33, pp.1 23.
- Haeckel, E. 1894. *Systematische Phylogenie der Protisten und Pflanzen*. Reimer, Berlin.

- Hendrizar, M., Kapid, R., and Djuhaeni. 2014. Biostratigraphy of the Late Miocene Halang Formation in the Loh Pasir succession, Banyumas, Central Java. *Berita Sedimentologi*, vol. 5, no. 30.
- Kamptner, E. 1954. Untersuchungen über den Feinbau der Coccolithen. *Anzeiger. Österreichische Akademie der Wissenschaften. Mathematische-Naturwissenschaftliche Klasse. Wien*, **87**: 152-158.
- Kleijne, A. 1993. *Morphology, Taxonomy and distribution of extant coccolithophorids (Calcareous nannoplankton)*. Drukkerij FEBO B.V., Katwijk, 321 pp.
- Kida, S., and K. J. Richards. 2009. Seasonal sea surface temperature variability in the Indonesian Seas, *J. Geophys. Res.*, 114, C06016, doi:10.1029/2008JC005150.
- Marshall, J. Harold. 1969. Phytoplankton Distribution Off the North Carolina Coast. *The American Midland Naturalist*, Vol. 82, No. 1 (Jul., 1969), pp. 241-257
- Matsuoka, H. & Okada, H., 1990. Time-progressive morphometric changes of the genus *Gephyrocapsa* in the Quaternary sequence of the tropical Indian Ocean, Site 709. *Proceedings of the Ocean Drilling Program. Scientific Results*, **115**: 255-270.
- McIntyre, A., Be., A.W.H., 1967. Modern coccolithophoridae of Atlantic Ocean. I. Placoliths and Cyrtoliths. *Deep-Sea Res.* 14, p. 561-597.
- Mohtadi, M., Oppo, D.W., Lckge, A., DePol-Holz, R., Steinke, S., Groeneveld, J., Hemme, N., Hebbeln, D. 2011. Reconstructing the thermal structure of the upper ocean: Insights from planktic foraminifera shell chemistry and alkenones in modern sediment of the tropical eastern Indian Ocean. *Paleoceanography*, vol. 26, PA3219, doi: 10.1029/2011PA002132
- Okada, H. & Honjo, S. 1973. The distribution of oceanic coccolithophorids in the Pacific. *Deep-Sea Research*, **20**: 355-374.
- Okada, H., 1983. Modern nannofossil assemblages of coastal and marginal seas along the western Pacific Ocean. *Utrecht Micropaleontol. Bul.*, 30: 171-187.
- Perch-Nielsen, 1985. Cenozoic calcareous nannofossil, in Bolli, H. M., Saunders, J.B., Perch-Nielsen, K. 1985. *Plankton stratigraphy*, Cambridge earth science series. *Cambridge University Press*, ISBN: 0521235766, 9780521235761.
- Qu, T., and G. Meyers. 2005, Seasonal characteristics of circulation in the southeastern tropical Indian Ocean, *J. Phys. Oceanogr.*, 35(2), 255–267, doi:10.1175/JPO-2682.1.
- Renaud, S., Patrizia Ziveri, Alexandra T.C. Broerse. Geographical and seasonal differences in morphology and dynamics of the coccolithophore *Calcidiscus leptoporus*. *Marine Micropaleontology* 46, p.363-385. PII: S 0 3 7 7 - 8 3 9 8 ( 0 2 ) 0 0 0 8 1 - 6
- Riebesell, U., Ingrid Zondervan, Björn Rost, Philippe D. Tortell, Richard E. Zeebe & Francois M. M. Morel. 2000. Reduced calcification of marine plankton in response to increased atmospheric CO<sub>2</sub>. *Nature*, Vol. 407.
- Silva, A., S. Palma, P.B. Oliveira, M.T. Moita. 2009. *Calcidiscus quadriperforatus* and *Calcidiscus leptoporus* as oceanographic tracers in Lisbon Bay (Portugal). *Estuarine, Coastal and Shelf Science* 81 (2009) 333–344. doi:10.1016/j.ecss.2008.11.010.
- Sprengel, C., Baumann, K-H., Henderiks, J., Henrich, R., Neuer, S. 2002. Modern coccolithophore and carbonate sedimentation along a productivity gradient in the Canary Islands region: seasonal export production and surface accumulation rates. *Deep-Sea Research II*, 49, 3577-3598
- Tapponnier, P., G. Peltzer, A. Y. Le Dain, R. Armijo. 1982. Propagating extrusion tectonics in Asia: New insights from simple experiments with plasticine. *GEOLOGY*, v. 10, p. 611-616, December 1982
- Tapper, N. J. 2002, Climate, climatic variability and atmospheric circulation patterns in the maritime continent region, in *Bridging Wallace's Line: The Environmental and Cultural History and Dynamics of the Southeast Asian–Australian Region*, edited by P. Kershaw et al., pp. 5–28, Catena, Reiskirchen, Germany.
- Young, J.R., Geisen, M., Cros, L., Kleijne, A., Sprengel, C., Probert, I. & Ostergaard, J. 2003. A guide to extant coccolithophore taxonomy. *Journal of Nannoplankton Research Special Issue 1*.