J. Trop. Resour. Sustain. Sci. 10 (2022): 20-27
https://doi.org/10.47253/jtrss.v10i1.894

Journal of Tropical Resources and Sustainable Science

journal homepage: jtrss.org

Biostratigraphy and paleodepositional environment of the Temburong Formation at Batu Luang, Klias Peninsula, Sabah based on calcareous nannofossil.

Nur Syahirah Binti Rosmadi[1], Nursufiah Sulaiman[1,*], Noorzamzarina Sulaiman[1] and Junaidi Asis[2]

[1]Department of Geoscience, Faculty of Earth Science, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia.
[2]Department of Geology, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 8840 Kota Kinabalu, Sabah Malaysia.

Received 29 October 2022
Accepted 23 May 2022
Online 30 June 2022

Keywords:
calcareous nannofossil, paleoenvironment, Oligocene, Temburong Formation, Klias Peninsula

⊠*Corresponding author:
Dr. Nursufiah Sulaiman
Department of Geoscience, Faculty of Earth Science, Universiti Malaysia Kelantan, Jeli, Kelantan, Malaysia.
Email: nursufiah@umk.edu.my

Abstract

Generally, the Temburong formation was observed for both research studies and hydrocarbon exploration. There was few research conducted on its lithostratigraphy and micropaleontological purposes in terms of research studies. However, there is no evidence suggested to observe the paleoenvironment condition of the formation based on the calcareous nannofossils occurrences. Therefore, this research was performed deliberately to identify paleoclimate prediction of Batu Luang, Klias Peninsular based on the assemblages of the calcareous nannofossils. 17 samples have been collected from a measuring section of a cutting hill along the road. Simple smear preparation was used and observed their assemblages were under the light microscope. As many as 27 species have been identified and dominantly preserved by discoasters and sphenolithus. Thus, this formation has been considered an oligotrophic condition and low latitude region due to the distribution of warm-water taxas. Plus, less contribution of cold-water taxa *Coccolitus pelagicus* to the formation is late Oligocene to early Miocene.

1. INTRODUCTION

Klias Peninsula is one of the most interesting places for various investigation purposes. The Temburong formation of the Klias Peninsular did been observed for its lithostratigraphy and micropaleontological purpose but they have been inconclusive to the calcareous nannofossil studies. The research was conducted at Klias Peninsula which is underlain by Paleogene-Neogene sediment, Crocker Formation, Temburong Formation, Setap Formation and Liang Formation. A previous study had suggested that the shale unit of Temburong Formation was deposited as a distal part of a deep-sea fan deposited based on the planktonic foraminifera analysis (Asis et al., 2018a). The age of the Temburong Formation is considered at late upper Oligocene to lower Miocene (N4 to N5 zones). However, no evidence been discussed its depositional environment (paleoenvironment) based on the calcareous nannofossil observation. Calcareous nannofossil was the most abundant calcareous phytoplankton and one of the smallest calcifying organisms inhabiting our planet.

This paper is focused on the biostratigraphy analysis based on the nannofossil assemblages. Plus, to analyze the correlation between the assemblages of calcareous nannofossil and their implication of depositional environment identification. The observation of the depositional environment is considered to relate to the paleoclimate (temperature of the sea) during the formation of the rocks. Coccolithophores and associated nannoplankton are important in this research as they were used to be the primary role in the global carbon cycle and employed for the paleoclimate indicator (de Vargas et al., 2007). The distribution patterns of the genera are generally supported by the paleoenvironmental determinations in reviewing the occurrence of the coccolithophores. The ichnofacies concept was used by previous researchers as it was used in determining the depositional environments (Uchman, 2007; Uchman and Wetzel, 2012).

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2. GEOLOGICAL SETTING

Based on Figure 1, the location of the sampling session for the Temburong Formation was conducted at Batu Luang, Klias Peninsular with the coordinates of longitudes 05° 31’ 23.83” N, latitudes 115° 31’ 25.66” E. Meanwhile, there were 17 outcrop samples (TSH201-TSH0205, TSH0301-TSH0312) were collected from a geological measuring section activity of a cutting hill along the local road of the study area. According to Asyila and Tahir (2013), Temburong Formation is the second oldest formation in this study area. The oldest formation is the Crocker Formation and followed by the Setap Shale formation, the Belait formation and the Liang formation. This formation is originated in the southern-west part of the Klias Peninsula, Sabah and extended to the Labuan. Stratigraphically, this formation is intercalated by the Crocker Formation and their boundary was not exposed which Temburong Formation overlies the lower part of the Crocker Formation. The lithology was very difficult to map as it was stratified by complex structures and quite similar to the Crocker Formation. It is more argillaceous than Crocker Formation which is known as arenaceous facies. It has been stratified by the argillaceous turbidite facies with a repetitive sequence of siltstone and shale units (Madon, 1994; Wilson, 1964; Brondijk, 1962). The deposition of this formation is unconformably overlain by the Middle Miocene shallow marine of Belait Formation. The rock sequences are difficult to map as it distributed by a complex Sabah lithostratigraphic units. A thick grey shale with intercalations of fine-grained, thin-bedded turbidite and suggested to be a deep marine depositional environment and isolate by the limestone lenticular bed.

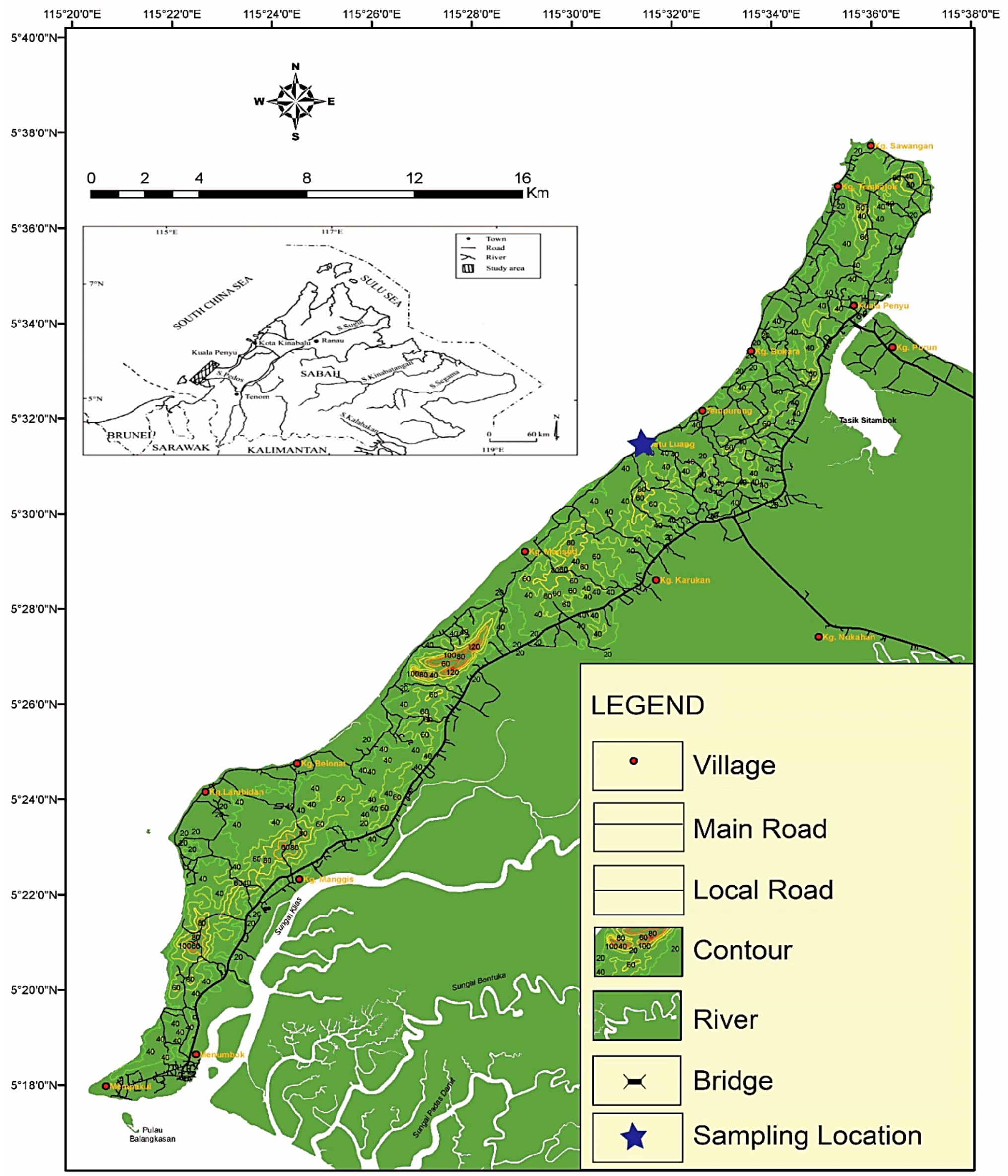

Figure 1: Modified map of the study area with the sampling location from Universiti Malaysia Sabah (UMS).

eISSN Number: 2462-2389

3. MATERIALS AND METHODS

This section discussed the samples and the methods used for this research. Eventually, all the rock samples had been collected by having a measuring section at the cutting hill along the local road. As many as 17 samples of shale from the study area were analyzed by having a simple smear preparation. This technique has been approved with the accuracy and reproducibility of the calcareous nannofossil assemblage counts (Blaj and Henderiks, 2007). The preparation of the smear slide was followed by the standard procedure that was already implemented and was widely used in both paleontological studies and the hydrocarbon exploration industry purposes. It was the most technique used by the researchers as it was quick, simple to perform and a less cost-consuming technique.

The process started by subsampled the raw samples sediment into 1cm^3 bulk measurement. Special care was taken to conserve the raw sediment of samples by trimming and cleaning away the surface of the samples. It was a necessary precaution to prevent the contamination of the surroundings due to the small size of nannofossils. Next, the small fraction of sediment was scraped by the wooden toothpick and mixed with a few drops of distilled water and smeared evenly across the glass microscopic slide (4cm x 2.5cm). A thinly smeared was needed across the surface of the glass slide until a thin layer of rippled material was obtained. Besides, the coarse grains have were discarded by dragging them to the edge of the slide. The slide was dried rapidly on the electric hotplate. 80°C of hotplate has been used to dry up the smeared sediment. Norland Optical Adhesive (NOA 60) was used to mount the glass slide to the coverslip. Add a dropwise NOA 60 to the center of the slides covered by the smeared residues. Then, the coverslip tilted 60° to the edge of the slides before being gently placed on the adhesive-laden surface. Light pressure is used on the slides to disperse the adhesive uniformly to the edges in coordination to eliminate any air bubbles formation. The appearance of the air bubbles in the form of dark rings covering some part of the specimen makes the observation more difficult. It was a required technique to get a consistent recovery of the nannofossils specimen and prevented low-resolution observations. Utilizing this adhesive as a drop or bead along the edge of the component is another technique that could use to insert it. The slides have been dried under ultraviolet light only just for 30 minutes. Lastly, cleaned the excess sediment after being cooled, and labeled the slide. The steps were repeated till all the samples had completed the preparation process.

Then, the samples were ready for the next observation which was light microscope analysis. This part is supported by high-quality optics and magnification polarized light microscope due to limited nannofossil sizes. The magnification was used for the biostratigraphy analysis in the range of x2500 to x5000. However, this study used Leica ICC50 E polarizing light-microscope with x1000 magnification aided with the x100 immersion oil for a clearer view. Both the cross-polarized (XPL) and plane-polarized (PPL) were used to identify the composition, structure and preservation of the coccoliths. Particular morphology features of the nannofossils taxonomic been determined by observing under XPL views. Hence, it was easy to recognize and locate them with a low abundance sample. The terminology and descriptive morphology features of the specimens been discussed based on (Young and Bown, 1997). The further observation of the morphology-based on the taxa referred to the (Young and Brown 1997; Young et al. 2005; Bown and Jones 2012).

The total abundance of the nannofossils was calculated by their occurrence of other inorganic components and biogenic particles. All the specimen abundances of individual specimens are distinguished by letter codes and were recorded according to the following definitions (Erba and Covington, 1992). The total abundance of the individual nannofossil species followed the codes: B = barren (no nannofossil), R = rare (<2% of the fine fraction), F = few (2% to 12% of the fine fraction), C = common (12% to 30% of the fine fraction), A = abundant (30% to 50% of the fine fraction), V = very abundant (>50% of the fine fraction). The preservation of nannofossils can vary significantly from calcite overgrowth, dissolution or etching. The state of preservation of the nannofossil assemblages in this study was recorded as follows: G = good (primary diagnostic features preserved, little or no evidence of dissolution and/or overgrowth, specimens are identifiable to the species level), M = moderate (primary diagnostic features somewhat altered but most specimens are identifiable to the species level, specimens exhibit some etching and/or overgrowth), P = poor (primarily diagnostic features largely destroyed, specimens are severely etched or exhibit overgrowth, many specimens cannot be identified, fragmentation occurred). The measurement of the percentage used by comparing to the specimen occurrences and preservation.

4. RESULTS AND DISCUSSION

4.1. Calcareous nannofossil assemblages

This section focuses on the discussion of species abundance variations that are used in determining paleoclimate change recovered within the Temburong formation. Generally, there are diverse assemblages of the calcareous nannofossils species distributed from the top to the bottom layers of the Temburong formation sections. A detailed total abundance data has been analyzed through all the samples of the formation in (Table 1). The percentage per total specimen was calculated and categorized into eight different genera. There are *Reticulofenestra, Cyclicargolithus, Coccolithus, Calcidiscus, Helicosphaera, Discoaster, Sphenolithus* and *Triquetrorhabdulus*. The results showed that *Sphenolithus* and *Discoaster* were dominated the nannofossil assemblages of the study area. *Discoaster deflandrei* is most common and almost dominated the assemblages of the research. It is structured with star-shaped asteroliths and calcifies with a single tubular form of calcite. Most of it consisted of complicated morphologies, but relatively with simple ultrastructure. It came from six rays or arms and ends with strong short wide bifurcations individually. It has been supported by a well-developed central area and featureless proximal side. Some of the species have a distal knob and weak distal ridges on the rays. However, it had been not useful for the nannofossil biomarker as it has been integrated or separated from its formation. *Sphenolithus heteromorphus* was mostly distributed within the samples as it gave most of the percentage observations. It has been extremely suggested to be the nannofossil markers for biozonation. Most of the morphological details of the sphenolithus can be seen through the XPL views which it formed with radial c-axes and calcite crystal. This species together with *Sphenolithus belemnos* were prominent with monocrystalline apical spines and the size is bigger than 5µm.

Table 1: Detail of total abundance data for all the samples of Temburong formation, showing *Sphenolithus* and *Discoaster* dominant the assemblages.

Taxonomy	Percentage per total specimens (%)	Total abundance (Ladner & Wise, 2001)
Reticulofenestra	0.4	R
Cyclicargolithus	11.5	F
Coccolithus	5.5	F
Calcidiscus	1	R
Helicosphaera	0.7	R
Discoaster	18.6	A
Sphenolithus	47.6	A
Triquetrorhabdulus	14.7	C
Total	100	

Note: R = rare, F = few, C = common, A = abundant,

The least abundance and almost rare of its occurrences dominantly by the species of Reticulofenestra, *Calcidiscus* and *Helicosphaera*. Their percentage per total specimen was less than 1% approximately. This may be due to the origin of the paleoenvironment of the formation which is dominated by the oligotrophic nannofossil species. Besides, the preservation of calcareous nannofossils in the samples are fairly dominated and moderately preserved by showing no evidence of dissolution or overgrowth recorded in (Table 2). Based on the observation, there were four samples were poorly preserved which almost shows no evidence of the nannofossils (barren). This significantly happened due to the diagenesis process in sandstone depending on specific effects such as geothermal gradient or the pressure of compaction. TSH0202-TSH0205 and TSH0307 are considered to be the best preservation as they gave a primary diagnostic feature with little evidence of dissolution.

Table 2: The preservation of the calcareous nannofossils is based on the specific samples.

Preservation codes	Condition	Nannofossil specimen occurrences	Samples
G	Good	-Primary diagnostic features preserved, little or no evidence of dissolution and/or overgrowth, specimens are identifiable to the species level.	TSH0202 - TSH0205 , TSH0307
M	Moderate	-Primary diagnostic features preserved, little or no evidence of dissolution and/or overgrowth, specimens are identifiable to the species level.	TSH0301 - TSH0306 , TSH0308 , TSH0310
P	Poor	-Primarily diagnostic features are largely destroyed, specimens are severely etched or exhibit overgrowth, many specimens cannot be identified, fragmentation occurred.	TSH0201 , TSH0309 , TSH0311 , TSH0312

27 species had been classified concerning the specific morphology features and structures. The selected taxas were illustrated in (Figure 2) and (Figure 3) and classified by their specific taxonomic classifications. They are *Cyclicargolithus abisectus, Coccolithus eopelagicus, Reticulofenestra reticulata, Coronocyclus nitescens, Coccolithus formosus, Coccolithus pelagicus, Helicosphaera recta, Discoaster petaliformis, Discoaster exilis, Discoaster patulus, Discoaster deflandrei, Discoaster moorei, Discoaster premicros, Discoaster arneyi, Sphenolithus belemnos, Sphenolithus disbelemnos, Sphenolithus heteromorphus, Sphenolithus moriformis,*

eISSN Number: 2462-2389

Sphenolithus conicus, Sphenolithus procerus, Sphenolithus microdelphix, Sphenolithus dissimilis, Sphenolithus tintinnabulum, Sphenolithus distentus, Sphenolithus puniceus and *Triquetrorhabdulus carinatus.*

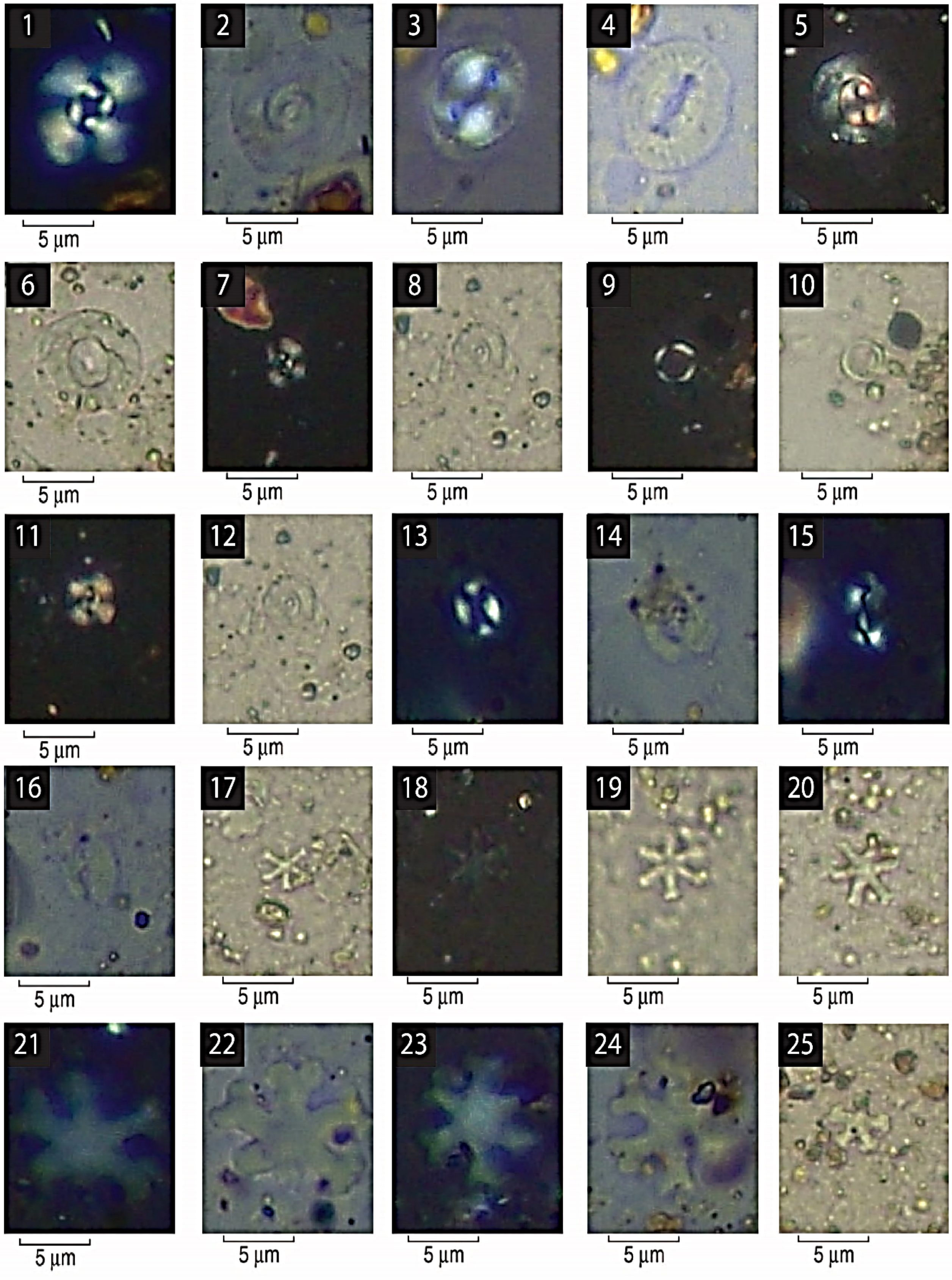

Figure 2: Images of selected calcareous nannofossil taxa from samples of Temburong formation. Scale bar 5µm with both XPL and PPL images. 1-2 *Cyclicargolithus abisectus* (Muller, 1970), 3-6 *Coccolithus eopelagicus (*Bramlette & Riedel, 1954), 7-8 *Reticulofenestra reticulata* (Gartner & Smith, 1967), 9-10 *Coronocyclus nitescens* (Kamptner, 1963), 11-12 *Coccolithus formosus*

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(Kamptner, 1963), 13-14 *Coccolithus pelagicus* (Wallich, 1877), 15-16 *Helicosphaera recta* (Haq, 1966), 17 *Discoaster petaliformis* (Moshkovitz & Ehrlich, 1980), 18-19 *Discoaster exilis* (Martini & Bramlette, 1963), 20 *Discoaster patulus* (Kaenel & Bergen in Kaenel et al. 2017), 21-24 *Discoaster deflandrei* (Bramlette & Riedel, 1954), 25 *Discoaster moorei* (Burkry, 1971).

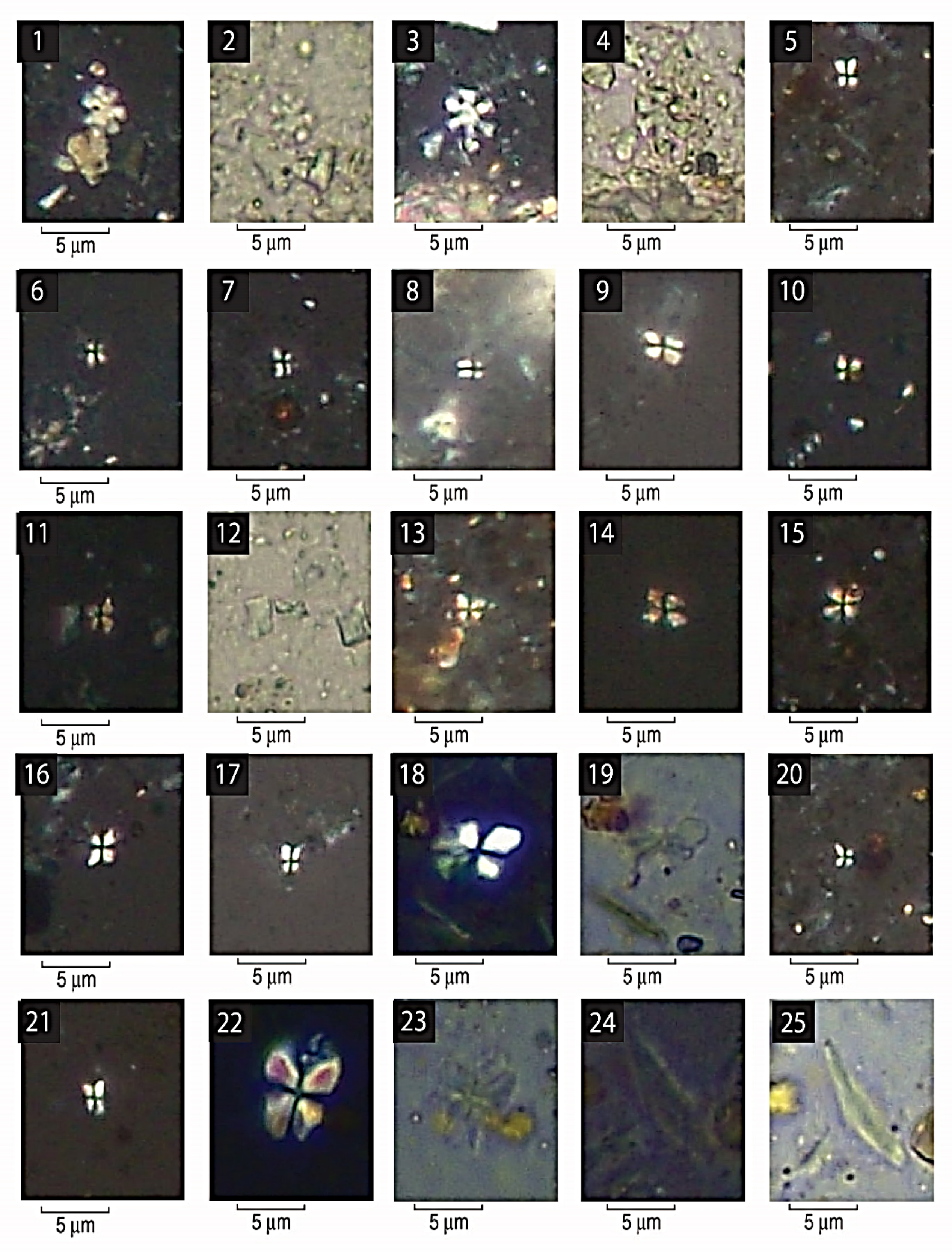

Figure 3: Images of selected calcareous nannofossil taxa from samples of Temburong formation. Both XPL and PPL images with a scale bar of 5µm. 1-2 *Discoaster premicros* (Kaenel & Bergen in Kaenel et al. 2017), 3-4 *Discoaster arneyi* (Kaenel & Bergen in Kaenel et al. 2017), 5-6 *Sphenolithus belemnos (Bramlette & Wilcoxon, 1967),* 7-9 *Sphenolithus disbelemnos* (Fornaciari & Rio, 1996), 10-12 *Sphenolithus heteromorphus* (Deflandre, 1953), 13-14 *Sphenolithus moriformis* (Bronnman & Stadner, 1960), 15 *Sphenolithus conicus* (Bukry, 1971), 16 *Sphenolithus procerus* (Maiorano & Monechi, 1998), 17 *Sphenolithus tintinnabulum*

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(Maiorano & Monechi, 1998), 18-19 *Sphenolithus distentus* (Bramlette & Wilcoxon, 1967), 20 *Sphenolithus microdelphix* (Bergen and de Kaenel in Bergen at al., 2017) 21 *Sphenolithus dissimilis* (Bukry & Percival, 1971), 22-23 *Sphenolithus puniceus* (Bergen and de Kaenel in Bergen et al., 2017), 24-25 *Triquetrorhabdulus carinatus* (Martini, 1965).

4.2 Biostratigraphy

The indicator of the biozonation has been followed by previous researchers which are Martini, (1971). The age of the sample studied from a total of 27 calcareous nannofossils species was determined from the First Occurrence (FO) and Last Occurrence (LO) of marker species. There was an interval from the LO of *Sphenolithus distentus* to the LO of *Sphenolithus ciperoencis* which mark the Sphenolithus ciperoencis Zone (NP25). *Cyclicargolithus abisectus* and *Helicosphaera recta* increases and are continuously present in the assemblages. Next, the Triquetrorhabdulus carinatus Zone (NN1) was defined at the range of LO *Sphenolithus ciperoencis* to the FO *Sphenolithus belemnos.* (NN3) zone has also been traced by the FO and LO of *Sphenolithus belemnos*. Last but not least, the mark of the zonal boundary of Sphenolithus heteromorphus Zone (NN4) by the FO *Sphenolithus heteromorphus* and FO *Discoaster deflandrei.* The relative abundance of *D. deflandrei was* observed at the base of the zone. Therefore, the age of the rocks in the Klias Peninsular outcrop based is NP25 – NN4 or equivalent to the Upper Oligocene to Lower Miocene.

4.3 Paleoenvironmental analysis

The identification of the Ophiomorpha rudis subichnofacies within the formation samples suggested occupying the submarine fan system (Jasin and Firdaus, 2019). Supported by the identification of the lower Miocene (N4 and N5 Blow Zone) planktic foraminifera which is equivalent to its paleoenvironment (Asis, Tahir, Musta, et al., 2018b) The paleoecological system eventually originated from the photic zone environment which is the top layer that nearest to the surface of the ocean. Most of this environment is exposed to sunlight and enough light penetrates allowing for the photosynthesis process. Discoaster spp. classified as holococcoliths preferences and considered to develop in warm water conditions (Haq and Lohmann, 1976). This species has been suggested to live under oligotrophic environments (Chepstow-Lusty et al. 1989; Gibbs et al. 2004). There were significant or specific components of the phytoplankton inhabitant at different photic zone levels that reflect the surface water condition. The characteristics of the Discoaster spp. are similar to the Florisphera profunda (Okada and Honjo, 1973) and indicated as lower-photic zone species. It is low latitude marker species that last appeared in 2.0 Ma. However, despite the wide distribution of this formation, no detailed research about the paleoclimate of the Temburong Formation determined by the calcareous nannofossil. As results, discoasters and sphenolithus (nannolith) are more diverse than other nannofossil taxa and developed almost all of the samples. These significant occurrences indicated a warm water environment in the study area. It is relevant to the results of previous researchers, that discoasters are a typical species for the photic zone environment, in the low latitudinal region (Farida et al., 2019). There is a living nannoplankton species, such as *Florispaera profunda*, presently found in the lower photic zone. It is a proxy to reconstruct the stability of the Quartenary sea surface condition with nutricline and thermocline (Meutia et al., 2014). Plus, this research suggested the formation contained higher nutrient conditions in deep environments due to the appearance of warm-water taxa. This species is not inhabited within Pliocene to older age as it is difficult to reconstruct the sea surface conditions during the Neogene age. Instead, the discoaster species inhabited during Paleogene to Neogene. Therefore, it can be considered that the number of discoasters is more dominant and responds to the oligotrophic condition during the late Miocene to the Pliocene. This species was used for the Oligocene low latitude indicator due to the clearest patterns of sphenolith assemblages and remained in low latitudes throughout the Oligocene age (Haq et al., 1977). It has been associated with oligotrophic conditions based on its ab. The occurrences of *Coccolithus pelagicus* are not affected due to fewer species assemblages, even though it is considered to be the indicator of cooler surface water.

5. CONCLUSION

A total of 27 different species had been identified and most of them are discoasters and sphenolithus. Most of the specimens were easy to classified into species level. Each of the calcareous nannofossil specimens is distinguished by diverse specific morphology features and structures. The records show that the Temburong formation originated in the range of Upper Oligocene to Lower Miocene age equivalent to previous planktonic foraminifera analysis. However, there were reworked specimens have been identified in this section; they were mainly Paleocene to early Eocene age. The presence of species from older deposits may be due to the transport of sedimentary material from older sedimentary rocks. This fact indicates that there was marine sedimentary rock older than the Temburong Formation which had been discussed in the geological setting part. The formation has been deposited in the oligotrophic condition which is warm water temperature due to the dominance occurrences of discoasters and sphenolithus species. There is no existence of the cold-water species within the formation.

eISSN Number: 2462-2389

ACKNOWLEDGEMENT

We would like to express our gratitude to the Department of Geoscience, Faculty of Earth Science, Universiti Malaysia Kelantan for providing the laboratory facilities and excellent research working offices. We were also grateful to the Geology Programme, Faculty of Science and Natural Resources, Universiti Malaysia Sabah for assisting us during the fieldwork at the Klis Peninsular. Besides we would like to thank Orogenic Resources Sdn. Bhd. of accepting the permission for completing the light microscope analysis by using the Leica ICC50 E polarizing light microscope.

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eISSN Number: 2462-2389