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# Larger benthic foraminifera occurrence from early Miocene limestone of Setap Shale formation at Batu Luang, Klias Peninsula, Sabah, Malaysia

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## Abstract

*Limestone unit of Setap shale formation was physically exposed at Batu Luang, Klias Peninsula, Sabah. The limestone consisted of well-preserved Larger Benthic Foraminifera (LBF). The study of its petrography, biostratigraphy and paleoenvironment gave some significance to the age and deposition paleoenvironment of the sediment. In addition, the impact and implication to the stratigraphy of Shale Setap in Klias Peninsula was thus of recent discovery. The objectives of this study were then to identify and classify the taxonomy of the larger benthic foraminifera species found in the limestone, besides determining the age and paleoenvironment of the limestone facies. Field observations carried out at the shoreline coast showed that the limestone color was grey, and consisted of encrusting coral at lower part of the bed, while the upper part was mostly massive limestone, rich in larger benthic foraminifera. The limestone lenses could be seen at the mudstone bed with some mudstones showing hummocky cross-stratification. Laboratory petrographic and fossils analyses were conducted from three samples of limestone collected. Thirty of thin section samples were prepared based on the standard procedure of the petrography analysis, and fossil classification were done using polarised microscope and photographed by using high performance camera. Species of LBF were identified with relation to the age assemblage, and environment. Eleven species of larger benthic foraminifera were identified i.e. Austrotrilina sp., Cycloclypeus sp. Lepidocyclina (Eulepidina) sp. Lepidocyclina (Nephrolepidina) acuta, Lepidocyclina (Nephrolepidina) parva, Lepidocyclina (Nephrolepidina) sumatrensis, Lepidocyclina (Nephrolepidina) verbeeki, Miogypsinoides sp., Miogypsinoidesdehaarti, spirocyclopeus sp. and Tansinhokellasp. Based on field observation, foraminifera analysis and environmental deposition, the foraminifera LBF limestone assemblage units of Batu Luang were found to be the remnants of bioherm that were indicative of $Te_5$ or Early Lower Miocene (Aquitanian) age which were much older than other previous researches.*

**Keywords:** Larger benthic foraminifera, early Miocene, setap shale formation, klias peninsula, petrography.

## Introduction

Miocene larger benthic foraminifera from limestone units are widespread in several localities in the Sabah region. However, since the last three decades, only a few studies had been conducted regarding the Larger Benthic Foraminifera (LBF) in Sabah. Examples of limestone units that had been discovered are at Labang, Gomantong Limestone[1-3], and limestone of the Kalumpang Formation[4]. Limited data had been reported regarding the significant foraminifera from the Setap Shale Formation at Klias Peninsula. Formerly, Liechti P. et al.[5] had described the Setap Shale formation as dark clay-shales with minor intercalation of thin-bedded sandstone and siltstone, and these had been dated back to the range from $Te_{1-4}$ to Tf of Letter Stage. Meanwhile, Brondijk J.F.[6] had revised that the age of Setap Shale formation was restricted to $Te_5$ to Tf. The same age was also reported by Wilson R.A.M. et al.[7] at the Setap Shale formation in Labuan and Klias Peninsula by the presence of planktonic foraminifera *Globigerinatella*. These findings were recorded back since six decades ago. Since the onset of the new millennium, no new information regarding LBF had been updated. However, some significant larger benthic foraminifera (LBF) were recently discovered from the limestone units of the Setap Shale Formation at Batu Luang of the Klias Peninsula in Sabah.

This study discovered that the larger benthic foraminifera layers could be beneficial for the petroleum industry. The significance of study on the LBF gave some significance to the age, deposition paleoenvironment of the sediment, and its implication to the stratigraphy of the Setap Shale Formation in Sabah. Hence, this study aims to identify and classify the taxonomy of the larger benthic foraminifera species found, and in addition, to determine the age and paleoenvironment of the limestone facies. This study would also help researchers to uncover the critical areas of hydrocarbon origins that many researchers were not able to explore. Thus, a new theory on LBF formation may be arrived at with specific discoveries on its hydrocarbon origins and maturation.

**General Geology of Study Site:** Klias Peninsula is located at the south-western part of Sabah (Figure-1). The study area was

underlained by Paleogene-Neogene sediment, namely, the Crocker Formation, Temburong Formation, Setap Shale and Belait Formation. The Temburong Formation could be concluded as a deep marine environment sediment deposited by turbidite current known as a flysch deposite[7-11]. The age of the formation ranged from Oligocene to Lower Miocene based on planktonic foraminifera assemblage[7]. Asis J. et al.[12] suggested an age of Late Oligocene to Late Early Miocene which was derived from the Temburong Formation at the Tenom Area.

The Setap Shale consisted of predominantly thick dark grey mudstone with minor sandstone intercalations. The shale was occasionally calcareous, silty and might contain carbonaceous material. The Setap Formation was unconformably overlying the Temburong Formation in Labuan Island[7,13,14]. In the study area, the contact between the Setap Shale Formation and the Temburong Formation was not exposed. Wilson R.A.M.[7] had reported that the age of the Setap formation had reached to Late Miocene. Jasin B.[13] and Jasin B.[14] suggested that the age of the formation was Early Miocene to Middle Miocene based on the study at the Labuan area.

The Belait Formation was widespread at North of Klias Peninsula with the formation predominantly of siliciclastic sequence in the Neogene Basin. The overall sedimentolofy characteristic of the Belait Formation consisted of six packages of repetitive Fining Upward Sequence (FUS); from basal very fine sandstones, to conglomeratic sandstones, to black coal, to mudstone (siltstone, claystone, or shale), and finally capped by very thick fine sandstones[8].

## Materials and methods

**Laboratory analysis:** Three samples of limestone were collected for laboratory petrographic and fossils analysis in this study. About 30 samples had been prepared from thin section samples of limestone. The thin section samples were prepared based on Kerr P.F.[15] the analysis of petrography, and identification of fossils by using polarised microscope and then photographed using a high performance camera for further examination. All the preparations of thin sections and their identifications were done in the thin section workshop and geo-science laboratory of the Faculty of Science and Natural Resources in University Malaysia Sabah, Malaysia. The stipulated time taken for field observations and laboratory work were in a duration of six months from January to June, 2017.

## Results and discussion

The limestone unit of the Setap Shale Formation was found to be exposed at the shoreline coast of Batu Luang area, in Klias Peninsula, as shown in the geological map of Figure-1. The outcrop consisted of limestone interbedded with thin calcareous mudstone, as shown in field observation photo at Batu Luang in Figure-2. The thickness of the limestone bed varied from 1.8meters to 12 centimetres as shown in Figure-2 and Figure-3 respectively. Field observation showed that the limestone was grey in colour, and consisted of encrusting coral at the lower part of the limestone bed and the upper part was mostly massive limestone, rich in larger benthic foraminifera. The limestone occurred as lenses in the Setap Shale Formation since it was only found at the site and no continuity at the surrounding area. The limestone lenses could be seen at the mudstone bed, and some of the mudstone showed the hummocky cross-stratification as photographed in Figure-2.

A total of 30 thin section samples had been analysed for petrographic and fossils analysis from the three samples of limestone collected which were then named as BLL01, BLL02 and BLL03. The petrographic and classification of limestone were based on[16]. The larger benthic foraminifera (LBF) were identified based on[2,4,17-20]. Distribution of LBF species in the samples were listed as in Table-1 and illustration of each species was portrayed picturesquely as shown in Figure-4, Figure-5 and Figure-6 respectively. Sample BLL01 was dominated by encrusting coral and coralline algae classified as boundstone as shown in Figure-4A and Figure-4B respectively. This limestone sample surrounded by sparite was taken from the lower part of limestone log section. Sample BLL01 consisted of *Lepidocyclina (Nephrolepidina) parva* Oppenoorth, *Lepidocyclina (Nephrolepidina) sumatrensis* Brady and *Tansinhokella* sp.

Sampel BLL02 and BLL03 were classified as packstone, as shown in Figure-4C and Figure-4D respectively. Sampel BLL02 were grains which were supported up to 80%. The grains were made up of predominantly larger benthic foraminifera, and matrix of sparite and micrite, namely, lepidocyclina and Tansinhokella with sparit, as shown in Figure-4C). Other fossils were fragments of algae, crinoid, coral, and gastropod. Ten larger benthic foraminifera species had been identified from this sample. The foraminifera were *Austrotrilina* sp., *Cycloclypeus* sp. *Lepidocyclina* (Eulepidina) sp., *Lepidocyclina (Nephrolepidina) parva* Oppenoorth, *Lepidocyclina (Nephrolepidina) sumatrensis* Brady, *Lepidocyclina (Nephrolepidina) verbeeki* Newton and Holland, *Miogypsinoides* sp., *Miogypsinoidesdehaarti* (van der Verk), *Spirocyclopeus* sp. and *Tansinhokella* sp.

Sample BLL03 was comprised of grains (70%), and was made up by larger benthic foraminifera with matrix of sparite and micrite. It had also been classified as packstone as in Figure-4D showing lepidocyclina was dominant with some sparite.

Small occurrences of fragments of coral, algae and crinoid were also present in the sample. Larger benthic foraminifera species that were found in sample were namely, *Lepidocyclina (Eulepidina)* sp., *Lepidocyclina (Nephrolepidina) acuta* (Rutten), *Lepidocyclina (Nephrolepidina) parva* Oppenoorth, *Lpidocyclina (Nephrolepidina) sumatrensis* Brady, *Miogypsinoides* sp., *Miogypsinoidesdehaarti* (van der Verk), *Spirocyclopeus* sp. and *Tansinhokella* sp.

**Table-1:** Larger Benthic Foraminifera Species Identified In Limestone Samples.

| | Larger Benthic Foraminifera Species | *Austrotrillina* sp. | *Cycloclypeus* sp. | *LepidocyclinaEulepidina sp.* | *Lepidocyclina (N.) acuta* (Rutten) | *Lepidocyclina (N.) parva* Oppenoorth | *Lepidocyclina (N.) sumatrensis* Brady | *Lepidocyclina (N.) verbeeki* Newton & Holland | *Miogypsinoides* sp. | *Miogypsinoidesdehaarti (van der Vlerk)* | *Spirocyclopeus* sp. | *Tansinhokella* sp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Limestone samples | BLL01 | - | - | - | - | X | X | - | - | - | - | X |
| | BLL02 | X | X | X | - | X | X | X | X | X | X | X |
| | BLL03 | - | - | X | X | X | X | - | X | X | X | X |

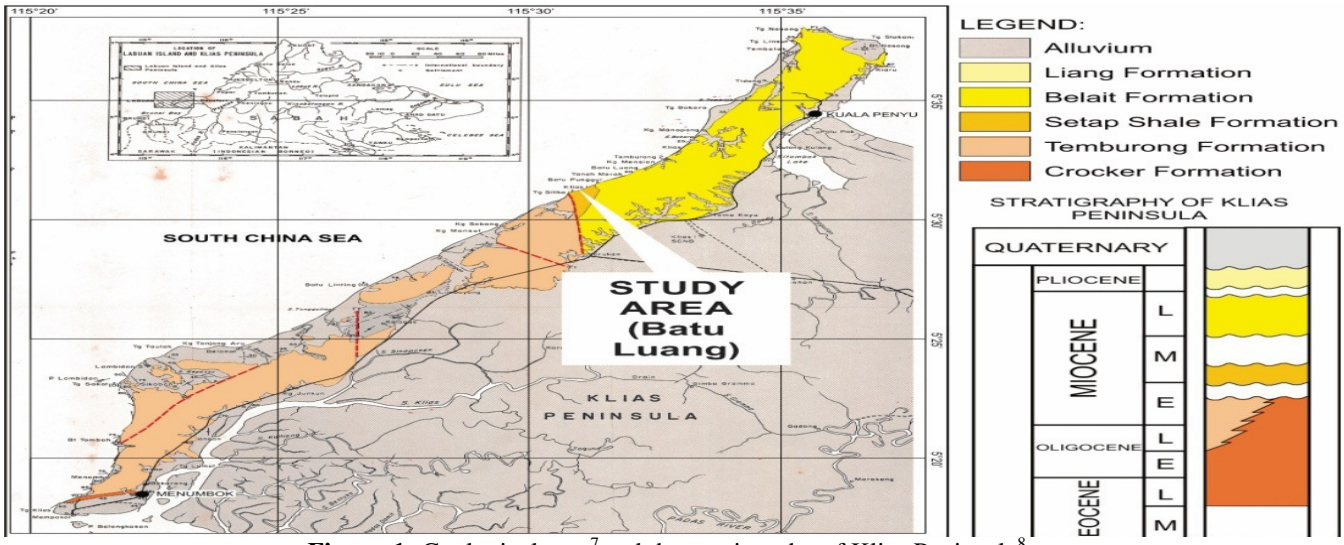



**Figure-1:** Geological map[7] and the stratigraphy of Klias Peninsula[8].

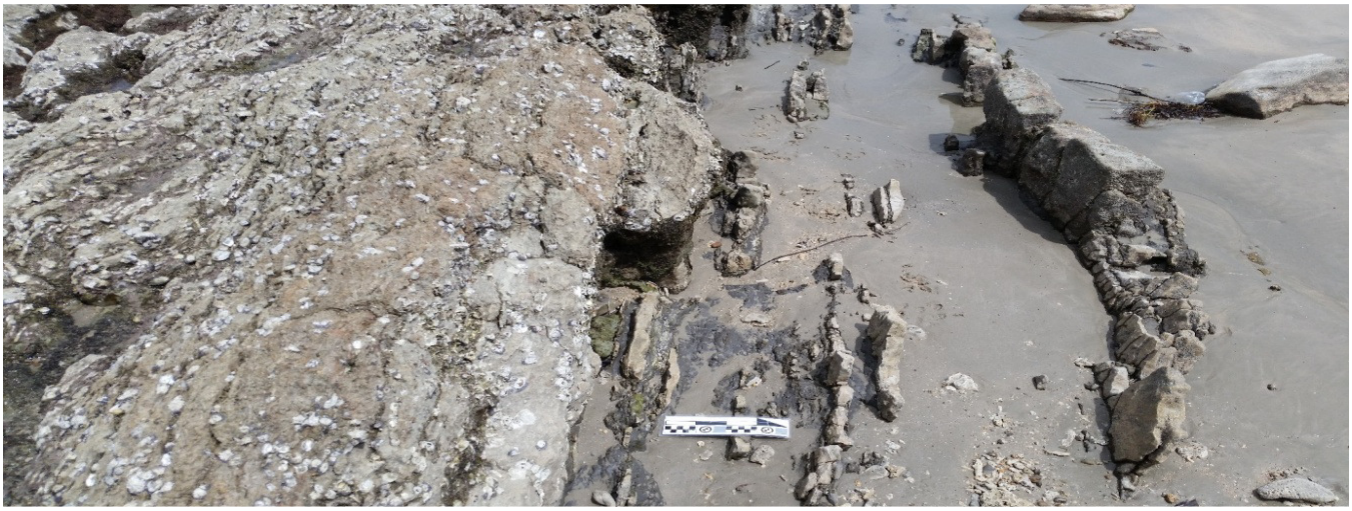


**Figure-2:** Field observation photo of limestone unit at Batu Luang.

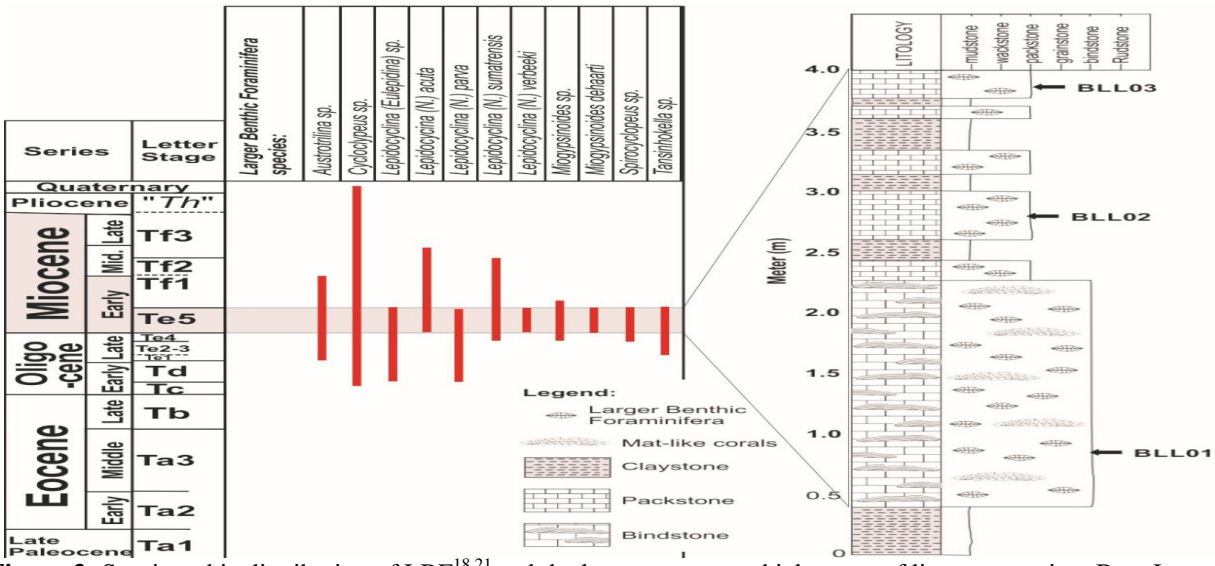



**Figure-3:** Stratigraphic distribution of LBF[18,21] and the log sequence or thicknesses of limestone unit at Batu Luang.

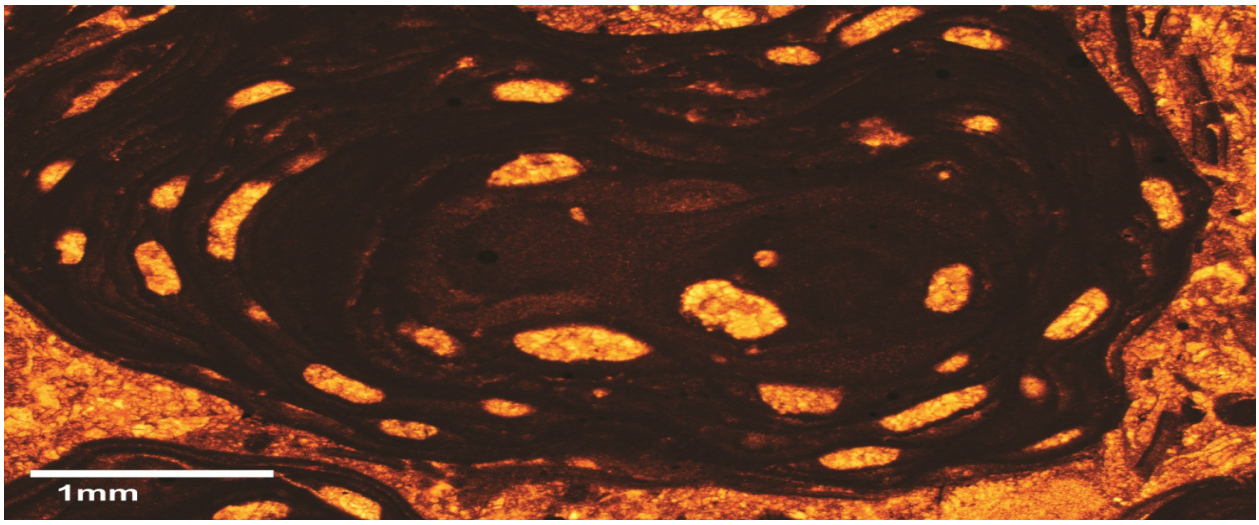



**Figure-4A:** Photomicrograph of thin section sample: BLL01 (boundstone).

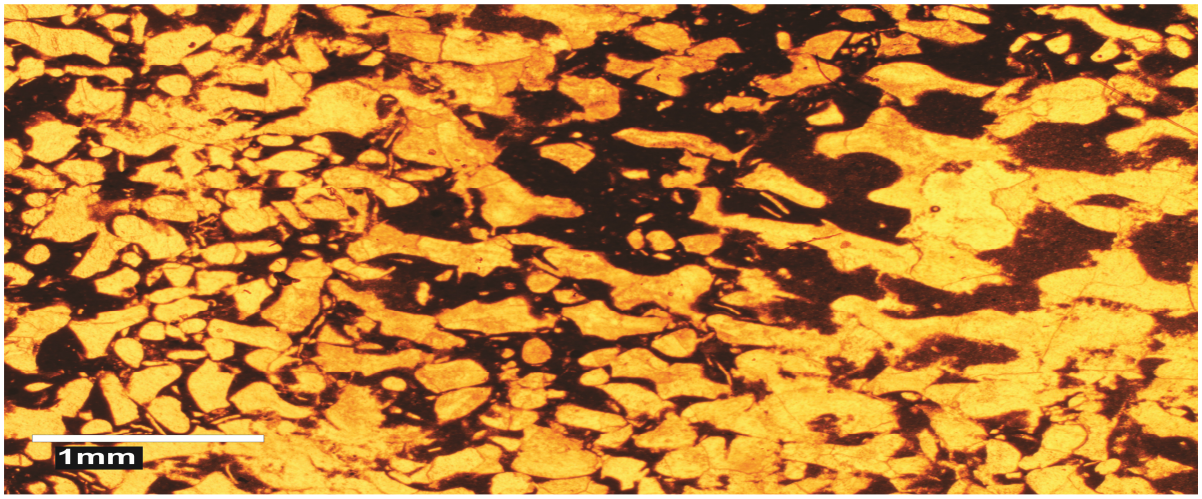



**Figure-4B:** Photomicrograph of thin section sample: BLL01 (boundstone).

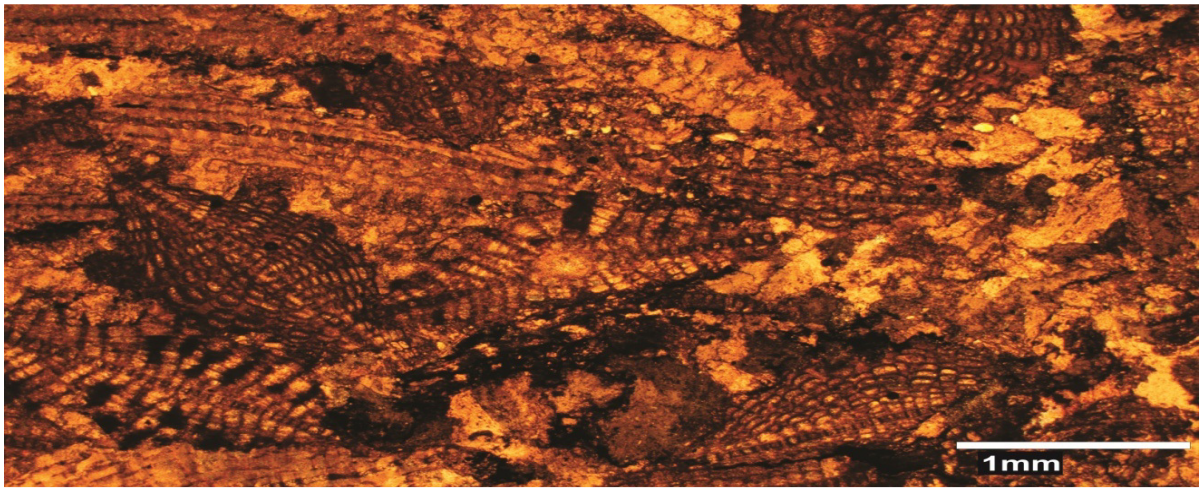


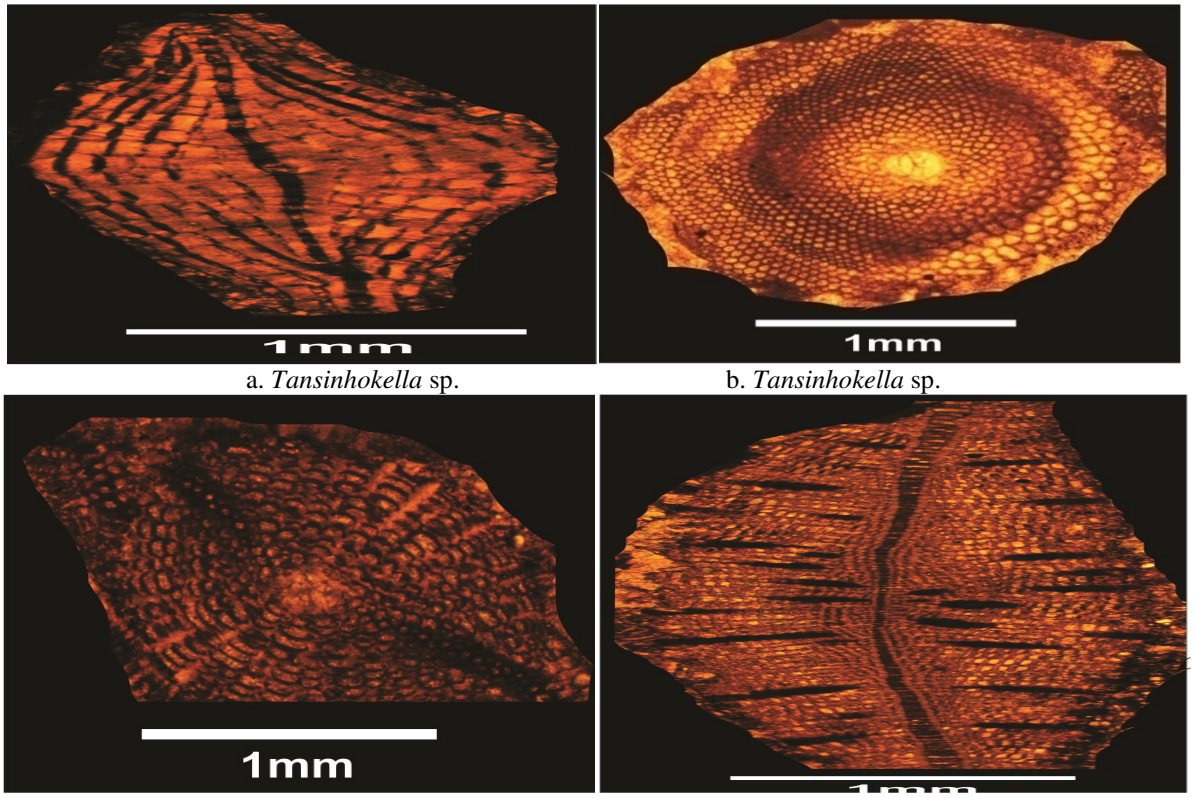

**Figure-4C:** Photomicrograph of thin section sample: BLL02 (packstone).


**Figure-4D:** Photomicrograph of thin section sample: BLL03 (packstone).

**Biostratigraphy:** The age determination of larger benthic foraminifera was based on "Letter Stage" published by Adams C.G.[18] and Lunt P.[21]. Eleven species of larger benthic foraminifera had been identified from three samples, namely, BLL01, BLL02 and BLL03, as shown in Table-1. The larger benthic foraminiferas were as follows: *Austrotrilina* sp., *Cycloclypeus* sp. *Lepidocyclina* (*Eulepidina*) sp. *Lepidocyclina* (*Nephrolepidina*) *acuta* (Rutten), *Lepidocyclina* (*Nephrolepidina*) *parva* Oppenoorth, *Lepidocyclina* (*Nephrolepidina*) *sumatrensis* Brady, *Lepidocyclina* (*Nephrolepidina*) *verbeeki* Newton and Holland, *Miogypsinoides* sp., *Miogypsinoidesdehaarti* (van der Verk), *Spirocyclopeus* sp. and *Tansinhokella* sp. The photographs of samples as vertical sections were shown in Figure-5, and Figure 6 respectively.

Adams C.G.[18] reported that the age of *Lepidocyclina (Eulepidina)* and *Lepidocyclina (Nephrolepidina) parva*Oppenoorth ranged from Td to $Te_5$. The *Lepidocyclina (Nephrolepidina) acuta* (Rutten) ranged from $Te_5$ up to $Tf_3$ and *Lepidocyclina (Nephrolepidina) sumatrensis* Brady was ranged from $Te_4$ to $TF_2$. The presence of *Spirocyclopeus* and *Tansinhokella* genus were indicative of $Te_2$ to $Te_5$[21]. The occurrence of *Lepidocyclina (Nephrolepidina) verbeeki* Newton & Holland and *Miogypsinoidesdehaarti* (van der verk) gave a consistence age of $Te_5$. Only one assemblage was identified based on biostratigraphy of the larger benthic foraminifera (LBF). The age of larger benthic foraminifera assemblage had indicated that it was of the $Te_5$ of Letter Stage or early Lower Miocene, as indicated in Figure-3.

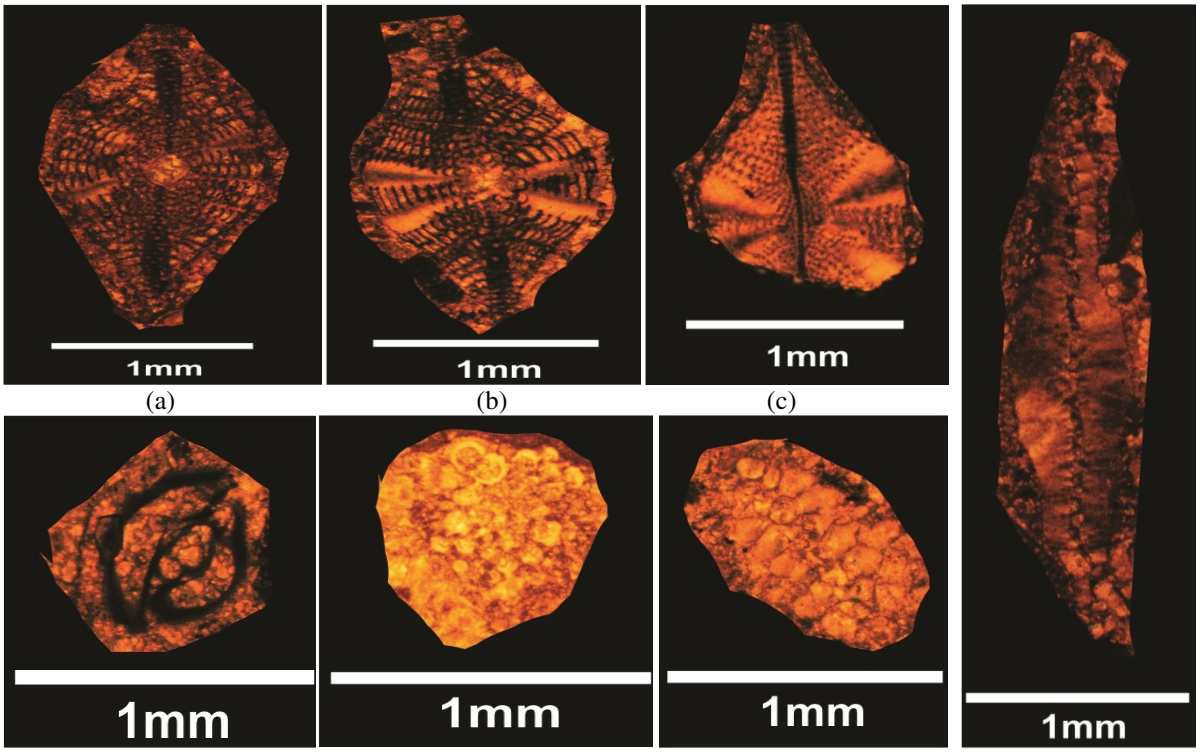
**Deposition environment of limestone:** Sampel BLL01 was interpreted as reef flat. The presence of larger benthic foraminifera (lepidocyclinid) associated with coral and coralline algae and surrounded by sparite indicated that this reef was formed at the reef front facing the open sea[22,23]. The coral and coralline algae formed the basis of the community by providing a hard framework within which the remaining organisms can either attach themselves or as shelter. The coarse grains of bioclasts and the low percentage of micrite indicated that the reef front environment deposited above the storm wave base which was the high-energy of wave current had winnowed away all the fine grains[2,4].




a. *Tansinhokella* sp. b. *Tansinhokella* sp.

c. *Lepidocyclina*(*N.*) *sumatrensis* d. *Lepidocyclina*(*N.*)*sumatrensis*

**Figure-5:** A-vertical sections: a,b-*Tansinhokella* sp., c-*Lepidocyclina* (*N.*) *sumatrensis*, and d-*Lepidocyclina* (*N.*) *sumatrensis.*




(a) (b) (c)

(d) (e) (f) (g)

**Figure-6:** A-Vertical sections: a-*Lepidocyclina (N.) parva*, b- *Lepidocyclina (N.) verbeeki*, c-*Lepidocyclina (N.) acuta*, d- *Austrotrilina sp*., e-*Miogypsinoidesdehaarti*, f-*Miogypsinoides* sp., g-*Cycloclypeus* sp.

Samples BLL02 and BLL03 contained dominant larger benthic foraminifera grains with low matrix which could be interpreted as of shallow open marine environment. Open marine or outer ramp was developed at the front of mid ramp of reef environment facing the open sea. In shallow open marine setting, low amount of coral debris mixed with high percentage of coralline algae and perforate foraminifera (lepidocyclinid and Miogypsinid[24]). Lack of coral and high occurrence coralline algae, perforate foraminifera and micrite suggested that this facies was formed at medium to low energy open marine environment in between fair-weather wave base and storm wave base[25].

The limestone unit from the Batu Luang area was as bioherm in open sea area. Field observations indicated that only small occurrence of limestone was exposed at the shoreline area of Batu Luang with only 4m thick (Figure-2), and there was no continuity to other areas in the Klias Peninsula. The bioherm did not have any protected area or lagoon behind the reefs, and this had proven the absence of dominant imperforate foraminifera such as millioid group microfacies in limestone of Batu Luang. This bioherm was a small reef flat and shallow open marine environment in the open sea which was developed during $Te_5$ or Aquitanian of the Early Miocene age.

**Stratigraphy of Setap Shale formation in Klias Peninsula:** Analysis of foraminifera limestone from this study showed that the stratigraphy of Setap Formation restricted to $Te_5$ or Aquitanian of Early Mioecene. This result was deferring from[7] which suggested an age range from $Te_5$ to Tf by the occurrence of *Globigerinatella* fauna, and there were no records of larger benthic foraminifera that had been reported in the Klias Peninsula. Balaguru A. et al.[26] suggested the age of Setap Formation at the Klias peninsula is Stage III of Sabah Stage or equivalent to $Te_5$ to Tf, but this list of foraminifera assemblage had not been published so far.

Setap Shale formation was exposed at the Labuan Island and the age was the same as reported at the Klias Peninsula[7]. Labuan Island was located to the south west of the Klias Peninsula. Jasin B. et al.[13] successfully retrieved some planktonic foraminifera from the Setap Shale formation in Kampung Sungai Berdaun, Labuan Island. The index fossils of planktonic foraminifera were *Praeorbulinasicana, Globigerinoidesbisphericus* and *Globigerina diminutus*, and represented the *Globigerinatellainsueta* Zone (N7) and the *Praeorbulinaglomerosa* Zone (N8) of the late Early Miocene. Jasin B.[14] revised the age of Setap Shale formation at Labuan Island restricted to N8 of Middle Miocene. The age of Setap Shale formation in Labuan Island was much younger (Middle Miocene) as compared to the age of limestone of Setap Shale formation in Klias Peninsula (Early Miocene in this study). The Limestone unit at Batu Luang, Klias Peninsula could be the basal part of Setap Shale formation and deepening towards Labuan area. The Setap Shale formation was unconformably overlying the Temburong Formation and the contact between the two formation was not exposed in Labuan and Klias Peninsula[7,13]. The Temburong formation was known as argiliceous sediment of turbidite of deep marine environment, and deposited during $Te_{1-4}$ of Oligocene[27-29]. In Early Miocene period, there were slightly change of sea level drop resulting in the deposition of the basal part of Setap Shale formation and transgression event occur during the Middle Miocene which was related to either sea level rise or the basin subsidence[14].

## Conclusion

Occurrences of limestone units from the Batu Luang were found to be significantly consisted of well-preserved larger benthic foraminifera. Eleven species of larger benthic foraminifera had been identified from the thin section analysis, The foraminifera were *Austrotrilina* sp., *Cycloclypeus* sp. *Lepidocyclina* (Eulepidina) sp., *Lepidocyclina (Nephrolepidina) parva* Oppenoorth, *Lepidocyclina (Nephrolepidina) sumatrensis* Brady, *Lepidocyclina (Nephrolepidina) verbeeki* Newton and Holland, *Miogypsinoides* sp., *Miogypsinoidesdehaarti* (van der Verk), *Spirocyclopeus* sp. and *Tansinhokella* sp., and this assemblage was indicative of $Te_5$ or Early Lower Miocene. The limestone unit was interpreted as reef flat, and shallow open marine of carbonate environment. The limestone of Batu Luang could thus be said as the the remnants of bioherm that were developed during the $Te_5$ or Early Lower Miocene (Aquitanian).

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