

Sedimentology and stratigraphy of the Miocene Kampung Opak limestone (Sibuti Formation), Bekenu, Sarawak

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Abstract: The Kampung Opak limestone, which is considered part of the Sibuti Formation, represents an approximately 44 m thick succession of regularly interbedded limestone and marl. The Kampung Opak limestone is mainly composed of mudstone and wackestone. These relatively thicker limestone beds (~20-50 cm) are interbedded with thin marls (~1-5 cm). Three facies were identified based on the percentage of quartz grains in the limestone: (1) Facies A with more than 5 % quartz, restricted to the lower part of the succession; (2) Facies B with 1 - 5 % quartz and forming the middle part of the succession; (3) Facies C with less than 1% quartz, forming the upper part of the succession. The facies generally form a fining upward succession.

The depositional environment is interpreted as a shallow marine shelf, in waters less than 40 m deep, based on sedimentary facies, ichnology and palaeontology. The fine grained facies indicate a low energy setting. The presence of the *Cruziana* ichnofacies in the limestone suggests a shallow marine environment on the shelf. The abundance of pelagic foraminifera suggests an open sea with high productivity. D/T ratio of *Amphistegina* sp. specimens from the limestone indicates a water depth of less than 40 m.

Twelve species of planktonic foraminifera were identified from the Kampung Opak limestone: *Cassigenella chipolensis*, *Globigerina venezuelana*, *Globigerinoides altiapertura*, *Globigerinoides immaturus*, *Globigerinoides obliquus*, *Globigerinoides subquadratus*, *Globigerinoides trilobus*, *Globoquadrina dehiscens*, *Globorotalia mayeri*, *Hastigerina aequilateralis*, *Orbulina bilobata* and *Orbulina suturalis*. The microfossil assemblage gives a Middle Miocene age (*Globorotalia peripheroronda* zone – *Globigerinoides subquadrata* zone, Tf stage). The Kampung Opak limestone probably represents the upper part of the Sibuti Formation. This further extends the age range of the Sibuti Formation from Early Miocene to late Middle Miocene age.

Keywords: Kampung Opak Limestone, Bekenu, Middle Miocene, planktonic foraminiferal zonation, Sibuti Formation

INTRODUCTION

Carbonates occur along the NW margin of onshore Sarawak as small, isolated bodies surrounded by shales representing the distal fringes of the Nyalau Formation in the SW and the Meligan-West Baram/Champion Deltas in the NE. The carbonates include the Subis Limestone complex and the thin limestone lenses and bodies, with associated calcareous shales, of the Sibuti Formation (*sensu* Liechti *et al.*, 1960). Unfortunately, much is not known regarding the sedimentology, stratigraphy and facies architecture of these carbonates. Rhythmically bedded limestone exposed in a quarry at Kampung Opak, near Bekenu, Sarawak, is considered as part of the Sibuti Formation. This paper provides a detailed sedimentological and biostratigraphic study of this limestone, referred to here as the Kampung Opak limestone.

The objectives of the present study are to describe the sedimentology and interpret the depositional environment of the Kampung Opak limestone and to study the stratigraphic relationship between the Kampung Opak limestone and adjacent, age equivalent deposits in Sarawak.

GEOLOGIC SETTING AND STUDY AREA

The study area is located 8 km NNE of Bekenu town and 26 km SW of Miri, Sarawak (Figure 1). It is a limestone quarry near Kampung Opak, which has been abandoned for more than 10 years and part of it has been densely

vegetated. Limestone beds are well exposed along an 800 m long NE-SW trending ridge that dips approximately 44 degrees NW. Stratigraphically, the Kampung Opak limestone is situated within the mapped Sibuti Formation (Rubiah, 1993). An Early Miocene age is indicated for the Sibuti Formation by larger foraminifera, planktonic foraminifera and pollen (Liechti *et al.*, 1960; Simmons *et al.*, 1999). The Sibuti Formation, as described by various authors (e.g. Liechti *et al.*, 1960; Wilford, 1961; Haile, 1962), is mainly comprised of clay and shale with subordinate siltstone and limestone. Liechti *et al.* (1960) interpreted an inner neritic depositional environment for the Sibuti Formation, with possible extension into a shallower, offshore environment, based on the presence of ripples. So far a detailed study of the depositional environment and biostratigraphy of limestone beds in the Sibuti Formation is lacking.

DATA AND METHODOLOGY

A sedimentological and biostratigraphic study was carried out at the Kampung Opak quarry. Limestone blocks were collected, described and polished to determine their ichnological aspect. Limestone facies were determined by examination of thin sections with a petrographic microscope. Microfossils were identified from the thin sections and used to date the limestone. The biostratigraphy was determined using the planktonic foraminifera zonation established for subtropical to tropical environments (Postuma, 1971).

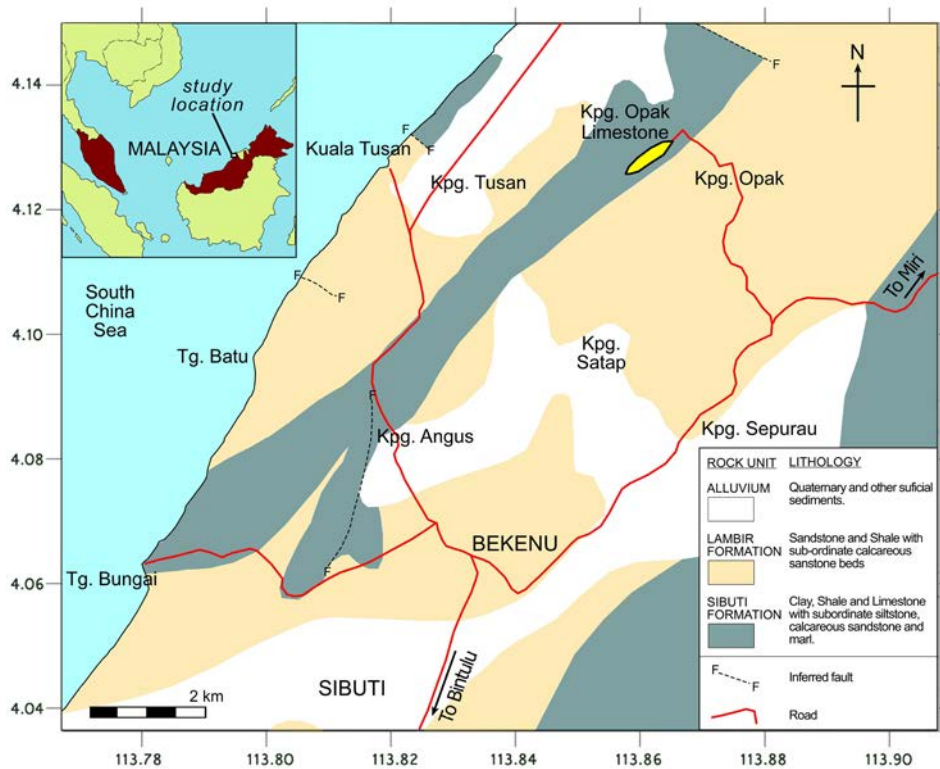


Figure 1: Location of Kampung Opak limestone within Sibuti Formation (modified from Rubiah, 1993).

SEDIMENTOLOGY

The Kampung Opak limestone is represented by an approximately 44 m thick succession composed of mud-supported wackestone and mudstone (Figs. 2A, B). The exposed succession in the quarry shows that the limestone is rhythmically interbedded with marly layers (Figure 2C). The two intercalated lithologies are distinguishable in the field, with the limestone beds being more resistant to weathering than the softer marly interlayers. The boundaries of the two lithologies are commonly sharp, but some show a gradual change from limestone to marl.

Limestone hand specimens were collected for petrological and microfacies study. These mud-supported limestones contain both carbonate and siliciclastic muds. The marly layers contain relatively more siliciclastic mud and are darker in colour. Very fine bioclast fragments and very fine sand to silt size quartz grains occur within the limestone. The limestone at the bottom of the succession is wackestone. The wackestone contains more than 10 % clasts, which include bioclasts (shell fragments and foraminifera) and terrigenous clastic grains (quartz). Mudstones are more common in the middle and upper part of the succession with less than 10 % clasts and have finer sizes of fragments and quartz grains.

Facies

Three microfacies are identified in the Kampung Opak limestone quarry succession, differentiated based on percentage of quartz grains and clast size. The three facies are stacked on top of each other. They are listed here from the lowermost to uppermost facies respectively: (1) Facies

Table 1: Summary of limestone facies in Kampung Opak quarry.

Facies	Lithology (Dunham, 1962)	Clasts (%)	Quartz grains		Interpretation	Retrogradation
			(%)	size		
C	Mudstone	< 5	< 1	silt	Very low energy environment	↑
B	Mudstone	< 10	1- 5	silt	Low energy environment	
A	Wackestone	> 10	> 5	very fine sand to silt	Low energy environment with higher clastic input	

A composed of wackestone with more than 5 % quartz; (2) Facies B composed of mudstone with 1-5 % of quartz; and (3) Facies C composed of mudstone with less than 1 % quartz. Table 1 summarises the characteristics of each facies, along with interpretations. A facies map for Kampung Opak limestone quarry is shown in Figure 3.

Facies A

Macroscopic characteristics: Regular interbedding of 25-55 cm thick, light grey to grey coloured, fine grained limestone beds alternating with 1-4 cm thick marls. Beds are planar and mostly display sharp upper and lower boundaries. However, some beds display normal grading from limestone into marl.

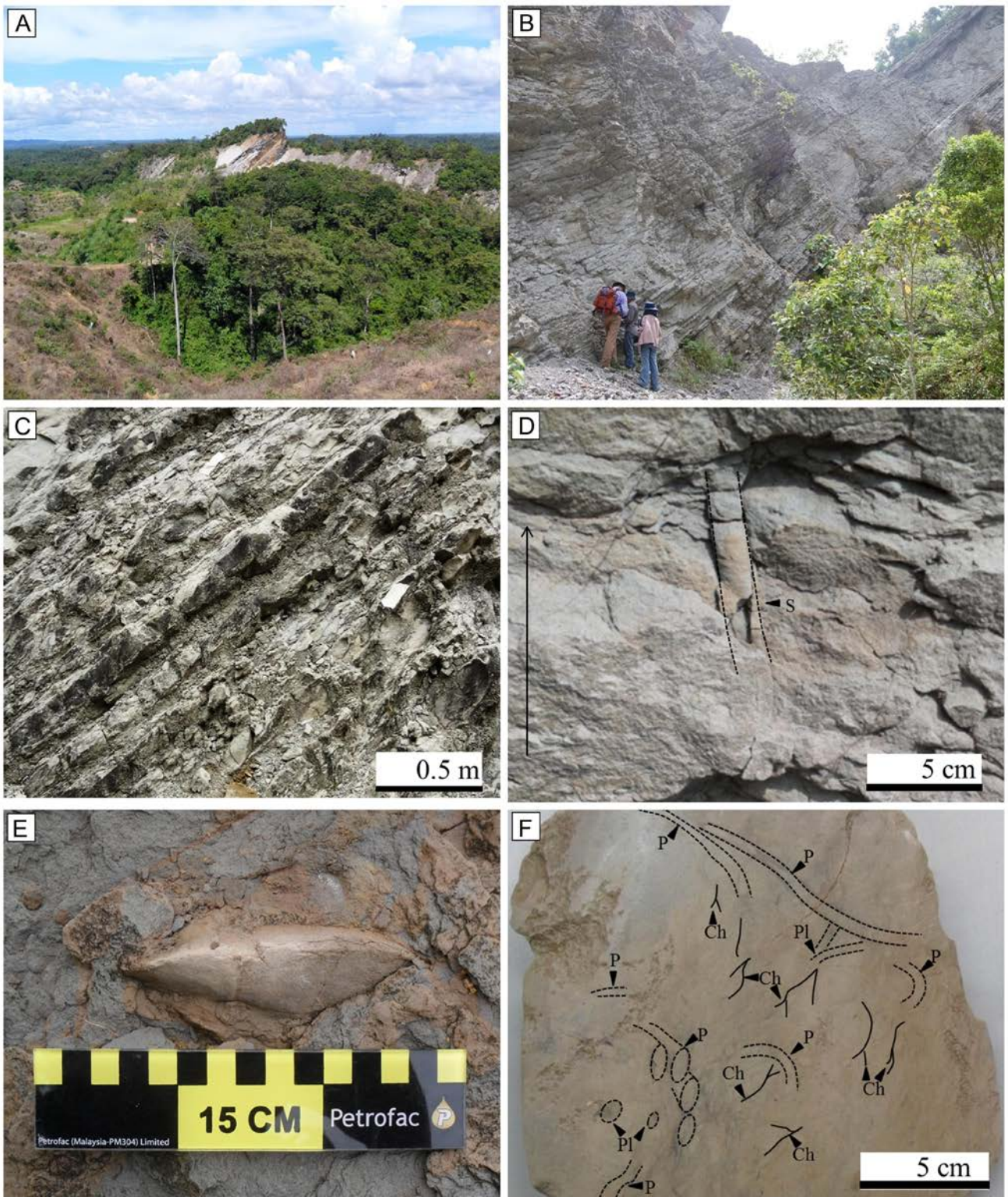


Figure 2: Kampung Opak limestone outcrop photos. (A) The limestone stands out as an approximately 800 m long ridge surrounded Sibuti Formation shales. (B) Approximately 44 degrees dipping beds of alternating limestone-marl. (C) Limestone beds are more resistant and stand out from the softer adjacent marls which show platy features. (D) *Skolithos* (S) in limestone bed; arrow showing upward direction. (E) Internal cast of a bivalve measuring 11 cm wide is oriented perpendicular to the limestone bed. (F) Polished limestone block showing *Cruziana* ichnofacies; *Chondrites* (Ch), *Palaeophycus* (P) and *Planolites* (Pl).

Ichnology: Bioturbation in Facies A ranges from moderate to strong (BI 3-5). Large (4 cm to more than 2 m in length), irregularly shaped, brownish coloured concretions are common in the limestone. Many of the concretions are tubular in shape and have a hollow centre, which is sometimes partly filled with silica and calcite cement. *Skolithos* is common in Facies A (Figure 2D).

Macrofossils: Casts of paired bivalve shells (hinge lengths ranging from 3-12 cm) are common in the limestone beds (Figure 2E). The bivalves are preserved in upright positions, perpendicular to bedding.

Microscopic characteristics: Facies A is a wackestone, based on the micrite-supported fabric and the presence of grains making up more than 10% of the rock (up to 30%) (Figure 3). Most of the grains are in the form of planktonic and benthic foraminifera. Approximately 10% of the grains are composed of subrounded to angular quartz grains, ranging in grain size from silt to very fine sand. Occasional dark patches probably represent organic matter.

Facies B

Macroscopic characteristics: Regular interbedding of 10-40 cm thick, light grey to grey coloured, fine grained limestone beds alternating with 2-12 cm thick marls. Beds are planar and mostly display sharp upper and lower boundaries. However, some beds display normal grading from limestone into marl.

Ichnology: Bioturbation ranges from moderate to strong (BI 3-5). Large irregular concretions identified as trace fossils

are also present in Facies B, but are less common compared to Facies A. Common trace fossils include *Thalassinoides*, *Planolites*, *Paleophycus*, and *Chondrites* (Figure 2F).

Macrofossils: No large fossils were identified from Facies B.

Microscopic characteristics: Facies B is a mudstone, based on the micrite matrix-supported fabric with grains making up less than 10% of the rock (Dunham, 1962) (Figure 3). Grains are mainly in the form of planktonic and benthonic foraminifera. Subrounded to angular quartz grains make up less than 5% of the grains, and are mostly silt sized.

Facies C

Macroscopic characteristics: Regular interbedding of 25-40 cm thick, light grey to grey coloured, fine grained limestone beds alternating with 1-3 cm thick marls. Beds are planar and display sharp upper and lower boundaries. Some beds display irregular bedding surfaces which grade vertically into marl.

Ichnology: Bioturbation ranges from moderate to strong (BI 3-5). Large irregular concretions identified as trace fossils are also present in Facies C, but are less common compared to Facies A. Common trace fossils include *Thalassinoides*, *Planolites*, *Paleophycus*, and *Chondrites*

Macrofossils: No large fossils were identified from Facies C.

Microscopic characteristics: Facies C is a mudstone, based on the micrite-supported fabric with grains making

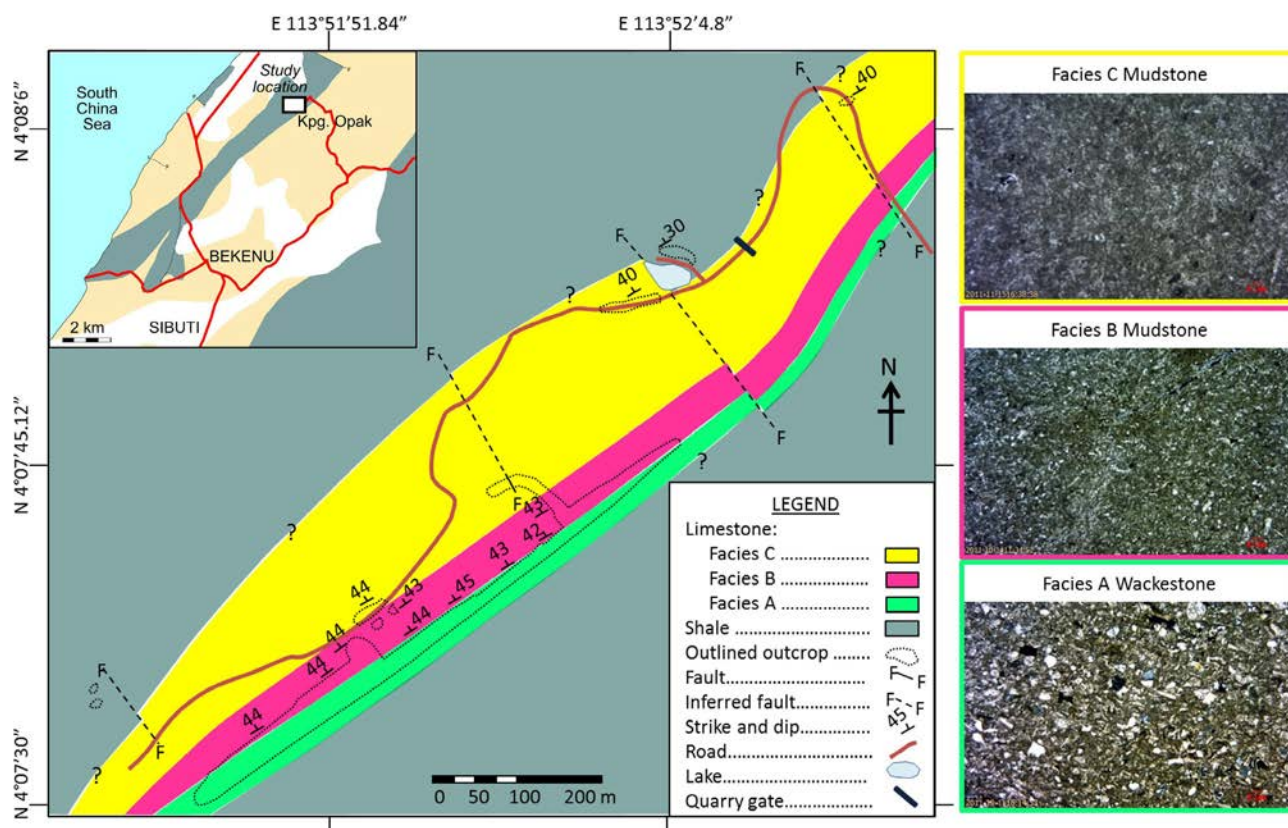


Figure 3: Facies map of Kampung Opak limestone quarry and thin-section photomicrographs of the three facies.

up less than 5% of the rock (Figure 3). Grains are mainly in the form of planktonic and benthonic foraminifera. Subrounded to angular quartz grains make up less than 1% of the grains, and are mostly silt sized. Organic matter is present as dark patches.

Facies Succession

The bedded limestone succession exposed at Kampung Opak is approximately 44 m thick. The three identified facies are vertically stacked on top of each other, with the lower beds composed of Facies A, the middle beds composed of Facies B and the uppermost beds composed of Facies C. Generally, the succession fines upward from wackestone (Facies A) to mudstone (Facies B and C) (Figure 4). Facies A in the lower part of the limestone has a relatively higher percentage of quartz grains than the overlying Facies B and C. Facies B and C have lower percentages of quartz grains, and the grain size is also finer.

INTERPRETATION

The predominance of fine grained micrite and marl indicates a low energy depositional environment. The regular interlayering of limestone and marl suggests that each bed

represents a depositional event of roughly equal magnitude. However, some limestone-marl contacts are gradational. This suggests that these regularly spaced limestone and marl beds may represent continuous deposition with fluctuating sedimentation rates, limestone beds formed during higher carbonate production and marls formed during higher clastic input periods.

Such alternations of limestone and marly layers are commonly attributed to climatic fluctuations caused by, for example, Milankovitch cycles as described by various workers (e.g. Arthur *et al.*, 1984; Sprenger and ten Kate, 1993; Bellanca *et al.*, 1996; Rehfeld *et al.*, 1998). However, regular limestone-marl interlayering may also be due to differential diagenesis, either with or without any associated climate-induced rhythms.

The limestone layers at Kampung Opak are characterized by higher carbonate content and are non-compacted, whereas the interbedded marly layers display relatively lower carbonate contents and are more compacted than the adjacent limestone beds, showing flaky and platy features. The typical non-compacted nature of the limestone beds suggests that the sediment was cemented during early diagenesis. Calcite cement was imported from an external source occluding the primary porosity of the limestones and hindering their compaction (Bathurst, 1972, 1987). The most likely sources of calcite cement were the vertically adjacent marls (Sujkowski, 1958; Eder, 1982; Walther, 1982; Ricken, 1986, 1987, 1992). Redistribution of calcium carbonate from some layers resulted in the formation of marl, while other layers were cemented to form interbedded limestone.

Some workers propose a purely diagenetic origin for some limestone-marl alternations (e.g. Hallam, 1964; Munnecke and Samtleben, 1996). It is also possible that in certain cases, subtle differences in primary carbonate content in the original sediment may have contributed to the strong lithologic contrast between the limestone and marl layers of the diagenetically altered rock (Reboulet and Atrops, 1997; Schwarzacher, 2000; Hilgen *et al.*, 2003). The initial composition of the limestone-marl sequence in Kampung Opak is believed to have been slightly different as the marly layers show more siliciclastic clay content than the adjacent thicker limestone beds. This is explained by fluctuation of climates and conditions of the depositional environment, whereby limestone beds formed during higher carbonate production and marls formed during higher clastic input periods. However, the compressed marls in between thicker limestones support the mechanism whereby the thicker and harder non-compacted limestones were cemented during early diagenesis by calcite cement from the adjacent marls, which resulted in the relatively lower carbonate content in the marl layers. The primary beddings of the sediments are more or less equal in thickness. Calcite was transferred from the marls layers into the limestone layers during early diagenesis through diffusional transport. The marl layers which have relatively lower carbonate contents were compressed later. This mechanism most likely produced the pronounced “a-b-a-b” pattern characteristic of the limestone-

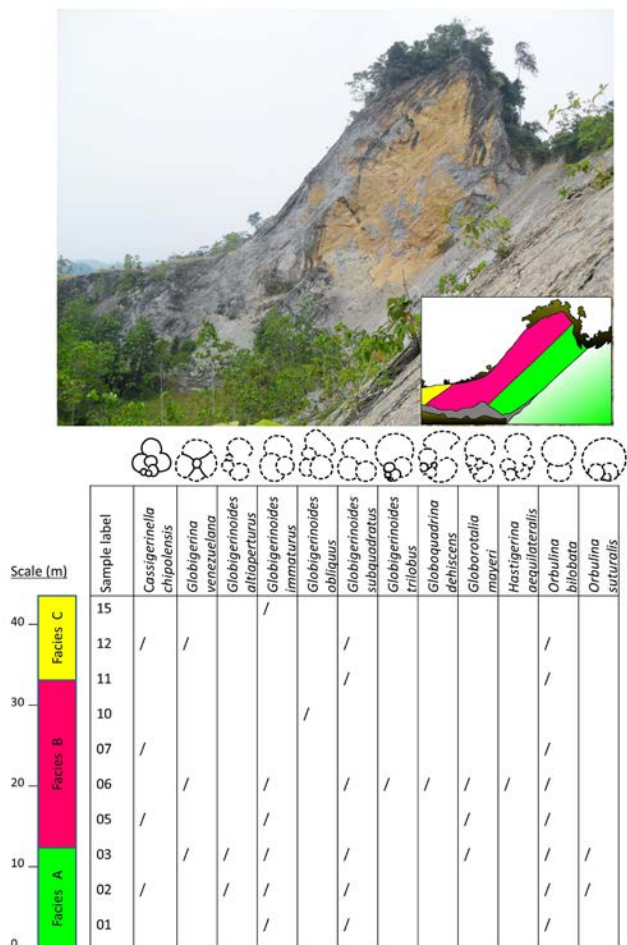


Figure 4: Kampung Opak limestone cross-section log with planktonic foraminifera sample location.

marl sequence in Kampung Opak as shown in Figure 5 (Einsele and Ricken, 1991).

The presence of abundant *Skolithos* in wackestone of Facies A is interesting. *Skolithos* is a common element of shallow marine ichnofacies, including the *Skolithos* and *Cruziana* ichnofacies (Pemberton *et al.*, 1992). It is usually associated with shifting sand substrates, e.g. tempestites or tidal dunes/ridges. However, the absence of coarse grained facies in the Kampung Opak limestone is not consistent with such an interpretation. It is also possible that the *Skolithos* in Facies A represents part of a firmground ichnofacies (*Glossifungites* ichnofacies, Pemberton *et al.*, 1992). Formation of a firm substrate is consistent with the interpretation of early cementation of the bedded limestone.

The trace fossil assemblage in Facies B and C are representative of the *Cruziana* ichnofacies. This ichnofacies is characterized by a mixed association of vertical, inclined, and horizontal structures, generally moderate to high diversity and abundance and common overprinting of trace fossils (Pemberton *et al.*, 1992). The depositional conditions for the *Cruziana* ichnofacies range from long-term moderate-energy levels in shallow water below fair-weather wave base but above storm wave base, to generally low-energy levels in deeper, quieter waters (Pemberton *et al.*, 1992). Overall, the trace fossils indicate a shallow marine, low energy depositional environment for the Kampung Opak limestone.

The sedimentary succession at Kampung Opak gradually fines upward from wackestone with relatively higher terrigenous clastic input displaying coarser grains (Facies A), into mudstone with gradually lesser terrigenous clastic input displaying finer grains (Facies B and C). The gradual decrease in clastic input and clastic grain size is interpreted as representing decreasing energy through time, probably brought on by relative sea level rise. Thus, the succession at Kampung Opak is interpreted as transgressive, with the vertical facies change reflecting lateral facies change from more proximal (Facies A) to more distal facies (Facies B and C), relative to shoreline. A similar trend is also observed in the trace fossil assemblage, where they gradually change from vertical trace fossils in the lowermost Facies A (indicative of a shallower, higher energy setting) into a *Cruziana* ichnofacies dominated by horizontal trace fossils in Facies B and C (indicative of a lower energy, more distal setting).

BIOSTRATIGRAPHY

One hundred thin sections were studied to determine the biostratigraphy of the Kampung Opak Limestone.

Twelve species of planktonic foraminifera were found in Kampung Opak Limestone: *Cassigenella chipolensis* CUSHMAN AND PONTAN, *Globigerina venezuelana* HEDBERG, *Globigerinoides altiapertura* BOLLI, *Globigerinoides immaturus* LEROY, *Globigerinoides obliquus* BOLLI, *Globigerinoides subquadratus* BRÖNNIMANN, *Globigerinoides trilobus* REUSS, *Globoquadrina dehiscens* CHAPMAN, PARR AND COLLINS, *Globorotalia mayeri* CUSHMAN

AND ELLISOR, *Hastigerina aequilateralis* BRADY, *Orbulina bilobata* D'ORBIGNY and *Orbulina suturalis* BRÖNNIMANN.

Nine genera of benthic foraminifera were identified from the Kampung Opak limestone: *Nodosaria* sp., *Amphistegina* sp., *Uvigerina* sp., *Gavelinella* sp., *Fursenkoina* sp., *Cibicides* sp., *Pseudolituonella* sp., *Eggerella* sp., and *Textularia* sp..

Age of the Kampung Opak limestone: The planktonic foraminiferal zonation of Postuma (1971) was adapted in this study. The planktonic foraminiferal assemblage ranges from the *Globorotalia peripheroronda* zone to *Globigerinoides subquadratus* zone (early to late Middle Miocene age, Tf stage of the Far East Letter Classification) (Figures 4 & 5). The occurrence of *Orbulina bilobata* and *Orbulina suturalis* in the Kampung Opak pelagic limestone marks the *Orbulina datum* (*Globorotalia peripheroronda* zone) and confirms the Middle Miocene age of the limestone unit. The species *Globorotalia mayeri* further confines the age of the limestone within the Middle Miocene (before *Globorotalia siakensis* zone). However, there is a species which does not fit into the age range concluded. *Hastigerina aequilateralis* has a stratigraphic distribution from lower part of *Globorotalia siakensis* zone to Recent. Therefore, it is suggested that the *Hastigerina aequilateralis* could possibly range from an even earlier *Globigerinoides subquadratus* zone onwards.

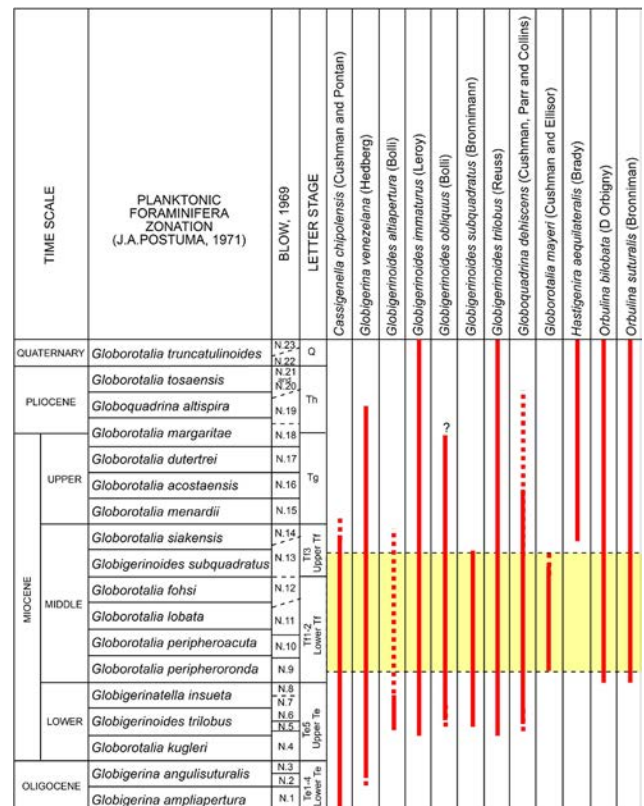


Figure 5: Biostratigraphy of Kampung Opak limestone based on planktonic foraminiferal zonation. An early to late Middle Miocene age (within *Globorotalia peripheroronda* zone to *Globigerinoides subquadratus* zone) for the limestone is concluded. (from Postuma, 1971)

AMPHISTEGINA SP.: PALEOWATER-DEPTH INDICATOR

Benthic foraminifera are abundant in the Kampung Opak limestone. Beavington-Penney & Racey (2004) studied the ecology of extant nummulitids and other larger benthic foraminifera and showed that the test shape of *Amphistegina* sp. is influenced by the interaction between the metabolic requirements associated with algal symbiosis, hydrodynamic factors and light.

Larsen (1976), in a study of Recent amphisteginids from the Gulf of Aqaba, cited by Beavington-Penney & Racey (2004), suggests that interspecific changes in the diameter to thickness ratio (D/T ratio) of four species can be related to the level of incoming light. He identified three groupings: the *Amphistegina lobifera* group, the *Amphistegina lessonii* group and the *Amphistegina papillosa*-*Amphistegina bicirculata* group. A general tendency towards increasing D/T ratio with depth was observed. This relationship is most clear in *A. lessonii*, where shallow-, medium- and deep-dwelling groups were identified. He suggests that the grouping of shallow populations sampled in dense *Halophila* vegetation (giving a shallow, shadowed biotope), together with medium depth populations, indicates that light is the determining factor for the shape index.

The D/T ratio for *Amphistegina* sp. of the Kampung Opak limestone is calculated and plotted in Figure 6. Most of the *Amphistegina* sp. display a D/T ratio value from 2 - 2.5, which is very similar to the group *A. lessonii* of Larsen, 1976 from Gulf of Aqaba. *A. lessonii* is characteristic of water depths of less than 40 m. This comparison also shows that the depositional environment for Kampung Opak limestone was most probably shallow marine, whereby sunlight can penetrate into the sea water for symbiont activity, i.e. within the photic zone (< 200 m below sea-level).

DISCUSSION

The Sibuti Formation is stratigraphically located below the sandstone and mudstone of the Middle Miocene Lambir Formation in the Lambir Hills area (Simmons *et al.*, 1999; Hutchison, 2005). Previous studies indicate an Early Miocene to early Middle Miocene age (Stages Te_5 to Tf_1) for the Sibuti Formation (Liechti *et al.*, 1960). In lithostratigraphic terms, the Kampung Opak limestone is considered part of the Sibuti Formation. Planktonic foraminifera collected from the Kampung Opak limestone give a Middle Miocene age (Stages Tf_{1-3}). This extends the biostratigraphic age of the Sibuti Formation from the Early Miocene into the late Middle Miocene.

The Lambir Formation represents part of a large delta system in NE Sarawak during the Middle Miocene, which is known as the West Baram/Champion Delta system (Simmons *et al.*, 1999; Hutchison, 2005). Biostratigraphy indicates that during the Middle Miocene, the sandy Lambir Formation was replaced by calcareous shale and limestone of the Sibuti Formation in the SW. The Sibuti Formation represented an area of fine grained siliciclastic deposition through suspension, and significant carbonate deposition, located

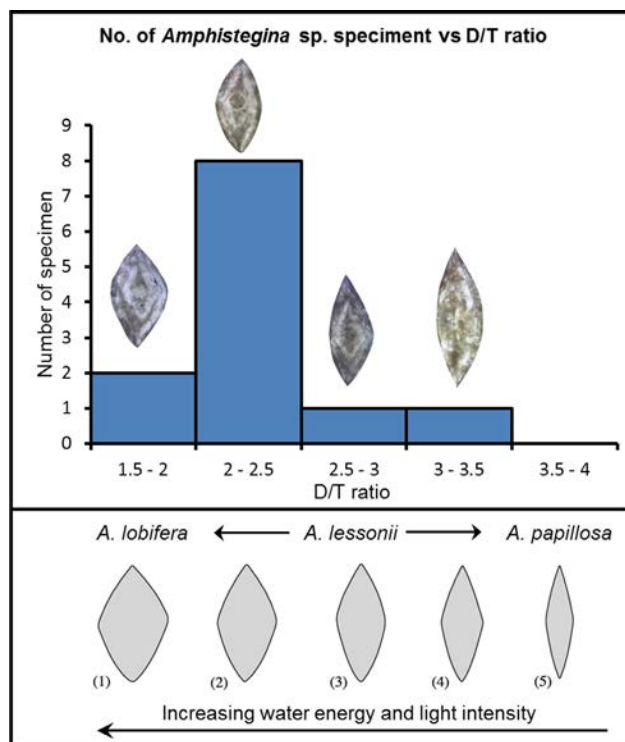


Figure 6: Column chart of number of *Amphistegina* sp. in Kampung Opak limestone vs D/T ratio. Data shows that the majority of the amphisteginids fall within the range of 2 – 2.5, which is similar to the ratio of *A. lessonii*. Silhouettes illustrating the range of shapes in three Indo-Pacific species of *Amphistegina*: (1) *A. lobifera*, high-energy, high-light environment; (2) *A. lessonii*, moderate-energy, high-light environment; (3) *A. lessonii*, low-energy, moderate-light environment; (4) *A. lessonii*, low-energy, low-light environment; and (5) *A. papillosa*, low-energy, very low light environment (modified from Hallock and Glenn, 1986).

away from main clastic input in the West Baram Delta further towards the northeast. Previous micropalaeontological work on the shales of the Sibuti Formation indicate a middle to outer neritic depositional environment in water depths of less than 50 m (Simmons *et al.*, 1999). Microfossils from the Kampung Opak limestone also indicate a shallow marine, neritic environment. However, fossils from the limestone indicate a slightly shallower water depth (less than 40 m).

The Subis Limestone of the Tangap Formation (Liechti *et al.*, 1960) is located approximately 34 km from the Kampung Opak limestone, and may provide further clues regarding the depositional environment. The Subis Limestone is an older (Early Miocene) carbonate, surrounded by fine grained siliciclastics of the Tangap, Setap and Nyalau Formations (Liechti *et al.*, 1960). It is characterised by coralgal and coralgal reef limestone, interpreted as representing inner neritic, isolated biohermal growth of shoal reef type, in water depths of between 30-60 m (Liechti *et al.*, 1960). Interestingly, the main reefal body of the Subis Limestone grades laterally into thin limestone beds with associated marls and calcareous shales. This distal facies resembles the facies observed in the Kampung Opak limestone. Therefore, it is most likely that the Kampung Opak

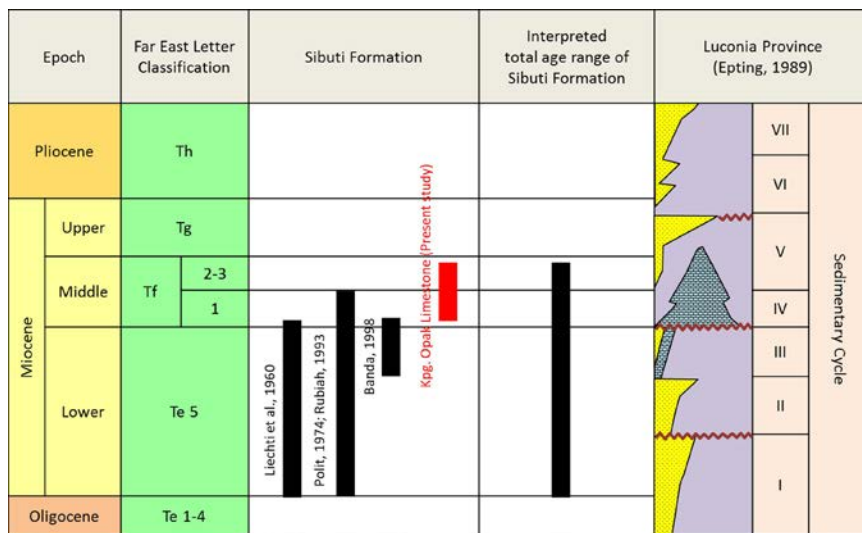


Figure 7: Correlation between Kampung Opak limestone of the Sibuti Formation and the Central Luconia Province. (note the extension of Sibuti Formation into the late Middle Miocene age and the adjacent main carbonate growth phase in the Luconia Province).

limestone represents the distal margins of a similar type of carbonate platform, located in intermediate depths between the carbonate platform and middle to outer neritic shales.

The combination of bedded mudstone and wackestone, absence of nodular fabric, shallow marine softground *Cruziana* ichnofacies and a shallow water fossil indicator in the form of *Amphistegina* (water depth of less than 40 m) lead to a low energy, shallow marine shelf interpretation for the Kampung Opak limestone. A more precise interpretation is not possible at this stage, due to the limited extent of the outcrop. However, the planktonic foraminifera-bearing wackestone, mudstone and marls with associated bivalves resemble Middle-Outer Ramp facies (Jones, 2010). Such an interpretation is also consistent with the presence of occasional normal graded beds, which may represent distal tempestites. This interpretation requires more work, but if this is the case, the wave base must have been very shallow during the Middle Miocene in order for distal facies to be deposited in water depths of less than 40 m.

Widespread development of carbonate platforms occurred further offshore of the study area, in the Central Luconia Province (Mohammad Yamin and Abolins, 1999; Hutchison, 2005). These carbonates formed isolated platforms and pinnacles on topographic highs surrounded by deep water. Widespread carbonate development on the Central Luconia Province during the Middle Miocene was due to extensive development of horst and graben topography as a result of rifting of the South China Sea marginal basin (Hutchison, 2005). The relationship between the Central Luconia Province carbonates and the Sibuti Formation carbonates is still unclear, as they are located far away from each other (the southernmost Central Luconia carbonate platforms are about 50 km N of the onshore Sibuti Formation exposures).

CONCLUSION

The Kampung Opak limestone represents an approximately 44 m thick succession of regularly alternating fine grained limestone (wackestone and mudstone) and marl

beds. The combination of fine grained facies, *Cruziana* ichnofacies and shallow marine benthic foraminifera indicate a shallow marine shelf depositional environment in water depths of less than 40 m. The biostratigraphic study indicates a Middle Miocene age (*Globorotalia peripheroronda* zone – *Globigerinoides subquadrata* zone) based on planktonic foraminiferal zonation. Comparison with the nearby Subis Limestone suggests that the bedded limestone facies of Kampung Opak limestone probably represents the distal margins of a carbonate platform.

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