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# The Setap Shale Formation on either side of the Baram Line Divide: Facies aspects and tectonic implications

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**Abstract:** Intermittent field work carried out over the years has revealed that the Oligocene to Miocene Setap Shale formation is of different character on either side of the (West) Baram Line in northern Sarawak. Within the Baram Delta Block (BD), the sequence contains shallow water carbonates, a green sand and siltstone rich in foraminifera and other marine biota. On the other hand, to the south of the Baram Line, in the Tinjar/Luconia Block (TL), the Setap Shale contains multiple slumps and turbidite complexes. Shallow water carbonates are missing within TL outcrops. The intriging contrast in paleo-environment and facies variations point to a complex tectonic activity likely related to the Baram Line strike-slip movements during the time of Setap Shale deposition. However, the source of the Setap Shale sediment in the northern Sarawak region remains relatively unknown, a conundrum to be resolved with further research studies.

**Keywords:** Setap Shale, Oligo-Miocene, Sarawak, claystone

## INTRODUCTION

A mighty clay sequence, roughly ranging from Oligocene to Mid Miocene in age is deposited in the foreland basins of NW Borneo, and is called Setap Shale after the Bulak Setap wells 1, 2 and 3 on Bukit Peninjau (Liechti *et al*., 1960, p. 326-329). The third Bulak Setap well drilled in 1952 by Sarawak Shell Berhad penetrated a sequence of 11633 feet of Cycles III and II, dominated by marine shales which is lean in organic content (Barrett & Kuek, 1986). Hutchison (2005) describes the sequence as follows:

"The Setap Shale formation is a thick, extensive and monotonous succession of shale with subordinate thin sandstone beds and a few thin lenses of limestone. It occupies the country from Batu Niah northeastwards to the base of the Lambir Hills, and inlands towards Limbang and beyond Mulu. The environment of deposition is wholly, ranging from inner, in the west, to middle and outer neritic marine eastwards. The common lithologies are grey shale, grey mudstone, sandstones and a few limestones."

The Setap Shale is mostly overpressured in the subsurface. It is abnormally pressured in the Jerodong field in Brunei, both in the core of the structure, and on the flank (Chapman, 1983; Sandal, 1996). It forms mud volcanoes in Brunei and Limbang, and in Bulak Setap (Wannier *et al*., 2011). The Karap mud volcano on the Engkabang-Karap carbonate anticline was visited and described by Kessler (2007) and summarised by Jong *et al*. (2016). A simplified geological map, showing the most important tectonic features and outcropping stratigraphic intervals is shown in Figure 1. Figure 2 shows a chrono-stratigraphic summary of the major formations of the Miri Zone covering northern Sarawak and the neighbouring Brunei area.

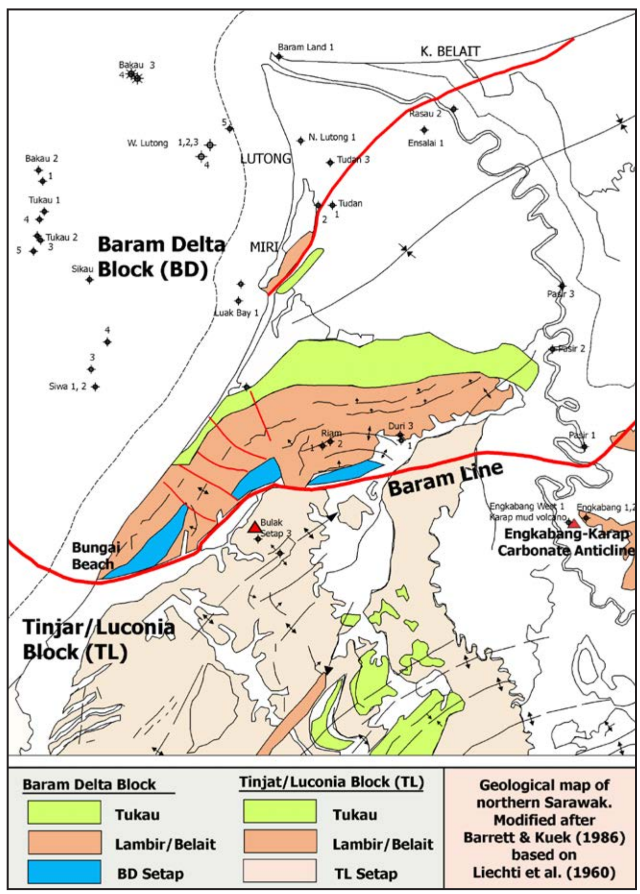


**Figure 1:** Simplified and updated geological map of the study area.

In addition to the availability of published data by Wannier *et al*. (2011), fieldwork carried out in the greater Miri area from 2004 to 2010, and a recent visit to a fresh outcrop in 2018 lead to the documentation of several new outcrops mainly along roadsides (Kessler, 2005, 2006 & 2009a; Kessler & Jong 2016a, 2017a & 2018). This field studies sparked a hypothesis that the Setap Shale south of the Baram Line, located in the Tinjar/Luconia Block (now called TL Setap) was markedly different in terms of facies and depositional environments from the Setap Shale found

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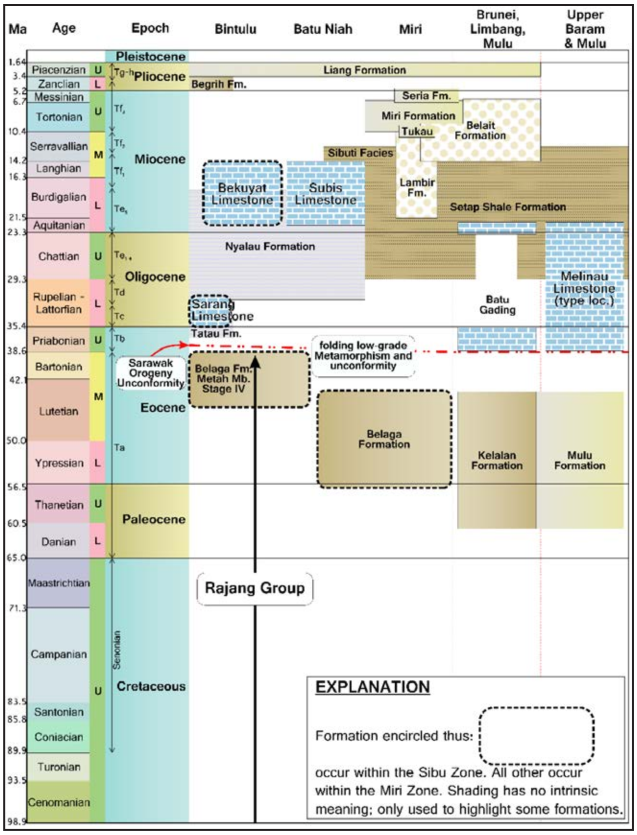


**Figure 2:** Chrono-stratigraphic summary of the major formations of the Miri Zone covering northern Sarawak and the neighbouring Brunei area. The Upper Cretaceous to Upper Eocene Rajang Group (flysch) forms the Sibu Zone and underlies the Miri Zone. It is noted that the sandy costal and shallow marine sediments of the Oligocene to Lower Miocene Nyalau Formation to the south of the study area is co-eval with the deposition of the Setap Shale. From Kessler & Jong ( 2016a), modified after Hutchison (2005, Figure 22).

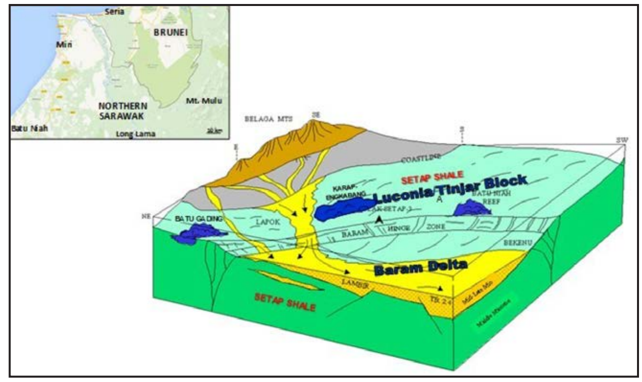


**Figure 3:** Schematic block diagram with a regional reconstruction of Late Miocene/Pliocene times of northern Sarawak. The Luconia/Tinjar Block constitutes the foot-wall, the Baram Delta the hanging-wall north of the Baram Hinge Zone (Baram Line). The latter constitutes an important facies boundary with carbonates dominate in Luconia/ Tinjar, and clastics in the Baram Delta. It is noted that the Setap Shale south of the West Baram Line, located in the Tinjar/Luconia Block is different in terms of facies from the Baram Delta Block, given it contains multiple distal turbidite sequences pointing to a neritic depositional environment. However, the Setap Shale in the Baram Delta Block as investigated in the S-Bend profile is clearly restricted shallow marine. Modified after Kessler (2009) and Jong *et al*. (2016).

in the Baram Delta Block (now called BD Setap) (Figure 3). It was noted at that time by Kessler (2009a) that the Setap Shale south of the Baram Line contained turbidite sequences, and slumped coastal sandstone olistoliths are pointing towards a neritic depositional environment (Kessler & Jong, 2016a, 2017a). The Setap Shale north of the Baram Line, however, hosted carbonate bodies such as shallow water carbonate shoals and oyster reefs (Kessler & Jong, 2018). Additional road constructions between Beluru and Long Lama allowed to substantiate the different facies signature further with additional details noted (Kessler & Jong, 2015a).

In March 2018, we discovered, on the occasion of an industry petroleum training class, a new carbonate outcrop on the Coastal Road (Kessler & Jong, 2018), and located in the Baram Delta Block. This profile clearly shows a restricted shallow marine sequence and bears a strong resemblance with a nearby Opak quarry section (Khor *et al*., 2014) and the Sibuti area outcrops (estimated 7 km to the northwest; Nagarajan *et al*., 2017). This latter outcrop, called S-bend, was combined with a near-by profile at the Bekenu Internment Camp (Figure 4), and the logged sequence measures 230 m long. With the presence of one good profile section it is now possible to achieve a good comparison with the long profile section (Figure 5) of the Long Lama road (Kessler & Jong, 2015a), and other minor occurrences.

## FACIES COMPARISON

As we noted lateral facies differences, we decided to address the problem by labeling the Setap Shale according to facies and area. The northern outcrops contain carbonate intervals, and lie north of the Baram Line divide (BD Setap). The southern outcrops (TL Setap), however do not contain any significant carbonate intervals, at least not in the studied outcrops immediately south of the Baram Line, but instead mostly turbidite sequences (Figure 6). As shown in Figure 3, the BD Setap and the TL Setap lie roughly next to each other, and are divided by the Baram Line. This lineament, however, is not easy to track, the course of which is still being discussed (Cullen, 2010; Kessler, 2009b; Kessler & Jong, 2016b). An overview index map for picture locations near Bungai Beach is shown in Figure 7.

### a) The Baram Delta "BD Setap" Facies

Figure 4 shows a composite Setap Shale profile, formed by black and grey shales, a few marly carbonate banks, plus several thin sandy passages and reddish concretion horizons. Greensand horizons are located just beneath the Base Lambir Unconformity (= Mid-Miocene Unconformity in places). In the so-called S-Bend location (Figure 8a), we logged an intriguing transition leading from massive, yet marly limestone to thin-bedded carbonate and claystone beds to massive, brittle shale. This transition points to a gradual change of sedimentary environment, possibly a change of sea level and/or water chemistry, which eventually

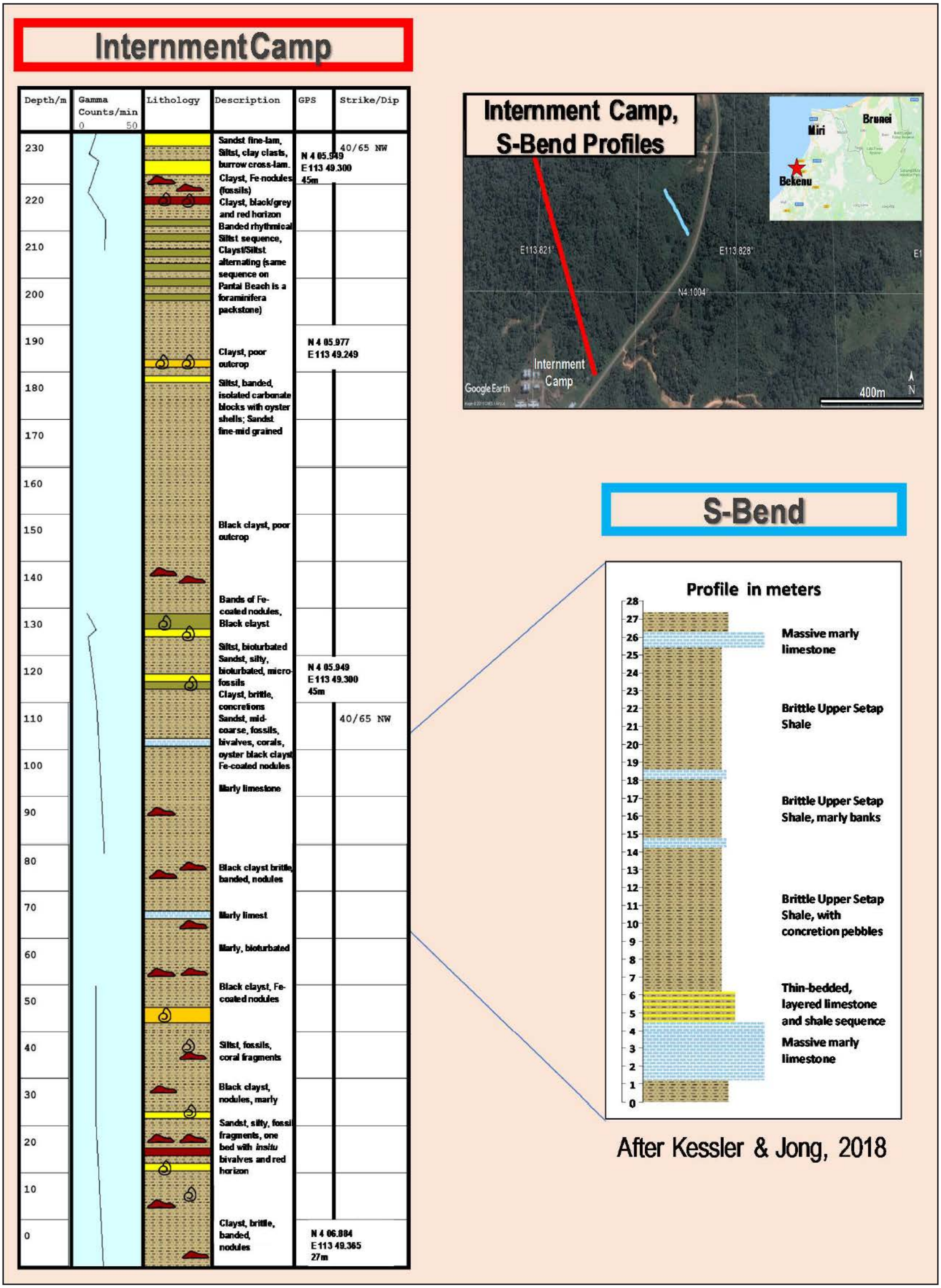


**Figure 4:** Setap Shale profiles near Tusan in Baram Delta Block (BD Setap).

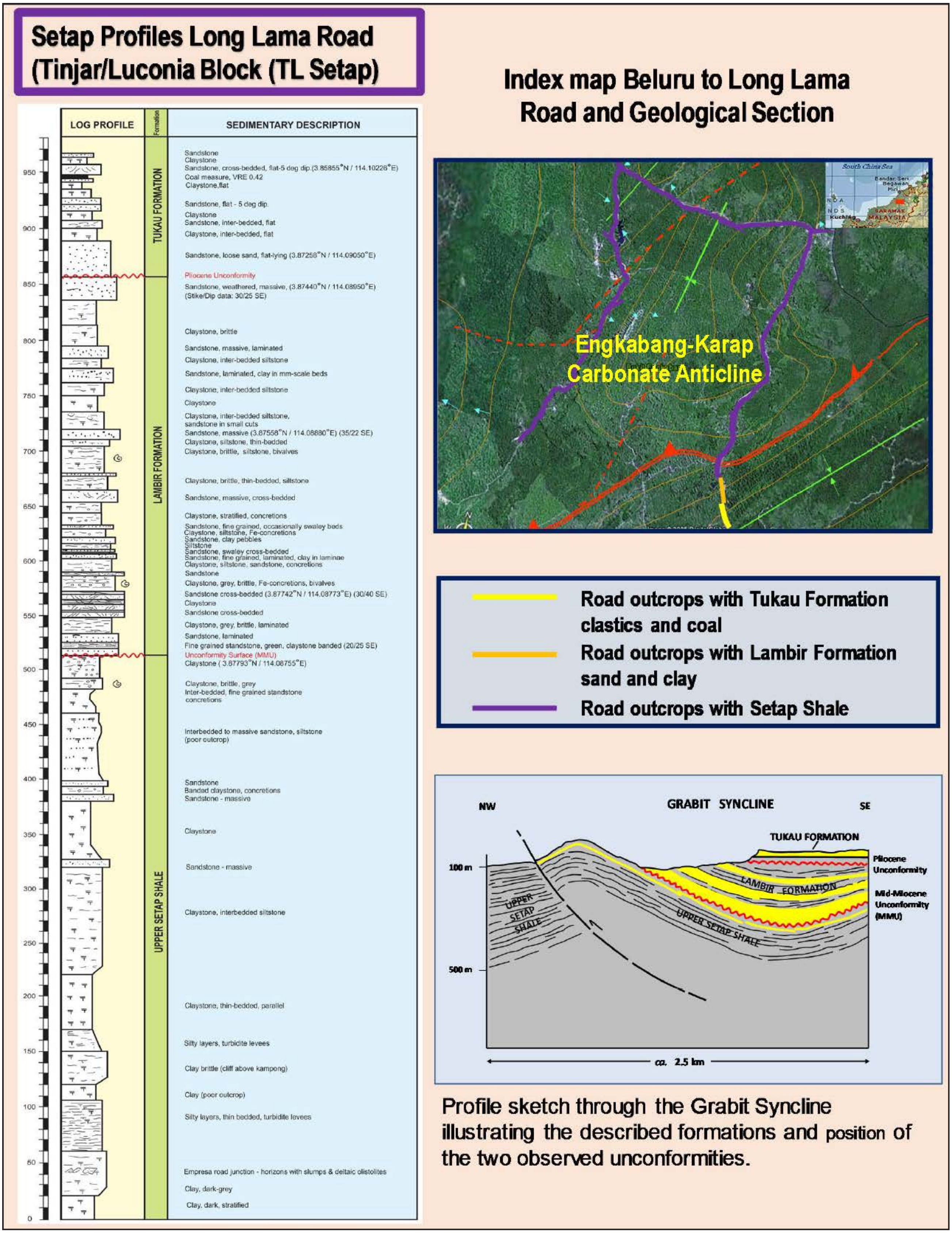


**Figure 5:** A logged Setap Shale profile with younger Lambir and Tukau formations along Beluru to Long Lama Road in Tinjar/Luconia Block (TL Setap). From Kessler & Jong (2015a).

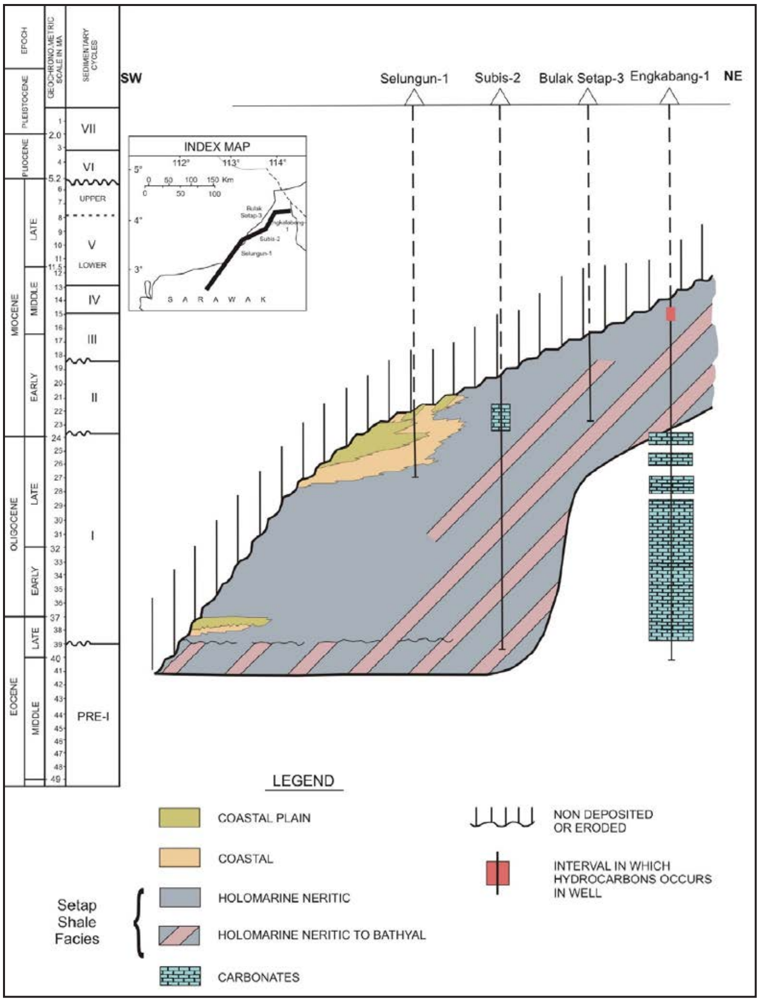


**Figure 6:** Tinjar Province schematic time-stratigraphic cross section (modified after Barrett & Kuek, 1986).

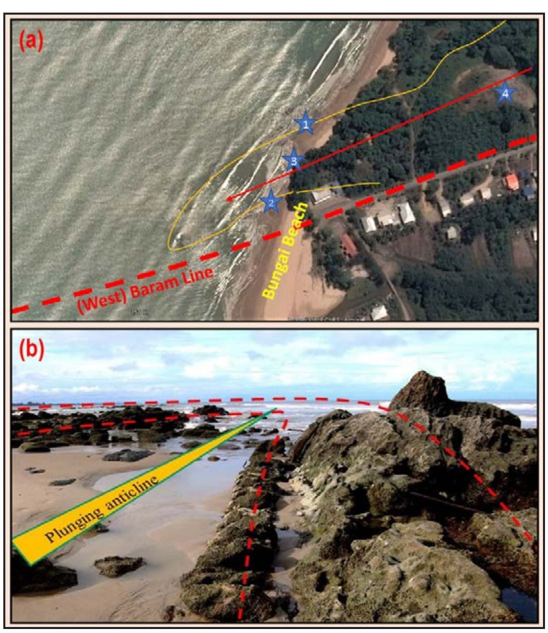


**Figure 7:** BD Setap outcrops in the core of the plunging Bungai Beach Anticline. (a) A location index map: star symbols: 1,2 = outcropping foraminifera greensands (see bottom photo); 3 = blocks formed by ostreid boundstone (Figure 9); 4= folded Sibuti Formation marl. (b) Outcropping sequence of Upper Setap Shale greensands at low tide.

stopped carbonate production. It is also noted that the rocks are fossiliferous, and detailed investigation of the marine species might reveal further interesting paleo-environmental indications during this time of carbonate growth in northern Sarawak (e.g., Kessler & Jong, 2017a).

Furthermore, a number of larger and spotty carbonate outcrops are noted:

- The Opak quarry (Figure 8b), a 44 m thick unit of marly limestone, as described by Khor *et al.* (2014): "The Kampong Opak limestone, which is considered part of the Sibuti Formation, represents an approximately 44 m thick succession of regularly interbedded limestone and marl. The 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

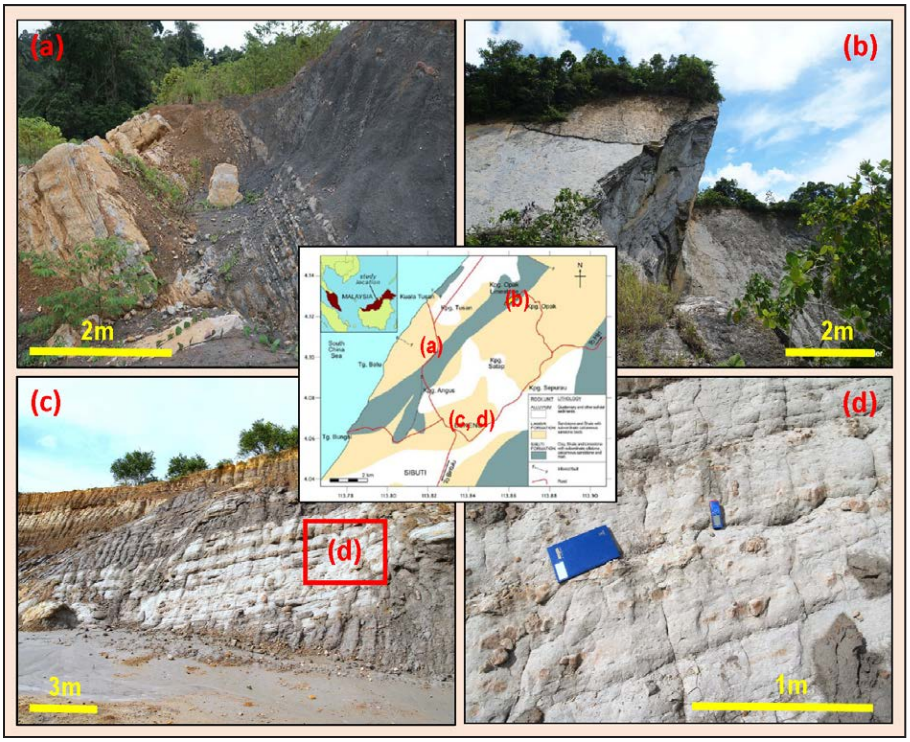


**Figure 8:** BD Setap carbonate facies within the Upper Setap Shale. (a) Lower carbonate unit in the Upper Setap Shale, S-Bend profile (Kessler & Jong, 2018). The massive marly carbonate developed upwards into a sequence of thin-bedded limestone, than calcareous claystone. (b) The Opak quarry is a several hundred meters long lense in the Upper Setap Shale. The carbonate unit contains a rich shallow marine fauna indicating a paleo-water depth of less than 40 m (Khor *et al*., 2014). (c) The marly limestone unit is located within the uppermost BD Setap near Kampong Sepurau in Bekenu district. The outcrop contains a shallow marine fauna of bivalves, gastropods, and, more rarely, coral. (d) In a close-up view, the unit contains reddish concretions with fossil remnants. Location map from Khor *et al*. (2014).

and paleontology. 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 Kampong 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: Figure 2). The Kampong 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".

- Several small outcrops of marly rock in the Sibuti area (Nagarajan *et al*., 2017); these outcrops (Figures 8c-d) are banked and contain shallow water fauna such as *gastropoda*, *lamellibranchiate* and (more rarely) coral. Hutchison (2005, p.125) characterises the Sibuti Formation as follows: "The calcareous mudstone contains foraminifera and crabs. The environment was shallow marine, as indicated by an abundance of gypsum. The sequence therefore shows a distinct shallowing upwards transition from marine to coastal environments."
- Isolated blocks of oyster reef limestone NE of the Bungai Beach (Figure 9). These should not be confused with Batu Niah boundstone blocks on the beach, which were laid to form a protection against high tide and surge; we mapped the oyster boundstone blocks before the coastal defense works were carried out in *ca.* 2011. However, this work remains unpublished.

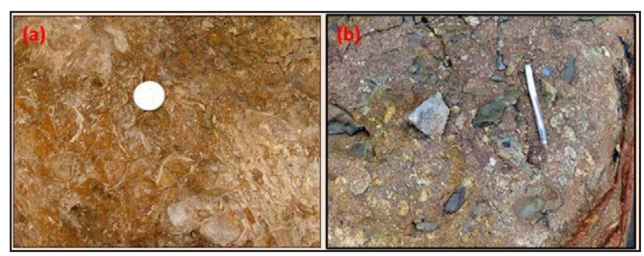


**Figure 9:** BD Setap fossil record of the uppermost Setap Shale beds with a 20 cent coin for scale. (a) In-situ Ostreid boundstone, Bungai Beach. (b) Carbonate boulders are remnants of isolated oyster patch reefs with a pen for scale. See Figures 1 and 7 for Bungai Beach location.

- Near to the Base Lambir Unconformity, on Bungai Beach, the sequence contains one fossiliferous green sand horizon. The latter contains large benthonic foraminifera, miliolid forams and marine shell debris and biota (Figure 10). The same horizon was sampled and analysed by Lesslar & Wannier (1998) in the Lambir Hills (Figure 11). The green sand appears to indicate fully marine conditions just before clastic deposition of the Lambir Formation (Cycle IV) started.
- Possibly, a carbonate buildup offshore, drilled with mixed success by Sarawak Shell Berhad called A1 (Kessler & Jong, 2017a). The well penetrated 800 feet (245m) of tight carbonate overlaid by Cycles II-V clastics section dominated by silty/shaly stratigraphy of the Setap Shale. The Cycle II carbonate has open

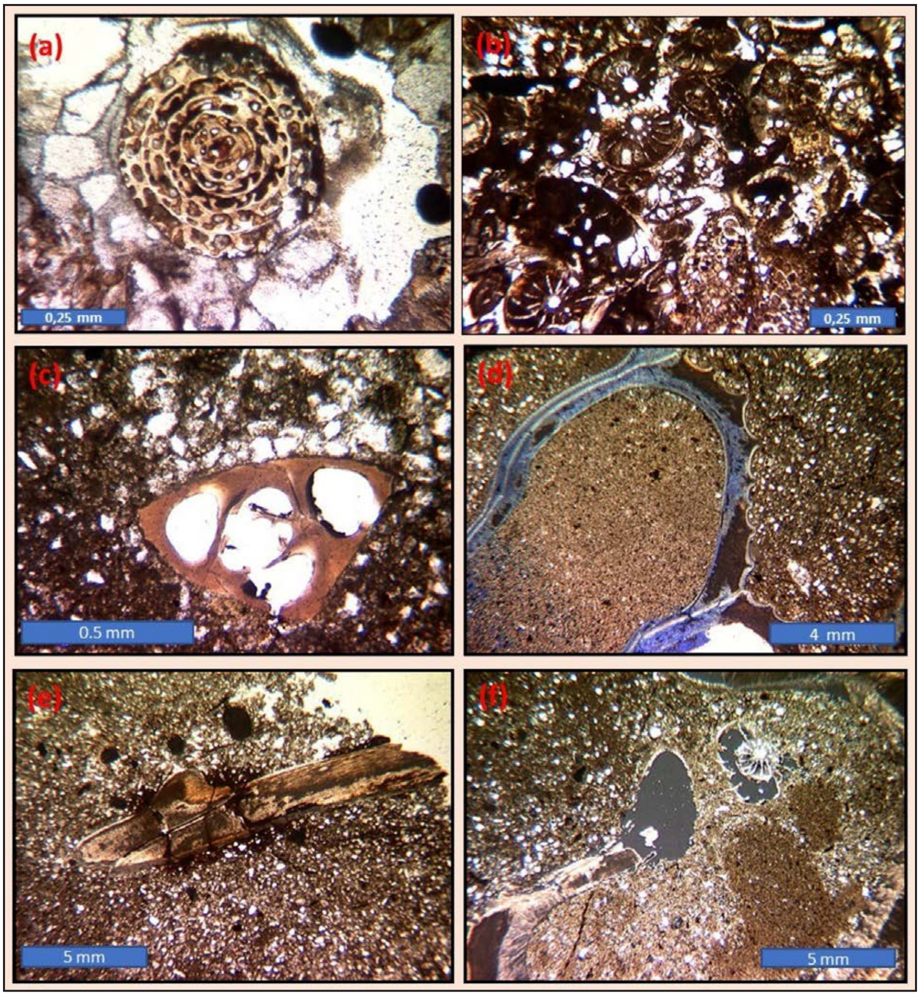


**Figure 10:** BD Setap fossil record of the uppermost Setap Shale greensand on the Bungai Beach (see Figure 7 for location map). Thin section provided by Sarawak Shell Berhad. (a) Thin section showing a quartz grainstone and a large benthonic foraminifera, *?Alveolina sp*., from the greensand beneath the Base Lambir Unconformity. (b) Thin section showing a grainstone formed by foraminifera and shell fragments. The dark staining of the forams may point to micritisation originating from fungi; greensand beneath the Base Lambir Unconformity. (c) *Quinqueloculina sp*., sub-angular grain quartz sand. (d) Large gastropod with micritised shell and micrite fill. (e) Thin section with phosphatic material. (f) Shell with peloids and foraminifera.

marine fauna within a platform margin environment of deposition. The BD Setap above the carbonate contains fluvio-marine influences, and shallow-up from inner neritic to lower coastal plain. The younger Cycles III-IV shales are holomarine to inner neritic.

According to van Hattum *et al*. (2013), the Setap Shale formation of SW Sabah, and in the vicinity of the BD is also a monotonous marine succession of dark clay and shale with minor intercalations of thin-bedded sandstone and siltstone (Wilson & Wong, 1962), and contains shallow-marine *Skolithos* burrows. In summary, the current data speak for a wide and shallow shelf area, in which carbonate and clay, and more rarely sand deposition occurred. The presence of oyster reefs might point to a partly brackish environment, as seen in the contemporary Baram Delta setting.

### b) The Tinjar/Luconia "TL Setap" Facies (Figures 5, 12-15)

Kessler (2009a) divided the TL Setap into two units:

- The lower unit is called "Black Setap Shale" and is formed by more than 2000 m of black, and brittle shale. The sequence appears not to contain any calcareous fossils, and most likely the calcareous content may have been removed during diagenesis. The presence of minor turbidite channels and levees is noted. One can observe gravity-induced folding, which points to a high angle of sediment deposition. In summary, the Black Setap Shale appears to be a deepwater sediment, with characteristics typically of a slope environment.
- The upper 500 -1000 m are called "Grey Setap Shale", given its grey color and traces of carbonate cement and shell fragments (Kessler & Jong, 2015a). Fe-stained concretions are common. The sequence contains turbidite complexes composed by very constrained sandy thalweg cores, and far larger levees. Within the latter we observe fossil debris and also trace fossil marks. One can observe the presence of slumped olistolites composed of sandstone that must have been sliding down from a coastal or at least sandy shelfal area (Figure 13). This would indicate the presence of a high relief gradient but also the vicinity of a probably narrow shelf and coast.

### c) TL Setap surrounding old carbonate stocks as country rock

- The Gunung Subis and Suai (Kessler & Jong, 2017a). The Subis limestone of the Tangap Formation (also called Subis Limestone Formation; Dedeche *et al*., 2013) represents a complex bioherm body of some 25 km$^2$. In well Subis-2, 945 m of carbonates, marls, and

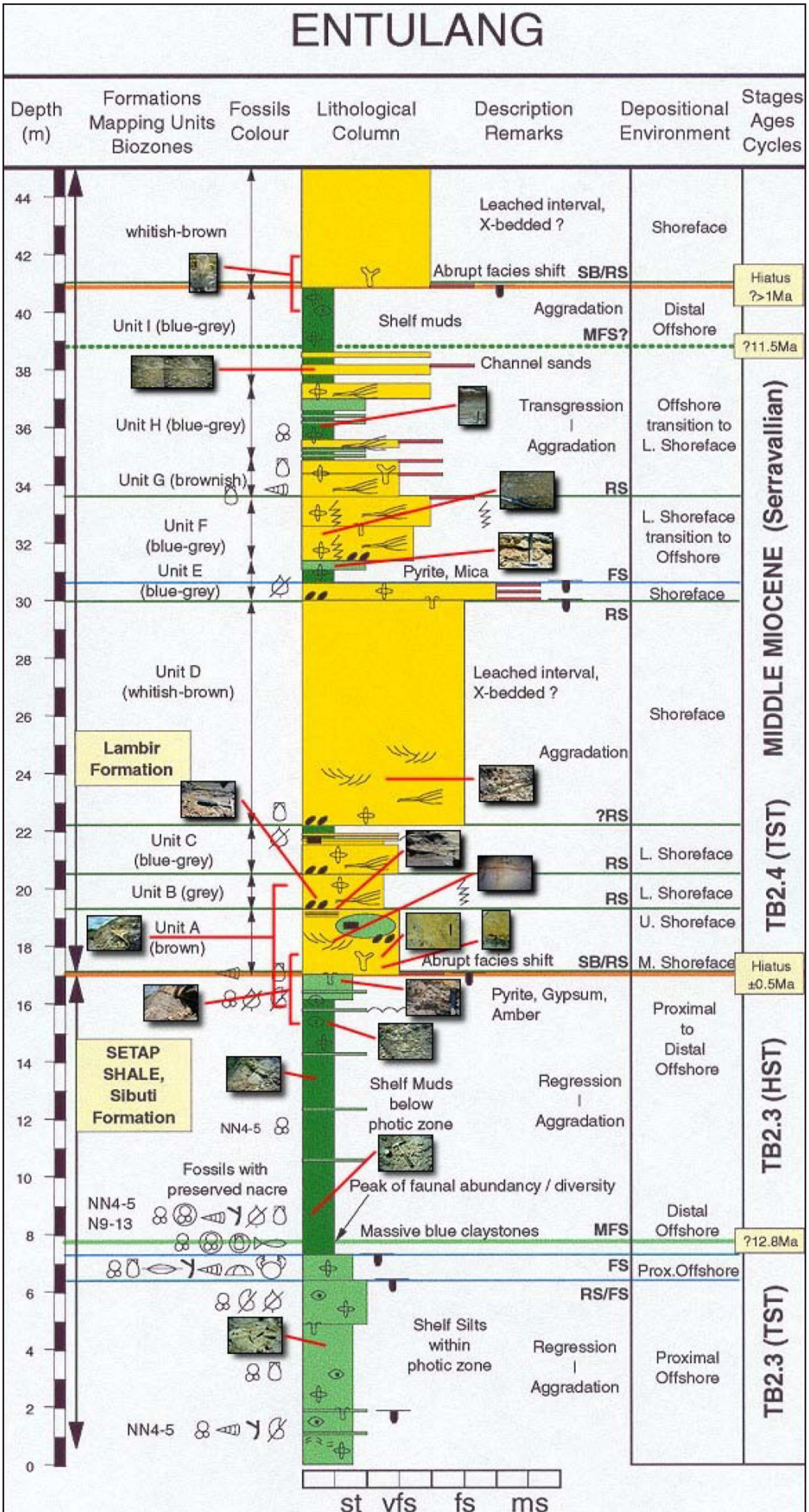


**Figure 11:** Setap Shale and Lambir Formation section in Entulang, Lambir Hills (from Lesslar & Wannier, 1998).

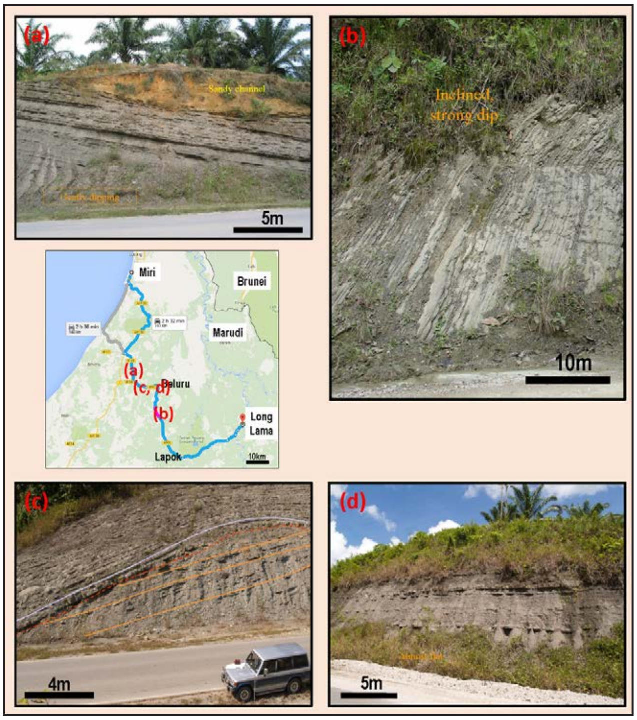


**Figure 12:** TL Setap fossil turbidite outcrops. (a) ) Setap Shale sequence formed by thin stacked turbidite levee deposits, and a sandy channel core. Miri-Beluru road. (b) Some fifty meter thick sequence of distal turbidite levees on the Beluru-Lapok road. (c) Amalgamated sequence consisting of two turbidite levee complexes near Beluru. (d) Upper Grey Setap Shale with two banks of turbidite levees

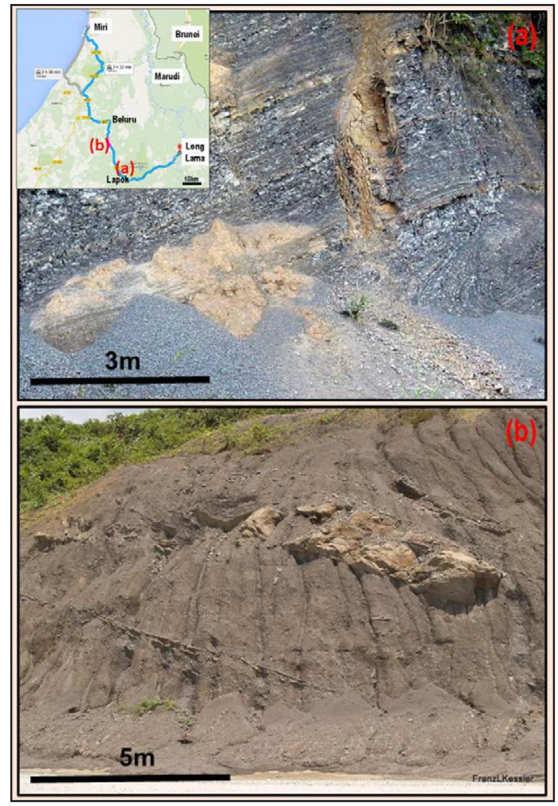


**Figure 13:** TL Setap as environmental indicators (a) Lapok area, gravity folded Setap Shale (lower right corner). (b) Outcrop along Beluru to Lapok/Long Lama road. The Grey Upper Setup Shale with sandstone olistoliths, shown  in the middle section of the picture. The sandstone slump blocks shown above illustrate the vicinity of a (probably narrow) sandy shelf, as well as the presence of a relevant angle such that mass gravity flow occurs (from Kessler & Jong, 2015a).

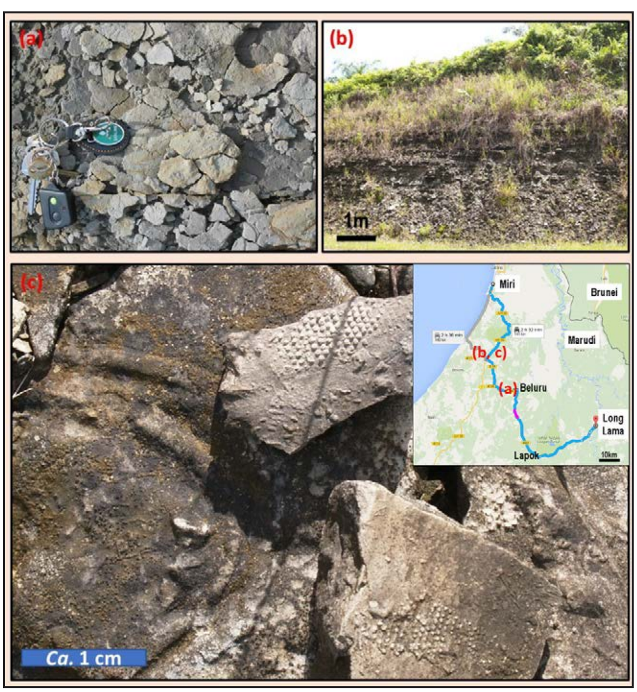


**Figure 14:** TL Setap fossils of the distal turbidite facies. (a) Turbidite sequence near Beluru, brittle shale, with trace fossils and a keychain for scale. (b) Turbidite sequence along the Miri-Kuching road, ahead of junction to Long Lama, a fossiliferous turbidite sequence. (c) Turbidite sequence along the Miri-Kuching road, close-up of Figure 14b. The outcrop shows trace fossils, sole marks, and occasionally echinodermata (?sea urchin) fossils.

little sand were penetrated (Figure 6). The core of the bioherm contains strata with coral. A rich foraminifera assemblage helped to date the reefal complex from Late Oligocene to Early Miocene age (Hutchison, 2005). The bioherm is enclosed by marly Setap Shale. However, the spatial and stratigraphic relationship between reef and the TL Setap country rock is not well understood. A large amount of the surrounding country rock may have been eroded.

- The Enkabang-Karap carbonate anticline (see Figures 1 & 5 for location; Figure 16). A very large carbonate shoal, of Cycles I or II, lies deeply buried below a flood plain of the Baram river. Its position in respect to the Baram Line is shown in Figure 17. An evaluation of the older Bukit Engkabang wells drilled by Sarawak Shell Berhad in 1959 and 1960, and also the more recent JX Nippon well in 2014 (Engkabang West-1), together with the structural development and depositional model of the area has been presented by Jong *et al*. (2016). Interpretation of the 2D seismic data confirmed the existence of a large carbonate-cored anticline overlaid by the Setap Shale, with a massive 272 m section of tightly cemented and dolomitised limestone encountered in Engkabang-1 (Figures 6 &

16). The Engkabang West-1 confirmed the presence of the massive carbonate section, consisting of mainly mudstone and wackestone. The latest biostratigraphic analyses of the Engkabang wells indicate the presence of a number of key stratal events related to regional unconformities and hiatuses, suggesting that the basin ramp area saw periods of compression, inversion and/or uplift. The seismic data also indicate significant structural deformation, including strike-slip tectonism and local over-thrusting, with evidence of a low-angle detachment plane, linked to a zone of increased tectonism commonly referred to as the Baram Line. Associated with elements of compressive folding, thrusting and strike-slip movements, the area seemed to have undergone strong tectonic stresses caused by movements along the nearby Baram Line and Belait Wrench systems resulted in active mud volcanism, with the active Karap mud volcano located to the southwest of Marudi Township (Figures 1 & 17). Observed also is the main carbonate buildup encased and overlaid by marine shales where carbonate developed on structural highs with shaly clastic sedimentation of Setap Shale in shallow to deepwater areas. However, similar to Gunung Subis, the spatial and stratigraphic relationship between the reef and country rock of Setap Shale is not yet well understood.

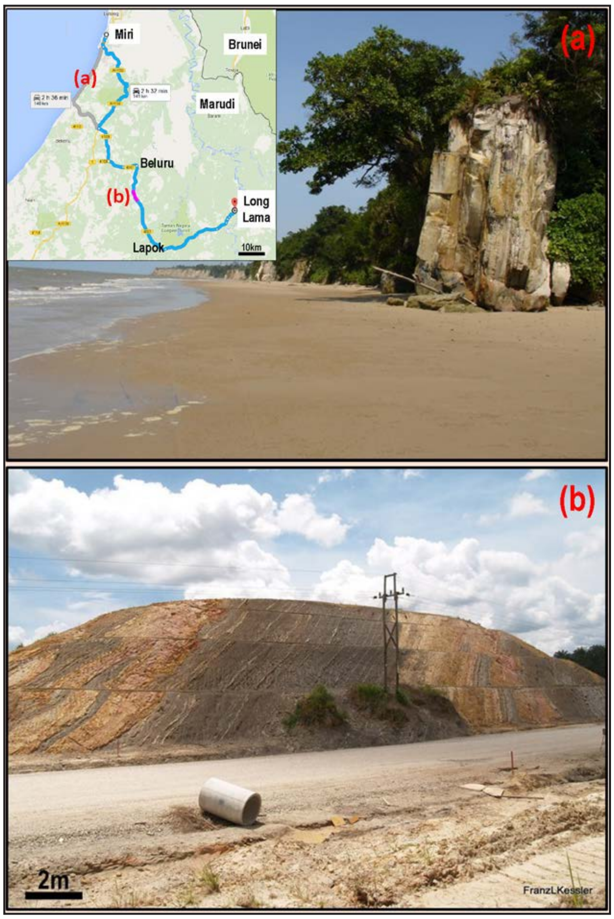


**Figure 15:** (a) BD Lambir sandstone in Peliau Beach. The sandy sequence can reach a maximum thickness of 1600 m (Hutchison, 2005). (b) TL Lambir Formation on the Long Lama Road. The half sandy, half shaly sequence reaches a thickness of 340 m only. The sands appear mostly laminar-layered, are clean of shale, as well as of coal.

## DISCUSSION

### Stratigraphic and tectonic implications of the comparison

There is little doubt, that the Setap Shale in both blocks constitutes a shallowing upwards sequence. Recent work by Kessler & Jong (2015b, 2016c & 2017b) points out, that the entire NW Borneo Foredeep subsided strongly during the Late Paleogene, but was filled up during Late Oligocene to the Neogene. The two BD and TL Setap sequences display a markedly distinguishable facies signature. Whilst the upper BD Setap is without doubt a shallow marine sequence, the corresponding interval in TL Setap is arguably a deep shelfal or even a neritic deposit. These differences in comparison can be summarised as follows (Table 1):

- The BD Setap hosts a number of marly carbonate shoals and patch reefs;

**Table 1:** Comparison of BD and TL Setap Shale outcrops.

| Features | BD Setap | TL Setap |
|---|---|---|
| Outcrop Thickness | Thick | Appeared thiner |
| Limestone | Yes | Shallow water carbonte missing |
| Turbidite | No | Yes |
| Fossiliferous marine green sand | Yes | Not observed |
| Depositional Environment | Shallow marine | Slope to outer shelf |

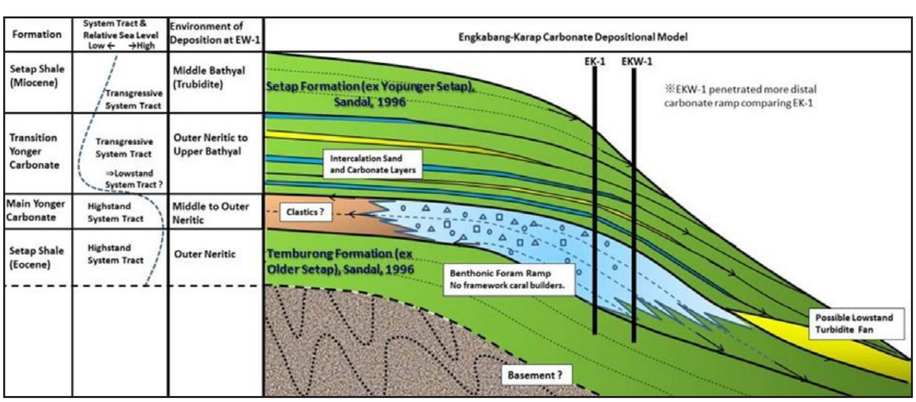


**Figure 16:** Postulated depositional model of the Engkabang-Karap carbonate with development of Middle - Late Eocene to Oligocene benthonic foram bioherm ramps (from Jong *et al*., 2016). Note Sandal (1996) defined the Miocene Setap Shale as Setap Formation, and Eocene Setap Shale as Temburong Formation in the neighbouring onshore Brunei.

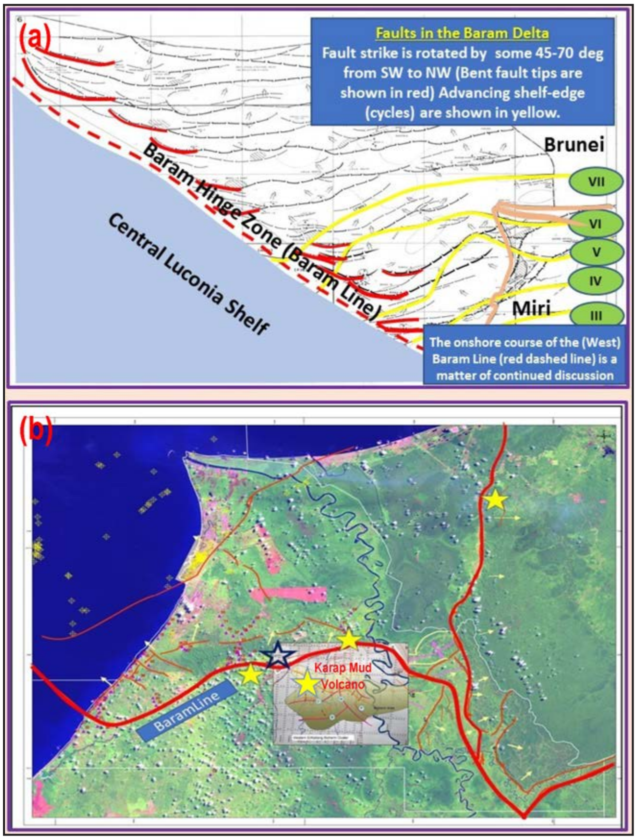


**Figure 17:** (a) Faults in the Baram Delta based on older Shell interpretations. Rotation of the Baram Delta faults in the viciniy of the Baram Line, and the Luconia Platform suggests a post-Pliocene (?Pleistocene) dextral movement of some 4-6 km of the Luconia/Tinjar Block in respect to the Baram Delta Block. (b) Tectonic summary of the study area. The Baram Line (strong red) is shown here as a network of faults. Yellow arrows indicate structural dip in the delta areas. Yellow stars are active mud volcanoes, purple ones are extinct. The inserted map in the middle of the picture shows the location of Cycles I/II Engkabang-Karap carbonate anticline.

- There is no sign of carbonate shoals in the TL Setap;
- There is no evidence to date of turbidite sequence in the BD Setap;
- There is evidence for at least one, but probably two or more distal Setap Shale turbidite sequences in TL Setap;
- Only the BD Setap shows fossiliferous marine strata beneath the Mid-Miocene Unconformity.
- Comparing the formation above the Setap Shale, the sand-dominated Lambir Formation, we also note marked differences. The TL Lambir Sequence is relatively thin (340 m), contains a significant amount of clay in several passages, and the Base Lambir Unconformity is not obvious (Figure 15b). Furthermore, the strongly fossiliferous green sand such as seen in the Baram Delta Block uppermost Setap Shale section appears to be missing.
- In comparison, the thickness of the Lambir Formation, north of the divide (BD Lambir) is up to 1600 m thick (Hutchison, 2005; Figure 15a), and the transition from the Setap Shale to the Lambir Formation is very marked.

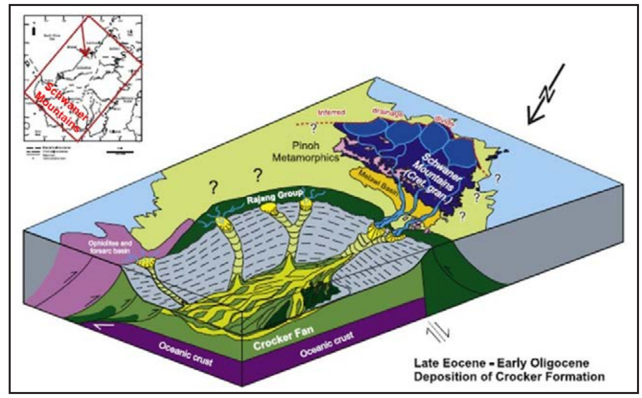


**Figure 18:** Depositional model for the Crocker Fan during the Late Eocene, showing the main source areas and transport paths (from van Hattum *et al*., 2013).

In Kessler & Jong (2016a & 2017a), we explained the facies differences in the Setap Shale by turbidites funneled between larger areas of shoals. This said, the distance between different facies in both Setap and Lambir formations is in the order of a few kilometers only and thus leading to the assumption, that facies differences on either side of the Baram Line may have been influenced by tectonic movements during the Early to Middle Miocene.

Given the northern Baram Delta Block Setap Shale appears to be shallower, hence closer to the coast, the predominant move direction might have been sinistral. However, during the opening of the Northwest Borneo Foredeep in Early Oligocene time, movements along the Baram Line were dextral. Adding to further complexity, there are strong indications that during the Late Pliocene to recent period, movements were again dextral, as shown on Figure 17a. In this figure we see anticline axis in the Baram Delta of Pliocene to Pleistocene being bent and dragged in a north-westerly direction by movements along the Baram Line. The amount of movement could be in the order of 5 kilometers. In a nutshell, the Baram Line acted as a dextral strike-slip zone during Oligocene time, was reactivated during Late Oligocene to Early Miocene times, and reactivated again as a dextral fault system in the latest Pliocene to Pleistocene times. However, this hypothesis of several phases of reactivation might require additional data to be substantiated and adopted.

In regard to the age question of the Setap Shale, recent studies by Asis *et al*. (2018) at the Klias Peninsula reviewed benthic foraminifera assemblages confirming an Aquitanian (Early Miocene) age. Eleven species of larger benthic foraminifera were identified, i.e., *Austrotrilina sp., Cycloclypeus sp., Lepidocyclina* (*Eulepidina*) *sp., Lepidocyclina* (*Nephrolepidina*) *acuta, Lepidocyclina* (*Nephrolepidina*) *parva,* (*Nephrolepidina*) *sumatrensis, Lepidocyclina* (*Nephrolepidina*) *verbeeki, Miogypsinoides sp., Miogypsinoidesdehaarti, spirocyclopeus sp.* and *Tansinhokella sp.* However, to which degree the above Klias study results allow an age or facies comparison with outcrops of the BD Setap remains to be determined.

### Deposition of Setap Shale Formation

In respect to the Setap Shale formation, be it on either side of the Baram Line divide, we are presented with a conundrum, a profound question: Where did all that sediment come from? The penetrated vertical thickness of the TL Setap in the well Bulak Setap-3 amounted to 11633 feet, and yet the source of the sediment remains relatively unknown. This means that several thousand meters of rock, lean in sand, must have been uplifted and eroded long before even the sand-prone Rajang Group was exhumed and reached surface.

According to van Hattum *et al*. (2013): "the voluminous Eocene-Lower Miocene deep marine Crocker Fan sediments were mostly derived from nearby acid plutonic sources on Borneo, the Malay Peninsula and the Sunda Shelf, by a drainage system different from today (Figure 18). During the Eocene mostly Cretaceous material was eroded and re-deposited, probably from the Schwaner Mountains and adjacent areas of the Sunda Shelf, and during the Oligocene an increasing amount of material was derived from the Permian-Triassic Tin Belt granites and its Proterozoic metasedimentary basement. Microcontinent collisions with Borneo in the Early Miocene terminated deep marine sedimentation, and changed the drainage pattern of Borneo. After closure of the Proto-South China Sea and cessation of deep marine deposition of the Crocker Fan, fluvio-deltaic to shallow marine deposition occurred in basins on and around Borneo. Sandstones of the Lower Miocene Setap Shale and Meligan formations of SW Sabah were mostly recycled from sediments of the Rajang Group and Crocker Fans on Borneo, now exposed in the main mountain range of Borneo. A smaller amount of material was supplied by local ophiolitic sources."

Large clay-dominated marine depocentres are common in foreland basins, and the geochemical fingerprints by Nagarajan *et al*. (2017): "strongly suggests that the sediment delivery occurred from an area of comparable, or identical to the Rajang-Crocker mountain belt in Borneo hinterland. Higher chlorite and magnesium contents in the sedimentary rocks of Belait Formation, however indicates a significant input of mafic minerals. The clay minerals are mostly derived from acidic igneous rocks and/or metamorphic lithologies and pre-existing sedimentary rocks. The strong physical erosion of parent rock suggests that the parent rock area was tectonically active during the formation of these sediments."

There are, however, some problems with the above explanation by van Hattum *et al*. (2013). Firstly, the Schwaner granites produced sediments with a high percentage of sand or silt rather than shale. Secondly, in the study area sandy levels in the Rajang Group were only exhumed in the Mid Miocene (and resulting deposition of the Lambir Formation), hence the clay must be derived from materials above the Rajang Group, or from other source. This said, the greater than 5000 m thick and mostly sand-prone and coastal Nyalau Formation exposed around Bintulu area (Hutchison, 2005) speaks for an earlier exhumation of Rajang Group rocks. According to Hutchison, the Nyalau Formation is of Late Oligocene to Early Miocene age (see also Hassan *et al*., 2013). Given the fact, that the Setap Shale and Nyalau formations were deposited during roughly the same time might suggest these formations are co-eval (e.g., Madon & Abdul Hadi, 2007), with the Setap Shale being the fine-grained outflow deposited in deeper waters.

However, given the anchi-metamorphic and partly recrystallised nature of today´s Rajang Group, it is inferred, that indeed several thousand meters of clay-dominated sediments must have been exhumed and eroded, but one can only speculate about the nature of these rocks as long as there is no erosional remnant found which could enable further studies.

## CONCLUSIONS

The Oligocene to Mid Miocene Setap Shale and the Mid to Late Miocene Lambir Formation are described as a shoaling upwards sequence. However, both the Setap Shale, and the Lambir Formation display different facies characteristics on either side of the Baram Line. Therefore, we labelled the above formations with BD (for Baram Delta Block) and TL (for Tinjar/Luconia Block). The Upper BD Setap was deposited within a shallow marine setting and is characterised by marly and fossiliferous carbonate shoals, and also hosts, just beneath the Base Lambir Unconformity, a greensand rich in foraminifera. The Upper TL Setap, however appears to be a slope to outer shelf sediment, and contains multiple turbidite complexes, olistoliths and gravity induced folding. Shallow water carbonates are missing. Nonetheless, it seems unlikely that the facies differences are caused by a lateral facies change alone, and may be at least partly influenced by a tectonic activity related to the strike-slip movements of the Baram Line. The strong tectonic stresses caused by these movements along the Baram Line is well-amplified at the Engkabang-Karap carbonate anticline, where the TL Setap country rock is an outer neritic deposition. With more than 3000 m of Setap Shale deposited in the study area, there is however, a conundrum that the source of the sediment remains relatively unknown, a dilemma remains to be resolved with further research studies.

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