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Two new important outcrops along the Pan-Borneo Highway in the Lambir Hills, Miri area, Northern Sarawak

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Abstract: Road construction work of the Pan-Borneo Highway at sections of the Lambir Hills has created a few fresh temporary outcrops. Of particular importance is an excellent outcrop of the Mid-Miocene Unconformity (MMU), which we called the "White Cliff". An equally spectacular outcrop shows Lambir sandstone offset in strike-slip against a sand wedge and the older Setap Shale, at the inferred (West) Baram Line location. The outcrop is an additional data point for the Baram Line regional strike-slip system, which has been mapped previously with some confidence on both seismic and gravity data.

Keywords: Outcrops, Miocene, MMU, Baram Line, Lambir Hills, Miri, Sarawak

INTRODUCTION

In April 2019, Dr. Kessler and Dr. Jong led a short field campaign in the surroundings of Miri, northern Sarawak, with the objective to investigate new outcrops suitable for studying Baram Delta reservoir depositional settings in relation to Baram Line (or West Baram Line) tectonics, reservoir prediction and paleoenvironmental indications.

Currently, there are many fresh outcrops exposed along the track of the Pan-Borneo Highway, and this paper addresses two new outcrops of the Mid-Miocene Unconformity (MMU), and the Baram Line.

In respect of the MMU, it has been postulated that the unconformity can be traced on seismic in many offshore areas of the South China Sea, and in such way providing a correlation tool to link sub-basins (Kessler & Jong, 2016a, 2017a). Unfortunately though, the calibration of the MMU remains spurious in mainly offshore exploration wells. The best so-far dated and analyzed onshore outcrop is located in Bukit Lambir (Lesslar & Wannier, 1998).

In regard to the Baram Line, there is a broad agreement that the lineament forms the eastern boundary of Central Luconia. However, the opinions are divided if and where there might be a continuation inland Borneo after landfall at the Pantai Bungai some 50 km to the south of Miri. The various opinions have been cited and discussed by Cullen (2014).

There was an exchange of ideas with the late Prof. Tija in 2016 (Kessler & Jong, 2016b). Fieldwork by Kessler (2009) plus seismic and gravity interpretation (Kessler & Jong, 2016c, 2017b; Jong *et al*., 2016, 2017) suggest the Baram Line is making a turn to the East, crossing Bukit Lambir, heading towards Gunung Mulu and eventually aligning with other fault systems in Sabah, separating the NW Borneo shelf and turbidite basin from the Crocker Basin. If we follow this interpretation, the Baram Line is a crustal detachment fault system which encloses areas of thinned continental crust of the South China Sea, overlain by some Oligocene but mainly Neogene sediments. Accordingly, it is important to map this lineament to our best endeavors.

By April 2019, the Pan-Borneo Highway road works had advanced to the Lambir Hills area, successively cutting through the younger Tukau Formation, into the intermediate Lambir Formation, and the older Setap Shale (see Figures 1 and 2).

A simplified litho-stratigraphic scheme of the investigated area is shown in Figure 2 (Kessler & Jong, 2017a):

- The Pliocene Tukau Formation unconformably overlies the Lambir/Miri formations and is formed by intertidal clastics, in particular tidal channel sand deposits, which appear strongly amalgamated, and are interbedded with parallel silty layers. Individual channel beds are often characterized by "side-stepping" and asymptotic foresets, the laminae in which may consist of thin, gray claystone or of lignite (Kessler & Jong, 2015, 2016d).
- The Mid-Late Miocene Lambir and Miri formations form the crestal area of the Bukit Lambir and Miri

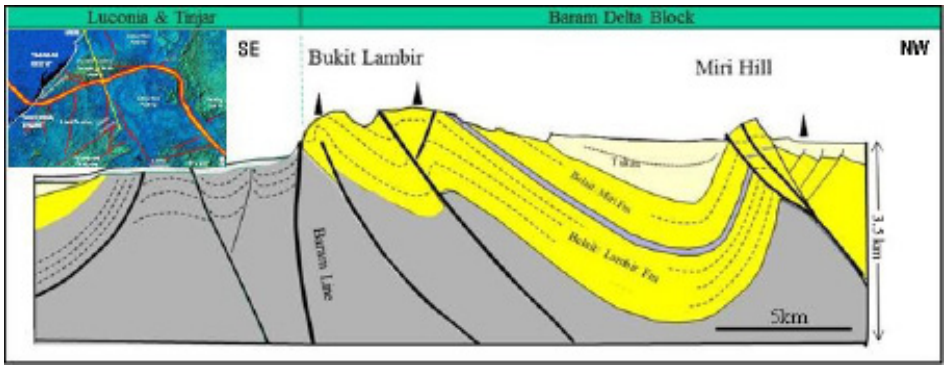


Figure 1: Tectono-stratigraphic cross-section showing folded Neogene sediments of northern Sarawak, see Figure 3 for line location. The black cones indicate the approximate positions of old exploration wells. From Kessler & Jong (2016d).

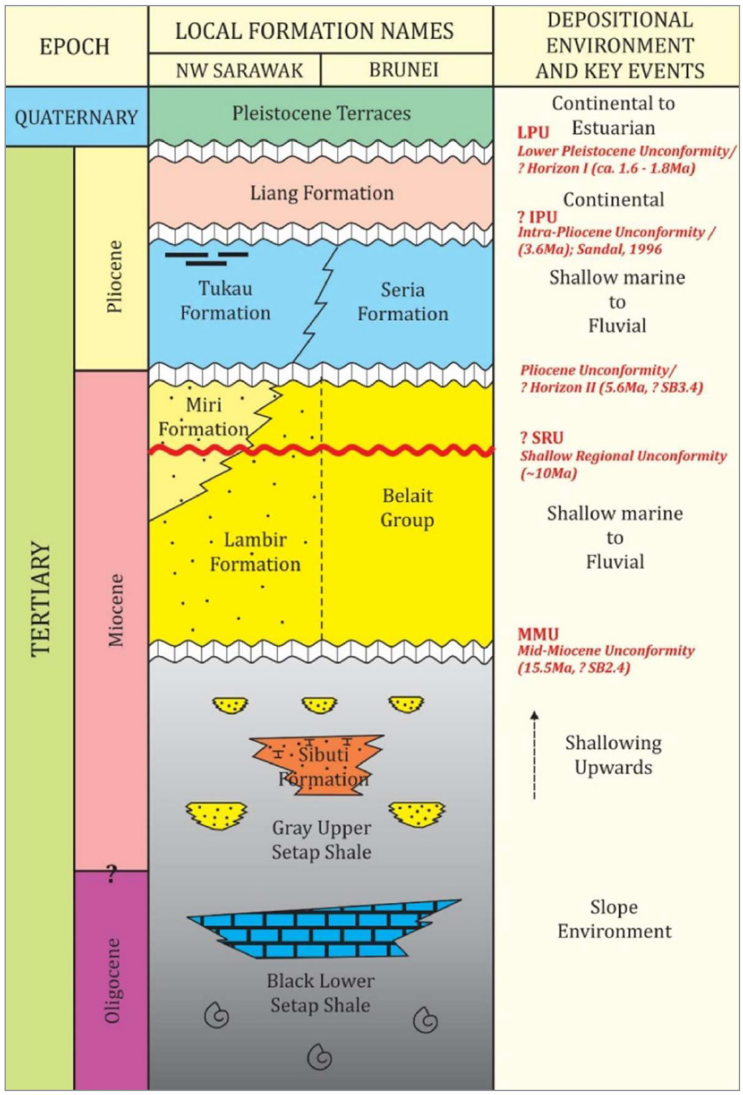


Figure 2: Simplified litho-stratigraphy of northern Sarawak. The term Miri Formation is generally used in the greater Miri area and is age-equivalent to the upper section of the Lambir Formation. Sandal (1996), however, placed the formation partially age-equivalent to the lower Tukau Formation. Likewise, the mid Early Miocene Sibuti Formation is more locally confined with the Subis Limestone Member deposited in the lower part of the Gray Upper Setap Shale (Banda & Honza, 1997). Carbonates are also widespread in the Palaeogene section, and are seen in a number of outcrops and wells (e.g., Batu Niah, Engkabang-1; Jong *et al*., 2016). The observed unconformity events as annotated are established by Kessler & Jong (2017a), and modified after Kessler & Jong (2015).

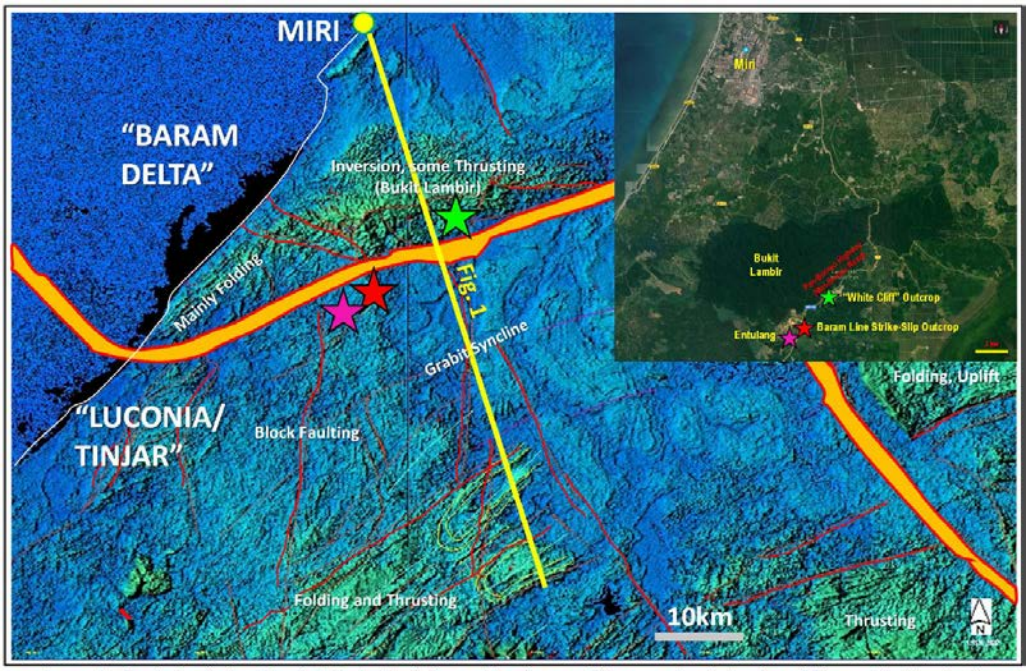
Hill (Figure 1). These formations contain about equal amounts of claystone and sandstone, the latter mainly formed by (sometimes nested) tidal channels and beach bars. Most channels are migrating and "reworked" hence are strongly amalgamated (Kessler & Jong, 2015, 2016d).

NEW OUTCROPS

The locations of the new outcrops investigated are shown in Figure 3.

The "White Cliff" outcrop (Coordinates: E 114.02648, N 4.179596)

The "White Cliff" outcrop is on the left side of the road, when approaching from Miri heading towards Bintulu, and located *ca.* 1 km after the Lambir National Park Headquarters. The outcrop is *ca.* 250 m wide (Figure 4a) and exposes a cliff section of some 8 m, the upper part of which is formed by Lambir sandstone, while the bottom part overlies the Setap Shale with a prominent unconformity, the Mid-Miocene Unconformity (see Figures



Legends: Faults (red); Syncline Axis (pale blue); Baram Line (orange fill); approximate location of Figure 1 (yellow line). Green star: approximate location of the MMU outcrop. Red star: approximate location of the fault zone currently correlated with the Baram Line track. Pink star: approximate location of the Entulang outcrop.

Figure 3: Approximate locations of the studied outcrops shown as green ("White Cliff" outcrop) and red (Baram Line strike-slip outcrop) stars in context of a regional tectonic map, and see text for exact location coordinates. The inset map shows the locations of the outcrops together with the mentioned Entulang outcrop (pink star) along the Pan-Borneo Highway (Miri-Bintulu Road). The orange Baram Line constitutes an important facies boundary, with carbonate dominate in Luconia/Tinjar area and clastics in the Baram Delta Block (Jong *et al*., 2017; Jong & Kessler, 2019; Kessler, 2009; Kessler & Jong, 2016c).

Figure 4a: Panoramic view of the "White Cliff" outcrop. A marked unconformity, interpreted as MMU, is seen incising a silty-shaly sequence of the Setap Shale.

Figure 4b: The base of the sandstone is uneven, there is a marked relief at the unconformity as seen behind the small girl of 1.2 m in height.

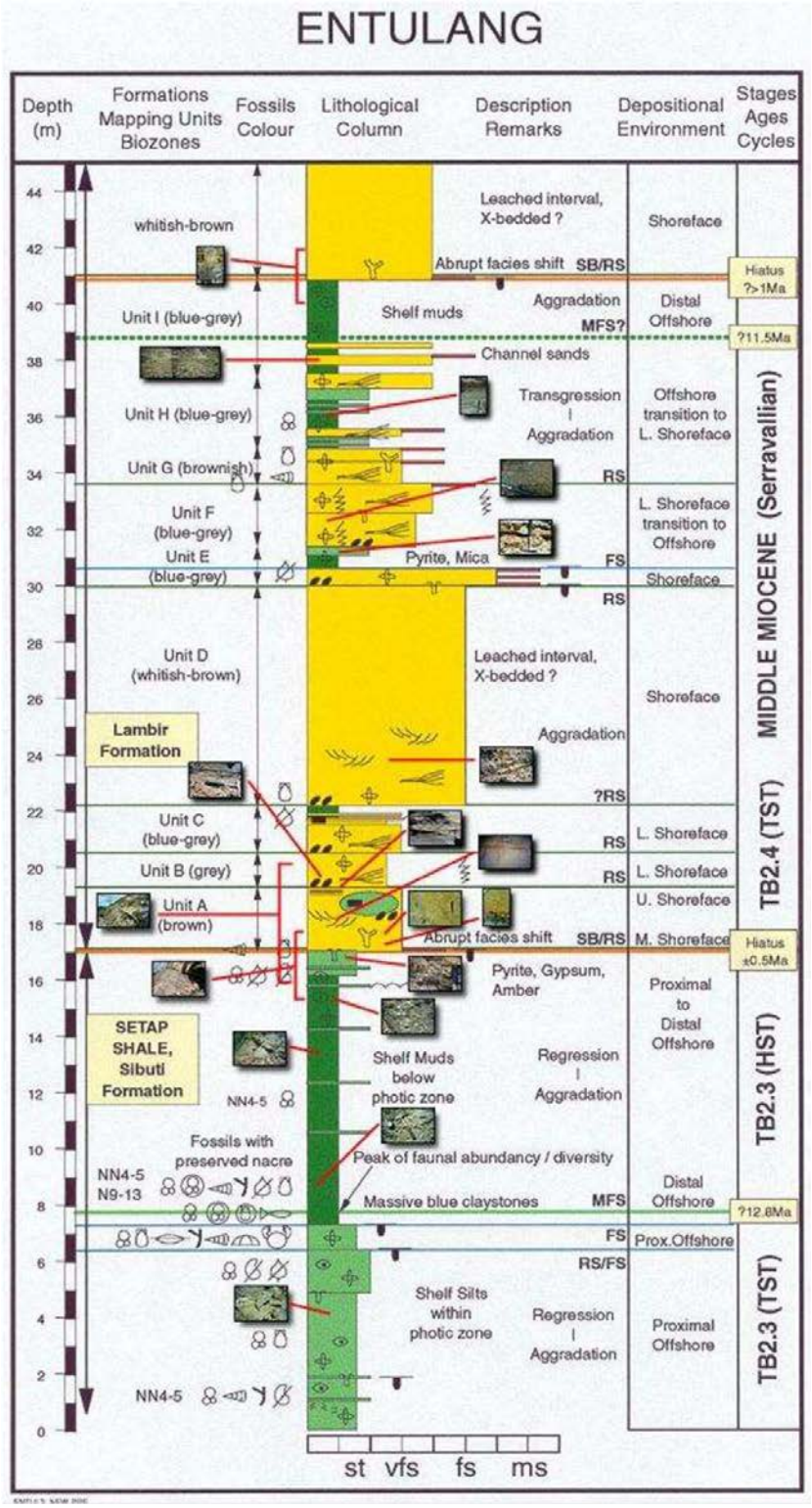


Figure 4c: Setap Shale and sand-dominated Lambir section in Entulang, Lambir Hills (from Lesslar & Wannier, 1998).

4a-e). The MMU was dated Middle Miocene by Lesslar & Wannier (1998) in the nearby Entulang outcrop (Figure 4c, see Figure 3 for location), is unevenly incised into the underlying claystone and siltstone beds (Figures 4b and 4d). The overlying Lambir sandstone beds dip at about 10° to NW and also contain clay-filled channels (Figure 4e).

Regional significance: The outcrop is outstanding because of its lateral extent. Together with additional outcrops on the same hill flank along the highway they form a combined exposure of some 500 m of the regional Mid-Miocene Unconformity not commonly seen in the older outcrops. The appearance of clay-filled channels are rare in a sand-dominated environment, which could be an analogue to subsurface "buried hills" with top and side seals provided by these clay-fill channels as a potential structural-stratigraphic trapping mechanism.

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Baram Line regional strike-slip system outcrop (Coordinates: E 114.02134, N 4.20420)

Further along the road in the direction to Bintulu, a tectonic contact between Lambir sandstone and Setap Shale can be studied. Several parallel fault zones appear to slice through the edge of the Lambir sand and offsetting it against the Setap clay (Figures 5a-c). The axis of this fault system appears to run parallel to, and possibly beneath, the highway (Miri-Bintulu Road) as shown on Figure 5a.

Figure 4d: Detail of erosion (with a 40 cm long knife enclosed in red circle for scale).

Figure 4e: The Lambir sandstone also hosts clay-filled channels. The field of view of the small channel in the middle of the photo is around 4 m wide.

Figure 5a: Panoramic view of a zone of faulting near to Entulang outcrop (located on the hill side at the bottom of the photo).

Figure 5b: Close-up of Figure 5a showing faulting (dashed red line to the right of warning panel).

Figure 5c: At this fault, we see massive, clean sandstone (left) juxtaposed against a sequence of channelized sand and siltstone, and sandstone above. A water spring seen at the bottom left marks the fault.

The history of the movements could be complex (Jong & Kessler, 2019), and a facies change is seen as a fault cutting through the Lambir sand (in the close-up pictures shown in Figures 5b and 5c). Here, we see on the right hand side channel features that are not visible in the more massive sand sheet to the left of the fault. A small spring with iron-laden deposits is seen on the fault plane.

Regional significance: There is plenty of literature about the Baram Line (e.g., Kessler, 2009; Cullen, 2014; Kessler & Jong, 2016b), but so far little or no fresh outcrop data showing the anatomy of the lineament have been published. This outcrop may be important for further studies of the lineament. For instance, tracing the Baram Line from offshore into onshore Borneo appears, at least at first glance, logical since another lineament further south, the so-called Tinjar Line, is similar in strike (but somewhat offset, by strike-slip fault?). However, the line cannot be mapped as a simple linear feature and examination of the outcrops such as this example, integrated with the available gravity, magnetics and 2D seismic in northern Sarawak area will help address the question in which direction the lineament continues onshore.

CONCLUSIONS AND FURTHER WORK

While older outcrops such as Entulang (Figure 3) may have been destroyed by the Pan-Borneo Highway construction, fortunately new ones are also created during the process. In summary, the two fresh outcrops offer an excellent opportunity for further research and academic studies. The spectacular "White Cliff" outcrop offers an unmatched location for a biostratigraphic investigation of the onshore Tukau, Lambir and Setap Shale formations. In addition, deposition environmental study ranging from shallow marine to fluvial deltaic with a regional unconformity for sea level movement can be studied also. The wide exposure of the outcrop could also serve to better constrain the magnitude of the hiatus (now set at 0.5 Ma at Entulang following the research by Lesslar and Wannier, 1998). On the second outcrop, the outcrop represents a good opportunity to investigate the tectonic implication of the strike-slip segment of onshore continuation of the Baram Line, which remains a topic of interesting debate. It is important, however, that these studies are carried out by local research institutions with applied geology program such as the Miri-based Curtin University Malaysia before they are degraded by weathering, erosion and vegetation of the unforgiving tropical climate.

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