

# Habitat and C-14 ages of lignitic terrace deposits along the northern Sarawak Coastline

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**Abstract:** The young terraces fringing the Miri coastline from Miri to Bekenu are formed by lignitic sands, fossil wood, and conglomeratic beds that contain reworked quartz pebbles derived from the older Tukai Formation. The sequence can be subdivided into four sub-units: I. Basal Conglomerate, II. Sandstone with fossil wood and *Ophiomorpha*, III. Cross-bedded lignitic sandstone, and IV. Bleached and weathered palaeosol. These sediments are indicative of a transgressive near-shore, fluvial to marginal marine depositional environment, as water energy peaked in cross-bedded sandstone of Sub-unit III. Radiometric C-14 based age determination in ten coastal locations indicates an age range from Late Pleistocene to Early Holocene ( $28,570 \pm 230$  to  $8,170 \pm 50$  years BP). Given the terraces were formed in the same environment, but are now located at different elevations and appear to be block-faulted, it might imply significant tectonic movements in the Holocene.

**Keywords:** terraces, Quarternary, Pleistocene, Holocene, Borneo, tectonics, *Ophiomorpha*, C-14 dating

## INTRODUCTION

Quarternary terrace deposits are very common along the northern Sarawak coastline, often in conjunction with mangrove swamp, fluvial to marginal marine depositional environments, and these have been preserved on land, where the terraces were uplifted above the present-day sea-level (Kessler and Jong, 2011). The terrace deposits lie above a marked angular unconformity that may have originated as an intra-tidal abrasion surface (Kessler, 2005). Since 2009, the Curtin University of Technology has carried out studies along outcrops flanking the new coastal road, between Miri and Niah (Figure 1).

In northern Sarawak, the terrace deposits were recognized early in the history of geologic research that started at the onset of the 20<sup>th</sup> century, and are marked on Sarawak Oil Field's maps (a precursor of Sarawak Shell) as early as 1930. Outside of the study area, terrace deposits are reported near Sandakan (Lee, 1970), as well as near Kota Belud, the Klias Peninsula and the Tutong area in Brunei (Wilford, 1968). Liechti *et al.*, (1960) mapped these terrace deposits at "low" and "medium" elevation overlying the older Tukai, Lambir and Setap Shale Formations (Figure 2). The current location of terrace deposits above present-day sea-level is also discussed by Tija (1983). Figure 3 shows the Baram Delta stratigraphic nomenclature and schematic lithostratigraphy of the study area.

In Miri, the Canada Hill is elevated up to almost 90 m above mean sea level, and is formed by sandstones of the Miri Formation; remnants of terrace deposits are seen on the flanks and even on the top of hill, deposited above the eroded Miri Formation sandstones. It is also noted that

there are no Tukai deposits on the Canada Hill, either due to non-deposition or erosion, and even the upper part of the Miri Formation is eroded. This observation points to the view, that a part of the Neogene sediment (upper Miri Formation and Tukai Formation) has been eroded ahead of the latest uplift, which supports the implication that the hill must have formed in relatively recent times. However, oil industry workers have indicated from seismic and well data that most of the uplift occurred during the Pliocene (post-Tukai Formation) until recent times. The potential presence of Quarternary tectonism, however, is particularly interesting from the angle of petroleum geology. Significant Quarternary tectonism would have considerable impact on hydrocarbon entrapment leading to potential fault movement and leakage of hydrocarbons trapped at the Miri Field.

This paper, in addition to characterize the depositional habitat of the terrace deposits also attempts, with the help of additional field data and geo-chronological assessment, to find more evidence in support or otherwise of Quarternary tectonism.

## STRATIGRAPHIC AND GEOLOGICAL SETTING

In the study area, located south of Miri along the coast (Figure 1), there may be more than one terrace levels (of different location and different age); remnants of which are located SW of Miri near Kpg. Beraya, and can only be seen there. The largest terrace (this article) however, is a raised beach shoulder, covers a coastal strip of 35 km length, and reaches typically 1 km wide inland, but occasionally extend more than 10 km (in the Miri suburbs of Taman Tunku and Riam) towards inland. Sandal's map (Figure 2) suggests

that terraces in the Marudi area might also belong to the same system. The flat and sharp unconformity surface, the base of the terrace deposits, was originated as a wave-cut platform, perhaps similar to present-day examples along the coast (Figure 4). Moving landwards, the fossil terrace deposits exhibit a gradual thinning of the section, sometimes overlapping against older formations. At one locality, a coastal beach conglomerate could be identified (Figure 5). In the Sungai Rait Valley (Sample Point No. 9), terraces are seen fringing a “palaeo-island”, with the core of the island formed by weathered clastics of the Tukau Formation, which are particularly quartz-rich and hold many layers of quartz pebbles that formed an erosion-resistant hill.

The terrace deposits overlie unconformably the older Miri, Tukau and Lambir Formations (Figures 1 & 6); they are in general flat-lying, hence the different elevations above sea-level. Interestingly, the sea-level curve in Figure 7 shows a drop in the Pleistocene, followed by a gradual sea-level rise until present-day. For this reason, given there was no higher sea-level observed during the last 30,000 years compared to present-day, the current locations of the terrace deposits cannot be explained by sea-level changes, but point instead towards differential uplift in segments of

the coast (e.g., by block-faulting; Tija, 1983). However, the currently available age data are insufficient for further-reaching conclusions.

### Sedimentary Sequence of the Terrace Deposits

Under the assumption that we are dealing with one single sedimentary sequence, there are a wide variety of environments to be resolved ranging from episodic high energy (cross-bedded sand layers, quartz pebble conglomerates); lignite and tree trunks (very low energy marsh); desiccation cracks (intermediate drying-up of sediment), and a very meager fossil record (*Ophiomorpha*-type only).

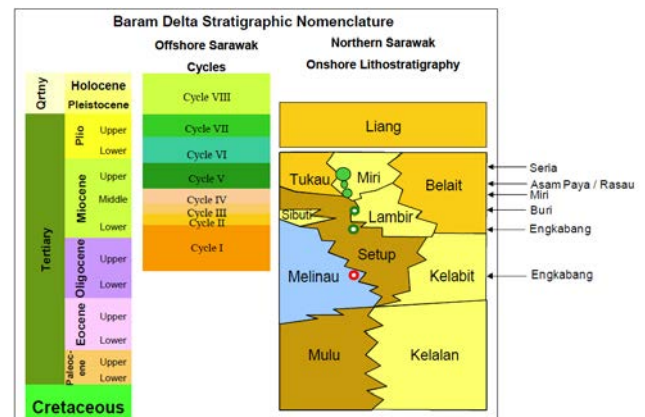
The tree trunks are possibly the best milieu-indicators, indicating that the sedimentary environment was inter-tidal to supra-tidal. The tree-trunk layer is characterized by fine-medium sand, and contains *Ophiomorpha* burrows, possibly *Callianassa* sp. The tree-trunk layer lies often buried beneath a high energy coarse-grained sand, that is conglomeratic in places.



**Figure 1: Top** - Google Earth view of the Baram Delta, Miri City, and coastal areas. The inland-boundary of the studied terraces, is shown as an orange line. Arrows show sample points and numbers. **Bottom** - sketch that shows the relative elevation of the terraces in respect to position above sea-level, and the underlying formations. The width of the purple colour indicates measured thickness of the terraces deposits. The lowest elevation of the terraces above sea-level is noted near Bakam, where the underlying Tukau Formation has maximum thickness.



**Figure 2:** Geological map of the Miri – Bekenu terrace areas, after Sandal, 1996 (modified after Liechti *et al.*, 1960). The map shows the distribution of the terrace deposits (pale-blue). Heights of terraces are shown as l=low (<15 m), m=medium (15-30 m).



**Figure 3:** Baram Delta stratigraphic nomenclature and schematic lithostratigraphy of northern Sarawak with key onshore exploration wells (Nippon Oil).



These high energy sediments formed in either brackish or freshwater environments – there is no indication of marine fossils, and the abundance of lignite is indicative for marshlands behind the coastline. The cross-bedded sands might be seen as relatively short-term events, in which periodic rivers (crevasse splay of a larger river system?) eroded lignitic marsh sediments, and deposited the mixed sediment load in a near-shore area. Occasionally, muddy intervals have preserved desiccation cracks.

The facies-indicative value of the *Ophiomorpha* fossils is controversial (Frey *et al.*, 1978). This view, however, is somewhat moderated by Pollard *et al.* (1993), who made a strong case for three *Ophiomorpha* facies zonations. In balance, a dense *Ophiomorpha* population (also referring to the recent occurrence of *in-situ* *Ophiomorpha*-type crab burrows on the present-day northern Sarawak coast) is suggestive for a facies range between shallow sub-tidal to brackish water coastal lagoonal environments. So-far, no other fossils have been found, but one has to consider the possible leaching and removal of calcite from this relatively acidic sediment.

The likely habitat of the terrace deposits is near-shore to supra-tidal occurred within freshwater-brackish lagoons; overlying a basal conglomeratic lag as indicated by the existence of reworked quartz pebbles. Indeed, the underlying Tukai Formation contains frequent quartz conglomerate layers, notably in the Bakam and Sungai Rait area, where the Tukai Formation forms “palaeo-islands” that were surrounded by marshlands documented in the terraces. In the same area, and a little further SW, quartz pebble layers, probably reworked from the underlying Tukai Formation dominate also the terrace deposits. On the contrary, quartz pebbles are less frequent and far smaller-sized in the now-elevated terraces of the Canada Hill area, where Tukai Formation sediments are either completely absent, or very thin and nearly devoid of quartz conglomerates. Hence there appears to be a positive correlation between the existence of quartz pebbles in the terrace deposits, and those in the subcropping Tukai Formation.

The terrace deposits can be described as a sequence between 1.5 and 7.5 m thick. In most outcrops, only parts of the sequence can be studied. Complete profiles can only be logged in the area of Beraya/Coastal Road (Samples Point No. 6, 7, and 10 – ‘m’ terraces on Sandal’s map, Figure 2). The sequence is flat-lying; in some areas the sediment dips with less than 5°, possibly resulting from de-watering and soil compaction processes. From several excellent outcrops along the coastal road from Miri to Bintulu, the terrace sequences can be divided schematically into four sub-units (Figure 8), which are described in detail below. Figure 9 shows examples for each of the cited environmental indicators.

#### Sub-unit I: Basal conglomerate (Figure 10)

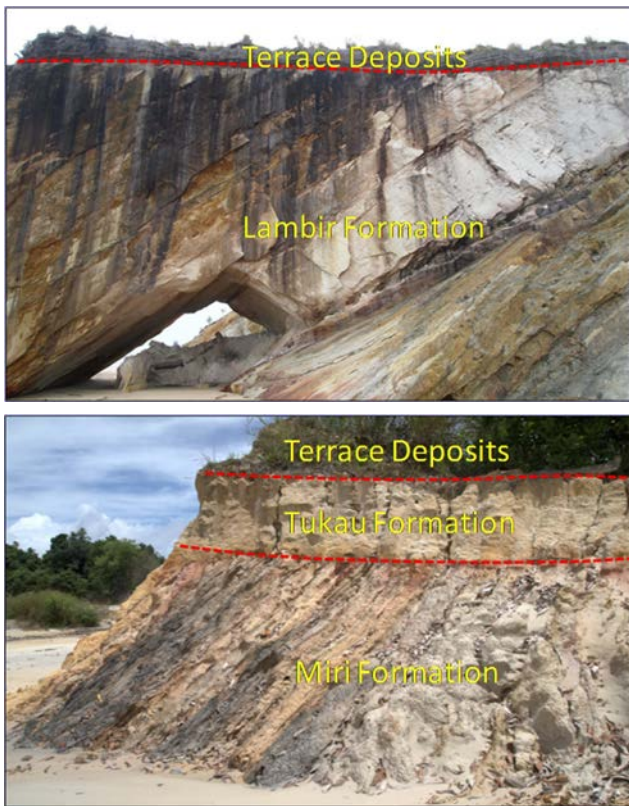
Sub-unit I is a basal conglomeratic layer consisting of conglomerate with quartz pebbles, interbedded with medium-to coarse-grained sandstones, and siltstones which exhibits



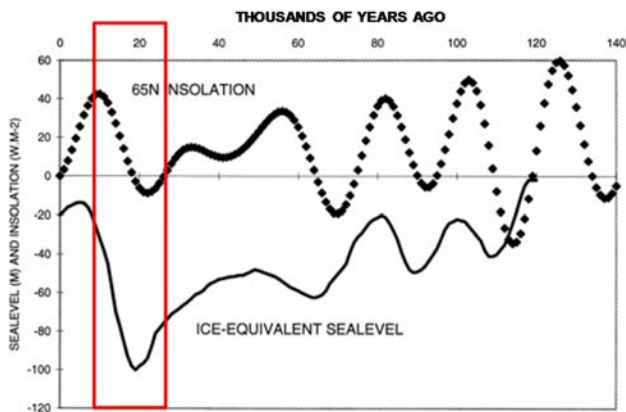
**Figure 4:** Present-day wave-cut platform in Pantai Bungai, 3 km south of the last terrace deposit. Low tide exposes here a platform strip more than 100 m wide, with the uppermost folded Setap Formation (Middle Miocene) being truncated. In the Pleistocene, wave-cut platforms seem to have occupied large areas, due to an implied sea-level fall.



**Figure 5: Top** - weathered terrace outcrop near to Sample Point No. 6, displaying cross-bedded sands alternating with lignitic beds, and frequent quartz conglomerates, in Sub-unit III. **Bottom** - Massive conglomerate, some 3 m thick, with extensive Fe-oxide cementation, probably formed at a palaeo-beach. The conglomerate (lower half of photo) overlies the Lambir Formation (cutting upper half of photo) consisting of vertical beds of claystone. Inset shows a 15 kg block of conglomerate with very large rounded pebbles.



**Figure 6: Top** - Headland Dua, beach SW of Miri, Tusan Cliff area. Note the razor-sharp abrasion unconformity above the 50° NW dipping Lambir sandstone, and the dark sands of the terrace, above the unconformity. The shown picture makes the case for a marine wave-cut platform. **Bottom** - Tukau Formation (low dip) above Miri Formation (vertical). The Pliocene Tukau Formation, that reaches a thickness of estimated > 300 m near Bakam, thins in NE direction towards Miri. In the suburb of Lopeng (picture), the Tukau deposits are only a few metres thick, and overly steeply dipping Late Miocene Miri Formation. The Tukau Formation is formed by fine- and medium-grained sand, and does not contain any quartz pebble conglomerates. No Tukau sediments are observed on the Canada Hill, either due to non-deposition or erosion.



**Figure 7:** Eustatic sea-level curve for the Pliocene-Holocene period, modified after Pillans *et al.* (1998). The dated terrace unit (red rectangle indicates the age range of dated terrace deposits) coincides with a mild drop, followed by a rapid and significant sea-level rise.

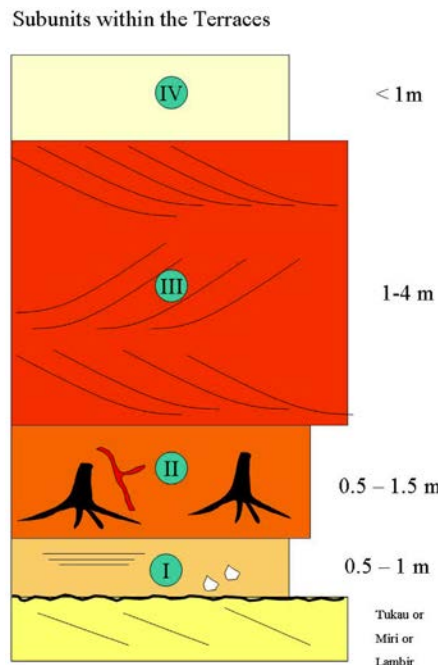
desiccation cracks and bioturbation, and devoid of any coaly materials. This sub-unit varies from 0.5 to 1 m thick (where present), and overlies unconformably the older Setap Shale, Lambir, Tukau or Miri Formations. The sediments are mainly semi-consolidated sand, silt and claystones containing large clasts and pebbles (conglomerate); desiccation cracks are seen on several clay-rich beds, in the lower part of the unit. These cracks are an indicator for a thorough drying, probably in excess of a typical low-tide period, hence indirectly point toward the proximal inter-tidal, or even a supra-tidal realm of sedimentation.

**Sub-unit II: Sandstone with fossil wood and *Ophiomorpha* (Figure 11)**

Sub-unit II is well-exposed in several locations along the Coastal Road, but is not present in the outskirts of Miri (Taman Tunku, Riam, Tanjung Lobang). The layer is between 0.5 and 1.5 m thick. The medium-grained sand layers are mostly dark-amber colored, whilst the coarse-grained and cross-bedded sands are light-brown coloured. Bioturbation is quite common, but confined to *Ophiomorpha*-type crab burrows. In several layers, tree trunks and their roots are preserved. The sediment is semi-consolidated. *Ophiomorpha* burrows, which indicate an aquatic environment, are commonly found in coastal sediments (both stenohaline and brackish), but possibly also in freshwater lagoons and swamps.

**Sub-unit III: Cross-bedded lignitic sandstone (Figure 12)**

This unit has the largest regional distribution of the four described sub-units, only thickness and the amount

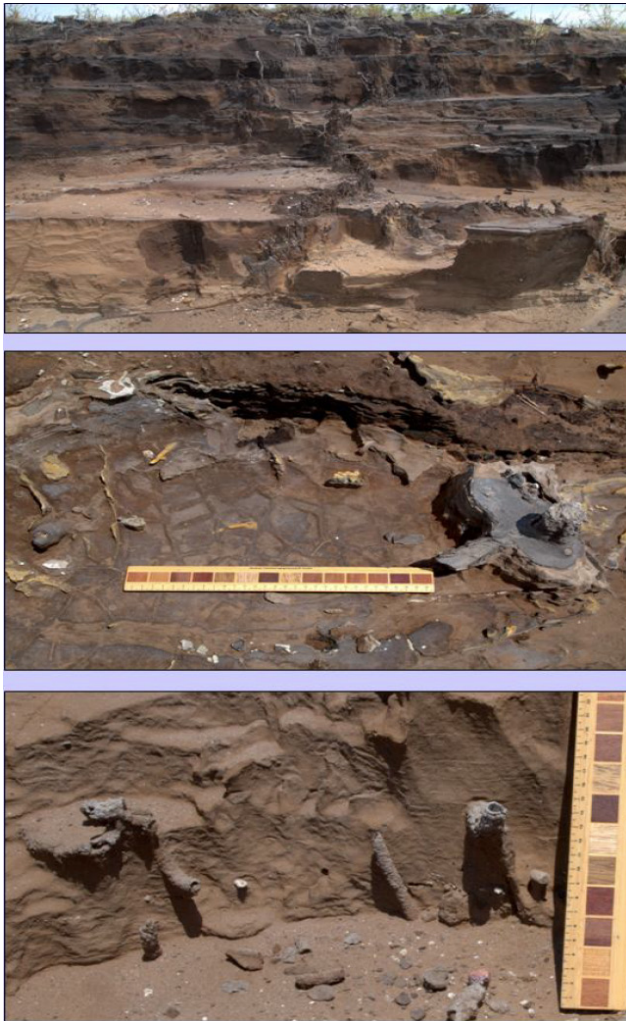


**Figure 8:** Schematic column of the terraces deposits. The picture shows the four Sub-units (I, II, III and IV), which are described in text.



of quartz pebble components vary. In the terrace deposit at the Beraya Boathouse (near Sample Point No. 7), Sub-unit III reaches a thickness of 4 m, which is the largest thickness seen in the study area. This sub-unit is cross-bedded, contains varying amounts of lignite and quartz pebble conglomerates within the cross-bedded sequence. This layer is devoid of any bioturbation. Quartz clasts are milky-white, more rarely clear crystalline quartz and probably stems from eroded quartz dykes and quartz layers within the anchi-metamorphic Rajang Group. Among the medium-grained sands, possible (< 1%) volcanic glass fragments and heterolithics are observed. The sediment varies from loose

sand to hard, consolidated sandstone. The cross-bedded lignitic sands contain quartz pebbles, and were deposited in a high energy, probably fresh water, near-shore fluvial channel system.



**Figure 9:** Facies indicators of the terrace deposits (location near to Sample Point No. 6). **Top** – Sub-units II-IV: Terraces, SW of Miri. Layered sand beds with *in-situ* fossil wood stems, and roots. The tree trunks appear to be mostly located in patches within the lower one third of the terrace deposits. **Centre** – Sub-unit I: desiccation cracks are seen on several clay-rich beds, in the lower part of the sequence. These cracks are an indicator for a thorough drying, probably in excess of a typical low-tide period, hence indirectly point toward the proximal inter-tidal, or even a supra-tidal realm of sedimentation. **Bottom** – Sub-unit II: *Ophiomorpha* burrows, which indicate an aquatic environment, and are commonly found in coastal sediments (both stenohaline and brackish), but possibly also in freshwater lagoons and swamps.



**Figure 10:** Sub-unit I basal conglomerate above an unconformity, which truncates vertical beds of the Tukai Formation below. The unconformity surface (red dashed line) in the centre of the picture is interpreted as a wave-cut platform.



**Figure 11:** Sub-unit II sandstone with fossil wood and *Ophiomorpha* beds, deposited in a shallow sub-tidal to brackish water coastal lagoon environments.



**Figure 12:** Sub-unit III cross-bedded lignitic sands with quartz pebbles, deposited in a high energy, probably fresh water, fluvial channel system.

**Table 1:** Summary of the 10 sampled terrace locations for radiometric C14 age dating. Samples were taken mainly from Sub-units II (fossil wood), and Sub-unit III (lignitic cross-bedded sands) given their organic content.

Sample Index	Northing	Easting	Altitude (m)	Above formation, dip, dip direction	Thickness	Area	C-14 Age (years BP)
1	04° 13.596'	113° 55.149'	18	20° NW, Tukau	> 1 m	Sewa Yaya	24,150 ± 170
2	04° 19.757'	113° 59.931'	23	5° NW, Tukau	> 1 m	Taman Tunku	25,580 ± 190
3	04° 15.174'	113° 55.758'	14	13° NW, Tukau	> 2 m	Bakam Sandpit	18,880 ± 140
4	04° 21.996'	113° 58.160'	38	30° NW, Miri	> 1.5 m	Miri Jalan Tanjung	24,140 ± 170
5	04° 21.107'	113° 59.801'	30	Probably Tukau	> 2 m	Riam	28,570 ± 230
6	04° 09.140'	113° 51.169'	23	80° NW, Lambir	2-3 m	Coastal road	8,880 ± 50
7	04° 02.153'	113° 53.555'	17	70° NW, Lambir	2-3 m	Coastal Road	16,360 ± 80
8	04° 07.403'	113° 49.289'	22	50° NW, Lambir	1-2 m	Tusan Cliff	15,550 ± 80
9	04° 15.293'	113° 56.955'	21	25° NW, Tukau	1-2 m	Sungai Rait Valley	11,230 ± 60
10	04° 11.376'	113° 52.708'	16	45° NW, Tukau	> 4 m	Beraya Boatshouse	8,170 ± 50

#### Sub-unit IV: Bleached, weathered palaeosol

This sub-unit occupies the top section of the terrace deposits, and is commonly composed of loose, white sand, often more than 2 m thick. The original texture within this layer is difficult to reconstruct, since the unit is heavily bleached and components other than quartz have been removed. The occurrence of quartz pebbles is noted. Possibly, the layer was formed originally by lignitic sandstone such as described in Sub-unit III.

#### SAMPLE ANALYSIS

Lignitic sandstone samples collected from 10 terrace locations (Figure 1) were extracted, and studied by the authors, assisted by Curtin University students undertaking their final year B.Sc. mapping project. Coordinates and other parameters of sample locations are summarized in Table 1. The following laboratory tests were carried out: analysis of carbon content; sediment composition and petrography; and composition of lignite. In addition, C-14 ages were determined by the Poznan Radiocarbon Laboratory (Poland).

#### Burning/Combustion Tests and Percentage of Lignite

Several samples were taken from Sample Point No. 6 and 7 of Sub-units II and III to analyze the amount of organic material. Examination of the organic-rich material under the microscope showed the lignitic clasts are equally distributed between sand grains, probably due to sorting within the shoreface environment. Lignite (weight) percentage in the sediment is established as follows: A lignite-bearing sample is dried, and then heated to 800°C, for 5 minutes. Ash is removed by sieving, and the weight of the lignite-free sediment compared to the original sample weight. The lignite percentage (weight) was found to be in the range of 2 to 10 % (Table 2).

#### Trace Elements (XRF Analysis)

The coaly sediment (Sub-unit III, Sample Point No. 1, Sewa Jaya) was also analyzed using a hand-held XRF tool.

**Table 2:** Percentage of lignite within the terrace deposit.

Area	Lignite (weight %, range)	
Bakam	5 – 10	( 6 samples)
Tanjung Lobang	6.5 – 7.3	(6 samples)
Coastal Road, Beraya	4.45	(1 sample)
Coastal Road, SG Uban	0.58 – 7.71	(6 samples)
Canada Hill	2.8 – 4.4	(8 samples)

The sediment was found to be relatively rich in antimony and tin for trace elements (Table 3). However, currently there is no explanation for their richness in the terrace sediments and further studies will be required to study the provenance of both trace elements. The samples do not contain any bitumen (no color change with toluene, and offer no fluorescence under UV lamp).

#### C-14 Age Determination

Field observations, in the context of stratigraphy, the presence of buried wood and degree of minor compaction suggested that the sediments might possibly be younger than 50,000 years, allowing for the radiometric C-14 analysis to be used for age dating of the terrace deposit samples. The summary of sample locations and the results of C-14 analysis are indicated in Table 1, which include age dates and uncertainty ranges. The data (all samples are taken from Sub-units II and III) indicate a range of ages from Late Pleistocene to Early Holocene (28,570 ± 230 to 8,170 ± 50 years BP). This means the terrace sediments were deposited during a period of continuous sea-level rise, and that their current elevation above sea-level suggests that uplift took place in recent times.

#### DISCUSSION OF RESULTS

Given the terraces are found at very different elevations, one would argue that they cannot originate from a sea-level change alone. Broadly speaking, the dated sediments correspond to an interval of mild sea-level drop, followed by a rapid and significant sea-level rise (Figure 7). The sediment



**Table 3:** Trace element composition of lignite-bearing terrace sediments (measurement 1, measurement 2), from Sewa Jaya S of Miri, Sub-unit III. Note the relative abundance of Sb, Sn and the complete lack of Fe, as a result of bleaching and quantitative removal.

ELEMENT	ppm	(+/-)	ppm	(+/-)
Sb	150.90	63.30	107.30	68.20
Sn	161.40	47.20	94.90	50.50
Cd	71.20	23.80	56.10	25.70
Ag	19.60	17.70	7.80	19.10
Rb	1.70	2.30	1.10	2.40
Se	3.00	3.00	2.30	3.10
Hg	0.20	4.40	0.40	4.80
Co	6.40	33.20	1.40	36.30
Mn	1.60	53.20	0	51.70
Cr	0.60	77.70	14.00	85.90

is marginal-marine to non-marine, and was deposited above a marine abrasion platform. Possibly, the formation of the terraces originated as a sea-level lowstand, as recorded by the documented shift in facies, followed by a sea-level rise, and later, differential uplift of coastline segments due to tectonic activity such as fault rejuvenation. The magnitude of faulting is best illustrated in the area of Miri City, where terraces are found at some 38 m (Jalan Tanjung, lower Canada Hill), and the upper Canada Hill plateau (*ca.* 90 m).

As always, new data resolve problems but raise new questions. One particular important question is, whether the terrace deposits constitute one single unit of sediments, or are composed by several distinct units welded together. A preliminary data analysis suggests, that samples taken near to the base of the laminated-lignitic sandstone sequence (Sub-unit II), are always delivering relatively old age values, mostly around 20,000 years. Younger values (Holocene) are found in sections of Sub-unit III in the greater Beraya area, where the sub-unit reaches its maximum thickness. Could it be that we are dealing here with a younger sequence that is particular to this area only? It seems possible, and therefore more C-14 and possibly other age dating methodologies will be required to better answer this important question.

### CONCLUSIONS

The young terrace deposits fringing the Miri coastline from Miri to Bekenu are formed by lignitic sands, fossil wood, and conglomeratic beds that contain reworked quartz pebbles derived from the older Tukai Formation. The sequence can be subdivided into four sub-units:

- I A basal transgressive muddy conglomerate located on an abrasion surface, containing reworked material from the underlying Tukai Formation; there may be a significant hiatus between the abrasion surface and the transgressive system tract (TST) of Sub-unit I deposits.
- II This clayey sandstone unit contains fossil wood, tree stems and tree roots, and *Ophiomorpha* burrows. These indicators are suggestive for a swampy environment,

perhaps mangrove estuaries, and characterize a generally low energy environment, comparable to the present-day Brunei Bay. This unit might equate to a highstand system tract (HST).

- III This cross-bedded, fine-medium grained sand, and occasionally pebble-rich unit contains significant amount of lignite; hence constitutes a layer of reworked marshland under temporarily elevated water energy, as for instance caused by a crevasse splay occurring on a broken levee in the hinterlands. Possibly this unit might correlate to an HST, but there is insufficient proof for such a conclusion.
- IV Bleached and weathered palaeosol. Composition and texture of this member is similar to Sub-unit III, however the rock has been bleached, with both lignite contents and iron removed from the sediment.

Radiometric C-14 based age determination was carried out in ten coastal locations, and samples were taken from the organic-rich layers of Sub-units II and III. Data from C-14 analysis indicate an age range from Late Pleistocene to Early Holocene ( $28,570 \pm 230$  to  $8,170 \pm 50$  years BP). Given the terraces are found on several elevations, it implies significant tectonic movement(s) after the Late Pleistocene/Early Holocene period. The highest terrace deposits, dated Pleistocene have been found on Canada Hill (Sample point No. 4, Jalan Tanjung), which could indicate a particular tectonic setting for the Canada Hill area.

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### REFERENCES

- Frey, R.W, Howard, J.D. and Pryor, W.A., 1978. *Ophiomorpha*: Its morphologic, taxonomic, and environmental significance. In: A.A. Ekdale (Ed.), Trace Fossils and their Importance in Palaeoenvironmental Analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology* 23, 199-229.
- Kessler, F.L., 2005. Comments on the evolution of Bukit Lambir area. *PGCE Bulletin* 2005, Kuala Lumpur.
- Kessler, F.L. and Jong, J., 2011. Habitat and C-14 age dating of lignitic terrace sands – implications for uplift on the Borneo coastline during the Holocene. *Warta Geologi* 37, 36.
- Lee, D.T.C., 1970. Sandakan Peninsula, Eastern Sabah, Eastern Malaysia. *Geol. Survey of East Malaysia, Report No.6.*
- Liechti, P., Roe, F.W. and Haile, N.S., 1960. The geology of Sarawak, Brunei, and the western part of North Borneo. *British Territories in Borneo Geol. Survey Dept. Bull. 3, Kuching.*
- Pillans, B., Chappel, J. and Naish, T.R., 1998. A review of

- Milankovitch climatic beat: template for Plio-Pleistocene sea-level changes and sequence stratigraphy, *Sedimentary Geology* 122, 5-21.
- Pollard, J.E., Goldring, R. and Buck, S.G., 1993. Ichnofabrics containing Ophiomorpha: significance in shallow-water facies interpretation. *Journal of the Geological Society*, 150, 149-164.
- Sandal, S.T. (Ed.), 1996. *The Geology and Hydrocarbon Resources of Negara Brunei Darussalam*. BSP and Brunei Museum Series Publication, 243 p.
- Tija, H.D., 1983. Quarternary tectonics of Sabah and Sarawak, East Malaysia. *Sains Malaysiana*, 12, 191-215.
- Wilford, G.E., 1968. Notes on the geomorphology of Sabah. In: Collenette, P. and Goh, J. (Eds.), *Geological Papers 1967*. Geol. Survey Borneo Region, Malaysia, Bull. 9, 1-22.