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# Synopsis of Upper Tukau Deposits along the Sungai Rait Road, Miri District, Sarawak, Malaysia

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**Abstract:** The Upper Tukau Formation is exposed along the Sungai Rait Road and can be described as follows: the lowermost member is formed by soft clay and silt, the "Brick Shale", and contains meandering sandy channels. The clay is thoroughly excavated in the area and used as raw material for bricks. The second and hilltop-forming layer is built by relatively hard amalgamated, and partly channelized sandstone layers, often lined with diagenetically precipitated iron minerals (i.e., pyrite and siderite concretions). The youngest member is characterized by intertidal channels and mud flats. Geochemical studies point to a polymictic source of already recycled sediments, deposited in predominantly oxic, partly suboxic environments, with rapid transitions observed from one milieu to the other. In broad terms, the entire sequence appears to be a shallowing-upwards cycle, leading from subtidal to intertidal realms. The surprising sharp boundaries between clay and sand packages are discussed and may be related to climate cycles.

**Keywords:** Tukau, Sungai Rait, Late Miocene, Pliocene, clastic sediments, sedimentology, geochemistry, paleoclimate, Sarawak, Northwest Borneo

## INTRODUCTION

The Sungai Rait Road is an old trail (Figure 1), which provided access to a few isolated settlements, as well as to isolated farms, clay quarries, and brick factories. In 2022, the road now links the Pan-Borneo Highway with the coastal Miri-Bintulu Road. Over the years, several quarries and outcrops were created and, unfortunately so, later destroyed, because of the ongoing construction activity of brick factories and claiming of farmlands. Given outcrops in soft formation have in general a very short lifespan, it is necessary to log fresh outcrops immediately, such that the rock information is recorded and not lost.

The exposed sediments belong to the Tukau Formation, a relatively soft sequence of sandstone and claystone. The term Tukau stems from a rural area South of Miri, and the formation name dates back to the Sarawak Oilfields Ltd. (Shell) geologists Braendlin and Trumpy who in *ca*. 1925 noticed that the deposits East of Miri's Canada Hill were much softer and younger ("Pliocene") compared to the outcropping strata seen outcropping on the crest of the Canada Hill, the so-called Miri Formation. During the 1920's correlations between Seria and Brunei were carried out, suggesting Tukau and Seria formations were coeval (correlation by Artis 1941, in Wannier *et al*., 2011 and Petroleum Museum, Miri, Sarawak).

The Tukau Formation outcrops are found in Miri (Kpg Lopeng, Ocean Park settlement), exposing at road cuts along the coastal road between Bakam and the Tusan junctions, also along the Pan-Borneo Highway between Miri and Sungai Liku, and following the Sungai Rait Road (Figure 1).

The (past and present) outcrops in Sungai Rait show segments of a *ca*. 120 m thick sequence of claystone and sandstone deposits. This study takes record of the now-and-then outcrops in the period between 2011 and 2023 and refers to additional fieldwork (e.g., Kessler & Jong, 2015a, 2016, 2017, 2019; Kessler *et al*., 2019), emphasizing on stratigraphy as well as results of bulk geochemistry. These were carried out at Curtin University Malaysia, and the University of Malaya between 2011 and 2017, partly in context with undergraduate mapping projects and post-graduate studies.

The Sungai Rait Road and its tributaries offer several very nice outcrops, that are easily accessed. Therefore, it is important to summarize the results of current and previous studies for the sake of further developing the catalog of geological study sites in the surroundings of Miri.

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**Figure 1:** Index map of the Tukau outcrops South of Miri. Outcrop locations along the Sungai Rait lace the northern boundary of the Bukit Lambir National Park Road are marked by blue pointers, Sg-1 to -5. The orange markers refer to road junctions on the main roads, which can easily be overlooked. The bold black line in the inset map shows the approximate line location of Figure 2.

## GEOLOGICAL AND STRATIGRAPHIC SETTING

The term "Tukau" refers to an area of small hamlets South of Miri airport, and in the foothills of Bukit Lambir. The clastic sequence of up to 2800 m was first mapped by a Shell geologist (Sarawak Oilfields Ltd), as well as later by the Geological Survey of Sarawak. The term "Tukau Formation" is used for a sequence of gently dipping clastic sediments between Miri and the Sungai Liku water intake along the Miri-Bintulu trunk road, now transformed by the Pan-Borneo Highway construction. The early geological works were summarized by Liechti *et al*. (1960) and Hutchison (1996; 2005). Liechti *et al*. (1960) also produced a very reliable geological map of the area. Wilford (1961) reviewed the mostly brackish microfauna, but clear age boundaries could not be established.

The Upper Tukau sequence is the southern leg of a prominent syncline South of Miri. The strata strike SW-NE and dip with an angle of some 15 ° in the north-western direction. The Tukau Formation overlies the Middle-Late Miocene Belait-Miri and Belait-Lambir formations, and is therefore without question of younger age (Figure 2). The exposed cliff sections of this study are the youngest of the folded sequences. Folding occurred, judging from the context of better-dated neighboring rocks, during the Early (?) Pliocene time.

It may be related to a Pliocene-Holocene reactivation of the Baram Line System leading to strike-slip movements and the rise of pop-up structures such as Bukit Lambir, and the Canada Hill in Miri. The movement affected the coastal area between Bekenu and Miri, and also Miri to Seria and the proximal offshore delta.

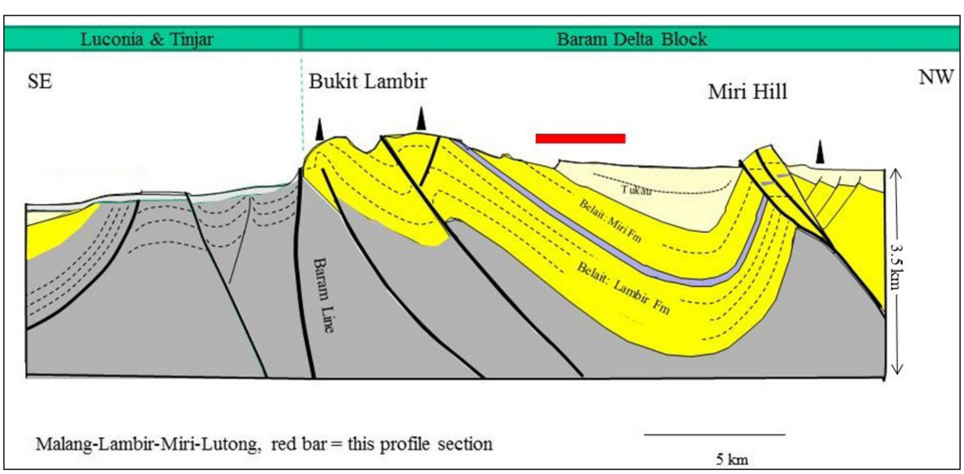


**Figure 2:** Geological section through Bukit Lambir, the Miri Hill and the Badas Syncline with the Tukau Formation at its center. The red bar indicates the area of outcrops. See Figure 1 inset map for line location. After Kessler & Jong (2016).

The Tukau Formation in Sungai Rait can be divided into three members (Figure 3):

1. The oldest member (Member 1), the "Brick Shale", consists of some 50 meters of laminated dark-grey to black silty claystones, the dark color being caused by the presence of pyrite in the rock (Figure 4). These are extensively mined in the area and burned in brick factories (Figure 5). The sequence is transected by a few channelized sandstone bodies, which were meandering through a low-energy subtidal shelf area. A world-class point bar section of one channelized body is exposed in outcrop Sg-4 (Figures 6a and b). The pictures show gently dipping accretional laminae of lenticular sandstone bodies, which appear to be overlain by a thin planar sandstone bed, and a silty abandonment unit above. A point bar is a depositional feature composed of alluvial sediments that develop on the inside bend of streams and rivers below the slip-off slope. Point bars are found in most mature or meandering streams, and the flow direction of the stream is perpendicular to the dip of the accretional laminae. The shown sequence of Sg-4 in Figures 6a and 6b is very sand-rich and contains hardly any clay.
   Unfortunately, the shown point bar section is an isolated outcrop, given that the updip and downdip continuations of the channel deposits are no longer preserved. Accordingly, the interpretation of the feature as a point bar could be judged interpretative. However, the feature has been examined extensively by oil company sedimentologists (Sarawak Shell, JX Nippon), and no alternative interpretation has ever been proposed to date.
   At Sg-2, Brick Shale Member 1 is seen intersected by canyons with sandy fill, above transition to the amalgamated sand sheet Member 2. The described point bar of Sg-4 may be coeval with the channel fill outcrop (Figure 7).
2. The middle member, (= Member 2), the amalgamated sand sheet is formed by a 30-60 m thick and compact sandstone sheet composed of amalgamated channelized sandstone, and exposed in outcrops Sg-2, Sg-3, and Sg-5. The sequence forms hilltops (Figures 8a and b), and the contemporary morphology is a remnant from a continuous layer, which later became incised during the Pleistocene (?). There is hardly any clay in this sequence. The sands appear to have been deposited in a mostly oxic, high-energy shelf environment, and the sequence is mainly composed of fine- and mid-grain sand, in places, one can see aggradation and herring-bone structures.
3. The deltaic tidally influenced sequence of Member 3 forms a (no-longer accessible) cliff of some 10 meters in height (see Figure 9). The "Chicken Farm Cliff" is formed by an assembly of smaller, partly amalgamated channels, as well as silty patches and discontinuous clay layers (Figure 10). In this one can observe coal clasts and amber. Sandy layers contain well preserved trace fossils of *Ophiomorpha labuanensis* and *Teichichnus*

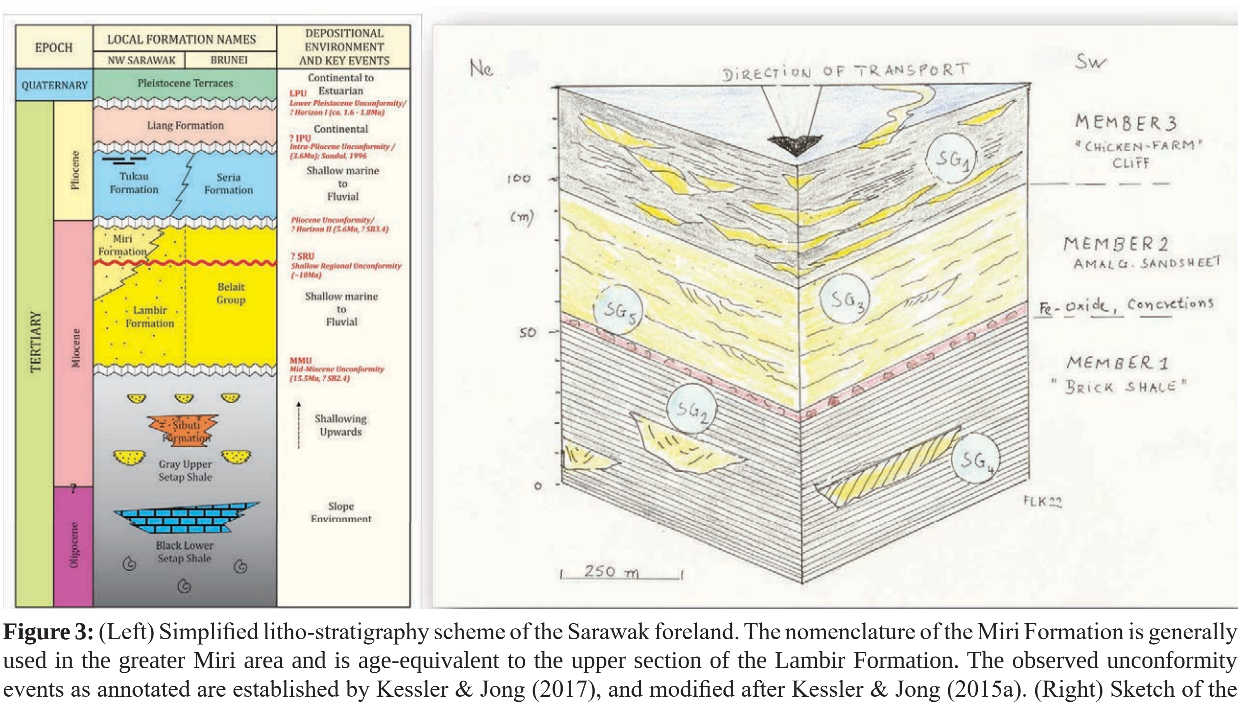


**Figure 3:** (Left) Simplified litho-stratigraphy scheme of the Sarawak foreland. The nomenclature of the Miri Formation is generally used in the greater Miri area and is age-equivalent to the upper section of the Lambir Formation. The observed unconformity events as annotated are established by Kessler & Jong (2017), and modified after Kessler & Jong (2015a). (Right) Sketch of the Tukau Formation at Sungai Rait Valley area with relevant stratigraphic locations of Outcrops 1-5 (Sg-1 to Sg-5) annotated, where Member 1 is dominated by "Brick Shale" black shale, Member 2 is formed by amalgamated sand sheets, while Member 3 lies within a tidal depositional environment.


**Figure 4a:** Laminated black Brick Shale (= Member 1) overlain by the channelized sand-sheet member (=Member 2), Sg-5. Picture *ca.* 2012. A very sharp boundary between sand and clay is noted.


**Figure 4b:** Outcrop Sg-5 area. Member 1 Brick Shale forms the bottom section, with the crest of Member 2 above. The latter forms a relatively hard, competent plateau. It was later incised by the Sungai Rait River and its tributaries. The picture was taken in 2022.

**Figure 5:** The brick factory in the Sungai Rait Valley. Bricks are manufactured from the local clay pits and burned with waste wood.


**Figure 6a:** Sg-4. Isolated channel located within Member 1. The meandering channel formed a point bar sequence, the flow was in an NE-SW direction (or in other words, parallel to the adjacent Sungai Rait Road). Picture *ca.* 2022.

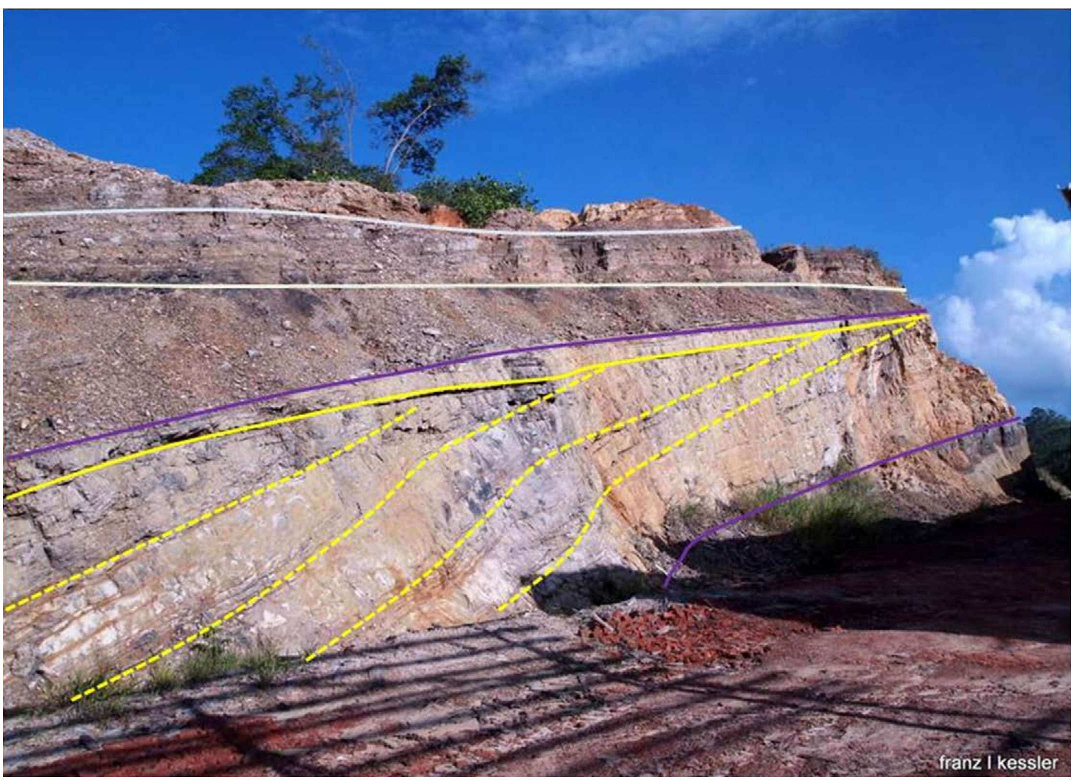


**Figure 6b:** Sg-4 point bar with interpretation overlay showing migrating accretionary system of the point bar, which was later covered by a flat-lying younger sequence on top.


**Figure 7:** Sg-2 Brick Shale Member 1 intersected by canyons with sandy fill, above transition to the amalgamated sand sheet Member 2. Photo from 2019. The point bar of Sg-4 may be coeval with the channel fill outcrop in the center of the picture.


**Figure 8a:** Sg-2 in 2011. The hill-top forming Member 2 above Brick Shale with channel fill.

(Figure 11), which might point towards varying salinity conditions.

## GEOCHEMICAL RESEARCH EFFORTS, 2011-2020

Since 2011, several mapping campaigns, bio-stratigraphic logging, geochemical sampling, and analysis projects, as well as several field visits were carried out. During such visits and mapping classes, a better understanding of the stratigraphic setting was achieved. Besides these general field studies, rock samples were taken for the determination of reservoir properties and facies in dedicated programs.

**Organic chemistry aspects.** Sampling and analysis of organic-rich deposits, mainly mudstones, are reported by some researchers from the Neogene Formations (Togunwa *et al*., 2015; Togunwa & Abdullah, 2017; Adepehin *et al*., 2019). The sampled formation is slightly older than Member 1 in Sungai Rait, and located at the Pan-Borneo Highway some 4 km away from the junction point with the Sungai Rait Road, and in the direction of Bintulu. The study results indicated the presence of organic-rich layers with a total organic carbon (TOC) content of more than 1.0 wt.%. The investigated biomarker parameters of acyclic isoprenoids, terpanes and steranes, and also saturated hydrocarbons

**Figure 8b:** The relatively hard amalgamated sandstone of Member 2 forms hilltop crests in the Sungai Rait area. In the background, Bukit Lambir is seen, as a pop-up structure, and driven by wrench-fault tectonics.


**Figure 9:** Sg-1. The "Chicken-Farm" Cliff displaying the deltaic Member 3 in this previous world-class outcrop is unfortunately no longer accessible since *ca.* 2018. This picture was taken in 2013.

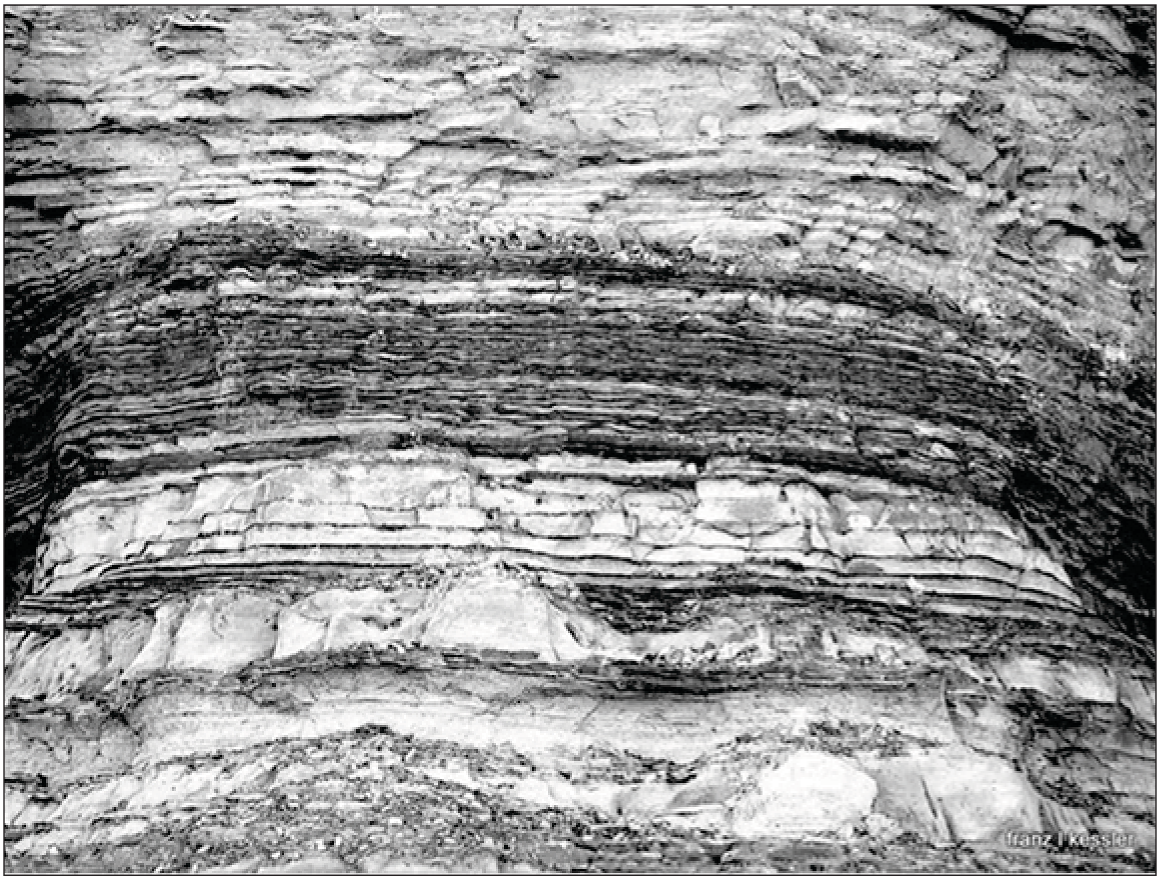


**Figure 10:** Detail of the deltaic assembly in the Chicken Farm Cliff, Sg-1, picture was taken in 2012. The vertical section shown is about 1 meter high.


**Figure 11:** Sg-1. Trace fossils of *Ophiomorpha labuanensis* and *Teichichnus* on a sandy layer at the base of Member 3, with a satellite phone for scale. The abundant presence of crab trace fossils might point toward varying salinity conditions.

pointed to a high contribution of land plants with minor marine organic matter input in the sediment. The sediments were deposited and preserved under generally oxic to suboxic conditions. This is further supported by low total sulphur (TS), high TOC/TN ratios, source- and redox-sensitive trace elements, (V, Ni, Cr, Co, U and Mo) concentrations and their ratios. Measured vitrinite and biomarker analysis describe the marginal source rock facies as immature, in a range of VRE values from 0.42 to 0.45.

**Inorganic chemistry aspects**. In parallel, further mapping campaigns and inorganic chemical research projects were carried out at Curtin University Malaysia (Nagarajan *et al*., 2014; 2017 a, b), both in the clay section of Member 1, the basal sand section of Member 2, and in the cliff of the Chicken Farm outcrop (Member 3). The rocks of the Member 3 unit were chemically classified as shale, wacke, arkose, litharenite, and quartz arenite and consist of quartz, illite, feldspar, rutile and anatase, zircon, tourmaline, chromite, and monazite. Illite is the dominant clay type compared to others and are rich in silty rock layers (Nagarajan *et al*., 2017a, b). All the minerals are highly matured and were derived from a moderate to intensively weathered source area, the metamorphic Rajang Group. Bulk and mineral chemistry suggested that these rocks were recycled from sedimentary to metasedimentary source regions with some input from granitoid and mafic-ultramafic rocks. The chondrite normalized REE signature indicated the felsic nature of source rocks, which have undergone multiple cycles of recycling. Zircon geochronology showed that the crystals in the Tukau samples were of Cretaceous and Triassic origin. Zircons of similar age and aspect are found *in-situ* within the granitoids of the Schwaner Mountains (southern Borneo) and Tin Belt of the Malaysia Peninsular (Van Hattum *et al*., 2003, 2006, 2013; Nagarajan *et al*., 2017b). Therefore, it was suggested that the principal area of provenance, the Rajang Group, was again uplifted and eroded during the Neogene. The presence of chrome spinels and their chemistry composition pointed to a minor share of mafic and ultramafic rocks present in the Rajang Group. The redox-sensitive trace elements, (V, Ni, Cr, Co, U, and Mo) concentrations and their ratios (i.e., V/Cr, Ni/Co, U/Th, Authigenic Uranium, etc.; Jones & Manning, 1994) further support that the sediments deposited majorly under oxic conditions. In addition, the bi-plots of these ratios (Figure 12) suggest that the mudstones of the Tukau Formation are deposited under oxic conditions. The mudstones of the Tukau Formation are characterized by the low abundances of $V_{EF}$, $Cu_{EF}$, $Zn_{EF}$, $Ni_{EF}$, $U_{EF}$ and $Cr_{EF}$, which are in the range of 0.30-0.99 (avg. 0.81), 0.24-2.01 (avg. 0.93), 0.36-1.38 (avg.0.67), 0.40-0.92 (avg. 0.67), 0.36-1.42 (avg.1.07) and 0.44-2.52 (avg. 0.95), respectively. The low values indicate that the water column during the deposition was well-oxygenated (Algeo & Liu, 2020). In addition, this condition is not supportive to preserve the labile organic matter (Canfield, 1994).

**Diagenetic phenomena**. Kessler & Jong (2019) documented the presence of iron and pyrite minerals at the interface between claystone and sandstone. The pyrite

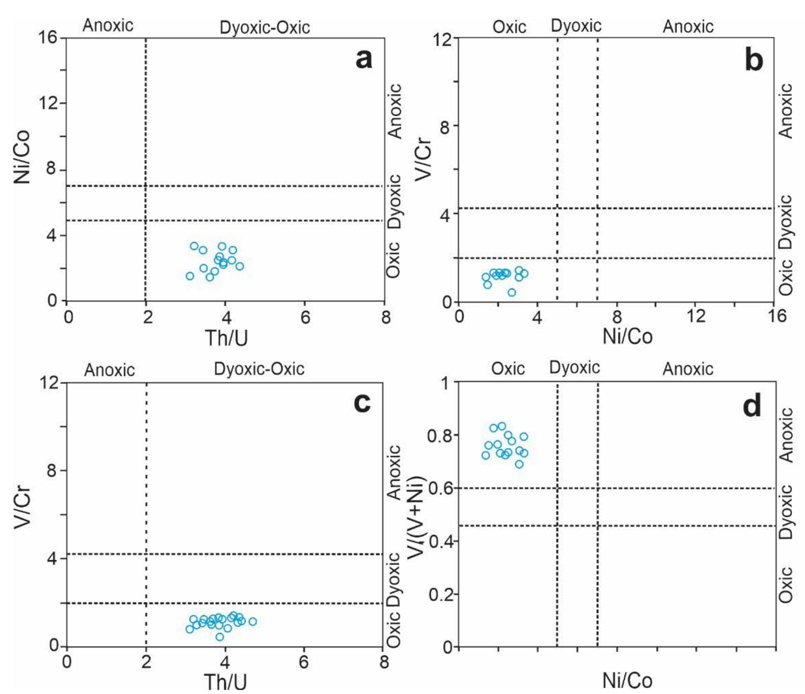


**Figure 12:** Biplots of redox-sensitive elements ratios show the redox conditions for the Tukau Formation mudstones. Redox proxies range from Hatch & Leventhal (1992) and Jones & Manning (1994).

concretions are formed in different shapes and sizes and mainly consist of quartz and pyrite minerals with the trace of cattierite, goethite, berlinite, and arsenopyrite (Nagarajan *et al*., 2022). When clay compacts, it releases cation-rich fluids, and again once more when the clay minerals recrystallize and eject additional fluids. Iron is also released when pyrite within the clay matrix is oxidized leading to Fe++ irons, these being mobilized as $Fe_2SO_4$. Clay-derived and relatively acidic fluids percolate in the sedimentary deposits, pervade sandstone reservoirs, and interact with the original, relatively alkaline reservoir fluids. These contain Ca++ and Mg++ ions in the form of calcium and magnesium carbonate ($CaHCO_3$, $CaMgCO_3$). The reaction leads to precipitation of siderite ($FeCO_3$) and dolomite ($MgCa(CO_3)_2$), accumulating in laminar deposits at the sandstone/claystone interface. In the studied outcrops, we observed siderite (mostly transformed to hematite) lacing the sandstone to clay boundaries. In the outcrops, the iron deposits reach a typical thickness of some 10 cm, forming an observed migration barrier for fluid mobility and reducing permeability (Kessler & Jong, 2019). Interestingly, the layers are of laterally constant thickness suggesting that the observed diagenetic deposits originated on a regional scale and are not a local process. Iron-rich crusts are a common phenomenon in Baram Delta reservoirs as well.

In a nutshell, the studied Tukau deposits derive from uplifted, eroded, and recycled Rajang Group materials, and are deposited in predominantly oxic (clay/siltstone/mudstone) and occasionally suboxic environments. In addition, the reducing conditions that prevailed during diagenesis helped to form pyrite concretions. At the boundaries between sandstone and claystone, fluid circulation has led to crusts of iron-rich diagenetic deposits. In the subsurface, the deposits commonly show up as hard layers on wireline logs that form migration barriers and are challenging for hydrocarbon production (Kessler & Jong, 2019).

## DISCUSSION

The available data are suggestive of a deposition environment under marginal marine conditions. The substantial outflow of several rivers may have led to brackish environments like contemporaneous shoreface areas adjacent to the Baram Delta, particularly in the uppermost Member 3. The entire sequence appears to be a shallowing-upward cycle leading from a low-energy subtidal realm to amalgamated subtidal channels and sand sheets to an intertidal sequence.

The rapid changes of water energy from clay/silt to sand and back, the sharp boundary between the lower and the middle unit is somewhat surprising (Figure 13). Even more so, given there is hardly any evidence of


**Figure 13:** Rhythmic changes from all-shale to all-sand are typical for the entire Tukau sequence. This example (we call it the pyramid) is in the Lower Tukau near Sungai Liku and exposed at the Pan-Borneo Highway. (Picture taken in 2022).

incision or scouring at the base of sand sheets. Such rapid changes from clay/silt sedimentation to massive sheet sand deposits and back are characteristic for the entire Tukau sequence with exception of the uppermost folded tidally influenced layers such as the Chicken-Farm Cliff sequence of Member 3. Although the sedimentary pattern is clearly a rhythmical feature, the reasons for the sharp sediment boundaries are poorly understood. Could they be caused by climatic patterns such as the intensity of the monsoon rain?

Alternatively, one might consider an interplay between sea level changes and a slowly rising Sarawak Foreland Basin. However, it appears unlikely that such drivers would result in the sharp sedimentary boundaries observed in the field, particularly between laminated sheet sand bodies and clay layers. In respect of the tectonic movements, it is known that a Tukau sequence of 2-3 km was deposited from 5.7 to 5.5 Ma, truncated and partly removed at *ca*. 4 Ma (Jong *et al*., 2017), during an important phase of folding and transpressional movements. Right now, there are no data available that could conclusively explain the processes which were responsible for the rapid sedimentological shifts within the Tukau sequence. The analysis of pollen and other microfossils may help to solve this question, and this may constitute a potential topic of future research (e.g., Liu *et al*., 2012; Kessler & Jong, 2015b).

## CONCLUSIONS

Fieldwork has established a sedimentary sequence of three members for the Tukau Formation: The Brick Shale, the amalgamated sandstone layers above, and finally the deltaic sequence of the Chicken Farm Cliff. Geochemical studies point to a polymictic source of already recycled sediment, which contains marginal source rocks of low maturity. In broad terms, the entire sequence appears to be a shallowing-upwards cycle, leading from subtidal to intertidal realms. The surprising sharp boundaries between clay and sand packages are discussed. These may be related to abrupt climate changes, tectonics and/or sea level changes and form an intriguing topic of further investigation on the overall depositional setting of the formation.

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## AUTHOR CONTRIBUTIONS

FLK - paper conceptualization, literature review, data analysis and interpretation, writing and editing, figure drafting; JJ – literature review, data analysis and interpretation, writing and editing, figure drafting. JJ and RN – literature review, data analysis and interpretation, writing and editing, figure drafting.

## CONFLICT OF INTEREST

The authors have no conflicts of interest to declare in connection with this article.

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