DOI : https://doi.org/10.7186/wg471202104

Reconnaissance of Kenny Hill Formation outcrops in the Rawang area, northern Selangor, Malaysia

Allan Filipov[1,*], John Jong[2], Mazlan Madon[3]

[1] GFSI LLC, Kuala Lumpur, Malaysia
[2] JX Nippon and Gas Exploration (Malaysia) Limited, KL, Malaysia
[3] Department of Geology, Universiti Malaya, 50603 Kuala Lumpur, Malaysia
* Corresponding author email address: allan.filipov@yahoo.com

Abstract: New outcrops of Paleozoic meta-sediments northwest of Kuala Lumpur expose the deformational effects of the Late Paleozoic-Mesozoic–collisions between various Gondwana-derived continental fragments as they amalgamated to form the core of SE Asia. Over a duration of 6 months, beginning in August 2020, we conducted field trips within northern Selangor to new laterally extensive outcrops for field observations, structural mapping and to measure and log the stratigraphic section. This paper focuses on Upper Paleozoic Kenny Hill Formation outcrops in northern Selangor. The most studied is the heavily weathered Jalan Rawang-Bestari Jaya (JRBJ) outcrop, which is characterised by a steeply dipping (southwest), upward-coarsening succession of sandstones and shales interpreted as a system of ephemeral fluvial channels possibly related to Gondwana glaciation. Concretions within bedding planes and fractures were possibly formed around organic material. Less than 4 km to the east, the Scientex development has excavated fresher outcrops of the same rocks dipping to the NE. Metamorphic lineation is not present in either outcrop location. In addition, a monocline is exposed at outcrop location number 3 nearby. Finally, at Bukit Botak, 14 km to the southwest, a system of westward verging thrust faults, back thrusts and normal faults can be viewed and an angular unconformity or decollement marks the contact between the Upper and Lower Paleozoic. These laterally extensive outcrops are rare and are quickly subject to intense tropical weathering, the encroachment of jungle vegetation and urban development. Historic mapping and prior stratigraphic, structural, and petrographic studies have been conducted in the area, but these relied on poor exposures. As suburban development escalates in the area, we hope that new outcrops, featuring multi-dimensional views of these formations, such as the four described in this paper, will complement the earlier work.

Key words: Upper Paleozoic, Kenny Hill Formation, Rawang

EARLIER WORK

The area of this study was first described by J.B. Scrivenor in "The Geological History of the Malay Peninsula" published in 1913. The earliest geologic mapping was published by Willbourn in 1922 and relied on tin mines for fresh rock exposures. At that time, without the benefit of urban development, fresh outcrops were rare and regional maps were constructed by recognizing the soils specific to the type of weathered bedrock below (Yin, 2011). Roe's (1951) report on the Rasa and Kuala Selangor areas for the Geologic Survey Department began prior to World War II, but many of his notes were lost during the occupation. J.B. Alexander (1959) compiled the works describing the pre-Tertiary successions in Peninsular Malaysia and published geologic maps (1965) as Director of the Geologic Survey. C.R. Jones (1966) applied the geosynclinal theory to the Paleozoic rocks on the Malay Peninsula. Gobbett (1965) and Yin (2011) described the formations of the Klang Valley. Yin's work was completed in 1961 and published by the Director General, Minerals and Geoscience Department Malaysia as Map Report 22 (2011) which includes the Kuala Lumpur geologic map. In 1973, Gobbett & Hutchison compiled "Geology of the Malay Peninsula (West Malaysia and Singapore)". This was the main reference for the stratigraphy, structural, and metamorphic history at the time and the forerunner to "The Geology of Peninsular Malaysia", edited by Charles Hutchison and Denis Tan (2009). Dr. Lee Chai Peng authored the chapter on Paleozoic Stratigraphy, which compiles the works of many of the previously cited researchers (Lee, 2009). He also chaired the Malaysian Stratigraphic Central Registry Database Subcommittee, responsible for publishing the Stratigraphic Lexicon of Malaysia (Lee *et al.*, 2004).

Of particular importance to this study is the earlier work on the Kenny Hill Formation by Tjia (1974, 1980 & 2004), works by Tan & Yeap (1977), Harun & Tjia (1984) and Tjia (1986) on structures, Hashim (1985) and

Chen (2004) on age, and by Lee (1996, 2001, 2009), Tjia (1974, 2004), and Dodd *et al.* (2019) on the depositional environment. Other important publications include the most recent publication by Metcalfe (2017) summarizing all his earlier work on the tectonic evolution of SE Asia. Other references cited within this paper and unpublished student theses contributed to the geological understanding.

REGIONAL GEOLOGY

The continental core of SE Asia was constructed by the amalgamation of continental fragments that were rifted from the northern and eastern margins of Gondwana and were reformed when the oceanic basins between them were subducted and destroyed (Hutchison, 2009b; Metcalfe, 2017 and references therein). The Sibumasu microcontinent (Figure 1), which extends from northern Thailand to Sumatra, rifted apart from Gondwana during the Early to Middle Permian and was pulled northward by the subduction of the Paleo-Tethys oceanic crust beneath Sukothai Island Arc on the margin of Indochina (Barber *et al.*, 2011). Indochina was itself a fragment that rifted from Gondwana during the Early Devonian, determined from the age of the oldest Paleo-Tethys sediments (Figure 2), and amalgamated with other Gondwana fragments. Note that SE Asia has been rotated clockwise by the Cenozoic collision of India with Asia, thus, the paleo-northward movement of Sibumasu now appears from the left in the figures.

The adjacent fragments, or terranes, often have vastly different fossil assemblages, such as the Late Paleozoic sediments on Sibumasu, which have cool weather flora and fauna (Fortey & Cocks, 1998; Metcalfe, 2017) and evidence of the Early Permian Gondwana glaciation (Stauffer & Lee, 1986; Tjia, 2004) while Indochina's Late Paleozoic climate was tropical (Cocks *et al.*, 2005; Hutchison, 2009b; Metcalfe, 2009). In addition, the fossil affinities on Sibumasu measure its progression northward over time, where Cambrian-Ordovician faunas have a strong resemblance with Australia, an independent biota developed during the Carboniferous to Permian followed by proximity dispersion with Indochina of similar flora and fauna (Fang, 1994). Paleomagnetic data supports a northward movement of Sibumasu, from high southern latitudes to the equator, while provenance studies using zircon geochronology are useful in Gondwana reconstructions and in dating the rifting and collision events of the various pieces (Searle *et al.*, 2012; Metcalfe, 2017).

During the Indosinian Orogeny, I-type granite plutons were emplaced on Indochina and the Sukothai Arc (Barber, *et al.*, 2011; Ghani, 2009) until Sibumasu reached the subduction zone in the Late Triassic. Heat from crustal thickening and decay of radioactive elements (Barber *et al.*, 2011; Searle & Morley, 2011) or slab break-off (Metcalfe, 2017) generated the heat that partially melted the crust, forming magma which rose and emplaced the tin-rich S-type granite plutons that coalesced into the Main Range granite batholith. Searle *et al.* (2012) propose that the subduction of the Meso-Tethys on the trailing edge of Sibumasu began much earlier (Late

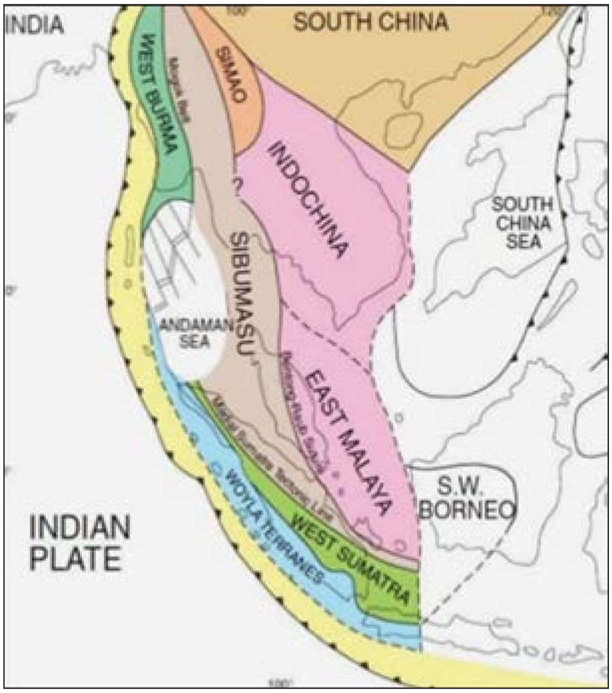


Figure 1: Gondwana derived microcontinents amalgamated to form the core of SE Asia (From Metcalfe, 2017).

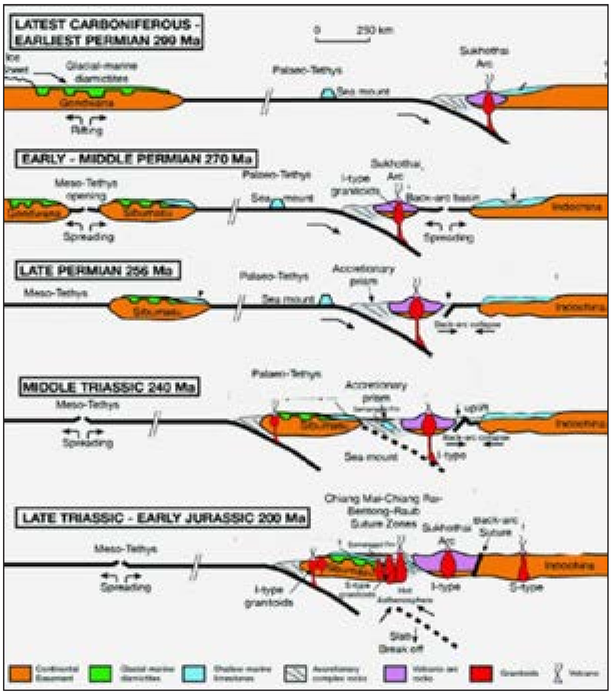


Figure 2: The collision of Sibumasu with Indochina.(Indosinian Orogeny) Modified from Metcalfe, 2017.

Permian) to explain the mixture of I and S-type granites across Peninsular Malaysia. Their emplacement created contact metamorphic aureoles in the sediments on the margins of both Sibumasu, the Sukothai Arc, and the accretionary wedge between them (Metcalfe, 2017). Away from this zone the effects were superimposed by regional metamorphism (Roe, 1951; Gan, 1992).

Recent publications suggest an alternative scenario for the extensive, lateral emplacement of S-type granite plutons, where the leading edge of Sibumasu became more buoyant following the slab break-off and was thrust over the Sukothai Arc (Leslie *et al.*, 2020). There are only three documented examples along the leading edge of Sibumasu, with one in Singapore and another in northern Thailand (Barber, 2011; Leslie *et al.*, 2020), suggesting this is a local occurrence while the dominant stress translated into the Upper Paleozoic sediments is away from the suture zone (presently westward), confirming our observations.

In either case, granitic intrusion and metamorphism of the accretionary wedge and continental margin sediments and westward verging thrust sheets of Paleozoic rocks on Sibumasu generated a variety of metamorphic rock types that have been exhumed and eroded. Though correlation within this zone is difficult it is now interpreted as a suture zone between accreted terranes that preserved a section of the Paleo-Tethys Ocean, which was subsequently nearly destroyed by the emplacement of the Main Range granites. Known as the Bentong-Raub Suture Zone, it can be traced along the margin of Sibumasu to the Inthanon Zone in Thailand, while similar zones are found between microcontinent fragments throughout SE Asia (Barber, 2011; Hutchison, 2009b; Metcalfe, 2017).

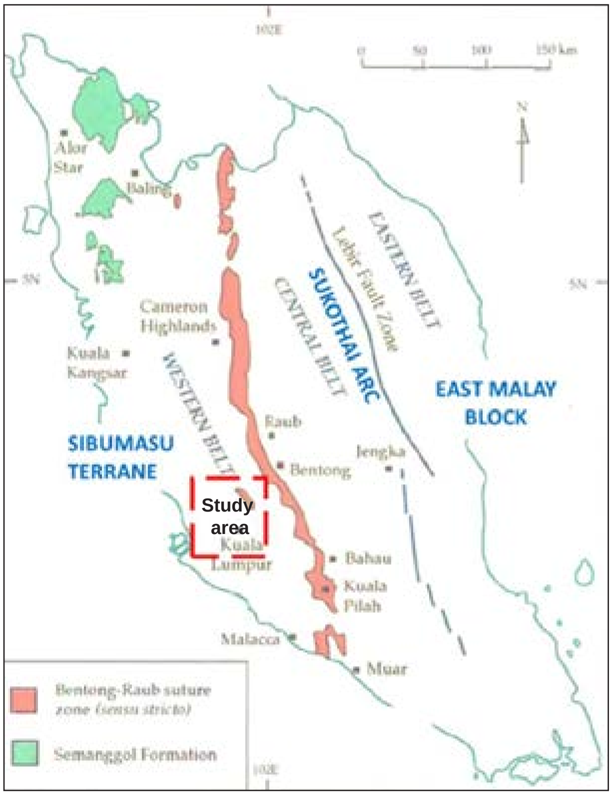


Figure 3: Peninsular Malaysia and study area.

The Bentong-Raub Suture Zone separates the Western Belt, or Sibumasu from the Indochina/East Malay Block, which also includes the Sukothai Arc. Together they form three elongate, northwest-southeast trending terranes on Peninsular Malaysia (Figure 3) which have long been recognized for their differences in geological, structural, and metamorphic characteristics, and in mineral emplacemen. Evidence of the continent and arc collision was preserved in the Lower Paleozoic sediments that were deposited along the margins of Sibumasu while it was still attached to Gondwana. The effects of the Indosinian orogeny subjected the Lower Paleozoic rocks to regional metamorphism, transforming them into phyllites, shists or quartzites. Orientation of the foliation in these rock types would preserve evidence of stress fields (Shuib, 2009; van der Wal, 2014). Within the study area, foliated Upper Paleozoic rocks were not well preserved, and Lower Paleozoic outcrops are rare. However, in the Upper Paleozoic rocks, such as the Kenny Hill Formation, large scale tectonic folding and thrusting shows a general westward (present day) transportation, which fits the general model of a foreland fold-thrust belt in a continent-to-continent collision (Tjia, 1980, 1986; Shuib, 2009). In the few places where the contact between the Upper and Lower Paleozoic is exposed, the Lower Paleozoic rocks have been reported to be intensely folded, the result of multiple deformations (Hutchison, 2009a; Roe, 1951). However, the only documented Paleozoic deformation event on Sibumasu, until recently, was Devonian rifting. Some of the deformation has been attributed to slumping (Shuib, 2009), others suggest it all occurred during the Indosinian Orogeny (van de Wal, 2014). An Early to Middle Ordovician absolute age has recently been proven from meta volcanic rocks in the greater Klang Valley (Long *et al.*, 2018). The interpretation of post-collision Andean style volcanics on the Sibumasu margin of Gondwana implies a dynamic stress regime capable of deforming the Paleozoic succession in Western Malaysia.

STRATIGRAPHIC SUCCESSION OF THE STUDY AREA

We relied on the published geologic maps for formation and ages of the outcrops. The most recent (9th) edition of the 1:750,000 Geologic Map of Peninsular Malaysia, published in 2014 by the Director General Minerals and Geoscience Department Malaysia, is based on time-rock units, however the scale is not sufficient. A grid of 1:63,360 geologic maps, entitled *New Series L 7010* are the latest edition published by the Department of Minerals and Geoscience and most of them are included in a geologic *Map Report* specific to the area they cover. A composite of 6 of the new geologic maps covering Selangor (Figure 4) illustrates some of the issues in an area where geologic mapping began in 1911. Maps were initially published using local formation names. As new data became available, updated maps were published using the coloring convention at that time. The Stratigraphic Lexicon, published in 2004 (Lee *et al.*), is a useful correlation reference while the ongoing studies continually contribute new information on the depositional and structural setting of the Paleozoic formations on Sibumasu.

The stratigraphic sequence for northern Selangor (Figure 5) is derived from the same geologic maps: No. 85, Rawang (undated), No. 94, Kuala Lumpur (Yin, 2011), and No. 102, Sepang (Baba, 2019). This study uses the succession on the far right of Figure 5.

LOWER PALEOZOIC

The study area lies mainly within the Rawang Sheet, Map No. 85. The map is a redrafted version of the Rasa and Kuala Selangor maps included in Roe's 1951 District Memoir 7, updated with modern geologic formation names (Figure 4). The oldest rock unit on Map 85 is the Ordovician-Silurian Terolak Formation, which is reported to consist of both arenaceous and argillaceous metaquartzite, schist, phyllite, pyroxene schist and limestone with graphite schist. Ordovician fossils were found in the limestone beds, which, along with the graphite schist continue south to the next sheet, Map 94, Kuala Lumpur. Here the pale green colors used for the Silurian to Ordovician sequence on Map 85 become tan on Map 94. This map is attached to Report 22 (Yin, 2011), where the Terolak Formation is the equivalent of the Hawthornden Formation.

UPPER PALEOZOIC

Across the entire study area, a sequence of fine to medium grained clastic sediments overlies the Lower Paleozoic formations, makes up most of the hilltops and weathers to a distinctive reddish-brown soil. Named Kenny Hill Formation, after the former name of the type-locality on Map 94, the Carboniferous rocks extend north on to Map 85, where the colors used on the maps change from light blue to brown, while the age changes from Carboniferous to Permian (Figures 4 & 5). The Belata Formation is named after the type-locality, Bukit Belata, on the next map to the north, Map 76, Tanjung Malim and extends southward across Map 85. Cited as equivalent formations (Lee *et al.*, 2004) The Kenny Hill

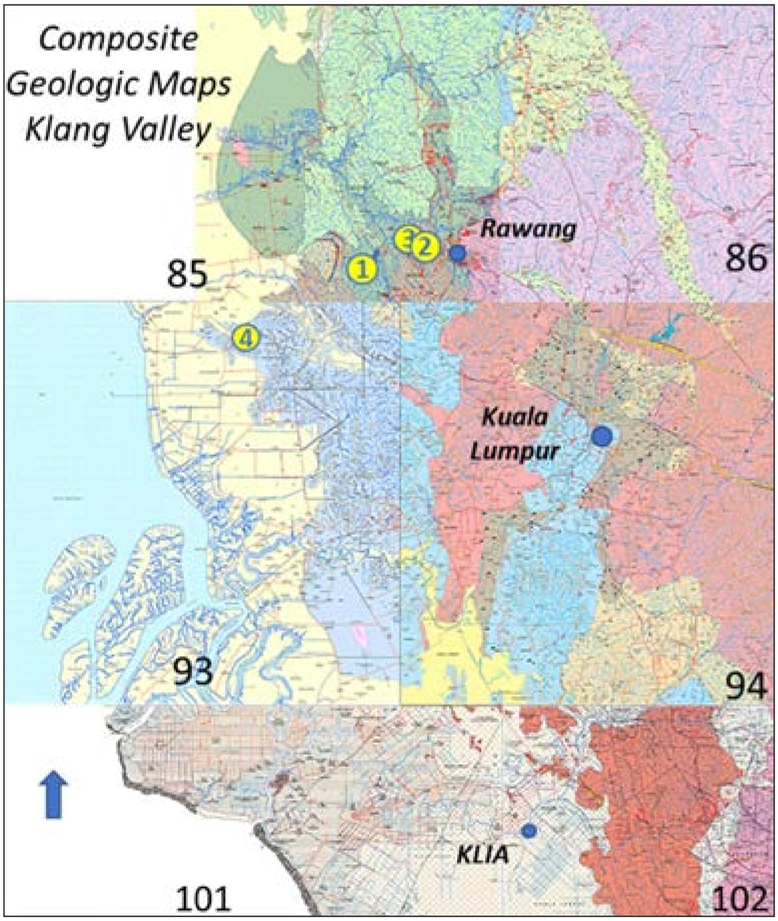


Figure 4: A merge of 6 geologic maps over the greater Klang Valley showing the locations of outcrops in this study. Maps: 85-Rawang, 86-Kuala Kubu Bahru, 93-Kuala Selangor, 94-Kuala Lumpur, 101-Telok Datok, 102-Sepang. Courtesy Director General, Minerals and Geoscience Department, Malaysia.

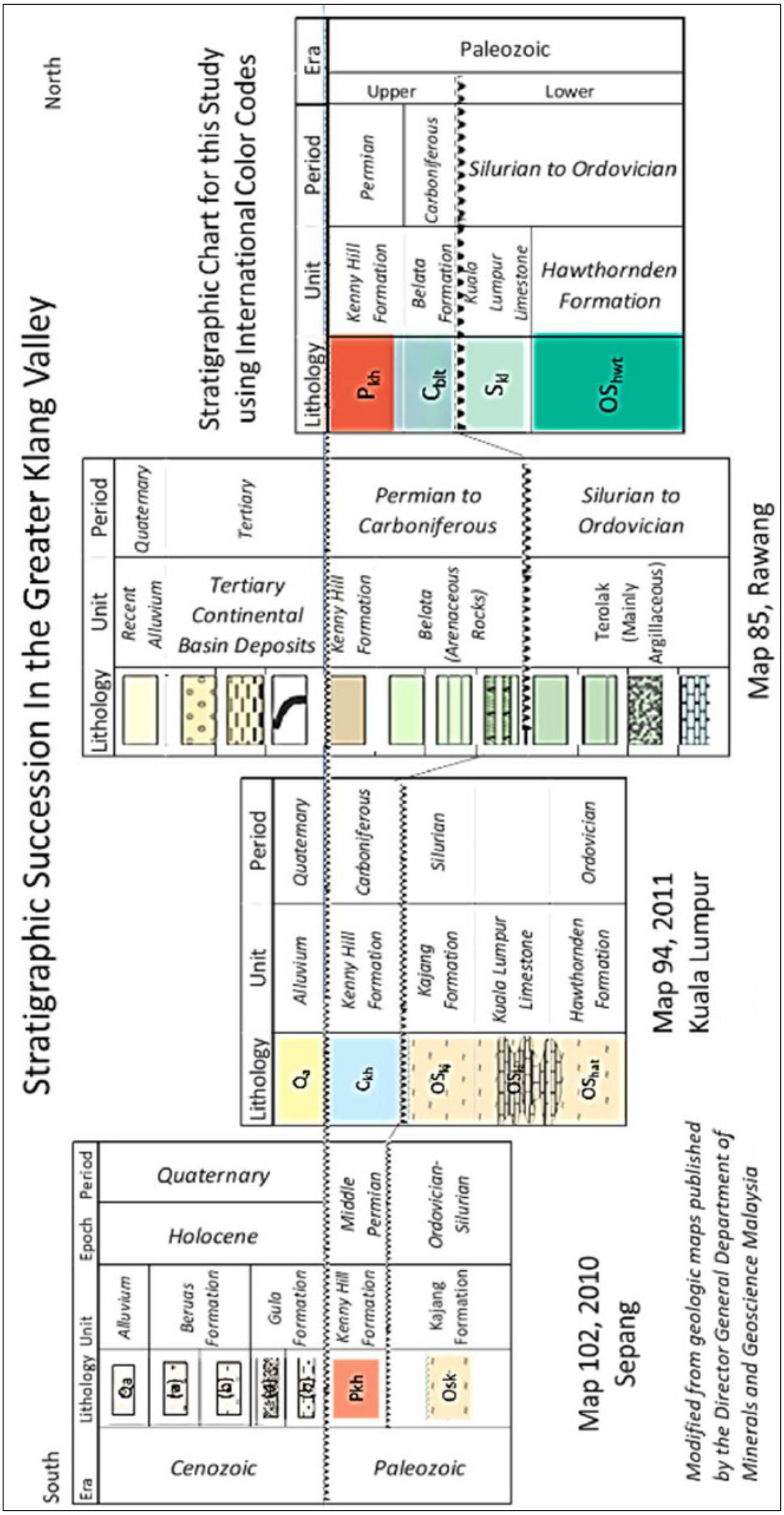


Figure 5: Stratigraphic succession defined on geologic maps across the study from south (left) to north. Modified from geologic maps published by the Director General Minerals and Geoscience Department Malaysia.

and Belata formations together make up the Carboniferous to Permian succession on Map No. 85 (Figure 5). At a convenient break in the mapping in the southern part of Map 85 the two formations change names and colors, though no difference in the rock descriptions is noted by Roe (1951) or by the authors of this study. Since the bulk of the study area lies within the south of Map 85, we use Kenny Hill Formation for all the Upper Paleozoic outcrops.

Because it covers much of the heavily urbanized greater Kuala Lumpur area, stratigraphic correlation of the upper Paleozoic is a tempting, but elusive endeavor. Generally barren of macrofossils, a Middle Permian age was assigned to the Kenny Hill Formation after identification of an ammonoid in the of southern Selangor (Hashim, 1985). The scarcity of macro fossils in the Kenny Hill Formation is thought to be related to the sub-polar climate (Lee, 1996; 2001). Lower Carboniferous radiolarian chert, indicative of a deeper ocean basin in a cool climate, are distributed along the margins of the Paleo-Tethys Ocean (Jasin & Harun, 2011) and in northwest Peninsular Malaysia, these cherts serve as the basal marker for the Carboniferous-Permian succession. In Northern Selangor, the Belata Formation has a basal chert facies while in Southern Selangor the cherts are grouped together with the Kenny Hill Formation. Laboratory testing of Kenny Hill Formation samples collected near the University of Malaya in Kuala Lumpur in 1993 identified several species of spores that individually ranged from the Lower Devonian to Jurassic (Chen *et al.*, 2002), with a Late Permian peak occurrence density (see Appendix A). Thus, the Kenny Hill Formation has been assigned to a deepwater, early Carboniferous cherts, Middle Permian shallow Marine sediments and Late Permian continental deposits.

Successful stratigraphic correlation of the Carboniferous to Permian succession elsewhere on Peninsular Malaysia, has led to alternative methods to uncover uniqueness in the Upper Paleozoic sediments. The Al_2O_3/SiO_2 ratio measured in Paleozoic black shales on Peninsular Malaysia (Baiomy *et al.*, 2016), determines if the source material for the shale was broken down primarily by chemical or mechanical weathering. This is usually a function of the climate, and intervals of Upper Paleozoic wet and dry cycles have been documented. Another study of the measure the changes over time in the primary stress fields that affected the Paleozoic rocks on Peninsular Malaysia, and their relative movement (Tjia, 1986b). Though geochemical and structural correlation cannot provide absolute dates, they would be useful tools for constraining the relative timing of structural deformation and correlation of coeval depositional environments. As excavation continues, there is always the possibility that new macrofossil specimens will be recovered that will further constrain the depositional facies and timing of the structural deformation.

OUTCROP DESCRIPTIONS

The outcrop locations on Figure 4 are described in Figure 6. Figures 10-27 are located on the satellite photo in Appendix B.

JRBJ outcrop

The JRBJ outcrop lies within a 20-hectare excavation on the north side of Jalan Rawang-Bestari Jaya (B29) near the intersection of Jalan Tasik Puteri (Figure 7). Initially cleared in 2013, aggregate from the site was used in the residential development south of the road. Activity abated in 2015 and only began again in 2020. Steeply dipping beds of sandstone, mudstone and shale are exposed on a steep slope along the northwest (335 degrees) boundary of the excavation site. Rather than just a single quarry face, this outcrop has ridges and a cleared floor so that one can view the strata from multiple angles.

When Roe (1951) mapped the area, he recognized similar facies in the metasediments and grouped them together, naming them the Arenaceous Series and Calcareous Series. He annotated the accuracy of his geological boundaries on his maps, using a solid line for "correct to within 100 yards", a dashed line for "correct within ¼ mile", and dotted lines where boundaries were less definite. Contacts in this area were usually obscured by thick tropical vegetation and Roe relied on topography

	Name	Full Name	Location-DMS	Location Decimal Degrees
1	JRBJ	Jalan Rawang-Bestari Jaya	3019'29.93"N 101030'28.80"E	3.323889 101.50778
2	Scientex	Scientex Rawang	3018'58"N 101032'34"E	3.31611 101.542778
3	Jalan Anggun 2	Monocline north of Jalan Anggun 2	3019'18"N 101030'18"E	3.321667 101.505
4	Bukit Botak 3 Unconformity outcrop	HW B104/Jalan Simpang Tiga Jeram-Bukit Botak 3 Unconformity outcrop	3014'01"N 101023'09"E	3.233611 101.385833

Figure 6: Outcrop names and locations.

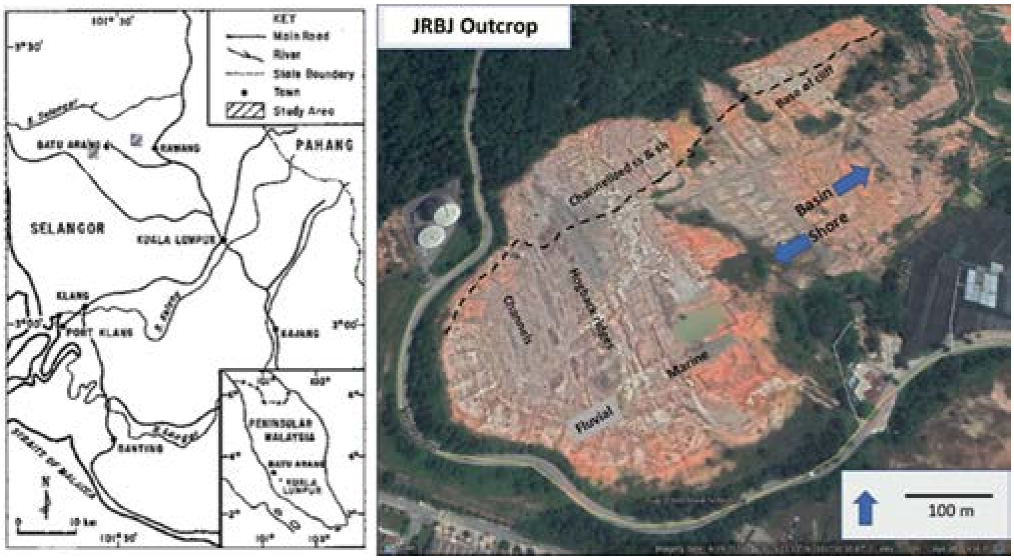


Figure 7: JRBJ location and satellite photo.

Figure 8: Formation contacts in yellow over satellite photo of the Rawang area. Satellite courtesy of Google maps.

and changes in soil characteristics and color to map the contact between the two series, annotating his map with a dotted line. This boundary is now recognized as an important unconformity between Upper and Lower Paleozoic formations. When his map was redrafted and replaced, all the geological boundaries on Roe's map were redrawn as solid lines on the current geologic map. In addition, Roe noted the strike and dip and the schistosity and jointing patterns; none were included on the new map. It is a shame in this digital age that important information is lost rather than being stored.

This boundary was superimposed onto a satellite photo covering of 3 of the 4 outcrops in this study (Figure 8). The yellow dashed line is the mapped contact between the Upper Paleozoic Kenny Hill Formation and the Lower Paleozoic Hawthornden/Terolak Formation. Lower Paleozoic rocks were not found at or near these 3 outcrops, confirming this contact is not exact and could mispositioned greater than ¼ mile (400 m.).

The cliff face exposes approximately 680 m of heavily weathered, slightly metamorphosed sandstone, siltstone, and shale dipping 30-50 degrees to the southwest. The rocks are described from freshly broken exposures and are consistent with observations at other outcrop locations. Because of intense tropical weathering, the colors may not be original (Figure 10).

Beginning at the northeast, or right edge as one faces the outcrop, thin beds (2-10 cm) of gray and maroon mudstone (Figure 11) are interspersed with thicker (~1 m) yellow mudstone, reddish-brown sandstone beds and

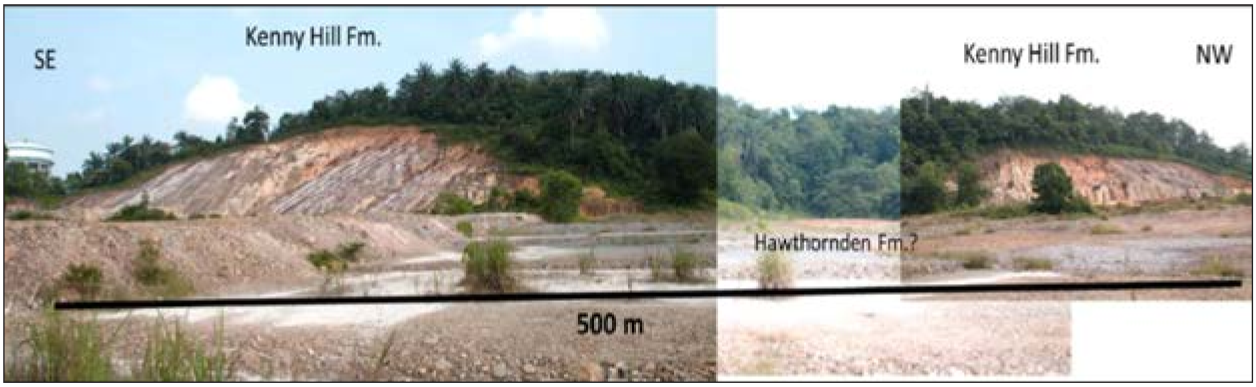


Figure 9: A composite photo of the JRBJ outcrop. The geologic map places the contact between Upper Paleozoic Kenny Hill Formation and Lower Paleozoic Hawthornden Formation in the low area between the hills, extending toward the viewer.

Figure 10: The heavily weathered northeast end of the outcrop. Top of bedding is to the left.

Figure 11: Finely laminated maroon and gray shale common in the Kenny Hill Fm. Arrow points to top of beds.

gray shales (Figure 12). These maroon and gray shales are common to every Kenny Hill outcrop in the area. A brown iron oxide cement fills fractures and joints, which are seen to stand out in relief due to differential weathering. Abundant lateritic concretions and nodules are present (Figure 13). Here the section is heavily weathered and gravitational slumping of the hillside, combined with the more resistant pattern of cement-filled joints complicated establishment of the bedding orientation. However, where the hillside is stable the beds strike NNW and dip 30-60 degrees WSW (Figure 11).

Continuing southwest along the outcrop, the gray to white shale and mudstone layers are up to 1.0 meter thick. Tan-gray sandstone units have sharp basal contacts showing load structures, well preserved ripples, cross stratifications, scours, pinch-outs, and ball-and-pillow structures are seen (Figure 14). The sands are riddled with concretions, generally near the base of the beds. Concretions have soft centers and ~1.0 cm iron oxide rims. Fractures are filled with the same iron oxide cement (Figure 15). Continuing along the outcrop, several black-purple layers of resistant sand separate bleached white siltstone layers that are approximately 1 meter thick (Figure 16). Studies referenced in this paper document the bleaching of sandstone and siltstone, where under reducing conditions, reservoir fluids will remove metal ions, especially iron. In addition, if CO_2 is present, it reacts with the iron (Fe^3) to form siderite concretions at impermeable barriers in the reservoir (Ming *et al.*, 2017). The fluid also interacts with calcite cement in fracture fillings or in the rock matrix to form siderite (Loope *et al.*, 2012).

Figure 12: Bleached massive sandstone, sharp basal contact with maroon and gray shale.

Figure 13: Concretions reforming (?) on iron rich cement between fractures and beds.

Figure 14: Bleached siltstone above iron-stained shale highlighting load structures.

Figure 15: Sharp basal contact between tan sandstone and maroon and white mudstone with load structures, concretions and fractures preserved by iron cement filling (upper 2 arrows). Eroded concretions with soft interiors (lower arrow).

Figure 16: Layers of bleached siltstone with black and purple sands between them.

Figure 17: Burrows or root casts.

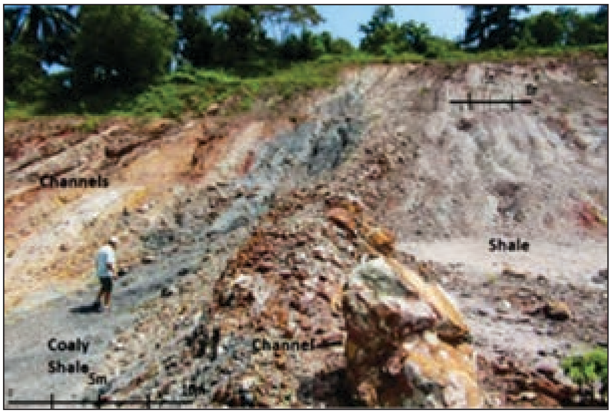


Figure 18: A sequence of channels sands and shales with a graphite rich layer dipping 48 degrees. to the SW. There are two scales in the photo to show bed thickness near the top and bottom of the outcrop. View is WSW.

The next sandstone units are yellow to reddish-brown. Tube-like burrows averaging 0.5 cm in diameter and matching previously described trace fossils (Stauffer, 1973; Tan & Yeap, 1977) were found where they had eroded from the formation and are indicative of a marine estuary (Figure 17).

Thicker, stacked channels of gray and buff-colored sandstone are more prevalent moving southwest along the sequence. Excavation and differential weathering created resistant hogback ridges of that strike, away from the cliff face outcrop, exposing the top and base of the layers. Here the thickest black shale (~3.5 m) is exposed (Figure 18). The basal contact of a shingled, stacked sandstone channel sequence is preserved on the escarpment below one hogback ridge (Figure 19). A large fault is noted parallel to the bedding plane, the softer fault

Figure 19: Basal contact of a shingled channel sandstone bodies below a hogback ridge formed by the 30 degree dip to the SSW.

gouge is weathered out, creating a trough that marks the fault (Figure 20). Nearby, the softer shale and mudstone is eroded in beds dipping 50-60 degrees, preserving a relief of channel lenses (Figure 21).

An interesting feature is seen along the dip slope of a ridge, at the paleo-top of a gray sandstone unit. A purple-gray, or yellow, crust has precipitated over underlying brown (iron-oxide?) material, which at first appeared to be roots or burrows (Figures 22-24). The coating occurs on the fracture-filling iron-oxide cement where it is exposed on southwest facing slopes. Between two ridges, in less resistant layers, the joint pattern is preserved by differential weathering (Figure 25). This phenomenon was previously described by H.D. Tjia in 1974 in the Kenny Hill Formation at Bukit Pantai in Kuala Lumpur. A sample of a concretion was later dissected using a rock saw and revealed a cross section that looks like a plant or tree root (Figure 26). It is still unknown at this time if the concretions have an organic origin or if roots had grown and propagated into the fractures. Nearby, a large, cylinder shaped object 28 cm in diameter and 80 cm long was found. Too large and heavy to carry from the field for proper analysis, we cannot help wondering if this was once of organic origin or a large concretion (Figure 27).

Figure 20: Fault parallel to bedding plane.

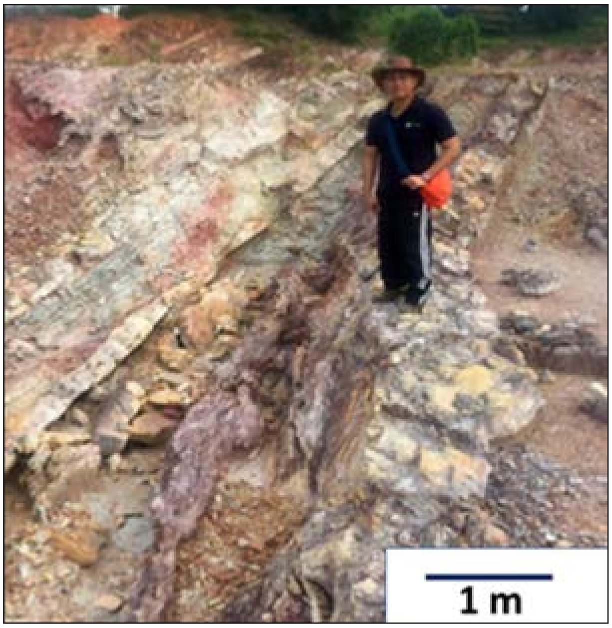


Figure 21: Sandstone channels dipping 50-60 degrees, as a result, the softer shales have differentially eroded.

JRBJ Discussion

Overall, the section coarsens upward from northeast to southwest as individual sandstone layers become thicker, though the grain size within the upper sandstone beds appears to be the same as the lower beds. A sedimentary log of the outcrop illustrates the facies objectively by highlighting the repeating facies and narrowing interpretation options. Figure 28 is a detailed composite log of the 9 depositional patterns and their grouping into mega-facies.

The complete log for the JRBJ outcrop is in Appendix C. The pattern of repeating Facies 1 and 2 is typical in a deltaic setting and possible in a tidal or wave dominated delta with an intermittent sediment supply. Overall, the facies are a shallow marine to continental environment, where intermittent flooding supplies plenty of sediment that is reworked into barrier mouth bars and shoals during dry periods. Sediment rates are high during floods, with rip-up clasts and erosive beds and soft sediment loading. An estuary or lagoon forms behind the barrier island, with bioturbated sediments in the lagoon and swallow nearshore. The clay and silt deposits of Facies 1a to Facies 1c are deposited in deeper water, while the silts and shale

Figures 22 and 23: The bluish concretion appears to be a precipitate on the iron oxide cement that fills the joints and is present between beds, as seen elsewhere in the outcrop.

Figure 24: A yellow concretion has precipitated where iron rich cement in the fractures is exposed along this dip-slope.

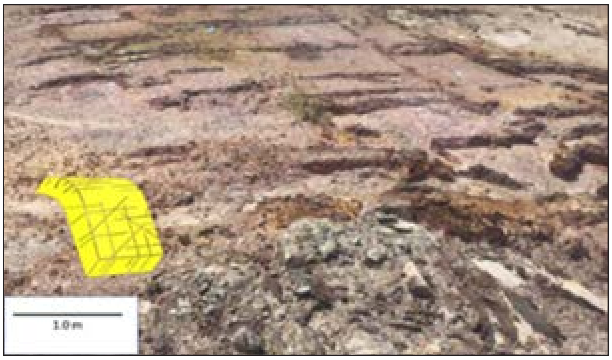


Figure 25: Fracture pattern in relief on ground excavated less than 5 years prior to the photo.

between the channel deposits in Facies 4a and Facies 4b are probably overbank deposits. While the bioturbated sands occurred a shallow marine environment or estuary, the rest of the outcrop appears devoid of any animal fossils or trace fossils, except for concretions. According to Lee (1996) the Kenny Hill Formation should have preserved fossils; the sediments are relatively unaltered by metamorphism and fresh samples, unaffected by weathering, can be found at new construction sites. Yet, the only fossils are a single Lower-Middle Permian ammonite and some crinoid stems found south of Kuala Lumpur (Hashim, 1984) the spores with a Late Permian-Triassic affinity near University of Malaya (Chen, 2002) and Devonian to Carboniferous radiolarians were found in cherts at Dengkil in southern Selangor (Jasin & Harun, 2011).

The large number of concretions merited an investigation, where it was learned that large concretions can form rapidly during early diagenesis and they often nucleate around decaying organic matter which could

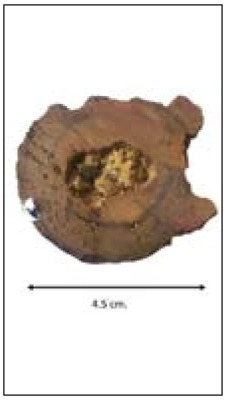


Figure 26: Small concretion from the JRBJ outcrop dissected by a rock saw.

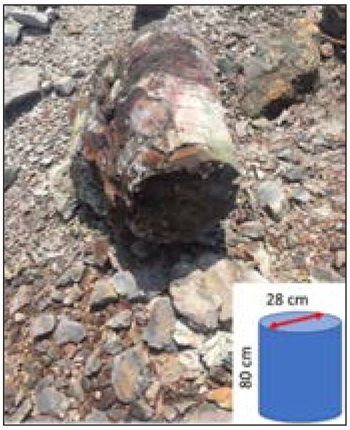


Figure 27: Unidentified object. Could it be a possible Permian palm plant?

explain the lack of fossils. More likely, at this location, the non-fossiliferous Kenny Hill Formation was deposited downstream from a barren, arid periglacial landscape of a distal outwash plain at low latitudes devoid of

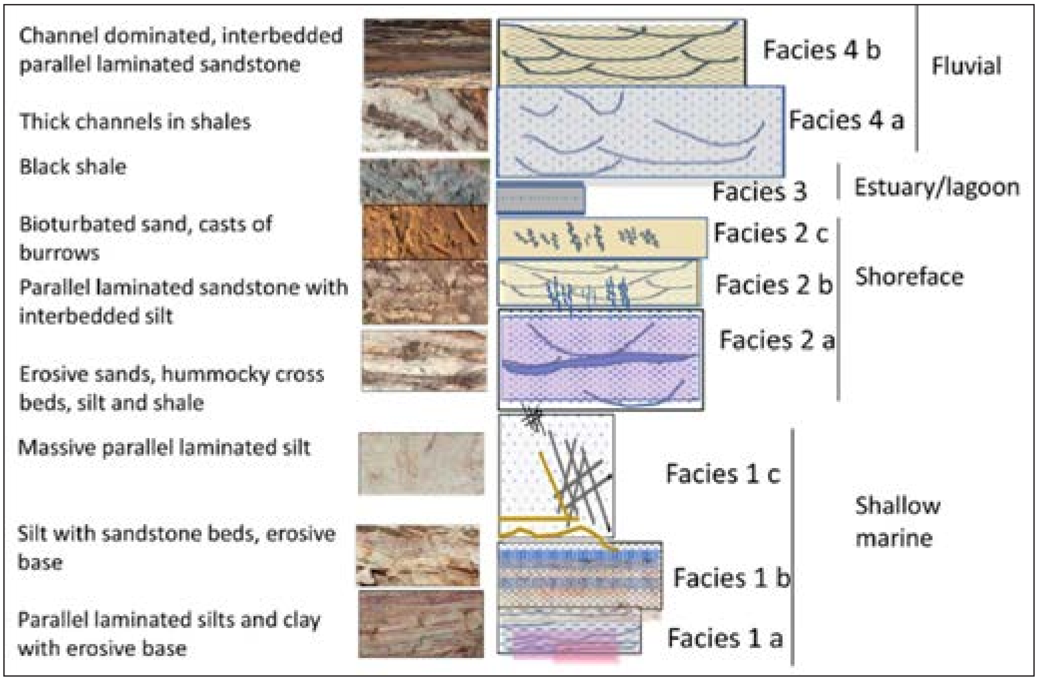


Figure 28: Composite facies log of the JRBJ outcrop shows the transition from shallow marine to littoral to fluvial deposition.

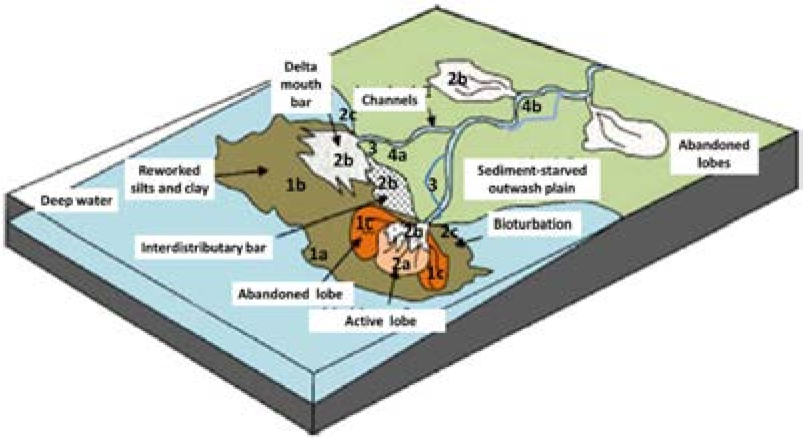


Figure 29: Interpretation of the depositional environment of Kenny Hill Formation sediments at the JRBJ outcrop, northern Selangor. Modified after Siddiqui *et al.*, 2017.

vegetation, such as the environment depicted in Figure 29 (Stauffer & Lee, 1986; Tjia, 2004). An ephemeral, fluvial-deltaic depositional setting, where sheet sands are rapidly deposited over soft sediments following periodic glacial outburst floods supplied the river systems and the delta with a rapid influx of sediment. (Dodd *et al.*, 2019). Facies 1a and 1b and Facies 2a and 2b are the result of rapid deposition on the shelf while Facies 1c appears to be sediments reworked by currents during times of low sediment input.

Glacial diamictites were deposited in grabens on Sibumasu as it rifted from Gondwana during the opening of the Meso-Tethys Ocean, and it is possible that Kenny Hill Formation sediments were preserved along its leading edge in grabens formed by earlier rifting of the Gondwana margin. The bulk of the Kenny Hill Formation continued to accumulate as a clastic wedge on the leading edge of Sibumasu, beginning with a deepwater accumulation siliceous sediments during the Lower Carboniferous. Progressively shallower marine sedimentation, and eventually continental deposits accumulated through the Permian, until the Indosinian Orogeny, when the Kenny Hill Formation was incorporated into the foreland-fold thrust belt which deformed the Paleozoic sediments.

ADDITIONAL OUTCROPS

Other outcrops in the vicinity that require further investigation are noted because of their unique characteristics and need for immediate study before they are destroyed.

Scientex Rawang

Less than 4 km due east from the JRBJ outcrop, on the east side of Persiaran Anggun, just north of Aeaon Mall Rawang, new excavation for a residential and commercial development have exposed sands and shales of the Kenny Hill Formation that dip 8-30 degrees to the northeast (Figure 30). Yellow to buff-colored massive sands up to 4 meters thick lie above the lower unit (Figure 30). The lower section is characterised by a fine-grained, thinly bedded maroon and white colored unit over 8 meters thick that weathers to gray. Tan sand lenses have developed Liesegang rings staining (Figure 31). This rock is remarkably like Facies 1 a and b, the maroon and white shale described at the JRBJ outcrop. Normal faults, downthrown to the west, are exposed in south-facing excavations. The faults appear to sole into a bedding-plane decollement (Figure 32).

Jalan Anggun 2

Across the road, just 0.8 km west, the hillside was cleared and excavated, revealing a large monocline fold in the Kenny Hill Formation (Figures 33 & 34). This outcrop was not yet investigated before press time due to the 2021 Covid-19 travel restrictions. Elsewhere in the Selangor, the Kenny Hill Formation has been deformed into isoclinal and even recumbent folds cut by low angle thrust faults that show a general westward tectonic transportation of the Kenny Hill formation resulting from stress perpendicular to the N-S striking fold axes (Harun & Tjia, 1984). We plan to study this fold in more detail.

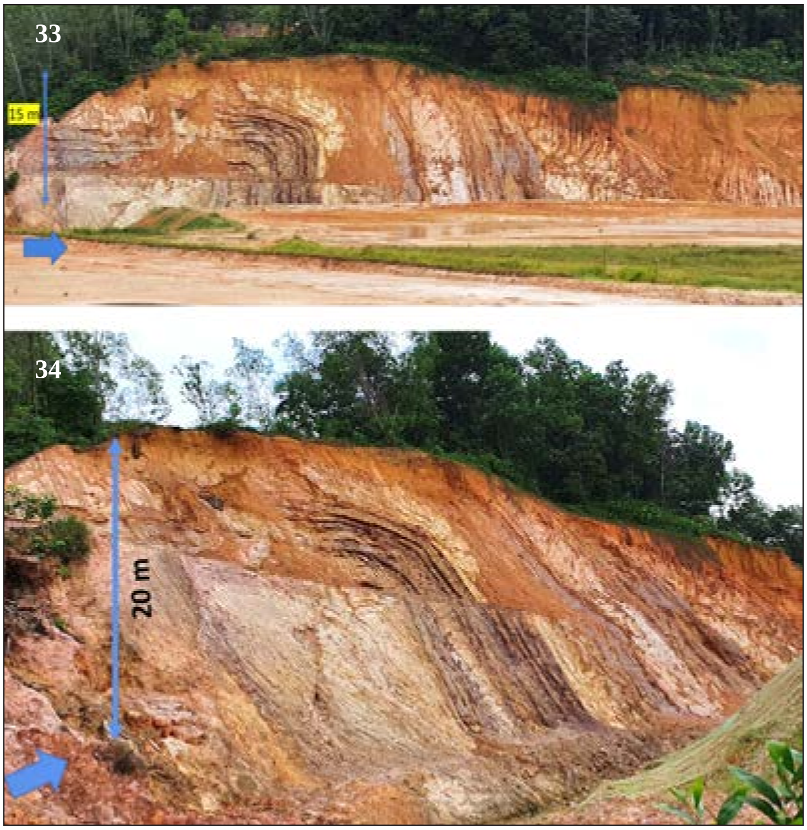
Puncak Alam

13 km southeast of the JRBJ outcrop, the Kenny Hill Formation is being quarried at Bukit Botak (also named Bukit Cerakah) along Jalan Simpang Tiga Jeram (B104) for road fill. The white and maroon silty layer we saw at the outcrops to the northeast (Facies 1a and b) are present here as well. The extensive outcrop of Kenny Hill Formation is cut by normal faults (Figure 35), an angular unconformity (Figure 36) and low angle thrust faults and back thrusts (Figures 37 & 38). Figure 39 is a possible interpretation of the thrust faults in the outcrop that shows tectonic movement is to the right (present day west). Near to the base of the hill an angular unconformity places the Kenny Hill Formation in contact with a highly deformed, dark. fine-grained sediment (Figures 40-41). This appears to be the Upper/Lower Paleozoic contact documented elsewhere in the Klang Valley, such as where the Kenny Hill Formation lies unconformably above the Hawthornden Formation (Yin, 2011). The outcrop is below Bukit Botak peak, a popular hiking destination just 4 km west of Puncak Alam. Based on the position of excavating equipment and the new West Coast Highway under construction nearby, it is likely that most of this outcrop will be removed or will be obscured by slope stability measures (Figures 42-43).

Figure 30: Sharp contact between maroon and white shale that weathers to gray overlain by a 1.5 m thick massive sandstone. The beds strike 50 degrees NW and dip 32 degrees NE.

Figure 31: Tan sandstone lens with Liesegang rings staining and cross-bedded maroon and white shale the weathers to gray.

Figure 32: Approximately 10 m cliff of Kenny Hill Formation at the Scientex outcrop showing faulting and folding typical at this site. View is to the southeast, beds are dipping 50 degrees NNE.



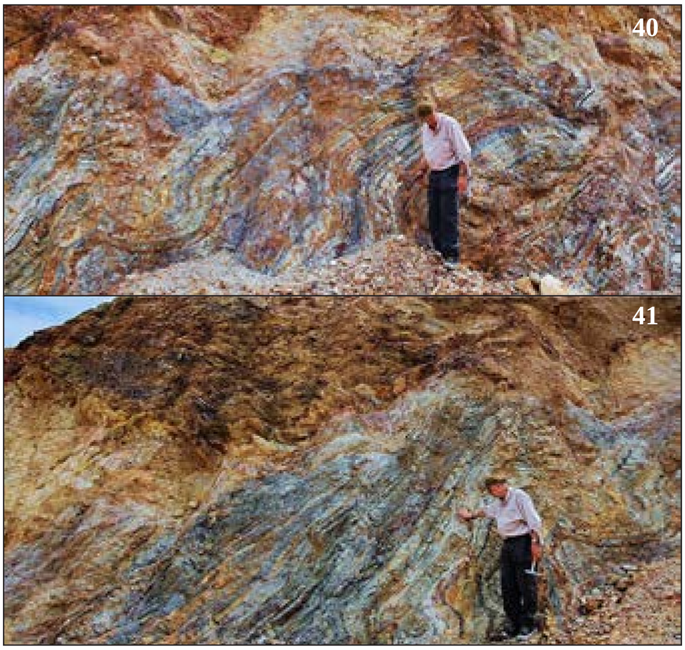
Figures 33 and 34: Monoclinal folding typical of the Kenny Hill Formation. Large arrow points northward.

Figure 35: Normal faults or back-thrusts in the Kenny Hill Formation at Bukit Botak. View is southwest.

Figure 36: Angular unconformity marked by red line, Kenny Hill Formation above red line.

Figures 37 and 38: View to the south of faulting and folding in the Kenny Hill Formation at Bukit Botak showing evidence of movement to the right.

Figure 39: A a possible interpretation of the faulting in Figure 38.



Figures 40 and 41: Views of an angular unconformity between the Upper Paleozoic Kenny Hilll Formation above and highly deforemed Lower Paleozoic sediments below in a north facing outcrop at Bukit Botak.

Figure 42: Heavy mining activity at Bukit Botak for new West Coast Hwy. Red arrow points to dragline excavator on the top, 120 m above viewer.

Figure 43: The outcome for many outcrops. The covered slope is 25 m high.

SUMMARY

The outcrops we investigated result from the ongoing development of the greater Klang Valley. New and equally large outcrops are expected to be exposed as more development occurs. These exposures supply a wealth of new data to supplement the earlier studies and improve understanding of the underlying bedrock. Because the Kenny Hill Formation underlies most of the area to the west of Kuala Lumpur, further sedimentological and biostratigraphic studies are important to assist future development, including minimizing risk above ground for building and infrastructure (Leslie *et al.*, 2020). From an exploration standpoint, the outcrops are useful analogues of co-eval subsurface sedimentary succession currently untested in the offshore basins (Mazlan *et al.*, 2020). We hope these observations inspire detailed studies in the future.

ACKNOWLEDGEMENTS

We greatly enjoyed the company of the friends and colleagues who attended the fieldtrips to the Rawang area during the more relaxed periods of movement control orders during the global COVID-19 pandemic. Attending the field excursions with Mr. Filipov were Robert C. Shoup, Dr. Meor Hakif Amir Hassan with four University of Malaya geology students: Muhammad Hafiz Bin Zulkifli, Farrah Aina Binti Mohd Zulkifli, Muhammad Amer bin Mahamad Apandi and local geologists, Peter Lunt, Dr. Peter Woodroof, Dr. Mazlan Madon, John Jong, Dayang Aimi Nuraini, Supian Suntek, Nursyazwani Abdul Jalil ("Wanie"), Mohd Shafiq Firdauz Abdul Razak, Puja Woodroof and Captain Samrull Zaman.

A special note of thanks to Dr. Peter Woodroof who contributed many hours in the field and over a rock saw and offered thoughtful discussion and helpful critique. We also appreciate the comments received from our reviewers that helped to improve the manuscript.

REFERENCES

Alexander, J.B., 1959. Pre-Tertiary Stratigraphic Succession in Malaysia. Nature, 183, 230-231.

Alexander, J.B., 1965. Geological Map of Malaysia, 6th edition (Diamond Jubilee), 1:500,000. Geologic Survey Department, West Malaysia.

Baba, Mohd Fadlee, 2019. Geology and Mineral Resources of Telok Datok-Sepang, Selangor. Director General Minerals and Geoscience Department, Malaysia.

Baiomy, H., Ulfa, Y., Mohd Nawawi, Padmanabhan & Mohammed Noor Akmal Anuar, 2016. Mineralogy and Geochemistry of Palaeozoic Black Shales from Peninsular Malaysia: Implications for their Origin and Maturation. International Journal of Coal Geology, 165, 90-105.

Barber, A.J., Ridd, M.F. & Crow, M.J., 2011. The Geology of Thailand. The Geological Society London. 626 p.

Chen, B., Mustaffa Kamal Shuib & Khoo, T.T., 2002. Dating the Kenny Hill Formation: Spores to the Fore. Warta Geologi, 28, 189-191.

Cocks, L.R.M., Fortey, R.A. & Lee, C.P., 2005. A review of Lower and Middle Paleozoic biostratigraphy in west peninsular Malaysia and southern Thailand in its context within the Sibumasu Terrane. Journal of Asian Earth Sciences, 24(6), 703-717.

Director General, Department of Minerals and Geoscience, 2009. Geological Map of Kuala Kubu Bahru. Director General Minerals and Geoscience Dept. Malaysia.

Dodd, T.J.H., Ng Tham Fatt, Qalam A'Zad Rosle, Leslie, A.G., Dobbs, M.A. & Gillespie, M.R., 2019. New insights into the sedimentology of the Kenny Hill Formation, Peninsular Malaysia. National Geoscience Conference Abstracts in Warta Geologi, 45, 196-197.

Fang, Zong-Jie, 1994. Biogeographic Constraints on the Rift-Drift-Accretion History of the Sibumasu Block. Journal of Southeast Asian Sciences, 9, 375-385.

Fortey, R.A. & Cocks, L.R.M., 1998. Biogeography and Paleogeography of the Sibumasu Terrane in the Ordovician: A Review. In: Hall, R. & Holloway, J.D. (Eds.), Biogeography and Geological Evolution of SE Asia. Backhuys Publishers, Leiden, The Netherlands, 43-56.

Gan, A.S., 1992. Geology and Mineral Resources of the Tanjong

Malim Area. Minerals and Geoscience Department Malaysia, Map Report 4. 115 p.

Geological Map of Rawang. Director General Minerals and Geoscience Dept. Malaysia.

Ghani, A.A., 2009. Plutonism. In: Hutchison, C.S. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. Universiti Malaya & Geological Society of Malaysia, Kuala Lumpur, 211-231.

Gobbett, D.J., 1965. The Lower Paleozoic Rocks of Kuala Lumpur. Federation Museums Journal, 9, 67-69.

Gobbett, D.J. & Hutchison, C.S., 1973. Geology of the Malay Peninsula. Wiley Interscience, New York. 438 p.

Harun, Z. & Tjia, H.D., 1984. Overturned Folds, Superposed Thrusts and Structural Overprints near Sungai Buah, Selangor. Bulletin of the Geological Society of Malaysia, 17, 225-236.

Hashim, A.S., 1985. Discovery of an Ammonoid (*agathiceras sp.*) and Crinoid Stems in the Kenny Hill Formation of Peninsular Malaysia, and its Significance. Warta Geologi, 11, 205-212.

Hutchison, C.S. & Tan, D.N.K., 2009. Geology of Peninsular Malaysia. Universiti Malaya & Geological Society of Malaysia, Kuala Lumpur. 479 p.

Hutchison, C.S., 2009a. Metamorphism. In: Hutchison, C.S. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. Universiti Malaya & Geological Society of Malaysia, Kuala Lumpur, 233-247.

Hutchison, C.S., 2009b. Tectonic Evolution. In: Hutchison, C.S. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. Universiti Malaya & Geological Society of Malaysia, Kuala Lumpur, 309-330.

Jasin, B. & Harun, Z., 2011. Lower Carboniferous (Tournaisian) radiolarians from Peninsular Malaysia and their significance. Bulletin of the Geological Society of Malaysia, 57, 47-54.

Jones, C.R., 1968. Lower Paleozoic Rocks of Malay Peninsula. American Association of Petroleum Geologists Bulletin, 52, 1259-1278.

Khoo, S. & Tan, B.K., 1983. Geological Evolution of Peninsular Malaysia. In: Proceedings of Workshop on Stratigraphic Correlation of Thailand and Malaysia, 1, Technical Papers Geological Society of Thailand & Geological Society of Malaysia, 253-290.

Lee, C.P., 1996. Probable reasons for the paucity of the fossil record in the Kenny Hill Formation. In: Seminar on Marine Sedimentation and Biota in Malaysian Geological Record-Abstracts. Warta Geologi, 22, 84.

Lee, C.P., 2001. Scarcity of Fossils in the Kenny Hill Formation and its Implications. Gondwana Research, 4, 675-677.

Lee, C.P., Leman, M.S., Hassan, K., Nasib, B.M. & Karim, R., 2004. Stratigraphic Lexicon of Malaysia. University of Malaysia, Kuala Lumpur. 162 p.

Lee, C.P., 2009. Paleozoic Stratigraphy. In: Hutchison, C.S. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. Universiti Malaya & Geological Society of Malaysia, Kuala Lumpur, 55-86.

Leslie, A.G., Dobbs, M.R., Ng Tham Fatt, Rosle, Q.A., Noh, M.R. Mohd., Dodd, T.J.H. & Gillespie, M.R., 2020. The Ukay Perdana Shear Zone in Kuala Lumpur: A crustal-scale marker of early Jurassic orogenic deformation in Peninsular Malaysia. Bulletin of the Geological Society of Malaysia, 69, 135-187.

Long, X.Q., Ghani, A.A., Yu-Ming, Hao-Yang, L. Saidin, M. Roselee, H. Hassan, M.H.A., Aziz, J.H.A., Tham., F.N., Ali, M.A.M. & Zulkifley, M.T.M., 2018. Absolute Age Evidence of Early to Middle Ordovician Volcanism in Peninsular Malaysia. Current Science, 115, 2291-2296.

Loope, D.B., Kettler, R.M., Weber, K.A., Hinrichs, N.L. & Burges, D., 2012. Rinded iron-oxide concretions: hallmarks of altered siderite masses of both early and late diagenetic origin. Sedimentology, 59, 1769–1781.

Mazlan, M., Jong, J., Kessler, F.L., M. Hafiz Damanhuri & Mohd Khairil Azrafy Amin, 2020. Pre-Tertiary basement subcrops beneath the Malay and Penyu basins, offshore Peninsular Malaysia: Their recognition and hydrocarbon potential. Bulletin of the Geological Society of Malaysia, 70, 163-193.

Meor Hafik Amir Hassan, Yeow Boon Sim, Lee Chai Peng & Abdul Hadi Abdul Rahmam, 2013. Facies Analysis of the Uppermost Kubang Pasu Formation, Perlis: A Wave-and Storm-influenced Coastal Depositional System. Sains Malaysiana, 42, 1091-1100.

Metcalfe, I., 2009. Late Palaeozoic and Mesozoic Tectonic and Palaeogeographical Evolution of SE Asia. In: Buffetaut, E., Cuny, G., LeLeouff, J. & Suteethorn, V. (Eds.), Late Paleozoic and Mesozoic Ecosystems in S.E. Asia. The Geological Society of London, Special Publications, 315, 7-23.

Metcalfe, I., 2013. Gondwana Dispersion and Asian Accretion: Tectonic and Palaeogeographic Evolution of Eastern Tethys. Journal of Asian Earth Sciences, 66, 1–33.

Metcalfe, I., 2017. Tectonic Evolution of Sundaland. Bulletin of the Geological Society of Malaysia, 63, 27-60.

Ming, X.R., Liu, L., Yu, M., Bai, H.G., Yu, L. Peng, X.I. & Yan, T.H., 2017. Bleached mudstone, iron concretions, and calcite veins: a natural analogue for the effects of reducing CO_2-bearing fluids on migration and mineralization of iron, sealing properties, and composition of mudstone cap rocks. Geofluids, 16, 1017-1042.

Parry, W. T., 2011. Composition, nucleation, and growth of iron oxide concretions. Sedimentary Geology, 233, 53-68.

Roe, F.W., 1951. The Geological and Mineral Resources of the Neighborhood of Kuala Selangor and Rasa, Selangor, Federation of Malaysia With an Account of the Geology of Batu Arang Coalfield. Memoir No. 7, Geological Survey Department, Federation of Malaysia. 164 p.

Scrivenor, J.B., 1913. The Geological History of the Malay Peninsula. Quarterly Journal of the Geological Society, 69, 343-371. https://doi.org/10.1144/GSL.JGS.1913.069.01-04.22.

Searle, M.P. & Morley, C.K., 2011. Tectonic and Thermal Evolution of Thailand in the Regional Context of S.E. Asia. In: Barber, A.J., Ridd, M.F. & Crow, M.J. (Eds.), The Geology of Thailand. The Geological Society London. 626 p.

Searle, M.P., M. J. Whitehouse, L. J. Robb, A. A. Ghani, C. S. Hutchison, M. Sone, S.W.-P. Ng, M. H. Roselee, S.-L. Chung & G. J. H. Oliver, 2012. Tectonic Evolution of the Sibumasu-Indochina Terrane Collision Zone in Thailand and Malaysia: Constraints from new U-Pb Zircon Chronology of SE Asian Tin Granitoids. Journal of the Geological Society, 169, 489-500.

Shuib, M.K., 2009. Structures and Deformation. In: Hutchison, C.S. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. Universiti Malaya & Geological Society of Malaysia, Kuala Lumpur, 271-308.

Siddiqui, Numair Ahmed, Abdul Hadi A. Rahman, Chow Weng Sum, Wan Ismail Wan Yusoff & Mohammad Suhaili bin

Ismail, 2017. Shallow-marine Sandstone Reservoirs, Depositional Environments, Stratigraphic Characteristics and Facies Model: A Review. Journal of Applied Sciences, 17, 212-237.

Stauffer, P.H., 1973. The Kenny Hill Formation. In: Gobbett, D.J. & Hutchison, C.S. (Eds.), Geology of the Malay Peninsula, Wiley Interscience, New York, 87-91.

Stauffer, P.H. & Lee, C.P., 1986. Late Paleozoic Glacial Marine Facies in Southeast Asia and its Implications. GEOSEA V Proceedings II. Bulletin of the Geological Society of Malaysia, 20, 363-397.

Tan, B.K. & Yeap, B.K., 1977. Structure of the Kenny Hill Formation, Kuala Lumpur, and Selangor. Bulletin of the Geological Society of Malaysia, 8, 127-129.

Tjia, H.D., 1974. Inverted facing of Kenny Hill Formation at Bukit Pantai, Kuala Lumpur. Geological Society of Malaysia Newsletter, 51, 1-2.

Tjia, H.D., 1980. Recumbent Folds in Rocks of Kenny Hill Formation Indicate Sense of Tectonic Transport. Warta Geologi, 6, 23-24.

Tjia, H.D., 1986. Geological Transport Directions in Peninsular Malaysia. GEOSEA V Proceedings Vol. II. Bulletin of the Geological Society of Malaysia, 20, 149-177.

Tjia, H.D., 2004. Periglacial involutions, large, folded recumbent folds and tectonic overprints at Putrajaya. Bulletin of the Geological Society of Malaysia, 48, 97-102.

Van der Wal, J.L.N., 2014. The Structural Evolution of the Bentong-Raub Zone and the Western Belt around Kuala Lumpur, Peninsular Malaysia. Master's Thesis, Utrecht University. 109 p.

Willbourn, E.S., 1922. An Account of the Geology and Mining Industries of South Selangor and Negeri Sembilan. Baptist Mission Press, Calcutta. 115 p.

Yin, E.H., 2011. Geology and Mineral Resources of the Kuala Lumpur-Kelang Area. Minerals and Geoscience Department Malaysia Map Report 22, 87 p.

Yoshida, H., Yamamoto, K., Minami, M., Katsuta, N., Sin-ichi, S. & Metcalfe, R., 2018. Generalized conditions of spherical carbonate concretion formation around decaying organic matter in early diagenesis. Nature.com Scientific Reports, DOI:10.1038/s41598-018-24205-5.

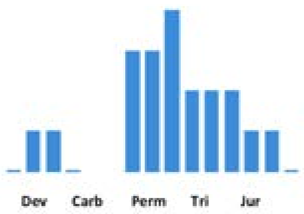
Manuscript received 4 April 2021
Revised manuscript received 27 April 2021
Manuscript accepted 28 April 2021

APPENDIX A - C

APPENDIX A

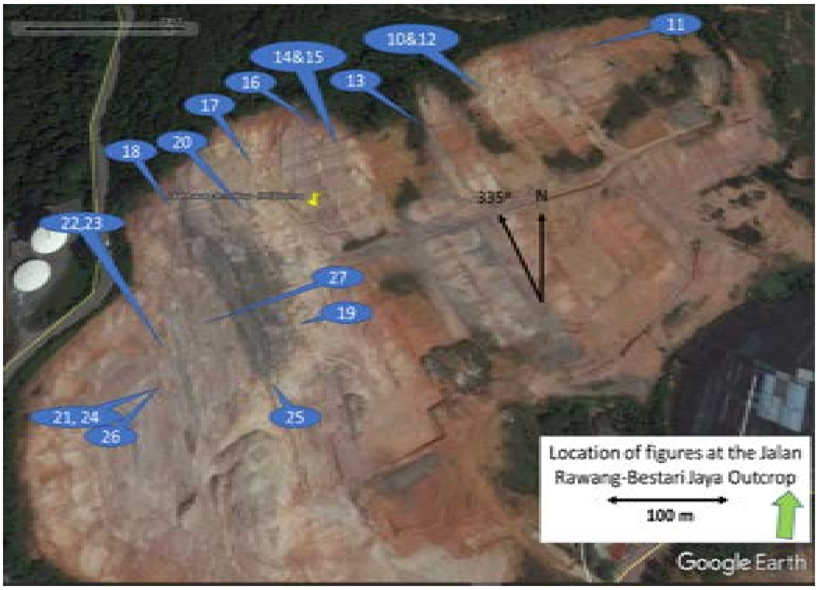
Distribution of Spores referenced in: Chen, B., Mustaffa Kamal Shuib & Khoo, T.T., 2002. Dating the Kenny Hill Formation: Spores to the Fore. Warta Geologi, 28, 189-191.

Graph showing the distribution of the spores listed over time.



- *Leiotriletes* sp
- *Punctatisporites* sp
- *Dictyotriletes* sp
- *Verrucosisporites microtuberculatus* (Loose) Smith and Butterworth
- ? *Lycospora* spp
- *Acanthotriletes* sp

APPENDIX B
Jalan Rawang-Bestari Jaya Figure locations



APPENDIX C
Sedimentary Logs