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Cover photo: *Geothermal site at Apas Kiri, Tawau, Sabah. Photo by: Dr. Mohd Hariri Arifin*

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The Kampar pinnacles: Sedimentology and depositional environment

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Abstract: The Kinta Valley of Perak, Malaysia is a geologically significant region characterized by Paleozoic carbonate deposits, karst landscapes, and a rich fossil record. This study focuses on the sedimentological description and depositional interpretation of carbonate pinnacles once exposed at Putra Terminal, Kampar, which have since been demolished due to urban development. A total of 26 pinnacles were surveyed, with seven logged in detail to construct two continuous lithostratigraphic sections. Five facies were identified: stylolitic limestone (M), laminated limestone (LL), oval detritus limestone (F), bioclastic limestone (BL), and brecciated limestone (Bc). The facies association indicates a dominantly shallow-marine depositional setting ranging from peritidal to a classic reef environments, with episodic higher-energy influences. Fossil assemblages, including gastropods, horn corals, and possible fusulinids, provide evidence for a Late Carboniferous to Permian age. Diagenetic overprinting, particularly dolomitization, was pervasive and restricts microfacies analysis. These results contribute to the broader understanding of the Kinta Limestone Formation and underscoring the importance of documenting rapidly disappearing geological sites within Malaysia's karst landscapes.

Keywords: Kinta Valley, limestone, sedimentology, pinnacles

INTRODUCTION

The Kinta Valley, located in Perak, Malaysia, has a rich history of geological usage over the past century, largely driven by its abundant tin deposits. During the late 19th and early 20th centuries, the valley became one of the world's largest alluvial tin mining areas, significantly contributing to Malaysia's economy (Lehmann, 2021). This tin boom spurred the development of infrastructure and construction not only in Ipoh but also in smaller towns such as Batu Gajah and Kampar. Post-independence, as tin prices declined and the industry waned, the region diversified its geological applications. The karst landscape of limestone hills and caves gained prominence, leading to the development of geoheritage sites and geotourism (Adnan Jusoh & Yunus Sauman Sabin, 2019). The study of Kinta Valley's geology, especially its stratigraphy, is crucial for understanding its geological history and resources potential (Aydin, 2000; Brookfield, 2004), aiding in mineral exploration, construction projects, and enhancing geotourism (Mohd Shafeea Leman *et al.*, 2007; Nordiana Mohd Muztaza *et al.*, 2025). The Kinta Valley is geologically notable for its extensive karst landscape, characterized by limestone hills and numerous caves formed through the dissolution of carbonate rocks. The limestone here primarily belongs to the Kinta Limestone Formation, which dates to the Paleozoic era, making it over 250 million years old. This formation includes significant deposits of limestone and dolomite while being flanked by younger granite (Lee, 2009).

Notable sites like Gua Tempurong, Sam Poh Tong, Perak Tong and Kek Lok Tong caves attracted tourists, emphasizing conservation and educational aspects of geology. The karstic hills in this valley are characterized by the presence of dolines, caves, and caverns, staged waterflow platform with needle-shaped stalactites hanging from the ceilings and stalagmites rising from

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the cave floors (Ros Fatihah & Ibrahim, 2003; Pierson, 2009; Choong *et al.*, 2014). Kinta Valley geological formations have been used in construction and industry, and today, the legacy of tin mining is preserved in museums and heritage trails, while the natural beauty of the limestone formations continues to attract visitors worldwide.

This study aims to give a detailed description and comprehensive sedimentological analysis of the carbonate pinnacles exposed at Putra Terminal, Kampar, Perak. These carbonate pinnacles are a distinctive feature of the local karst landscape, representing ancient reef structures that have been exposed through erosion. Studying these formations provides valuable information about the paleoenvironment and geological history of the region. Moreover, these rocks have been demolished for housing development, making these reported sites not available for future visits.

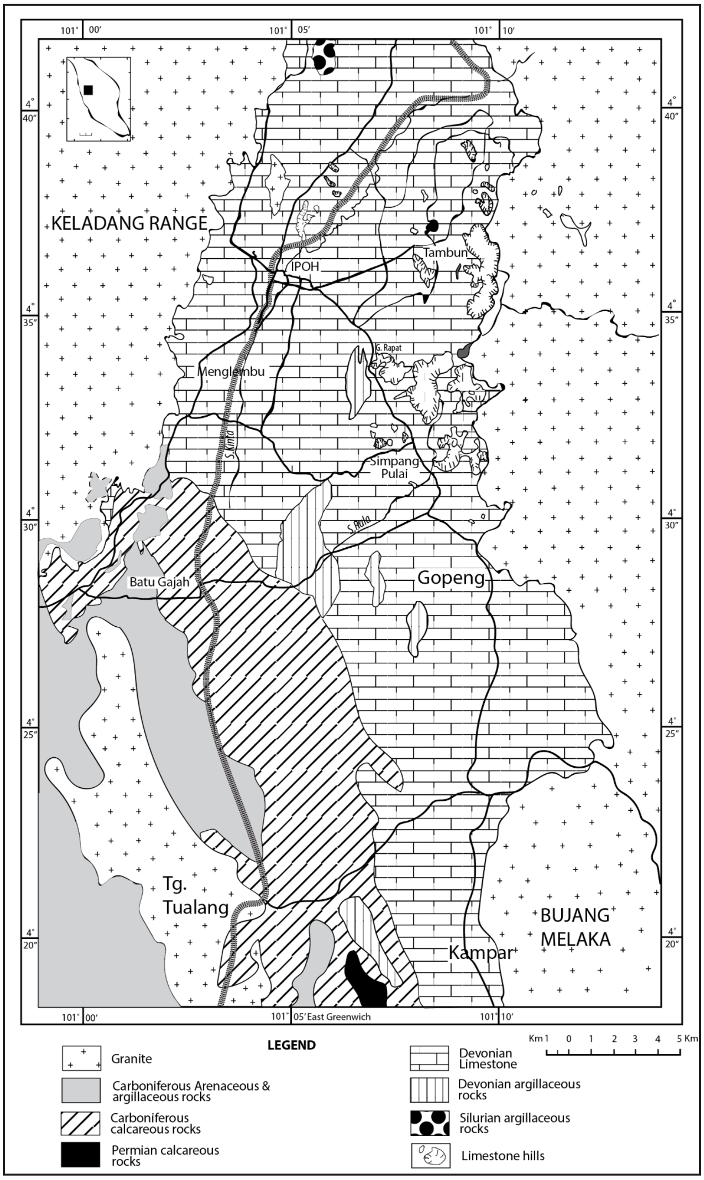

Figure 1: Geological map of Kinta Valley (adapt from JMG, 2024).

OVERVIEW OF KINTA VALLEY

Kinta Valley is located at the Western Belt of Peninsula Malaysia in the state of Perak. It is drained by the Kinta River, which originates from Mount Korbu at Ulu Kinta flowing southward to Tanjung Rambutan, Kampung Gajah and finally join up with the Perak River and at Kampung Bandar.

The geology of Kinta Valley is characterized by a combination of complex stratigraphy primarily consisting of sedimentary and volcanic rock units. It is bounded by Kledang Granite Range north and eastward. While the western margin is bounded by Kati Formation and Bujang Melaka (Figure 1). The dominating lithological units present in Kinta are limestone, shaley limestone, sandstone and mudstone.

The nomenclature of Kinta Limestone Formation is established based on localities such as mines and settlements. Based on Suntharalingam (1968); Rajah (1979) and Henri & Ibrahim Amnan (1995), the stratigraphy of Kinta Limestone comprises shallow water sediments that can be distinguished into six lithological units. These lithological units are i) "Kim Loong Beds No. 1", ii) "Thye On Beds", iii) "Kuan On Beds", iv) "Kim Loong Beds No. 3", v) "Nam Loong Beds", and the youngest, vi) "H.S. Lee Beds" (Figure 2). "Kim Loong Beds" is reported to be cream-coloured dolomite limestone. This unit is assigned to age from Givetian, Lower Devonian to Silurian, in particular Givetian in age (Henri & Ibrahim Amnan, 1995), making it the oldest unit. The thickness is estimated to be 600 m and distributed mainly around Gunung Kanthan. Tabulate corals and conodonts reportedly found in the unit (Alexander & Muller, 1963; Metcalfe, 2000). "Kim Loong Beds" was also reported to be similar with Chemor Limestone by Gobbett (1971). Overlying the "Kim Loong Beds" is the 150 m thick "Thye On Beds". This unit consists of massive grey recrystallized calcitic limestone distributed at the southern end of Kinta Valley. Several fossils were reported, including conodonts, Murchisoniidae gastropods, onocerid nautiloids, ambocellid brachiopod stringocephalus perakenis and tabulate corals (Gobbett, 1966; Metcalfe, 2000). "Kuan On Beds" is aged Lower Carboniferous with estimated thickness of 500 m and is exposed near Batu Gajah, west of Kampar, in the vicinity of Kampung Sungai Kroh and northeast of Malim Nawar. "Kuan On Beds" is predominantly greyish and thinly bedded recrystallized calcite

Age	Thick-ness	Member	Lithology	Description	Fossil	Locality
Lower Permian	20 m	H.S. Lee Beds		Biohermal limestone	i. Gastropod, ostracods, cidaroid, corals ii. Chiton valves, bivaves, nautiloid	i. East of Batu Gajah
	20 m			Grey bioclasts & fusulinid limestone	i. Larger foram ii. Broken or complete gastropod shells	i. East of Batu Gajah
	60 m	Nam Loong Beds		Impure carbonaceous brachiopod - polyzoan limestone	i. Brachiopods & gastropods ii. Small brachiopods (Gobett, 1970)	i. East of Batu Gajah
	100 m			Crinoidal	i. Crinoid cups & columnal ii. Small brachiopods	i. West of Kampar
Upper? Carbo-niferous	100 m	Kim Loong Beds No. 3		Pyritic black shale & argillaceous mudstone	Unfossiliferous	i. West of Kampar
Lower Carbo-niferous	~500 m	Kuan On Beds		Thin bedded grey recrystallized calcite limestone with dolomite beds interbedded with calcareous and carbonaceous shale	i. Gastropods, bivalve Schizodus (Gobett, 1970) ii. Corals, gastropod (Jones, 1966)	i. Near Batu Gajah ii. West of Kampar iii. near Kampung Sungai Kroh & NE of Malim Nawar
Middle? to Upper Devonian	150 m	Thye On Beds		Massive grey recrystallized calcitic limestone	i. Conodonts (Metcalfe, 2000) ii. Murchisoniidae gastropods, onocer-id nautiloids, & amboceliid brachio-pod stringocephalus perakenis (Gobett 1966) iii. Tabulate corals (Gobett, 1970)	i. Southern end of Kinta Valley
Lower Devonian to Silurian?	~600 m	Kim Loong Beds No. 1		Cream-coloured dolomite	i. Tabulate corals (Jones, 1973) ii. Conodonts (Alexander & Muller, 1963; Metcalfe, 2000)	i. Gunung Kanthan, or Chemor Limestone

Figure 2: General stratigraphy of Kinta Valley and study area (after Gobbett, 1973).

limestone and ooids limestone with minor interbedded dolomite, calcareous and carbonaceous shale. Gastropods, bivalve Schizodus and corals have been discovered in this unit (Gobbett, 1971). Overlying the "Kuan On Beds" is the 100 m thick Upper Carboniferous aged "Kim Loong Beds No. 3". This unit consists of unfossiliferous sandstone, pyritic black shale and argillaceous mudstone. The youngest two units, with the latter being younger, "Nam Loong Beds" and "H.S. Lee Beds" are both reported to be Lower Permain in age with relative thickness of less than 100 m. These two units are rich in fossils, namely, gastropod, ostracods, cidaroids, corals, chiton valves, bivalves, nautiloid, larger foram, smaller brachiopod and crinoid (cups and columnal).

The arenite series in Kinta Valley was initially described and named by Ingham & Bradford (1960) as Kati Beds. Later the term Kati Formation was introduced by (Foo, 1983; Alkhali & Sum, 2015). This Carboniferous to Upper Permian aged unit is exposed westward of Batu Gajah. It is reported that Kati Formation is highly weathered and folded. The lithological unit comprises massive sandstone, interbedded sandstone & shale and greyish shale with iron concretion (Khan & Gámez Vintaned, 2022).

METHOD AND MATERIALS

For sedimentological and stratigraphical studies, the limestone pinnacles in the area were measured and correlated from a lithostratigraphic perspective. The exposed limestone pinnacles, located at 4.316789°N, 101.130865°E near Terminal Putra Kampar were examined for their sedimentological characteristics and fossil content. A total of 26 pinnacles were mapped, and seven correlatable pinnacles were logged to produce

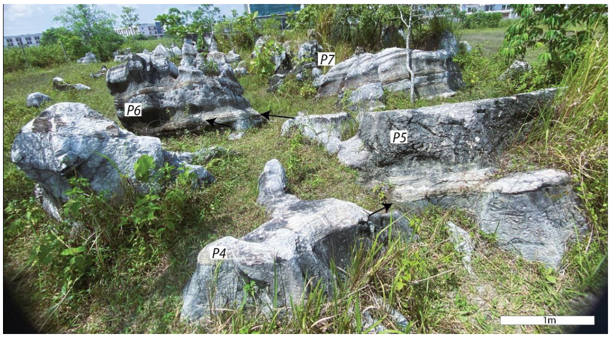

Figure 3: Overview of the exposed pinnacles. The logged seven sections identified (P1 – P7).

continuous sections (Figure 3 & 4). The fundamental elements and features of carbonate facies, facies model and their generally accepted interpretations, were adapted from Tucker (1985) to support further interpretation. This study attempts to characterize the carbonate through physical characteristics (Flügel, 2004; Tucker, 2009). In these studies, three shallow-marine carbonate settings that may evolve into one another were proposed: 1) platforms, 2) shelves, and 3) ramps.

The dataset used in this research can be obtained from Khor *et al*. (2025). It contains recorded sedimentary logs, XRD results, petrography data, photographs of pinnacles, lithologies and fossils from the study area.

RESULT AND DISCUSSIONS

The exposed rocks are rather monotonous, relatively crystallized and thinly bedded succession. In this paper, the facies is classified based the physical observation and sedimentary characteristics. Likewise, facies classification based on microphotographs/microfacies were done by

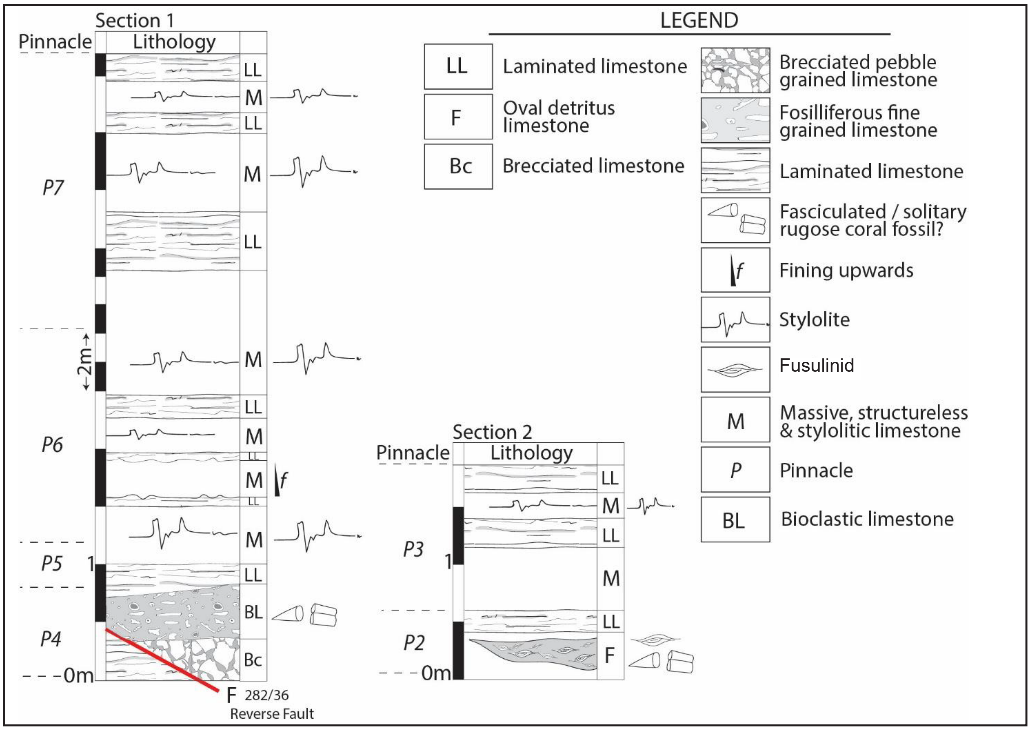

Figure 4: Two sections of continuous logs (13.5 m and 2 m thick). Section 1 consist of pinnacles P4, P5, P6 and P7. Section 2 consist of pinnacles P2 and P3.

Table 1: List of the five facies identified in study area.

No	Facies	Code	Color	Texture	Description	Fossils	Boundaries	Thickness
1	Stylolitic Limestone Facies	M	Greyish white and minor yellowish hue	Mudstone	Structureless, stylolitic	Gastropod	Irregular and planar lower contacts	20 cm to 4 m
2	Bioclastic Limestone Facies	BL	Grey micrite and greyish white bioclasts	Wade-stone and minor grain-stone	Mud-supported, no imbrication	Tabulate coral, isolated coral, crinoid stem?	Irregular/ scouring bottom contact with LL facies	1 m in Pinnacle 4
3	Oval Detritus Facies	F	Grey micrite and greyish white bioclasts	Wade-stone	Imbricated, rounded clasts include 1-1.5 cm oval detritus with minor rounded clasts – averaging 1 cm in diameter	Tabulate coral, fusulinid, isolated coral	Planar lower contact with M	60 cm thick in Pinnacle 2
4	Brecciated Limestone Facies	Bc	Greyish white and greyish brown	Breccia	No imbrication, polymictic, angular clasts less than 5 cm in diameter, matrix supported, clasts in-clude both laminated and structureless limestone	Wood fragment 10 cm long	Planar top contact with Bc facies	Wedge-like, 40 cm thick in Pinnacle 4
5	Laminated Lime stone Facies	LL	Darker grey mi-crite/fine materials with white calcite bands. Lamina-tions are dark grey	Mudstone	Lamination trough stratification	-	Sharp contact and transition with M facies	Averages 30 cm in thickness

Poon *et al*. (2022). Five facies identified are i) Stylolitic limestone facies (M), ii) Bioclastic limestone facies (BL), iii) Oval detritus limestone facies (F), iv) Brecciated limestone facies (Bc), and v) Laminated limestone facies (LL) (Table 1).

Stylolitic limestone facies (M)

This facies is composed of structureless stylolitic limestone, predominantly greyish-white in color. The outer portions of the rock often exhibit a yellowish hue due to weathering. Bed thickness varies from 20 cm to 4 m, with some beds appearing graded to the naked eye. Hand samples reveal rhombic cleavage. The stylolite sutures are seam- or horsetail-like with amplitude not exceeding 1 cm and commonly infilled with greyish mudstone. Rounded clasts are occasionally observed at the base of the beds, while scoured and planar lower contacts are common. The upper contact is typically gradational into the laminated limestone facies (LL). Facies M is commonly found in most pinnacles. Gastropod fossils are present within this facies. Stylolitic structures in limestone represent pressure dissolution that occur due to overburden pressure resulting in bed thickness, permeability and porosity reduction (Norman, 2015; Magni *et al*., 2025). Seam-like stylolites are interpreted to be from an impermeable layer (Sadd & Alsharhan, 2000; Gomez-Rivas *et al*., 2022) along with scoured bottom contacts indicate the participation of wave action. The presence of gastropod which are more diverse in shallower environment, possibly mid-shelf to intertidal, eliminate the likelihood of open-ocean (Dahl, 2012).

Bioclastic limestone facies (BL)

This facies is composed of bioclasts which include rugose corals, isolated corals, and possibly crinoid stems. According to Dunham's classification, the rock is primarily mud-supported which can be classified as a wackestone. The facies is one meter thick and occurs exclusively in Pinnacle 4 (P4) (Figure 4). In some instances, certain sections contain a higher percentage of grains, locally transitioning into grainstone. This facies portrays similarities to facies F, except for the presence of imbrication. This facies shows similarity to the described Nam Long Beds in Gobbett (1973) which is rich with crinoid, foraminifera, brachiopods, gastropods and fusulinids. Based on Henri & Ibrahim Amnan (1995) this facies is deposited in calm environments and are habitual to such organisms.

Oval detritus facies (F)

In Pinnacle 2 (P2), this facies reaches a thickness of 60 cm, forming wedge-like bed. It is dominated by elongated, wheat-like oval detritus, averaging 1-1.5 cm in length, with some exceeding 2 cm, set within micrite matrix. Minor rounded clasts, averaging 1 cm in diameter, are also present. The primary distinction between this facies and the bioclastic limestone facies (BL) lies in its detrital composition and structure. The oval detritus, possibly Triticites, representing recrystallized medium to large fusulinid fossils, which were widespread and peaked during Carboniferous (Sims, 2020; Huang *et al*., 2023). Vertical line patterns (fusiform shape) observed in some specimens may

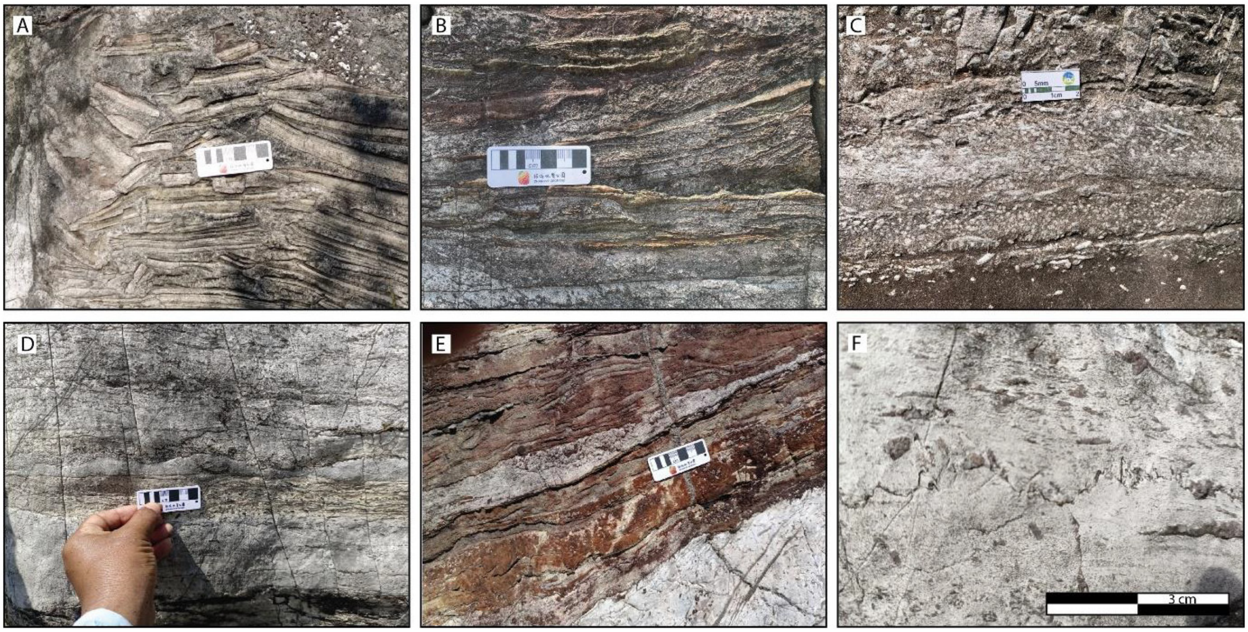

Figure 5: Photos of identified facies. A & B) laminated with platy calcite bands (LL), C) bioclastics limestone with rounded clasts, D & E) laminated greyish limestone, and F) horse-tailed stylolite.

correspond to chamber accretion, as indicated by groove features known as furrows. Additionally, elongated spicules within the facies could represent isolated horn corals, which were abundant before the K-T extinction. The occurrence of this facies as a single wedge-like bed, along with the random orientation of detrital grains, further supports evidence of reworking before final deposition. However, larger fusulinids are known to delve in high energy environments, particularly wave-dominated zones and the random orientation could be a common occurrence in such environments (Sarwary *et al.*, 2022).

Brecciated limestone facies (Bc)

This facies consists of broken, angular carbonate clasts (Figure 7D), with rare instances of clast-supported texture within a predominantly matrix-supported framework, suggesting *in-situ* deposition with minor fine sediment influx. It is classified as a polymictic, matrix-supported breccia, with observed clasts including laminated limestone and greyish structureless fragments. A 10 cm long wood fragment imprint is also present. Diagenetic alterations are evident, with some minor clasts appearing more rounded and exhibiting cul-de-sac pores. The brecciated clasts range from milimeters to 4 cm in diameter and remain predominantly angular. It can form due to failed cave, *in-situ* formation or lag deposit (Scholle *et al.*, 1992).

Laminated limestone facies (LL)

This facies consists of light greyish limestone, averaging 30 cm in thickness, with laminations of darker bands (Figure 6). It is composed predominantly of fine-grained carbonate mud with minor platy bedding and is classified as a wackestone. The laminations are not sharply defined and occasionally appear trough-shaped, with diameters ranging from 2-5 cm and heights of up to 20 cm, suggesting minor wave influence in a low-energy environment. A gradual and transitional contact with the stylolitic limestone facies (M) is commonly observed. This concaved trough is interpreted as bioturbation by trace fossils in a shallower water environment, possibly lagoonal area (Kamal Roslan Mohamed & Che Aziz Ali, 2010; Alonso-Zarza *et al.*, 2011). The laminated fine materials in this facies is likely consisting of algae, organic materials, carbonate mud or possibly siliceous mud. The lamination observed indicates low-energy and rapid, alternating input suggesting deposition in a protected lagoonal or tidal flat environment.

FOSSILS

The fossils identified and available in this dataset are i) isolated horn coral, ii) gastropod, iii) fragmented tabulate coral, possibly iv) fusulinid, and v) crinoid stem (Figure 7).

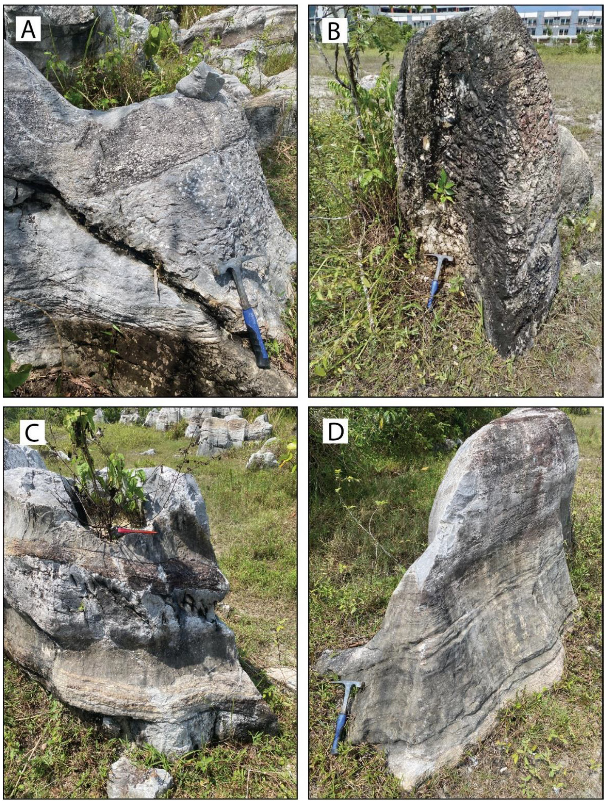

Figure 6: Photos of logged pinnacles. A) Pinnacle P4 – Faulted pinnacle with bioclastic facies overlaying stylolitic and laminated limestone facies at the right, B) Fractured pinnacle with orthogonal joints C) Pinnacle P6 – stylolitic facies overlaying laminated limestone facies, and D) Pinnacle P7 – laminated limestone facies.

i. Isolated horn coral

The other possibility is that it can be sponge skeletal spicules. However, the fact that the vertical lines feature on the fossils and larger size rule out the possibility of being megascleres sponge skeletal spicules (cf. Łukowiak *et al.*, 2022). Likewise, preserved bryozoans are usually the y-shape brunch, fan- and net-like cast (cf. Ernst *et al.*, 2024).

ii. Fusulinid

The identification of fusulinid in facies F is lacklustre as it lacks petrography evidence. The early assumption obtained from this study is that the oval detritus in facies F is most possibly fusulinids. Fusulinid is widely spread especially in Permain aged limestone. Fusulinid is also reported in the Permian aged limestone such as Kubang Pasu Formation (Shirin Fassihi *et al.*, 2024) and Triassic aged limestone in Gua Musang Formation.

DIAGENESIS

Dolomitization in Kinta Valley has been well described by (Poon *et al.*, 2022) from metamorphosed dolomite, early and late dolomitization to sucrosic dolomite. The extensive

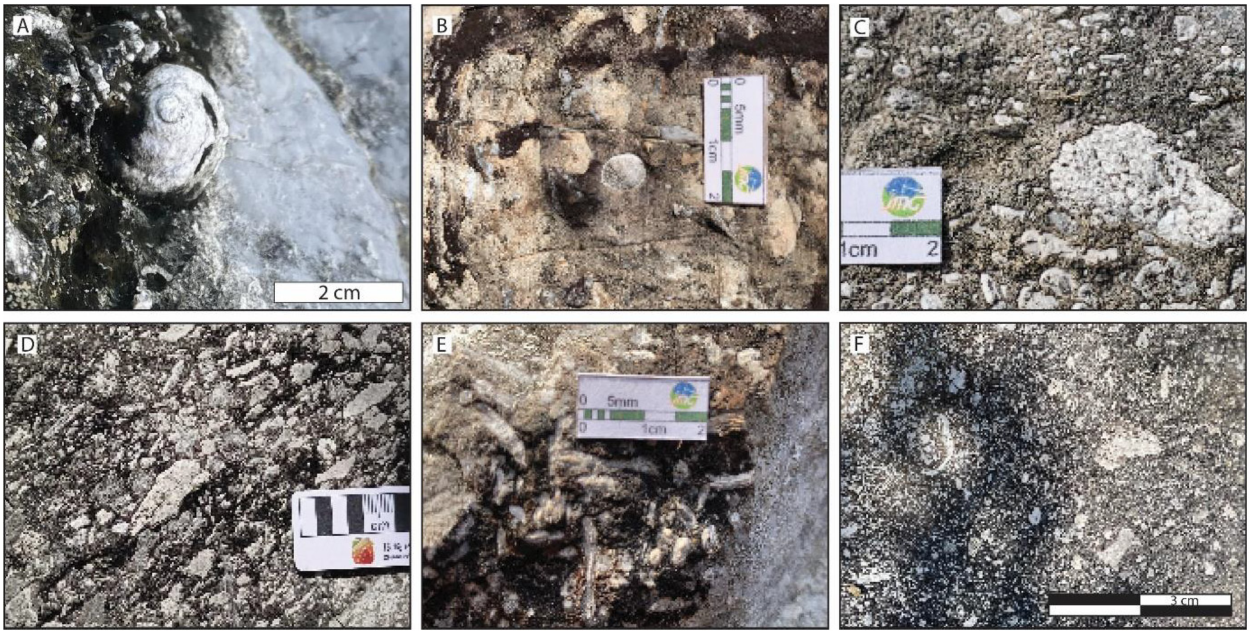

Figure 7: A) gastropod, B) isolated coral, horn? C) wackestone, tabulate coral clast in, D) *in-situ*? breccia, E) Elongated fusiform and rounded detritus wackestone (fusulinid and corals?), F) wackestone - redeposited bioclasts with possible disarticulated brachiopods, carbonaceous fragments.

recrystallization, dolomitization and occurrence of host calcareous mudstone (HCM) were said to be the result of thermal events (Henri & Ibrahim Amnan, 1995). Poon *et al.* (2022) further noted that multiple phases of dolomitization were caused by deep-circulating crustal hydrothermal fluids associated with tectono-thermal events. Occurrence of Sr element based on the XRD done on stylolitic limestone facies (M) suggest diagenesis through fluid development and selective dolomitization (Nurul Afiqah Mohammad Zahir *et al*., 2020). The carbonate pinnacles studied are dolomitic and recrystallized. Thin section observation identified dormant partial or selective dolomitization. It is interpreted that episodic dolomitization in Kinta Valley took place during Permian to Cenozoic (Ramkumar *et al*., 2019). During these periods the paleoenvironment transitioned from marine to terrestrial. The presence of Sr plays an important role in dolomitization (Veizer, 1978). Higher value of Sr could indicate the presence of aragonite during dolomitization process than those originating from calcite.

DEPOSITION ENVIRONMENT

The discussion is based solely on the physical characteristics observed at the pinnacles. Microphotography is not possible with the degree of crystallization present in the prepared thin sections. The facies identified in this study show similarities to the Lower Permian aged Nam Loong and H.S. Lee Beds as compiled in Gobbett (1971). Previous studies suggest that the Kinta Limestone was deposited in a range of marine environments, from deep-marine lower slope settings to shallower facies such as platform margins and lagonal areas toward the east (Pierson *et al.*, 2011). Gebretsadik *et al*. (2015) interpreted parts of the Kinta Valley as representing slope and intrabasin-margin settings, based on the presence of chert, the distribution of conodonts in the northern sector, and southward thinning of sedimentary beds. It is also described that Kinta Valley limestone was deposited in a pelagic to hemipelagic environment. Henri & Ibrahim Amnan (1995) interpreted a calm and subtidal environment for limestones around Kampar region. More recent works, including Gebretsadik *et al.* (2014) and Mahendran (2021) suggested rimmed platform model for the limestone in Kampar area.

The pinnacles in this study show the dominance of stylolitic limestone (M) and laminated limestone (LL) with subordinate oval detritus limestone (F) and underlain by bioclastic limestone (BL). Brecciated limestone (Bc) should not be taken into consideration as it forms independently from localized process such as collapsed cave, failed bank or could potentially form at the upper slope (Figure 8). The facies assemblage documented indicates deposition on a classic reef carbonate model, positioned along the western margin of the Kinta Valley during the Late Carboniferous-Permian. The succession is dominated by low-energy limestones (stylolitic limestone, M facies; laminated limestone, LL) interbedded with localized bioclastic and fusulinid-rich horizons (Bc and F), suggesting a reef interior setting punctuated by episodic high energy events. Although facies LL indicates low-energy settings, its laminations can form in various environments, including restricted lagoon, tidal flats or even deep basins under anoxic conditions. Facies F records

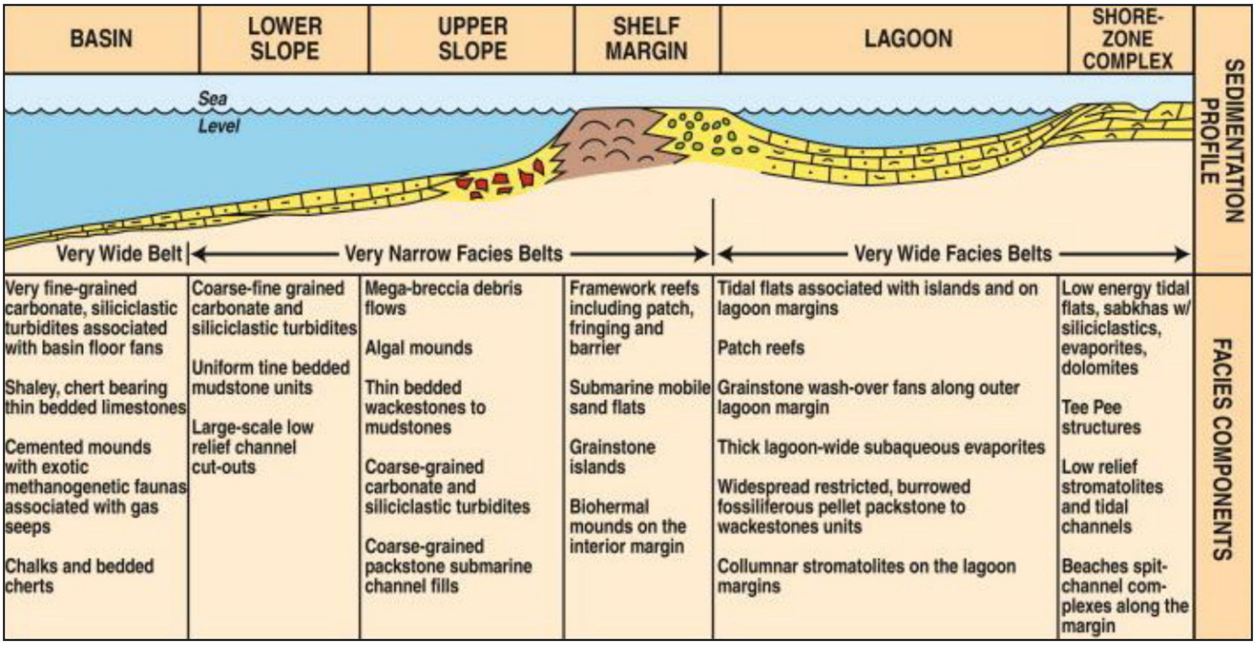

Figure 8: Proposed classic reef model carbonate model for Kampar Limestone. Modified from Wilson (1975).

possible fusulinid fossil content where it indicates a wide range of depositional environment, occurring in shallow water to deeper areas of a carbonate platform setting (Avendaño-Pazos *et al.*, 2024).

Together, these facies suit a classic reef system (Figure 8), where energy is concentrated along the reef, rapidly decreasing landward into a protected lagoon. The absence of deepening-facies, storm-dominated outer ramp deposits, siliciclastic facies or gradual proximal-distal transitions further argues against a unrimmed platform model.

CONCLUSION

This study aims to preserve, document, and share valuable geological information on the now-demolished limestone pinnacles, which were removed due to ongoing urban development. The findings are significant as they provide one of the few remaining sedimentological records of the Kampar carbonate pinnacles, contributing essential data for reconstructing the depositional history and paleoenvironments of the Kinta Limestone.

The rock sequence recorded in this study suggests a repetitive occurrence of stylolitic limestone (facies M) and laminated limestone (facies LL), interpreted to have formed in wide range of settings including peritidal, lagoonal to tidal flat. The subordinate occurrence of oval detritus limestone (facies F) and bioclastic limestone (facies Bc) in isolated pockets indicates possible reworking or localized periods of biogenic accumulation.

However, further evidence is required, as stylolitic limestone facies can develop as a result of diagenesis in a wide range of depositional settings. Additional studies focusing on the types of stylolites present may provide better insight into the original characteristics of limestone prior to diagenesis. It is likely that formation of stylolites occurred between two units with contrasting porosity. Likewise, laminated limestone facies also deposit in a wide range of environments. Distinguishing between ramp, platform and shelf would require longer vertical sections with clear bathymetric gradient indicators, microfacies and biofacies zonation. A classic reef model is proposed for these pinnacles.

From a rock fabric perspective, more extensive studies on the fossil content and its incorporation into facies characterisation could help overcome observational challenges posed by intense recrystallization within these limestones.

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AUTHORS CONTRIBUTION

KWC - Drafting and data acquisition; MSL - data acquisition, drafting and thin sections; NABMN - field organizer and mapping; MAD - data acquisition, paleontological studies and thin sections; MNBAR - field organizer and data acquisition; MAA - XRD and geochemistry.

ETHICS

This study does not involve humans or animals as test subjects. Data collection and field excursions were conducted in accordance with government and Shariah laws.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Rare earth element enrichment in the southern part of Taiping pluton

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Abstract: This study investigates rare earth elements (REE) occurrences in the southern part of Taiping pluton, part of Bintang batholith in Peninsular Malaysia. 36 samples were collected from three outcrops (PSS, PUK, MJ) across four weathering horizons (A, B, C, D) and analysed using X-ray fluorescence (XRF), X-ray diffraction (XRD), petrography and inductively coupled plasma mass spectrometry (ICP-MS). The granitic bedrock (horizon D) is amphibole-bearing I-type granite, averaging 389.00 ppm REE. The granite was observed containing zircon and apatite as the main REE-bearing minerals. Among the weathered profiles, horizon C shows the highest enrichment, averaging 683.00 ppm, compared with 258.00 ppm in horizon B and 119.75 ppm in horizon A. The strong enrichment of REE occurred in horizon C due to the closer depth to the granite and REMs. This finding provides new insight for the enrichment of REE within the weathered profiles of Taiping pluton.

Keywords: REE, Main Range Granite, Bintang batholith, Taiping pluton, geochemical

Abstrak: Kajian ini menyiasat kehadiran unsur-unsur nadir bumi (REE) di bahagian selatan pluton Taiping, yang merupakan sebahagian daripada batolit Bintang di Semenanjung Malaysia. Sebanyak 36 sampel telah diambil dari tiga singkapan (PSS, PUK, MJ) yang merentasi empat lapisan luluhawa (A, B, C, D) dan telah dianalisa menggunakan pendarfluor sinar-X (XRF), pembelauan sinar-X (XRD), petrografi, dan ICP-MS. Batuan dasar (lapisan D) adalah granit jenis-I yang mengandungi amfibol, dengan purata 389.00 ppm REE. Batuan dasar ini mengandungi zircon dan apatit sebagai mineral utama pembawa REE. Antara lapisan – lapisan profil terluluhawa yang terbentuk di lapangan, lapisan C mempunyai pengayaan yang tertinggi, dengan purata 683.00 ppm, berbanding 258.00 ppm di lapisan B dan 119.75 ppm di lapisan A. Pengayaan REE yang tinggi berlaku di lapisan C disebabkan oleh kedalaman yang lebih hampir dengan batuan dasar dan mineral nadir bumi (REMs). Penemuan ini memberikan pandangan baharu untuk pengayaan REE dalam profil terluluhawa pluton Taiping.

Kata kunci: REE, Granit Banjaran Utama, batolit Bintang, pluton Taiping, geokimia

INTRODUCTION

Background

Rare earth elements (REE) comprise of seventeen elements in the periodic table, of which fifteen are from the lanthanide group and the remaining are scandium (Sc) and yttrium (Y). REE have emerged as critical components in modern technologies such as renewable energy systems, electronics and defence applications. This growing importance has become the drive factor for researchers to develop sustainable extraction strategies (Ibad *et al*., 2024). Among a few deposit types of REE, ion – adsorption clay deposits are getting attention due to their lower environmental impact during mining, which involves non – radioactive leaching processes.

REE can be commonly found in higher concentrations within some specific geological environments. These include alkaline and peralkaline igneous rocks, carbonatite intrusions, as well as certain sedimentary formations (Haxel *et al*., 2002). Under Malaysia's moist and warm climate, with consistently uniform temperatures throughout the year (Malaysian Meteorological Department, 2025), bedrocks undergo intense weathering processes that contribute to the breakdown of REE – enriched minerals or also known as Rare Earth Minerals (REM). Released REE from the REM are typically mobilised in ionic state and subsequently adsorbed to the weathering products of host rocks, particularly clay minerals. Over time, this process leads to the ion-adsorption clay-type deposits,

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which can develop into economically valuable secondary source of REE (Mouchos *et al*., 2017).

Previous studies

Malaysian granite plutons, especially the Taiping pluton, were previously studied by Ghani (2005); Ghani *et al*. (2013) and Quek *et al*. (2015, 2016, 2017). Taiping pluton is found to be a large, elongated igneous body that stretches from Kupang in Kedah to Beruas in Perak (Figure 1). Geologically, studies conducted by Ghani *et al*. (2013) and Husin *et al*. (2015), found that Taiping granite complex is one of prime examples for amphibole – bearing granite with large crystal sizes and prominent K – feldspar phenocrysts. It also exhibits a strong flow alignment and research by Quek *et al*. (2016) found that the amphibole content varies from accessory to minor, containing more than 1000 ppm of total rare earth elements (TREE) concentration (Quek *et al*., 2017).

The (Akademi Sains Malaysia, 2014) initiated a study on REE hosted in ion-adsorption clay-type deposits, with particular focus on HREE derived from granite weathering products. The behaviour of REE in chemically weathered granites, especially in tropical environments, are not widely documented and poorly understood (Mohamad & Ghani Rafek, 1993). To date, there has been no publicly available information or data on the REE for the weathered profiles of Taiping pluton. Hence, this paper aims to investigate the geochemical distribution of REE content in the weathered products of Taiping pluton.

Study area

The study area is located at the southern part of Taiping pluton and is divided into three sampling locations. First sampling location, PSS, is located approximately 2.0 kilometres southwest of Kampung Sauk. The second sampling location, PUK, is located approximately 500 metres from Kampung Ulu Kernas. Lastly, the third sampling location, MJ, is located at Madu Jaya Quarry which is located approximately 3.3 kilometres from Kampung Sungai Air Terjun.

MATERIALS AND METHODOLOGY

Soil and rock sampling

A total of 36 representative samples were collected systematically, starting from horizon A (approximately around 0.2m to 0.5m below the surface), and continuing through horizon B, horizon C and the underlying rock (horizon D). Soil sampling and classification was carried out based on characteristics described by Sanematsu *et al*. (2013). The samples were acquired from three sites, namely PSS, PUK and MJ (Figure 1).

According to Keller (1963), horizon A is composed of dark brown soil. This horizon is rich in organic material, clay minerals and quartz while only containing very small quantities of primary rock – forming minerals. Horizon B is characterised by reduced organic content and displays yellowish to reddish – brown coloration. Granitic textures generally cannot be seen within this horizon. Horizon C is represented by a fragile weathered layer developed on the parent granite, typically displaying yellowish to greyish colour. In this horizon, granitic textures and primary minerals such as feldspars and biotite are still identifiable. The writer also noted that the transition from horizon C to horizon B would occur gradually and without any distinct boundary.

The regolith samples were analysed using X-ray fluorescence (XRF), X-ray diffraction (XRD) and inductively coupled plasma mass spectrometry (ICP-MS). Prior to these geochemical and mineralogical analyses, the samples were air dried, ground using a Fritsch mortar and sieved through 75 micrometre mesh. For the granite samples, in addition to laboratory-based geochemical and mineralogical analyses, thin sections were prepared and examined under a petrological microscope

Laboratory analyses

Geochemical analyses

Geochemical analyses, which include XRF and ICP-MS, was conducted at Bureau Veritas Commodities, Vancouver, Canada. XRF analysis was conducted to obtain the major elemental compositions such as SiO_2, Fe_2O_3, CaO, TiO_2, K_2O, P_2O_5, Na_2O, MnO, and MgO. Loss on ignition (LOI) values were measured in accordance with standard laboratory protocols. The ICP-MS analysis, using a standard analytical procedure, was conducted to obtain the concentration of REEs, U and Th. Total REE (TREE), total light REE (TLREE) and total heavy REE (THREE) were calculated by summing the appropriate values. The minimum, maximum and average values for each element were determined, including TLREE, THREE and TREE, along with the calculation of Ce/Ce*, Eu/Eu* and La/Yb ratio. REE concentrations were normalised to chondritic values using the elemental abundances of (Sun & McDonough, 1989), from which the chondrite-normalised REE plot diagram was constructed.

XRD analysis

XRD analysis was conducted in the Centralised Analytical Laboratory (CAL) at Universiti Teknologi PETRONAS for all samples. The analysis aims to identify the mineral content in the soil and in rock samples. Samples were pulverised to <75µm prior to the analysis. Diffractograms were acquired between 0 and 100 2ϴ peaks and the data were then processed using Panalytical's Xpert Highscore Plus™ software.

Petrographic study

All collected rock samples were prepared for petrographic study. The granitic rocks were first cut into rectangular size chips then glued and ground to

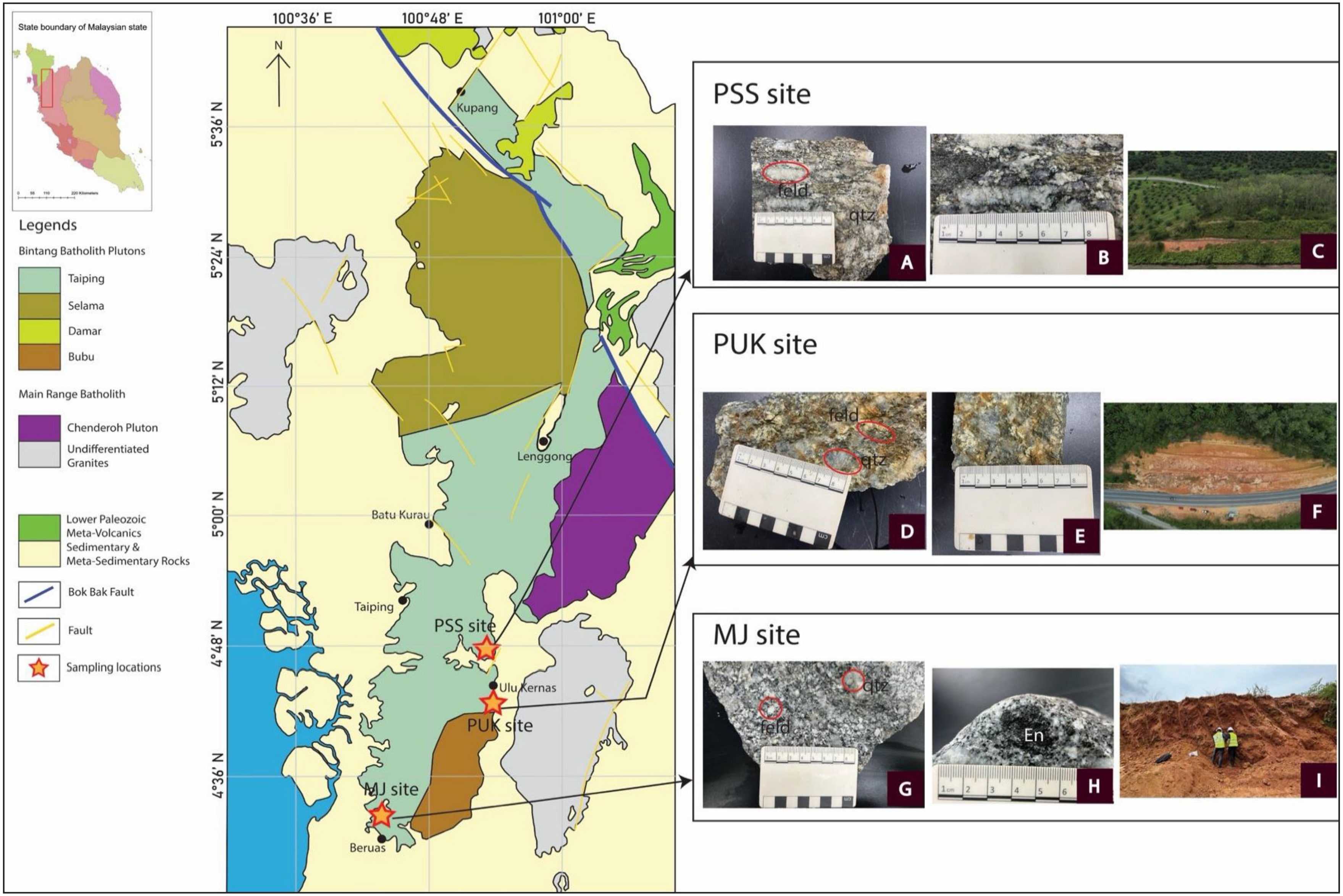

Figure 1: The figure shows the divisions of Taiping pluton, modified from Quek *et al*. (2016). The sampling locations are marked with stars. Feld is feldspar, qtz is quartz, en is enclave.

the thickness of approximately 30 micrometres, or the thickness which is suitable for the microscopic observations.

RESULTS

Field observations

The weathered granite profiles in all 3 sampling sites (PSS, PUK and MJ) range from 7 to 15 metres in thickness. Horizon A (Figure 3) consists of dark brown to reddish brown soil, enriched with plant roots, can be easily crumbled by hand and has thickness ranging from 20 to 50 centimetres.

The B horizon was identified to have yellowish to reddish brown in colour and lacks any visible granitic texture. When moistened, the soil can be rolled between fingers. The presence of feldspar minerals residues is scarce due to its highly weathered nature of horizon B, but they still can be identified with mineral remnants having white colour, contrasting to the colour of matrix. This horizon is highly enriched with clay minerals with little to no organic matter or plant roots.

The C horizon displays a distinctive brown to dark reddish-brown coloration while retaining remnants of its granitic textures. The darker colour likely reflects the melagranitic composition of the Taiping pluton, which is enriched in mafic mineral components. Despite weathering, the primary rock-forming minerals remain identifiable. Compared to the overlying B horizon, the soil material in this layer exhibits reduced plasticity when rolled between the fingers and can be easily disintegrated.

Horizon D, which is the bedrock, can be easily identified from the profile. The bedrock samples are derived from the amphibole-bearing melagranite of Taiping pluton. These samples display quartz and feldspar minerals ranging from 3 cm to 70 cm in length. The mafic microgranular enclaves (MME) observed within the granite are generally only a few centimetres in size and exhibit sharp contacts with the surrounding granitic host rock. At the MJ site, located in the southernmost part of the Taiping pluton, the granite appears noticeably lighter in colour compared to samples collected from more northern areas as noted by Quek *et al*. (2015). Variations in the thickness of the weathered profiles from each site are likely due to erosional processes that thinned out the weathered crusts. On average, the weathered crusts are mostly developed with the thickness of 7 metres.

XRF and Loss on Ignition (LOI) results

The XRF analysis for soil the samples (Table 1) shows that Al_2O_3 content is highest in horizon B for

Figure 2: Exposed weathered granite profiles together with the bedrock at PUK site showing all the horizons.

Figure 3: One of exposed horizon A (left), horizon B (middle) and horizon C (right) profiles.

Table 1: Results of XRF, LOI and ICP - MS analyses for all samples. XRF and LOI results are shown in percentages (%), while ICP – MS results are expressed in parts per million (ppm).

Sample	MJ A	MJ B	MJ C	MJ D	PUK A	PUK B	PUK C	PUK D	PSS A	PSS B	PSS C	PSS D
Horizon	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**	**A**	**B**	**C**	**D**
SiO_2	58.06	44.43	58.63	70.30	65.51	59.86	61.17	74.09	62.08	59.64	59.47	66.42
Al_2O_3	22.84	32.14	24.09	14.20	20.33	24.44	23.32	13.99	20.94	23.58	22.50	13.64
Fe_2O_3	3.91	6.96	3.99	2.90	4.49	5.35	5.05	1.59	4.57	5.31	4.56	4.76
K_2O	0.73	0.64	4.08	5.25	0.19	0.20	0.38	5.22	0.11	0.11	5.92	3.60
TiO_2	0.65	1.03	0.64	0.50	0.75	0.73	0.71	0.34	0.76	0.84	0.73	0.84
Na_2O	0.03	<0.01	0.10	2.69	<0.01	<0.01	<0.01	2.87	<0.01	<0.01	0.18	2.03
CaO	0.04	0.03	0.05	2.22	<0.01	<0.01	0.02	1.20	4.57	5.31	4.56	4.76
MgO	0.08	0.13	0.37	1.36	0.02	0.02	0.03	028	0.06	0.06	0.48	3.11
MnO	0.01	0.01	0.02	0.05	0.02	0.02	0.02	0.02	<0.01	<0.01	0.03	0.06
P_2O_5	0.05	0.07	0.11	0.16	0.04	0.02	0.04	0.09	0.05	0.04	0.05	0.33
LOI	13.00	14.80	7.90	0.90	9.10	9.80	9.70	0.90	11.10	9.40	6.10	1.70
Total	99.40	99.60	99.98	99.87	100	100	99.65	99.80	93.14	94.89	98.48	99.55
Sc	5.40	12.80	9.50	6.60	4.10	5.80	7.10	2.60	9.10	10.00	9.90	4.10
Y	3.73	6.16	42.64	22.17	1.91	2.82	4.35	108.05	1.45	1.53	37.05	12.34
La	18.00	34.90	310.60	58.00	12.10	12.50	25.80	80.20	5.20	5.50	136.50	91.20
Ce	138.10	342.60	338.60	122.20	50.90	107.50	297.80	120.60	74.50	177.00	193.10	176.60
Pr	4.27	8.51	71.40	13.98	2.89	2.92	6.21	19.69	1.29	1.34	37.46	19.43
Nd	14.80	27.85	236.13	49.22	10.36	10.58	21.84	76.13	4.91	5.01	140.92	65.72
Sm	2.86	5.50	35.29	8.53	1.87	1.94	3.87	18.09	1.00	0.96	21.64	8.67
Eu	0.18	0.50	3.45	0.29	0.03	0.08	0.11	1.60	0.13	0.13	2.66	0.65
Gd	2.00	3.81	17.58	6.08	1.30	1.49	3.01	19.47	0.74	0.94	12.17	5.20
Tb	0.23	0.45	2.04	0.78	0.14	0.16	0.30	3.19	0.08	0.09	1.44	0.56
Dy	1.16	2.30	10.66	4.23	0.63	0.78	1.39	19.64	0.44	0.44	7.85	2.71
Ho	0.17	0.33	1.74	0.74	0.08	0.12	0.20	3.65	0.07	0.07	1.38	0.44
Er	0.45	0.85	5.04	2.17	0.18	0.30	0.49	10.22	0.20	0.20	4.15	1.21
Tm	0.06	0.11	0.72	0.30	0.02	0.04	0.06	1.29	0.03	0.03	0.58	0.15
Yb	0.38	0.69	5.02	1.99	0.10	0.23	0.36	8.09	0.21	0.21	4.02	0.92
Lu	0.05	0.08	0.66	0.28	0.02	0.03	0.05	1.05	0.03	0.03	0.53	0.13
Th	70.50	115.60	66.60	42.40	62.60	77.50	89.10	25.70	74.80	87.50	69.50	63.80
U	9.50	19.00	19.60	13.50	2.60	3.00	11.80	8.80	5.30	6.00	16.90	10.50
`TLREE	180.21	423.67	1013.05	258.30	79.45	137.01	358.64	335.78	87.77	190.88	544.45	367.47
THREE	6.23	10.97	68.52	32.66	3.08	4.48	7.20	155.18	2.51	5.60	57.00	18.46
TREE	186.44	434.64	1081.57	290.96	82.53	141.49	365.84	490.96	90.28	196.48	601.45	385.93
Ce/Ce*	3.79	4.78	0.55	1.03	2.07	4.27	5.66	0.73	6.92	15.67	0.65	1.01
Eu/Eu*	0.06	0.07	0.01	0.02	0.03	0.06	0.02	0.01	0.36	0.30	0.02	0.03
La/Yb	47.63	50.83	61.98	29.21	121.18	54.52	71.77	9.92	24.80	26.23	34.05	9.24

all sites, with values of 32.14% (MJ B), 24.44% (PUK B) and 23.58% (PSS B). High Al_2O_3 content generally reflects higher concentrations of clay minerals, particularly kaolinite and gibbsite (Keller, 1963). Despite this, high TREE concentrations are found in the C horizon. SiO_2 is generally found in high concentrations in horizon A, ranging from 58.06% to 65.51%. Fe_2O_3 is highest within the B horizon with values ranging from 5.31% to 6.96%. LOI values generally show an increasing trend towards a higher weathering grade soils and are directly proportional to the increasing contents of Al_2O_3.

XRF analysis of the rock samples indicates higher concentrations of SiO_2 (66.42% to 70.30%), CaO (1.20% to 3.59%) and P_2O_5 (0.09% to 0.33%) compared to the soil samples. In contrast, Al_2O_3 (13.64% to 14.20%) and Fe_2O_3 (1.59% to 4.76%) contents are lower in the rock samples.

XRD results

According to XRD analysis results of soil samples (Figure 4), horizon A is dominated by quartz (75% to 78%) with the remainder consisting of clay (22% to 25%). This mineralogical composition is similar in all horizon A from each site, with no other significant minerals present.

In horizon B, quartz content drops to 43% to 54% while the clay content increases to 30% to 46%. At MJ site, gibbsite (27%) is also present. This horizon generally shows a reduction in quartz compared to horizon A, with more secondary minerals appearing.

The MJ C sample shows a balanced mix of minerals with quartz at 31%, clay at 15%, K – feldspar at 30% and vermiculite at 24%. PSS C sample is dominated by K – feldspar (52%) with smaller amount of quartz (22%), followed by clay (16%) and gibbsite (10%). The PUK C sample remains quartz – rich (67%) but also contains clay (23%) and gibbsite (10%). This layer marks the introduction of feldspars and vermiculite, especially prominent at the MJ and PSS sites, within the weathered profiles of Taiping pluton.

The MJ D sample contains quartz (29%), a high proportion of K – feldspar (41%) and biotite (30%). The PSS D sample includes quartz (29%), albite (22%), biotite (17%) and K – feldspar (32%). The PUK D sample is dominated by albite (40%), with quartz (22%), K feldspar (33%) and minor amount of biotite (5%). This horizon is clearly more enriched with feldspars and marks the transition into the parent rock's mineralogy in the study area.

Although hornblende was previously reported in Taiping pluton by Ghani *et al*. (2013), it was not detected in the present XRD analysis. This absence may be due to the low abundance of the mineral in the samples, which may fall below the detection limit of the laboratory's XRD instrument. The same reason explains why the REMs were not detected in the bulk powder analysis of the Taiping pluton samples. REMs present at low concentrations (typically below 1-2 %) might fall below the XRD detection limit and thus remain undetected (Keller, 1963).

ICP-MS results

Results of ICP-MS analysis are shown in Table 1. Analysis of soil samples shows that TREE concentrations for horizon A range from 70.00 ppm to 771.00 ppm, with an average value of 291.00 ppm. These concentrations are dominated by LREE, which range from 67.00 ppm to 702.00 ppm, while HREE are significantly lower, ranging from 2.51 ppm to 155.00 ppm. Notably, the MJ C soil sample recorded the highest TLREE content, dominated by Ce, Nd, and Pr.

Thorium (Th) concentrations in the soil samples range from 62.60 ppm to 115.60 ppm, while uranium (U) contents vary between 2.60 ppm and 16.90 ppm. Among the samples, MJ B has the highest Th content, whereas MJ C shows the highest U concentration.

ICP-MS analysis of the rock samples reveals TREE values between 233.00 ppm and 411.00 ppm, with an average of 313.00 ppm. Similar to the weathered profiles, the LREE are more abundant than the HREE. TLREE concentration ranges from 200.00 ppm to 276.00 ppm,

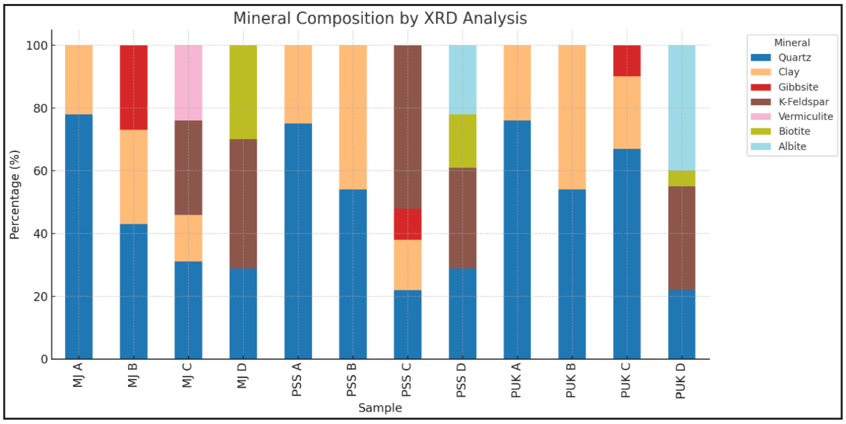

Figure 4: Results of XRD analyses for each sample.

whereas THREE values range between 18.00 ppm and 155.00 ppm. In the rock samples, Th contents range from 25.70 ppm to 63.80 ppm, while U contents range from 8.80 ppm to 13.50 ppm. PSS D and MJ D contain highest Th and U concentrations, respectively.

Chondrite-normalised plot

The chondrite-normalised REE patterns (Figure 5) are derived from the ICP-MS analysis results. The plotted patterns show generally the same variations between the fresh rock and the overlying weathered products of the Taiping pluton. Negative Eu anomalies are observed in both rock and soil samples of the Taiping pluton. The Ce anomalies, in contrast, shows positive anomalies for all samples, except for horizon C samples from MJ and PSS sites.

The positive Ce anomalies are likely attributed to the oxidation of Ce^{3+} to the less soluble Ce^{4+} under near surface oxidative conditions, before being adsorbed onto secondary clay minerals. In this study, Ce enrichment occurs in horizon C and negative Ce anomalies can be observed within C horizons at all localities, except for the PUK site, while other samples are showing positive Ce anomalies.

The La/Yb ratio shows higher values in the soil samples compared to the rock samples.

Petrographic study

The micro-scale images from mineralogical studies of the Buloh Pelang unit, under the petrological microscope, are shown in Figure 6. As the sites are hosted on the same bedrock, the mineral contents are generally consistent, comprising quartz, K-feldspar, plagioclase and biotite as the dominant minerals. Hornblende can be observed in the MJ rock sample as an accessory mineral while REMs like zircon and apatite occur as inclusions within biotite. All the rock samples have the same REMs contain within them, which are apatite and zircon. Textures indicative of radiation damage (or metamictisation) in biotite was observed, such as the presence of a black halo around zircon inclusions. The metamictisation process will cause the mineral textures to be destroyed and creates zoning appearance due to the high abundance of radioactive elements within the zircon (Yaraghi *et al*., 2020).

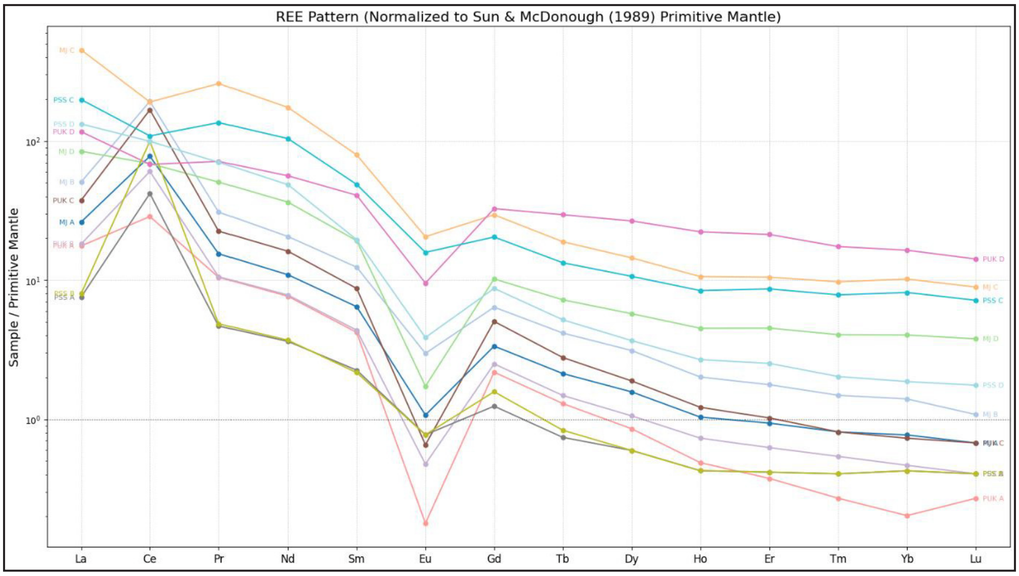

Figure 5: Chondrite - normalised diagram for REE concentrations for each sample. Details of concentration for each sample are given in Table 1.

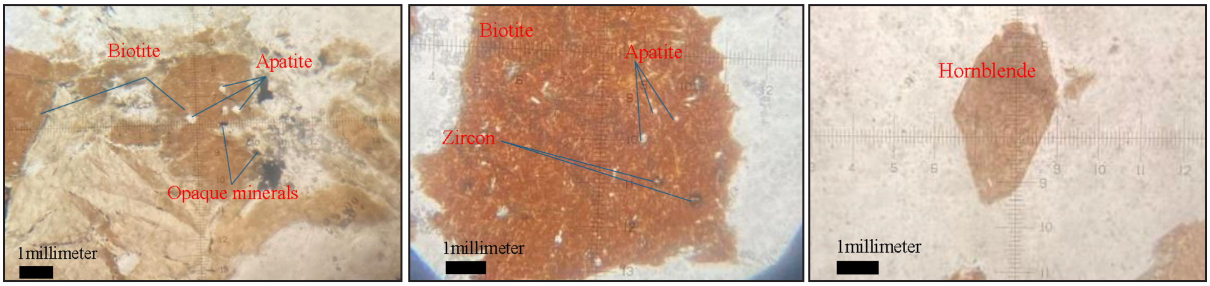

Figure 6: Thin section images from PSS D (left), PUK D (middle) and MJ D (right), as viewed under plan-polarised light.

Among the observed REMs, apatite is the most likely source of REE enrichment within the weathered profiles. Although it occurs as an inclusion within biotite, it has higher solubility, especially in acidic to slightly acidic pH environments, making it prone to breakdown and LREE release during weathering processes. In contrast, zircon with high resistance to chemical weathering, contributes minimally to REE release.

Although zircon can be observed in thin sections of the rock samples, the REE distribution patterns, as shown in Figure 5, are LREE-enriched with no HREE peaks. This indicates that apatite is the primary source for the REE enrichment in the profiles.

DISCUSSION

Weathering profile development

The variation in horizon thickness and mineralogical composition across the three sites reflects the different duration of exposure towards weathering processes within the Taiping pluton. The gradual transition from horizon A that are rich in quartz to clay-rich B horizons and feldspar-bearing C-horizons proves the progressive decomposition of the silicate minerals, consistent with the classical granite weathering sequence described by Keller (1963). Higher Al_2O_3 and LOI contents in the soil horizons also reflect significant chemical weathering, where K-feldspar and plagioclase are weathered into clay minerals under reducing conditions (Yaraghi *et al*., 2020). The darker coloration in horizon B and C corresponds to the melagranitic composition of the parent rock, which contains proportions of mafic minerals hence making the horizon to be enriched with dark minerals.

Enrichment patterns across horizons

Observed chondrite-normalised REE patterns show enrichment of LREE over HREE across all horizons. This fractionation indicates that the LREE are more mobile and released during the weathering of lower resistant REM such as apatite, while HREE remain immobile as the more resistant REM such as zircon are less affected during weathering processes. The highest TREE values can be found in C horizon, moderate in B horizon and lowest in A horizon. This suggests a downward migration and accumulation of REE near the weathering front.

Based on the ICP-MS results, horizons with negative Ce anomalies are showing higher TREE contents compared to soil horizons with positive Ce anomalies, in the Taiping pluton's weathered profile. The overall pattern of Ce anomalies is consistent with the finding of Sanematsu *et al*. (2013), who noted that positive anomalies of Ce are characteristics of shallow leaching zones of REE, while negative Ce anomalies typically develop in deeper in deeper horizons where REE accumulates. The enrichment of REE within the weathered profiles is primarily attributed from the weathering of apatite. This process results in significant enrichment of LREE relative to HREE, as observed in chondrite-normalised pattern, which display absence of distinct HREE peaks.

Eu anomalies are found to be uniformly negative across all samples, indicating a strong depletion in Eu content. Eu^{2+} typically substitutes for Ca^{2+} in plagioclase during crystallisation, resulting in preferential partitioning of Eu into feldspar (Compton *et al*., 2003). Feldspar is then removed via fractional crystallisation processes during magma evolution, leading to the negative anomalies characteristics of granites (Duzgoren-Aydin & Aydin, 2009). Therefore, the negative Eu anomaly in the weathered profiles of the Taiping pluton reflects the original magmatic differentiation history of the parent rock, rather than being produced by later weathering processes.

As for the La/Yb ratio, it is found that the ratio is higher in the weathered materials compared to rock. According to Sanematsu *et al*. (2013), this is indicative of LREE are more enriched compared to HREE.

CONCLUSION

The decisive factor that controls the enrichment of LREE and HREE during rock weathering is primarily governed by the presence of REM and their susceptibility to alteration. This study investigated weathering profiles derived from the amphibole – bearing granite of the Taiping pluton. Sampling was conducted along vertical profiles at three different localities, and the samples were subjected to characterisation using geochemical analyses, XRD and petrographic analyses (rock samples only).

The weathering crust is divided into four main horizons. Horizon A is an organic-rich layer enriched with plant roots. Horizon B is dominated by clay with no obvious relict granite structures while horizon C is differentiated by the presence of identifiable relict or weathered rock – forming minerals from the Taiping pluton. Horizon D represents the unweathered granite bedrock. Petrographic analyses confirmed the presence of apatite and zircon, with apatite being the likely source of REE release during weathering. Metamictisation is observed around zircon inclusions. The radiation effect can be seen on biotite mineral, and it is due to the high content of radioactive elements within the zircon itself.

Based on the XRF results, SiO_2 together with Al_2O_3 are found to be the most abundant oxides in all analysed samples. XRD analyses show that quartz is present in all collected samples. Secondary minerals, such as clay, gibbsite and vermiculite, are present in the weathered profiles of the Taiping pluton.

Based on the ICP-MS analysis results, TREE is the highest at 490.96 ppm in PUK site for the rock sample. The average TREE for the three sampled Taiping pluton rocks is 389.28ppm. For the soil samples, it is observed that REE is concentrated at the lower weathering profile. It is likely due to the continuous REE supply from apatite weathering near the bedrock zone. Horizon C has an average TREE concentration of 682.95 ppm, while horizon B and horizon A have average TREE concentrations of 257.54 ppm and 119.75 ppm, respectively. The high TREE content in horizon C is most likely due to the horizon being deeper, which makes it closer in proximity to the bedrock and to the REMs. The ICP-MS results show good corresponding to the findings of (Sanematsu *et al*., 2013), who reported REE enrichment is observed to occur within soil horizons characterised with negative Ce anomalies.

Future investigations should incorporate advanced techniques such as LA-ICP-MS for mineral characterisation and leaching experiments to evaluate REE mobility within horizons.

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AUTHORS CONTRIBUTION

IDM, NSZA and BCB contributed to the field sampling activities. Sample preparations, data analysis and interpretations were performed by IDM. IDM wrote the whole manuscript, NSZA and BCB contributed ideas to improve the paper.

CONFLICT OF INTEREST

The authors declare there is no conflict of interest.

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Characterisation and palaeoenvironmental significance of amber from the Tukau Formation, NW Sarawak, Malaysia

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Abstract: Amber fragments recovered *in situ* from the Tukau Formation (Middle Miocene to Pliocene) in northwest Sarawak were analysed to assess their physical and chemical characteristics. Amber samples were collected from ten different localities and underwent diagnostic tests to evaluate hardness, solvent solubility, buoyancy, UV fluorescence, and burning reaction. The samples display melting points above 160 °C, hardness between 3-4 on the Mohs scale, non-reactivity to acetone, and a characteristic resinous odour upon heating, properties consistent with fossil amber. Fourier Transform Infrared (FTIR) spectra reveal consistent absorption bands at approximately 2920, 2863, 1694, 1454, 1374, 1042, and 887 cm^{-1}, and display absorption patterns comparable to fossil dipterocarp (Class II) resins and distinct from succinite. When considered together with the diagnostic physical properties and the Neogene age of the host sediments, these observations support classification of the material as fossil amber rather than weakly polymerised resin. The spectral profile closely corresponds to that of resins from Dipterocarpaceae trees, suggesting a tropical lowland forest origin. The preservation of amber within fluvio-deltaic to shallow marine deposits indicates burial under conditions favourable for the preservation of organic matter. Tukau amber is thus comparable to Neogene dipterocarp-derived amber elsewhere in Borneo, providing insights into Miocene palaeoenvironments and vegetation in the region.

Keywords: Borneo amber, Tukau Formation, palaeoenvironment, Miocene, Dipterocarpaceae

INTRODUCTION

Organic constituents preserved within sedimentary successions provide valuable proxies for reconstructing past terrestrial environments. Natural resins, organic hydrocarbon compounds produced by plants, are commonly classified as copal or amber based on their degree of polymerisation and diagenetic maturation (Grimaldi *et al*., 1994; Lambert *et al*., 2012). Copal forms through the evaporation of volatile components from fresh resins, while progressive burial and diagenetic processes, such as devolatilisation, polymerisation, and oxidation, may eventually transform copal into amber (Brody *et al*., 2001; Lambert *et al*., 2012). It is important to note that the chemical pathways and maturation indicators of this transformation may vary depending on the botanical origin and resin class. Amber is particularly informative for palaeoenvironmental and palaeoecological reconstructions (Karolina *et al*., 2022; Garcia-Valles *et al*., 2023; Li *et al*., 2023; Murillo-Barroso *et al*., 2023), as it retains chemical signatures of its botanical source plant and depositional history, thereby bridging palaeobotany, organic geochemistry, and sedimentology. Analytical techniques, such as Fourier Transform Infrared (FTIR) spectroscopy, enable the identification of diagnostic functional groups in fossil resins, providing insights into their botanical affinity, maturation state, and diagenetic history (Langenheim, 2003; Seyfullah *et al*., 2018).

Amber occurrences are globally significant indicators of terrestrial forest ecosystems and resin-producing flora, often associated with tropical and subtropical climates conducive to resin exudation and preservation (Bisulca *et al*., 2012; Álvarez-Parra *et al*., 2024). The earliest known amber record dates to the Early Pennsylvanian (~320 Ma), although macroscopic biological inclusions do not become common until the mid-Early Cretaceous (~125 Ma) (Labandeira, 2014). Fossiliferous amber from Cenozoic deposits originates mainly from two angiosperm lineages with distinct chemical compositions, as summarised in Sadowski *et al*. (2021). Eocene and Miocene ambers from India and China primarily derived from Dipterocarpaceae

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and are classified as Class II dammar resins (Dutta *et al*., 2009; Rust *et al*., 2010; Shi *et al*., 2014). In contrast, Baltic amber succinites originate from conifers and are classified as Class Ia resins (Bray & Anderson, 2009).

In Southeast Asia, particularly in Borneo, amber has been documented in several Neogene formations, including the Liang, Seria, Miri and Belait formations. It has generally been attributed to resins secreted by Dipterocarpaceae trees (Kocsis *et al*., 2020). Amber pebbles and flakes have been reported from the Tukau Formation by several researchers (Hutchison, 2005; Kessler & Padmanabhan, 2008; Kessler & Jong, 2014, 2015, 2016; Nagarajan *et al*., 2022; Kessler, 2023; Kessler *et al*., 2023). Despite these observations, the amber from the Tukau Formation has not been systematically characterised, and its botanical affinity and depositional significance remain poorly constrained. This study aims to characterise and classify the amber pebbles of the formation through a combination of diagnostic physical and chemical tests, as well as FTIR spectroscopy. By comparing the resulting spectral data with those of known fossil and modern resins, this study seeks to identify probable botanical sources and to interpret the depositional and diagenetic conditions under which these resins were preserved.

GEOLOGICAL SETTING

The Tukau Formation is situated within the Miri Zone, the youngest of three tectonostratigraphic zones in onshore Sarawak, which also includes the Kuching and Sibu Zones (Liechti *et al*., 1960; Madon, 1999). These zones are separated by the Lupar Line and the Tatau-Mersing Line, with ages becoming progressively younger northward; the Miri Zone represents the youngest succession (Upper Eocene to Recent) (Liechti *et al*., 1960; Madon, 1999). The Miri Zone comprises a stratigraphic sequence that includes the Rajang Group, Mulu, Kelalan, Tatau, Melinau Limestone, Nyalau, Setap Shale, Subis Limestone, Lambir, Belait, Tukau, Miri, Seria, Bergrih, and Liang Formations (Jong & Kessler, 2019).

The Tukau Formation forms part of the Neogene succession within the Baram Delta Province (BDP), which also includes the Setap Shale, Lambir, Tukau, Miri and Liang formations (Togunwa *et al*., 2015). The Neogene succession represents a substantial 9 to 12 km thick sequence of primarily progradational to strongly aggradational coastal-deltaic to shelf deposits, interpreted as mixed-energy-influenced deposition (Collins *et al*., 2017, 2018). The formation occurs within the BDP, which evolved as a deltaic province from the Middle Miocene to the present day, transitioning from a foreland basin to a shelf margin setting (Morley *et al*., 2003; Collins *et al*., 2017, 2018).

While some researchers have combined the Lambir and Tukau formations due to their lithostratigraphic similarities and uncertain ages (Banda & Honza, 1997; Collins *et al*., 2020), this study follows the formation boundaries delineated by Liechti *et al*. (1960), recognising them as distinct stratigraphic units. The age of the Tukau Formation spans from Tf to Tgh (equivalent to Middle Miocene to Pliocene) based on strike correlation with the fossiliferous Miri and Seria formations (Liechti *et al*., 1960; Wilford, 1961). Hutchison (2005) refined this age assignment to Late Miocene to Early Pliocene. The finding from Nagarajan *et al*. (2017) aligns with the statement, as they suggested that the Tukau rocks were deposited approximately 10 to 2.58 Ma. Two significant unconformities bound the Tukau Formation: 1) an Intra-Pliocene Unconformity (IPU) separating the Tukau Formation from the overlying Liang Formation, and 2) a Lower Pleistocene Unconformity (LPU) between the Tukau Formation and the overlying Pleistocene coastal terraces (Kessler & Jong, 2017).

METHODOLOGY

Thirteen amber samples were collected *in situ* from outcrops using a geological hammer and chisel during fieldwork. The host rocks of the ambers are all organic-rich mudstones and heterolithic units. The collected samples were cleaned with a soft brush and an ultrasonic cleaner to remove sediments, then air-dried at room temperature for several days. Sample C1Abr1 was chosen for thin section preparation and microscopic study as it was among the larger and more intact specimens, allowing for proper embedding and sectioning without fracturing. The amber thin section was prepared using standard petrography procedures described by Brasier *et al*. (2009); Lewis & McConchie (2012).

Chemical and physical tests were conducted to distinguish amber from other types of resins. They examined the melting point, hardness, solubility, flotation, solvent reaction, UV fluorescence, and burning behaviour of the samples. Samples were heated at 160 °C to differentiate amber (melting point 200–380 °C) from copal (<150 °C) (Poinar, 1992). Hardness was tested using the Mohs scale, and solubility in acetone was observed after 5 minutes and overnight. Seawater from Lutong Beach (salinity 27–28 ppt) was used for flotation testing to assess buoyancy under natural marine conditions. Long-wave UV light (365 nm) was used to examine the appearance of the samples, as amber will demonstrate luminescence properties under UV illumination.

FTIR analysis was employed to identify differences in functional group composition among amber samples from the Tukau Formation, offering insight into the resin-producing vegetation and palaeoenvironmental conditions. For this, the Tukau ambers were crushed with an agate mortar and pestle, sieved to 63 µm, and pressed onto the Attenuated Total Reflectance (ATR) crystal. Analyses were performed using an Agilent Cary 630 FTIR spectrometer with MicroLab 1.0.0.7 software at Curtin University Malaysia, covering a wavelength range of 4000–650 cm^{-1} at a resolution of 4 cm^{-1}. The purpose of the background scan is to exclude the effect of background signals on the samples. Location of the outcrops is shown in Figure 1, and Figure 2 shows some of the fossilised amber *in situ*. Table 1 lists the amber samples collected from each outcrop and their coordinates.

RESULTS

Physical and chemical characteristics of ambers

The results of the diagnostic physical and chemical tests performed on the Tukau amber samples are summarised in Table 2.

Thirteen samples were tested, and all exhibited melting points above 160 °C. Most specimens exhibited hardness values of 3 on the Mohs scale, with one specimen reaching a hardness value of 4 (Table 2). When samples were submerged in acetone, no changes were observed after 5 minutes; however, after overnight submersion, the acetone turned yellow in three cases (C2, M1, REB), and all samples developed a whitish surface. These limited reactions indicate a high degree of polymerisation and chemical stability, as less mature or subfossil resins typically exhibit stronger dissolution or surface degradation in acetone.

All samples sank in the local seawater when tested for buoyancy. Given that seawater at a salinity of 27 to 28 ppt, has a density slightly above 1.02 g/cm^3, the negative buoyancy of the samples indicates a higher specific gravity, which suggests that the samples are relatively dense and chemically mature. Progressive polymerisation and loss of volatile components during diagenesis increase resin density; therefore, fresh resin or weakly polymerised copal may float, whereas mature amber commonly exhibits negative buoyancy in seawater. Each sample exhibited a faint bluish fluorescence under UV light, typical of fossilised amber. Freshly broken and polished surfaces were uniformly dark brown and opaque to translucent. When subjected to a hot needle, the samples melted easily and emitted white smoke accompanied by a resinous odour.

The combination of these characteristics, including melting points above 160 °C, hardness between 3 and 4, non-reactivity to acetone, and the resinous odour upon heating, confirms the samples as true amber. Petrographic observations of C1Abr1 revealed fine, irregular fractures and minor impurities, with no visible plant or animal inclusions. Stress lines were absent, and no clear flow structures were identified.

FTIR spectra of ambers

The FTIR spectra of all the Tukau amber samples and the approximate vibrational assignments of the specimens are shown in Figure 3 and Table 3. Although minor variations exist among samples, the spectral profiles consistently exhibit a set of major absorption bands at approximately 2920, 2863, 1694, 1454, 1374, 1042,

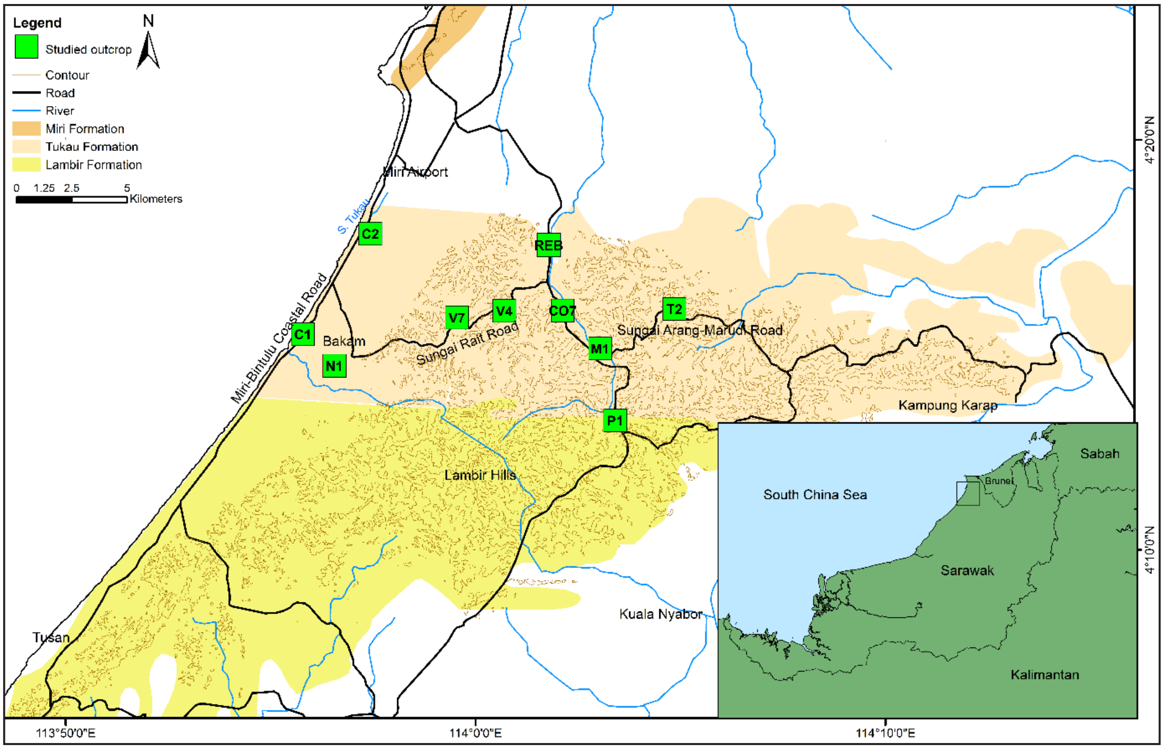

Figure 1: Geological map showing the locations of outcrops visited in this study (modified after Liechti *et al*., 1960).

Table 1: List of amber samples, corresponding outcrops and coordinates examined in this study. Detailed graphic logs for several of these outcrops are provided in Fong *et al.* (2024). Additional stratigraphic logs will be made publicly available upon the release of the author's forthcoming publications and doctoral thesis.

Sample	Outcrop	Coordinates (°N, °E)	Log height where the samples were collected (m)
C1Abr1	C1	4.2543, 113.9298	11.5
C1Abr2	C1	4.2543, 113.9298	20.5
C1Abr3	C1	4.2543, 113.9298	31.2
C1Abr4	C1	4.2543, 113.9298	34.8
C2Abr1	C2	4.2952, 113.9572	0.2
V4Abr1	V4	4.2638, 114.0117	11.0
V7Abr1	V7	4.2611, 113.9925	1.5
N1Abr1	N1	4.2415, 113.9427	0.6
M1Abr1	M1	4.2485, 114.0507	7.0
T2Abr1	T2	4.2646, 114.0808	0.1
P1Abr1	P1	4.2193, 114.0568	61.2
CO7Abr1	CO7	4.2639, 114.0354	51.5
REBAbr1	REB	4.2906, 114.0298	4.0

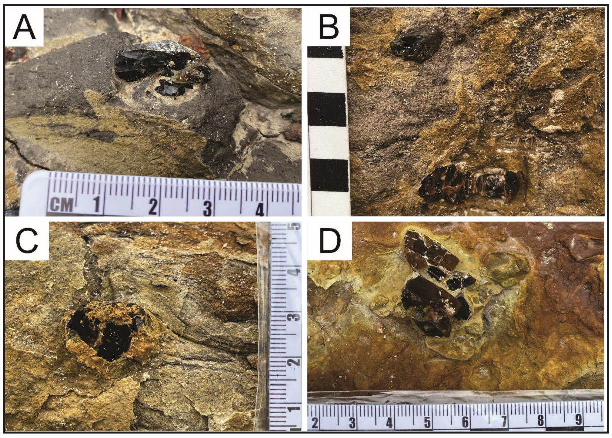

Figure 2: In situ ambers found at respective outcrops. A: Outcrop M1; B: Outcrop T2; C: Outcrop C1; and D: Outcrop V4.

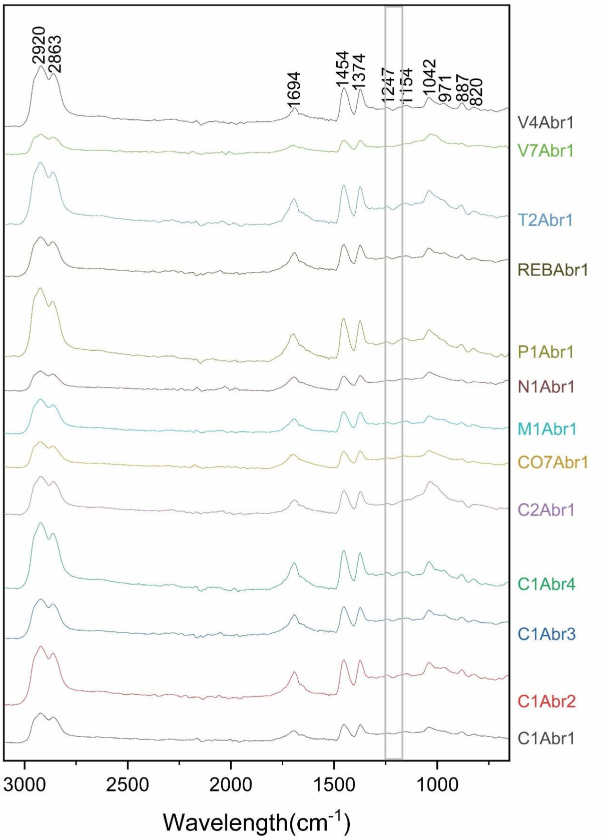

Figure 3: FTIR spectra of thirteen amber samples from the Tukau Formation. The vertical axis is not to scale; this figure is intended only to illustrate peak positions. The grey box highlights the "Baltic shoulder".

and 887 cm^{-1}, respectively. In the region of symmetric and asymmetric C-H stretching, the most prominent absorbance peaks occur around the wavelength of 2920 and 2863 cm^{-1}. The carbonyl (C=O) stretch commonly occurs around 1694 cm^{-1}, while bands in the single-bond regions (C-O and C-H) are observed at approximately 1454, 1374, and 1042 cm^{-1}, reflecting the general functional group composition of the samples. These absorption features describe the general functional group composition of the Tukau amber samples and provide a basis for comparison with fossil and modern resins of known botanical affinity.

DISCUSSION

The occurrence and preservation of amber clasts in the Tukau Formation provide important insights into deposition conditions and the resin's original botanical source. The observed physical and chemical characteristics: melting points above 160 °C, hardness of 3-4 on the Mohs scale, and minimal reaction to solvents, are consistent with those of fossil amber rather than subfossil copal (Anderson, 1994; Langenheim, 2003). FTIR analyses provide additional compositional context

Table 2: Summary of the physical and chemical test results for thirteen Tukau amber samples. Common properties for all samples include a melting point >160 °C, no reaction in the acetone test, and consistent faint blue UV fluorescence with a resinous odour upon burning. Abbreviation: X = No visible changes in acetone or amber; Y = Acetone turned yellow and the amber surface turned white.

Sample	Colour (Munsell)	Clarity	Hardness	Floatation Test	Acetone Test (5 mins)	Acetone Test (Overnight)	UV Fluores-cence	Burning Reaction
C1Abr1-C1Abr4	5Y 7/10 to 7.5RP 3/2	Opaque–translu-cent	3	Sank	X	X	Faint bluish	Melted easily, white smoke, resin smell
C2Abr1	Ditto	Semi-transpar-ent	3	Sank	X	Y	Faint bluish	Ditto
V4Abr1	Ditto	Translu-cent	3	Sank	X	X	Faint bluish	Ditto
V7Abr1	Ditto	Translu-cent	3	Sank	X	X	Faint bluish	Ditto
N1Abr1	Ditto	Opaque	3	Sank	X	X	Faint bluish	Ditto
M1Abr1	Ditto	Translu-cent	3	Sank	X	Y	Faint bluish	Ditto
T2Abr1	Ditto	Semi-transpar-ent	3	Sank	X	X	Faint bluish	Ditto
P1Abr1	Ditto	Translu-cent	3	Sank	X	X	Faint bluish	Ditto
CO7Abr1	Ditto	Translu-cent	4	Sank	X	X	Faint bluish	Ditto
REBAbr1	Ditto	Opaque	3	Sank	X	Y	Faint bluish	Ditto

Table 3: The wavelength and approximate vibrational assignments for the Tukau samples tested.

Assignment Samples	C-H stretching		C=O stretching	C-H bending	C-H symmetric bending	C-O stretching			C-H bending		
C1Abr1	2922	2868	1695	1454	1373	1244	1155	1039	970	885	823
C1Abr2	2922	2870	1695	1457	1375	1243	1157	1041	969	885	823
C1Abr3	2918	2866	1697	1457	1375	1243	1155	1045	970	883	825
C1Abr4	2920	2866	1699	1457	1375	1243	1151	1043	971	881	827
V4Abr1	2922	2861	1694	1452	1374	1243	1152	1038	970	880	824
V7Abr1	2922	2861	1703	1454	1372	1245	1157	1032	921	883	796
C2Abr1	2922	2861	1694	1452	1372	1247		1034		883	818
M1Abr1	2924	2861	1694	1452	1372	1245	1155	1040	971	883	826
T2Abr1	2922	2861	1696	1452	1374	1245	1152	1040		885	827
N1Abr1	2926	2863	1696	1452	1375	1241		1040		880	826
P1Abr1	2924	2864	1696	1454	1374	1249	1167	1040	970	883	827
CO7Abr1	2924	2863	1696	1452	1374	1247	1161	1038		885	827
REBAbr1	2922	2863	1707	1454	1374			1032			

when evaluated in conjunction with these physical properties and the geological age of the host sediments. Comparative spectral data (Figure 4) show that the Tukau amber lacks absorption features characteristic of Class I labdane-based diterpenoid resins, such as those reported for some copals (Abduriyim *et al*., 2009; Montoro *et al*., 2018). This observation should be interpreted in the context of resin class, as Dipterocarpaceae produce Class II resins, which are dominated by sesquiterpenes and triterpenes; in such resins, these features may be weak or absent, even in modern resins. Likewise, the "Baltic shoulder", a broad absorption feature between 1250-1200 cm^{-1} associated with succinic acid in Baltic succinite (Karolina *et al*., 2022; Murillo-Barroso *et al*., 2023), is absent in all the 13 Tukau samples. Instead, the Tukau amber spectra display a pattern consistent with

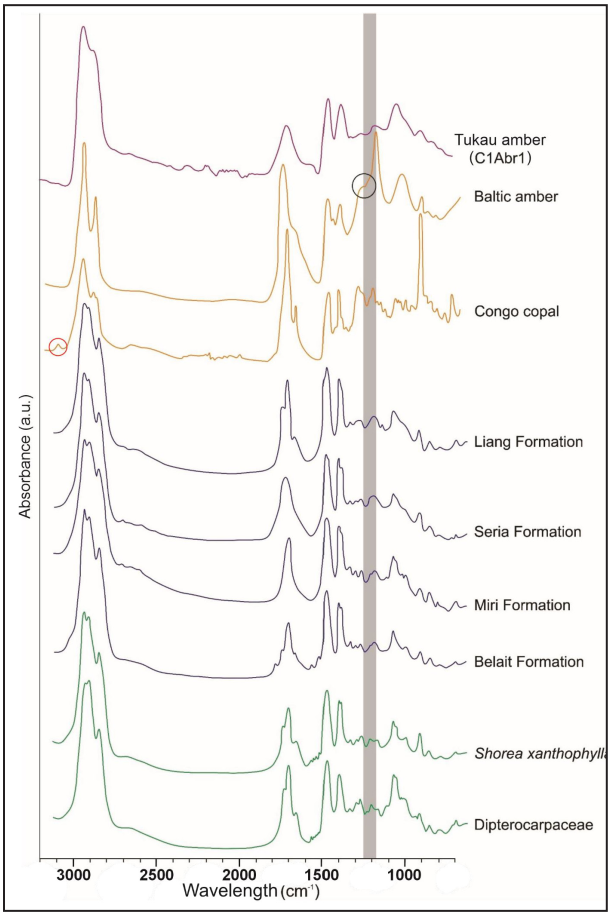

Figure 4: FTIR spectra of amber sample C1Abr1 from the Tukau Formation in comparison with spectra for Baltic amber, Congo copal (Garcia-Valles *et al*., 2023), fossil amber from Liang, Seria, Miri, and Belait formations, and the modern tree resins from *Shorea xanthophylla* and dipterocarpaceae trees (Kocsis *et al*., 2020). The black circle indicates the characteristic "Baltic shoulder" observed in the Baltic amber spectrum, and the grey band indicates the range of wavelength where the "Baltic shoulder" occurs. The red circle highlights the 3075 cm^{-1} absorption band commonly reported in Class I diterpenoid resins.

fossil and modern resins produced by Dipterocarpaceae trees (Kocsis *et al*., 2020).

Palynological data further support this interpretation: Dipterocarpaceae pollen is present within the formation (Fong *et al*., 2024), and similar amber has been reported from the Liang, Seria, Miri, and Belait formations of northwest Borneo (Kocsis *et al*., 2020). These regional occurrences confirm that dipterocarps were a persistent element of local Neogene Forest ecosystems, and their resins are preferentially preserved due to chemical resistance to corrosion. The Merit-Pila coal basin in Sarawak provides a key regional analogue: amber is abundant there and the locality is widely cited as one of the major amber-bearing coal deposits globally, with the botanical source commonly interpreted as dipterocarps (Langenheim, 2003). This interpretation is reinforced by recent palaeobotanical work from the Tebulan coal pit within the Merit-Pila succession, which documents abundant dipterocarp macrofloral remains, including leaf impressions attributed to *Dryobalanops* (Dipterocarpaceae) (Othman *et al*., 2026).

Dipterocarpaceae is a family of large, resinous, predominantly evergreen trees that dominate the canopy and emergent layers of Old World lowland tropical rainforests (Ashton, 2003). The family shows a pantropical but disjunct distribution, comprising three main evolutionary lineages: the species-rich Asian Dipterocarpoideae, the African-Madagascan and South American Monotoideae, and the South American monotypic Pakaraimoideae (Maury-Lechon & Curtet, 1998; Ashton, 2003; Ghazoul, 2016). The Asian subfamily Dipterocarpoideae comprises most genera and species, representing the principal centre within diversity of the family, with Southeast Asia supporting the highest concentration of species (Brearley *et al*., 2017). Within this region, Borneo is consistently recognised as the area of greatest dipterocarp diversity (Slik *et al*., 2003).

This compositional similarity suggests that the Tukau amber was derived from dipterocarp forests, either from localised resin production within lowland settings (autochthonous or parautochthonous) or from material transported downstream from upland forest communities (allochthonous) (Seyfullah *et al*., 2018). The robust chemical structure of amber (Martínez-Delclòs *et al*., 2004; Álvarez-Parra *et al*., 2024) enables long-distance transport without substantial alteration of its diagnostic infrared features.

Resin production likely originated as a defensive response in living dipterocarp trees, with viscous resin exuded following injury or environmental stress (Langenheim, 2003; Seyfullah *et al*., 2018). After secretion, resin either hardened on the tree surface or accumulated on the forest floor, where early dehydration and partial polymerisation occurred. Subsequent mobilisation by surface runoff, floods, or river systems facilitated transport of resin clast together with other possible plant debris (Poinar, 1992; Seyfullah *et al*., 2018). Progressive polymerisation increased resin density, and rapid burial under reduced oxygen conditions limited microbial degradation and oxidation, allowing continued diagenetic maturation and transformation of the resin into amber (Seyfullah *et al*., 2018; Saitta & Kaye, 2025).

Amber deposition is typically favoured in lowland, nearshore, and deltaic environments where reduced oxygen conditions promote organic preservation (Bisulca *et al*., 2012; Seyfullah *et al*., 2018). This is consistent with sedimentological interpretations of the Tukau Formation as a mixed fluvio-deltaic to shallow marine setting influenced by marine incursions.

CONCLUSION

Amber clasts preserved within the Tukau Formation are fossil resins derived from Dipterocarpaceae trees that flourished in tropical lowland forests during the Neogene. Diagnostic physical and chemical characteristics, including melting points exceeding 160 °C, hardness of 3-4 on the Mohs scale, solvent resistance, negative buoyancy in seawater, and a resinous odour upon heating, indicate a high degree of polymerisation consistent with fossil amber rather than fresh or weakly polymerised resin. FTIR spectra provide complementary compositional information, displaying C-H, C=O, and C-O absorption patterns consistent with dipterocarp-derived fossil resins and lacking features characteristic of succinite. When considered together with the physical properties and the Neogene age of the Tukau Formation, these observations support the classification of the material as fossil resin, also known as amber.

The occurrence of amber within mixed fluvio-deltaic to shallow-marine facies of the Tukau Formation suggests resin production in nearby dipterocarp forests and subsequent transport and burial under low-oxygen conditions, which are favourable to preservation. Together with regional reports of similar ambers from the Liang, Seria, Miri, and Belait formations, the Tukau amber provides clear evidence for Dipterocarpaceae-dominated forests across northwest Borneo during the Middle Miocene or later. Its preservation within organic-rich mudstones and heterolithic units, and is associated with fluvial-deltaic sediments, further attests to the interplay between terrestrial vegetation, resin production, and sedimentary processes within tropical deltaic systems.

Beyond its botanical significance, the Tukau amber record contributes to a broader understanding of Neogene landscape evolution in northwest Borneo, reflecting the lowland forest cover and active sediment routing from terrestrial to marginal marine environments. This study represents the first systematic characterisation of amber from the Tukau Formation, providing new constraints on its botanical origin and depositional context. The result established Tukau amber as a palaeoenvironmental proxy for reconstructing Neogene tropical forest ecosystems, resin-producing vegetation, and deltaic conditions in northwest Borneo, and provides a framework for future comparative studies of Southeast Asian amber-bearing successions.

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AUTHORS CONTRIBUTION

YNF (70%): fieldwork (strata logging, sampling, sample preparation), data analysis, writing original draft; DDW (25%): manuscript review and editing; MVP (5%): manuscript editing.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare relevant to the content of this article. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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CERAMAH TEKNIK TECHNICAL TALK

Earthquake and tsunami: Challenges, science, & action

Harry Telajan Anak Linang (Department of Geology UM)
Mazlan Madon (Academy of Sciences Malaysia)
Norhadizah Mohd Khalid (MET Malaysia)
Meldi Bin Suhatril (Department of Civil Engineering UM)
Date: 18 November 2025
Venue: DKG, Department of Geology, Universiti Malaya

Summary:
A half-day seminar titled "Earthquake & Tsunami: Challenges, Science, & Action" was successfully conducted on 18th November 2025. This event was organized through a strategic collaboration between the Department of Geology UM, MET Malaysia, and the Geological Society of Malaysia. Bringing together experts and practitioners, the seminar focused on Malaysia's seismic landscape and the critical need for disaster risk reduction through integrated geomorphological history and urban planning. The seminar featured four distinguished speakers who provided a comprehensive overview of tectonic activity and seismic engineering:

1. The Tectonics of SE Asia: Situating Malaysia on the Sunda Plate - (Dr. Harry Telajan Linang)
- *This session explored the regional geological framework, focusing on how Malaysia's position on the Sunda Plate influences its stability and seismic potential.*

2. Earthquake Fault-finding in Intraplate Settings - (Dr. Mazlan Madon)
- *Delivered via Zoom, this talk focused on the challenges of identifying active faults within stable intraplate regions, emphasizing the need for historical terrain analysis.*

3. Earthquakes and Tsunamis in Malaysia - (Dr. Norhadizah Mohd Khalid)
- *An overview of historical events and the specific risks Malaysia face from both local and regional tsunami triggers.*

4. Seismic Hazard Assessment for earthquake-resistant design of buildings and infrastructures in Malaysia - (Assoc. Prof. Ir. Dr. Meldi Bin Suhatril)
- *The final speaker emphasized the integration of geological data into urban planning and structural engineering to mitigate future disasters.*

The seminar also hosted several booth exhibitions featuring key national agencies. These included displays by Jabatan Meteorologi Malaysia (MET Malaysia), Agensi Nuklear Malaysia (ANM), and the Jabatan Mineralogi dan Geosains (JMG). Additionally, student chapters from UMGSM and AAPG participated, showcasing their contributions to the Society's activities and the broader geological community. In addition to the static displays, participants engaged in hands-on activities designed to provide practical insights into Malaysia's geological heritage, which includes rocks and minerals, as well as showcase of ancient fossils found locally.

Prepared by,
Harry Telajan Linang
Senior Lecturer, Department of Geology, UM

CERAMAH TEKNIK TECHNICAL TALK

Foraminifera: The ocean and climate storyteller

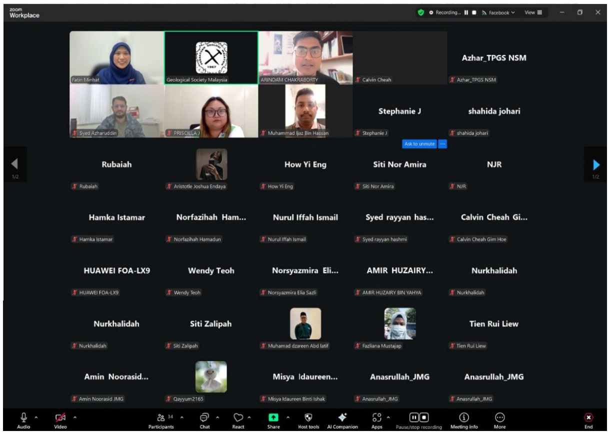
Fatin Izzati Binti Minhat
Faculty of Science & Marine Environment, UMT
Date: 20 November 2025
Platform: Zoom

Moderator : Arindam Chakraborty

On 20th November, 2025, Geological Society of Malaysia (GSM) in partnership with Department of Geology, Universiti Malaya hosted a technical talk titled "Foraminifera: The ocean and climate storyteller". The talk was delivered online using Zoom by Associate Professor Fatin Izzati Binti Minhat (UMT). 40 members participated online through Zoom, and others viewed the talk on GSM's YouTube channel (https://www.youtube.com/watch?v=yCkAzY0eFMk).

Abstract of the talk: Foraminifera, the microscopic single-celled protists with calcareous shells, are among the most powerful natural recorders of environmental change in the ocean. Their biological sensitivity and geological persistence make them invaluable tools for understanding both modern and ancient climate systems. In living communities, larger benthic and planktonic foraminifera respond rapidly to variations in temperature, salinity, nutrient levels, and water quality, serving as bioindicators for reef health and coastal ecosystem stability. In the geological record, their fossil assemblages and shell geochemistry preserve detailed archives of past ocean conditions, providing insights into sea-level fluctuations, monsoon variability, and carbon cycle dynamics through time. This talk will explore how the integration of biological and geoscientific approaches enhances our ability to reconstruct past climates and predict future ocean changes. By listening to the "stories" told by foraminifera, we gain a deeper understanding of the interconnectedness between marine life and the Earth's changing climate.

Synopsis of the talk: The speaker detailed the multifaceted role of the microscopic protists foraminifers in reconstructing paleoenvironments and monitoring modern coastal health. Foraminifera, characterized by their diverse calcareous and agglutinated tests, serve as exceptional bio-indicators due to their rapid evolution and high fossilization potential within the sediment archive. The presentation highlighted the functional distinction between benthic assemblages, which are instrumental in interpreting past sea-level fluctuations and assessing modern reef health via specialized monitoring indices and planktonic species that record water column properties such as temperature and salinity. She also discussed the applications including the identification of major geological events like the K-Pg boundary, the development of sea-level curves to analyze the environmental factors affecting ancient civilizations such as Kedah Tua, and the use of geochemical proxies to refine climate projection models. The session concluded by emphasizing the strategic shift of micropaleontology from traditional petroleum biostratigraphy toward addressing contemporary challenges in anthropogenic pollution, climate change mitigation and carbon sequestration.



We thank Associate Professor Fatin for her support and contribution to the Society's activity.

Prepared by,
Arindam Chakraborty
Chair, Quaternary and Marine Geology Working Group, GSM
Senior Lecturer and Supervisor, Geology Museum, Dept. of Geology, UM

CERAMAH TEKNIK TECHNICAL TALK

Geoheritage and Geopark Virtual Forum 2025 : The role of geoscientists in geopark development

Nickolas C. Zouros
Department of Geography, Faculty of Social Sciences, University of the Aegean
Date: 3 December 2025
Platform: Zoom

The 10th series of the Geoheritage and Geopark Virtual Forum 2025 was a special edition that explored the role of geologists in the development and establishment of geoparks since their inception. To address this topic, a highly experienced speaker, Dr. Nickolas C. Zouros, Professor at the Department of Geography, Faculty of Social Sciences, University of the Aegean, was invited. He is a founding member of the UNESCO Global Geoparks programme.

Dr. Zouros shared insights on the evolving and expanding role of geologists in geoparks, drawing from over 20 years of experience as Coordinator of the Lesvos Geopark, UNESCO Chair on Geoparks and Sustainable Development of Insular and Coastal Areas, and President of the Global Geoparks Network from 2015 to 2025, following its recognition as a full-fledged UNESCO programme. He currently serves as the General Secretary of the Global Geoparks Network.

The forum examined how the role of geoscientists in geoparks has evolved from basic identification and assessment to the promotion and development of geoheritage within the context of geotourism and geopark management. The role of geoscientists now extends beyond compiling inventories of significant geoheritage to providing well-researched information on conservation, promotion through geotourism, long-term sustainable planning, and the translation of geological knowledge into public-friendly formats such as panels, museums, and brochures.

Dr. Zouros emphasized the need to involve more geoscience experts within geoparks to strengthen geological interpretation, while also fostering interdisciplinary collaboration. He concluded that geoscientists will always remain central to geoparks, as geology forms their fundamental basis.

The forum attracted 223 registered participants, with 162 attending online, representing 18 countries across the Asia–Pacific region. A recorded version of the forum has been uploaded to the LESTARI, UKM YouTube channel for public viewing under the title *Geoheritage & Geopark Virtual Forum 2025: The Role of Geoscientists in Geopark Development*.

Prepared by,
Tanot Unjah
Chairman of Working Group Geoheritage and Geopark

CERAMAH TEKNIK TECHNICAL TALK

Case study on stabilization of a rock slope at a former quarry in the Kuala Lumpur Limestone

John Kuna Raj
Consultant
Date: 17 December 2025
Platform: Zoom

The above talk was delivered by P.Geol. Dr. John Kuna Raj (Consultant) on 17th December 2025 via Zoom. Some 50 members participated. An abstract of the talk is given below:

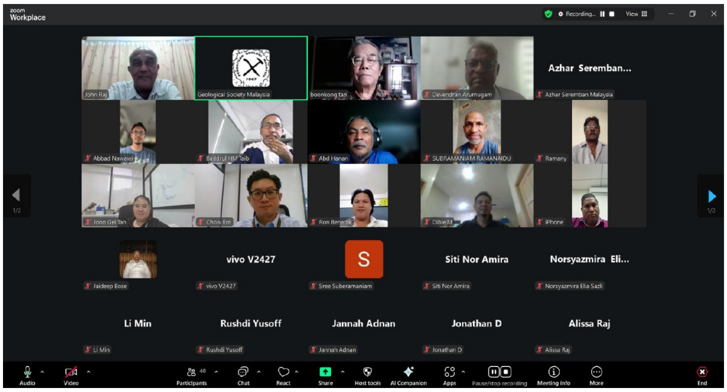
Abstract: Mine pits and quarries in the Sungai Way - Puchong area exposed Quaternary alluvial sediments of mainly sands and gravels, some 5 to 35 m thick, overlying the Kuala Lumpur Limestone along a very irregular bedrock surface of pinnacles and troughs. The Kuala Lumpur Limestone, of a Middle to Upper Silurian age, is mostly a crystalline calcitic limestone with several discontinuity (joint and fault) planes of variable strikes and dips.

The initial study for development of a former quarry proposed (Proposal 1) that an existing, vertical rock face, some 100 m long and about 30 m high be retained with appropriate reinforcement measures. Site visits revealed the presence of fractured bedrock (due to bulk blasting) and a number of small rock falls, block and slab slides, delimited by discontinuity planes. Several oriented and vertical boreholes were then drilled at the back of the slope to provide more data on the discontinuities present. The boreholes revealed the presence of cavities (empty or sand filled) as well as two main sets of day-lighting discontinuities; one set of very steeply dipping, continuous and smooth planes, and the other of steeply dipping, discontinuous, rough to smooth, planes.

In view of the definite need for reinforcement measures, two additional slope designs were proposed. Proposal 2 retained the lower half of the existing slope but replaced the upper half with two vertical benches separated by 2.5 m wide berms after bulk, and pre-split, blasting operations. Proposal 3 involved pre-split, post-split, and bulk, blasting operations to excavate three new benches with face angles of 70o, and 2.5 m wide berms to give an overall slope angle of 63°. Comparing costs of reinforcement measures against plane failure involving the use of grouted rock anchors led to the selection of Proposal 3. Calculation of the needed reinforcement involved consideration of factors influencing failure of grouted rock anchors, including calculations of grout, and free, anchor lengths.

Bulk, pre-split, and post-split blasting works were then carried out to create new rock slopes as per Proposal 3. Following excavation works, the new rock faces were inspected and mapped by walk-over surveys, to identify potential failures as well as unstable blocks. Several stabilization measures were then proposed, including scaling, horizontal drains and wire mesh (or wire netting) as well as the use of dowels and rock anchors.

This case study presents a practical application of geological principles in industry and construction.



We thank Sdr John for his support and contribution to the Society's activities.

Prepared by,
Tan Boon Kong
Chairman, Working Group on Engineering Geology & Environmental Geology

CERAMAH TEKNIK TECHNICAL TALK

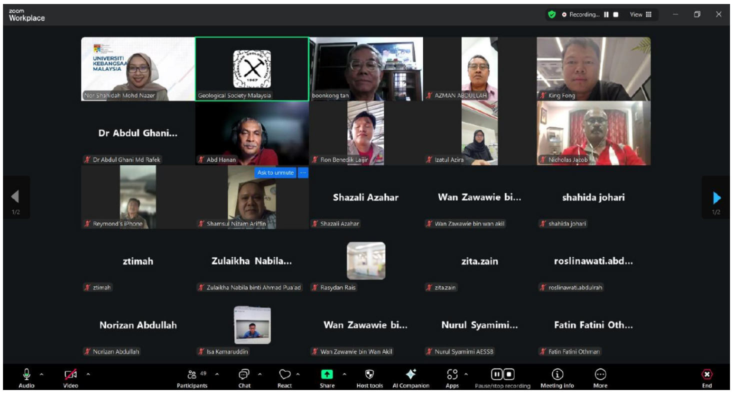
Potensi hakisan, runtuhan & pelembutan tanah baki granit bergaram

(Potential erosion, slope failure & softening of dispersive granitic residual soil)

Nor Shahidah Mohd Nazer
Universiti Kebangsaan Malaysia (UKM)
Date: 21 January 2026
Platform: Zoom

The above talk was delivered by P.Geol. Dr. Nor Shahidah Mohd Nazer (UKM) on 21st January 2026 via Zoom. Some 100 members participated. An abstract of the talk is given below:

Abstrak: Tanah baki granit merupakan antara kumpulan tanah baki yang dominan di Malaysia. Topografi perbukitan yang dilapisi oleh tanah baki granit sering merekodkan kejadian tanah runtuh janaan hujan terutatam ketika musim Monsun Timur Laut. Kehadiran garam natrium di dalam tanah dikenal pasti menimbulkan banyak masalah kepada kawaan cerun dan pendasaran melalui sifat penyerakan mineral lempung. Keadaan ini menyumbang kepada perubahan geokimia tanah yang menyebabkan pelemahan struktur tanah dan berpotensi mencetuskan tanah runtuh. Berdasarkan dapatan kajian, tanah baki granit menerima limpahan garam natrium daripada mineral kaya garam seperti albit ($NaAlSi_3O_8$) dari kumpulan feldspar. Komposisi tanah baki granit tinggi pasir dan lodak mengawal proses pengasingan di dalam tanah melalui sifat keporosan yang tinggi serta menjadi pemangkin tindakbalas penyerakan oleh mineral lempung pada tahap lemah ke sederhana. Ujian *Flume* yang dijalankan di makmal mendapati kadar pengasingan oleh tanah baki granit berjulat antara 0.000582 kg $s^{-1}m^{-2}$ hingga 0.007684 kg $s^{-1}m^{-2}$. Nilai ini menandakan potensi hakisan yang boleh berlaku di permukaan dan juga di bahagian dalam tanah apabila berinteraksi dengan air. Kajian ke atas runtuhan di Cameron Highland mencadangkan pengaruh serakan sebagai medium pencetus tanah runtuh berskala besar di Malaysia. Berdasarkan sifat pengangkutan ion di dalam tanah, proses pembasuhan mineral menyebabkan ion natrium dibawa dari Zon Eluviasi di horizon A (bahagian atas) ke Zon Iluviasi di bahagian bawah yang terletak di horizon B. Kedudukan zon kaya garam natrium ini berada pada profil tanah baki yang tebal (di bahagian dalam) dan berpotensi mencetus pembentukkan satah gelinciran bagi pembentukan tanah runtuh berskala besar (*deep seated*). Kajian kini memfokuskan potensi pelembutan tanah hasil pelarutan in-situ (*In-situ leaching*) bagi penerokaan unsur nadir bumi (*Rare Earth Elements*) di kawasan tanah baki granit. Fenomena pelembutan tanah dijangka berlaku di kawasan perbukitan yang terlibat dalam perlombongan mampan melalui proses penstrukturan semula struktur tanah hasil tindak balas berganda ke atas mineral lempung terjerap (*ion-adsorption clay*) oleh molekul air dan ammonium sulfat (reagen kimia) secara penyerakan dan pelarutan. Kejadian ini secara langsung menjejaskan kestabilan struktur tanah bagi jangka masa panjang dan pertimbangan terhadap faktor ini amat penting dalam pelaksanaan kerja geoteknikal bagi mengelakkan masalah dan bencana yang serius di Malaysia.



We thank Sdri Shahidah for her support and contribution to the Society's activities.

Prepared by,
Tan Boon Kong
Chairman, Working Group on Engineering Geology & Environmental Geology

CERAMAH TEKNIK TECHNICAL TALK

Active tectonics and seismic source in Peninsular Malaysia: A case study of the Johor Fault System

Felix Tongkul
Universiti Malaysia Sabah (UMS)
Date: 11 March 2026
Platform: Zoom

The above talk was delivered by Prof. Emeritus P.Geol. Dr. Felix Tongkul (UMS) on 11th March, 2026. Some 100 members participated. An abstract of the talk is given below:

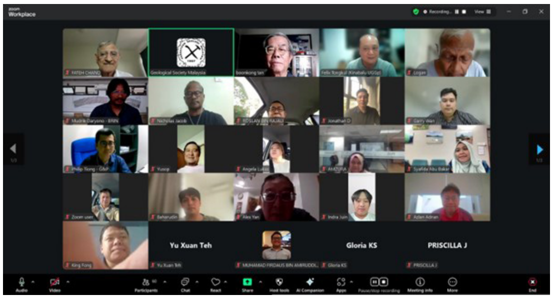
Abstract: Peninsular Malaysia is often perceived as lying within a tectonically stable region, distant from the plate boundaries of Southeast Asia. Yet, localized seismicity and structural evidence suggest that intraplate deformation processes may still influence the peninsula. This talk explores the Johor Fault System as a representative case study for understanding active tectonics and potential seismic sources in Peninsular Malaysia.

The presentation begins with an overview of the tectonic framework of Peninsular Malaysia and its relationship to regional stress regimes, including distant effects from the Sumatra subduction zone. It then shows the presence of potential active faults and earthquakes in Peninsular Malaysia. Finally it focuses on the Johor Fault System—its structural trends, geological history, and signs of Quaternary reactivation.

The Johor Fault System is an extremely wide zone of subparallel faults striking WNW-ESE to NW-SE, commonly known as the Mersing Fault Zone, spanning 80-km wide from Endau in the north and Kota Tinggi in the south. To the west it can be traced through Layang-Layang and Segamat. It is parallel to and along strike to the Kuala Lumpur-Bukit Tinggi-Seremban Fault Zones. The WNW-ESE to NW-SE faults cut and displace a set of sub-parallel NNW-SSE trending older faults. Other less prominent faults oriented N-S, E-W and NE-SW cuts though the older fault. The older NNW-SSE faults are right lateral (dextral) strike-slip whereas the younger WNW-ESE to NW-SE are left lateral (sinistral) strike-slip. The age of the Mersing WNW-ESE to NW-SE faulting could be similar to the Kuala Lumpur-Bukit Tinggi-Seremban Fault Zones which was Late Cretaceous (70-100 million years ago).

The WNW-ESE to NW-SE faults cut across Jurassic-Cretaceous (70-200 million years old) and Tertiary (2-65 million years old) basins showing that the Mersing Fault Zone was reactivated several times. The presence of linear valleys, drainage offsets, and subtle geomorphic scarps suggest possible Quaternary (last 2 million years ago) reactivation of the Mersing Fault Zone. Recent seismic monitoring and historical records document low-to-moderate seismicity in southern Peninsular Malaysia, raising the likelihood that this fault system, though relatively quiet, may act as a localized source of ground shaking.

By situating the Johor Fault System within the broader stress regime of Southeast Asia—including influences from the Sumatra subduction zone—this case study demonstrates how hidden intraplate faults can contribute to seismic hazard in regions traditionally assumed stable. The findings highlight the importance of continuous active faults mapping and monitoring, improved hazard assessment, and incorporation of intraplate faults into planning and risk mitigation strategies for Peninsular Malaysia.



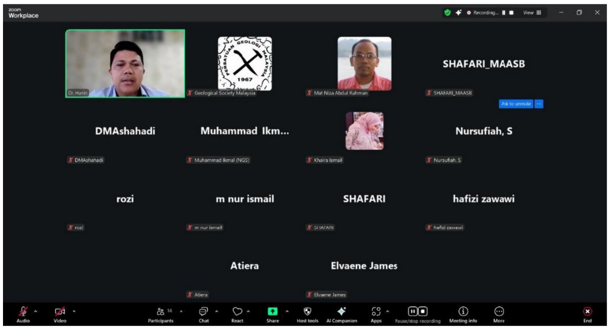
We thank Sdr Felix for his support and contribution to the Society's activities.

Prepared by,
Tan Boon Kong
Chairman, Working Group on Engineering Geology & Environmental Geology

RINGKASAN CERAMAH TEKNIK

Kerjasama Persatuan Geologi Malaysia dengan beberapa pihak seperti Program Geologi UKM, Institut Geologi Malaysia (IGM) dan Pertubuhan Geoterma Malaysia atau lebih dikenali Malaysia Geothermal Association (MyGA) terus disuburkan. Kemahiran En. Hanif juga telah memberi manfaat kepada peserta yang dahagakan ilmu dalam penyiasatan subpermukaan. Prof. Yunus pula telah meluangkan masa beliau dalam berkongsi ilmu eksplorasi sumber geoterma. Manakala Prof. Yukihiro dari Jepun sempat mengadakan satu ceramah sempena lawatan beliau ke Malaysia. Pihak Persatuan Geologi Malaysia juga sedang menggerakkan pasukan penyediaan kamus istilah geologi yang sudah bersidang dan menubuhkan jawatankuasa mengikut kepakaran bidang-bidang yang ada dalam geologi. Malah kerjasama terkini bersama pihak Kolej Tun Hussein Onn UKM telah berjaya membawa seorang penceramah dalam bidang ketenteraan dan beliau berkongsi peranan ahli geologi dalam membantu pasukan pertahanan negara. Selain itu, En. Zahari selaku peguam berpengalaman dalam membantu syarikat geologi turut hadir selaku panel gandingan bersama Ustaz Wan Jamizan yang telah banyak bekerjasama dalam sumbangan telaga tiub bersama Program Geologi UKM. Maka sejak November 2025 sehingga Mac 2026, sebanyak 5 aktiviti telah dianjurkan seperti maklumat di bawah:

1. Reimagine Subsurface with GSSI Ground Penetrating Radar (GPR) Technology - 18 November 2025
2. Magnetotelluric (MT) Technology for Geothermal Exploration- 10 Disember 2025
3. Past and Future Collaboration between Malaysia and Japan in Geoscience – 12 Januari 2026
4. Mesyuarat Pembangunan Kamus Istilah Geologi Edisi Semak – 10 Februari 2026
5. Sesi Pengembangan Ilmu JSBAS Siri 1/2026 – 13 Mac 2026



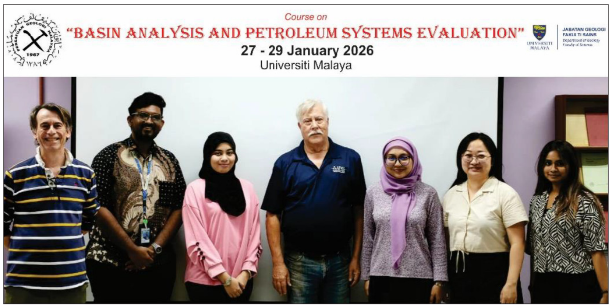
Disediakan oleh,
Mohd Hariri Arifin
Program Geologi, UKM

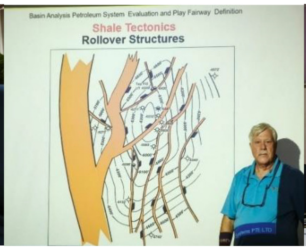
SHORT COURSE

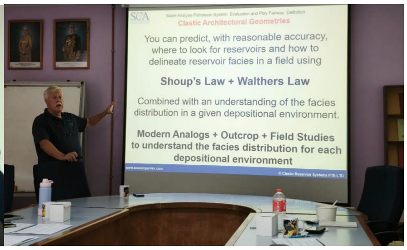
Course on “Basin Analysis and Petroleum System Evaluation”

Robert Shoup
Board Certified Petroleum Geologist
Date: 27-29 January 2026
Venue: Department of Geology, UM

The short course on “Basin Analysis and Petroleum System Evaluation,” jointly organized by the Department of Geology, Universiti Malaya, and the Geological Society of Malaysia, was held from 27 to 29 January 2026 at Universiti Malaya. The program featured a well-calibrated curriculum that balanced theoretical lectures with practical exercises, utilizing high-quality instructional materials and real-world case studies to enhance comprehension. With a limited enrolment of eight participants, the instructor was able to maintain an engaging and interactive atmosphere, fostering critical thinking and ensuring that interpretations remained logically consistent. The course was segmented perfectly, covering all aspects of basin analysis through lectures and exercises. The lecture displays were excellent, with plenty of real-world examples and exercises for each topic. The instructor and his teaching style was effective in engaging the students and encouraging discussion. The course were full of valuable informations, and the exercises were timed to create the right balance of lectures, discussion, and practice. The learning outcomes for each segment were stated upfront, which was important for any unfamiliar subjects. Throughout, the instructor’s knowledge of the subject matter, patient style, and the interactive exercises ensured maximum comprehension. Day one of the course started with a discussion of the Earth Model, data integration and interpretation, followed by the tectonic framework for the various structural systems. The second day class was focussed on cross sections to validate correlations and define the stratigraphy. A key takeaway for this day was learning to define and predict the reservoir facies and to assess the aspects of a play that will affect its commerciality. The third and the last day was combined with all the previous two days material for defining the petroleum system. A learning outcome was how to delineate the elements of a petroleum system and how to put them together to define exploration plays and play fairways. Throughout, the elements of logic and critical thinking were emphasized to ensure that interpretations were consistent and that all components of the petroleum system fit together. Upon completion of the course, attendees understand how examine all elements of the petroleum system and how they must come together to make a play or a prospect. This course was also approved by Board of Geologists.







Prepared by,
Arindam Chakraborty and Meor Hakif Amir Hassan
Department of Geology, Faculty of Science, Universiti Malaya

Acknowledgement to Peer Reviewers (2025)

In appreciation of the enormous contribution they make to the Society's publications, we would like to thank the scholars and experts below who have participated in the peer review process of manuscripts submitted for consideration for publication in the Bulletin of the Geological Society of Malaysia and Warta Geologi in 2025:

Abdul Halim Abdul Latiff
Ahmad Khairut Termizi Mohd Daud
Ahmad Zulkifli Kamaruzaman
Afikah Rahim
Arindam Chakraborty
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Noer El Hidayah
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THANK YOU

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26. Muhammad Ammar Asymawi Mohd Sani
27. Muhammad Arieffi Muhamad
28. Muhammad Daniel Irwan Shah Rasli
29. Muhammad Danish Mohd Aidil
30. Muhammad Fazley Kamaruzaman
31. Muhammad Firdaus Dhiyauddin Ami-Sharil
32. Muhammad Hafizzuddin Hamzah
33. Muhammad Haiqhal Halimi
34. Muhammad Ikhmal Danial Mohd Tarmizi
35. Muhammad Muizuddin Mansor
36. Muhammad Nabil Halimi
37. Muhammad Nur Aiman Mazlan
38. Muhammad Nur Farhan Mohd Hasri Hafizi
39. Muhammad Syafiq Azim Ismail
40. Muhammad Umar Aiman Mohd Zamri
41. Nazlan Irfan Sabaruddin
42. Nik Aiefa Nik Rosdi
43. Noor Khuzairi Bacho
44. Noor Syakinah Md Salleh
45. Nur Aina Safia Jelatulah
46. Nur Amani Maisara Mohd Afzal Mizan
47. Nur Ameera Nadia Mohd Ali
48. Nur Diyanah Suandi
49. Nur Ezzatul Liyana Anuar
50. Nur Irsalina Nadirah Abdul Razak
51. Nur Zahida Affrina Zahir
52. Nurfarah Diyana Daud
53. Nurfarah Mat Jaya
54. Nurharisha Alia Abdul Halim
55. Nurshafiah Ahmad Nordin
56. Nurul Farhana Muhammad Firdaus Chan
57. Pravin Yogeswaran
58. Pung Ruo Xin
59. Puteri Erysha Md Zamri
60. Rafiqi Haziq Razali
61. Saharah Sahari
62. Shamini Kannan
63. Shim Ci Yau
64. Syed Izzat Hamizan Wan Azman
65. Wafin Wardah Rizal

Current email address of members required

The Society would like to have the current email address of the following members:

1. Ahmad Yasin Ab Aziz
2. Aisyah Azhar
3. Chan Eng Hoe, Keith
4. Emelia Paul Henry Paul
5. Ernie Syahirah Bunut
6. Felson Petrus
7. Francis Paul Benjamin
8. Iffa Maisarah Ahmad
9. Jennytah Julimin
10. Kattily Grain
11. Liya Saffura Roeslan
12. Mario M A Wannier
13. Mohd Khairil Faizi Ismail
14. Mohd Muzamil Mohd Hashim
15. Muhamad Fuad Noor Faidzal
16. Muhammad Aiman Fikri Mohd Sena
17. Muhammad Danish Amri
18. Muhammad Danish Muhammad Ramizu
19. Muhammad Hilman Mohamad Hazahari
20. Muhammad Irfan Busrah
21. Noor Balqis Mohd Nordin
22. Noris Ariza Syahirah Noris Azwie
23. Nur Adila Roslan
24. Nur Aina Maisara Ariff Marlino
25. Nur Alia Amira Azhar
26. Nur Amirah Kautsar Abd Fadzir
27. Nur Khairunnisa Mohd Hanif
28. Nur Rabiatul Adawiah Mohd Azani
29. Nurazni Adrina Azman
30. Richlin Martin
31. Siti Atiqah Ayub
32. Siti Nurfatimah Hamidan
33. Sufeeya Zulkiflee

ANNOUNCEMENT

GEOLOGICAL SOCIETY OF MALAYSIA

GSM AWARDS 2025

Award Categories:

N.S. HAILE PUBLICATION AWARD

- Any paper on the Earth Sciences relevant to Malaysia or Southeast Asia published in any peer - reviewed journal is eligible for this prize.
- The author (or the first author) must not be more than 30 years in age.
- The paper must have been published within three years prior to the date of the award.
- PRIZE: RM 1000.00 & PLAQUE/CERTIFICATE

HUTCHISON BEST STUDENT AWARD

- Final year students at Geology Departments in Malaysian universities are eligible for this prize.
- PRIZE: RM 1000.00

DJ GOBBETT AWARD "GEOSCIENTIST AWARD"

- GSM Members who have made significant contributions to research in Malaysian Geology are eligible for this award.
- PRIZE: PLAQUE

MORE INFORMATION

CONTACT MS. NORAZIANTI ASMARI
CHAIRPERSON GSM AWARDS 2025

017-6166158

ANNOUNCEMENT

GEOLOGICAL SOCIETY OF MALAYSIA

2025 DATO' SIA HOK KIANG ECONOMIC GEOLOGY RESEARCH GRANT

REQUIREMENTS

- The GSM Endowment Fund is providing grants of up to RM 5,000.00 for research in metallogenic and ore geology, mineral processing and mining in Malaysia.
- Recipients of the fund must publish the results in a Malaysian indexed journal and make a presentation at a GSM seminar or conference.

APPLICATION PERIOD

- April 2025 until 15 March 2026

APPLICATION FORM

- To obtain an application form, send email to geologicalsociety@gmail.com

FOR MORE INFORMATION, CONTACT

MS. NORAZIANTI ASMARI | 017-6166158

DR. ZAKARIA BIN ENDUT | 019-9828334

REPORT

Earth Observation Training Program and launch of the TRIGGER Project

Joy Jacqueline Pereira & Navakanesh M. Batmanathan
SEADPRI-UKM, Universiti Kebangsaan Malaysia
Nikhil Nedumpallile Vasu & Alessandro Novellino
British Geological Survey (BGS)
Date: 16 December 2025 (Tuesday)
Time: 14:00 – 17:30
Platform: Zoom

The Geological Society of Malaysia (GSM) hosted the Earth Observation (EO) Training Program on 16 December 2025 to mark the official launch of the "Trigger Index for Rainfall-Induced Landslide Risk Assessment for Enhanced Resilience" (TRIGGER) project. This international collaboration is led by the British Geological Survey (BGS) and Universiti Kebangsaan Malaysia's Southeast Asia Disaster Prevention Research Initiative (SEADPRI-UKM), with support of partners including the GSM. The initiative is supported by the UK Government's Climate Action for a Resilient Asia (CARA) program through the Foreign, Commonwealth & Development Office (FCDO).

The TRIGGER Project
The TRIGGER project aims to enhance climate adaptation and resilience across the Indo-Pacific region by developing advanced landslide risk assessment tools. The EO Training Program was specifically designed to equip geoscientists, disaster management professionals, and environmental scientists with remote sensing skills to improve early-warning systems and inform risk-informed adaptation finance.

Highlights

The session opened with introductions by Prof. Dr. Joy Jacqueline Pereira and Dr. Nikhil Nedumpallile Vasu. The technical presentations included:

- **Landslides in Selangor:** Mr. Navakanesh Batmanathan provided insights into local landslide occurrences and challenges in Selangor.
- **EO and the Copernicus Programme:** Dr. Alessandro Novellino (BGS) introduced the Copernicus programme and the use of satellite data for hazard monitoring.
- **Practical Session:** A hands-on technical session led by Dr. Novellino focused on mapping landslides using open-source tools, including the BGS Landslides Tracker, North Carolina State University's HazMapper, and the Copernicus Browser.

The event saw a diverse turnout of 27 participants from various sectors. Participants came from the education and industry sectors as well technical agencies and professional bodies. The feedback was very positive. Participants noted that the session was "very useful for modern assessment" and provided "good exposure for awareness". Several attendees expressed interest in future technical training to further build research capacity and suggested expanding the project's scope to regions such as Borneo.

Concluding Remarks

The successful launch of the TRIGGER project and the accompanying EO training signify a major step forward in integrating satellite technology into Malaysia's disaster risk reduction strategies. The collaboration between GSM, UKM, and BGS continues to strengthen the professional geoscience community's ability to manage natural hazards in a changing climate.

Prepared by,
Navakanesh M. Batmanathan
Member, Working Group on Disaster Risk Reduction & Climate Change

Board of Geologists Malaysia

BOG
Lembaga Ahli Geologi Malaysia

Board of Geologists Malaysia celebrates National Geologists Day 2026

The Board of Geologists Malaysia (BoG) is pleased to announce that the National Geologists Day 2026 will be celebrated on 28 April 2026. This annual celebration aims to honour and elevate the professional status of geologists in Malaysia by highlighting the contribution of the geoscience community; address pressing issues such as climate change and increasing geological hazards; and promote economic growth through geoscience activities, including the establishment of Geoparks across Malaysia.

An oline meeting was convened on 12 February 2026 to discuss and coordinate the organization of the National Geologists Day 2026.

The event will feature the launch of a key guideline, thematic technical sessions, industry showcases and interactive exhibitions, among others. Several committees have been formed to ensure the smooth execution of this celebration, each tasked with specific responsibilities to manage different aspects of the event.

BoG invites all registered geologists to participate and support this important event in celebrating the contribution of geologists to sustainable development and disaster risk reduction in Malaysia.

Prepared by,
Nur 'Izzati Binti Md Hussin
Registration and CPD Executive, BoG

Key Committee Members for the National Geologists Day 2026

Protocol & Ceremony
- Chair: Mr. Nor Azmi bin Ahmad @ Mohamad (NRES)
- Ms. Siti Sarah Bt Mohd Padzil (BoG)
- Representatives from NRES & BoG

Promotion & Technical
- Chair: P.Geol. Abd Rasid bin Jaapar (BoG)
- Mr. Muhammad Ilmam bin Mohd Sabri (BoG)
- Mr. Mohd Shafiq Farhan bin Mohd Zainudin (JMG)
- Ms Suhailah & Mohd Azrul bin Aziz (JMG)

Placement & Catering
- Chair: Mr. Syed Omar (JMG)
- Tengku Intan Juliana (BoG)
- Representatives from JMG, BoG & NRES

Registration & Invitation
- Chair: Ms. Hasnida binti Zabidi @ Zainudin (JMG)
- P.Geol. Amiruddin bin Mansor (BoG)
- Assoc. Professor P.Geol. Dr. Habibah (BoG)
- Ms. Siti Sarah Bt Mohd Padzil (BoG)
- Ms. Nur 'Izzati Binti Md Hussin (BoG)
- Mr. Haziq bin Firdaus Ridzuan Teng (JMG)

Official Speeches & Souvenir
- Ms. Hasnida binti Zabidi @ Zainudi (JMG)
- P.Geol. Mohd Badzran Bin Mat Taib (BoG)
- P.Geol Dr Siti Sarah Binti Ab Rahman (IGM)
- Mr. Ahmad Abqari Binti Ahmad Tarmidzi (BoG)
- Representatives from JMG, BoG & NRES

AAPG UM Student Chapter

UMGC X FTS launches "Conservation Project: Urban Forest Initiative" planting 1,100 trees for a greener future

Environmental responsibility took center stage at the University of Malaya as 75 volunteers came together for the UMGC X FTS: Conservation Project: Urban Forest Initiative, a two-day volunteer planting program dedicated to restoring green spaces and promoting urban sustainability.

Held from 2nd to 4th January of 2026, the program took place at the UM Zero Waste Centre, committed to transforming the area into a lively hub of environmental action. The initiative was organized by Universiti Malaya Green Community (UM GC) under Sekretariat Sukarelawan Universiti Malaya (SEKRUM), in collaboration with the Free Tree Society (FTS) and the American Association of Petroleum Geologists UM Student Chapter (AAPG UM SC).

Over the course of the program, volunteers successfully planted a total of 1,100 plants, contributing significantly to the development and conservation of a mini urban forest within the campus area. The plants included a diverse range of species such as Bamboo Orchid (*Arundina Graminifolia*), Cat's Whiskers (*Orthosiphon aristatus*), Kacip Fatimah (*Labisia Pumila*), and many other native and adaptive plants selected for their ecological value, medicinal properties, and suitability for urban environments.

"This initiative reflects our commitment to long-term environmental stewardship"

Participants, consisting mainly of students and young environmental advocates, worked in organized teams to prepare plant saplings and ensure proper watering and site maintenance. Briefings were conducted to educate volunteers on correct planting techniques and the importance of urban forests in improving air quality, supporting biodiversity, reducing heat-island effects, and enhancing overall campus sustainability.

Beyond planting activities, the program also fostered collaboration between student organizations and environmental groups, highlighting the importance of collective effort in conservation work. Volunteers described the experience as both meaningful and empowering, as they were able to contribute directly to a project with lasting environmental impact.

"Seeing 1100 planted plants we achieved together in just a few days is truly inspiring"

The UMGC X FTS: Conservation Project: Urban Forest Initiative is expected to continue with frequent follow-up maintenance by the committees of UM Green Community, monitoring activities, and future planting phases. Organizers hope the initiative will serve as a model for sustainable campus projects and encourage more young people to actively participate in environmental conservation.

As the final seedlings were planted and watered, the UM Zero Waste Centre stood greener than before—a living reminder that meaningful change can begin with a simple act of planting and a shared commitment to protecting the environment.

Participants' picture captured on the first day.

Prepared by,
Nurnajmina Imanni
President, AAPG UM SC 2025/2026

UPCOMING EVENTS

May 3-8, 2026: European Geosciences Union General Assembly (EGU26); Vienna, Austria & Online. For more information, please visit https://www.egu26.eu/about/egu.html.

May 4-7, 2026: Offshore Technology Conference (OTC); NRG Park, Houstan, Texas, USA. More details at https://2026.otcnet.org/.

June 1-3, 2026: International Conference on Geology and Geophysics (ICGG 2026); Xiamen, China. For details, visit https://www.academicx.org/ICGG/2026/.

June 8-11, 2026: 87th EAGE Annual Conference & Exhibition; Aberdeen, UK. For further information about the event, please check https://eageannual.org/.

June 22-24, 2026: Unconventional Resources Technology Conference (URTeC); Houstan, Texas. More details at https://urtec.org/2026/Save-the-Date.

August 2 -7, 2026: 23rd annual meeting of the Asia Oceania Geosciences Society; Fukuoka International Congress Centre, Japan. Visit event website at https://www.asiaoceania.org/AOGS2026/Home for further details.

August 17-20, 2026: International Meeting for Applied Geoscience & Energy (IMAGE); Houstan, Texas. More details at https://www.imageevent.org/about-image26.

September 2-3, 2026: Latin America Geothermal Systems Workshop 2026: Exploring Sustainable Solutions to Meet the Region's Energy Demand; Mexico City, Mexico. More details at https://www.aapg.org/events/details/event/articleid/69394/latin-america-geothermal-systems-workshop-2026-exploring-sustainable-solutions-meet-regions-energy-demand.

September 4-12, 2026: 9th Asia Pacific Geoparks Network (APGN) Symposium 2026; Langkawi, Kedah, Malaysia. More details at https://apgn2026.lada.gov.my/.

September 9-11, 2026: Discoveries in the Tasmanides Conference; New South Wales, Australia. Checkout https://discoveriesinthetasmanides.com.au/ for more details.

September 28-30, 2026: AAPG/EAGE Hydrocarbon Seals of the Middle East GTW; Kuwait City, Al Ahmadi, Kuwait. Visit https://www.aapg.org/events/details/event/articleid/69371/5th-edition-aapgeage-hydrocarbon-seals-middle-east-gtw to learn more about this event.

October 1-3, 2026: National Geoscience Conference (NGC) 2026; Miri, Sarawak, Malaysia. More details at https://gsm.org.my/event/national-geoscience-conference-ngc-2026/.

October 30- November 6, 2026: XV IAEG 2026 World Congress; Delft, The Netherlands. More details at https://iaeg2026.org/.

November 2-5, 2026: 55th IAGI-GEOSEA XIX 2026 Annual Convention; Yogyakarta, Indonesia. Visit https://www.pitiagi.cloud/ for details.

November 11-15, 2026: International Association for Gondwana Research (IAGR) 2026 Convention, the 23rd International Conference on Gondwana to Asia, and the International Conference on Tectonics of Southeast Asia (ICTSEA 2026); Chiang Mai, Thailand. More details at https://iagrglobal.org/iagr-2026-annual-convention-chiang-mai-thailand/.

December 7-9, 2026: AAPG International Conference & Exhibition (ICE) 2026; Jakarta, Indonesia. More details at https://www.aapg.org/news-and-media/details/explorer/articleid/69424/preview/43C7C2A4520551011F83B55E36524056.

February 3-5, 2027: NAPE Summit; Houstan, Texas. More details at https://napeexpo.com/.

March 24-26, 2027. The International Petroleum Technology Conference (IPTC) 2027; Bangkok, Thailand. More details at https://www.iptcnet.org/iptc.

UPCOMING EVENTS

FIRST CIRCULAR

ORGANISERS

Curtin University Malaysia

39th National Geoscience Conference (NGC 2026)

"Innovation and Sustainable Geoscience for a Resilient Future"

01 - 03 OCTOBER 2026

PULLMAN MIRI WATERFRONT, SARAWAK

Call for Submissions

Join us for the 39th National Geoscience Conference (NGC 2026), the premier gathering of geoscience professionals, researchers and students. Explore the latest advancements, challenges and innovations in the field of geosciences. We invite abstracts for oral and poster presentations that will fit the sub theme of the conference.

Abstracts submission: geologicalsociety@gmail.com

Submission Deadline: 1st July 2026

Themes:

- Disaster Risk Reduction, Climate Hazards,
- Climate Change & Engineering Geology
- Energy & Mineral Resources
- Groundwater Resources
- Conservation Geology & Geotourism
- Quaternary, Coastal & Marine Geology
- Tectonics & Structural Geology
- Stratigraphy, Sedimentology & Palaeontology
- Karst
- Geochemistry
- Geophysics, Geospatial Applications & Geotechnology
- Policies, Ethics & Professional Practice
- Petroleum Geology

Attractions:

- Conference Field Trip
- CPD points (BOG)
- Best Oral and Poster presentation awards
- Full paper can be published in Bulletin of the Geological Society of Malaysia/Warta Geologi (Scopus, AAPG Datapages and MyJurnal/MyCite indexed) after peer review

Contact Us: https://gsm.org.my geologicalsociety@gmail.com 03-79577036

FIRST CIRCULAR

ORGANISERS

Curtin University Malaysia

39th National Geoscience Conference (NGC 2026)

"Innovation and Sustainable Geoscience for a Resilient Future"

01 - 03 OCTOBER 2026

PULLMAN MIRI WATERFRONT, SARAWAK

Abstract Submission guidelines

Abstracts should be sent to **geologicalsociety@gmail.com,** with Subject NGC 2026 Abstract_Author name

Guidelines

- The abstract will only be accepted if they pay their conference registration fees.
- English abstract should not exceed 300 words.
- Please provide 3–5 keywords for your abstract.
- Participants are encouraged to present their research in the English language.
- The mode of presentation (Oral/Poster) will be conveyed to the Participants later after acceptance.
- Participants are not allowed to revise their abstracts after submission.

Title: Title must be informative and reflects the content of the paper. Title in Bahasa Malaysia should include an English translation. It should be concise (less than 20 words). Avoid using abbreviation in the title.

Author's Address: Affiliations and addresses of all the authors must be provided. The email address of the corresponding author must be indicated.

Abstract: Should **not exceed 300 words**. It should clearly identify the subject matter, results obtained, interpretations discussed and conclusions reached. The abstract should not contain any undefined abbreviations or references. Abstract in Bahasa Malaysia should also have an abstract in English.

Keywords: Please include maximum 5 keywords (including in Malay language for manuscript in Malay) that best describe the content of the manuscript.

Contact Us: https://gsm.org.my **geologicalsociety@gmail.com** **03-79577036**

FIRST CIRCULAR

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39th National Geoscience Conference (NGC 2026)

"Innovation and Sustainable Geoscience for a Resilient Future"

01 - 03 OCTOBER 2026

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Registration Fees

Registration Type	Early Bird Registration (by 01 August)	Late Registration (after 01 August)
GSM/IGM Member (**with paper** presentation)	RM 400	RM 500
GSM/IGM Member (**without paper** presentation)	RM 500	RM 600
Non-GSM Members (inclusive of 1-year GSM membership fee)	RM 700	RM 800
GSM Student members	RM 300	RM 400

Post Conference Field Trip Fee: to be announced later (open to conference participants only)

Payment Method:

1. Bank transfer to **Account Details:** **Geological Society of Malaysia**
   Bank Name: Standard Chartered Bank
   Account no.: 794105402263

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UPCOMING EVENTS

55th IAGI Annual Scientific Meeting - GEOSEA XIX Convention & Exhibition YOGYAKARTA 2026

CALL FOR PAPER

A Premier International Geological Gathering

The 55th IAGI Annual Scientific Meeting – GEOSEA XIX Convention & Exhibition 2026 is organized by the Indonesian Association of Geologists (IAGI). This landmark event facilitates high-level exchange between geologists, industry leaders, and researchers across the globe.

TIMELINE

- **Abstract Submission**
  February 9 - March 21, 2026
- **Announcement of Selected Paper**
  May 7, 2026
- **Manuscript Submission**
  May 7 - August 7, 2026
- **Main Event**
  November 2-5, 2026

TOPICS & SUB-TOPICS

- **Fundamental & Digital Geoscience**
  - Geodynamics, Seismology, Petrology and Volcanology
  - Sedimentology and Paleontology
  - Pore Pressure and Geomechanics
  - Remote Sensing
  - Technology and Application of Big Data, Machine Learning and Artificial Intelligence in Geoscience
- **Advanced Mining & Mineral Technology**
  - Economic Minerals and Coal Exploration
  - Economic Minerals and Coal Resources Conservation
  - Economic Minerals Processing and Refining
  - Mine Geology, Grade Control and Reconciliation
  - Mine Geotechnical and Hydrogeology
  - Geometallurgy
  - Gemology
- **Petroleum Geoscience, Engineering and Management**
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  - Petroleum Engineering and Production Technology
  - Enhanced Oil/Gas Recovery and Drilling Well Completion
  - Reservoir and Production Management
- **Engineering Geology, Environment and Geohazard**
  - Engineering Geology for Infrastructure Development
  - Monitoring and Instrumentation in Geotechnical Projects
  - Environmental Geology and Land Use Planning
  - Geohazards and It's Risk Assessment, Mitigation and Prevention
- **Energy Transition & Sustainable Future**
  - Unconventional and Renewable Energy
  - Geothermal
  - CCS/CCUS
  - Natural Hydrogen
- **Governance, Culture and Social Impact**
  - Energy and Economic Mineral Policies
  - CSR and Social Impact
  - Health, Safety and Environment (HSE)
  - Natural Resources of Indonesia
  - Geotourism, Geoheritage and Geopark
  - Geomithology

INDEXING

1) Scopus-Indexed Journal
2) IAGI Journal
3) 55th PIT IAGI Proceedings

Terms and conditions will apply

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- Please send the completed form together with the remittance payable to GSM email address at geologicalsociety@gmail.com

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Geological Society of Malaysia Publications

Instruction to Authors

General Policy

Manuscripts should be as concise as possible. Original results of basic, applied and policy research in geology that is of national or international significance are welcome. Current reviews and discussion on techniques, research programs, organisations, information, or national and international policies related to geology are also acceptable.

Submission of Manuscripts

Only manuscripts that have not been published elsewhere including electronically, will be considered for publication. Authors must agree not to publish elsewhere the submitted or accepted manuscripts in the same form, in English, Malay or other languages. Similarity detection services will be used to check your manuscript to verify its originality. Only manuscripts that clear a preliminary compliance check will be sent for review.

All manuscripts will be subjected to review by two or more reviewers. Authors wishing to include published and unmodified figures or text passages are required to obtain permission from the copyright owner(s). Authors of English manuscripts are strongly urged to have their manuscript edited for language before submission by a person whose first language is English.

The Editor reserves the right to reject all or any part of the manuscript submitted. The Geological Society of Malaysia assumes no responsibility for statements made by authors. The paper should be submitted to:

The Editor,
Geological Society of Malaysia
c/o Department of Geology,
Universiti Malaya,
50603 Kuala Lumpur, Malaysia
Tel: (603) 7957 7036
Fax: (603) 7956 3900
Email: geologicalsociety@gmail.com

Authors are required to check the online Guide to Authors available at the GSM website (https://gsm.org.my/instruction-to-authors) before submission to ensure that the paper meets the latest requirements of the journal.

The Manuscript

The manuscript can be written in Bahasa Malaysia (Malay) or English. For English manuscripts, use either British or American spelling but not a combination of both. The paper should be thoroughly checked for grammar and spelling. The manuscript must be printed at 1.5 spacing in a single column on A4 paper. All pages should be numbered. Length of paper should be between 3,000 and 10,000 words for Bulletin of the Geological Society of Malaysia, and between 2,000 and 3,000 words for Warta Geologi, excluding abstract, references, tables, and illustrations. Metric units should be used and all non-standard symbols, abbreviations and acronyms must be defined.

Title

The title must be informative and reflects the content of the paper. It should be concise (less than 20 words). Avoid using abbreviation in the title. Titles in Malay should include an English translation.

Author's Address

Affiliations, address, and email of all authors must be provided. The addresses should be sufficient for correspondence.

Abstract

Abstracts in Malay (optional for manuscripts in English) and English, each in one paragraph and should not exceed 300 words, is mandatory. It should clearly identify the subject matter, results obtained, interpretations discussed, conclusions reached and significance of the study. The abstract should not contain any undefined abbreviations or references.

Keywords

Four to eight keywords (including in the Malay language for manuscripts in Malay) that is relevant to the content of the paper is mandatory.

Acknowledgements

Acknowledgement to reviewers and institutions or agencies must be included at the end of the text. All funding sources must be mentioned in this section and acknowledged accordingly.

Authors Contributions

A statement of the roles played by each author, e.g. data analysis, experimental design is required.

Declaration of Competing Interest

A declaration of any conflict of interest must be communicated in a statement in the published paper.

References

In the text, references should be cited by author and year and listed chronologically (e.g. Smith, 1964; Jones *et al*., 1998; Smith & Tan, 2000). For both Malay and English paper, all references must be listed in English. Title of non-English manuscripts should be translated to English. Where available, include Digital Object Identifier (DOI) and URLs for the references that have been provided. Self-citations should be limited to less than 10% of the total citations in the paper.

The list of references should only include articles cited in the text and figure/table captions. The list should be arranged in alphabetical order. Please ensure that the reference list is complete and the bibliographical details are accurate. The references should be in the following manner:

Journal article:
Suntharalingam, T., 1968. Upper Palaeozoic stratigraphy of the area west of Kampar, Perak. Bulletin of the Geological Society of Malaysia, 1, 1-15.

Book:
Hutchison, C.S., 1989. Geological Evolution of South-east Asia. Clarendon Press, Oxford. 368 p.

Chapter of book and Symposium volume:
Hosking, K.F.G., 1973. Primary mineral deposits. In: Gobbett, D.J. & Hutchison, C.S. (Eds.), Geology of the Malay Peninsular (West Malaysia and Singapore). Wiley-Interscience, New York, 335-390.

Article in Malay:
Lim, C.H. & Mohd. Shafeea Leman, 1994. The occurrence of Lambir Formation in Ulu Bok Syncline, North Sarawak. Bulletin of the Geological Society of Malaysia, 35, 1-5. (in Malay with English abstract).

Online document:
Smith, J., 2019. Minerals and rocks are valuable natural resources. Minerals Web Society. http://minerals.org/articles/12/32/index. Accessed 20 July 2020.

Tables

Use the table function in Word to insert tables. Tables are limited to a maximum of five (5) and these should be cited in the text and numbered consecutively. Do not submit tables as images. Tables should have a title and a legend explaining any abbreviation or symbol used. Insert the caption at the top of each table. The captions should begin with the term Table followed by the number and a colon, all in bold. The text after the colon should be in regular font. Avoid excessive tabulation of data. Tabulated data may be included as an Appendix or Supplementary Data.

Illustrations

All illustrations must be useful, necessary and of good quality. A maximum of ten illustrations (photographs, graphs and diagrams) are allowed and these should be cited in the text and numbered consecutively as Figures. The scales for maps and photomicrographs should be drawn on the figure and not given as a magnification. Illustrations should be drawn to fit and be legible at a maximum one full page of A4 size. High resolution illustrations, photographs, drawings, figures, and images shall be requested upon acceptance for publication. Each figure should have a caption describing the figure accurately and concisely. Insert the caption after each figure. The captions begin with the term Figure followed by the number and a colon, all in bold. The text after the colon should be in regular font.

Preferred Software

- *Text*: Microsoft Word.
- *Tables*: Microsoft Word or Microsoft Excel.
- *Illustrations – Vector Graphics*: Adobe Illustrator (preferred), CorelDraw and Freehand. For other software, please submit one copy in the native file format and export one copy as a PDF file with all fonts embedded as a high resolution TIFF or JPEG image.
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