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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.

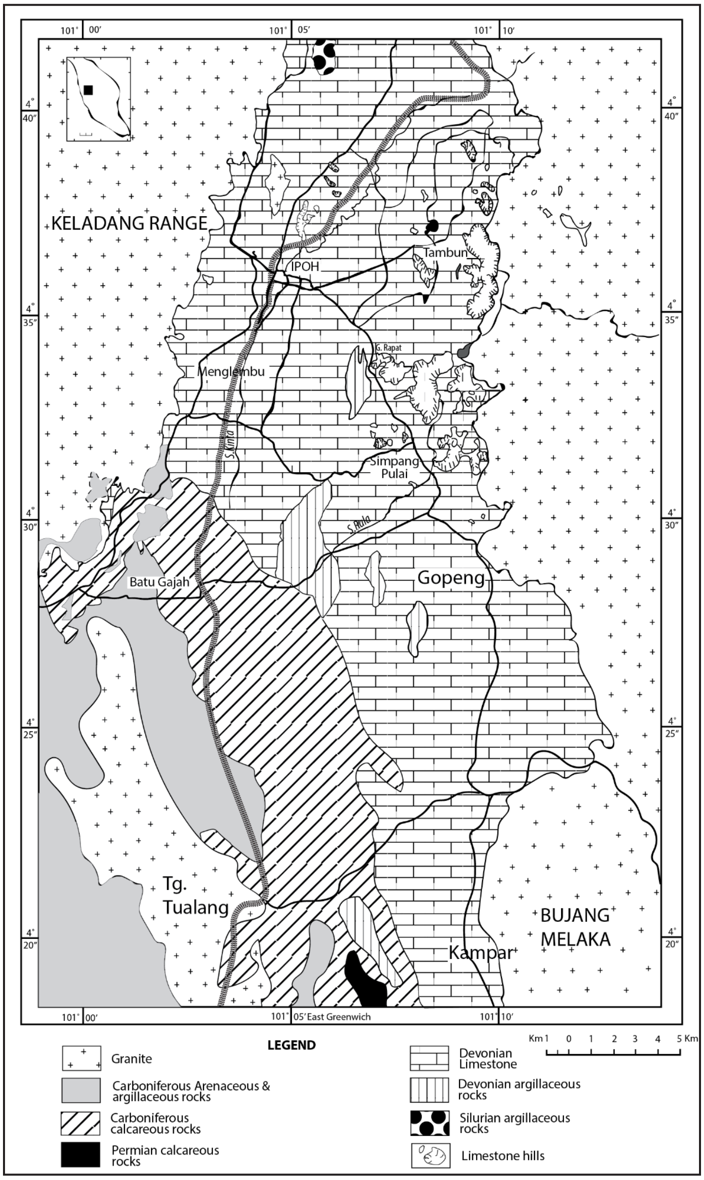

Figure 1: Geological map of Kinta Valley (adapt from JMG, 2024).

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

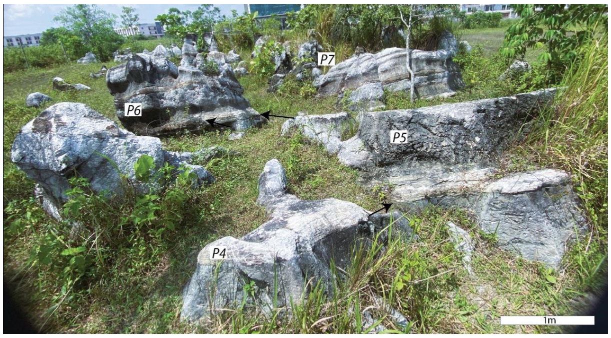

Figure 3: Overview of the exposed pinnacles. The logged seven sections identified (P1 – P7).

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

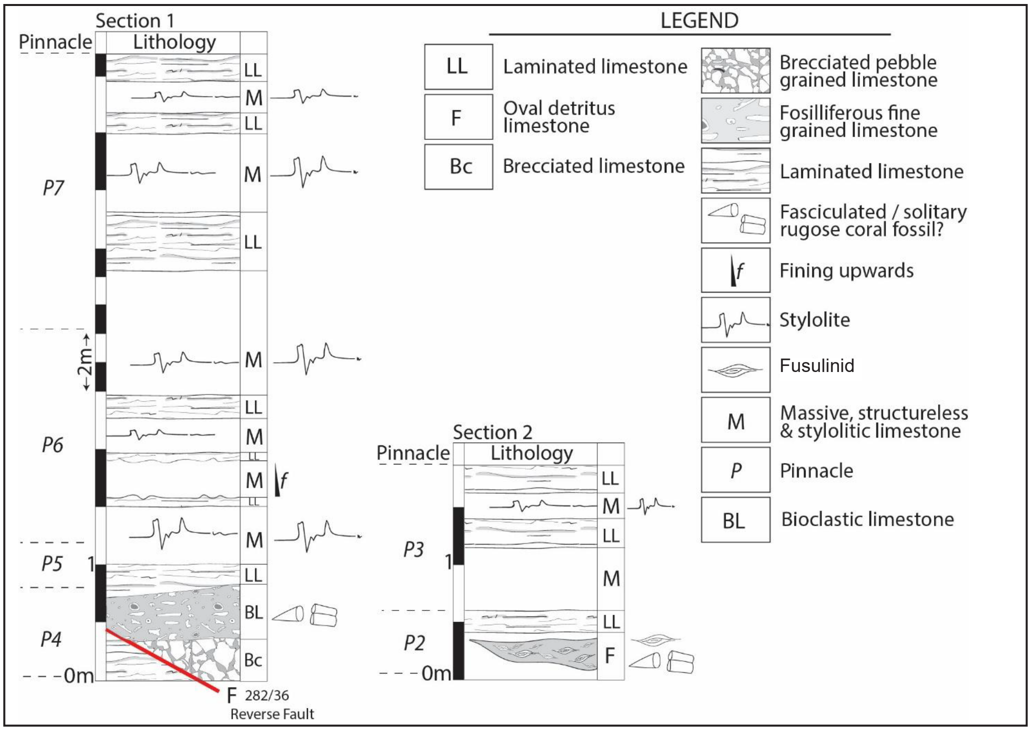

Figure 4: Two sections of continuous logs (13.5 m and 2 m thick). Section 1 consist of pinnacles P4, P5, P6 and P7. Section 2 consist of pinnacles P2 and P3.

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

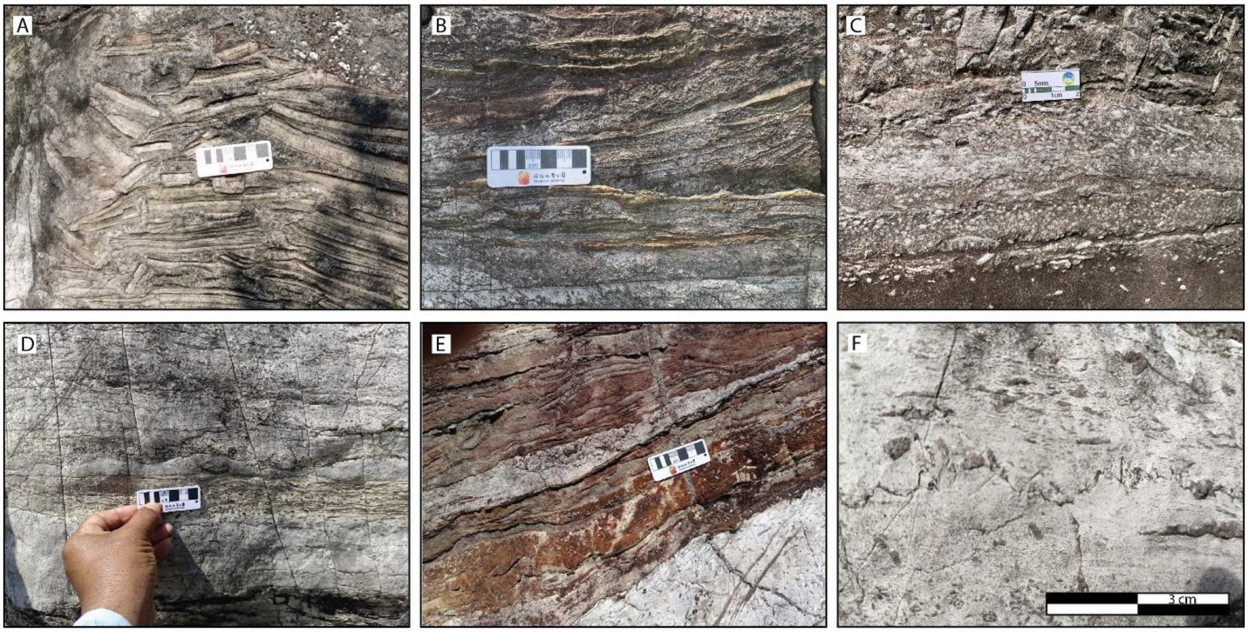

Figure 5: Photos of identified facies. A & B) laminated with platy calcite bands (LL), C) bioclastics limestone with rounded clasts, D & E) laminated greyish limestone, and F) horse-tailed stylolite.

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).

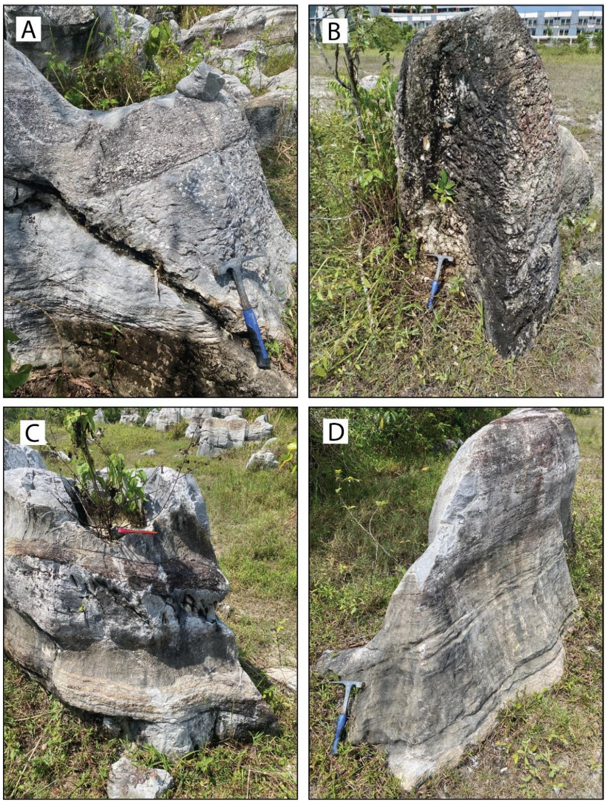

Figure 6: Photos of logged pinnacles. A) Pinnacle P4 – Faulted pinnacle with bioclastic facies overlaying stylolitic and laminated limestone facies at the right, B) Fractured pinnacle with orthogonal joints C) Pinnacle P6 – stylolitic facies overlaying laminated limestone facies, and D) Pinnacle P7 –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

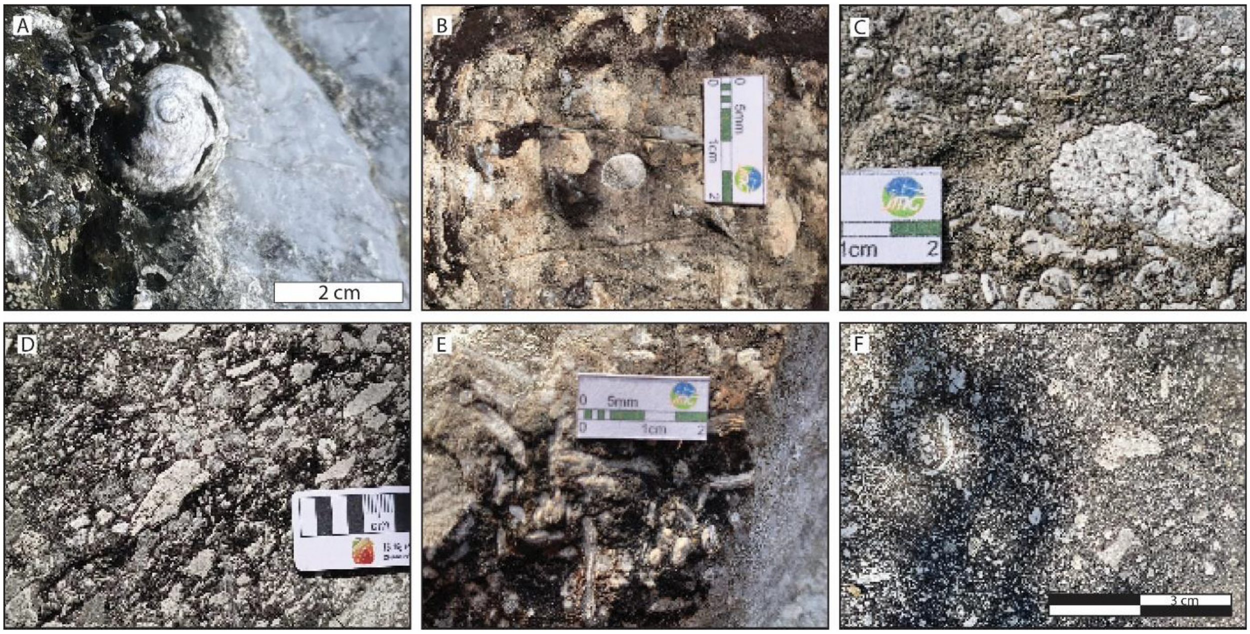

Figure 7: A) gastropod, B) isolated coral, horn? C) wackestone, tabulate coral clast in, D) *in-situ*? breccia, E) Elongated fusiform and rounded detritus wackestone (fusulinid and corals?), F) wackestone - redeposited bioclasts with possible disarticulated brachiopods, carbonaceous fragments.

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

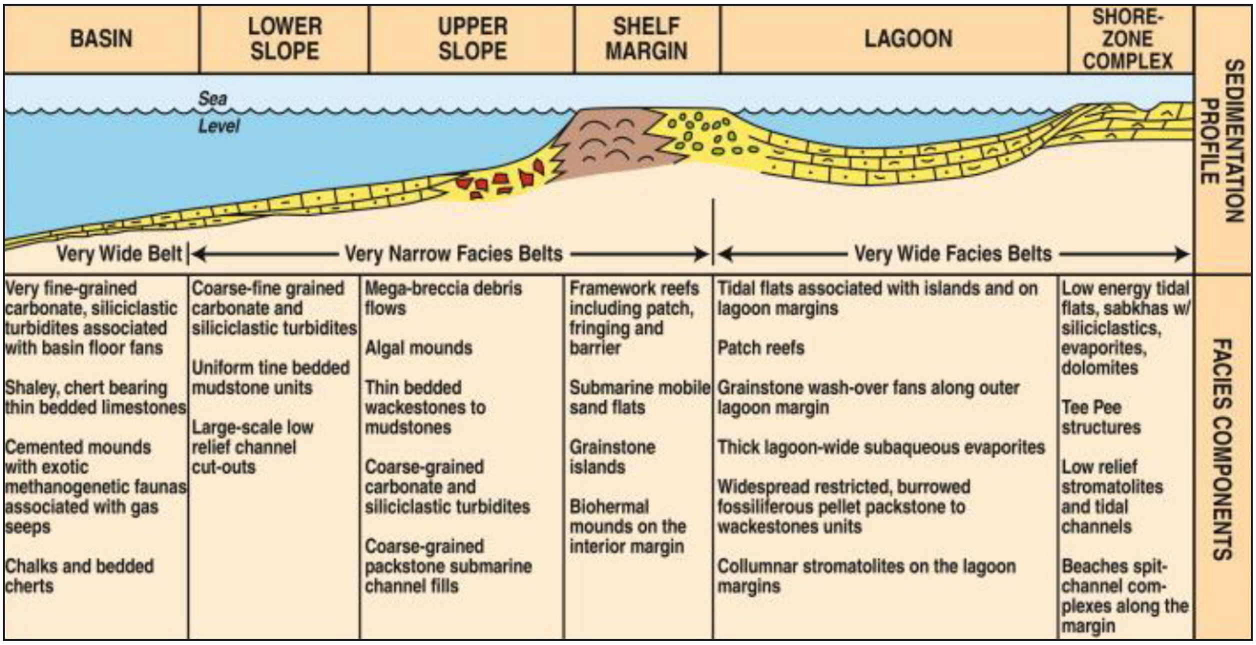

Figure 8: Proposed classic reef model carbonate model for Kampar Limestone. Modified from Wilson (1975).

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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