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FACIES ANALYSIS AND DEPOSITIONAL MODEL OF THE MIDDLE-UPPER TRIASSIC SEMANTAN FORMATION, CENTRAL PAHANG, MALAYSIA

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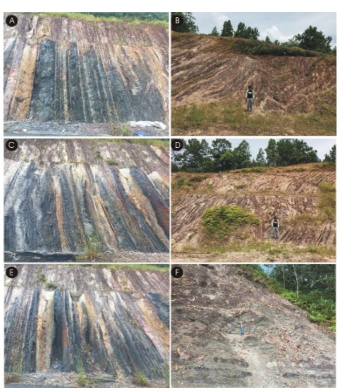
Graphical abstract



Abstract

This study details the sedimentological analysis of the Middle-Upper Triassic Semantan Formation in the Jerantut-Temerloh-Kemayan region of central Pahang. Seven (F1-7) facies have been identified which are; F1) poorly sorted conglomerate, F2) pebbly sandstone, F3) structureless-to-parallel laminated sandstone, F4) wavy-to-ripple fine-to-medium laminated sandstone, F5) slumped thin-interbeded sandstone and shale , F6) interbedded sandstone and shale, and F7) shale, represent a subordinate part of the Semantan Formation. Examination of the succession of the vertical facies resulted in concession of genetic units (FA1-FA5) which are; FA1) deep channel complex, FA2) distal lobe, FA3) hybrid gravity flow deposit, FA4) channelised lobe and FA5) non-channelised lobe. It is believed that these five genetic units were deposited within four proposed laterally contiguous depositional environments which are; 1) Inner fan – deep channel-levee complex (represent by FA1), 2) Mid fan – channelised lobe (represented by FA5 and FA3), 3) Mid Fan – non-channelised lobe (represented by FA4 and FA3), and 4) Outer fan – distal lobe (represented by FA2). The Semantan Formation deep-water fan is analysed as a sand-rich fan system, based on its sediment types.

Keywords: Semantan Formation, sedimentological, facies associations, channel-levee, Lobes, hybrid gravity flow deposit, Central of Pahang.

1.0 INTRODUCTION

The development of a deep-water environment (e.g. Semanggol and Semantan Formations) located in the Central Belt of the Peninsular Malaysia and formed during the Permian-Triassic period (e.g. [1], [2]. This study focuses on the sedimentological characteristics of the deep-sea rock succession of Semantan Formation, which is exposed along the Lanchang-Temerloh route, Jerantut and Kemayan area. The main objective of this research is to infer the deposition of the Semantan Formation, a sedimentary succession of Permo-Triassic turbidity strata.

Exhibited rocks from seven different locations were logged with information (Figure 1) to further explore the different sedimentary facies, depositary processes and relative age of formation of the Semantan Formation.

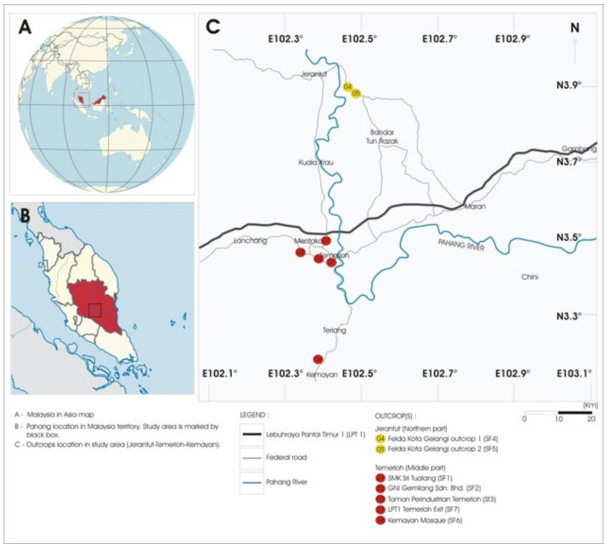


Figure 1 A & B) Location of the study area in central Pahang, Peninsular Malaysia (black box). C) Simplified location map of the study area illustrating the location of seven outcrop localities named in the text. 01) SMK Sri Tualang (SF1/SMKST) 02) GNI Gemilang Sdn Bhd (SF2/GNI) 03) Taman Perindustrian Temerloh (SF3/TPT) 04) Felda Kota Gelanggi outcrop 1 (SF4/FKG1) 05) Felda Kota Gelangi outcrop 2 (SF5/FKG2), 06) Kemayan Mosque (SF6/KM) and 07) LPT 1 Temerloh Exit (SF7/LPT).

2.0 METHODOLOGY

Geological Background

The western part of Malaysia (Peninsular Malaysia) is divided into three north-south aligned structural domains, Eastern, Central and Western (Figure 2). These structural domains vary in a variety of geological properties, such as composition, age, lithology, tectonics and paleo-geography.

The Semantan Formation is situated in the vicinity of Temerloh and stretches north to Jerantut-Kuala Lipis-Raub and up to Air Hitam, Johor to the south (80km2). The Semantan Formation, Middle to Upper Triassic Period [3]; [1]; [4]; [5], consists of a rapidly alternating series of carbonaceous shale, siltstone and rhyolite tuffs with a few chert, conglomerate and re-crystalline lenses. The lithological features, the sedimentary composition and the assemblage of fossils suggest that the Semantan Formation was mainly deposited in a deep marine environment. According to [6], parts of the Semantan Formation display evidence of underwater mass-transport deposits. He studied a newly uncovered outcrop at Chenor Exit, km 139, Lebuhraya Pantai Timur Fasa 1.

As noted by [6], because of gravitational instability near the slope or shelf area, the underwater mass transport deposit causes the re-mobilization of pre-existing sediments and is transported downhill to the abyssal plain. It forms a significant component of deep-sea sequences, often in close association with turbidity current deposits.

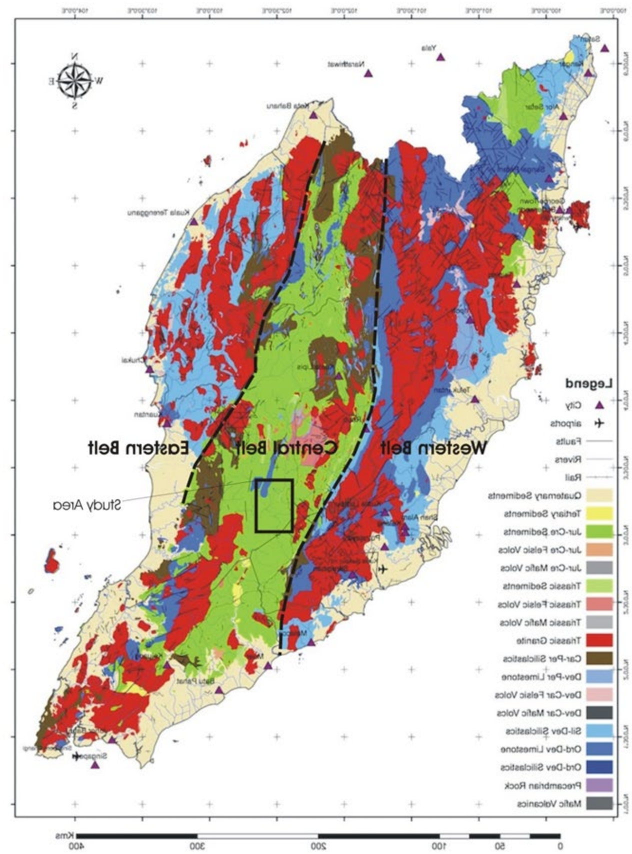


Figure 2 Simplified geological map of Peninsular Malaysia, showing the regional geology of Western Belt, Central Belt and Eastern Belt (from Geological Survey of Malaysia map, 1985).

Data Sources

The research area is situated within 80 km of the Temerloh district (Figure 1c and Figure 2). The outcrops are aligned in the north-south direction from Jerantut to Kemayan along the Pahang River. Outcrops are mainly exposed in a sequence of sloping strata with sloping parts.

The Semantan Formation was studied in seven outcrops (Figure 1c), comprising a total of 400 m of measured strata. Figure 3, Figure 4 and Figure 5 shows the sedimentary logs of the seven outcrops of study area. The logs locate in the northern part (Jerantut area: logs SF4 and SF5), middle part (Temerloh area: logs SF1, SF2, SF3 and SF7) and southern part (Kemayan area: logs SF6). The new seven exposed localities were: SF1 - SMK Sri Tualang, SF2 - GNI Gemilang Sdn Bhd, SF3 - Taman Perindustrian Temerloh, SF4 - Felda Kota Gelanggi outcrop 1, SF5 - Felda Kota Gelangi outcrop 2, SF6 - Kemayan Mosque and SF7 - LPT 1 Temerloh Exit (Figure 1c). Patches of Semantan Formation exposure along Temerloh-Karak road and Temerloh-Karak highway were previously studied [3]; [7]; [1]; [8]; [5]; [9] and [6].

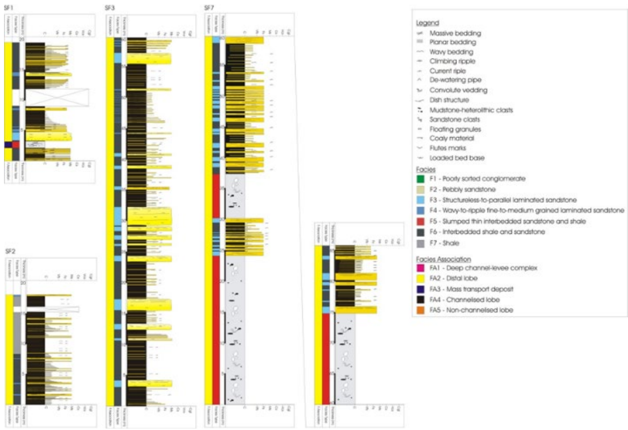


Figure 3 Representative sedimentary logs for the northern part of study area. SF4/FKG1 and SF5/FKG2 in represents a Semantan Formation in northern region of the study area, characterised by fining/thinning upward succession comprising F1, F2, F3, F4, F6 and F7.

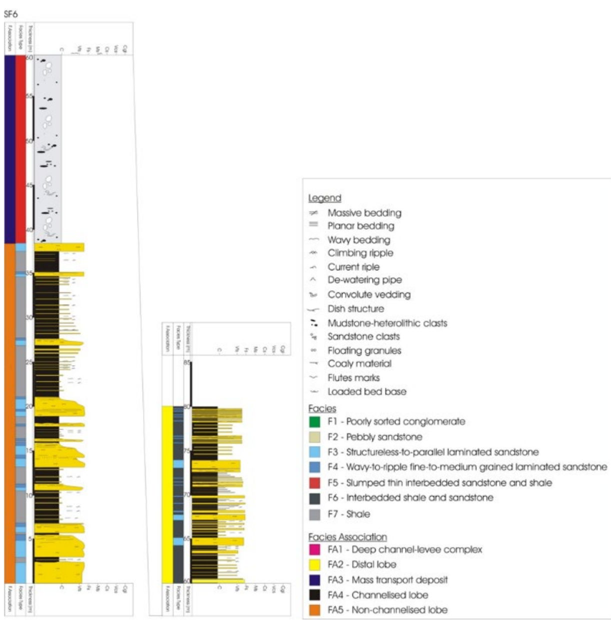


Figure 4 Representative sedimentary log for the middle part of the study area, which is dominated by distal lobe facies association, FA2 (SF1/SMKST, SF2/GNI, SF3/TPT, and SF7/LPT outcrops).

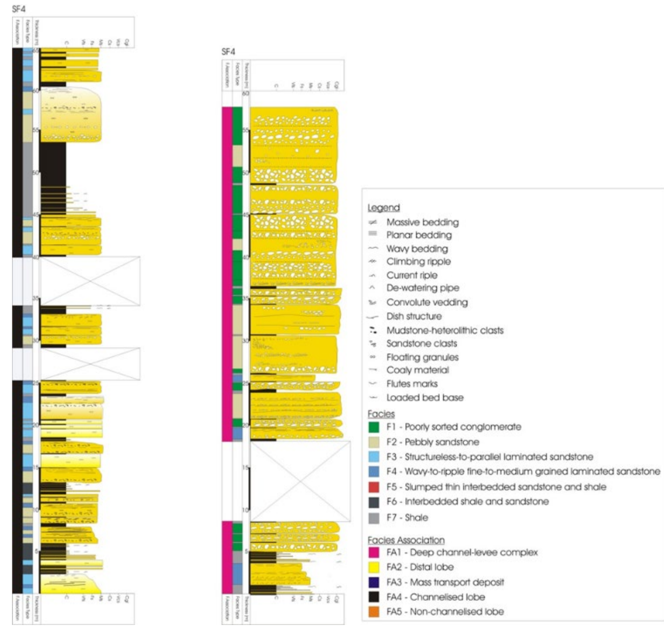


Figure 5 Representative sedimentary log of Southern part of the study area, illustrating facies association FA2, FA3 and FA4.

3.0 RESULTS AND DISCUSSION

Sedimentology Facies

Seven facies have been recognised in Semantan Formation, including poorly sorted conglomerate (F1), pebbly sandstone (F2), structureless-parallel laminated sandstone (F3), wavy to ripple fine to medium grained laminated sandstone (F4), slumped thin interbedded sandstone and shale (F5), interbedded shale and sandstone (F6), and shale (F7). The sedimentological logs are shown in Figures 3 to 5 and field images of the facies are included in Figures 6 to 10.

F1 – Poorly sorted conglomerate

F1 corresponds to white-to-greyish clast-supported conglomerates (80% clasts) with bed thickness ranging from 10 cm to 1.5 m. They comprise sub-angular to sub-rounded mudstone, siltstone and sandstone clasts and quartz pebbles, measuring 5 to 30 cm and white-to-greyish brown coarse-grained sandstone matrix. Most of the beds are poorly sorted with some of the clasts showing imbrication features. The conglomerates are invariably overlain by or interbedded with F2 and F3 facies. Both the upper and basal contact of the beds are erosive and sharp. F1 can be classified as oligomict orthoconglomerate according to [10] classification based on clasts composition and clast type. Poor sorting, lack of stratification and disorderly structure indicate that these sediments have been deposited rapidly with reduced energy conditions associated with debris flow. Debris flows reflect a variety of sediment-gravity flows, such as coherent debris flows, density-modified grain flows, and liquefied flow [11]. In the submarine fan system, such sediment gravity flows are generally, but not uniformly, associated with channels [12].

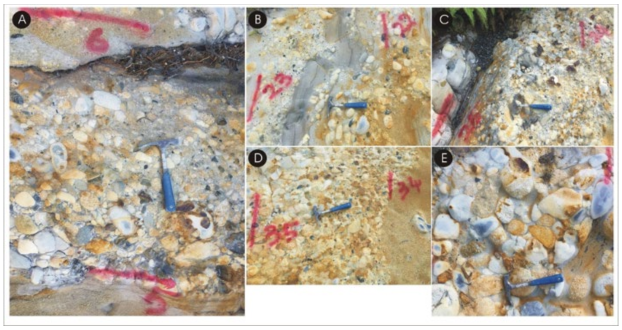


Figure 6 Field photographs illustrating the sedimentological characteristics of conglomerate facies (F1) in Semantan Formation. (A-E) Poorly sorted conglomerate containing a variety of a clast size (ranges from 3cm to 30cm) and clast type includes sandstone, quartz pebble and mud clast, located at outcrop SF5/FKG2.

F2 – Pebbly sandstone (Sandy conglomerate)

F2 consists of medium-to-coarse grained sandstones with sub-angular to angular grains. The thickness of the beds varies from 1 m to 3 m and contains randomly dispersed mudclasts. At outcrop SF4, the clast is between 10% and 30% of the unit (Figure 7). Clasts are typically concentrated towards the base of the beds and may exhibit preferential orientation, forming planar laminations locally. In certain parts, clasts ranging from a few cm to 7 cm in diameter are randomly distributed in the upper part. F2 is also present at the outcrop SF5, a display clast varying from 5 cm to 30 cm in diameter. F2 shows the erosive bottom contact and the gradational upper contact.

A gradual reduction in grain size from pebble/cobble to medium/coarse-grained sand suggests that sediments have been deposited rapidly in a high energy environment. Imbrication trends are thought to be linked to a fast-growing regime [13].

F3 – Structureless-to-parallel laminated sandstone

These facies are characterized by fine-to medium-grained and moderate to well-sorted grained sandstone (Figure 8). It has sharp, loaded or locally erosive basal contact and is generally associated with granules to pebbles-filled load/flute castings (Figure 8). Upper contact of the bed typically tends to be a sharp and sometimes irregular contact. Sandstone beds are usually amalgamated or isolated by thin interbeds of shale. The thickness of the individual beds varies from 1 to 3 m, but the beds are mostly medium to thick. Internally, these beds are sometimes massive or unstructured and grade upwards into sometimes flat-parallel laminated sandstone (Figure 8). sandstone bed. C & D) F3 in outcrop SF4/FKG1 is characterised by scattered mud clast in the middle of the beds, with some bed, the mud clast are scattered at the upper part of the bed.

Figure 7 Field photographs of pebbly sandstone facies (F2) at outcrops SF4/FKG1 and SF5/FKG2. Measuring tape and geological hammer are used to illustrate the younging direction for each bed (younging to the left). A & B) F3 in outcrop SF5/FKG2 is characterised by pebble to cobble size clast consisting of mud, sandstone clast and quartz clast randomly scattered.

Structures such as parallel lamination, current-ripple and climbing current ripple lamination can occur in the finer-grained section towards the upper part of this bed. Floating granules and mudstone clasts are randomly dispersed or form discreet horizons, generally towards the tops of the bed. Soft sediment structures, such as dewatering structures, dish structure and flame structure, are well formed within sandstone beds, usually in the middle and upper sections of the bed. Bioturbation is normally uncommon.

Thick, structureless sandstone is deposited by rapid deposition of high-density turbidity current [14]; [15]; [16]. The lack of the primary sedimentary structures as well as the dewatering structures indicate a rapid freezing or rapid deposition of the turbidity flow with sediments arriving too rapidly at the bed to be reworked by traction [17]. The formation of planar parallel lamination indicates grain traction and segregation in the upper flow regime during the deposition process. Current ripple structures provide evidence of momentum and segregation of grain by reduced flow at the end of the flow event {14}]. The presence of a single mark, such as a groove and a few flute marks at the base of a large sandstone, may be due to the strong erosive intensity of a powerful unidirectional flow. Flame structures are generally related to the loading phenomenon resulting from uneven loading and liquefaction; sand appears to sink into the underlying soft muddy layer and creates tongue-like structures that protrude into the excessively sandy layer [18].

Figure 8 Field photographs illustrating the characteristic of structureless-to-parallel lamination sandstone (F3) in Semantan Formation. A - C) Well-developed planar-parallel lamination (Tb interval of Bouma, 1962) overlain massive sandstone interval (Fa interval of Bouma, 1962), located at outcrop SF4/FKG1, Jerantut. D – E) Sharp and erosive basal contact with granule-pebble deposit preserved at the bottom of the sandstone bed.

F4- Wavy-to-ripple fine-to-medium grained laminated sandstone

This sandstone consists of light grey, fine-to-medium grained sandstone interlaced with hemipelagic mudstone. It shows sharp, flat bases, and the thickness ranges from 5 to 60 cm. Current-ripples or wavy lamination are mainly found in the upper part of the sheet. F4 defined as a low-density turbidity current depletion product [14]; [16]; [19]; [20].

F5 - Slumped interbedded thin sandstone and shale

This facies consists of deformed interbeds of dark grey to black shale and sandstone. F5 is typical in outcrops of SF6 and SF7, ranging in thickness from a few cm to 1 m of sandstone, while the shale is between mm and cm. This involves an extremely chaotic mixture of sandstone and mudstone, contorted clay and, at some intervals, substantial sand and mud injection.

This facies explains the deposition of the slumps associated with the gravity-driven mass movement. Based on [21], modern fans, minor failure can lead to slump/debris flow deposits tens of meters thick. It is therefore tempting to view the dense slumped masses of thin-bedded turbidites (Figure 10) as having initially been deposited at the levees.

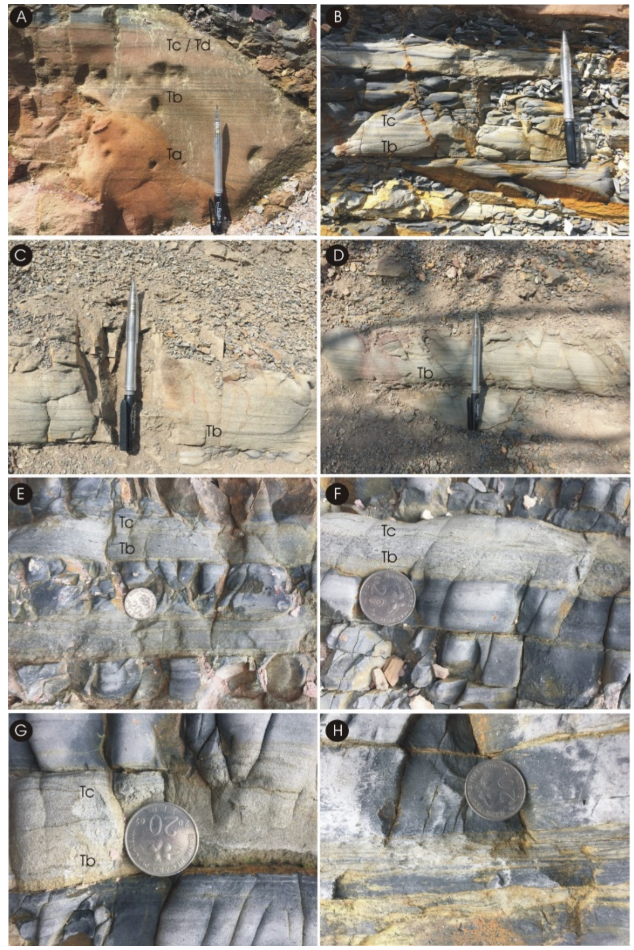


Figure 9 Field photographs illustrating the sedimentological characteristic of fine-to-medium grained, wavy-to-ripple, thin-bedded sandstone (F4) in Semantan Formation. (A) Most complete Bouma Sequence found in studied area near SMK Seri Tualang illustrating Ta, Tb, Tc / Td and Te interval of Bouma (1962). (B – H) Details of F4 beds, illustrating wavy bedding passing upwards into ripple lamination (Tc interval of Bouma, 1962) in low-density turbidites deposition.

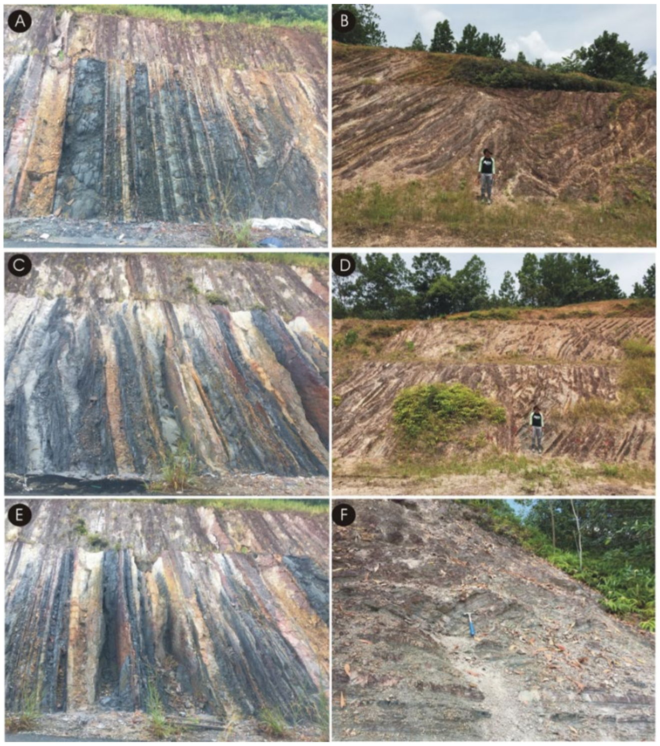


Figure 10 Photographs of mud-dominated facies (F5 – F6), which were deposited mostly in low-density turbidity current. F6 is characterised by (A, C, and E) Interbedded low-density turbidites (F6) and basin-floor shales (F7) in the distal lobe depositional element, Kemayan. Field of view is 2-3 m wide and the succession is younging from left to right for A, C and E. F5 (B, D and F) is characterised by deformed interbeds of dark grey to black shale and light grey, fine grained, poorly sorted sandstone. F5 is common at outcrops SF6/KM and SF7/LPT, with some of the sandstone beds contain mud clast and mud drapes.

F6 – Interbedded sandstone and shale

This facies is known as classical turbidite, characterized by a monotonous alternation of sharp fine grain sandstone and interlaced shale/mudstone. F6 is the most typical facies in the SF7 outcrop and accounts for almost seventy percent (70 percent) of the SF6 outcrop. The individual sandstone and mudstone beds are fairly uniform in lateral thickness, varying from less than 1 mm thick laminate to 20 cm thick beds. Shale/mudstone is very soft and fissile and tends to be massive. The thickness of the bed is consistent on the outcrop scale. Both the sharp and the irregular base of sandstone layers are present, the latter displaying scours and small-scale flute castings. The upper contact of the sandstone layers is smooth and sharp.

F6 is comparable to [22] and [23] Facies D strata, equivalent to Waker's classical/traditional distal turbidite (1967). The most common Bouma sequences shown by sandstones are the Ta-c sequences. Finely laminated siltstones and mudstones indicate deposition in periodic muddy turbidity currents in low-energy or low-density conditions, slightly changed by poor tractional processes at the tail end of the flow for laminated siltstones. Minimum bioturbation implies a highly stressed ecosystem caused by gravity-flows and anoxic-basin-floor conditions.

F7 – Shale

F7 is dominated by dark-black, non-bioturbed carbonaceous mudstone, with the presence of interspersed light grey siltstone lamination bands. F7 accounts for almost thirty percent of the rock exposure in the outcrop of SF6. The thicknesses for this facial unit vary from less than 1 m to 2 m.

F7 is known as the deposition of suspension of fine grained particles. In a turbidite environment, the deposition of coarse sediments can result in a residual suspension of fine-grained sediments. These residual fine-grained sediments can decrease and appear to be deposited under low energy turbidity currents. In addition, these fine-grained materials may also be connected with and transported within the flow in response to rapid settlement [24]. The lack of bioturbation suggests either stressed environmental conditions, which could be associated with high sedimentation rates associated with regular inflows and rapid deposition of sand-loaded turbidity currents, or an oxygen-depleted state.

Facies Association (FA)

Facies belonging to the Semantan Formation can be grouped into five facies associations: FA1: Deep channel, FA2: Distal lobe, FA3: Mass transport deposit, FA4: Non-channelised lobe, and FA5: Channelised lobe.

Facies Association 1, (FA1) - Deep channel

Facies Association 1 (FA1) consists primarily of series F1 and F2 with a combined thickness of up to 50 m. The lower part of the FA1 consists of a clast-supported conglomerate forming amalgamated thick beds that can reach up to 10 thicknesses (Figure 3) and move up into a pebbly sandstone face (F2). FA1 is largely maintained in the northern part of the study area (SF5 outcrop). Figure 3 shows the sedimentary log in this segment. According to [25], the conglomerate facies (F1 and F2) show up-current location in the slope-submarine fan deposit system, possibly connected to the feeder channel complex, mainly due to slurry or debris-flow processes [26].

Facies Association 2, (FA2) - Distal lobe

FA2 consists of vertical alternation of the shale-dominated facies F7 and the fine-grained sandstone of the facies F4 and F6 (Figure 4). This series is arranged into 2-20 m thick thickening and less frequently thinning-up sequences. Distal lobe FA2 occurs in a variety of locations (e.g., SF1, SF2, SF3 and SF7 outcrops in middle part and SF6 outcrop in southern art). Examples of sedimentary lobe distal logs are shown in Figure 5.

The FA2 is deposited in the outer fan environment. In the typical submarine fan system, the outer fan usually starts outside the limits of the distribution channel deposits. According to [22], it was deposited by alternating the low-density turbidity present and the suspension of hemipelagic mud. The occurrence of both thickening and thinning upward succession in these shale-dominated sequences is likely to reflect the active progression and migration of the lobe or fan fringe to the basin floor [27].

Facies Association 3, (FA3) – Hybrid Gravity Flow (HGF)

The FA3 is dominated by F5, consisting of a chaotic deposit of up to 20 m thick. The interaction of HGF facies exists at many sites (SF1, SF7 and SF6). At SF6, FA3 forms a 22 m thick series above the FA4 facies association, while FA3 dominates the SF7 succession (Figure 5).

FA3 is interpreted as a mass transport deposit due to the deposition of unlit sediment from unstable slopes, which is presumably initiated by tectonic activity. In addition, this deposit may also be created more locally, such as a failure of the channel flanks associated with more upslope canal erosion. Based on the facies analysis in this study region, FA3 is most likely to be deposited in the proximal part of the middle fan environment.

Facies Association 4, (FA4) - Channelised lobe

FA4 primarily alternating between F2, F3 and F4 (Figure 3). It consists of 5 to 15 m thick intervals of massive amalgamated sandstone F2 and F3, accompanied by a thinning upward series of facies F4. Some sandstone bodies show sharp basal contact with low-relief or shallow erosion surfaces directly overlain by granular lags, which alternate with 5-7 m thick coarsening and upward thickening of F8 (Figure 3). Overall, the FA4 facies relation is shown in Figure 3.

According to [28], channelized lobes are deposited in the proximal part of the mid-fan environment system. It is distinguished by the lateral migration of the distribution channel piling, which has been retained as multi-storey and multi-storey, fining upward sandstone bodies. The dominant medium to thick sandstone units, with a high sandstone to mud ratio, indicate a rapid flow position [14]; [16], while the presence of amalgamated sandstones indicates rapid multiple flow events.

Facies Association 5, (FA5) – Non-channelised lobe

FA5 dominated by alternations of the F4 and F6 facies. It is 5–20 m thick, thickening upward sequences and usually overlaid with thin sandstone and hemipelagic shale layers. The FA5 is maintained at SF3 and SF6.

FA5 is a non-channelised lobe deposit accumulated in the mid-fan environment system. The thickening upward sequences are interpreted as progressive lobes. In some parts, this pattern was overlaid by fining and thinning-upward sequences of thinner shallow channels, distinguished by low relief and scouring surfaces. The occurrence of coarsening and fining upward sequences is likely to reflect the active migration of lobes in the mid-fan environment.

Depositional Environment

The sandstone-shale ratio and the characteristic facies of the Semantan Formation are made up of a sand-rich submarine fan. The conceptual submarine fan model has been used to evaluate 2 repository regions. The northern part of the region studied comprises a rich succession of sand, represented by the inner fan-deep channel levee complex, represented by the FA1. F1, F2 and F3 facies suggest the deposition in the proximal part of the fan, likely connected to the inside of the fan channel and the levee complex near the mouth of the canyon. This architecture is seen in the sedimentary successions of SF5. The lower sequence of the succession of SF5 typically shows a thickening upward trend from the overlaid shale/sandstone facies moving through the conglomerate facies, possibly linked to the progressive fan system (Figure 3).

Southern part of the study area characterized by a mix of sand-shale succession consists of the medium fan-channeled lobe, the middle fan-non-channeled lobe and the outer fan-distal lobe. The middle fan – the channeled lobe was represented by the FA4 and FA3 facies association. This zone is distinguished by an alternation of thinning-upward sequences with thinner upward thickening sequences. This alternating sequence indicates a mixed repository environment setting that varies from channel-dominated and lobe-dominated areas. The local occurrence of slump/sliding deposits within this zone could be due to either localized (e.g. channel margin) or more regional (e.g. updip, continental slope) failure. The architecture and associated stacking patterns of this part of the Semantan Formation fan system are shown in the SF4 sedimentary sequences (Figure 3).

Deposition of the middle fan – a non-channeled lobe represented by the FA5 facies association. In contrast to zone two, this zone consists of thickening upward sequences alternating with thinner upward sequences. The thickening-upward sequences indicate the mid-fan lobes and sheet deposits, while the thinning-upward sequences are interpreted as low-relief, non-levee channels [6].

Deposition of the outer fan-distal lobe is characterized by FA2, which displays high lateral continuity, sometimes alternated with fine-grained sandstone and low erosion bed contact (distal Bouma sequences). According to [29], these muddy distal lobe deposits may gradually merge into the basin plain. The occurrence of several thinning-upward sequences in this distal lobe is the active progression and migration of the fan margin to the basin plain region [29]. This distal lobe setting is well displayed in SF1, SF2 and SF7 outcrops (Figure 4).

Depositional Model

The deposits of the Semantan Formation in the studied area are dominated by the medium and outer fan environment and the intermittently inner fan channel-levee deposits as shown in the conceptual depositional model of Semantan Formation (Figure 11). This interpretation is based on the characteristic sandstone facies, geometries and their association with other facies in the vertical stacking pattern (e.g. interbedded of thin bedded sandstone-shale bed in Figure 4). These characteristics are rarely found in sloping apron deposits due to lack of mass transport deposits. The geometry and morphology of the submarine fan system are significantly controlled by the type of sediment feed systems (i.e. sand-rich or mixed sand-mud or mud-rich) [30];[31]. Sand-rich systems develop a radial-shaped fan, while the mud-rich system tends to be longer. In the case of the Semantan Formation, the predominant sand-rich sediment type probably indicated a sand-rich fan system.

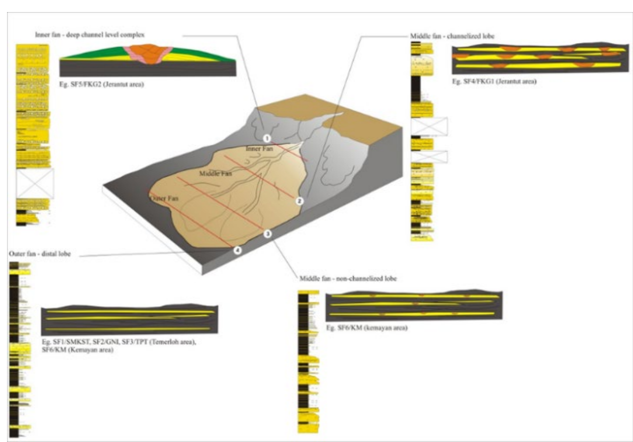


Figure 11 Conceptual depositional model of Semantan Formation submarine fan system incorporating all the five facies association

discussed earlier, from proximal to distal parts of the fan and highlighting representative outcrop (modified after [29]).

4.0 CONCLUSION

The Semantan Formation consists of eight (8) types of facies (F1-F8) which are grouped into five facies associations (FA1–FA5) which are interpreted as being deposited in a sand-rich submarine fan system. Volumetrically, sandstone facies (F1-F5) represent a major component of the sand-dominated facies in the Semantan Formation, approximately seventy-five per cent of the total facies occurring on the basis of 400 m of logged area. The five facies associations represent the following depository environments (from inner fan to outer fan): 1) inner fan – deep channel levee complex (represented by FA1), 2) mid fan – channeled lobe (represented by FA5 and FA3), 3) mid fan – non-channeled lobe (represented by FA4 and FA3), and 4) outer fan – distal lobe (represent by FA2). Based on the outcrop studied, the main deposition process for Semantan Formation consisted of high-to-low-density turbulent gravity-flows, followed by sandy and muddy debris and suspension-flows. Slumps, in the form of a Mass Transport Deposit, are relatively small deposits.

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