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Submarine mass-transport deposits in the Semantan Formation (Middle-Upper Triassic), central Peninsular Malaysia

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Abstract — Relatively fresh exposures of the Semantan Formation along the East-Coast Highway (Lebuhraya Pantai Timur – Fasa 1) between Karak and Kuantan, central Peninsular Malaysia, have given new insights into the sedimentary processes in the Triassic flysch basin that once separated west and east Malaya. An eastward change from distal to proximal facies between Karak and Maran indicates a west-facing, active continental shelf to slope sedimentation. Outcrops between Karak and Temerloh, east of the Late Triassic-Early Jurassic Bentong-Raub collisional suture, are generally characterized by "classical" flysch-like, thinly-bedded sandstone-mudstone facies. Further east of Temerloh towards Maran, and nearer to the paleo-shelf and slope, more sandy and thick-bedded turbidite facies occur. A proximal deep-marine facies association in the Semantan Formation is exposed at the Chenor Junction (Exit 821), kilometre 139 along the highway. South- and north-facing cuts on either sides of the highway reveal large gravity-slide blocks (megaclasts), slumps, debris flow deposits, and associated syn-sedimentary thrust faults and glide surfaces. These features are strongly indicative of large-scale submarine mass-transport processes on the palaeo-slope of the Triassic active margin. The Chenor mass-transport complex is made up of zones of incoherent slump deposits intercalated with well-bedded turbidite/debrite facies. In the lower part of the succession, there are megaclasts of sandstone-mudstone facies, measuring several metres in size, encased in a plastically deformed silty matrix. The megaclasts are highly deformed internally by numerous meso-scale normal faults, probably due to gravitationally-induced extension. Along with other smaller sandstone blocks, these megaclasts are interpreted as slide blocks due to slope failure up-dip. There are other gravity-induced structural features such as rotational slumps, glide surfaces, thrust faults and associated soft-sediment folds. The slump folds and thrusts show vergence to the west, as opposed to the generally eastward tectonic vergence. A few of the well-stratified units show strongly inclined stratal surfaces which may be attributed to lateral accretion of turbidite fan lobes. Several sets of these inclined surfaces are bounded by erosional surfaces which could have resulted from different episodes of turbidity flow. The association of incoherent mass-flow units with the more well-stratified deposits reflects the close spatial and temporal relationship between submarine mass-transport events and turbidity flows on the Triassic active slope and basin plain.

Keywords: mass-transport deposits, Semantan Formation, turbidites

INTRODUCTION

Submarine mass-transport deposits (MTDs) are the product of large-scale, submarine mass wasting, whereby gravitational instability causes re-mobilisation of pre-existing sediments in the shelf and slope areas downslope into the abyssal plain. They form a very significant component of deep-marine sequences, often in close association with turbidity current deposits (turbidites). A wide variety of catastrophic depositional processes, such as rock falls, slides, slumps and debris flows, fit into this category of mass-transport process in the deep sea. Lateral associations of different parts of the mass transport system are sometimes termed "mass transport complexes" or MTCs (Moscardelli & Wood, 2008; Butler & McCaffery, 2010). The understanding of MTDs is important in petroleum exploration and production, as they may form a significant percentage of the sediment in a submarine fan. MTDs are also of interest to engineers as they pose potential hazards to offshore installations and may indicate risks of future submarine mass-failures. A brief but useful overview of MTDs is given by Weimer & Shipp (2004).

In the geological record, MTD's are common in, though not necessarily restricted to, tectonically active margins, which are susceptible to gravity-induced down-slope mass movements. In the axial region of Peninsular Malaysia (Figure 1), a large expanse of Triassic sedimentary rocks of mainly deep-marine origin has been mapped by Jaafar (1976) as the Semantan Formation. This flysch-like rock succession represents deposition in a tectonically active margin during Triassic times. Detailed sedimentological descriptions of the Semantan formation are lacking, despite many references made to it as being submarine fan deposits. In this paper, the sedimentological characteristics of the formation are described, based on field observations in central Pahang, mainly along the East Coast Highway (Lebuhraya Pantai Timur - Fasa 1) between Karak and Kuantan (Figures 1 and 2). In particular, the occurrence of mass-transport deposits with associated turbidites and debrites, give further insight into the sedimentary processes in this Triassic basin. Preliminary sedimentological descriptions of the outcrops were given by Madon (2006) and Hasnol *et al*. (2007).

BASIN FRAMEWORK AND TECTONIC SETTING

Peninsular Malaysia has been traditionally divided into three north-south aligned structural domains: the

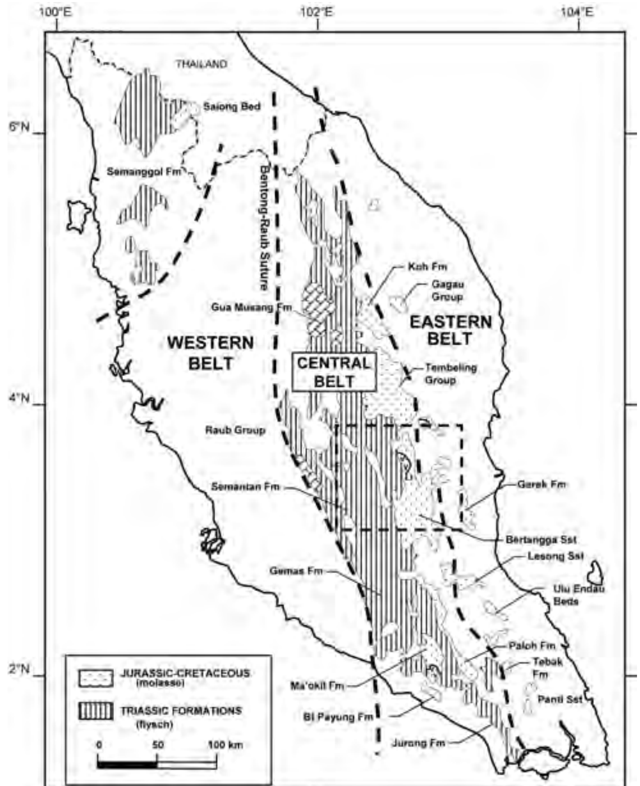

Figure 1: Simplified geological map of Peninsular Malaysia, showing the pre- and post-Indosinian formations (from Geological Survey of Malaysia Map, 1985). Dashed rectangle is the blow-up of the study area, shown in Figure 2.

West, Central and Eastern belts (Lee, 2009; Figure 1). The Central Belt region of Peninsular Malaysia, covering mainly central Pahang and Johor, is dominated by middle-upper Triassic flysch-like rocks, which are thought to represent a fore-arc "accretionary" complex (e.g. Hutchison, 1989). It represents the relict of, the Paleo-Tethys Ocean, a deep marine basin that once separated West and East Malaya. Its western margin is marked by the Bentong-Raub Suture, comprising ophiolites and olistostromes, while the nature of its eastern margin remains inconclusive. Eastern Malaya is characterized by a volcano-plutonic arc during Permo-Triassic times (Hutchison, 1989). The deep marine basin underlying the Central Belt is filled with flysch and associated rhyolitic/andesitic volcanism, alternating carbonaceous shale, siltstone, and volcaniclastics. Shale and tuffaceous siltstone sequences make up the bulk of the Semantan (Jaafar, 1976), are highly fossiliferous locally, but are mostly barren. Bivalves and ammonites of Middle Triassic age have been found in the Mentakab-Temerloh Bypass area (e.g., Metcalfe & Chakraborty, 1994).

The depositional environment and origin of the Semantan Formation is still being debated. The apparent lack of imbrication and thrusting was quoted by Metcalfe & Chakraborty (1994) as evidence against the Semantan being an accretionary wedge or prism. The regional geology, however, indicates that the Semantan basin was the foreland basin associated with the subduction and collision at the western margin of Eastmal.

THE SEMANTAN FORMATION

The term "Semantan Formation" was first introduced by Jaafar (1976), who mapped the formation in road cuts from Karak to Temerloh and assigned the age as Middle to Upper Triassic based on palaeontology. From exposures near Lanchang, Metcalfe *et al*. (1982) reported bivalves, ammonites, plant fragments and trace fossils of late Middle Triassic age. Mohd Shafeea and Sone (2001) also found the ammonoid *Paraceratites* sp. in shale beds near Temerloh, which affirms the age. During this field study, fossils were also found in the Semantan Formation, and indicate Middle to Upper Triassic age (Hasnol *et al*., 2007). They include *Posidonea* sp., *Daonella* sp. and some gastropods in mudstone layers. Trace fossils occur in sandstone beds.

Based on the evidences from lithological characteristics, sedimentary structures and fossils, the Semantan Formation consists predominantly of deep marine, possibly bathyal (slope) sediments. There have been reports of shallow marine indicators, e.g. oolitic limestones and gastropods (e.g. Kamal Roslan & Ibrahim, 1993; Khoo, 1998) but for the most part, the Semantan represents a deep-marine setting. Metcalfe *et al*. (1982) reported a muddy sequence in interbedded mudstone and tuffaceous siltstone, with graded bedding, erosive bases, and intraformational slumps indicative of sediment-gravity flow or turbidity current deposits. There is graded bedding in tuffaceous sediment, some more than a metre thick, with paleocurrent directions mainly to the west or southwest, some easterly and southeasterly.

Metcalfe & Chakraborty (1994) had also described a thick succession of the Semantan containing slump and soft-sediment deformational features, although no detailed description or interpretation was given. The widespread occurrences of volcanic and tuffaceous sediment in the Semantan (e.g. Azhar, 1992; Metcalfe & Chakraborty, 1994; Ong, 2001) indicates proximity to a volcanic arc, which is probably related to the closure of the Paleo-Tethys Ocean. Thus, there had been gradual shallowing of the Semantan foreland basin, synchronous with uplift of the Main Range batholiths in Late Triassic times. Flysch sedimentation may have progressively changed to continental molasse, through shallow water (littoral) facies, during the time leading up to the collision between West and East Malaya, and the complete closure of the Paleo-Tethys. The post-orogenic continental (molasse) sedimentation is recorded by the Jurassic-Cretaceous formations of the Central Belt.

The Semantan Formation typically consists of thin-bedded sandstone-mudstone alternations, which are characteristic of a muddy flysch or "distal" basin floor turbidite deposits. Thin-bedded turbidites are the dominant facies type, as seen in many outcrops along the highway between Karak and Temerloh. An example from km 114.3 along the highway is shown in Figure 3 (location 1 in Figure

2). The predominant facies type in the Semantan Formation is dark grey to black mudstone or shale, with thinly (cm-scale) stripy appearance due to the lighter-coloured, cm to mm-thick sandy, often tuffaceous layers. The thin-bedded nature, with sharp bases and gradational tops (Figure 3B), and sheet-like geometry suggest that these are mainly basin-floor 'distal' turbidites laid down by dilute flows. Generally, the net-to-gross sand is low, with sand-shale ratio estimated at between 5% and 10%. Individual turbidite beds are rarely a metre thick, and most are less than 50 cm thick. The main facies characteristics have been described briefly by Hasnol *et al*. (2007).

A change from distal to proximal facies eastwards between Karak and Maran suggests a west-facing, active continental shelf-slope sedimentation. Outcrops between Karak and Temerloh, east of the Bentong-Raub suture, are characterized by "classical" flysch-like, thinly-bedded sandstone-mudstone facies ('distal turbidites'), whereas to the west of Temerloh, and probably nearer to the palaeo-shelf and slope region, more sand-rich facies and thick-bedded ('proximal') turbidites occur.

Structural Style

In most of the outcrops along the highway, the Semantan Formation is steeply dipping (60-70°), suggesting strong folding into tight folds due to the Late Triassic-Early Jurassic compression. The bedding attitude varies somewhat from place to place; there are places where moderate to low dips (<20°) are observed, where the formation appears to be only slightly deformed into broad open folds.

The steeply dipping beds, which are mostly of thin-bedded turbidites striking mainly NNW, also show evidence of low-grade metamorphism; they are highly indurated and have a slaty cleavage. Cleavage-associated deformation of fossils was reported by Metcalfe *et al*. (1982). It is likely that the beds are isoclinally folded and imbricated, but the structures are obscured by the poor exposure. In some places, thinly-bedded sandstone-mudstone, probably of distal turbidite origin, are cut by several small-scale thrusts and reverse faults, verging eastwards. The deformation style of Semantan Formation was studied by Tjia (1996). Tectonic overprinting onto soft-sediment deformational structures caused disharmonic fold styles and complex structures. According to Hutchison (1989), the main phase of deformation was dated approximately as Rhaetic (late Triassic) to Early Jurassic and probably partly diachronous, ranging from Middle to Upper Triassic. There seems to be a general younging of the deformation eastwards, where beds are less deformed. There could be areas where tectonic deformation is superimposed on syndepositional deformation, as documented by previous workers (review in Mustaffa Kamal, 2009).

THE CHENOR JUNCTION OUTCROP

Relatively fresh outcrops of the Semantan Formation along the highway, particularly between Temerloh and Maran, reveal some interesting features that represent a variety of deep-marine transport processes and their related deposits, including slumps, debrites, and turbidites. Of

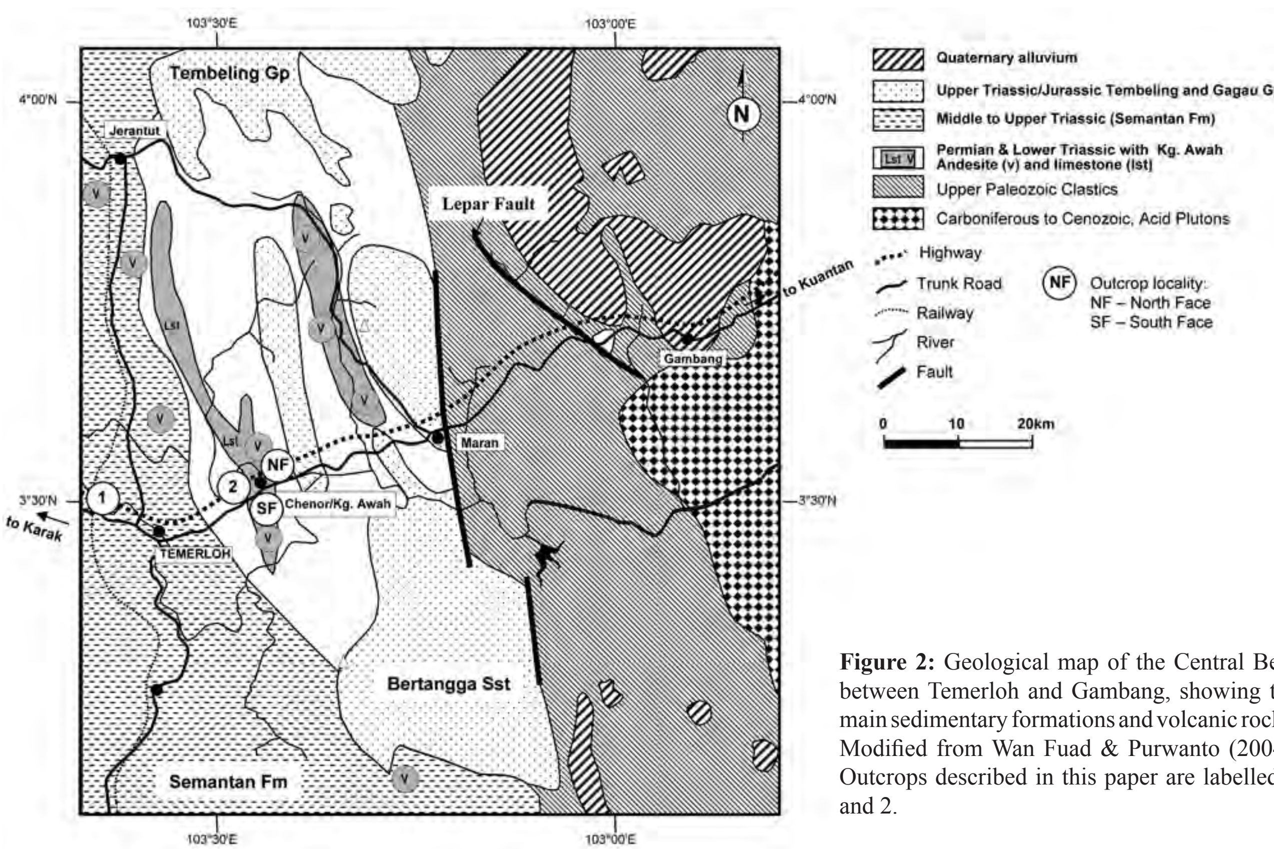

Figure 2: Geological map of the Central Belt, between Temerloh and Gambang, showing the main sedimentary formations and volcanic rocks. Modified from Wan Fuad & Purwanto (2004). Outcrops described in this paper are labelled 1 and 2.

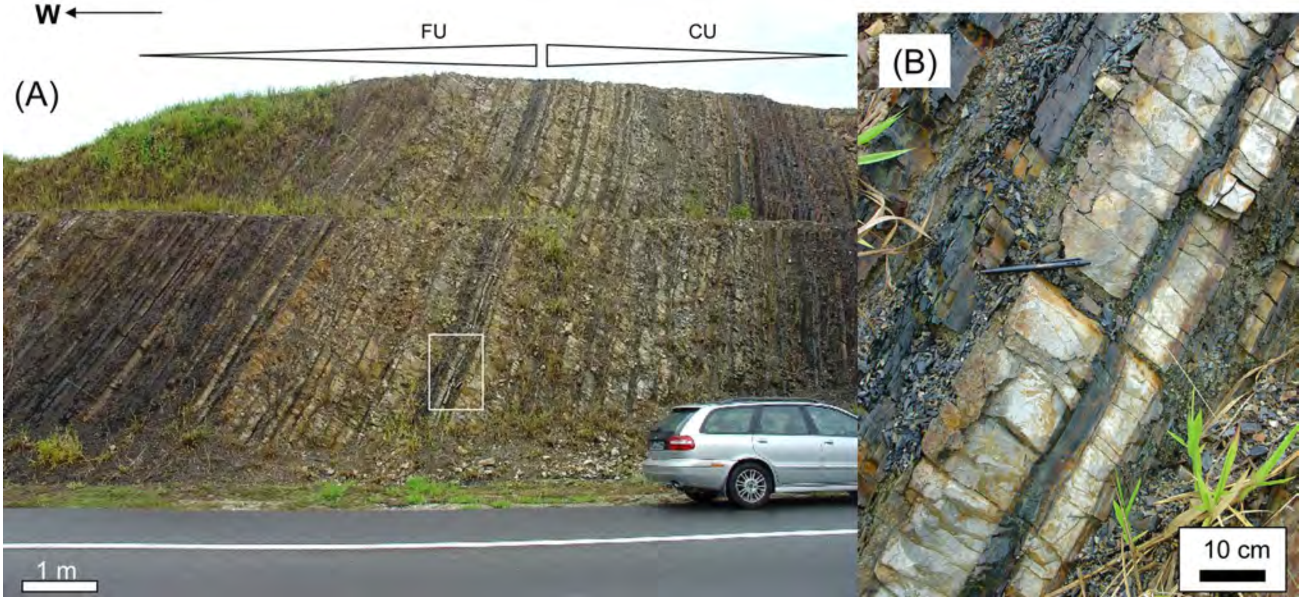

Figure 3: Typical facies in Semantan Formation: thin-bedded turbidites, (A) with coarsening (CU) and fining (FU) upward trends (Km 114.3,) Karak-Kuantan Highway, location 1 in Figure 2. Inset shows close-up of turbidite beds (B) with normal-graded fine sand/silt characterised by sharp bases and gradational tops (way up to top left hand corner).

particular interest to the present study is the occurrence of mass-transport deposits in the Semantan Formation at the Chenor Junction, km 139, on the highway (location 2 in Figure 2). Here, a mixture of slump, slide and debris flow deposits occurs. They reveal many features that are indicative of submarine mass-transport processes along the active Triassic continental margin of East Malaya. The west-facing continental margin shelf-slope sedimentation is implicated by the change from distal to proximal facies from west to east along the highway. Hence, the outcrops between Karak and Temerloh, east of the Bentong-Raub suture is characterized by "classical" flysch-like deep-marine sediments, dominated by thinly-bedded turbiditic sandstone-mudstone successions. Westwards from Chenor, more thickly bedded turbidites and mass-transport complexes occur, due to proximity to the Triassic hinterland (Eastern Belt of Malaya). Further east, near Sungai Lebir and beyond, continental redbeds and fluvial deposits of Jurassic-Cretaceous age occur.

CHARACTERISTICS OF THE MASS-TRANSPORT DEPOSITS

The Chenor mass-transport deposits are exposed on both sides of the highway. Photomosaic of the outcrops are shown in Figures 4, 5 and 6. Sedimentary logs of the outcrops are shown in Figure 7. The exposure on the south side of the highway is here referred to as the 'South Face' (looking south, with traffic heading to Kuala Lumpur) while on the north side is the North Face (looking north, traffic to Kuantan). Generally, the beds dip moderately, at about 30-35° to the west, and consists of interbedded sand-shale at the base, overlain by thick succession of slumps and debris flow deposits. The deposits show a variety of sedimentary and structural features that are indicative of deposition by large-scale sediment gravity-flows. Some examples are shown in Figures 8 through to 12.

These exposures were first studied in detail by the author in mid-2006. Weathering has caused the muddy intervals to deteriorate with time. At the time of writing (November 2008), the entire North Face has been sprayed with grass seed and lime slurry to prevent slope failure. It is fortunate that the South Face is relatively intact and available for viewing.

South Face

The south face exposes a succession of sandstones and mudstones with abundant deformational features (Figure 4). The log in Figure 7 shows the succession which comprises slope and basin-plain facies, characterised by large sandstone-shale blocks that are incorporated in the muddy debrites. The lithology and bedding style are suggestive of basin plain or outer fan lobe where distal turbidites and debrites are more common. Numerous slump-related features, such as listric faults and convolute bedding ("jam-roll") structures are indicative of proximal slope or base-of-slope setting for the mass-transport complex. The sediments are predominantly argillaceous, with thin interbeds of sandstone. Only a few sandstone beds are a metre or so thick. Shallow water fossils (gastropods and bivalves) found in the matrix surrounding the sandstone blocks (reported by Hasnol *et al*., 2007) indicate that the blocks could have been derived from re-mobilisation of shallow water deposits.

The large sandstone blocks show internal stratification made up of heterolithic facies (interbedded sandstone-mudstone). They have sharp boundaries encased in argillaceous matrix, and are internally deformed by numerous normal (extensional) faults (Figures 8A, 8B) as well as minor thrusts (Figure 8C), which could have formed during the

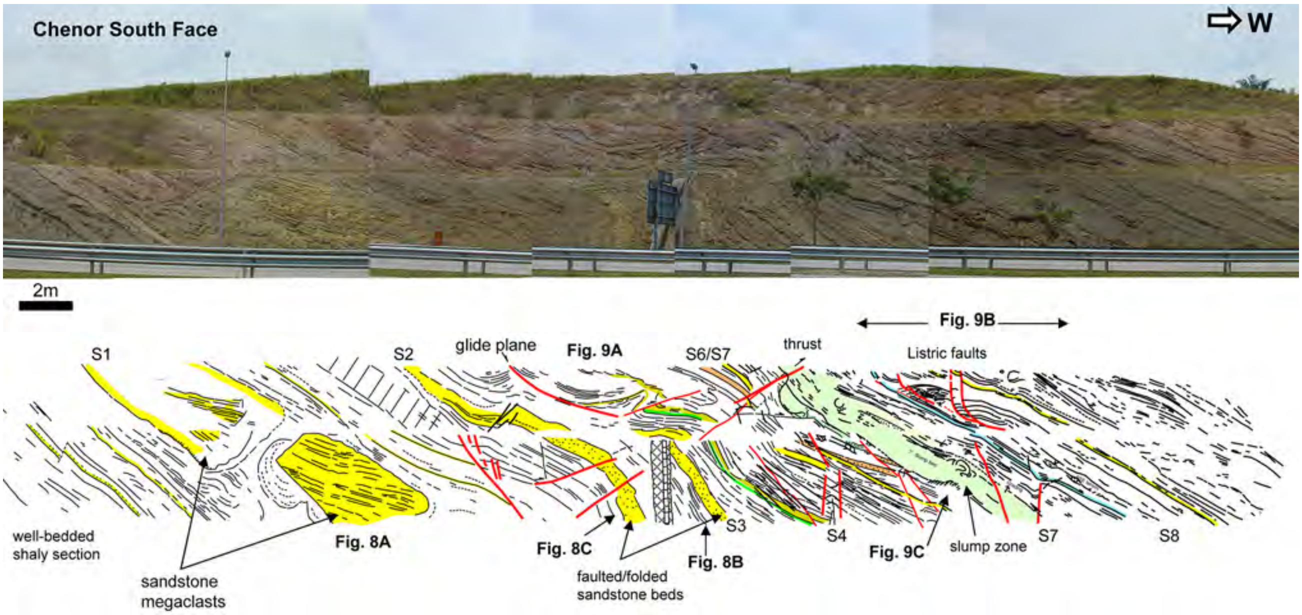

Figure 4: Photomosaic of Chenor Junction outcrop, South Face (i.e. view to the south), showing a moderately dipping succession of debrites and turbidites, with common intercalations of chaotic slump deposits. Way up to the west/right. Some details are shown in the line drawing below. S1 to S8 refers to the major sandstone beds identified in the sedimentary log in Figure 7. The location of photographs shown in Figs. 8 and 9 are also indicated for reference.

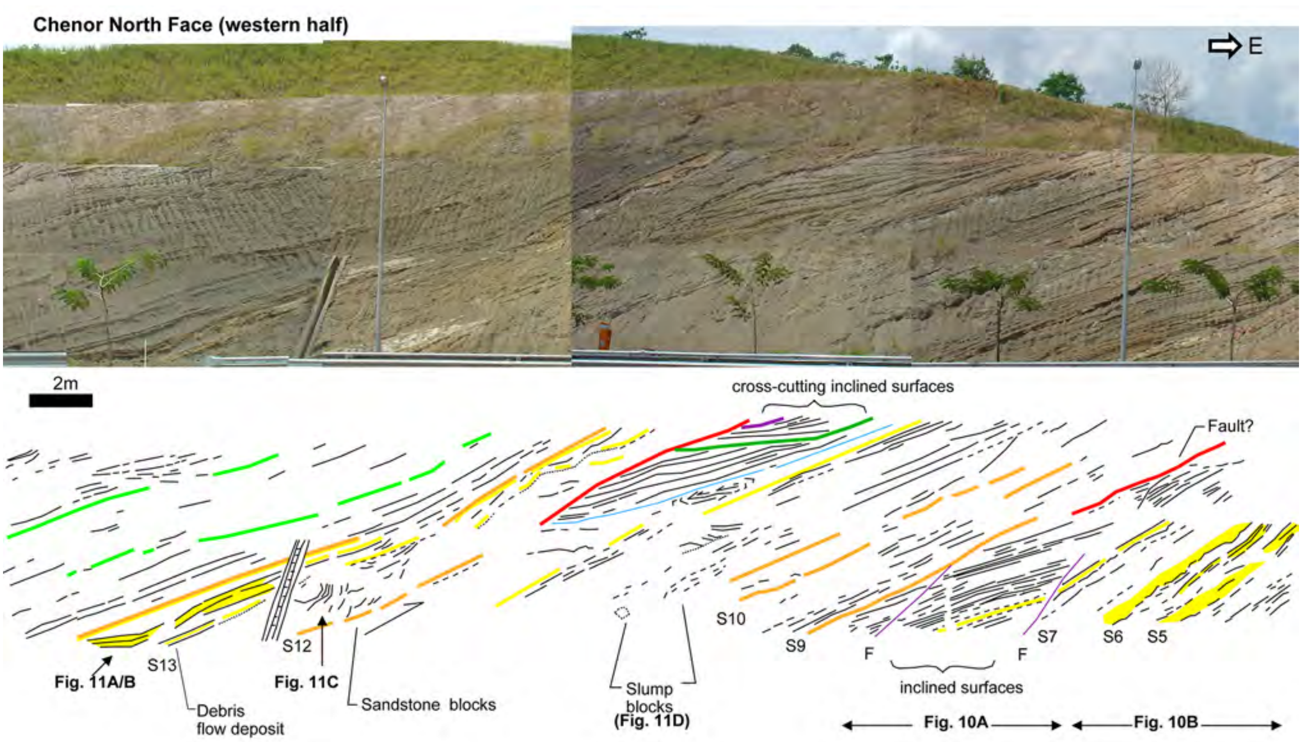

Figure 5: Eastern half of North Face, Chenor outcrop, showing numerous sedimentary and deformational features such as chaotic mud-rich debris flow deposits with floating sandstone blocks alternating with zones of regulary bedded turbidites, with common occurrence of cross-cutting inclined surfaces that indicate coalescing turbidite fan channels or lobes. Way up to the west/left. S5 to S13 refer to main sandstone marker beds indentified in Figure 7 for reference. The locations of photographs shown in Figs. 10 and 11 are also indicated.

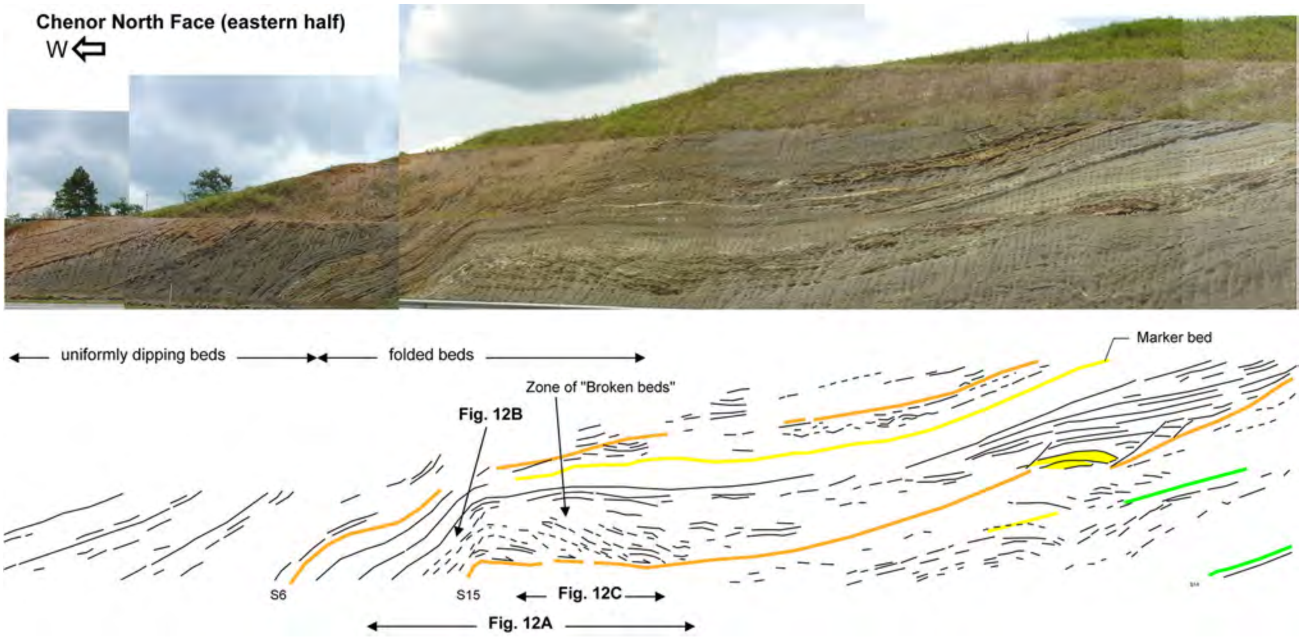

Figure 6: Western half of North Face, Chenor outcrop (viewed North), comprising mainly alternating muddy slump zones and well-bedded debrites and turbidites. Way up to the west/left. A distinctive feature is the sharp fold verging to the west, in contrast with the commonly tight folding and eastward vergence seen in outcrops of the Semantan Formation elsewhere along the highway. Within the core of the fold, there is a zone of "broken beds" which may have resulted from the deformation. Photographs in Figure 12 were taken at the locations shown. S6 and S15 refer to the marker beds in Figure 7.

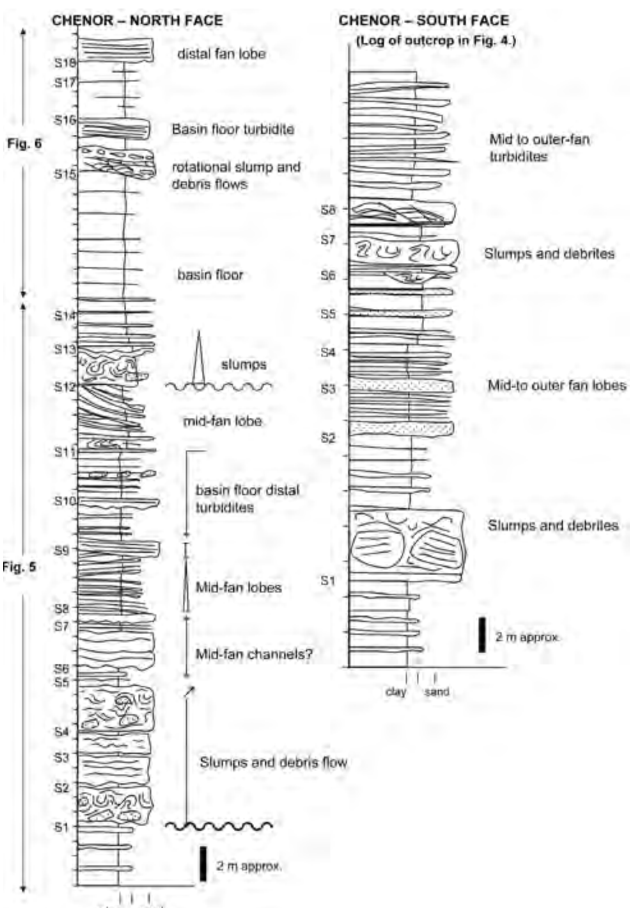

Figure 7: Schematic logs of Chenor Junction mass-transport deposits , south and north faces. S1 to S8 refer to major sandstone units used as reference in the field; some are marked in Figures 4, 5, and 6 for reference.

down-slope re-mobilisation under gravity. The surrounding shale is also highly deformed, and show flowage structure, indicating that it was unconsolidated during deformation.

The thick sandstone beds also show folding and thrusting associated with the deformation (Figure 9A). The thrust vergence is towards the east, which is counter to the overall vergence of the Semantan Formation. This strongly suggests that these structures are soft-sediment deformational structures, or slump folds.

Besides the folds and thrusts, there are also rotational slumps or glide surfaces associated with extensional deformation under gravity. These occur in the upper part of the succession (Figure 9B) in the predominantly muddy interval, where a couple of curved (listric) normal faults act as glide surfaces that accommodate the syndepositional extension of the strata. Rotation of the hangingwall strata towards the faults indicate synsedimentary deformation, also in an apparent westward direction, as in the thrust faults mentioned above.

North Face

Over 300 m of sand-shale succession occurs on the north side of the Chenor Junction outcrop, with more evidence of mass-transport processes. Photomosaics of the outcrop are shown in two parts, in Figs. 5 (eastern part) and 6 (western part). The succession comprises chaotic/slumped sandy deposits at the base, generally fining upward into interbedded heterolithic sand-mud facies displaying cross-cutting lateral accretion surfaces (Figure 10). This facies is interpreted as forming a major channel complex, fining upward into levee and overbank facies of a submarine fan environment. These are in turn overlain by very thinly

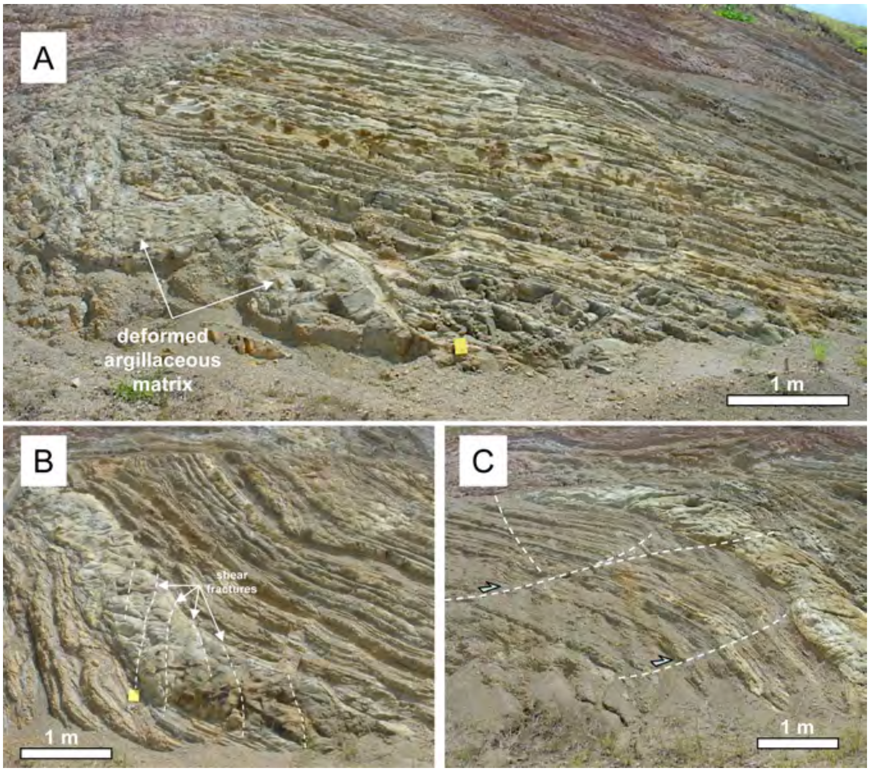

Figure 8: (A) Large sandstone block enclosed in argillaceous 'matrix'. The block is made up of alternating sand-shale that appears to be of different facies from the surrounding rocks, indicating its allochthonous origin. Evidence of extensional and compressional deformations in the Chenor mass-transport deposits. (B) Thick sandstone bed showing numerous shear fractures, as a result of extension due to slumping and sliding on the depositional slope. (C) Small-scale thrusts and reverse faults in mud-rich interval with thin beds of sandstone. Folding of the sandstone layer above the mud-rich interval appear to be related to these faults, and are probably of synsedimentary origin, i.e. when the sediment is still unconsolidated.

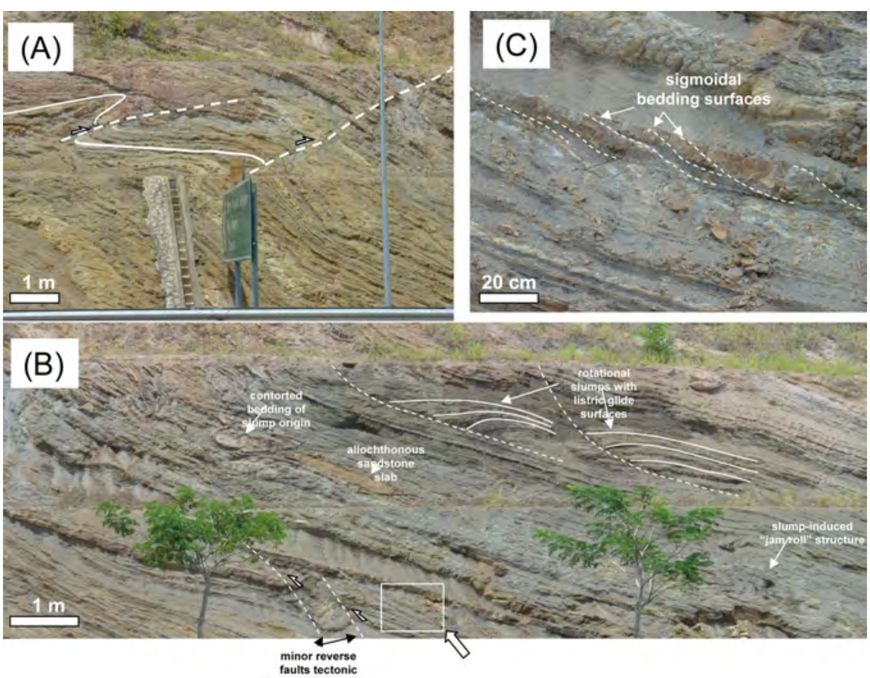

Figure 9: Gravitationally induced deformation in the Chenor mass-transport deposits include (A) tight folds with thrust surfaces (B) rotational glide planes due to slumps. Note the associated contorted bedding in the muddy intervals and minor faults. (C) sigmoidal bedding surfaces representing accretion of sedimentary packages. Location in inset marked by arrow in B.

bedded basin plain facies, dominated by mudstone with slump features and allochthonous sandstone blocks. The succession is repeated vertically several times, but with lesser occurrence of the coarse-grained facies, indicating progradation of the submarine fan system into the basin plain.

Stratigraphically, the North Face section lies above the sequences on the South Face. There is less sand in this section. It shows more of the alternating muddy slump zones and well-bedded debrites and turbidites. Features such as rotational slumps, floating sandstone blocks, and "broken beds" are also observed (Figures 11 and 12), indicating deposition in a gravitationally unstable slope condition.

In the lower part of the succession (to the east) there is thinly interbedded sandstone-mudstone showing complex internal bedding architecture, with numerous cross-cutting surfaces (Figure 10). These surfaces are discordant, inclined surfaces at low to moderate angles to the general bedding surfaces, and are truncated by subsequent packages of

Figure 10: (A) Well-stratified section of the Chenor MTD, showing cross-cutting inclined stratal surfaces, probably produced by lateral accretion of turbidity flow deposits at channel margins or overbank environments. Note minor fault cutting through the succession. (B) View of a major slump zone at eastern end of road-cut, showing chaotic and discontinuous bedding.

inclined strata. They probably represent macro-scale erosional scour-and-fill surfaces or resulted from several pulses of turbidity flows, whereby lateral accretion of migrating channel-levee complexes are associated with overbank spill of individual flow events.

Much of the lithology in the northern side of the Chenor Junction outcrop is of dark grey argillaceous beds with slump structures (Figure 11). Many features of slumping, such as chaotic beds, sandstone blocks and soft-sediment deformation, are common. Stratigraphically higher, in the upper (west) end of the North Face, there is a fold in the strata (Figure 6), which appears to be associated with a zone of "broken beds" and slump features (Figure 12). These include "broken" beds of heterolithic sandstone-mudstone interbeds in plastically-deformed muddy matrix, including large blocks or "megaclasts" of measuring several metres in size, and a variety of syn-sedimentary deformational features which include rotational slumps and glide planes, thrust faults and associated soft-sediment folds. This association of structures, including disharmonic folding, suggests that the folding could be due to syn-sedimentary deformation and not tectonically induced. The gentle folding and westward vergence are in contrast with the tight folding and eastward vergence seen in outcrops of the Semantan further to the west. The close association of extensional and compressional structures is indicative soft-sediment deformation.

DISCUSSION

The general depositional environment of the Semantan Formation was interpreted to be deep-marine based on previous work, which has been reviewed recently by Nuraiteng (2009). Hasnol *et al*. (2007) described the major facies types along the HIGHWAY, which represent from distal to proximal with respect to the sediment source area. Thin bedded facies and mudstone facies are generally indicative of distal turbiditic deposits at the lower (outer), distal part of the submarine fan system.

A schematic model of the depositional system is shown in Figure 13. Turbidite deposition was probably via a submarine fan system that received sediment through a delta-fed point source, supplied by alluvial systems draining a volcanic source area. Slumping of the actively deforming shelf-slope system triggered down-slope mass-transport processes, depositing high-density turbidity currents and debris flows. This resulted in close association of turbidites and debrites/MTDs. The MTDs interdigitate with the regular turbidites, while some extraneous "outrunner" blocks may be carried further out into the basin, to be incorporated into the surrounding distal turbidite and muddy basin plain sediments. This model assumes that the turbidites and slumps/debrites were produced by separate flows and separate sources (Figure 14), the former through river-fed canyons while the latter through submarine slope failures due to a triggering mechanism (e.g. earthquakes).

Alternatively, some of the debrites and turbidites could have been generated by the same flow. It is quite well-documented in many outcrop studies (e.g. Haughton *et al*., 2003) that linked turbidite-debrite occurrences are the result of flow transformation of a single event as the flow moves and interact with the substrate downslope. This explains the common occurrence of clast-rich debrites in the outer fan areas, where intuitively we would expect only thin-bedded turbidites to occur.

The different parts of a mass transport complex, having different structural characteristics and deformation styles, may be related to the process of the mass-transport itself. In general, submarine mass-wasting or landslide could be envisaged as a continuum of processes from brittle fracturing of the substrate (which results in translational sliding along a basal shear surface) to chaotic fragmentation of the sediment substrate through distributed strain. This continuum reflects increasing deformation in the direction of downslope translation, from 'proximal' or updip direction (nearer to the source of slide) to the more 'distal' or downdip direction, away from the source into the receiving basin floor. Bryn *et al*. (2005) illustrate this idea to explain the development of the Storegga Slide offshore Norway (Figure 15). Such a mechanism of generating MTD is also a triggering mechanism for debris flow and turbidity currents into deep water; the debris flow and turbidity currents represent the 'diluted' part of the entire sediment gravity flow system. Similarly, Bull *et al*. (2009) illustrated this by classifying MTDs into three main domains in the downslope direction:

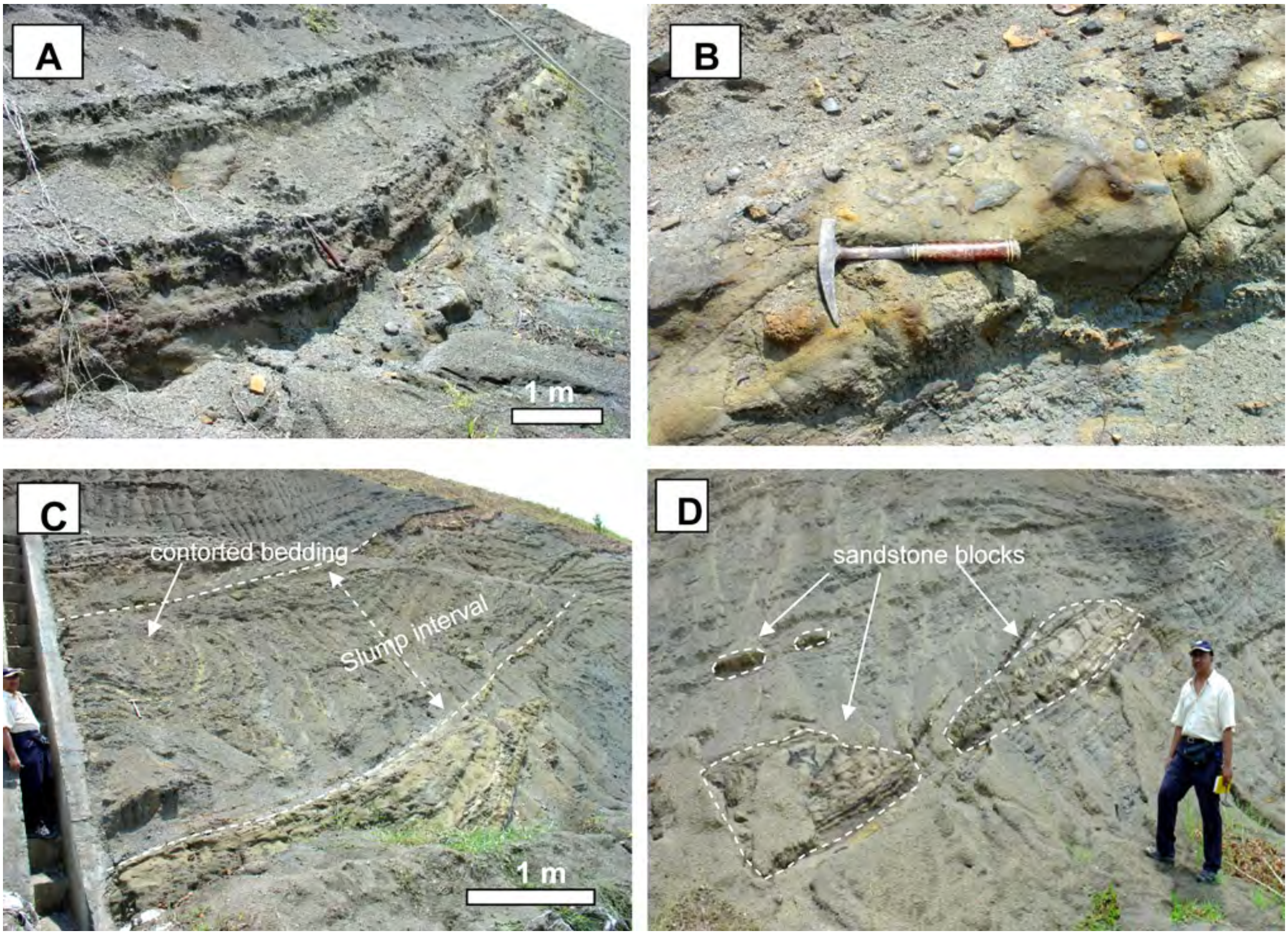

Figure 11: (A) Thin beds of debrite intercalated with argillaceous zones. (B) Debris flow deposit with characteristic floating shale clasts in sandy matrix. (C) Slump interval showing chaotic bedding and convoluted layering as the result of syn-sedimentary deformation. (D) Sandstone blocks in argillaceous matrix.

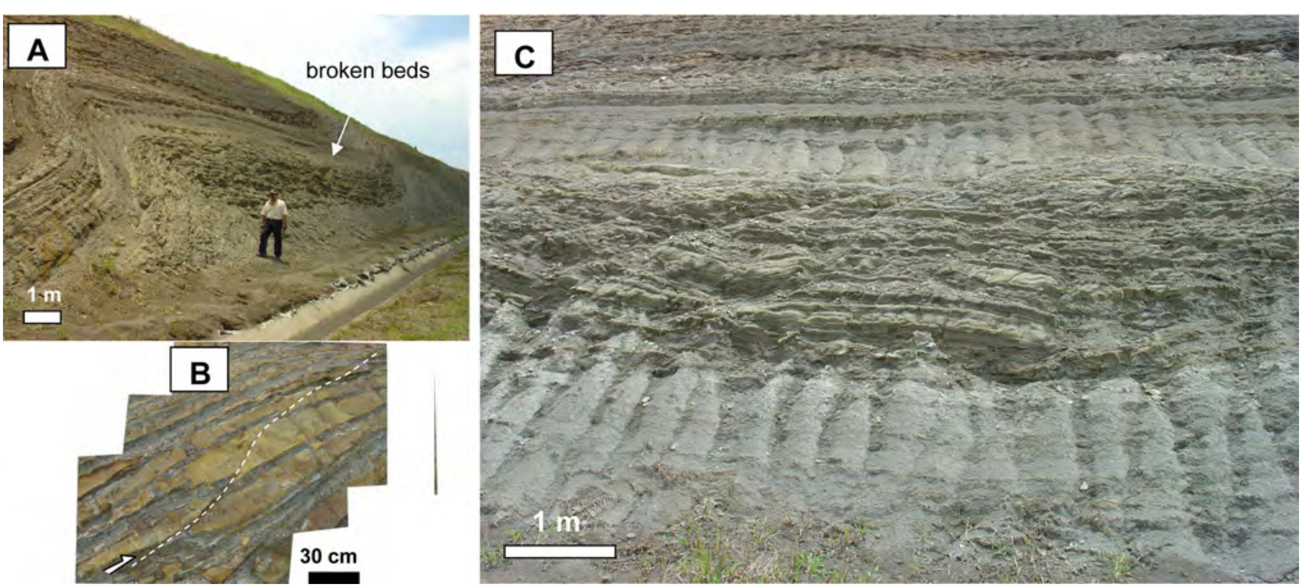

Figure 12: Evidence of synsedimentary and tectonic deformations (A) large fold verging to the west, with a layer of 'broken beds'. (B) Minor thrust fault in sand-shale interbeds at the western edge of fold shown A. (C) View of "broken beds" zone consisting of heterolithic sand-shale facies, now fragmented by numerous small-scale faults that are limited to the sandy interval.

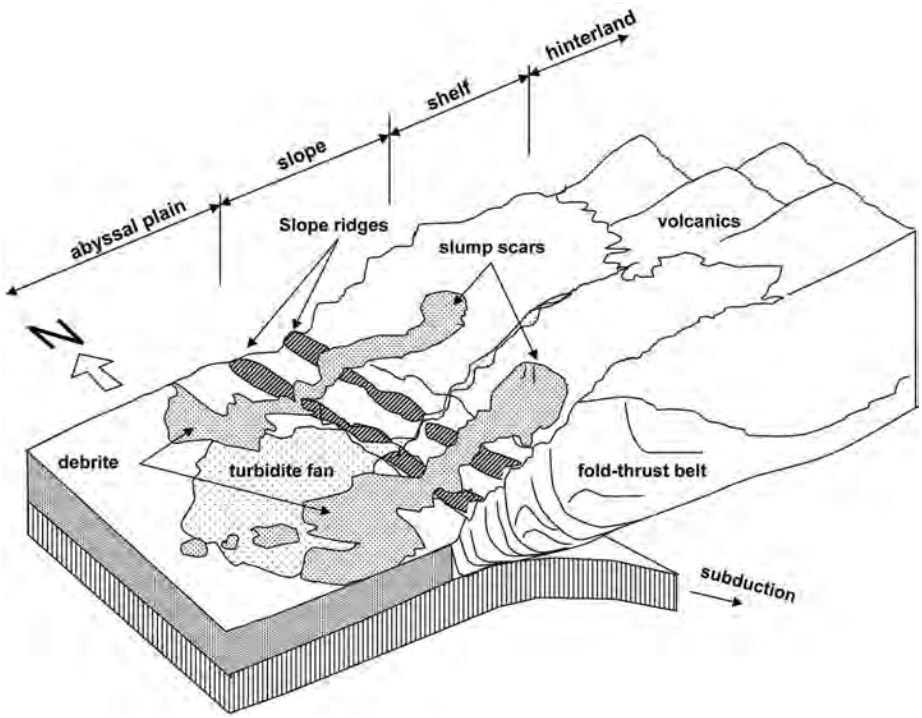

Figure 13: Schematic depositional model of turbidites and mass-transport deposits on the Triassic Andean-type margin during the deposition of the Semantan Formation. A west-facing foreland basin resulted from eastward-subduction of Paleo-Tethyan oceanic crust.

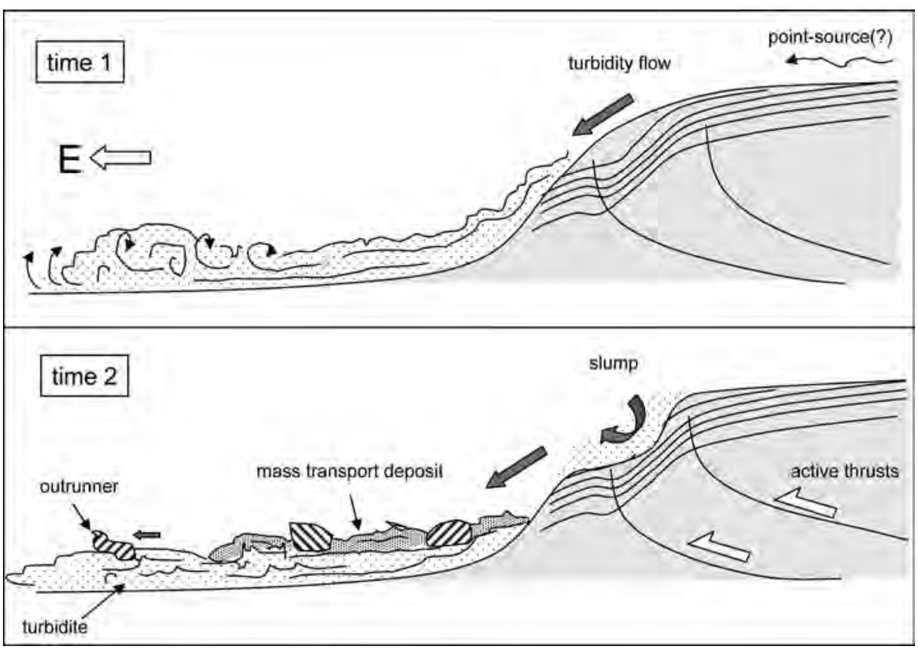

Figure 14: One possible explanation of the close association of turbidites and debrites in the mass-transport complex, such that observed in Chenor. Here, the turbidites and slumps are separate events, derived from different sources: turbidity currents are point-source generated (river or canyon-fed) whereas the slumps are triggered by slope failures (via fault activity, earthquakes, or oversteepened slopes).

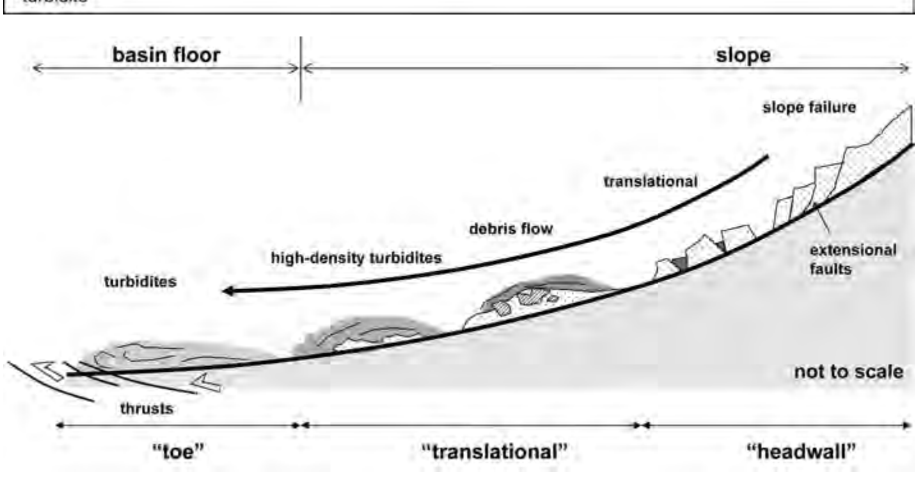

Figure 15: General process of turbidite and debrite emplacement through sediment gravity flow triggered by slope failure (modified after Bryn *et al*., 2005). Updip mass movement involves mainly extension and translation, passing gradually into debris flows. Turbidites are generated downslope as the flow becomes diluted. The downslope transition from headwall to toe domains follows the terminology of Bull *et al*. (2009). The toe domain is characterised by thrusts caused by the impingement of the decelerating flow on the substrate.

the headwall, the translational, and the toe domains. These domains may be identified by kinematic indicators. The headwall domain is dominated essentially by extensional/rotational slumps whereas the toe domain is dominated by basinward-verging compressional/thrust structures.

The Chenor Junction outcrop is interpreted as mass-transport deposits based on the occurrence of chaotic sandstone blocks and slump zones in an otherwise regularly bedded succession. In addition, there are many examples of disharmonic or incongruent deformation structures such as the extensional shear fractures, compressional thrust surfaces, and rotational/listric glide planes. In a gross sense, we can interpret the large sandstone blocks as the deposit of debris flow in the middle (translational) 'fan' or even basin-floor setting. The absence of extensional structures and the chaotic nature of the slump interval surrounding the blocks suggest that they were far-travelled, and deposited a long distance from the origin. In contrast, the interval with thrusts and reverse faults represent the compressional deformation in the toe domain, at the front of the flow, some distance away from the source. The intervening mud-rich slump zones with abundant transported clasts are interpreted as the main body of the flow, made up largely of muddy debrites formed of entrained clasts as well as intraformational material ripped-up from the substrate (see Figure 15).

CONCLUSION

Based on sedimentary facies and structures, most of the outcrops of the Semantan Formation in the Central Belt area of Peninsular Malaysia represent mostly the distal parts of a submarine fan or basin plain environment. Occasionally, as observed in the Chenor Junction outcrop, intervals of mud-rich slumps, debrites and turbidites form thick packages of MTD, which represent large-scale mass-wasting events in the Triassic active margin of East Malaya.

The sedimentary and structural features of the Chenor MTD are interpreted to represent different parts of the mass-transport complex, ranging from extensional headwall domain characterized by rotational listric gravitational faults to compressional low-angle thrust structures in the toe domain in the downdip or basin floor region. Such structures may be useful as kinematic and depositional indicators in deep-marine settings where outcrops are sparse, and when integrated with other field evidence, may provide additional clues to the depositional history of complex, deformed basins.

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