

Deep-marine sedimentary facies in the Belaga Formation (Cretaceous-Eocene), Sarawak: Observations from new outcrops in the Sibü and Tatau areas

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Abstract: Deep-marine rocks of the Belaga Formation (Cretaceous-Eocene) in the Sibü-Tatau area, Sarawak, show a variety of facies types, which are characterized by grain fabric, bed thickness, and sedimentary structures. The main facies types are (A) thick-bedded sandstone, (B) thinly-bedded heterolithic sandstone-mudstone interbeds, and (C) mudstone facies. These facies may be interpreted in relation to a submarine fan model, in which facies A represents a proximal position (near to source area) while facies B and C represent deposition in the middle to distal parts of the system, respectively. Within this general fan model, a detailed characterization of the facies can be made to understand the depositional processes operating in the deep-marine environment. Facies A, for instance, comprises massive and graded sand beds that appear to be linked genetically; the massive bed, often with floating mudclasts at the top, probably represent a debris flow deposit laid down over a pre-cursor turbidity flow deposit, which is commonly preserved as a thin graded bed at the base of the sandbody. Such linked debrite-turbidite facies association seems to be a common feature in the Belaga Formation, similar to many other deep-marine depositional systems, including the West Crocker in Sabah.

INTRODUCTION

Flysch sediments dated as Upper Cretaceous to Upper Eocene, assigned to the Rajang Group, form a major fold-and-thrust belt that stretches along the northwestern and central parts of Sarawak and into Sabah, and commonly referred to as the “Rajang Fold-Thrust Belt” (Madon, 1999). The geology of the area between the Sibü and Tatau districts is characterized by the Belaga Formation, which forms the greater part of Rajang Group. The availability of relatively recent exposures of the Belaga Formation in this area has enabled a closer examination of its sedimentological aspects.

This study is aimed at improving the understanding of deep-marine sedimentation, and in particular, the Belaga Formation. Several outcrops of the Belaga around Sibü and Tatau were examined in order to characterize the main features of the deep-marine sediments deposited in the extinct proto-South China Sea ocean basin, which separated the geological provinces of Central Luconia and West Sarawak during Late Cretaceous to Eocene times. The sedimentary characteristics and facies associations are described from outcrop study to interpret the depositional processes within the framework of a deep-marine depositional system. This study was undertaken during two field outings in January and February 2007. The area of study and location of outcrops studied are shown in Figure 1.

REGIONAL SETTING

The Rajang Group, to which the Belaga Formation belongs, represents an uplifted accretionary wedge complex

formed by the subduction of an oceanic lithosphere beneath Borneo, from Late Cretaceous to late Eocene times. The existence of a flysch fold-and-thrust belt in Sarawak and Sabah indicates a major ocean seaway (“proto-South China Sea” or Rajang Sea), what Dickinson (1974) called a “remnant ocean basin”. This ocean seaway was consumed in a diachronous fashion, the deformation younging from west to east (Madon *et al.*, 2007). The deposition of the Rajang Group in relation to the evolution of the Sarawak Basin is illustrated in Figure 2. Deep-sea fans are supplied by the recycled sediments of the uplifted flysch and transported parallel to the trough axis, as indicated by paleocurrent directions of the Crocker Formation (Hutchison, 2005).

THE BELAGA FORMATION IN SIBÜ-TATAU AREA

The Rajang accretionary wedge comprises highly deformed strata often with steeply dipping beds. The Belaga Formation, is one of the better known formations of the Rajang Group, which crop out in the central to southwest Sarawak between Tatau and Sibü. The Belaga Formation ranges in age from Late Cretaceous to Late Eocene (Wolfenden, 1960), and occupies a large part of central and northern Sarawak. Estimates of its total thickness are between 4.5 and 7.5 km (Hutchison, 2005). The formation was first mapped by Kirk (1957) and Wolfenden (1960), and was subdivided into five members based on palaeontology. These units are (in ascending order) Layar, Kapit, Pelagus, Metah and Bawang, younging northwards away from the Lupar Line (Liechti *et al.*,

1960), which is thought to be the ophiolitic suture zone marking the site of the former Rajang or proto-South China Sea (e.g. Hutchison, 1996). A chronostratigraphic table showing the subdivision of the Belaga Formation in Central Sarawak is shown in Figure 3 (after Hutchison, 2005). A large part of this formation has undergone mild to moderate regional metamorphism, which produced slaty and phyllitic characters of the rocks. Much of the formation is intensely folded, faulted and sheared, resulting in the steeply dipping to subvertical bedding, and even overturned beds.

The maps of Wolfenden (1960), Haile and Ho (1991) and Tongkul (1997) showed the Sibü and Tatau areas underlain by the younger members: Pelagus, Metah and Bawang, of Early-Late Eocene age. A simplified geological map (Figure 4) shows the distribution of these members of the Belaga Formation. The Pelagus Member (Lower to Middle Eocene) characterises the Sibü area, extending some 30 to 40 km NNE. along the Sibü-Bintulu road. The Metah Member (Middle to Upper Eocene) occurs as a belt to the north and is conformable with the Pelagus (Haile and Ho, 1991). The youngest unit, the Bawang Member (Late Eocene), occurs extensively in the Sg Arip area and along the Tatau Horst area. Good exposures of this member occur near the Tatau town. At Bukit Rangsi, the exposed contact between the steeply dipping Bawang Member of the Belaga Formation and the overlying basal conglomerates of the Tatau Formation is a spectacular angular unconformity, which marks the northern limit of exposure of the Belaga Formation in the study area.

Lithologically, the Belaga consists of steeply dipping strata of thin- to thick-bedded, fine- to medium-grained sandstone and meta-sandstone or greywacke, interbedded with argillaceous rock. The sandstones are off-white to grey in colour, may be graded or massive, and are moderately to poorly sorted. The muddy and feldspathic sandstones, termed greywacke or sub-greywacke, contain high amounts of clay matrix and labile rock fragments (Haile and Ho, 1991). The shale and mudstone are hard and splintery, and commonly occur as thin intercalations with the fine-grained sandstone or siltstone. Fresh samples display colours ranging from grey to dark grey (for carbonaceous shale), and some shales are reddish to purplish. In general, the Pelagus and Metah Member are lithologically similar; they are predominantly thinly interbedded argillite and fine-grained sandstone. Intercalation of thicker sandstone beds (>0.2 m) in the thinly bedded units occur in both members but are less common in the Metah compared to the Pelagus. In contrast, the Bawang member is characterised by a thick succession of amalgamated or stacked sandstone beds separated by thinner argillaceous units.

Bioturbation is sparse, but vertical and horizontal burrows can be identified in some beds, especially in the Pelagus and Metah members. Sedimentary structures, such as groove and scour marks, load moulds, and water-escape structures, are common in the mudstone and sandstone

interbeds. Deformation features are apparently more common in the older parts of the Belaga Formation near Sibü (Pelagus Member) compared to those to the north towards Tatau (Metah and Bawang Member).

FACIES DESCRIPTION

Based on lithology, bedding characteristics, and sedimentary structures, the Belaga Formation facies observed in the studied outcrops may be classified into 3 main types. The facies are described below.

Facies A – Thick bedded sandstone

This grey-coloured sandstone facies seems to dominate a large part of Belaga Formation outcrops in the study area. The facies has somewhat muddy appearance, have moderate to poor sorting, and ranges from medium to fine grained. Individual bed thickness ranges from 20 to 200 cm. The beds are either amalgamated or separated by thin shale or mudstone layer (Figure 5A). Each bed generally has a uniform thickness laterally, and therefore appears sheet-like. Its basal contacts are commonly sharp, and with scours into underlying units (Figure 5B). Most beds are massive and but some show graded bedding. A distinctive character of this facies is the presence of “floating” or rafted, angular mud clasts or breccia in sandy matrix, often becoming more abundant towards the top of the beds, as shown in Figure 5C. In some beds, sand granules occur near the base of the bed or in the basal scour surface.

Stacked or amalgamated sandstone beds as well as intercalations with mudstone facies are common. In many instances, thick massive sandstone overlies a thinner graded bed with a sharp erosional base (Figure 6), and are particularly common in the outcrops at Tatau (example: Tatau telecom hill). Load structure and mud injection structure (Figure 7), due to loading of top sediment can be easily identified at base of sand. Scour and tool marks, such as flute and groove cast, are common indicating current movement. (Figures 8 and 9). Burrows are also observed in this facies; the mainly recognizable one is the *Ophiomorpha*-type burrow (Figures 10 and 11).

Interpretation: Facies A has the characteristic attributes of sediments deposited by mass flow or debris flow process. According to Shanmugam (2006), debris flow is a sediment gravity-flow with plastic rheology and laminar state; from which deposition occurs through freezing *en masse*. The presence of flow structure seen in the sandstone’s matrix also indicating a deposition by viscous or plastic flow (Figure 12). A distinctive feature of the debris flow deposit, as observed in Facies A, is the occurrence of mudstone clasts, often in the middle or near the top of beds, which produces an apparent “inverse grading” to the sand bed (Figure 5C). The uniform thickness and apparent lateral continuity of the beds indicates deposition on a gentle slope or smooth basin topography. The term “debrite” has been used for debris flow deposit of this kind (Pluenneke

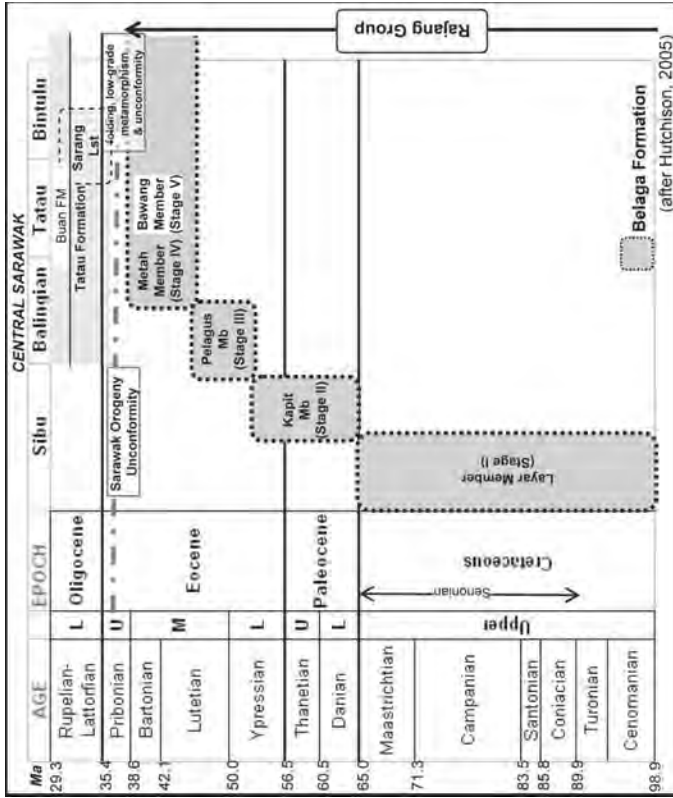


Figure 3: Chronostratigraphic table showing sub-division of Belaga Formation in Central Sarawak (after Hutchison, 2005)

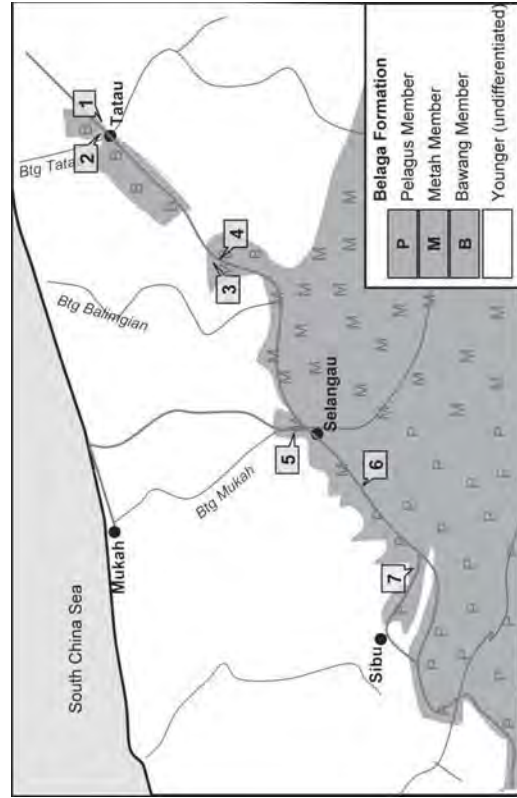


Figure 4: Distribution of Belaga Formation exposure within the Tatau-Sibu area (Modified based on geological maps by Wolfenden (1960), Haile and Ho (1991) and Tongkul (1996). Location of outcrops studied is also shown in the map. Outcrop location: 1-Tatau Pine housing area 2-Tatau telecom hill 3- Km 74.3 Bintulu-Sibu road 4- Km 76.5 Bintulu-Sibu road 5- Km 2.5 Selangau-Mukah road 6. Km 131.5 Bintulu-Sibu Road 7- Sibu Airport road.

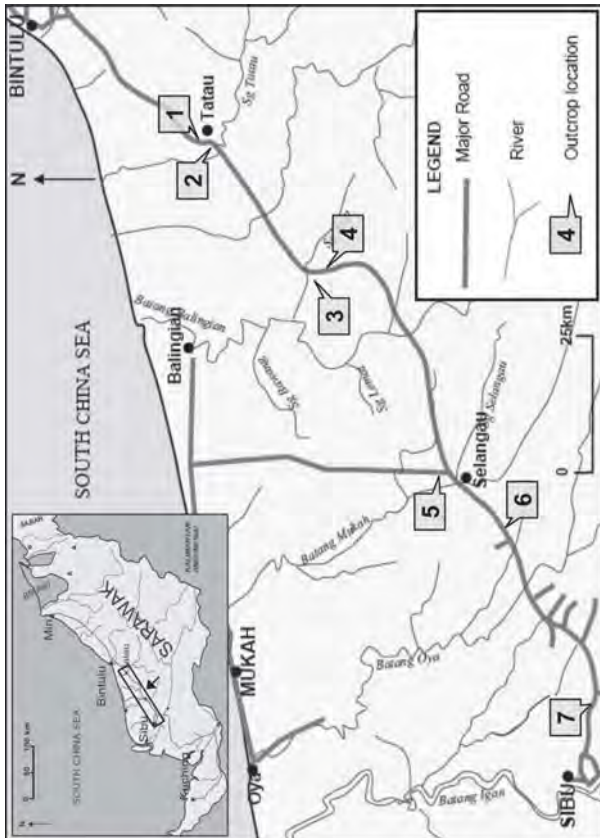


Figure 1: Location map showing the area of study and location of outcrops studied. Outcrop location: 1-Tatau Pine housing area 2-Tatau telecom hill 3- Km 74.3 Bintulu-Sibu road 4- Km 76.5 Bintulu-Sibu road 5- Km 2.5 Selangau-Mukah road 6. Km 131.5 Bintulu-Sibu Road 7- Sibu Airport road.

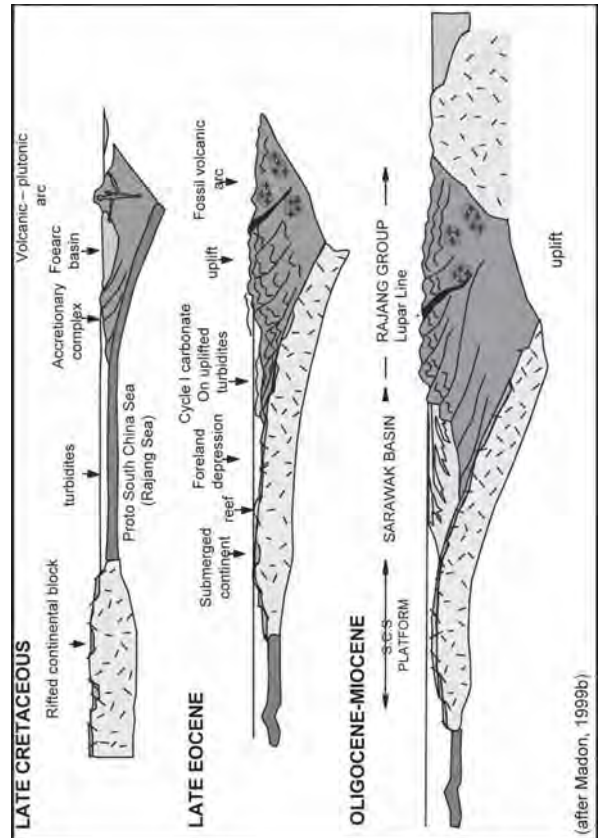


Figure 2: Illustration depicting the formation of the accretionary wedge complex, represented by the Rajang Group, formed by the subduction of an oceanic lithosphere (proto-South China Sea/Rajang Sea) beneath Borneo. (after Madon, 1999b)

(1976) and Stow (1984), in Shanmugam, (2006)). While debris flows may be a dominant process, the graded bedding at the base of many sandstone beds indicates deposition primarily by turbidity currents. The close association of debrite and turbidite suggests a possible genetic association between the two types of deposits, and they are referred to as “linked debrite” (Haughton *et al.*, 2003). These linked debrites appear to be more common in the Pelagus and Bawang members, although the latter have greater overall composite thickness.

Facies B – Heterolithic sandstone-mudstone

Facies B comprises of thinly and rhythmically interbedded, fine- to very fine-grained or silty sandstone and mudstone, hence termed “heterolithic”. The sand is off-white or yellowish, while the mudstone is purplish grey or dark grey in color, and often carbonaceous. The sandstone and shale beds are fairly uniform in thickness, laterally and vertically, ranging from less than 1 cm-thick laminites to 20 cm-thick beds. Sandstone beds are generally well-bedded, tabular or sheet-like, and some with ripple or wavy appearance as shown in Figures 13A and 13B. The outcrop in Figure 6A may be regarded as the type outcrop for this facies, located at the km 3.0 Selangau-Mukah road. Sand-mud alternation is laterally continuous and fairly thick in vertical section. Sand beds have straight or undulatory but sharp basal contacts, and show normal grading, fining upward into cross or climbing ripple laminated sandstone (Figures 13B and 14). Sedimentary structure such as load structures is commonly found at the base of sand layers in the heterolithic interbeds (Figure 15).

No general vertical trends are apparent, although a clear thinning and fining/claying upward trend can be recognized in some cycles. Vertical and horizontal burrows are common but restricted to the thin sandstone beds within the muddy intervals (Figures 16 and 17).

Interpretation: Facies B shows features that are typical of basin-floor or “distal” turbidites: thin beds, parallel lamination and climbing ripple lamination, suggestive of Bouma Tc-Td (Figure 14) divisions resulting from waning turbidity currents, and Te division mudstone formed by settling of finer sediment during final waning-flow stage. The facies has sheet-like geometry with thin mud interbeds, characteristic of submarine fan lobes (e.g. Mutti *et al.*, 2002). Although this facies is a common in all units of the Belaga Formation, thick successions are seen only in the Pelagus and Metah members.

Facies C – Mudstone

Facies C is a mudstone facies consists of dark grey carbonaceous shale with, in places, some bands of red-coloured shale. There are also mm-thick laminations of very fine-grained or silty sand in this facies (Figure 18A). An extensive outcrop of Facies C, located at km 74.3 Bintulu-Sibu road, is shown in Figure 18B. The sand laminae are normally graded and have gradational contacts

with mudstone at the top. A variety of sedimentary structures can be recognized in this facies, such as graded laminae, convolute lamination, current ripple cross-lamination, and soft sediment deformation (Figure 18C). Horizontal burrows are common in the shale beds.

Interpretation: This facies is observed in the Metah and Pelagus members, although the red-coloured shale is found exclusively in the Metah Member. Mudstone facies suggests deposition predominantly from suspension in quiet, low-energy environments. In the deep-marine setting, mudstone represents abyssal plains where hemipelagic/pelagic sediments are laid down. Occasional input of fine silt into the basin results in the silty laminae observed in this facies. The differences in colour may be due to compositional variation in the mudrocks, enhanced by superficial weathering.

BELAGA FACIES IN RELATION TO FAN MODELS

The different facies types in the Belaga Formation described above may be interpreted in the relation to general submarine fan models (e.g. Mutti *et al.*, 2002). Generally, the facies may be placed in the approximate location within a hypothetical submarine fan, from proximal (i.e. nearer to the source area or shelf) to distal (i.e. towards the basin). Facies A represents a proximal facies while Facies B represents a more distal facies. Facies C represents the most distal part of the system, probably on the outer reaches of the submarine fan and even into the basin plain.

The interbedding of Facies A and B, observed in the outcrops of the Bawang Member in Tatau (Figs 19 and 20) and of the Pelagus Member in Sibu (Figures 21, 22 and 23A), appear to be a common feature, which indicates deposition in submarine fan lobes in which the flows are non-channelised, resulting in sheet-like sandbodies. Channelised sandbodies were not encountered in the outcrops studied, but their occurrence would indicate a more proximal, upper fan environment. Thus, the outcrops studied so far are from the middle to outer fan environments.

The sedimentary characteristics of the Belaga sandstones of Facies A indicate deposition both by turbidity currents and debris flows (of high-density turbidity currents). These two main sediment-gravity flow processes in deep-marine environments have one fundamental difference: turbidity currents are low-density flows in which sediment is in turbulent suspension, forming “turbidites”, whereas debris flows are high-density viscous flows in which the sediment and water mixture move downslope in a coherent mass and give rise to “debrites” (e.g. Middleton and Hampton, (1976), in Reineck and Singh, 1980). In the sand-rich outcrops of the Bawang Member studied near Tatau town, debrites appear to be more common than turbidites. The close association of debrites and turbidites in the Belaga Formation is a possible

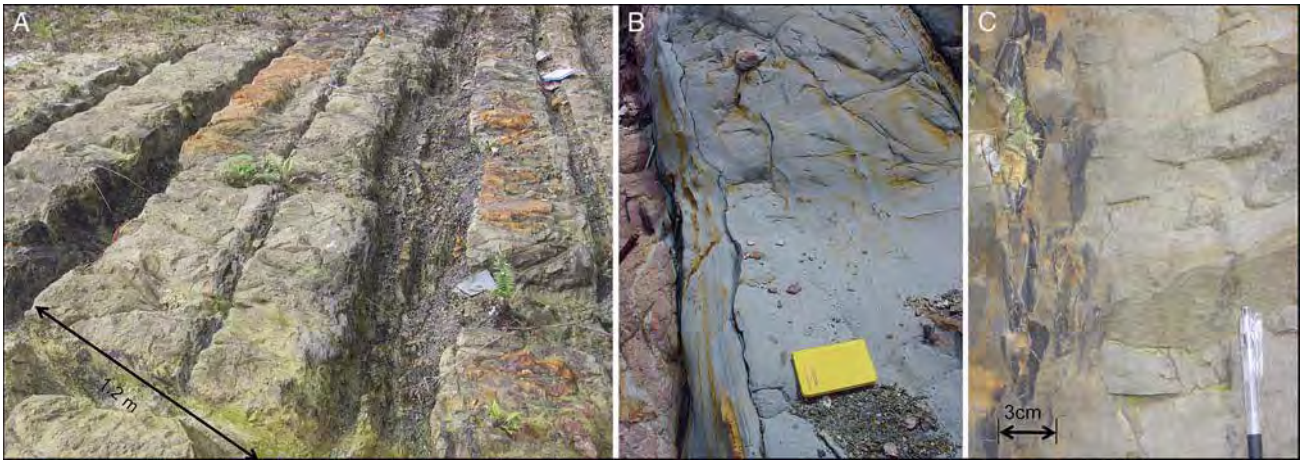


Figure 5: A- Facies A sandstone beds with mudstone intercalations. (Bawang Member, Middle submarine fan. Location: Tatau Pine housing area). B- Basal scouring contact of Facie A thick sandstone bed over thinner bed. (Pelagus Member, Outer submarine fan. Location: km 131.5 Bintulu-Sibu road) C- Floating mud clasts at top of sandstone bed of Facies A. (Bawang Member, Middle submarine fan. Location: Tatau Pine housing area)



Figure 6: Thinner graded bed overlying massive sandstone with a sharp erosional base indicates different type of depositional processes i.e. by turbidity current and debris flow. (Facies A, Bawang Member, Middle submarine fan. Location: Tatau telecom hill)



Figure 7: Well-developed flame structure originated from thin shale bed underlying the sandstone, indicating of unequal loading and liquefaction effect. The pen use as scale is 13 cm long (Facies A, Bawang Member, Middle submarine fan. Location: Tatau telecom hill)



Figure 8: Small, discontinuous flute mark on the lower surface of sand bed indicating scouring of sediments by down-current. The pen used as scale is 13 cm long (Facies A, Pelagus Member, Outer submarine fan. Location: Sibu Airport road)



Figure 9: Sole marking preserved as groove mark on the underside of sandstone beds indicating movement of object by current along soft surface of sediments. (Facies A, Pelagus Member, Middle to outer submarine fan, Location: km 76.5 Bintulu-Sibu road)



Figure 10: Finer grained sandstone (with *Ophiomorpha*-type burrow), overlain by the graded, coarser sandstone at the top with scouring basal contact. The pen is 13 cm long (Facies A, Pelagus Member, Outer submarine fan. Location: km 131.5 Bintulu-Sibu road)



Figure 11: *Ophiomorpha* burrow in medium-grained sandstone. The burrow is sub-parallel to the bedding. The pen is 13 cm long. (Facies B, Pelagus Member, Outer submarine fan. Location km 131.5 Bintulu-Sibu road)



Figure 12: Flow structure cause by the random fabric of debris flow sandstone matrix suggesting deposition by viscous flow (Facies A, Bawang Member, Middle submarine fan. Location: Tatau telecom hill)

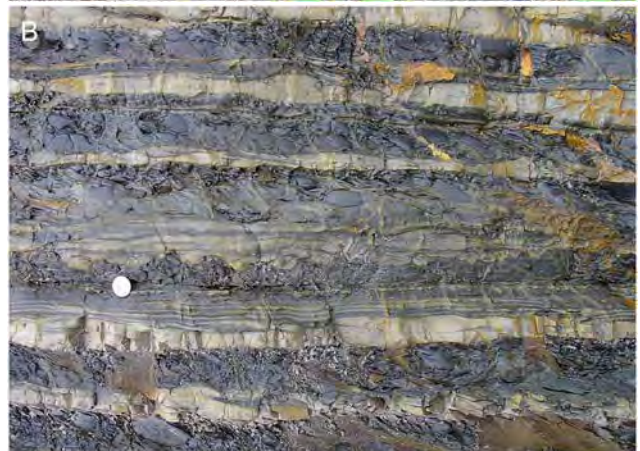


Figure 13: A- Outcrop displaying rhythmic interbedding of thin heterolithic of Facies B in Mukah-Selangau road cut. The geologist in the picture is approximately 1.7 m tall. (Metah Member, Outer submarine fan) B- Wavy beds with internal structures such as climbing ripples and parallel lamination of Facies B heterolithic. Coin diameter is about 2cm. (Pelagus Member, Outer submarine fan. Location: Sibu Airport road)

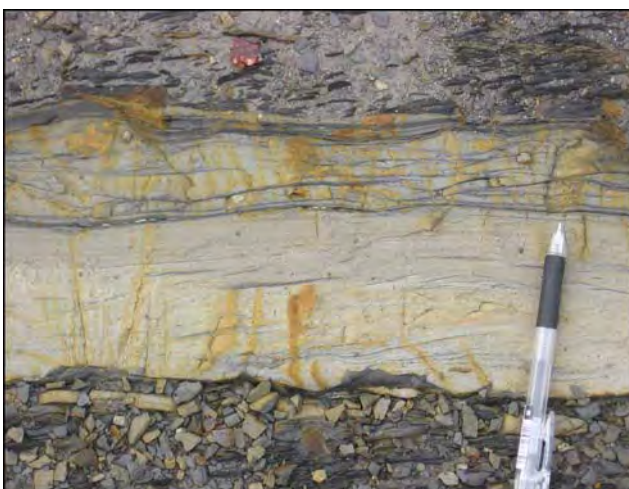


Figure 14: Turbidite sandstone with cross and climbing ripple and parallel lamination, displaying Tc-Td division of Bouma. The pen is 13 cm long. (Facies B, Pelagus Member, Outer submarine fan. Location: Sibu Airport road)

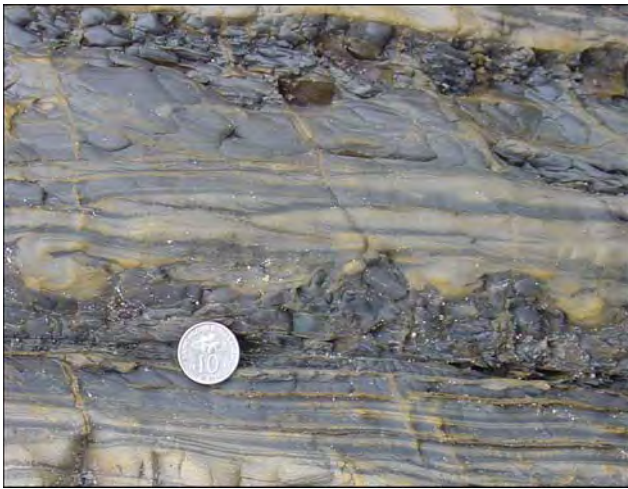


Figure 15: Irregular load structures on the lower-side of a sand layer overlying a mud layer resulted from loading of the heavier sand grain layer on mudstone bed. Coin diameter is about 1.5 cm. (Facies B, Pelagus Member, Outer submarine fan. Location: Sibü Airport road)



Figure 16: A vertical burrow in thinly bedded heterolithics. Coin diameter is about 1.5 cm (Facies B, Pelagus Member, Outer submarine fan. Location: km 131.5 Bintulu-Sibu road)

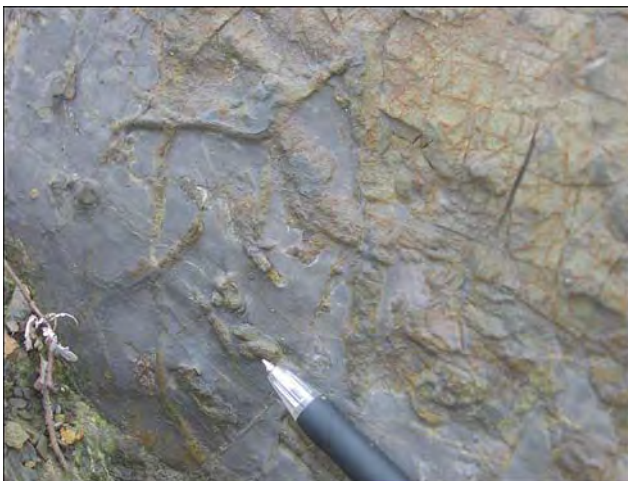


Figure 17: Horizontal burrows in mudstone bed. Tip of the pen in the picture is 4 cm in length. (Facies B, Pelagus Member, Outer submarine fan, Location: km 131.5 Bintulu-Sibu road)



Figure 18: A- Facies C mudstone with thin, parallel sand laminites. Coin diameter is about 2 cm. (Metah Member, Basinal plain. Location: km 74.3 Bintulu-Sibu road) B- Outcrop of carbonaceous dark grey and reddish mudstone succession of Facies C. The geologist is approximately 1.75 m tall (Metah Member, Basinal plain? Location: km 74.3 Bintulu-Sibu road) C- Convolute laminae of fine sand in mudstone matrix probably resulted from liquefaction and sediment loading (Facies C, Metah Member, Basinal plain, Location: km 3.0 Selangau-Mukah Road)



Figure 19: Outcrop at Tatau telecom hill showing thick uniform steeply-dipping strata of massive sandstone and heterolithic (Facies A-B) interbeds. (Bawang Member, Middle submarine fan)



Figure 20: Outcrop at Pine Tatau housing area showing lower section of an overturned beds of thick stacking sandstones (Facies A) and thin heterolithics (Facies B) in between. Beds younging direction is from top to bottom of the picture. The geologist is approximately 1.75 m tall. (Bawang Member, Middle submarine fan)



Figure 21: Outcrop at km 131.5 Bintulu-Sibu road showing heterolithic-dominated succession with thick sandstone beds in between. Beds younging direction is from bottom-left to top-right of the picture. The geologist is approximately 1.7 m tall. (Pelagus Member, Outer submarine fan).



Figure 22: A small isolated outcrop at Sibu Airport road showing an almost 2 m thick amalgamated sandstone intercalated within dark heterolithic units. Beds younging direction is from left to right of the picture. The geologist is approximately 1.7 m tall (Pelagus Member, Outer submarine fan)



Figure 23: A- Main outcrop at Sibu Airport road with about 40 m continuous section of turbidite heterolithic-dominated succession with occasional thick sandstone beds (0.5 to 1 m) in between. Beds younging direction is from left to right of the picture. (Pelagus Member, Outer submarine fan) B- A section from the main Sibu Airport road outcrop of intensely deformed strata showing tight and ptygmatic folds. (Pelagus Member, Outer submarine fan)

example of a linked debrite, in which viscous debris flows carrying mud clasts are emplaced soon after a pre-cursor, genetically related turbidity current has deposited a turbidite bed, and explains the common occurrence of irregular scour surfaces between the massive mudclast-rich sandstone and the underlying graded sandstone. The implication of linked debrites is that thick massive sandstone beds may be found farther downslope than was previously envisaged, as the debris flow achieves significant mobility by riding on the turbidity current beneath. "Linked debrites" have important implications for petroleum reservoir distribution in a deep-marine environment.

The Bawang Member outcrops, both at the Tatau telecom hill and Pine Tatau housing area (Figures 19 and 20), show general coarsening- and thickening-upward cycles suggestive of sediment progradation, probably in the middle to outer fan transition or the outer fringes of a depositional lobe. The Sibul outcrops of the Pelagus Member, for example at km 131.5 Bintulu-Sibu road and Sibul Airport road (Figures 21, 22 and 23A), show a similar facies relationship (interbedding of Facies A and B), and represent a more distal position in the fan system, although the actual stratigraphic relationships between these two areas are not known. Sedimentological logs for these outcrops are shown in Figures 24 and 25. The Metah Member outcrop at the km 74.3 Bintulu-Sibu road (Figure 18B), which typifies Facies C, represents the most distal part of the system, probably on the outer reaches of the submarine fan and even into the basinal plain.

Based on these observations, it can be inferred that the depositional environment of the Belaga Formation in the Tatau-Sibul areas ranges from middle fan (Bawang Member, and probably Pelagus Member), through outer fan (Pelagus and Metah members) and to basinal plain (Metah Member). A deep-marine depositional facies model for the Belaga Formation in the study area is shown in Figure 26, using Mutti and Ricci Lucchi's submarine fan model (Mutti *et al.*, 2002).

CONCLUSIONS

A study of the Belaga Formation in the Tatau and Sibul areas indicates variation in facies types, from sandy through heterolithic to muddy facies. These general facies types may be placed within the context of a submarine fan system, from proximal to distal, relative to the sediment source area. The different members of the Belaga Formation may also be differentiated by the dominant facies type occurring in the study area. Although the stratigraphic relationship between outcrops are difficult to ascertain due to poor exposure, detailed sedimentological studies of some of the better-exposed succession can give useful insights into the sedimentological processes operating in the deep-marine environment of the Cretaceous-Eocene Rajang Sea oceanic seaway. The Belaga facies show a close association of debris flow and

turbidity flow deposits within a vertical succession, a phenomenon that have been described from other deep-marine systems in the northern North Sea Jurassic, the Permian Tanqua Fan in the Karoo, South Africa, and in the Miocene Marnoso Arenacea Formation, Italy (Haughton *et al.*, 2003; Amy and Talling, 2006; Hodgson *et al.*, 2006). Similar sandbody types and facies associations were also observed in the West Crocker Formation of NW Sabah, which is also the subject of on-going research (e.g. Abdullah Adli *et al.*, 2007; Madon *et al.*, 2006; Nizam *et al.*, 2006). Further detailed work on the Belaga Formation is being carried out to characterise the facies and sandbody types for a better understanding of the Rajang deep-marine depositional system.

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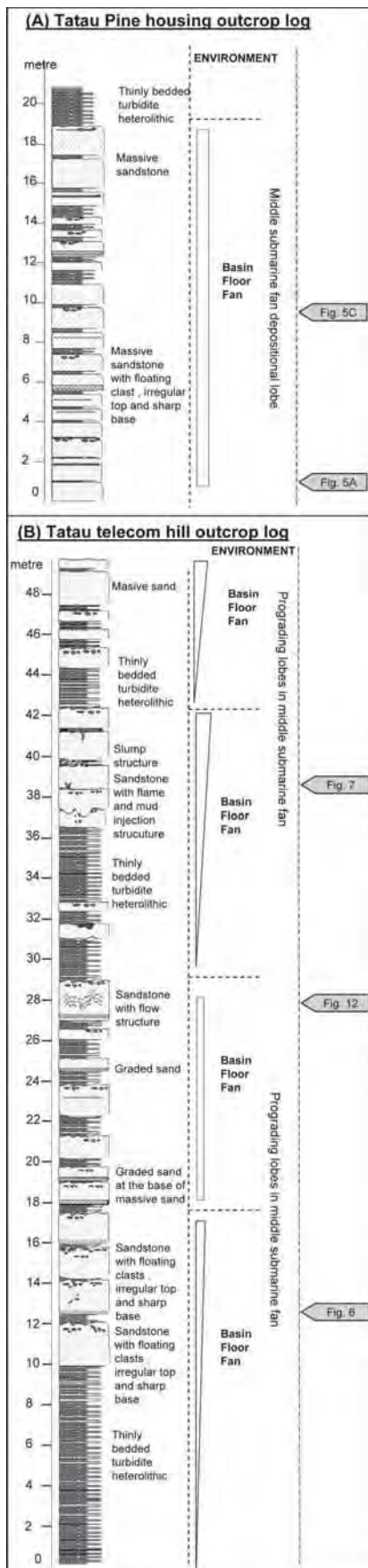


Figure 24: Sedimentological logs of outcrop at (A) Tatau telecom hill, and (B) Tatau Pine housing.

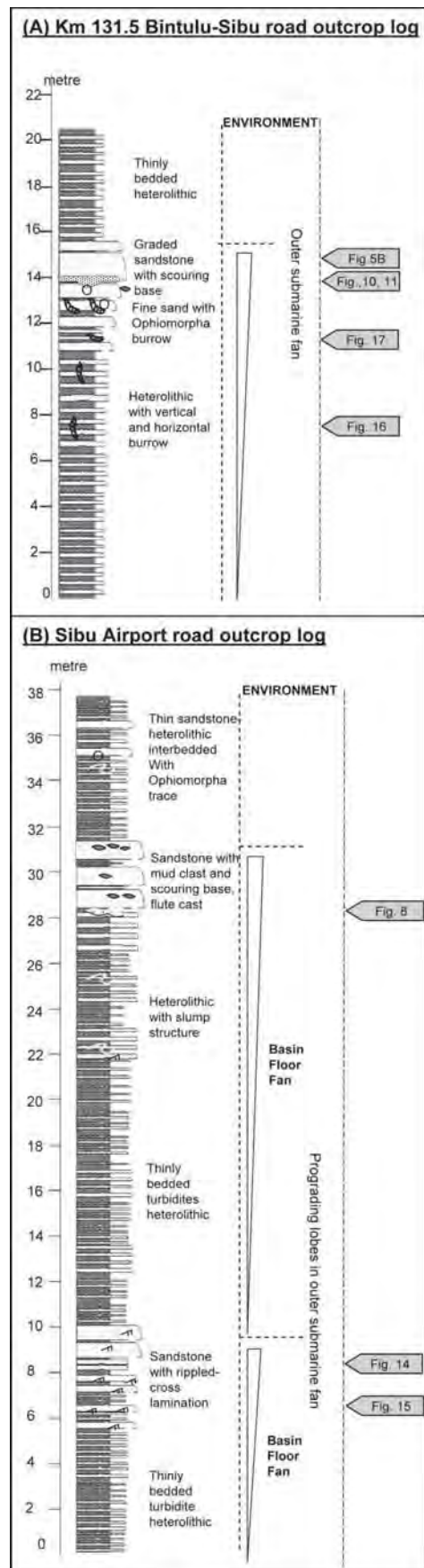


Figure 25: Sedimentological logs of outcrop at (A) km 131.5 Bintulu-Sibu road, and (B) Sibu Airport road.

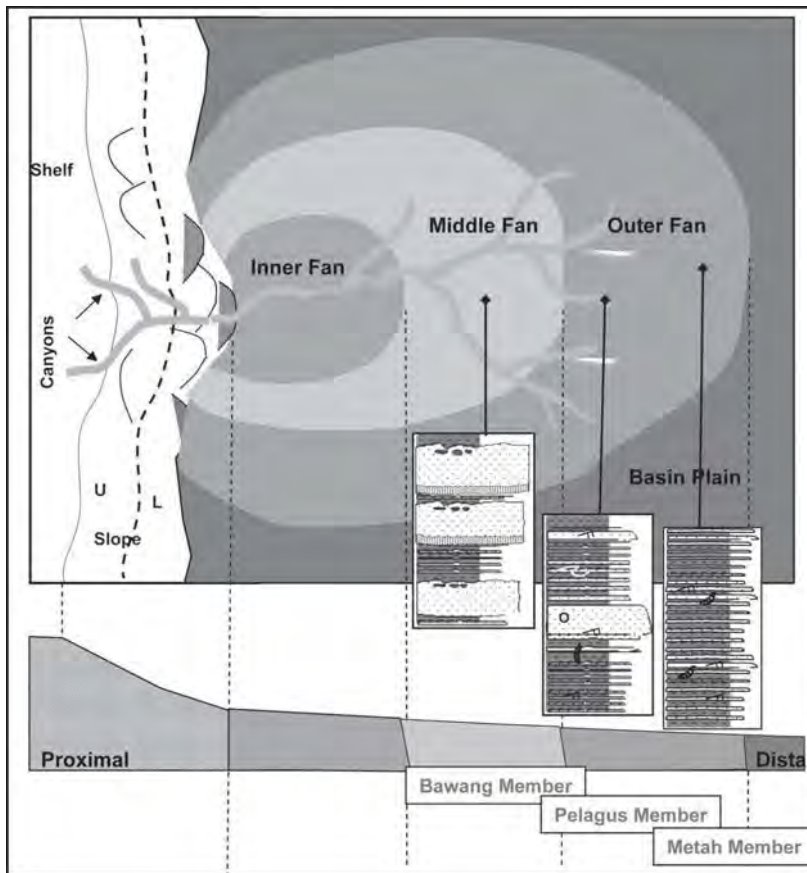


Figure 26: Facies model and depositional setting of Belaga Formation in Tatau-Sibu area. The Fan model are based on Mutti and Ricci Lucchi (Mutti *et al.*, 2002).

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