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Sedimentary Facies of the West Crocker Formation North Kota Kinabalu-Tuaran Area, Sabah, Malaysia

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Abstract. Newly outcrops exposed in the West Crocker Formation have led to the detail sedimentological analysis of the formation. Eight sedimentary facies have been recognised in which it was divided into three main groups: (1) sand-dominated facies (F1-F2), (2) poorly-sorted unit mixed sand and mud-dominated facies (F3), and (3) mud-dominated facies (F4-F5). These are: F1-graded sandstone (massive to planar laminated), F2-ripple-cross laminated, wavy and convolute lamination sandstone, F3-chaotic beds of mixed sandstone and mudstone blocks and clasts, F4-lenticular bedded of sandstone, and F5-shale. The studies of the formation has come out that it was deposited in a sand-rich submarine fan with specific location located at (1) inner fan channel levee complex; (2) mid-fan channelised lobes, and (3) outer fan.

1. Introduction
Sabah which is located at the Northern part of Borneo Island lies within the active tectonic plates of Pacific, Philippine, Eurasia and Australia. The formation of the NW Borneo accretionary belt is closely related to the opening of the South China Sea. The West Crocker Formation of Oligocene to Early Miocene age which is mostly concentrated in the western part of Sabah is the main focus in this research. This sand-rich turbidite formation was deposited in an accretionary fore-deep basin forms part of this accretionary belt. This deep-water succession is well exposed over a large part of the coastal ranges of NW Sabah area can be up to 10 km in thickness (Stauffer, 1967). Newly exposed outcrops scattered at the North Kota Kinabalu to the Tuaran area, will be the focus in detail sedimentological analysis (Figure 1.0).

2. Geological Setting of the study area
The West Crocker Formation in NW Borneo had undergone two distinct periods of basin filling (Mazlan, 1999). It was first evolved during the Paleocene to Eocene period when deep-water sediments of the Rajang-Embaluh Group (Trusmadi Formation and East Crocker Formation) were deposited. These formed part of an accretionary complex due to the subduction of the South China Sea margin beneath Borneo at the North Borneo-Luzon Arc. The ongoing continuous subduction and compression processes caused the Rajang-Embaluh Group accretionary complex to be uplifted, folded and eroded which resulted in the formation of a major unconformity during the Late Eocene.

Due to ongoing subduction and compression, a second NE-SW trending accretionary complex was developed outboard of the topographic range represented by the newly uplifted Rajang-Embaluh Group. The complex comprised sediments of the West Crocker Formation (Sand-dominated facies) which is laterally equivalent with Temburong Formation (Mud-dominated facies) (Stauffer, 1967; Hutchison, 1989).

During Early Miocene, East Sabah was rifted and infilled with shallow marine sediments. At that time, the collision of Reed bank Terrane with Rajang Embalu Group resulted in uplifting of the West Crocker Formation. The uplifting of Northwest Borneo occurred during Middle Miocene due to ongoing subduction of the South China margin. This resulted in the uplift, folding and thrusting of the
West Crocker Formation. The deformed, folded, imbricated and thrust deep-water of the West Crocker Formation (Leong, 1999) which represents a northeast-southwest trending, elongate trough, part of a large submarine fan, built out northward from the Sunda Shelf in Eocene to Oligocene times, which was accreted against Borneo in the Late Oligocene to Early Miocene to form part of the Northwest Borneo Subduction Complex (Tongkul, 1987).

3. Methodology
The geological mapping involved details descriptions, measurements and sampling at seven exposed localities near the town of Kota Kinabalu and Tuaran area, NW Sabah. The sections with total measured thickness of 227.25 m were extensively been logged, and based on 1:50 and 1:100 scales. The seven selected localities are: 1) SMK Taman Ria (WCF-1), 2) Kampung Setinggan (WCF-2), 3) Jalan Telipok Lama (WCF-3), 4) Jalan Universiti Prima (WCF-4), 5) Jalan Sulaman (WCF-5), 6) KFC (WCF-6), 7) Lok Kawi (WCF-7).

The sedimentology logging was documented with emphasis on the lithology, sandstone thickness, grain size, morphology of the beds contact, sedimentary structures, bioturbation style and internal characteristics. These features will be used to interpret facies and facies association of the successions and the depositional will be constructed for the West Crocker Formation, NW Sabah, Borneo.
4. Sedimentary facies
The West Crocker Formation can be divided into eight sedimentary facies.

4.1. Graded Sandstone (Massive to Parallel Laminated)
This facies consists of light grey, fine to coarse grained with moderate sorted of sandstone. It shows medium to thick-bedded with individual thicknesses between 3 to 5 meters (Figure 2A). Basal contacts of beds are sharp, or locally erosive with abundant of granule to pebbles which can result the normal grading (Figure 2B). Generally, these beds are massive or display as feint horizontal stratification (Figure 2C). Soft sediment deformation such as dewatering structures, dish structures, dewatering pipes and mudclasts are common either at the middle or at the top of beds. The sandstones show parallel lamination, current-ripple and climbing current ripple lamination developed in the finer-grained at the upper part of this beds (Figure 2D). The flute cast and groove marks are common. Massive character implies of rapid deposition from highly concentrated turbulent flow (Tongkul, 1987). The poor development of internal deposition structures indicates that these sandstones were deposited rapidly by processes of traction and fallout from short-term turbidite flow (Collenette, 1958; Tongkul, 1987).

4.2. Ripple-Cross Laminated, Wavy and Convolute Lamination of Sandstone
F3 contains of light grey, very fine-grained sandstone with interbedded with hemipelagic mudstones. This facies resembles alternation of laminated mudstone with sharp, planar bases with lack of flute casts or tool marks. This facies is typically 0.5 to 1 m in thickness. Internally, F3 consists of intervals of current-rippled to climbing current ripple very fine-grained sandstone which repetitively alternate with wavy and convolute mud drapes of flaser bedding (Figure 3E).

This F2 can be interpreted as lower density turbidity current deposit with extensive uni-directional flows in respond to sediment supply and hemipelagic setting. Current-ripples to climbing-current ripples indicates that late stage uni-directional traction modification processes occurred during deposition of F2 suggesting that sediment supply to the bed was relatively high with some additional energy and balanced the transport of sediment across the bed which allowing ripples to aggrade (Middleton, 1993). The presence of wavy mud drapes indicate the more extensive tractional modification with more incoming sediments input and these uni-directional flow were pulsatory in nature and allowing mud-sized particles to settle out or fallout of suspension on a form of mud drapes (Lowe, 1982).

4.3. Chaotic Bed of Mixed Sandstone-Mudstone Blocks and Clasts
This facies refers to a chaotic combination of sandstone and mudstone. Mudstone commonly appears in dark grey-coloured while sandstone is yellowish or light-grey in colour. Fine-grained sandstone significantly contains more mud than high-density turbidite sandstone. The contacts may be gradational or sheared. This facies consists of clast rich units, with 1 to 2 m in thickness. Internally, this facies is always chaotic and poorly sorted, structureless, and ungraded (Figure 3F). The sandstone and mudstone clast shows tabular to sub-spherical. The coal form as finely-disseminated chips within matrix exists in this facies. This facies is sharply overlain by sandy high-density turbidites of facies 1 sandstone unit.

Facies 3 is interpreted as a debrite, which was deposited by a flow either in laminar or weakly turbulent. The ungraded nature of both of the structures and clasts in different size suggested that this facies is deposited as a single phase of the flow in which whole mass undergoes large and continuous deformation by freezing off en masse, rather than by progressive settling (Muddler and Alexander, 2001). The variety clast shapes within this facies and their internal structure information is strong evidence to show that this facies is formed of debris flow in which normally tend to be supported by matrix strength, dispersive pressure, and buoyancy (Middleton, 1993). Clasts in this facies are internally deformed suggesting that the clasts are poorly lithified at the beginning of the deposition and later it may be deformed by internal shearing or the interaction of clasts within the flow.
4.4. Lenticular Bedded Sandstone

This sandstone lenses is yellowish in colour while the shale is dark grey. These occurrences are generally fine- to medium-grained sandstone. The composite thickness of this facies ranges from 3 to 5 m. The sandstone lenses are about 0.5 to 2 cm and shale layer is about 4 to 8 cm (Figure 3G). The unit extends laterally about 5 m. Most of sandstone beds have sharp basal and top contacts and are capped with shale layers. Internally, the sandstone beds consist of parallel lamination and climbing lamination. The deposition of the alternations between sandstone and shale requires fluctuating flow conditions, where it represents a quiet and low energy of turbidity current, which has fall-out and repetitively. The variable thickness in this facies suggested that it formed at a moderately strong, intermediate cycle of flow. The existence of parallel lamination and climbing ripples in the sandstone beds imply a waning turbidity current.

4.5. Shale

F5 is shale in dark grey-coloured. The F5 unit range from 0.5 to 1 m in thickness. Its displays as a sharp top and bottom contact of the beds. Its lateral continuity is about 5 m. Stratigraphically, F8 commonly occurs above F1 or F2. F5 is interpreted to present deposition of suspension fallout of finer grained particles. In turbidite system, deposition of coarse sediments may leave a residual suspension of fine grained sediments. This residual fine grained sediment will wane and tend to deposit under lower energy of turbidity currents. This fine grained material could also associate with and transported within the flow with response to a rapid settle down (Amy et al., 2005).

Figure 2: Main characteristics of facies 1: (A) massive thickly bedded unit of sandstone; (B) massive sandstone with granule to pebbles lags; (C) medium to fine-grained sandstone with feint parallel stratification; (D) ripple cross-stratification, climbing ripples in the sandstone unit.
5. Depositional Environment
The West Crocker Formation, NW Sabah is characterised by high amount of sandstone content dominated by thick amalgamated, channel-levee, channelized and distal lobe sandstones. Based on the documented five sedimentary facies, a sand-rich submarine fan depositional model is proposed for the West Crocker Formation, as following (Mutti and Normark, 1987) model. This model is generally divided into Inner, Mid, and Outer fan (Walker, 1978).

6. Conclusions
1. Five facies were identified based on the lithology, sandstone bed thickness, grain size, bed contact, sedimentary structures and bioturbation style. These are: 1) F1- Graded sandstone (Massive to Parallel Laminated), 2) F2- Ripple-cross laminated, wavy and convolute lamination sandstone, 3) F3- Chaotic beds of mixed sandstone and mudstone blocks and clasts, 4) F4- Lenticular bedded sandstone, 5) F5- Shale.

2. Based on the integration studies, the studied sedimentary successions were deposited in a sand-rich submarine fan specifically located at (1) inner fan channel-levee complex; (2) mid-fan channelised lobes, and (3) outer fan distal lobes.
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8. References