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THE WEST CROCKER FORMATION (EARLY OLIGOCENE TO MIDDLE MIOCENE) IN THE KOTA KINABALU AREA, SABAH: FACIES, SEDIMENTARY PROCESSES AND DEPOSITIONAL SETTING

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The West Crocker Formation in Kota Kinabalu area in Sabah is one of the best exposed examples of deepwater sedimentary sequence in Malaysia. This paper describes and documents the detailed facies characteristics and sedimentology of outcrops, and proposes a depositional framework for the West Crocker Formation in the Kota Kinabalu area.

Based on lithology, sedimentary structures, geometry, trace fossil assemblages, and paleocurrent data, the sediments are grouped into seven major facies. These are; i) facies A - thick, massive, and structureless sandstone; ii) facies B - thick, and massive sandstone with the presence of post-depositional dewatering structures; iii) facies C - graded sandstone and occasional complete Bouma Sequence; iv) facies D - thin-bedded fine-grained sandstone and siltstone and graded into base-absent Bouma sequences; v) facies E - sandstone and shale interbedding, and frequently marked with lenticular bedding; vi) facies F - slump beds, and vii) facies G - shale. Table 1 summarises the characteristics of the different facies in the study area.

Four deepwater architectural elements had been identified based on the study of vertical successions of facies. These are: i) slopes are made up of turbidite facies F, G, and E; ii) channels are represented by coarse- and medium-grained massive sandstone with predominantly facies A and B; iii) depositional lobes are formed by medium grained sheet sands, made up of facies C and D, and showing a coarsening- and thickening- upward sequences; iv) heterolithic levee-interchannel facies association, predominantly shale with thin, fine-grained sandstone, and siltstone, made up of turbidite facies D, E, F, and G, and showing a coarsening- and thickening- upward succession. Table 2 shows the characteristics and pattern of facies associations in the study area.

This study has shown that the West Crocker Formation, which previously has been referred to as "turbidites", is not composed of solely turbidity current deposits, but includes debris flow, slumps and other submarine mass-transport deposits.

Table 1: Summary of characteristics of the different facies of the study area

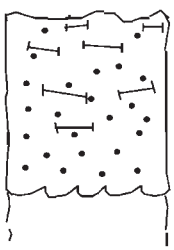
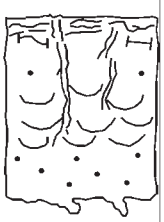
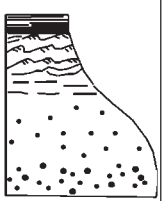
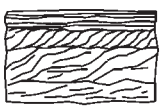
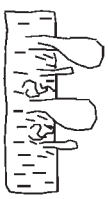
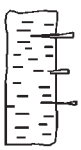
Characteristics	Facies A	Facies B	Facies C	Facies D	Facies E	Facies F	Facies G
Sketch							
Colour	Gray	Light gray	Gray to dark gray	Light gray to light purple	Dark gray (sandstone) to black (shale)	Dark gray (sandstone) to black and red (shale)	Black and red
Thickness	1.0m to ≥ 5.0m	0.5m to 5.0m	≤ 1.0m to 2.0m	≤ 0.5m	Sandstones are ≤ 0.3m	≤ 0.5m to 10.0m	≤ 0.1m to 2.0m
Grain Size	Pebbly and/or gravely medium- to-coarse grained sandstone. Mixture with finer grained beds	Fine- to- coarse-grained sandstone. Gravelly in places	Fine- to- coarse-grained sandstone	Very fine sandstone to siltstone	Very fine sandstone and siltstone, with shale	Very fine sandstone and siltstone, with shale	Shale
Grading/ Sorting	Poorly sorted. Show graded, non-graded or reverse graded	Poorly sorted. Occasionally graded, from gravelly base to silty sands top	Graded. Organized into Bouma sequence that contains Ta division. Ta - Tb division is common	Graded. Organized into Bouma sequence, but Ta division is absent	-	-	-
Geometry	Amalgamated. Continuous sandstone bodies	Continuous sandstone bodies	Amalgamated	Continuous thin siltstone bodies	Heterogeneity	'Chaotic' slump beds. Heterogeneity	Continuous and traceable

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Table 1: Continued

Sedimentary Structures	Faint laminations, mud drapes, and flame and load structures	Dewatering structures of dish and pipe marks. Subparallel laminations, cross stratification, and climbing ripples. Flute and tool marks marking the base	Massive graded. Plane parallel laminae, climbing ripples, and upper parallel laminae of siltstone and shale	Cross stratification, climbing ripples, wavy, and convoluted laminae. Upper part normally showing parallel-laminations of siltstone-shale-carbonaceous laminae. Mud drapes	Lenticular bedding. Sandstones showing some climbing ripples, cross-stratifications, and micro cross-laminations. Sole and tool marks marking the base	Slumping. Isolated, connected, folded, or 'floated' of sandstones in muddy matrix	Isolated, few, and very thin layers (mm scale) of very fine sandstone and siltstone (wavy) occasionally associated with this facies in some places
Fossil/Trace Fossil/Coal/Plant Fragment	Mud clasts and intraformational rip-up clasts- high concentrated at the upper part of beds. Coal clasts in places	Mud clasts and intraformational rip-up clasts are common	Mud clasts in some places	Trace fossils exhibit occasionally. Bioturbated at the top part in some places	Bioturbated at the top part of the sandstones in places. Intraformational rip-up clasts display occasionally. Trace fossils are very common; *Nereites, Spirorhaphe, Megagrapton, Paleodictyon, Cosmorhaphe*, and *Helminthoida*	Bioturbated commonly occurred in those sandstones	Mud clasts and coal clasts in places
Top and Bottom Contact	Top irregular. Bottom usually erosional surfaces	Sharp top and bottom. Basal occasionally showing erosional surfaces	Sharp top and bottom. Basal occasionally showing erosional surfaces	Sharp top and basal surfaces	Irregular top and bottom surfaces	Irregular top and bottom surfaces	Sharp and commonly irregular patches. Some rather showing load and flame structures

Table 2: Summary of characteristics and pattern of facies associations of the study area

Characteristics	**Slope**	**Channel and channel-fill**	**Depositional Lobes**	**Levee - Interchannel**
1. Common thickness	0.5m to 10.0m	1.0m to 50.0m	1.0m to 15.0m	1.0m to 15.0m
2. Lithology	Sandstone, Shale	Sandstone (dominant), Shale barriers	Sandstone (dominant), Shale barriers	Sandstone, Shale (dominant)
3. Sedimentary features	Slumping, folding; sandstone bodies floating in muddy matrix	Erosive bases, rip-up clasts, massive, and thick sandstone bodies	Complete and partial Bouma sequences, continuous sheet-like sandstone bodies	Heterogeneity, lenticular bedded. Sandstone marks by climbing ripples, cross-stratification, and micro cross-laminations. Trace fossils are common.
4. Turbidite facies	A, E, F, G	A, B, C, E	A,B, C	D, E, F, G
5. Grain size trend	Chaotic beds. No regular trend	Fining upward	Coarsening upward	Coarsening upward
6. Bed thickness trend	No regular trend	Thinning upward	Thickening upward	Subtle thickening upward
7. Mass transport processes	Rock fall, slump, slide, creep	Debris flows, high density turbidity currents, slump	Grain flows, turbidity currents	Low density turbidity currents, surface currents and pelagic settling
9. Vertical succession trend