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TURBIDITE, DEBRITE OR SOMETHING IN BETWEEN: RE-THINKING THE WEST CROCKER FORMATION

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The Oligo-Miocene West Crocker Formation (WCF) of West Sabah is often referred to as a sand-rich turbidite system, and has been the subject of detailed sedimentological studies during the last few years. The essential features of the WCF sediments can be observed at outcrops scattered within driving distance from Kota Kinabalu (Fig. 1).

For the most part, thickly bedded facies, representing the high-density, sandy turbidites is found in most of the outcrops studied, with the exception of Taman Maju, Sepangar (Fig. 1), where there are more of the "classical" flysch-like, thin-bedded turbidites. In general, the Crocker is sand-rich and very thickly bedded (> 1 m), commonly 1.5-3 m thick, while some may be up to 35 m. Based on the presence of subtle scour and amalgamation surfaces, these thick beds were formed not by a single flow but multiple flow events. Internally, the thick beds, most of which are poorly sorted despite the overall normal grading, are characterized by faint low-angle laminations, resulting from traction, passing upwards into contorted bedding due either to deposition from a slurry, or to soft-sediment deformation and dewatering. Deposition from slurry involves rapid dumping of a dense muddy and water-saturated mass of sediment. Hence, in these types of beds at least, there is strong evidence for some form of high-density (sandy) turbidity flows, slurry, or both. Erosion at base of the flows, indicated by flute casts and various other sole marks are common. Well-developed load structures, including large ball-and-pillow (or "jam roll") structure due to loading and sinking of these dense flows into water-saturated muddy substrate are indicative of the scale and dynamics of these flows.

The turbidites in the WCF are also often characterized by the Bouma-type beds (Fig. 2), passing upward from sharp-based massive sandstone, into low-angle lamination, into convolute lamination, and rippled muddy tops, with floating shale clasts at top of bed. These beds are repetitive vertically, some with well-developed climbing ripples, indicative of rapid deceleration and simultaneous aggradation of flows. Soft-sediment deformation and remobilization is also a common feature of the Crocker – sliding of sandstone beds indicate unstable slopes that resulted in large-scale slumps or slides, possibly triggered by earthquakes in this formerly active margin. Clastic injection structures, predominantly clastic dykes, both of shale and sand are moderately abundant (Madon et al., 2006).

A further facies type frequently interbedded with the thick sand beds is muddy sandstone, with internally structureless or chaotic, and often with shale or heterolithic clasts in them. These overlie the sandstone beds very abruptly, often filling hollows or subtle topographic lows at the top of the massive sands. These muddy facies are probably debris flow deposit laid down soon after the deposition of the massive sand. In most places, the apparent paleocurrent directions measured from the almost vertical beds, generally indicate north to northeasterly directed flows. There is evidence at Lok Kawi Heights, south of Kota Kinabalu (Fig. 1), of southerly directed flows. Whether this is a local phenomenon or is more widespread is being investigated.

Current re-thinking of deepwater depositional process provides better insights into the understanding of Crocker deepwater and turbidite facies in general. In this paper, facies of the West Crocker Formation are described and interpreted in terms of this new model versus the traditional turbidite paradigms (e.g. Middleton and Hampton, 1973 and Shanmugam, 2006). New terms such as high-density and low-density turbidity currents, slurry flow and linked debrite-turbidite systems have been introduced into the literature based on studies in the subsurface of the North Sea together with outcrops in Ireland and Spain (e.g. Haughton et al., 2003; Lowe & Guy, 2000). We show some outcrop examples from the West Crocker Formation to illustrate the different facies that may be interpreted using this new paradigm. While some of the WCF facies may have been formed by turbidity flows (Fig. 2) and debris flows (Fig. 3), there are also other bedding types that represent a different depositional process (Fig. 4), and require re-consideration of the existing models. The ability to discriminate the different types of deposits that result from these various processes is important because of the potential implications for reservoir geometry and heterogeneity.

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Figure 1: Location map of West Crocker outcrops in Kota Kinabalu area.

Figure 4: Sharp-based massive sandstone with internal flow-induced structures, probably indicative of deposition by slurry.

Figure 2: Turbidite bed with Bouma divisions (note book for scale).

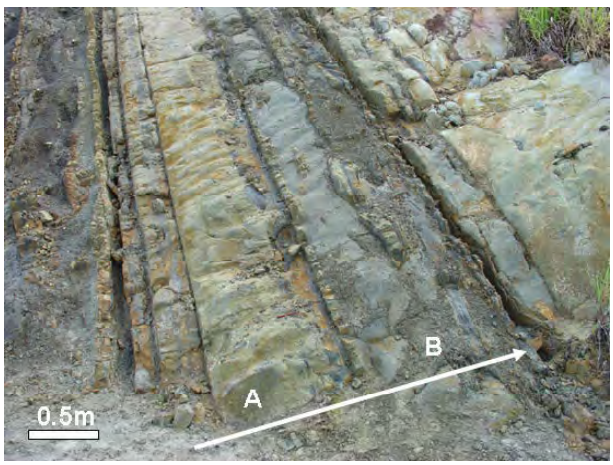

Figure 3: A possible linked turbidite-debrite couplet? Normally graded massive sandstone (A) with floating shale clasts, overlain by muddy sandstone (B) with heterolithic rip-up clasts.