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Sedimentary facies analysis and depositional model of the Palaeogene West Crocker submarine fan system, NW Borneo

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ABSTRACT

This study outlines a sedimentological analysis of the Palaeogene West Crocker Formation (WCF) around the Kota Kinabalu area of SW Sabah, which represents a large submarine fan depositional system within part of what was the complex and tectonically active margin of NW Borneo. The newly acquired and often extensive outcrop data summarised in this study has resulted in a more complete synthesis of the Crocker fan depositional system than has been previously possible. Seven facies (F1–F7) have been identified which constitute three main facies groups: (1) sand-dominated facies (F1–F3), comprise high- to low-density turbidites and form the dominant part of the WCF, (2) debris flow-dominated facies (F4–F6) comprises mud- and sand-dominant debris flows and mass transport deposits (MTD), which form a secondary but highly distinctive part of the WCF, and (3) mudstone-dominated facies (F7), represent a subordinate part of the WCF.

Analysis of the vertical facies successions (from proximal to distal), has resulted in recognition of five major genetic units: (1) channel-levee complex; characterised by thick (30–60 m) thinning and fining upward facies succession, which are dominated in their lower part by thick-bedded (1–6 m), amalgamated high-density (Lowe-type) turbidites with rare debrite beds; the upper part is dominated low-density (Bouma-type) turbidites, without associated debrite beds. (2) Channelised lobes; characterised by 2–10 m thick, coarsening upward, which are overlain by 5–20 m thick fining upward facies successions; these successions are dominated by high-density turbidites (c. 0.5–1 m thick) and linked co-genetic turbidite–debrite beds (0.1–0.5 m thick), with subordinate mudstone facies. (3) Non-channelised lobes; comprise 5–20 m thick coarsening upward facies successions; these start with mudstone facies, which pass gradually upwards into linked co-genetic turbidite–debrite beds; sandstone bed thickness increases upwards, while the debrite caps tend to become thinner upwards; high-density turbidites (2–3 m thick beds) form amalgamated units at the top of these successions. (4) Distal lobes; represented mudstone-dominated intervals with mainly thin (1–10 cm thick) low-density turbidites and occasional muddy debrites. (5) Mass transport complexes (MTCs); characterised by highly deformed slumped units (up to 2.5–5 m thick).

It is inferred that the five genetic units were deposited within four proposed laterally contiguous depositional environments are: (1) inner fan channel-levee complex; (2) mid-fan channelised lobes; (3) mid-fan non-channelised lobes; and (4) outer fan distal lobes. The West Crocker submarine fan is interpreted as a multiple-sourced, shelf-fed, Type II, low-efficiency, sand-rich depositional system.

1. Introduction

The Oligocene to Early Miocene West Crocker Formation (WCF) is a major sand-dominated basin-floor fan complex that was deposited in an accretionary foredeep basin and forms part of the Crocker-Rajang fold-thrust belt, NW Sabah (Fig. 1). This sandstone-dominated succession is several kilometres thick, more than 25,000 sq. km in extent (250 km long by 100 km wide), and is exposed over a large part of the coastal ranges of NW Sabah, northern Borneo. Its SW–NE structural trend controls the present day shoreline orientation (Fig. 1B; Stauffer, 1967; Tongkul, 1987; Hutchison, 1996; Crevello et al., 2007). Regional palaeographic reconstructions and a provenance analysis of constituent sandstones suggest sediment derivation from a continental source area to the south and south-west of Borneo (including the Schwaner Mountains), located ca. 400 km to the SW of the present study area

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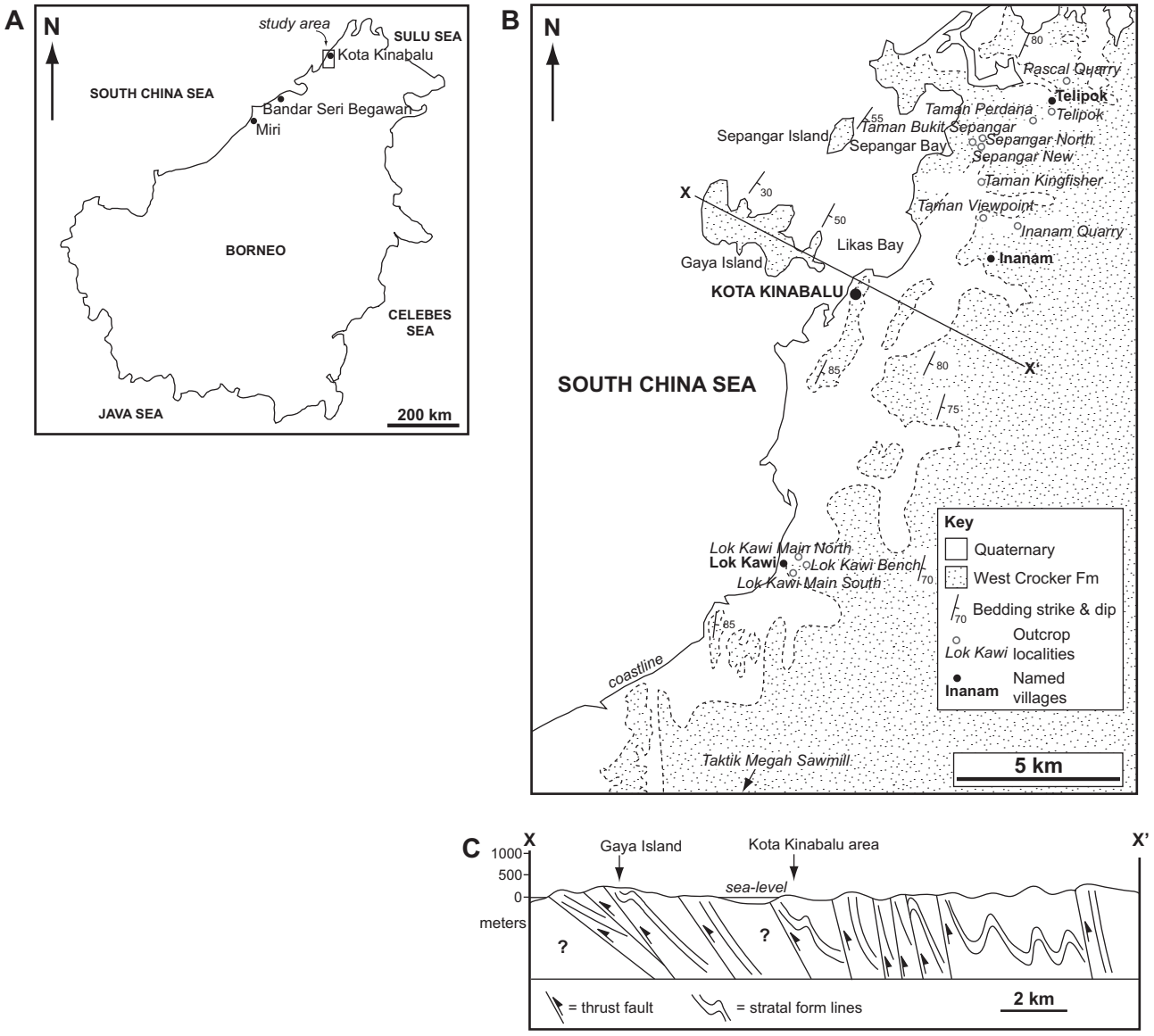

Fig. 1. Location of the study area in NW Sabah region, Borneo. (A) Regional map of Borneo indicating the location of the study area around the Kota Kinabalu area (boxed). (B) Simplified geological map of the study area illustrating the inferred outcrop extent of the West Crocker Formation (WCF) and location of localities named in the text (modified from: Tongkul, 1987; Crevello et al., 2007; Jackson et al., 2009). Note that much of the WCF outcrop is heavily vegetated and poorly-exposed or inaccessible. X–X′ shows location of cross-section illustrated in (C). (C) Structural cross-section across the study area (X–X′) in a NW–SE direction, illustrating deformation of the WCF outcrop belt by easterly-dipping thrust faults (modified from: Tongkul, 1987; Crevello et al., 2007; Jackson et al., 2009).

in southern Sarawak, Borneo (Fig. 2; Tongkul, 1994; Wilson and Moss, 1999; Hutchison, 2005; Van Hattum et al., 2006).

There are very few examples of outcropping deep-water deposits throughout the SE Asian region, despite their importance in ongoing deep-water exploration. From the point-of-view of gravity flow deposits and their bed scale characteristics, the outcrop sections described in this paper provide analogues for productive, Miocene deep-water sandstonereservoirs in other parts of southeast Asia, particularly in offshore northwest Sabah and offshore eastern Kalimantan. However, the tectono-stratigraphic setting of the onshore Paleogene successions described here and the offshore hydrocarbon-bearing Neogene deep-water reservoirs are dramatically different: syn-tectonic, accretionary prism (Palaeogene) versus post-tectonic/post-collision and toe-thrust-related fans (Neogene). Nonetheless, the Palaeogene outcrops afford an exceptional opportunity for analysing deep-water deposits from the bed-scale through to 10's m-thick architectural elements of a major submarine fan complex.

The availability of new, fresh outcrops (from civil engineering projects during the period 2002–2008), with individual stratigraphic thicknesses of up to 350 m, was an important primary motivation of this project. This has resulted in the analysis of around 2000 m of total stratigraphic thickness of exposed deep-water sediments, which had only been logged previously at a relatively low-resolution scale (Crevello et al., 2007). The initial objectives of this work were, therefore, as follows: (1) to develop a, high-resolution sedimentological inventory of all available WCF sections at the time of study (2006–2010), and (2) to provide a comprehensive synthesis of the WCF fan depositional system, particularly in terms of its sub-environments. Specific aims were to document, the bed-scale sedimentology and the internal facies architecture of gravity-flow deposits. Particular emphasis was placed on grain-size, sorting and sphericity of matrix and clasts, sedimentary structures, bed thickness, vertical stacking patterns and a synthesis of the main genetic units and architectural elements. Detailed stratigraphic logs are documented to determine