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Facies associations, depositional environments and stratigraphic framework of the Early Miocene-Pleistocene successions of the Mukah-Balingian Area, Sarawak, Malaysia

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ABSTRACT

Thirty-five stratigraphic section exposed along the Mukah-Selangau road in the Mukah-Balingian area have been studied. Sedimentological and palynological data have been integrated to gain a better insight into the depositional architecture of the area. Broadly, the Mukah-Balingian area is dominated by fluvial, floodplain and estuarine related coal-bearing deposits. The Balingian, Begrih and Liang formations have been described and interpreted in terms of seven facies association. These are: FA1 – Fluvial-dominated channel facies association; FA2 – Tide-influenced channel facies association; FA3 – Tide-dominated channel facies association; FA4 – Floodplain facies association; FA5 – Estuarine central basin-mud flats facies association; FA6 – Tidal flat facies association and FA7 – Coastal swamps and marshes facies association. The Balingian Formation is characterised by the transgressive phase in the base, followed by a regressive phase in the upper part. On the basis of the occurrence of *Florscheutzia trilobata* with *Florscheutzia levipoli*, the Early to Middle Miocene age has been assigned to the Balingian Formation. The distinct facies pattern and foraminifera species found from the samples taken from the Begrih outcrop imply deposition in the intertidal flats having pronounced fluvio-tidal interactions along the paleo-margin. Foraminiferal data combined with the pronounced occurrence of *Stenochlaena laurifolia* suggest at least the Late Miocene age for the Begrih Formation. The internal stratigraphic architecture of the Liang Formation is a function of a combination of sea level, stable tectonic and autogenic control. Based on stratigraphic position, the Middle Pliocene to Pleistocene age for the Liang Formation is probable. The Balingian, Begrih and Liang formations display deposits of multiple regressive-transgressive cycles while the sediments were derived from the uplifted Penian high and Rajang group.

1. Introduction

Coastal succession of the Mukah-Balingian area has been considered to be the most prolific producer of the humic coals in Malaysia. It is characterised by the strongly folded Late Cretaceous to Eocene turbidites of the Belaga Formation and the gently dipping Early Miocene-Pleistocene coal-bearing succession. This succession is composed of the Balingian, Begrih and Liang formations. The earlier studies on the Mukah-Balingian area were restricted to general accounts (Liechti et al., 1960; Visser and Crew, 1950; Wolfenden, 1960), the quality and reserves estimation of the coal (Chen, 1986) and lithostratigraphy (De Silva, 1986). Recent studies include the geochemical and petrographic analyses of coal (Hakimi et al., 2013; Sia and Abdullah, 2012b), palynology and depositional environment (Murtaza et al., 2015; Sia et al., 2014), concentration of minor and trace elements in coal (Sia and Abdullah, 2011, 2012a) and reservoir characteristics (Nugraheni et al., 2014).

Coastal plains and marginal marine environments are exceptionally complex as they are impacted by the interactions of fluvial and marine processes (Ainsworth et al., 2011; Bhattacharya and Giosan, 2003; Boyd et al., 1992; Dalrymple, 1992; Dashtgard et al., 2009; Yang et al., 2005). These processes produce composite interbedding of sedimentary facies in rock record. In coal-bearing succession, palynological analyses offer a crucial data to determine the plant type, peat mire type, climate and sedimentation style in a particular coal system (Nichols, 2005). The deposition of allochthonous palynomorphs in coastal plains and marginal-marine settings provide a mechanism to distinguish terrestrial, transitional and fully marine deposits (Loboziak et al., 2005; MacDonald, 1990). The thickness of each coal horizon, with the associated facies reflects the interaction of relative sea level, accommodation space and sediment input (Opluštil, 2005). The identification of *in situ* pollen and spores in the sediment record, integrated with the

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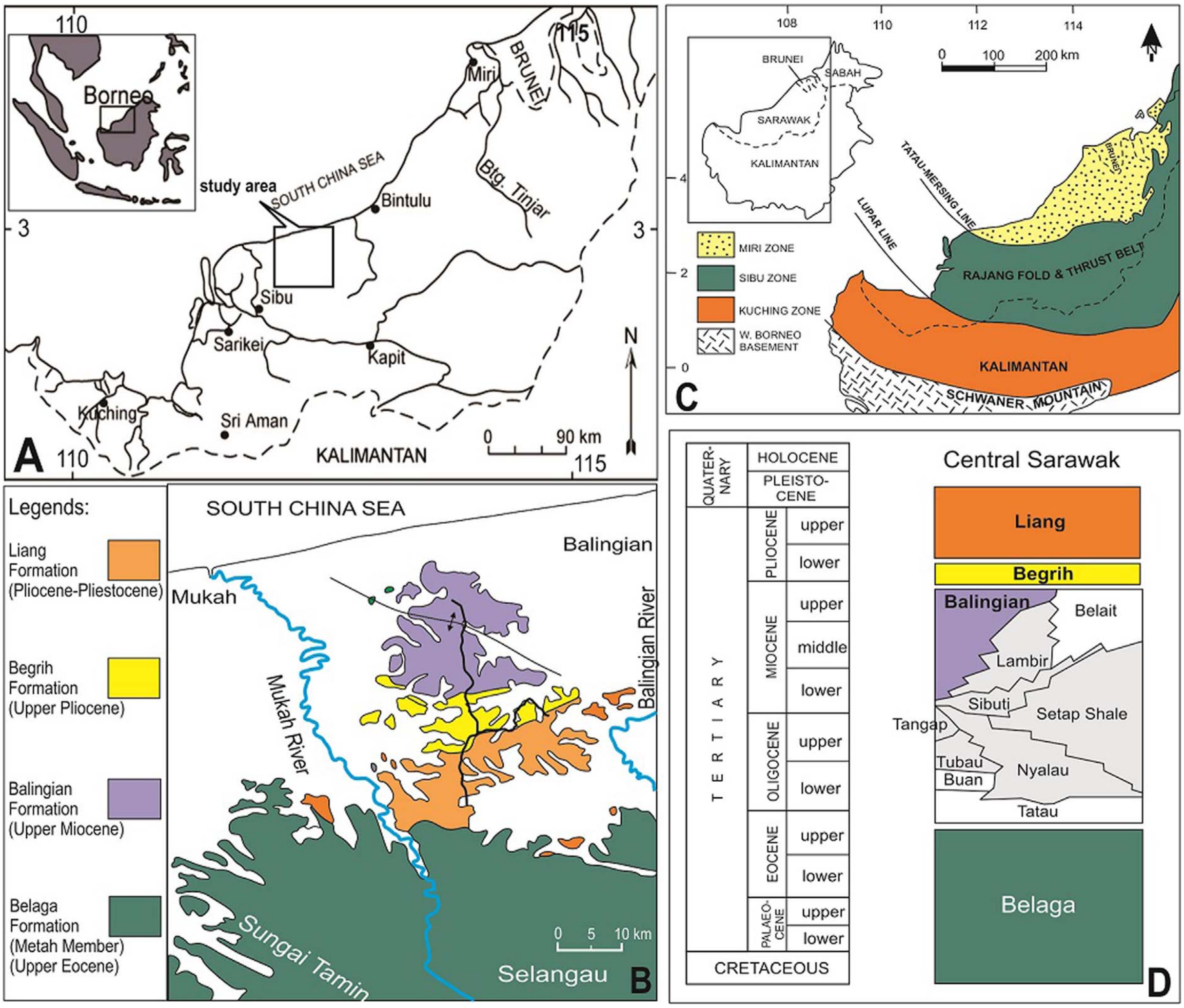

Fig. 1. Map showing the location of the study area. (A) A regional map of Sarawak showing the study area in the Mukah district, Central Sarawak. (B) A close up map showing the distribution of the Balingian, Begrih and Liang formations exposed in the study area. (C) A map illustrating the onshore structural sub-division of Sarawak (based on Liechti et al., 1960 modified by Madon, 1999). (D) The stratigraphic chart of the Central Sarawak. The Balingian Formation and Begrih Formation are only exposed in the Mukah-Balingian region.

sedimentary characteristics and biogenic structures may offer better understanding of the depositional environment (Batten, 1982; Czarnecki et al., 2014; de Oliveira et al., 2012; Hoorn, 1994; Pittet and Gorin, 1997; Tyson, 1993).

In this paper, we evaluated the sedimentological and palynological characteristics of the Balingian, Begrih and Liang formations that are exposed along the coastal areas of the Central Sarawak (Fig. 1). The detailed analyses of the facies architecture in the study area, integrated with the palynomorph prevalence from coal and carbonaceous rocks reveal the fluctuation of relative sea level and interaction of fluvial and marine processes. The objectives of this paper are: (1) to characterise the facies and facies associations of the Balingian, Begrih and Liang formations; (2) to interpret the depositional environment of the different facies associations; (3) to propose a stratigraphic framework and; (4) to interpret the paleogeographic evolution of the Early Miocene-Pleistocene succession of the Mukah-Balingian sub-basin.

2. Geological setting

2.1. Tectono-stratigraphic framework of Sarawak

The Sarawak foreland basin consists of the coastal area of central Sarawak and the offshore area that extends northwards. The basin fill is characterised by more than twelve (12) kilometres of a thick succession of the Late Eocene-Recent strata (Madon, 1999). The Sarawak basin succession unconformably overlies the tightly folded and deformed rocks that belong to the Rajang Group (Fig. 1). This foreland basin is formed as a result of the closure of the Proto-South China Sea. According to Hazebroek and Tan (1993), Hazebroek et al. (1994), Dickinson (1974), Madon, (1999) and Hutchison (2005), the closure occurred when the Luconia Block collided with the West Borneo Basement during the Late Eocene. However, Hall (2012) proposed a Late Cretaceous collision while Fyhn et al. (2009) argued for a Paleogene event (Fyhn et al., 2009; Hall, 2012). This collision thrusted the deep marine turbidites of the Rajang Sea (Proto-South China Sea), eventually forming the Rajang fold and thrust belt. The fold and thrust belt is referred to as the Sibu Zone in the onshore Sarawak (Haile, 1974; Hutchison, 1988; Madon, 1999). Uplifting and associated weathering of the Rajang fold & thrust belt provided the sediment source for the Sarawak basin (Madon, 1999).

Based on the history of the structural characteristics and overall subsidence, Mat Zin (1996); Mat-Zin and Swarbrick (1997), interpreted the Sarawak basin as a strike slip basin (Mat-Zin and Swarbrick, 1997; Mat Zin, 1996). They suggested that the Sarawak basin might have originated as a foreland basin that was later modified by strike slip tectonic processes. The presence of a fold and thrust belt implies a major compressional orogen in the northern part of the West Borneo Basement (WBB). This could be explained as the collision between the