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Geochemistry of Neogene sedimentary rocks from Borneo Basin, East Malaysia: Paleo-weathering, provenance and tectonic setting

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ABSTRACT

Multi-element geochemistry and mineralogy are used to characterize the chemical composition, degree of paleo-weathering, provenance and tectonic settings of the Neogene sedimentary rocks of Borneo Basin of east Malaysia. Sedimentary rocks are classified as extremely weathered sandstones (i.e. wacke, arkose, litharenite, Fe-sandstone and quartz arenite). Wacke, arkose, litharenite and Fe-sandstone are characterized by post-depositional K-metasomatism and zircon enrichment through sediment recycling. Geochemical characteristics suggest a mixed-nature provenance for the sandstones and the variable tectonic settings possibly mirror the complexity of the basin. Enriched Cr in quartz arenite and Fe-sandstone are related to the contribution from ophiolite or fractionation of Cr-bearing minerals.

1. Introduction

The Borneo Basin of south-east Asia is spread over Indonesia, Brunei and east Malaysia (Fig. 1a). It is surrounded by plate boundaries, marginal ocean basins and arc systems (Fuller et al., 1999) and had experienced significant tectonic activity and volcanism over the Cretaceous to Miocene period (Van Gorsel, 2012). The Sarawak province of east Malaysia hosts the western and north-western parts of the basin and the sedimentary deposits comprise siliciclastic rocks such as sandstone, siltstone and shale (Figs. 1b and 2). Previous studies on the basin have focussed on regional geology (Liechti et al., 1960; Banda, 1998; Hutchison, 2005), stratigraphy (Peng et al., 2004), sedimentology (Kessler, 2009; Tsing et al., 2012), tectonic (Haile, 1969; Hutchison, 1996; Morley et al., 2003, 2008; King et al., 2010) and faunal assemblage (Wilford, 1961). The geochemical characteristics of the sedimentary rocks have received less attention (Kessler and Nagarajan, 2012).

The geochemical signatures comprising of mineralogy and multi-element geochemistry of siliciclastic sediments from different parts of the world are used to infer the source rock composition (Hayashi et al., 1997; Bhat and Ghosh, 2001; Dayal and Murthy, 2006; Nagarajan et al., 2007a,b; Paikaray et al., 2007; Manikyamba et al., 2008; Chakrabarti et al., 2009; Bakkiaraj et al., 2010; Roy and Smykatz-Kloss, 2007; Roy et al., 2010, 2012; Akarish and Gl-Gohari, 2011; Etemad-Saeed et al., 2011; Armstrong-Altrin et al., 2012; Cao et al., 2012), climate, mode of transportation, depositional environment, degree of source rock weathering (Nesbitt and Young, 1982; Raza et al., 2002; Dey et al., 2008; Chakrabarti et al., 2009; Saxena and Pandit, 2012), tectonic setting and post depositional processes such as diagenesis and metasomatism (Feng and Kerrich, 1990; Banerjee and Bhattacharya, 1994; Rao and Prasad, 1995; Joo et al., 2005; Dey et al., 2009; Concepcion et al., 2012; Sun et al., 2012).

In this study, we present inorganic geochemistry (major and trace element composition) and mineralogy of the Neogene clastic sedimentary rocks of Tukau Formation exposed in the north-western part of the Boneo Basin to decipher provenance, degree of paleo-weathering, post-depositional diagenesis and possible tectonic settings of the depositional environment.

2. Geological setting

The sedimentary rocks of the north-western Borneo Basin (i.e. Sarawak province) are fluvial deposits transported by the Baram

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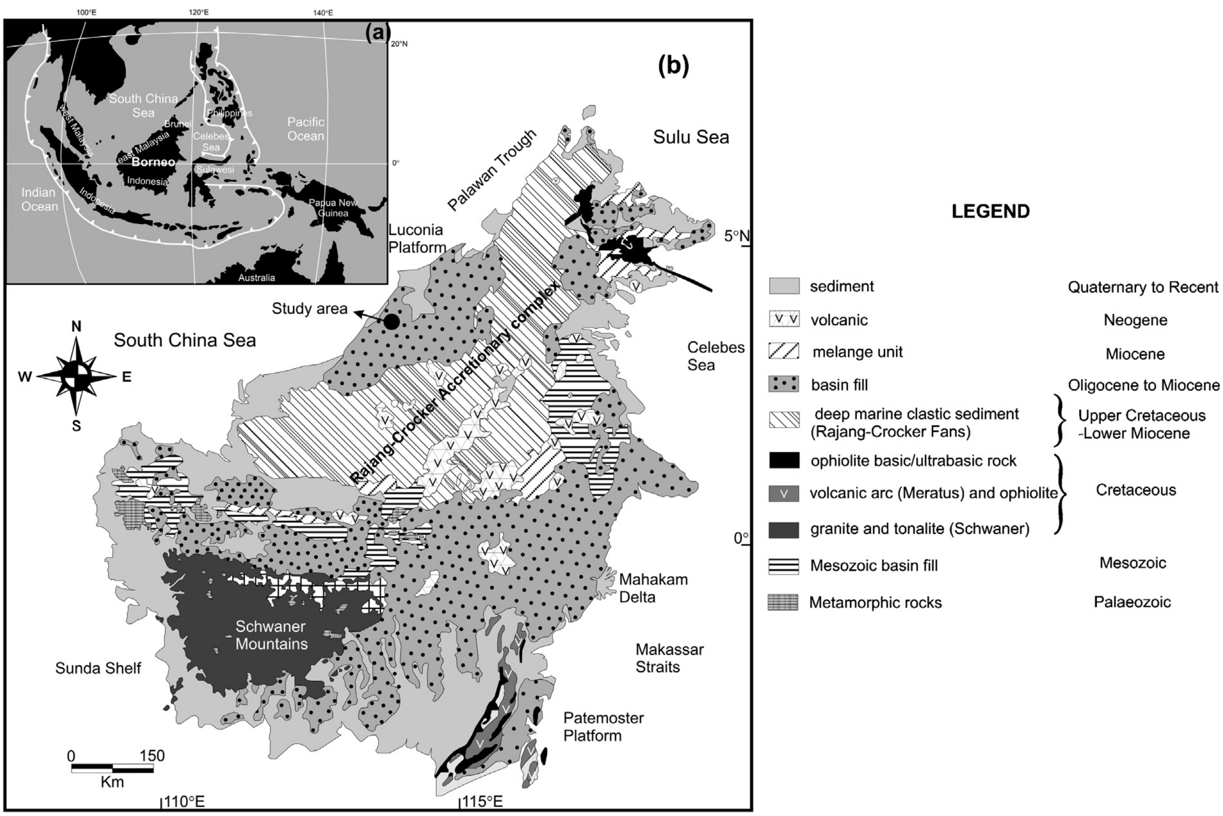

Fig. 1. (a) Location and (b) geology of the Borneo Basin (after Hall et al., 2008). East Malaysia hosts the western and north-western parts of the basin.

River and tributaries (Hutchison, 1989). They are underlain by Palaeogene molasse sediments and geology of the sub-surface rocks is unknown as the oil exploration wells have not penetrated into the deeper sequences (Liechti et al., 1960). The Nyalau, Setap, Tangap, Sibuti, Belait, Lambir, Miri and Tukau Formations are exposed in the north-western part of the Borneo Basin and range in age from Oligocene to Pliocene (Fig. 2).

The sedimentary rocks of Tukau Formation are preserved in a relatively simple synclinal structure dissected by strike–slip fault systems and consists of both clay and sandstone beds. The lenticular-shaped channelized deposits are present both at the lower and upper parts of the section. They are composed of medium to coarse grained sandstone with occasional micro-conglomerates at the channel base, representing deposition in a shoreface environment (Kessler, 2010). Absence of foraminifers (except for brackish water forms) and presence of lignite layers and amber balls in layered strata inferred that the Tukau Formation was deposited in a coastal plain (Hutchison, 2005). However, the age of the Formation is uncertain as Wilford (1961) could not determine the age from the brackish water fossil foraminifers present in the sediments. We have considered the stratigraphy to assume that the sedimentary rocks of Tukau Formation belong to the age range between Upper Miocene and Lower Pliocene (i.e. Neogene) as it conformably overlies the Lambir Formation (Mid-Late Miocene) near Sungai Liku in the eastern Lambir Hill.

3. Material and methods

A total of 15 sediment samples were collected from the lower part of the Tukau Formation exposed in the northwest Sarawak of east Malaysia (Fig. 2). The samples were oven dried at 40 °C, homogenized and subsequently powdered to 230 mesh in an agate mortar. The oxides of 10 major elements (Si, Al, Ti, Fe, Ca, Mg, Na, K, Mn and P) were measured in fused discs and trace elements (Rb, Sr, Ba, Pb, Th, Zr, Y, Sc, V, Cr, Co, Ni, and Zn) were analyzed in pressed pellets after the methods of Verma et al. (1996) and Lozano and Bernal (2005) in a Siemens SRS 3000 wavelength dispersive X-ray fluorescence (XRF) spectrometer. The precision of the analysis is <10% for both major and trace elements (Roy et al., 2010; Kessler and Nagarajan, 2012). Identification of different minerals and their abundance were carried out in a Siemens D 5000 X-ray diffractometer in 2θ range of 4 and 70° and using Cu-tube as the X-ray source. The clay minerals were identified by comparing diffractograms generated from un-treated bulk sample and diffractograms obtained after heating the same sample up to 500 °C (Brown and Brindley, 1980).

4. Results

4.1. Major elements

The samples from Tukau Formation show variable geochemical composition. Based on the classification diagram of Herron (1988), the sedimentary rocks are divided into different sandstones such as wacke, arkose, subarkose, litharenite, sub-litharenite, Fe-sandstone and quartz arenite (Fig. 3). Due to the less number of samples in each sub-group, we grouped sub-litharenite and sub-arkose samples into litharenite and arkose, respectively. Table 1 presents the description of different geochemical indices calculated for the samples and Table 2 shows the concentrations of major element oxides and different elemental ratios in the sandstones. Both quartz arenite and wacke show homogeneous composition compared to the rest. SiO_2 and Al_2O_3 are the two abundant elements and are negatively correlated ($r^2 = 0.9$). Quartz arenites are enriched in SiO_2 (96.8–98.9%) compared to Fe-sandstone (88.3%), litharenite (78–97.3%), arkose (73.1–95.3%) and wacke (68.1–72%). Wacke (17.2–19.9%), arkose (3–15%), and litharenite (2–10.5%) have higher contents of Al_2O_3. Both K_2O (2.4–3%) and MgO (0.5–0.6%) are higher in wacke. The TiO_2 content is low in quartz arenite (0.1–0.2%) and Fe-sandstone (0.3%) and higher in wacke (0.8–1%). Both arkose (0.2–0.8%) and litharenite (0.1–0.6%) show variable TiO_2 concentrations. The concentrations of CaO, Na_2O and P_2O_5 are low and vary between 0–0.2%, 0–0.2% and 0–0.1%, respectively. The quartz arenite, arkose, litharenite and wacke have SiO_2 concentrations similar