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Tectonic evolution of the Malay Peninsula inferred from Jurassic to Cretaceous paleomagnetic results

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ABSTRACT

A primary remanent magnetization is identified in the Jurassic-Cretaceous red bed sandstones of the Tembeling Group in Peninsular Malaysia. This high-temperature magnetic component is unblocked at 680–690 °C, revealing a clockwise deflected direction of $D_s = 56.8°$, $I_s = 31.6°$ (where $k_s = 8.5$, $\alpha_{95} = 11.3°$ and N = 22) in stratigraphic coordinates. The primary origin of this component is ascertained by a positive fold test and a geomagnetic polarity reversal in the Kuala Wau section. Secondary remanent magnetizations are identified in the rocks of the Tembeling and Bertangga basins, which indicate a counter-clockwise deflection in the geographic coordinates ($D_g = 349.1°$, $I_g = 15.3°$ where $k_g = 11.8$, $\alpha_{95} = 5.1°$, N = 72). The comparison with the expected paleomagnetic directions from the 130 Ma and 40 Ma Eurasian poles indicates two-stages of tectonic movement in the southern Malay Peninsula: (1) a clockwise rotation of 61.1° ± 11.9° accompanied by a 13.3° ± 8.1° southward displacement after the Cretaceous; and (2) a subsequent counter-clockwise rotation of 18.5° ± 5.0° to the present day position. The first stage of rotation is ascribed to tectonic deformation caused by the indentation of India into Asia after 55 Ma, while the second stage is attributed to the collision of the Australian Plate with SE Asia after 30–20 Ma. The present paleomagnetic results from the Jurassic-Cretaceous Tembeling Group thus reveal impacts of both of these collisions on SE Asia in general and on Peninsular Malaysia in particular.

1. Introduction

The India-Asia collision marks one of the most important tectonic episodes that occurred on the meso-Cenozoic Earth. This event gave rise tectonic deformation on Southeast (SE) Asia (Fig. 1). The three-decade-old "extrusion" model proposed by Tapponnier and colleagues (Tapponnier et al., 1982; Peltzer and Tapponnier, 1988; Replumaz and Tapponnier, 2003) has proved highly influential in explaining the subsequent regional-scale deformation pattern for the Asian continent. Based on analogue models, they envisaged that India's indentation into Asia induced clockwise (CW) and the south-eastward displacement to mainland SE Asia and its offshore extension, "Sundaland" (Borneo, Java Sumatra) from the main part of the continent. It is clear from paleomagnetic and geological data that the near-field areas of Indochina have moved in the manner described by Tapponnier et al. (1982) (Fig. 1) e.g., CW rotation (Yang and Besse, 1993; Aihara et al., 2007; Tanaka et al., 2008; Takemoto et al., 2009; Otofuji et al., 2010, 2012; Kornfeld et al., 2014) and the south-eastward displacement of SE Asia (Leloup et al., 1995; Ali et al., 2010; Sato et al., 2011; Cogné et al., 2013; Tsuchiyama et al., 2016).

The southern part of Sundaland, however, does not fit this pattern. For instance, paleomagnetic declinations from Cenozoic rocks from Peninsular Malaysia, Borneo, western Sulawesi and Celebes Sea indicate counter-clockwise (CCW) (Fig. 1) rather than CW, rotations. (Haile et al., 1977; Haile, 1978; Sasajima et al., 1980; Schmidtke et al., 1990; Shibuya et al., 1991; Fuller et al., 1999; Richter et al., 1999). Moreover latitudinal motions are thought to be negligible (Fuller et al., 1999). Furthermore, Clift et al. (2008) suggest that a plate boundary may tectonically decouple mainland SE Asia from large portions of Sundaland.

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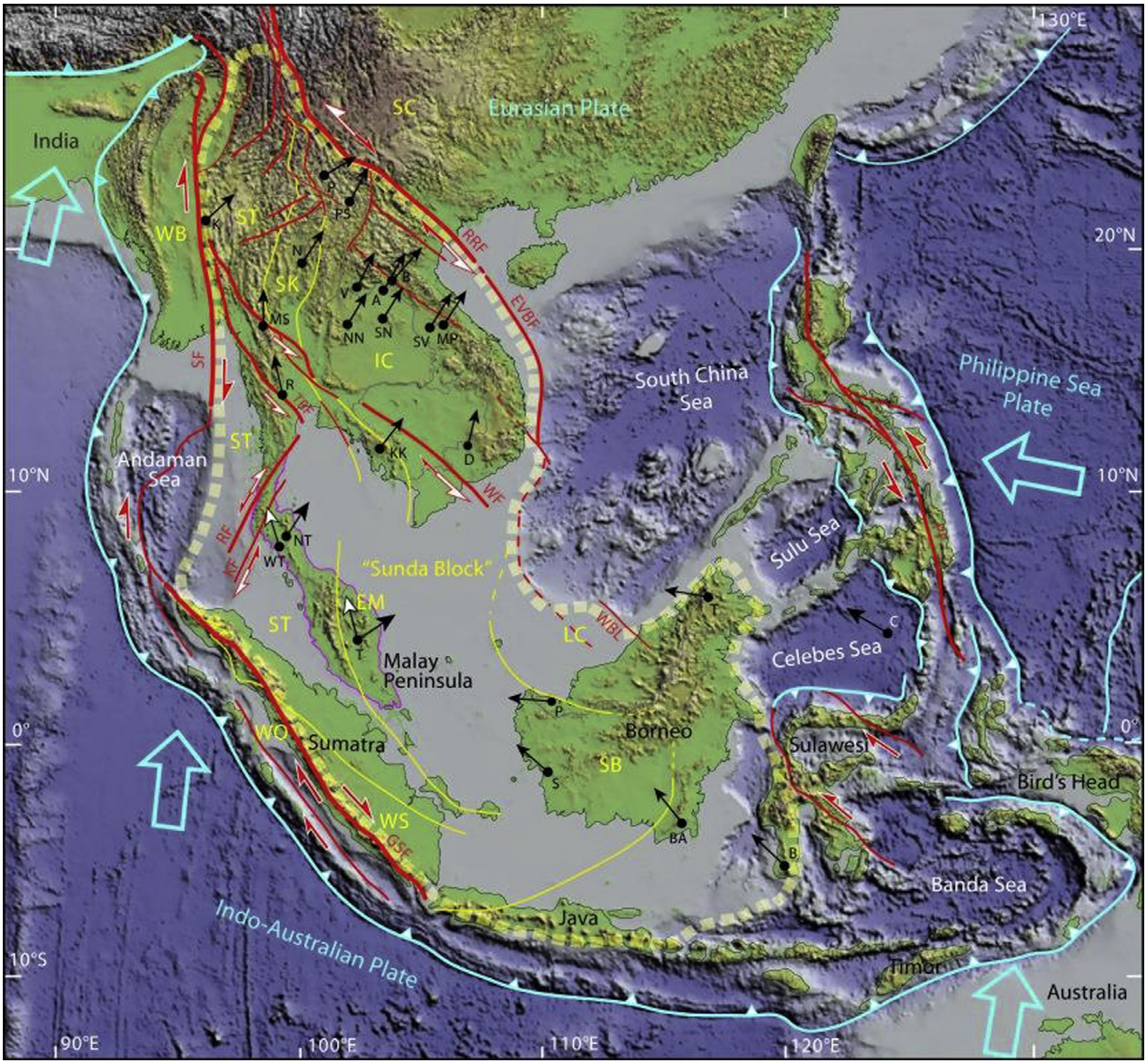

Fig. 1. Structural sketch map, and tectonic subdivision of the modern Sunda block and surrounding regions (modified from Morley (2012), Hall (2012) and Metcalfe (2013)). Base map from the ETOPO2 Shuttle Radar Topography Mission (SRTM) image. The Sunda block (*s.l.*) consists mainly of the Indochina (IC), Sukhothai (SK), Shan-Thai (ST), East Malaya (EM), West Sumatra (WS), Southwest Borneo basement (SB), and Luconia (LC) blocks. Other blocks include the: South China (SC) and West Burma (WB). The faults or tectonic lines include the: Red River fault (RRF), East Vietnam Boundary fault (EVBF), Wang Chao fault (WF), Sagaing fault (SF), Three Pagodas fault (TPF), Ranong fault (RF), Khlong Marui fault (KF), Great Sumatran fault (GSF), Philippine fault (PF), and West Baram line (WBL). Half arrows indicate directions of strike-slip fault movement; white (or red) half arrows for ductile (or brittle) shear sense. Black arrows with dot ends indicate the observed declinations of the late Mesozoic–Cenozoic rocks in each area (Extended data Table 3); closed (or open) arrows indicate data from primary (or secondary) remanent magnetizations. Abbreviations attached to the arrows are based on locations of palaeomagnetic studies, as referred to in Table 3. T = study area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

The aim of this study is therefore to deduce the location of this cryptic tectonic feature by identifying areas within the Malay Peninsula with distinctive palaeomagnetic histories (based on their vertical axis rotations and/or latitudinal motion histories). A CCW tectonic rotation of the Malay Peninsula is predicted by Richter et al. (1999), although their interpretation is based only on secondary magnetization found in rocks of the Jurassic-Cretaceous Tembeling Group from Peninsular Malaysia. Hence, a discovery of primary remanent magnetization from the area is required to confirm the predicted phenomenon of CCW rotation.

2. Geological setting

SE Asia is a complex collage of continental fragments, consisting mainly of Indochina, Sukhothai and Sibumasu (including the Inthanon zone) blocks from east to west (Metcalfe, 2011; Morley, 2012; Sone et al., 2012) (Fig. 1). These blocks accreted to the southeastern margin of the proto-Asian continent by the Late Triassic after breaking from Gondwanaland and drifting northward. In the present-day tectonic framework SE Asia is bounded by the Indian-Australian Plate to the west and the Philippine Sea Plate to the east.

Peninsular Malaysia is divided into three north-south extended geological belts; the western, central and eastern belts (Fig. 2a). The central and eastern belts are regarded as parts of a single tectonic block (the East Malaya Block) derived from Gondwana in the Devonian. In contrast, the western belt forms part of the Sibumasu Block, which was also derived from Gondwana later in the Permian. The western belt and the East Malaya Block collided with each other along the Bentong-Raub suture zone in the Late Triassic (Ng et al., 2015).