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Spatial variations in the effective elastic thickness of the lithosphere in Southeast Asia

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ABSTRACT

As a proxy for long-term lithospheric strength, detailed information on lateral effective elastic thickness (T_e) variations can aid in understanding the distribution pattern of surface deformation and its response to long-term forces. Here we present high-resolution maps of spatial variations of T_e for the complex SE Asian region by analyzing the coherence of topography and Bouguer gravity anomaly data. We find that after considering the gravity deficit of less dense sediment, the recovered T_e maps are more representative of the geology, particularly in elongated rift basins. The results show that the T_e variation pattern in SE Asia, in general, agrees well with its tectonic provinces and major tectonic boundaries. The oceanic basins, the Indosinian suture zones between the Indochina and Sibumasu blocks, and the Makassar Strait are characterized by low T_e, while moderate and high T_e values are recovered in the Khorat plateau, West Burma, the Singapore Ridge, the Con Song Swell, Borneo, the northern Australian margin and the Molucca Sea. The T_e pattern in the south Indonesian margin is complicated by the approach and collision of oceanic plateaus and seamounts with the fore-arc region. The heterogeneous strength features are consistent with the complex assemblage of different tectonic units, and significant deformation during Cenozoic tectonic events. In the Indochina Peninsula, the extruded displacement during the India-Eurasia collision might have been partitioned and absorbed by the combined mechanism of the extrusion and viscous tectonic models. As a result, the offshore displacements of the major strike-slip faults in the South China Sea are much smaller than originally assumed, thus having less effect on the development of the South China Sea than other mechanisms such as the slab pull of the proto-South China Sea. Since the displacement driven by the boundary tectonic forces has been greatly absorbed and decreased by subduction and deformation in the active margins and adjacent weak regions, the motion velocity of the interior regions is greatly lower than the boundary active margins, and they are largely free of seismicity and volcanism. Our results suggest that East Borneo might share a similar crustal basement, and represent a broad tectonic zone of the destroyed Meso-Tethys Ocean extending from West-Middle Java, through East Borneo to northern Borneo of the Sarawak and Sabah. The Indosinian zones between the Indochina and Sibumasu blocks might extend further southeastward across Billiton Island to offshore of southern Borneo, and the Singapore platform and SW Borneo might belong to the same block. The results also show that the internal load fraction F is high in the coastal area of South China, the northern margin of the South China Sea, and the coastal area of Indochina, which, in general, agrees with the distribution of a high-velocity lower crustal layer and Late Cenozoic basaltic rocks.

1. Introduction

Mechanical properties of the lithosphere are of primary importance in controlling its response to long-term forces and, therefore, the temporal evolution and spatial configuration of the lithosphere (e.g., Tassara et al., 2007; Burov, 2011). Lithospheric strength can be measured by analyzing the resistance to vertical deformation (>10^5 year), which can be parameterized as flexural rigidity or, equivalently, its effective elastic thickness, T_e (Watts, 2001). The effective elastic thickness corresponds to the thickness of an idealized elastic beam or plate that would bend similarly to the actual lithosphere under the same applied loads (Watts, 2001), and primarily depends on parameters of power law creep, i.e., temperature, crustal thickness, fluid, lithologic variations, and to a lesser degree strain rate (Burov and Diament, 1995; Lowry and Smith, 1995; Ranalli, 1997). Therefore, although T_e does not represent an actual depth to the base of the mechanical lithosphere, it could provide important insight into its rheology and state of stress, and

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could be used to improve our understanding of the relationship between tectonic styles, distribution of earthquakes and lithospheric rheology in various tectonic settings (Lowry and Smith, 1995; Tassara et al., 2007; Pérez-Gussinyé et al., 2007).

Southeast Asia (SE Asia), located in the southeastern part of the Eurasian Plate (Fig. 1), comprises a complex assemblage of allochthonous continental fragments, volcanic arcs, suture zones and marginal oceanic basins (e.g., Metcalfe, 2011; Hall, 2012). It is bounded by tectonically active margins which exhibit intense seismicity and volcanism. On the contrary, the interior of SE Asia is largely free of seismicity and volcanism. However, this tectonically quiet feature does not mean that the interior of SE Asia is a single homogeneous block (Hall and Morley, 2004; Takemoto et al., 2009; Yang et al., 2015). Therefore, a high resolution spatial variation map of T_e is necessary for understanding the tectonic formation variation, earthquake distribution, stress and strain transfer, and examining the different dynamic models proposed to explain large-scale tectonic structure in SE Asia (e.g., Tapponnier et al., 1982; England and Houseman, 1986). Since the strength contrast between different lithospheric domains could control the localization of deformation in response to tectonic forces (Tassara et al., 2007), a high-resolution T_e map might provide some valuable clues of the extension of block boundaries in regions which remain understudied due to difficulty of access, vegetation and climate (Hall and Spakman, 2015).

Spectral methods are one of the most commonly used methods to calculate the effective elastic thickness (Kirby, 2014). The cross-spectral analysis of gravity anomalies and topography permits assessment of the nature of isostatic compensation within a region, and has been widely applied to the estimation of lithospheric elastic effective thickness over a wide range of tectonic environments (e.g., Lowry and Smith, 1995; Swain and Kirby, 2006; Tassara et al., 2007; Pérez-Gussinyé et al., 2007; Mao et al., 2012; Jiménez-Díaz et al., 2014). In the following sections, we first briefly introduce the wavelet method (Kirby and Swain, 2004, 2009, 2011) and data employed for estimating T_e, then present the high-resolution spatial variations of T_e and the fraction of the initial internal load in SE Asia. Finally, we examine the T_e variations in different tectonic provinces, and discuss the possible tectonic implications of the spatial variations of T_e and the internal load fraction.

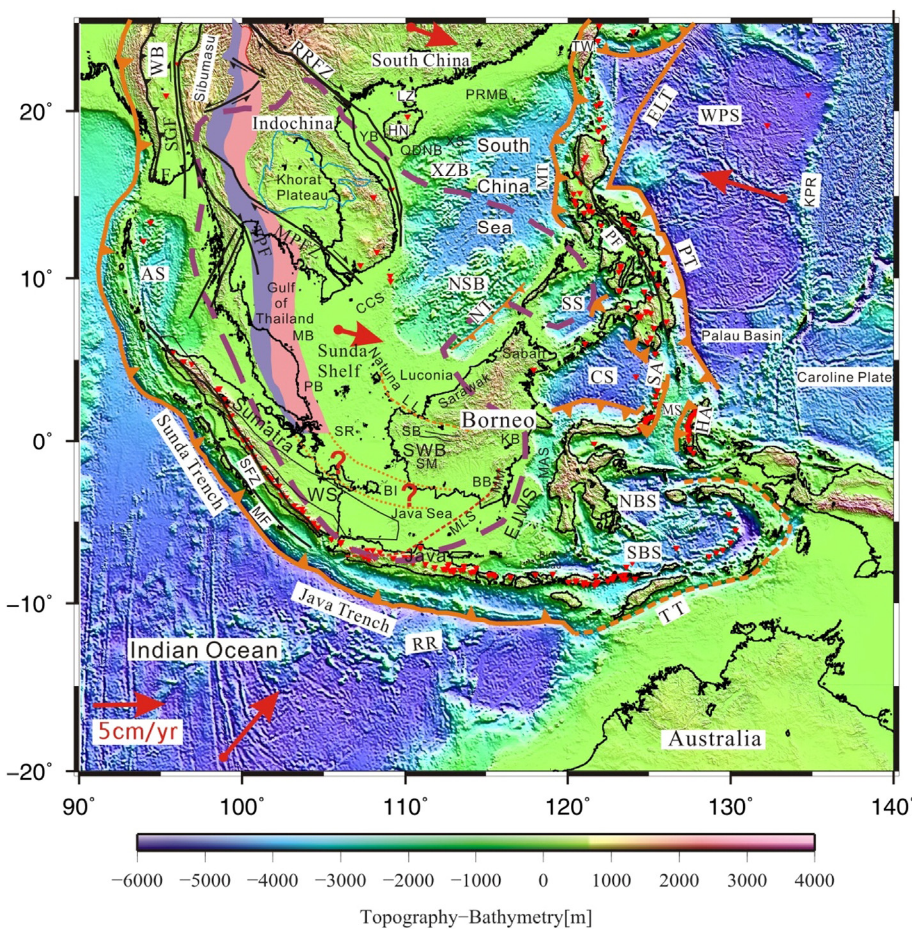

Fig. 1. Tectonic outline and topography/bathymetry in and around SE Asia. The purple and pink regions denote the Indosinian suture zones and the relative Permian and Triassic Granite Belt between the Indochina Block and the Sibumasu Block, respectively. From north to south, the former comprises the Changning–Menglian suture in southwest China, the Inthanon suture in Thailand, and the Bentong-Raub suture in the Malay Peninsula, the latter comprises the LincangGranitoid Batholith in China, Sukhothai in Thailand, and East Malaya in the Malay Peninsula) in the east (Metcalfe, 2011). The region with question marks encompassed by the thin, dotted orange thin curves denotes the supposed southeastward extension of the Indosinian suture zones and the Granite Belt. The region encompassed by the thick, dashed, deep red curve is the undeformed core of SE Asia suggested by Simons et al. (2007). Red arrows denote the approximate (absolute/ITRF2000) motions of different plates (after Simons et al., 2007). The red triangles denote Holocene volcanoes from the Global Volcanism Program. Abbreviations: AS, Andaman Sea; BB, Barito Basin; BI, Billiton Island; CCS, Con Song Swell; CS, Celebes Sea; EJWS, East Java-West Sulawesi Block; ELT, East Luzon Trough; HA, Halmahera Arc; HN, Hainan Island; KB, Kutai Basin; KPR, Kyushu-Palau Ridge; LL, Lupar Line; LZ, Leizhou Peninsula; MAS, Makassar Strait; MB, Malay Basin; MF, Mentawai Fault; MLS, Meratus and LukUlo Sutures; MM, Meratus Mountains; MPF, Mae Ping Fault; MS, Molucca Sea; MT, Manila Trench; NBS, North Banda Sea; NSB, Nansha Block (Dangerous Grounds and Reed Bank); NT, Nansha Trough (NW Borneo Trough); PB, Penyu Basin; PF, Philippine Fault; PRMB, Pearl River Mouth Basin; PT, Philippine Trench; QDNB, Qiongdongnan Basin; RR, Roo Rise; RRFZ, Red River Fault Zone; SA, Sangihe Arc; SB, Semitau Block; SBS, South Banda Sea; SFZ, Sumatra Fault Zone; SGF, Sagaing Fault; SM, Schwaner Mountains; SR, Singapore Ridge; SS, Sulu Sea; SWB, Southwest Borneo Block; TPF, Three Pagodas Fault; TT, Timor Trough; TW, Taiwan Island; WB, West Burma; WPS, West Philippine Sea; WS, West Sumatra Block; XS, Xisha Trough; XZB, Xisha-Zhongsha Block; YB, Yinggehai Basin.