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Effective elastic thickness and mechanical anisotropy of South China and surrounding regions

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ABSTRACT

South China and surrounding regions extend from the eastern Tibetan plateau, through the tectonically stable Sichuan basin and the broad Mesozoic magmatic and fold belt, to the trench-arc-basin system in the western Pacific which provide an ideal place to study deformation of the continental lithosphere under long-term magmatism and oceanic subduction. We obtained the effective elastic thickness (T_e) and its anisotropy of South China and surrounding regions from the analysis of coherence between topography and satellite gravity using wavelet methods. The T_e values of the study area vary from 2 to 75 km, with relatively low T_e values (≤30 km) along the tectonic boundaries, the North–South Gravity Lineament (NSGL) and seismic zones, and in the regions with high surface heat flow. The evenly low T_e values in the Lower Yangtze region and the Cathaysia block can be attributed to the long-lived subduction of the Paleo-Tethys and the Paleo-Pacific ocean basins beneath the South China block (SCB). The NSGL in the SCB may separate the unmodified (high T_e) and thermally weakened (low T_e) continental lithosphere due to oceanic subduction. Despite different distances to the tectonic boundaries, earthquakes occur more frequently in regions with T_e values of 10–30 km, implying strain concentration in the low-T_e regions. A positive correlation between seismic activity and the magnitude of T_e anisotropy suggests that a highly anisotropic mechanical structure will promote strain localization and brittle failure in the lithosphere. The poor correlation between the weak axis of T_e anisotropy and the dynamic indicators of the present tectonic regime (the shear-wave splitting direction, the maximum horizontal compressive stress direction) confirms that T_e anisotropy mainly reflects tectonic inheritance of the continental lithosphere.

1. Introduction

Spatial variation of the lithospheric strength is a key to link the distribution of orogens, faults and earthquakes with dynamic forces (e.g., plate boundary forces). Unfortunately, it is very difficult to measure the lithospheric strength directly. As a proxy for the integrated lithospheric strength, the effective elastic thickness of the lithosphere (T_e) is defined as the thickness of an ideal elastic plate that floats over viscous fluid and would bend by the same amount as the lithosphere under the same applied loads (e.g., Watts, 2001). The relationship between T_e and the flexural rigidity (D) is

$$D = \frac{ET_e^3}{12(1-\nu^2)} \quad (1)$$

where E is the Young's modulus and ν is the Poisson's ratio of the lithosphere. Because T_e is a measure for the integrated yield strength of a lithosphere that is both brittle and ductile, the lateral variations of T_e can be used to investigate the correlation between surface tectonics and lithospheric structure (Pérez-Gussinyé et al., 2009), and to predict the strain concentration and hence locations of brittle failure in the lithosphere (Audet et al., 2007; Lowry and Smith, 1995). For the oceanic lithosphere that is young and can be approximated as a single-layer rheological structure, T_e depends on the thermal age of the lithosphere and varies from 2 to 50 km (Burov and Watts, 2006; Watts, 1978). By contrast, the continental lithosphere has a long evolution history, very heterogeneous composition and a multi-layer rheological structure. T_e of the continental lithosphere is primarily controlled by temperature, composition and state of stress of the lithosphere, with values from 2 km in some active orogens and rifts to ~100 km in stable cratons (Burov and Diament, 1995; Hyndman et al., 2009; Pérez-Gussinyé et al., 2004).

T_e anisotropy reflects the azimuthal difference in mechanical strength of the lithosphere and may be influenced by many factors including localized brittle failure of crustal rocks under deviatoric stress (Lowry and Smith, 1995), “frozen” deformation by alignment of olivine in the lithospheric mantle (Kirby and Swain, 2006; Simons et al., 2003), and large-scale tectonic features and faults (Audet and Mareschal, 2004; Burov et al., 1998). T_e anisotropy fills the gap between deep

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anisotropy (e.g., seismic anisotropy) and surficial mechanical anisotropy. Different relationships between the weak axis of T_e anisotropy (φ_e) and dynamic indicators (e.g., shear-wave splitting directions (φ_s), maximum horizontal compressive stress direction (φ_h)) have been proposed, which provide valuable information on the evolution of the continental lithosphere. For example, Kirby and Swain (2006) found that φ_e is nearly perpendicular to φ_s in Australia, while Audet et al. (2007) obtained φ_e parallel to both φ_s and φ_h in western Canada, suggesting that T_e anisotropy is not only determined by the present tectonic regime. According to the lack of preferred angular relationship between T_e anisotropy and the dynamic indicators in a worldwide comparison, Audet and Burgmann (2011) proposed that T_e anisotropy is mainly inherited from pre-existing tectonic structures.

South China and surrounding regions extend from the eastern Tibetan plateau, through the cratonic Sichuan basin and the broad Mesozoic magmatic and fold belt, to the trench-arc-basin system in the western Pacific (Fig. 1). So far our knowledge about T_e and T_e anisotropy of South China is only from a global study of Audet and Burgmann (2011), which hampers our understanding of the complex deformation in the continental lithosphere under long-term magmatism, oceanic subduction and continental collision. In addition, the relationships of T_e and T_e anisotropy with other geophysical proxies are not clear yet. It is necessary to perform an integrated study to clarify tectonic implications of T_e and T_e anisotropy.

In this paper, we present high-resolution T_e and T_e anisotropy of South China and surrounding regions using a wavelet coherence method. The low T_e values in eastern part of South China correspond to the high heat flow and widespread Mesozoic and Cenozoic igneous rocks. The correlation between the earthquake distribution, T_e and T_e anisotropy suggests that the way of the lithospheric stress release strongly depends on T_e. Comparison of T_e anisotropy with the dynamic indicators of φ_s and φ_h confirms that T_e anisotropy is mainly controlled by pre-existing tectonic structures.

2. Geological setting

The South China block (SCB) was formed by collision of the Yangtze and Cathaysia blocks around 0.8–1 Ga (Li et al., 2002; Zhou and Zhu, 1993). Recent U/Pb and Sm/Nd dating on ophiolitic rocks of the Song Ma suture zone (northern Vietnam) indicates the existence of Paleotethyan lithospheric remnants at 387–313 Ma between South China and Indochina (Vuong et al., in press). The final closure of the Paleo-Tethys ocean and subsequent subduction of the Indochina block beneath the SCB probably occurred in the early-middle Triassic along the Song Ma suture zone, according to the coeval eclogite facies (243–238 Ma) and high-pressure granulite facies metamorphism (233 ± 5 Ma) in this region (Nakano et al., 2008, 2010), ductile deformation and high-temperature metamorphism (250–240 Ma) in northern Vietnam (Carter et al., 2001; Lepvrier et al., 2004), and syn-collisional granites in the Yunkai massif (250–242 Ma) and the Shiwandashan granitoid belt (236–230 Ma) in the southwestern SCB (e.g., Deng et al., 2004; Wang et al., in press; Zhou et al., 2006). In the north, the SCB subducted beneath the North China block in the early Triassic and the syn-collisional exhumation of the continental crust resulted in the widespread high-pressure and ultrahigh-pressure metamorphic rocks in the Qinling-Dabie-Sulu orogen (e.g., Liou et al., 2009; Xu et al., 2009; Zheng, 2010). By the late Triassic, the South China, North China, Indochina, Simao and Sibumasu blocks have accreted to form the proto-East Asia (e.g., Lepvrier et al., 2004; Metcalfe, 2006).

South China is famous for the massive Mesozoic granitoids and volcanic rocks (Fig. 2). The early Mesozoic magmatism (Indosinian episode, T_1–T_3) in the SCB is characterized by dominant S-type granites and minor calc-alkaline I-type granites (e.g., Li and Li, 2007; Zhou et al., 2006), with coeval volcanic rocks restricted in the western Youjiang basin (Ren et al., 1999). The outcrop area of the Triassic

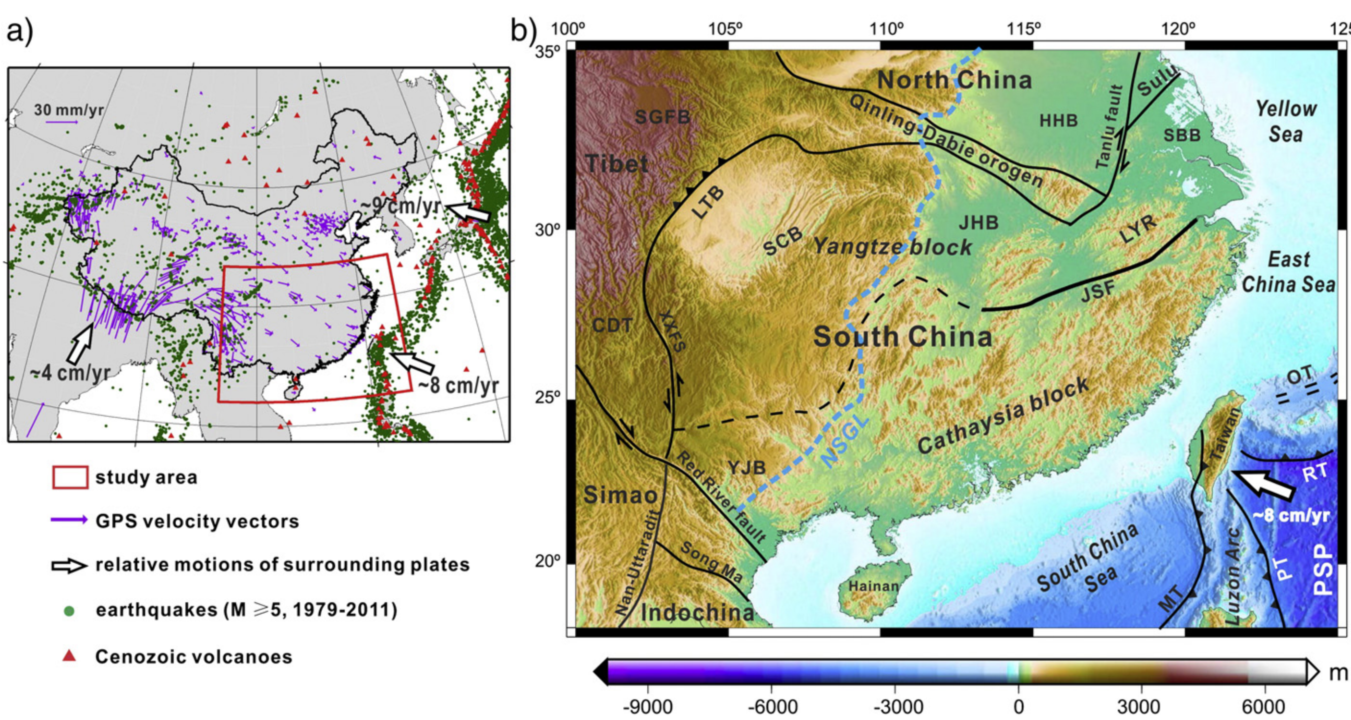

Fig. 1. Topography/bathymetry (a) and tectonic outline (b) of South China and surrounding regions. The solid black lines refer to faults and block boundaries and the dashed black line indicates a suspicious extension of the Jiangshao fault (modified after Yin, 2010). Both the GPS velocity vectors and the relative motions of surrounding plates are with respect to the stable Eurasia (after Wang et al., 2001). The bold arrows denote the motion directions of the Indian, Pacific and the Philippine Sea plates relative to the Eurasian plate. The seismic data are from IRIS, and the volcanic data are from Global Volcanism Program. Abbreviations: CDT: Chuandian terrane; HHB: Hehuai basin; JHB: Jianghan basin; JSF: Jiangshao fault; LTB: Longmenshan thrust belt; LYR: Lower Yangtze region; MT: Manila Trench; NSGL: North–South Gravity Lineament; OT: Okinawa Trough; PSP: Philippine Sea plate; PT: Philippine Trench; RT: Ryukyu Trench; SBB: Subei basin; SCB: Sichuan basin; SGFB: Songpan-Ganzi fold belt; XXFS: Xianshuihe–Xiaojiang fault system; YJB: Youjiang basin.