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Variations of the effective elastic thickness over China and surroundings and their relation to the lithosphere dynamics

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ABSTRACT

The effective elastic thickness (T_e) characterizes response of the lithosphere to a long-term tectonic loading. As a proxy of the lithospheric strength, T_e can be used to address mechanical behavior and deformation of the blocks with complex geological structure. Here we use the multitaper coherence method to determine spatial variations of T_e in China and surroundings based on the topography and Bouguer gravity anomaly data. The results show that the T_e values are high (>70 km) over the cratons, e.g. India craton, the Siberian Craton, North China Block and also variations of these values are significant over these blocks. Low T_e corresponds to the young orogens, e.g. Himalayas, Altun Shan–Qilian Shan–Longmenshan, Qinling–Dabie, and Daxing'anling–Taihang Mountains etc. Combined with other data, the lateral variations of T_e within the North China and South China Blocks and the Tibetan Plateau indicate that the lithospheric strength in China Mainland depends on both lithospheric structure and mantle dynamics. We guess that during the Mesozoic–Cenozoic period, the strength of the lithosphere might have been significantly altered by the thermodynamic processes associated with the India–Eurasia collision in the southwest and the subduction of the Pacific plate in the east. The T_e variations also play a major role in the lithospheric evolution and deformation since the Mesozoic.

1. Introduction

Mechanical strength is one of the primary factors in controlling deformation processes of the lithosphere in response to the long-term ($>10^5$ yr) tectonic loading (Burov and Diament, 1995). It is commonly described by the flexural rigidity (D) or effective elastic thickness of the lithosphere (T_e) (Watts, 1978). These parameters are related as: $D = ET_e^3/[12(1-\sigma^2)]$, where E is the effective Young's modulus and σ is the Poisson's ratio. T_e of the continental lithosphere depends on its composition, structure (e.g. crust–mantle decoupling or coupling) and temperature distribution (Burov and Diament, 1995; Tesauro et al., 2009a, 2009b, 2012). In the past forty years, a lot of studies were focused on T_e determinations in various continental regions, and finding a link of this parameter with the lithosphere evolution and dynamics (e.g. Banks et al., 1977; Bechtel et al., 1990; Pérez-Gussinyé and Watts, 2005). For the first time, Lewis and Dorman (1970) calculated an isostatic response function between the gravity field and topography to yield the compensating density distribution over the conterminous United States assuming a local compensation model. Later, Banks et al. (1977) adopted a regional compensation model to estimate T_e and density structure of the United States. McNutt and Parker (1978) have calculated flexural rigidity of the lithosphere in Australia and found it to be considerably different from that one of the United States. Zuber et al. (1989) have also determined T_e for separate tectonic units in Australia, which indicate that T_e increases with time since last modifications of the lithosphere. Based on the T_e variations in Europe, Pérez-Gussinyé and Watts (2005) pointed out that the strength of the continental lithosphere could reflect the processes, which formed plate structure. Recent studies of the T_e distribution and its anisotropy on a global scale provided evidence that the pre-existing mechanical structure had a significant influence on continental deformation and evolution (Audet and Bürgmann, 2011).

Compared to other regions, only few studies on T_e variations over China Mainland were carried out. Wang and Xu (1996) estimated the average T_e of the main blocks by analyzing a mechanism of the isostatic compensation beneath China. Braitenberg et al. (2003) and Jordan and Watts (2005) calculated spatial variations of T_e over the Tibetan Plateau. In addition, several studies were performed for limited regions and along 2D profiles (e.g. Yuan et al., 2002; Zhao et al., 2004; Fielding and McKenzie, 2012).

The Chinese Mainland is not a single giant craton; it comprises a number of the stable blocks (Fig. 1): including the North China

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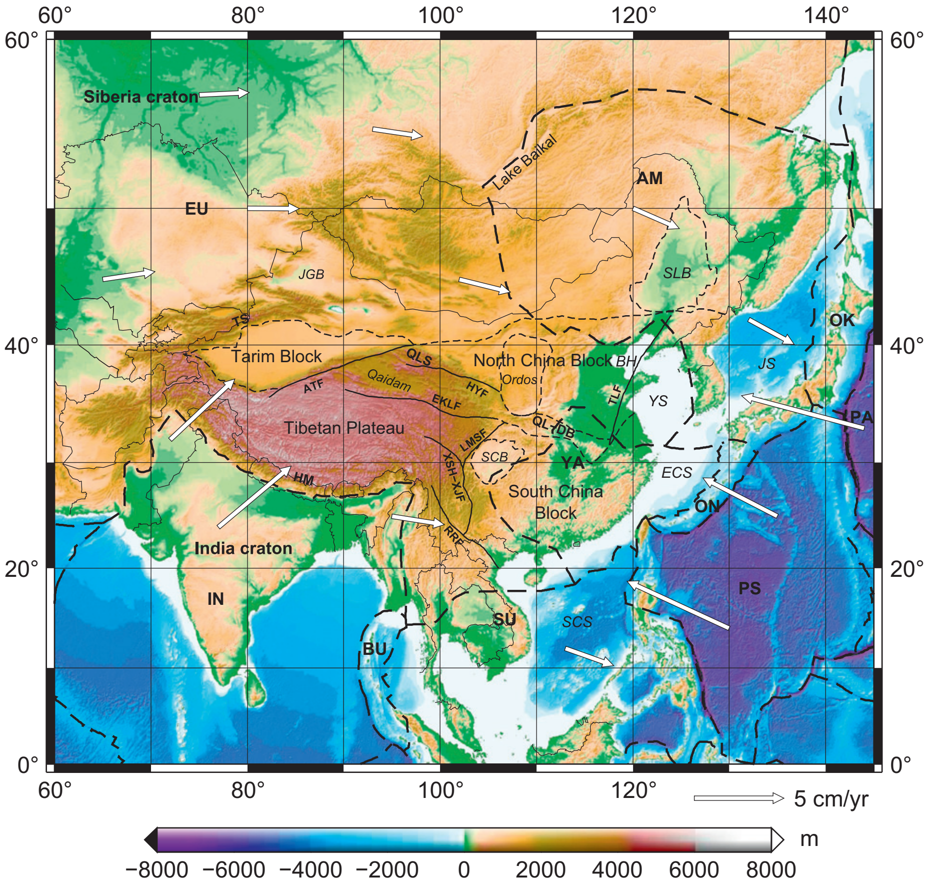

Fig. 1. Topography and geotectonic setting of China and adjacent regions. The bathymetry and topography are from ETOPO2v2 digital data (http://www.ngdc.noaa.gov/mgg/global/etopo2.html). Thick dashed lines are the boundaries of the plates (AM, Amur; BU, Burma; EU, Eurasia; IN, India; ON, Okinawa; OK, Okhotsk; PA, Pacific; PS, Philippine Sea; SU, Sunda; YA, Yangtze) from model PB2002 (Bird, 2003). White arrows denote vectors of the plate motion with respect to GSRM v1.2 (Kreemer et al., 2003) as calculated with the Plate Motion Calculator (http://www.unavco.org/community_science/science-support/crustal_motion/dxdt/model.html). The medium solid lines with names are the major faults (ATF, Altyn-Tagh fault; EKLF, East-Kunlun fault; HYF, Haiyuan fault; LMSF, Longmenshan fault; RRF, Red River fault; TLF, Tan-Lu fault; XSH-XJF, Xianshuihe-Xiaojiang fault). Thin dashed lines denote the main tectonic units: BH, Bohai Sea; JGB, Junggar basin; QLS, Qilian Shan orogen; HM, Himalayan orogen; SCB, Sichuan basin; SLB, Songliao basin; ECS, East China Sea; SCS, South China Sea; QL-DB, Qinling–Dabie orogen; JS, Japan Sea; YS, Yellow Sea.

Block, South China Block, Tibetan Plateau and Tarim block, and several active orogens, e.g. Himalayas, Tien Shan and Qinling–Dabie. Several major processes control its tectonics: the rapid collision of the India–Australia plates with Eurasia in the southwest, the subduction of the Pacific and Philippine Sea plates in the east (Fig. 1), and the continental extension in the Baikal rift in the north (Schellart and Lister, 2005). Due to such complex structure and dynamics, it is necessary to investigate in detail T_e distribution for the whole Chinese mainland, in order to better understand evolution and deformation of the lithosphere and to characterize interaction between major blocks.

Up to now, several methods have been employed to estimate T_e, such as forward modeling of deformations (Karner and Watts, 1983), spectral techniques (i.e. admittance and coherence) based on the cross-spectral analysis of the gravity and topography data (Dorman and Lewis, 1970; Forsyth, 1985), and direct estimations of T_e based on the yield strength envelope (Goetze and Evans, 1979; Burov and Diament, 1992; Tesauro et al., 2009a, 2012). The topography and gravity data used in the spectral technique are widely available; therefore this technique is used more often than other methods. The coherence technique, which is based on a spectral analysis of the observed fields, is employed in this study. Used in the pioneer studies (Lewis and Dorman, 1970; Zuber et al., 1989; Bechtel et al., 1990), the periodogram spectral technique may result in a spectral leakage. In order to reduce the leakage, the multitaper technique (Thompson, 1982) was introduced to improve the coherence method (McKenzie and Fairhead, 1997; Simons et al., 2000). However, even with the multitaper technique the T_e values might be underestimated due to a limited size of the analyzing window. Later on, the wavelet technique has been suggested to estimate T_e (Stark et al., 2003; Kirby and Swain, 2004). Furthermore, Pérez-Gussinyé et al. (2007, 2009a, 2009b) have applied a window correction to reduce the bias caused by the multitaper method. They suggested merging the T_e values evaluated by windows with various sizes to obtain more accurate T_e estimations than that by the pure wavelet method.

In this study we employ the multitaper Bouguer coherence method (Pérez-Gussinyé et al., 2009a, 2009b) based on the topography and Bouguer gravity data analysis, to estimate T_e variations in China and surrounding areas (60°E–145°E, 0°N–60°N). First, the multitaper coherence technique is introduced. Then, we estimate spatial variations of T_e for China and surroundings. Finally, we discuss the results combined with the information from geology, GPS, and seismic tomography in order to understand a relation between the lateral variations of T_e, and lithospheric structure and dynamics of the main blocks (North China, South China, and Tibetan Plateau).

2. Multitaper Bouguer coherence method

The effective elastic thickness can be estimated by analyzing the spectral coherence between the external load (e.g. topography)