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Upper crustal anisotropy from local shear-wave splitting and crust-mantle coupling of Yunnan, SE margin of Tibetan Plateau

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The upper crustal anisotropy of Yunnan area, SE margin of Tibetan Plateau, is investigated by measuring the shear wave splitting of local earthquakes. The mean value of the measured delay times is 0.054 s and far less than that from Pms splitting analysis, indicating that the crustal anisotropy is contributed mostly from mid-lower crust. The fast polarization directions are mostly sub-parallel to the maximum horizontal compression directions while the stations near fault zones show fault-parallel fast polarization directions, suggesting both stress and geological structure contribute to the upper crust anisotropy. Comparing fast polarization directions from shear wave splitting of local earthquakes and Pms, large angle differences are shown at most stations, implying different anisotropy properties between upper and mid-lower crust. However, in southwestern Yunnan, the fast polarization directions of Pms and S-wave splitting are nearly parallel, and the stress and surface strain rate directions show strong correlation, which may indicate that the surface and deep crust deformations can be explained by the same mechanism and the surface deformation can represent the deformation of the whole crust. Therefore, the high correlation between surface strain and mantle deformation in this area suggests the mechanical coupling between crust and mantle in southwestern Yunnan. In the rest region of Yunnan, the crust-mantle coupling mechanisms are supported by the lack of significant crustal anisotropy with N–S fast polarization directions from Pms splitting. Therefore, we conclude that the crust and upper mantle are coupled in Yunnan, SE margin of Tibetan Plateau.

1. Introduction

The TP (Tibetan Plateau) was formed as a result of the progressive continental collision between the northward-moving Indian plate and the relatively stationary Eurasian plate approximately 50 million years ago [1]. GPS (Global Positioning System) measurements [2] revealed southeastward movement of the Tibetan upper crust. As the margin of TP's southeastward expansion and the tectonic transitional zone between the Yangtze block and the uplifting TP, the SE margin of TP is an ideal region to investigate the geodynamic evolution of TP [3]. The bulk of the SE margin of TP is the Yunnan area, which is located between the EHS (eastern Himalayan syntax) is and the Yangtze Platform and is characterized by several sub-blocks bounded by extensive strike-slip faults (Fig. 1). Its deformation has been influenced by the northward subduction of the Indian plate [1,4], the block age from the rigid Sichuan Basin [5] and the eastward subduction of the Burmese microplate [4].

Different geodynamic models have been proposed to explain the uplift and deformation of the plateau, among which there are three models that get much attentions, i.e., the lateral extrusion of rigid blocks along major strike-slip faults [6,7], the continuous lithosphere deformation as a viscous thin sheet [8,9], and the ductile

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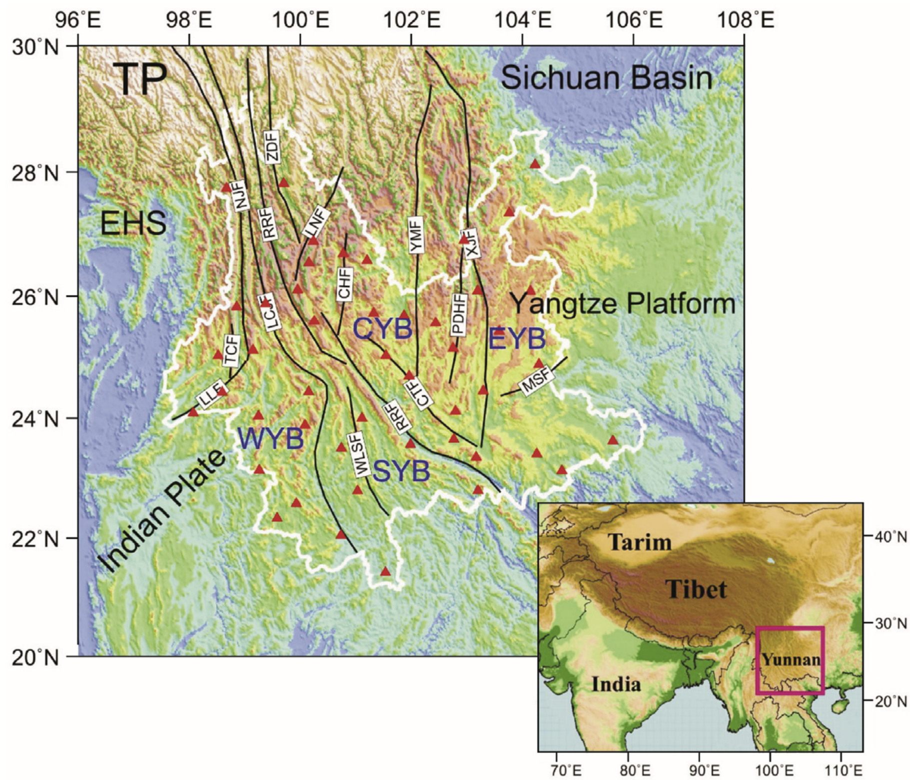

Fig. 1. Topographic map of study area and distributions of faults and stations used in this study. Red triangles denote 48 seismic stations, and the white and black solid lines indicate the boundary of Yunnan area and main faults, respectively. NJF: Nujiang fault; ZDF: Zhongdian fault; LCJF: Lancangjiang fault; RRF: Red River fault; LLF: Longling fault; LJNLF: Lijiang-Ninglang fault; WLSF: Wuliangshan fault; CHF: Chenghai fault; PDF: Puduhe fault; YMF: Yimen fault; XJF: Xiaojiang fault; MLSZF: Mile-Shizong fault; CXTHF: Chuxiong-Tonghai fault; TCF: Tengchong fault. TP: Tibet Plateau; EHS: Eastern Himalayan syntaxis; CYB: Central Yunnan sub-block; WYB: Western Yunnan sub-block; EYB: Eastern Yunnan sub-block; SYB: Southern Yunnan sub-block. The magenta rectangle in the insert map is the study area.

mid-lower crustal channel flow [10,11]. Different models support different coupling mechanisms between the crust and upper mantle. The vertical coherent deformation model argues that the crust and upper mantle are coupled, which was supported by consistent GPS surface deformation and mantle anisotropy [12], while the crustal channel flow model [13] supports a decoupled crust and lithosphere mantle. Moreover, the lower crustal flow model and crustal-mantle coupling mechanisms may be reconcilable [14]. The contradictions suggest that the crust-mantle coupling mechanisms of SE margin of TP are still unclear.

The comparison between upper mantle anisotropy and surface deformation is usually used to infer the coupling mechanisms. Joint analysis of mantle deformation infer red from shear wave splitting of mantle P-to-S converted phases (XKS, including SKS, SKKS, and PKS) and surface deformation measured with GPS suggested vertically coherent deformation of crust and mantle in SETP with decoupled lithosphere to the south of 26°N in Yunnan [15–17]. On the contrary, Wang et al. [12] argued that the crust and mantle were coupled in Yunnan area from comparison between more shear wave splitting data and GPS measurements.

Such interpretations of coupling mechanisms from comparison between shear wave splitting and GPS data rely on the assumptions: (1) the seismic anisotropy from XKS shear wave splitting analysis has contributions from upper mantle, while crustal contribution is neglected; (2) crustal anisotropy is uniformly distributed in the whole crust and the measured surface deformation represents the whole crustal deformation. However, crustal anisotropy intensity of SE margin of TP remains debatable. Significant crustal anisotropy beneath SE margin of TP was observed by Sun et al. [18], while Chen et al. [19] found the crustal anisotropy was weak. Furthermore, whether the crust anisotropy is uniformly distributed with depth remains controversial since previous crustal anisotropy studies [18,19] mainly focused on the whole crust using Moho converted Ps waves (Pms), thus crustal anisotropy at different depths beneath SE margin of TP is unclear. A detailed quantification of upper crust anisotropy can help reveal crustal anisotropy at different depths.

Seismic anisotropy, which depicts the directional dependence of seismic velocities, is widely distributed at different depths in earth's crust and mantle [20]. The most commonly used method to characterize seismic anisotropy is measurements of shear wave splitting. When shear wave travels through an anisotropic medium, it will split into two approximately perpendicular polarizations with different velocities [21]. Measurement of shear wave splitting yields two splitting parameters, i.e., polarization directions of fast waves (ϕ) and splitting delay time (δt) between the fast and slow shear waves [22,23]. In the upper crust, the most likely cause of crustal anisotropy is stress-induced alignment of fluid-saturated vertical micro-cracks or shape preferred orientation (SPO) of layering minerals with contrasting elastic properties [21,24]. The dominant fast polarization directions (FPD) are sub-parallel to the maximum horizontal compression directions (S_{Hmax}) [25] or strike of the faults [26], and δt is related to the strength of anisotropy and the crack density of upper crust [25].

In this study, the upper crustal anisotropy of Yunnan area was investigated using an automated shear wave splitting analysis code MFAST [29]. We first compared the upper crustal anisotropy with anisotropy measurements from Pms splitting analysis to judge whether the crustal anisotropy can be regarded as uniformly distributed. Then we compared the strain-rate field from Pan and

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