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Teleseismic shear-wave splitting in SE Tibet: Insight into complex crust and upper-mantle deformation

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ABSTRACT

We measured shear-wave splitting of teleseismic XKS phases (i.e., SKS, SKKS and PKS) recorded by more than 300 temporary ChinArray stations in Yunnan of SE Tibet. The first-order pattern of XKS splitting measurements shows that the fast polarization directions (φ) change (at ∼26–27°N) from dominant N–S in the north to E–W in the south. While splitting observations around the eastern Himalayan syntax well reflect anisotropy in the lithosphere under left-lateral shear deformation, the dominant E–W φ to the south of ∼26°N is consistent with the maximum extension in the crust and suggest vertically coherent pure-shear deformation throughout the lithosphere in Yunnan. However, the thin lithosphere (<80 km) could account for only part (<0.7 s) of the observed splitting delay times (δt, 0.9–1.5 s). Anisotropy in the asthenosphere is necessary to explain the NW–SE and nearly E–W φ in these regions. The NE–SW φ can be explained by the counter flow caused by the subduction and subsequent retreat of the Burma slab. The E–W φ is consistent with anisotropy due to the absolute plate motion in SE Tibet and the eastward asthenospheric flow from Tibet to eastern China accompanying the tectonic evolution of the plateau. Our results provide new information on different deformation fields in different layers under SE Tibet, which improves our understanding on the complex geodynamics related to the tectonic uplift and southeastward expansion of Tibetan material under the plateau.

1. Introduction

The Tibetan Plateau (Fig. 1a) due to the continental collision of the Eurasian and Indian plates since ∼50 Ma is the most dramatic plateau in the Earth (e.g., Tapponnier et al., 2001). Different models have been proposed to explain the evolution the plateau, such as the lateral extrusion of the lithospheric materials along major strike-slip faults (e.g., Tapponnier et al., 1982, 2001), the thickening of the Asian crust (England and Houseman, 1989), and the ductile flow in the mid-lower crust (e.g., Royden et al., 1997, 2008). The structures and dynamics beneath SE Tibet is important for understanding the tectonic evolution of the Tibetan Plateau. It is characterized as extensive strike-slip faults and the accompanying shear zones along major tectonic boundaries at surface (Fig. 1b). The Ailao Shan–Red River (ASRR) fault zone is the original southwestern boundary of South China Block (Fig. 1a) (e.g., Ren, 1999). The southwestern part of South China (or Yangtze Craton) (i.e., to the west of Xiaojiang Fault at ∼103°E; also SE Chuan-Dian Block) has been evolved into the active tectonics of SE Tibet, which is indicated by high topography, many active faults (Fig. 1b) and extensive low velocity anomalies in the upper mantle (Huang et al., 2015a).

Seismic anisotropy that results from deformation of the materials in the Earth is essentially important for understanding the deformation styles at different depths (e.g., Karato et al., 2008; Mainprice, 2007; Savage, 1999; Silver and Chan, 1991; Silver, 1996). Many previous studies with teleseismic shear-wave (XKS; i.e., SKS, SKKS and PKS) splitting analysis revealed the first-order pattern of anisotropy in the upper mantle in and around east Tibet that the fast polarization rotates clockwise around the eastern Himalayan syntax and changes abruptly from nearly N–S to E–W at ∼26°N in Yunnan (e.g., Flesch et al., 2005; Huang et al., 2011, 2007; Lev et al., 2006; Sol et al., 2007; Wang et al., 2008, 2013; Zhao et al., 2013b). There are ongoing debates on whether the crust and upper mantle are decoupled or not based on the comparison between surface deformation field revealed by GPS and

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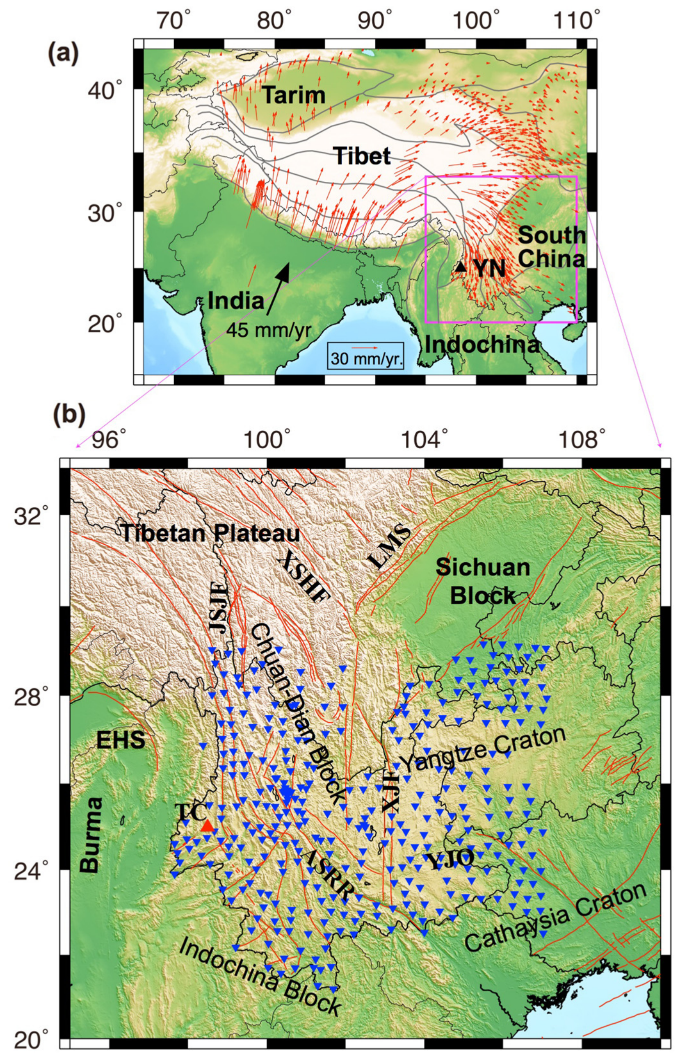

Fig. 1. (a) Tectonics in and around the Tibetan Plateau. Red arrows denote the crustal motion revealed by GPS observations (Gan et al., 2007). The black arrow denotes the motion of the Indian Plate relative to the stable Eurasian Plate (Argus et al., 2011). Gray curves show major tectonic boundaries in and around the plateau (Ren, 1999). (b) Distribution of the 343 portable broadband stations (inverted blue triangles) deployed by the ChinArray project. The Chuan-Dian Block (CDB) is surrounded by major faults, i.e., Xianshuihe fault (XSHF) to the north, Jinshajiang fault (JSJF) to the west, Ailao Shan–Red River fault (ASRR) to the south, and Xiaojiang fault (XJF) to the east. The red triangle shows Tengchong (TC) volcano. The red curves denote active faults. EHS: eastern Himalayan syntax; LMS: Longmenshan fault; YJO: Youjiang orogen. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

geological observations and upper mantle deformation field revealed by XKS splitting measurements (e.g., Flesch et al., 2005; Sol et al., 2007; Wang et al., 2008; Chang et al., 2015). Moreover, recent seismic images and numerical simulation indicate extensive asthenospheric flow extruded from the plateau to eastern China (e.g., Huang et al., 2015a, 2015b; Li et al., 2008; Liu et al., 2004; Zhang et al., 2014), which could induce significant anisotropy in the asthenosphere and makes the XKS splitting observations more complex than expected.

Previous XKS splitting parameters were measured at permanent and temporary stations with lateral spacing of generally 50–100 km. In this study, we measured shear-wave splitting of teleseismic XKS phases recorded by more than 300 temporary stations (with lateral spacing of ∼30 km) deployed by ChinArray project in Yunnan of SE Tibet, which provides more information on the lateral variations of XKS splitting observations and thus the

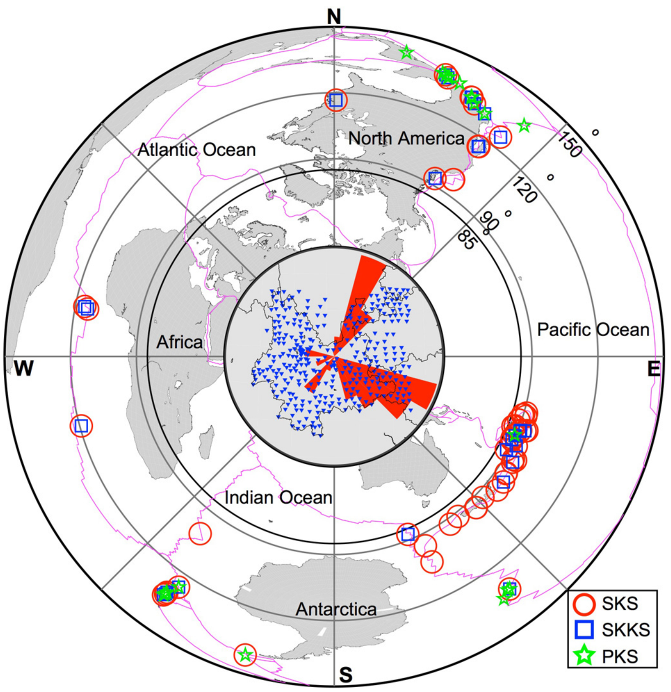

Fig. 2. Distribution of the 67 events used in this study. The red circles, blue squares, and green stars denote the events whose SKS, SKKS, and PKS phases are used, respectively. The magenta curves denote the plate boundaries (Bird, 2003). The four great circles denote the epicentral distances of 85°, 90°, 120°, and 150° from the study region. The red rose diagram in the central inset shows the statistic of the back-azimuths of the events relative to the stations (inverted blue triangles). (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

crust and upper mantle anisotropy. We then compared the XKS splitting measurements with crustal deformation field (from GPS and geological observations and focal mechanism solutions) and anisotropy (by Pms splitting), and P wave velocity anomalies in the asthenosphere. The results indicate that the lithosphere under Yunnan of SE Tibet is probably suffering vertically coherent deformation. The anisotropy in the lithosphere explains a large portion of the XKS splitting observations, but significant anisotropy in the asthenosphere is necessary to explain measurements especially in south Yunnan with thin lithosphere.

2. Data and method

2.1. Data

The waveform data used in this study is recorded by 343 portable stations (Fig. 1b) of the ChinArray project deployed in SE Tibet (mostly in Yunnan province) during one year from August 2011 to August 2012. Most of the stations were equipped with a Guralp CMG-3EPC three-component broadband seismometer and a Reftek-130 digitizer. The sampling rates are 100 samples per second. We selected 67 events (Fig. 2) with magnitude >5.8 and epicentral distances of 88°–140° and used their core phases (XKS) for shear-wave splitting analysis. In general, the SKS and SKKS phases are clear for events with epicentral distances <120° while the PKS phases become dominant for events with epicentral distances >130°. Most of the events occurred in the Tonga and New Zealand subduction zones in Southwest Pacific and in the subduction zones in North America. Some events occurred in the mid-ocean ridge in the Atlantic Ocean and Indian Ocean. The events are generally concentrated in very narrow back-azimuths (Fig. 2), which is actually not ideal for shear-wave splitting anal-