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Seismic anisotropy and mantle dynamics beneath China

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ABSTRACT

We analyzed the shear-wave splitting at 138 permanent seismograph stations to study seismic anisotropy and mantle dynamics under Mainland China. To obtain reliable results we used three different methods to measure the shear-wave splitting parameters using core phases (SKS, SKKS, SKiKS and PKS) as well as the direct S waves from regional and distant earthquakes. Our results show that the fast orientations of the anisotropy (WNW–ESE) in eastern China are generally consistent with the absolute plate motion (APM) direction of the Eurasian plate, suggesting that the anisotropy is mainly located in the asthenosphere resulting from the lattice-preferred orientation of olivine due to the shear deformation there. The fast axes in western China generally agree with the strikes of the orogens and active faults, while they are perpendicular to the direction of the maximum horizontal stress, suggesting that the anisotropy in the lithosphere contributes significantly to the observed shear-wave splitting. The fast axes in western China are also consistent with the APM direction, suggesting that the APM-driven anisotropy in the asthenosphere is another source of the shear-wave splitting there. These results suggest that APM-driven anisotropy commonly exists under continents, similar to that under oceanic regions, even though the continental lithosphere has suffered extensive deformation.

1. Introduction

Seismic anisotropy describes the directional dependence of seismic velocity within the Earth and it is a characteristic feature of the Earth's interior structure. It may exist at different depth ranges in the crust, mantle and inner core (see Mainprice, 2007 and references therein). Different factors dominate in producing the anisotropy at various depths, such as aligned cracks in the upper crust (e.g., Crampin, 1984) and the lattice-preferred orientation (LPO) of minerals in the lower crust and upper mantle (see Karato et al., 2008; Mainprice, 2007 for comprehensive reviews). The LPO (or the anisotropic fabric) in the upper mantle is generally considered to be the result of dislocation creep of the minerals (mainly olivine) above a depth of ~300 km (e.g., Gung et al., 2003; Panning and Romanowicz, 2006). The anisotropic fabric depends on both the type and extent of strain (Savage, 1999). Many experimental studies and theoretical models have focused on the development of different fabrics for simple shear, pure shear, axial and uni-axial compression. In general, the fast orientation of the anisotropy (e.g., a-axis of olivine) is subparallel to the extension or shear direction in the upper mantle (e.g., Karato et al., 2008; Nicolas, 1993; Savage, 1999; Silver and Chan, 1991; Zhang and Karato, 1995). For simple horizontal mantle flow, the fast direction is usually parallel to the flow direction (Karato et al., 2008).

Because of the close relationship between the anisotropy and strain in the upper mantle, observations of seismic anisotropy can in principle be used to constrain the lithospheric and sublithospheric mantle deformation that produces this anisotropy (Conrad et al., 2007). Shear-wave splitting is a popular tool for characterizing anisotropy in the Earth (e.g., Long and Silver, 2009; Silver and Chan, 1988, 1991; Vinnik et al., 1992). Shear-wave splitting, also called seismic birefringence, is a phenomenon in which a shear wave splits into two polarized shear waves with different velocities when traveling though an anisotropic medium. Two splitting parameters (φ, δt) can be measured from seismograms, which correspond to the polarization direction of the fast quasi-S phase (φ) and the delay time (δt) between the fast and slow components, respectively (Long and Silver, 2009). By using the long-period core phases, such as SKS, SKKS, SKiKS and PKS (hereafter, we call them XKS phases), the observed shear-wave splitting is usually considered to reflect the anisotropy in the crust and upper mantle under the seismograph stations. Hence the splitting parameters can be used to study the anisotropy and deformation in the upper mantle.

Many researchers have used splitting parameters to constrain the global mantle flow and the absolute plate motion (APM) (e.g., Becker et al., 2006, 2008; Conrad et al., 2007; Kreemer, 2009; Kustowski et al., 2008). Comparisons of the XKS observations with the LPO derived from the numerical modeling show that the predictions of upper mantle anisotropy made by the global mantle circulation models match the observations well beneath the oceans but poorly under the continents (Conrad et al., 2007; Long and Becker, 2010). The fit under the continents, however, can be improved when considering lateral variations in the lithospheric

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thickness (Conrad et al., 2007). These results suggest that the anisotropy in the continental lithosphere, which may suffer extensive deformation, contributes significantly to the observed shear-wave splitting (e.g., Fouch and Rondenay, 2006; Savage, 1999; Silver, 1996; Vinnik et al., 1992). It is far from clear, however, which of the sources—the anisotropic structure in the lithosphere or the contemporary flow in the asthenosphere—dominates in the observed anisotropic signal in the continental regions (Long and Becker, 2010).

China provides an ideal site to estimate the contribution from the continental lithosphere. The Chinese continent is composed of various lithospheric blocks formed during its long geological history (e.g., Ma, 1987, 1988; Ren et al., 1999). While retaining several stable Archean blocks, China has been suffering extensive deformation in the Cenozoic (see Yin, 2010 for a comprehensive review). The eastern and western parts of China (Fig. 1), however, have experienced completely different tectonic evolutions. The Cenozoic tectonics of western China (or even the entire Asia region) is most dramatically expressed by the development of the Tibetan Plateau resulting from the India–Asia collision (Tapponnier et al., 1982, 2001). In the Middle to Late Miocene (i.e., 18–8 Ma), the N–S contraction of the early stage was replaced by the coeval development of conjugate strike-split faults and E–W extension which continues until today (Tapponnier and Molner, 1977; Yin, 2010 and references therein). The far-field effect of the India–Asia collision is considered to have reached the Tienshan orogen and the Baikal rift zone thousands of kilometers northward (Molnar and Tapponnier, 1975; Tapponnier and Molner, 1979). Eastern China, in contrast, is characterized by the development of the back-arc extensional system as a result of the subduction of the Pacific and Philippine Sea plates (e.g., Ren et al., 2002; Tian et al., 1992; Zhao et al., 2011a). Debates, however, are continuing on whether the India–Asia collision has influenced the tectonic evolution of eastern China (e.g., Liu et al., 2004). The existence of various tectonic elements (blocks, orogens, faults, etc.) in China allows us to better understand the origin of seismic anisotropy in the lithosphere and asthenosphere under a continental region.

In this study, we analyzed the shear-wave splitting at 138 permanent digital seismograph stations in Mainland China. The measured splitting parameters are then used to estimate the first-order anisotropic patterns in the upper mantle, including the lithosphere and asthenosphere. Although many previous studies have investigated the anisotropic structure in various parts of China, the present work has the following advantages over the previous studies. (1) We analyzed the shear-wave splitting at 138 permanent stations across China. Many of the stations have been deployed for more than ten years (Fig. 1), and so much more high-quality data are available for us to better understand seismic anisotropy and mantle dynamics under the entire Chinese continent. (2) Three different methods are used to make the shear-wave splitting measurements, and the results by the different methods are carefully compared and analyzed to avoid any potential bias. While our results are generally consistent with many of the previous results, the present work has provided important new insights into the seismic anisotropy and deformation under the Chinese continental region.

2. Data and method

The 138 seismograph stations used in this study (Fig. 1) are broadband, permanent stations operated by the China Seismic Network Data Center. Most of the stations are equipped with CTS-1, KS-2000 and JCZ-1 seismometers, while several stations have GS-13, STS-2 and CMG-3 type

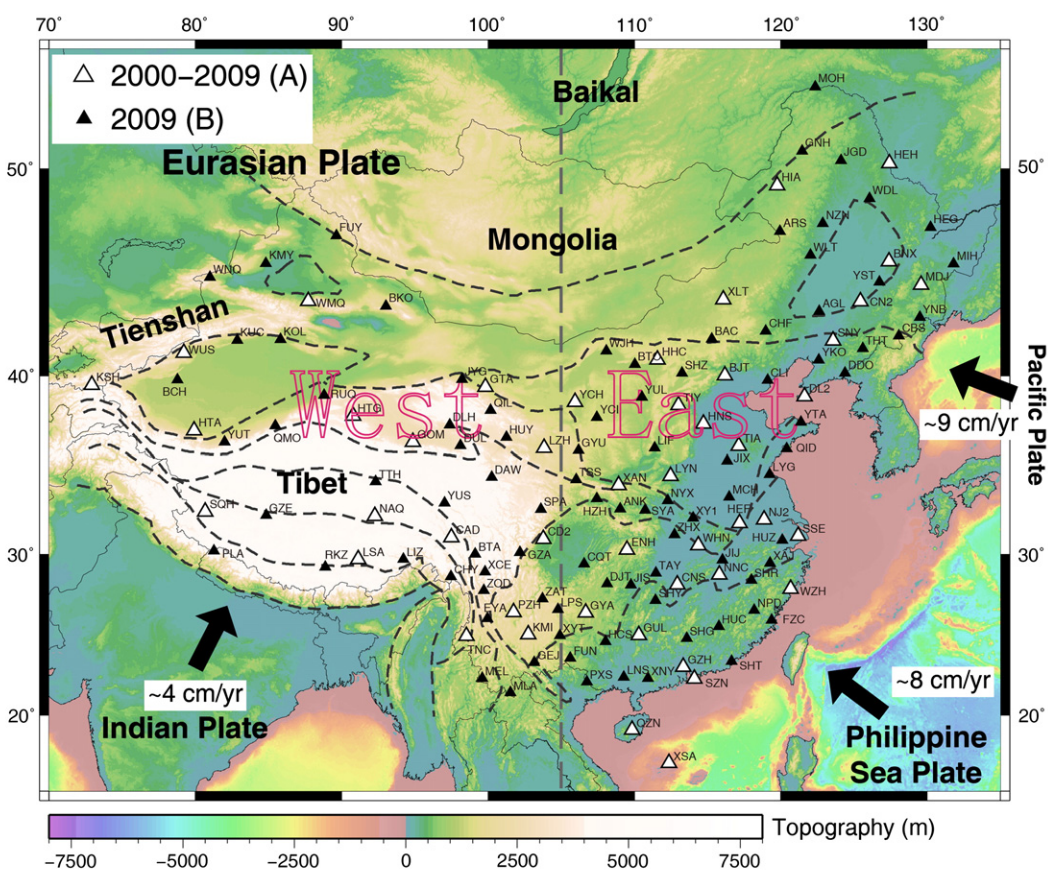

Fig. 1. Distribution of the 138 seismograph stations used in this study. The surface topography is shown in color with its scale shown at the bottom. The white triangles denote the stations of group A with data available during 2000 to 2009, while the black triangles show the stations of group B with data only in 2009. The dashed lines indicate the boundaries between different tectonic blocks (Ren et al., 1999). The bold arrows denote the motion directions of the Indian, Pacific and the Philippine Sea plates relative to the Eurasian plate. The vertical dashed line shows the rough boundary between western and eastern China investigated in this study.