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Complicated seismic anisotropy beneath south-central Mongolia and its geodynamic implications

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ABSTRACT

Two years of high-quality broadband seismic data from 69 temporary stations deployed in south-central Mongolia provide an opportunity to study the anisotropy-forming mechanisms in this area. The majority of shear wave splitting observations determined from the analysis of teleseismic SKS phase are characterized by NW–SE trending fast directions with large splitting delay times (greater than 2.0 s at six stations), which is inferred to be generated by active asthenospheric flow. The variation of the fast direction may be associated with deflection of asthenosphere around the deep Siberian cratonic keel at the base of the lithosphere. Several of the NE–SW trending fast directions with relatively small delay times observed in the Gobi Desert are parallel to the strike of the main faults and sutures, which may represent lithospheric deformation. In addition, it is inferred that small-scale hot mantle upwelling is responsible for generating a cluster of null measurements observed on the south of the Hentiy Mountain.
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1. Introduction

Mongolia is located in the core part of the Central Asian Orogenic Belt (CAOB) (Fig. 1) and is one of the largest Paleozoic orogens on Earth, which evolved from the latest Mesoproterozoic to the late Paleozoic, with the accretion of ophiolites, island arcs, accretionary wedges, oceanic islands and microcontinental fragments (Windley et al., 2007). It is widely accepted that the multiple sets of external boundary conditions most likely resulted in a suite of observed surface deformation patterns within the Mongolia plateau. For example, in western Mongolia, which is influenced by the India–Eurasia collision, several NW–SE trending dextral strike-slip faults and the Altay range are well developed under NS compression (Molnar and Deng, 1984). While in eastern Mongolia, little stress is transmitted from the India–Eurasia collision and the eastern boundary is relatively open towards the Pacific subduction zone (Vergnolle et al., 2007). However, the behavior of underlying mantle, which may play a significant role in deformation of the continent, is more controversial. The long-lived and low-activity Cenozoic intraplate volcanism has occurred throughout Mongolia and the Baikal region for the past 30 Ma (Barry, 2003), and is explained by various models including: (1) mantle plumes or hotspots (Windley and Allen, 1993); (2) subhorizontal asthenospheric flow driven by a variation in the lithosphere thickness (Lebedev et al., 2006); (3) thermal blanketing caused by the convergence between India and Eurasia (Petit et al., 2002).

Seismic anisotropy determined by the splitting of shear waves, especially the core-refracted phases like SKS, is one of the most direct and effective ways to image the deformation in the interior of the Earth (e.g., Savage, 1999; Long and Silver, 2009). The accretionary process of microcontinental fragments during the formation of CAOB can generate an anisotropic fabric that will be preserved in the lithosphere as fossil anisotropy, as well as Cenozoic tectonic processes such as mantle plume activity (Zorin et al., 2003, 2006) that will be disturbed by present day asthenospheric flow (Lebedev et al., 2006; Barruol et al., 2008) and/or the ongoing India–Eurasia collision (Calais et al., 2003). In this study, we try to differentiate the hypotheses relating to how continental lithosphere and deep mantle interact through the analysis of seismic anisotropy determined by shear wave splitting analysis using data from a new broadband seismic experiment in south-central Mongolia.

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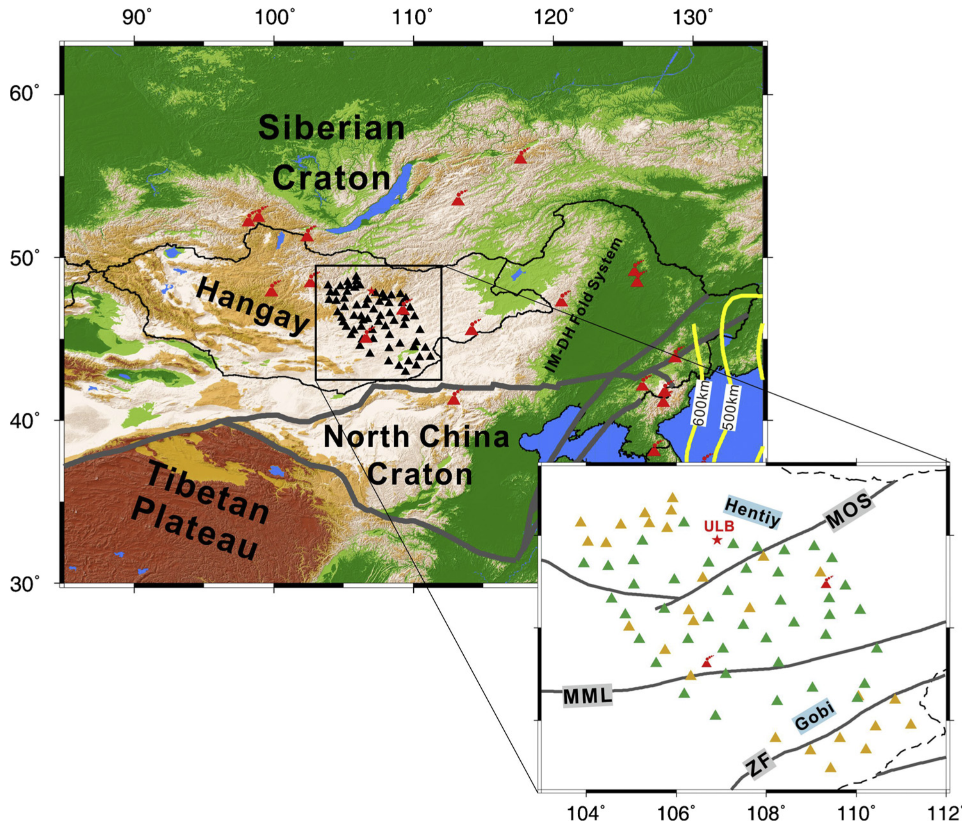

Fig. 1. Topographic map of Mongolia and surrounding countries showing major tectonic structures and political boundaries. The Holocene volcanoes are represented by red symbols (from Crosweller et al., 2012). The yellow lines denote the isobaths curve of the subducting Pacific plate. An expended map of the station distribution is shown in the bottom right inset. The green and yellow triangles represent the stations with two and one year's observation, respectively. Major faults are depicted by bold grey lines (from Yang et al., 2015 and Windley et al., 2007). Red pentagram indicates the location of the city ULB (Ulaanbaatar). Abbreviations on the map are as follows: MOS, Mongol-Okhotsk Suture; MML, Main Mongolia Lineament; ZF, Zuunbayan Fault. (For interpretation of the colors in this figure, the reader is referred to the web version of this article.)

1.1. Tectonic setting

The history of the Mongolian lithosphere has been a succession of subduction-accretion of micro-continents and island-arcs around the central Siberian craton during Caledonian, Hercynian and Mesozoic times, caused by the progressive closure of the paleo-oceans (e.g., Zorin, 1999). During the Later Silurian–Early Devonian, the development of the Pri-Baikal folds and thrust belt along the southeastern margin of the Angara plate affected the western part of Mongolia and led to NW–SE trending crustal structures such as an oblique subduction zone active between the Altai-Mongol and Kazakhstan block (Delvaux et al., 1995). From the Devonian to Triassic, the southeastern area of Siberia underwent significant deformation leading to an active margin trending NE–SW along a northwest-dipping subduction zone caused by the progressive eastward closure of the Mongol-Okhotsk ocean (Delvaux et al., 1995). Final closure of the Mongol-Okhotsk Ocean at the Middle Jurassic times gave rise to thrusting, folding and built the NE–SW trending Mongol-Okhotsk belt through the complete collision of Siberia and Mongolia (Zorin, 1999). In summary, the strike direction of active margins appears to wrap around the stable Siberian craton (Barruol et al., 2008); in western Mongolia, the accretion of micro-continents and the generation of mountain belts trend NW–SE and rotate to NE–SW in eastern Mongolia (Fig. 1).

1.2. Previous geophysical studies

In the summer of 1992, twenty-eight seismic stations were deployed across the Baikal rift system, extending from the South Mongolia fold belt to the Siberian platform (Gao et al., 1994). Later, in 2003, a seismic profile trending NS was deployed in the southern Siberian craton, Sanyan Mountain, Hangay plateau and Gobi-Altay, which consisted of eighteen seismic stations and two permanent IRIS stations TLY and ULN (Barruol et al., 2008). Data from these deployments were used for teleseismic tomography that show an upper-mantle low-velocity zone under the Baikal rift and Hangay dome, suggesting a possible existence of asthenospheric upwarp (Gao et al., 2003; Zhao et al., 2006). This assumption has also been supported by receiver function and shear-wave tomography analyses, indicating a relatively thin lithosphere and high topography above the area where asthenosphere uplift has occurred (Mordvinova et al., 2007). Shear wave splitting studies suggest a rift-normal asthenospheric flow close to the rift and a rift-parallel away from the rift (Gao et al., 1994). In addition, NW–SE trending fast directions and relatively large delay times were measured in central Mongolia, which requires a thick anisotropic zone that favors a joint contribution from both the lithosphere and asthenosphere (Barruol et al., 2008). A two-layer anisotropy structure was also identified in the permanent station ULN, which was interpreted to reflect the NE–SW trending lithospheric anisotropy over the NW–SE trending asthenospheric flow (Barruol et al., 2008).

2. Data and method

From Aug. 2011 to Aug. 2013, sixty-nine three-component broadband stations are deployed in south-central Mongolia (Fig. 1). In this study, teleseismic SKS phases from that deployment are used to determine receiver side seismic polarization anisotropy. We selected teleseismic events with epicentral distances larger than

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