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Distinct lateral contrast of the crustal and upper mantle structure beneath northeast Tibetan plateau from receiver function analysis

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ABSTRACT

We investigate the crustal thickness, Poisson's ratio, and the thickness variation of the mantle transition zone using the P receiver function technique on data recorded by the 68 seismic station of the ASCENT experiment beneath the northeast Tibetan plateau. Our results reveal a distinct crustal and upper mantle structure contrast between the western and eastern part of the northeast Tibetan plateau along two migrated profiles. In the eastern region the Moho is relatively smooth and continuous and varies in depth between ~80 and 51 km, whereas the depth of the Moho beneath the western region varies between ~77 and 52 km and is offset ~20 km beneath the boundary between the Kunlun fault and Qaidam basin. The delay times for the Ps phases from both the 410-km and 660-km discontinuities in the western region are ~1.2 s later than that in the eastern region, indicating that the average velocities of the upper mantle in the western region are lower than that in the eastern region. Crustal rocks with low- to moderate Poisson's ratios are interpreted to be dominated by felsic to intermediate compositions, implying that large scale middle-lower crustal flow does not occur easily. The nearly constant thickness of the mantle transition zone, with an average value of ~255 km (24.4 s) from south to north, implies that no lithospheric fragments correlating to the India–Asia collision have entered into the mantle transition zone.

1. Introduction

The northeastern Tibetan plateau consists of five east-trending terranes, which from north to south include, the Qilian Shan (QLS), Eastern Kunlun–Qaidam (EKQ), Songpan-Ganzi (SG) and Qiangtang (Fig. 1). These terranes were sequentially accreted onto the southern margin of Eurasia since the early Paleozoic and are separated by the South Qilian suture (SQS), Kunlun fault (KLF), Jinsha River suture (JRS), and Bangong-Nujiang suture (BNS), respectively (Searle et al., 2011; Yin and Harrison, 2000).

On the basis of previous geological and geophysical observations, various models have been proposed to explain the northward growth of the Tibetan Plateau. The successive oblique subduction of the Asian lithospheric mantle and eastward extrusion of the lithosphere is one such model that could explain the uplift of the northeast Tibetan plateau (Tapponnier et al., 2001). This interpretation is partly supported by seismic images from receiver function studies (Kind et al., 2002; Zhao et al., 2011). Alternatively, inferences from regional topographic gradients suggest that crustal thickening and uplift may be the result of ongoing lower crustal flow toward the southeast and northeast of the plateau (Clark and Royden, 2000). This model is supported by wide-angle seismic data, which indicate that the Songpan-Ganzi lower crust is underthrusting northward into the south Qaidam basin (Karplus et al., 2011). However, conclusions drawn from ambient noise tomography (Yang et al., 2010) and regional seismic attenuation tomography (Bao et al., 2011) suggest that the low velocity zones, which are one of the necessary conditions of the low crustal flow model, are mostly located at mid-crustal level beneath the northeast Tibet plateau. Moreover, some scholars further argue whether the mechanism of lithospheric deformation is vertically coherent (Chang et al., 2008; Zhang et al., 2011a) or whether mid-crustal strain-transfer occurs across the northeast Tibetan plateau (Wang et al., 2011). Finally, seismic images reveal a sharp 15–20 km Moho offset beneath the Qaidam–Kunlun border implying vertical crustal thickening in the northeast Tibetan Plateau (Shi et al., 2009; Vergne et al., 2002; Zhu and Helmberger, 1998). It can be concluded from the above summary that the mode of northward growth of the northeast Tibetan plateau remains unclear. Moreover, the paucity of seismic stations in this region makes it much more difficult to understand the pattern of the lithospheric deformation.

Imaging the topography of the 410-km and 660-km discontinuities (410 and 660) mantle transition zone (MTZ) can play an important role in understanding the thermal and material transfer of the upper mantle. The 410 and 660 are likely the result of

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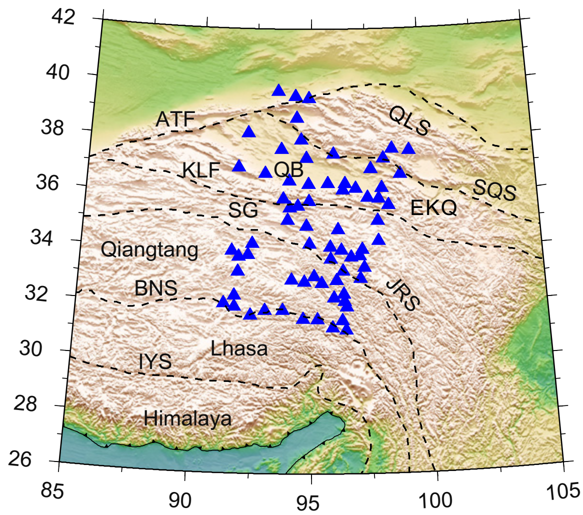

Fig. 1. Topographic map showing the main tectonic units of Tibetan plateau, and the seismic stations utilized in this study are shown as the blue triangles. IYS, Indus-Yarlung suture; BNS, Bangong-Nujiang suture; JRS, Jinsha river suture; SQS, South Qilian suture; KLF, Kunlun fault; ATF, Altyn Tagh fault; QB, Qaidam basin; SG, Songpan-Ganzi terrain; QLS, Qilian Shan; EKQ, Eastern Kunlun–Qaidam. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

pressure- and temperature-induced phase changes in the olivine system, characterized by opposite Clapeyron slopes (Bina and Helffrich, 1994; Helffrich, 2000). Therefore, if a subducting slab hits the MTZ, the 410 is elevated while the 660 is depressed resulting in the thickening of the MTZ with a reduced temperature. By contrast, these responses are reversed in the presence of upwelling mantle plumes. Although detached lithospheric fragments within the MTZ are observed beneath the eastern Himalaya, P-receiver function migration images of southern and central Tibet along north–south profiles suggest a normal thickness of the MTZ (Chen and Tseng, 2007; Singh and Kumar, 2009), with northward parallel deepening of the 410 and 660 due to low shear velocity above the 410 in the northern part of these profiles (Zhao et al., 2010). However, knowledge on the nature and geometry of MTZ discontinuities beneath the northeast Tibet plateau is still unclear.

This study presents new estimates of crustal thickness and average Poisson's ratio, based on P-receiver function methodology on the recently released data of the ASCENT project conducted in the northeast Tibet plateau (Fig. 1). In particular, the Poisson's ratio provides important information on the bulk composition of crustal rocks, which aids in differentiating the above-mentioned interpreted models. In addition, we also investigate the lateral variation of the MTZ discontinuities and discuss the tectonic implications.

2. Data and methods

2.1. Data

The data used in this study is comes from the 68 seismic stations of the ASCENT project deployed from 2007 until 2009. We select seismic events with epicentral distances between 30° and 95° and with magnitudes greater than 5.5. The data are demeaned, detrended and filtered using a low-pass filter of 1s, and the resulting waveforms are then cut 10 s prior and 100 s after the predicted P onset. We visually pick the events with clear P wave arrival and high signal-to-noise ratio for the calculation of P receiver functions (PRFs). Fig. 2 shows the distribution of the 454 teleseismic events used in this study, most of which occur within the circum-Pacific seismogenic belt.

2.2. P-receiver function technique

At present, the P-receiver function method (P-RF) is a routinely used technique for determining the crustal and upper mantle structure. Calculation of PRFs mainly includes coordination rotation and deconvolution. The raw Z, NS and EW (ZNE) components are rotated into the local P-SV-SH ray-based coordinate system using back azimuths and theoretical incident angles. The advantage of using the SV component instead of the radial component is the disappearance of projected P-energy at P arrival time in the resulting PRF, which can detect the conversions from shallow discontinuities more easily. The PRFs are then obtained by deconvolving the SV components from the P components using a time domain Wiener filtering method (Yuan et al., 1997). After deconvolution, all components are aligned and normalized to the maximum amplitude of the spike in the L component. Deconvolution removes the interference of source, propagation path and instrument response. This results in PRFs that predominately contain the P-to-S converted waves (Ps) and their multiple reflection waves (PpPs, PsPs + PpSs, etc.) originating from the discontinuities at different depths below the seismic stations. In addition, we apply moveout correction to the Ps conversions or multiples of all the PRFs at a reference slowness of 6.4 s/° in order to make the PRFs from different epicentral distances comparable and to lessen noise.

2.3. Joint application of semblance analysis and moveout correction

Based on the delay times and amplitudes of Ps phase from the Moho and its crustal multiples, the H–κ stacking method has been introduced to jointly determine both the Moho depth and Vp/Vs ratio of each station (Zhu and Kanamori, 2000). To make both the estimated Moho depths and Vp/Vs ratios more stable and reliable, we put forward the joint application of semblance analysis and moveout correction. In the following, we outline the processing steps.

Firstly, the so-called semblance analysis adds the semblance parameter into the objective function of the widely used H–κ

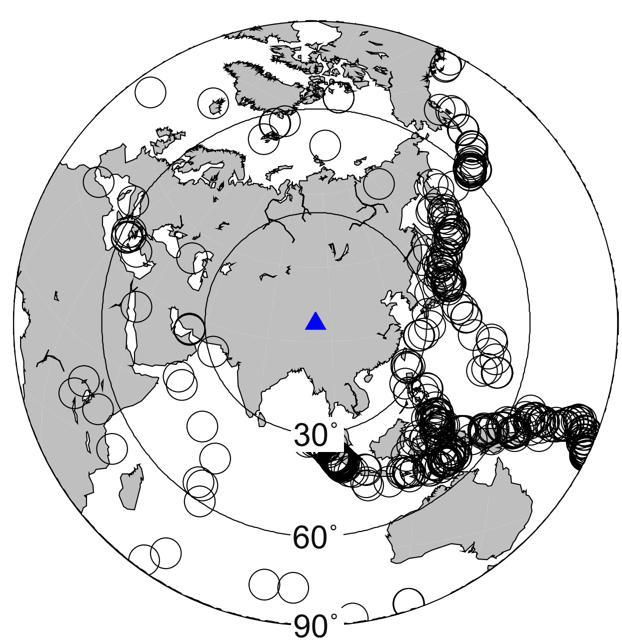

Fig. 2. Distribution map of the teleseismic events used in the receiver function analysis. The blue triangle denotes the approximate position of the network. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)