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Receiver function images of the mantle transition zone beneath NE China: New constraints on intraplate volcanism, deep subduction and their potential link

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ABSTRACT

In order to better understand the deep subduction geometry of the Pacific plate and genesis of intraplate volcanism in northeast China (NE China), we computed a total of 45,505 receiver functions from 788 teleseismic events recorded by 255 stations (NECESSArray temporal and permanent stations) in NE China. We used a common-conversion-point stacking (CCP) method to generate a 3D reflectivity volume beneath the study area. To position the P-to-S conversions to the correct depths, we employed 3D crustal and mantle models as references to make time to depth conversion. The 3D reflectivity volume was generated in an area between 115°–135°E and 40°–49°N, in the depth range of 300 to 800 km. We found significant topographic relief on the 660-km discontinuity across the study area. In particular, in a westward Pacific plate subduction section between 40°N and ∼45.5°N, the 660-km discontinuity is depressed by as much as ∼30–40 km along the western extension of the deep seismicity. The depression is elongated along the strike of the deep seismicity and is confined to a 200–300 km region in the E–W direction of subduction. To the west of this depression the 660-km discontinuity is uplifted by 5–10 km in a rectangular area of ∼100 km by 200 km centered at about 125°E and 43°N. In the north, the 660-km discontinuity is moderately depressed (∼20 km) in a broad area that extends further west. The high and low regions in the 660-km topographic map correlate, respectively, with low- and high-velocity anomalies in the P- and S-wave tomographic velocity images at the same depth. Our results suggest that slab stagnation might not be occurring in the southern part of the NE China, where the Changbaishan volcanic complex is located, thus the magmatism is unlikely caused by dehydration of the flat-lying Pacific slab in the transition zone. The low velocity mantle upwelling arising from a gap of stagnant slabs is a likely source that feeds the volcanic complex in NE China.

1. Introduction

Northeast China (NE China) consists of the northeast China plain (Songliao Basin) in its center, the Great Xing'an Range in the west, and the Changbai Mountain Range (as known as Paektu in North Korea, Baekdu in South Korea) in the southeast. NE China is presently located ∼1300 km away from the Japan Trench where the Pacific plate begins subducting and reaches approximately 600 km deep near the eastern edge of the area (Fig. 1). Many tomography models (Fukao et al., 2003; Huang and Zhao, 2006; Li and van der Hilst, 2010; Wei et al., 2012) suggest that the subducting Pacific plate starts to bend upward and lies flat within the transition zone beneath NE China. The total length of the high velocity anomaly revealed by these models is <2000 km, much less than the estimate based on plate reconstruction (Engebretson et al., 1992), which shows that roughly 5000 km of Pacific plate has subducted at the Japan Trench during the past 50 Ma. The

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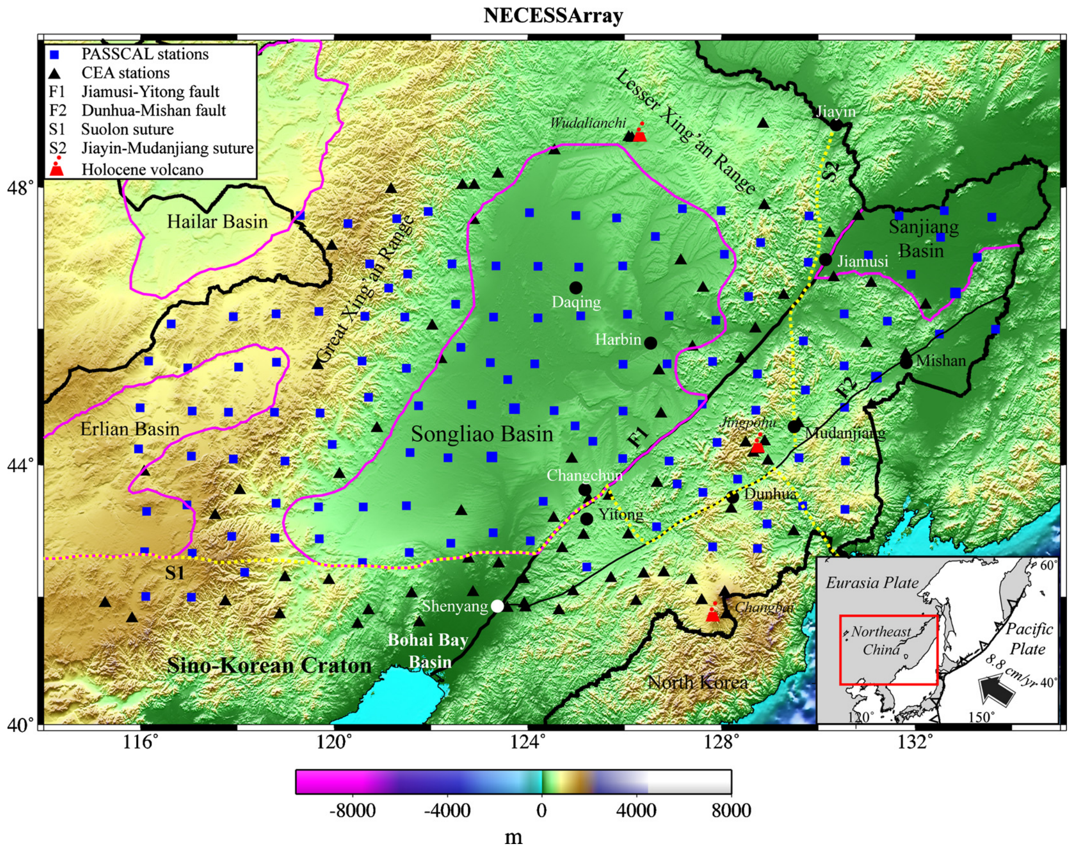

Fig. 1. Map showing topography, major faults, and tectonic units of NE China. The purple lines outline major basins in the area. The black solid lines and the dotted yellow lines represent the large strike-slip faults and major suture zones, respectively. Blue solid squares and black solid triangles represent the 127 temporary and 128 permanent broadband stations of the NECESSArray, respectively. The temporary stations were deployed under an international collaboration between 09/2009 and 08/2011. The permanent stations are part of the provincial seismic networks operated by the China Earthquake Administration (CEA). The array covers an area of 116°–134° east and 40°–48° north, roughly ∼1800 km and ∼800 km in the EW and NS direction, respectively. Red volcanic symbols show the three magmatic centers in the area, Wudalianchi, Jingpohu, and Changbaishan, among which Changbaishan is the largest active magmatic center in China. Solid circles indicate major cities in the area. The bottom-right inset shows the motion of the Pacific plate relative to the Eurasia plate. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

limited resolution in seismic tomography due to the lack of seismic stations in the area may have partly contributed to this discrepancy. There are only 3 ISC stations in NE China, which were used in the tomography study by Fukao et al. (2003). Several recent studies (Huang and Zhao, 2006; Li and van der Hilst, 2010; Wei et al., 2012) used the provincial networks in the area; station distribution of these networks is, however, highly uneven (black triangles in Fig. 1). There are very few stations inside the Songliao Basin and the great Xing'an Range, which are crucial in resolving the leading edge of the subducting Pacific plate beneath the area. The geometry of the subducting slab in this area is thus not well constrained.

It is known that the Songliao Basin was a rifting basin started at ∼157 Ma in late Mesozoic when the shallow subducted Paleo-Pacific plate began to rollback (Ren et al., 2002). Mesozoic volcanic rocks are widely distributed in the region, indicating that active volcanism occurred during the rifting. Volcanism continued in the Cenozoic time in a rather episodic and sporadic manner (Liu et al., 2001). Although it is generally believed that the Cenozoic volcanism in NE China is somehow related to the subduction of the Pacific plate beneath the area, detailed mechanism on the origin of the volcanism, such as the formation of the active Changbai volcano located on the border between China and North Korea, is still not well understood. Based on tomographic imaging using two GSN stations and a small array (18 stations) deployed along the China–North Korea border, Lei and Zhao (2005) found a "columnar low-velocity anomaly extending to 400 km depth" beneath the Changbai volcano and interpreted it as an upwelling from dehydration of the slabs in mantle transition zone, which drives the extension and magmatic activity in the region. Zou et al. (2008) suggested that the piling up and thickening of the stagnant slab in the transition zone could drive asthenospheric upwelling and induce decompression melting at shallow depths. On the other hand, Niu (2005) speculated that edge-driven small-scaled convection along the edges of the Songliao Basin might be responsible for the observed magmatism.

This study is part of the international collaborative project, NECESSArray (the NorthEast China Extended SeiSmic Array), which deployed a total of 127 portable broadband seismographs in NE China. The goal of the project is to build high-resolution seismic images of the mantle beneath NE China in order to better constrain the subduction geometry of the Pacific slab and to understand the formation of the widespread magmatism in the area. In particular, here we intend to delimit cold subducting slabs and hot mantle upwellings within the mantle transition zone by investigating the depth variations of the 410-km and 660-km seismic discontinuities.

The 410-km and 660-km seismic discontinuities that bound the mantle transition zone are thought to be associated with the temperature-sensitive phase transitions from olivine to wadsleyite (e.g., Katsura and Ito, 1989), and from ringwoodite to perovskite plus magnesiowüstite (e.g., Ito and Takahashi, 1989; Katsura et al., 2003), respectively. The latter is also known as the post-spinel transformation. Because these two phase-transitions have a positive and negative Clapeyron slope, respectively, an increase (or decrease) in temperature results in an increase (or de-