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Seismic images of the mantle transition zone beneath Northeast China and the Sino-Korean craton from P-wave receiver functions

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ABSTRACT

Seismic data from northeast (NE) China and the Sino-Korean craton were combined to image the upper mantle discontinuities at 410 and 660 km. Fine-scale topographic variations on these two discontinuities provide important clues for both delineating geometry of the subducting Pacific slab particularly at arc–arc junction and interpreting regional Cenozoic intraplate volcanism. We used over 90,000 receiver functions from 1916 teleseismic earthquakes recorded by 584 broadband seismic stations, primary those of temporary seismic arrays. We found the average depths of the two discontinuities to be 410 km and 672 km, respectively, beneath the study area. Results show that the 660-km discontinuity is strongly depressed by about 20–30 km in a narrow region beneath and around the Changbaishan volcano, consistent with the results of previous receiver function studies. In contrast, much of the Sino-Korean craton exhibits typical transition zone thickness (~260 km) and thus offers no evidence of a stagnated Pacific slab. Our results also reveal an elevated 660-km discontinuity and a thinner transition zone both to the west of the observed depression region and beneath the Kuril–Japan arc junction. This feature is most likely due to a tearing of the descending Pacific plate at both its leading and junction edges. An additional elevated 660-km discontinuity together with a thinner transition zone appears in the vicinity of the Dariganga lava field, supporting interpretations of a deep-rooted mantle plume. Our observations of an elevated 410-km discontinuity and a thicker transition zone correlate spatially with the diffuse distribution of volcanism around Hannuoba, Aershan and Wudalianchi. This correlation may suggest lithospheric removal as a mechanism for these magmatic activities.

1. Introduction

Northeast China and the Sino-Korean craton are two major tectonic units of northeastern Asia. Northeast (NE) China lies within the eastern segment of the central Asian orogenic belt (CAOB), one of the world's largest accretionary orogens (e.g., Sengör et al., 1993). South of the CAOB, the Sino-Korean craton contains Late Archean basement (Liu et al., 1992). The Suolun suture and the Xilamulun belt, which separate the CAOB from the Sino-Korean craton, formed during the Late Permian and Early Triassic and marked the final closure of the Paleo-Asian ocean (e.g., Zorin, 1999; Xiao et al., 2003).

Since the Late Mesozoic, NE China and the Sino-Korean craton have become an important part of the circum-Pacific tectonic–magmatic zone. The tectonic features of these two regions have been particularly influenced by separation of the Japanese island arc from the Asian mainland during the Late Cretaceous (e.g., Peng et al., 1986). The Bohaiwan basin of the Sino-Korean craton also probably developed in this tectonic environment.

Different with the extensive eruption of intermediate-acidic volcanic rocks and widespread emplacement of granites during the Late Mesozoic (Wu et al., 2003), Cenozoic volcanic rocks in NE China and the Sino-Korean craton are predominantly alkaline basalts and occur as relatively small eruption (e.g., Fan and Hooper, 1991; Liu et al., 2001). They are widely distributed along the valleys and mountains trending NNE or NE on the flanks of basins (Liu et al., 2001) and also occur outside basins in association with large extensional or transtensional faults (for example, near Hannuoba within the Sino-Korean craton). The largest exposure is the Changbaishan volcanic group (42° N, 128° E), which covers a 1500 km^2 area around the China–Korea border. Widespread and diffuse Cenozoic alkalic volcanism also occurs in Mongolia and the Baikal Rift Zone in Siberia. The Dariganga Plateau of southeastern Mongolia and its continuation in NE China, the Abaga volcanic field, consist of the largest Cenozoic lava field in central and eastern Asia and cover a ~20,000 km^2 area.

The cause of melting is a key unknown concerning the origin of Cenozoic intraplate volcanism in NE China and adjacent region. Alkali basaltic magmas are widely believed to occur in areas of lithospheric

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extension and/or heating (e.g., Fitton et al., 1998). A single melting mechanism however cannot explain widely distributed intraplate volcanism (Hunt et al., 2012). Mechanisms proposed for continental intraplate volcanism include (1) an upwelling plume or hotspot (e.g., Deng et al., 2004), (2) lithospheric extension or rifting, which would facilitate decompression melting of shallow asthenosphere (e.g., back-arc extension caused by subduction of the Pacific plate; Ren et al., 2002) and (3) removal of the base of the lithosphere and replacement by upwelling asthenosphere (e.g., Menzies et al., 1993). These mechanisms are generally derived from geochemical and petrological studies.

Additional geophysical constraints on mantle processes can help to distinguish these mechanisms. Seismic tomography could image a mantle plume and a cold subducting slab (or detached lithosphere) with higher and lower respective temperatures relative to surrounding mantle. Presently available geophysical data provide a few basic constraints on the origin of intraplate volcanism in NE China and adjacent regions. The Pacific plate is currently converging to the northwest beneath the Kurile and Japan arcs at a rate of 8.2–9.2 cm/year (Wei and Seno, 1998). Slab contour delineated by seismicity has shown that the subducted Pacific slab reaches ~600 km depth beneath NE China (Gudmundsson and Sambridge, 1998; Fig. 1). Previous P-wave tomography studies using regional seismic networks in China (e.g., Huang and Zhao, 2006; Li et al., 2006; Fukao et al., 2009; Zhao and Tian, 2013) show pronounced low P-wave velocity (Vp) anomalies atop 410 km depth beneath the Changbaishan volcano, directly above the high Vp anomalies imaged in the mantle transition zone (TZ). These results therefore suggest that the Changbaishan volcano is back-arc magmatism related to the descending Pacific slab, rather than an isolated hot spot. A recent P- and S-wave travel-time tomography study using more data recorded by a temporary seismic array in NE China detected high velocity anomalies in the mantle following the western edge of the Wadati–Benioff zone and a low cylindrical anomaly appearing as a hole within the high velocities (Tang et al., 2014). The low velocity anomaly suggests a hot upwelling from just below 660 km depth that feeds the Changbaishan volcano. In the study of Tang et al. (2014), the low velocity anomaly is more pronounced in the S-wave velocity models than in the P-wave models. Subsequent tomography using P-wave traveltimes of both initial and secondary phases observed at triplicated distances has not detected a clear low velocity anomaly in the TZ argued by the S-wave tomography however (Takeuchi et al., 2014). Due to the lower data volume, resolution for S-wave velocity models is typically lower than that of corresponding P-wave models.

In addition to seismic tomography, lateral variations in depths to the 410-km and 660-km discontinuities (hereafter referred to simply as the 410 and 660) have been taken as another indicator of upper mantle temperature structure. The 410 and 660 are generally interpreted as phase transitions from olivine to wadsleyite and ringwoodite to perovskite plus magnesiowüstite, respectively (e.g., Ito and Takahashi, 1989). Since the 410 and 660 phase transitions have respective positive and negative Clapeyron slopes, a shallower 410 coupled with a deeper 660 would appear as a thicker TZ in cold areas in contrast to a thinner TZ expected in hotter regions. Detailed studies of the two discontinuities can thus be used to examine lateral temperature variation in the TZ.

Receiver function studies have generated a complicated topography on the 660 beneath NE China and the adjacent Sino-Korean craton. In NE China, several previous receiver functions studies imaged a depressed 660 over a ~400 km area beneath the Changbaishan volcano (Li and Yuan, 2003; Ai et al., 2003). In addition to this local depression, a recent receiver functions study by Liu et al. (2015) mapped a broad

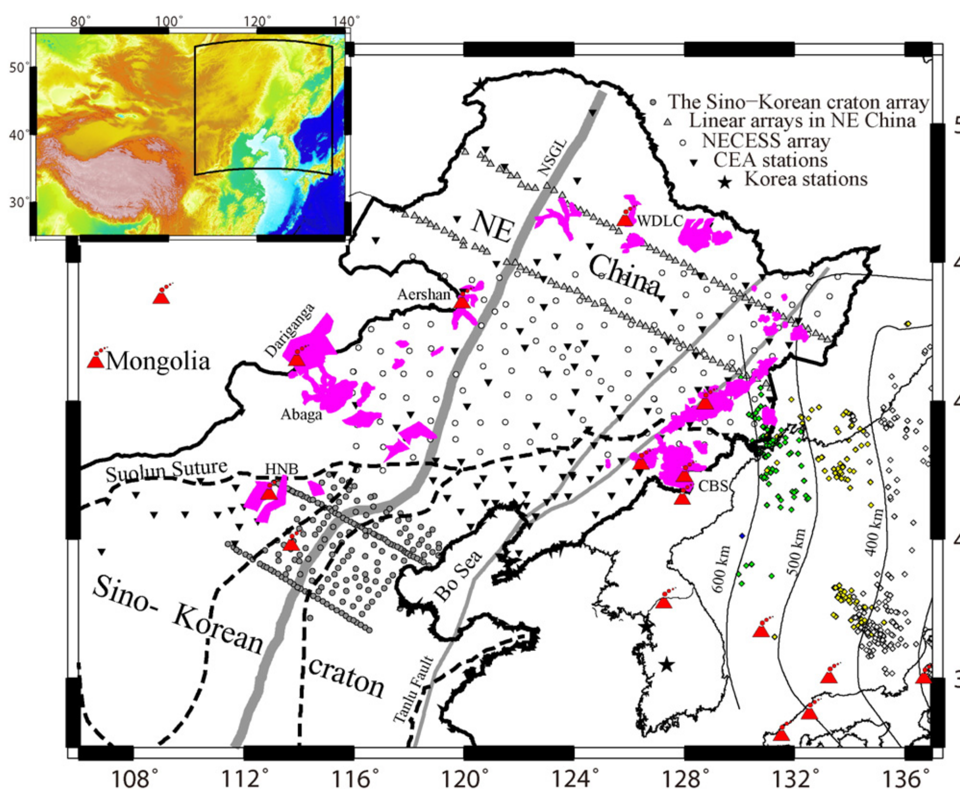

Fig. 1. Map of northeast China and the Sino-Korean craton with Cenozoic volcanism indicated. Dashed lines correspond to the boundary between eastern, central and western areas of the north China craton (the Chinese part of the Sino-Korean craton). Wudalianchi and Hannuoba volcanism are labeled as WDLC and HNB, respectively. Data used in this study were collected by two linear temporary arrays (gray triangles) and the NECESSArray (unfilled circles) in NE China, one experiment in the Sino-Korean craton (gray circles), regional permanent stations in northeast China (black inverted triangles) operated by the China Earthquake Administration (CEA) and stations in Korea (black stars). Gray lines represent the north–south gravity lineament (NSGL) and Tanlu faults. Blue, green, yellow and unfilled diamonds denote earthquakes with focal depths of more than 660 km, 500–600 km, 400–500 km and less than 400 km, respectively. Red, smoking triangles indicate volcanoes. The slabs of northwestern Pacific plate (Gudmundsson and Sambridge, 1998) are presented in black lines.