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Thick crust beneath the Ordos plateau: Implications for instability of the North China craton

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A B S T R A C T

Surrounded by seismicity and other manifestations of active deformation, the Ordos plateau, or the western portion of the North China craton (NCC), is a uniquely stable terrane in Asia. Results from virtual deep-seismic sounding and crustal receiver functions suggests that the crust under the eastern Ordos is thicker (at least 60 km) than expected from previous studies and from its modest elevation ($\sim$1500 m above sea-level). Receiver functions also reveal a pronounced elastic impedance contrast within the crust (at $\sim$40 km depth), which we interpret as the Conrad discontinuity. The presence of a 20 km thick layer of mafic lower crust between the Conrad and Moho discontinuities would maintain crustal isostasy. The $\sim$1000 km long seismic profile from the Ordos plateau in the west to the North China basin in the east reveals that crustal thickness changes by almost a factor of two across the active Shanxi rift in central NCC (over a distance of only about 100 km). Insofar the current configuration of the lithosphere under the Ordos plateau might serve as a proxy for the initial condition prior to reactivation of the eastern part of NCC—where a cratonic keel no longer seems to exist—our results support the hypothesis that lower crust foundering was due to transformation of a thick mafic lower-crust to a garnet-rich assemblage (possibly caused by hydration associated with subduction during and/or before mid-Mesozoic times).

1. Introduction

Archean shields mark the oldest and the most stable region of continents. The longevity of shields is generally attributed to the existence of a highly viscous, refractory lithospheric mantle "keel", which is neutrally buoyant due a balance between thermal contraction and a depleted chemical composition (e.g., Jordan, 1978, 1981; Pearson, 1999). These deep and, presumably, ancient continental keels are typically characterized by seismic wave speeds that are higher than the global average for those depths (Jordan, 1978, 1988; Polet and Anderson, 1995).

The North China craton (NCC) is overlain by Archean crust (e.g., Liu et al., 1992) but deviates in several ways from the general characteristics of cratons. In terms of both tectonic stability and structure of the lithospheric mantle, there are substantial differences between its western and eastern parts. Along the Shan-Xi graben and farther to the east, the NCC is tectonically active, as manifested by the occurrence of many devastating intra-continental earthquakes (see e.g., Chen and Nabelek, 1988 and references therein; Fig. 1). Moreover, low seismic wave speeds in the shallow mantle inferred from tomography (Zhao et al., 2009; Huang et al., 2009) and thin lithosphere inferred from receiver functions (Chen et al., 2006, 2009) argue against the presence of a thick refractory keel. Indeed, the composition and geochemical characteristics of igneous rocks suggest that the eastern NCC has been reactivated since the Mesozoic, often viewed as a notable example of decratonization (e.g., Gao et al., 2008; Griffin et al., 1998; Menzies et al., 1993, 2007; Wu et al., 2005).

In contrast, the western part of the NCC, or the Ordos plateau, has been tectonically stable since the early Proterozoic (Kusky et al., 2007; Zhao et al., 2005) and seems to be underlain by a thick keel of high seismic wave speeds (Chen et al., 2009; Huang et al., 2009; Li and Van der Hilst, 2010). The plateau is surrounded by active tectonic belts delineated by abundant historical

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seismicity (562 Brigade, 1979; Fig. 1) and its stability is corroborated by a thick cover of undeformed sedimentary rocks, reaching thicknesses of up to 10 km in places and dating back to the middle Proterozoic (Yuan et al., 2007).

Whereas remobilization of the eastern NCC has been the topic of much debate, little attention is paid to deep crustal properties of the western NCC (cf. Gao et al., 2004; Menzies et al., 2007; Xu, 2001). Judging from its modest elevation of about 1500 m, Airy isostasy predicts a crustal thickness of about 45–50 km beneath the Ordos plateau, a value that has been generally accepted by previous studies of crustal structure in this area (e.g., Li et al., 2006; Tian et al., 2011; Zheng et al., 2012). If correct, this inference from the Airy model would imply that there are only modest variations in crustal thickness between the eastern and western NCC.

With new seismic array data and an innovative method to construct deep seismic profiles over a distance of about 1000 km across the NCC, we show that across the Shan-Xi graben—over a lateral distance of ~100 km—crustal thickness increases westward by more than 20 km to over 60 km beneath the eastern margin of the Ordos plateau. Our results also reveal a strong interface near 40 km depth beneath the Ordos plateau. In previous studies of crustal structures at other locations of the Ordos plateau, this interface was identified as the Moho (e.g., Teng et al., 2010; Tian et al., 2011; Zheng et al., 2012). However, clear evidence for a deeper, strong interface around 60 km, and modeling of scattered *P*- and *S*-waveforms indicates that the interface near a depth of 40 km is likely the Conrad discontinuity between the upper crust and a compositionally distinct lower crust. The lower crust, likely of mafic composition (mafic granulite not yet transformed to eclogite), maintains crustal isostasy and provides a constraint on the initial condition of the NCC before remobilization.

2. Data and methods

We analyze broadband waveforms collected by Peking University between 2007 and 2010 as part of the Destruction of the North China Craton Project. Overall, six linear segments are combined to form an approximately east–west trending profile over a distance of about 1000 km (Fig. 1a). The deployment of each segment, at a station spacing of 10–15 km, lasted about 1 yr.

We use two complementary methods to investigate the crust and the upper mantle under the area of study: virtual deep seismic sounding (VDSS) developed by Tseng et al. (2009) and traditional receiver functions (RFs; Langston, 1979; Ammon, 1991). VDSS produces large, clear reflections that are insensitive to details of the Moho, thus providing a robust estimate of overall crustal thickness. In contrast, signals of interest in RFs are often small in amplitude but are more sensitive to impedance contrasts across subsurface discontinuities than VDSS. In their simplest forms, both approaches assume laterally homogeneous structures; thus we also augment these investigations with finite-difference modeling of laterally varying media.

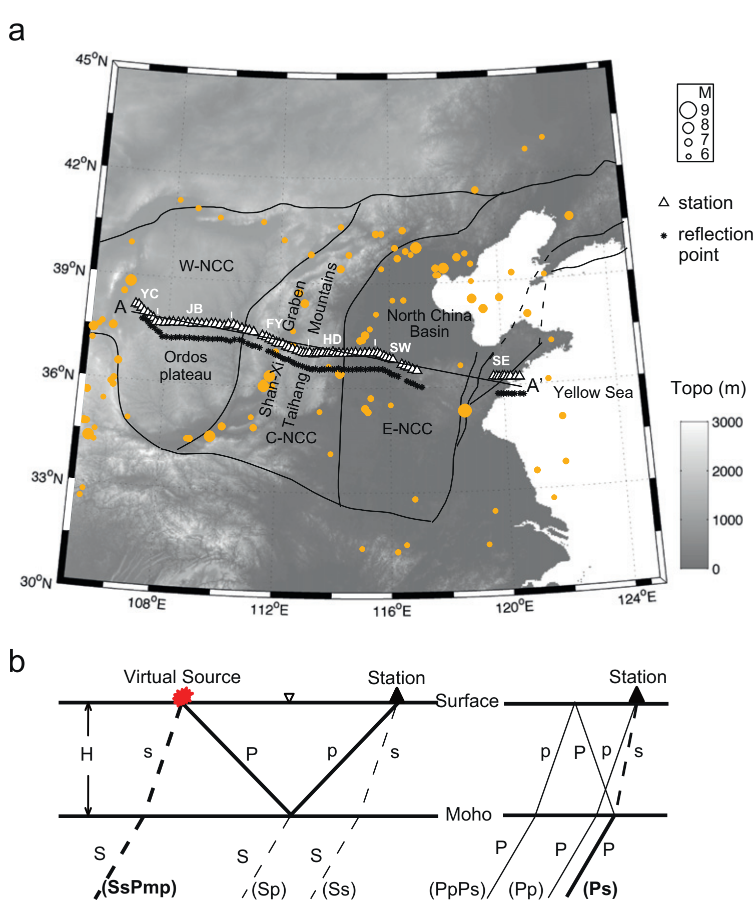

Fig. 1. (a) Topographic map (in gray-scale) showing locations of seismograph stations (open triangles) and corresponding positions of reflection off the Moho for the *SsPmp* phase (asterisks; estimated using a nominal crustal thickness of 40 km). Two-letter codes refer to individual segments of the long seismic profile. Solid curves are boundaries of distinct geologic units within the North China craton (NCC; W-, C- and E- mark the western, central and eastern NCC, respectively; after Zhao et al. 2005). Circles (in bronze) depict epicenters of large historical earthquakes ($M \geq 6$) between 1 and 2010 CE. (b) Schematic cross-sections illustrating paths of main seismic phases related to scattering of teleseismic (left) *S*-wave and (right) *P*-wave near the receiver. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this article.)