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Seismic evidence for significant lateral variations in lithospheric thickness beneath the central and western North China Craton

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ABSTRACT

We have migrated teleseismic S-receiver functions to construct detailed lithospheric structure images that cover the three constituent parts of the North China Craton (NCC). Our images show that in contrast to the eastern NCC where significantly thinned lithosphere (60–100 km) is widespread, the central and western NCC are characterized by the coexistence of both preserved thick and dramatically thinned lithosphere. The thick lithosphere (>200 km) is present beneath the stable Ordos Plateau and the thinned lithosphere (up to 80 km) is found in the late Cenozoic Yinchuan–Hetao and Shaanxi–Shanxi rift areas, with sharp changes occurring over a lateral distance of <200–400 km. Near the boundary between the eastern and central NCC, a rapid thickening of the lithosphere by 20–40 km over ~100 km laterally is observed, concordant with abrupt changes in surface topography and roughly coincident with the North–South Gravity Lineament (NSGL). Together with petrological and geochemical data these structural features suggest that lithospheric remobilization and thinning may have affected the NCC much further to the west than previously thought. Compared to the widespread reactivation and destruction of lithospheric mantle in the eastern NCC, lithospheric modification of the central and western NCC may have been less intensive and spatially more localized. Rifting and lithospheric reactivation probably occurred at mechanically weak boundary zones, but the cratonic nucleus of the Ordos block (which forms the western part of NCC) seems to have retained its rigidity, thickness, and stability over long periods of geological time. The long-term survival of such lateral contrasts suggests that the thick lithosphere is compositionally distinct from the convecting upper mantle.

1. Introduction

Cratons, formed mainly in the Archean era, are generally considered to be underlain by a thick, cold, and refractory mantle lithosphere and free from tectonic activity for billions of years. However, recent work suggests that cratons may not be as stable as previously thought. The cratonic lithosphere in some regions has been severely disturbed or reactivated, resulting in significant losses or modifications of the mantle root (e.g., Eggler et al., 1988; Menzies et al., 1993; Griffin et al., 1998; Brown et al., 1999; Lee et al., 2001). The North China Craton (NCC), the largest and oldest craton in China, is perhaps the most striking example of such reactivation (Carlson et al., 2005).

The NCC consists of three major parts (Fig. 1): the eastern NCC and the western NCC of Archean age, and the Trans-North China Orogen (the central NCC) which formed during the assembly of the eastern and western NCC ~1.85 Ga ago (Zhao et al., 2001). While the NCC was tectonically stable as a whole for more than 1 Ga and exhibited features similar to typical cratons ca 450 Ma ago (e.g., Menzies et al., 1993; Griffin et al., 1998; Gao et al., 2002), it experienced widespread thermotectonic reactivation in Phanerozoic time, with the three parts of the NCC evolving differently.

The eastern NCC was severely affected by this cratonic reactivation process. Abundant petrological and geochemical data (e.g., Menzies et al., 1993; Griffin et al., 1998; Fan et al., 2000; Xu, 2001; Wu et al., 2005; Menzies et al., 2007 and references therein) suggest that during the late Mesozoic, the eastern NCC was characterized by intensive lithospheric extension, high heat flow and voluminous magmatism. The thick cratonic lithosphere (>180 km) in this region lost a significant proportion of its deep mantle keel, accompanying a change in the nature of the lithosphere from cratonic to more fertile. Recent seismological investigations also have revealed a substantially thinned lithosphere on the order of 60–100 km and a well-marked lithosphere–asthenosphere boundary (LAB) beneath the eastern NCC (Zhu et al., 2002; Huang et al., 2003; Chen et al., 2006, 2008), which can be ascribed to the Mesozoic lithospheric reactivation of this region.

How the old lithosphere beneath the central and western NCC evolved in response to the late Mesozoic lithospheric reactivation or other tectonic events is still a matter of debate. Compared with the eastern NCC, these parts of the craton show little magmatic activity, relatively low heat flow (Wang et al., 1996; Hu et al., 2000) and generally thick crust (Ma, 1989; Li et al., 2006b) and lithosphere (Chen et al., 1991). Sharp changes in both surface topography and the gravity

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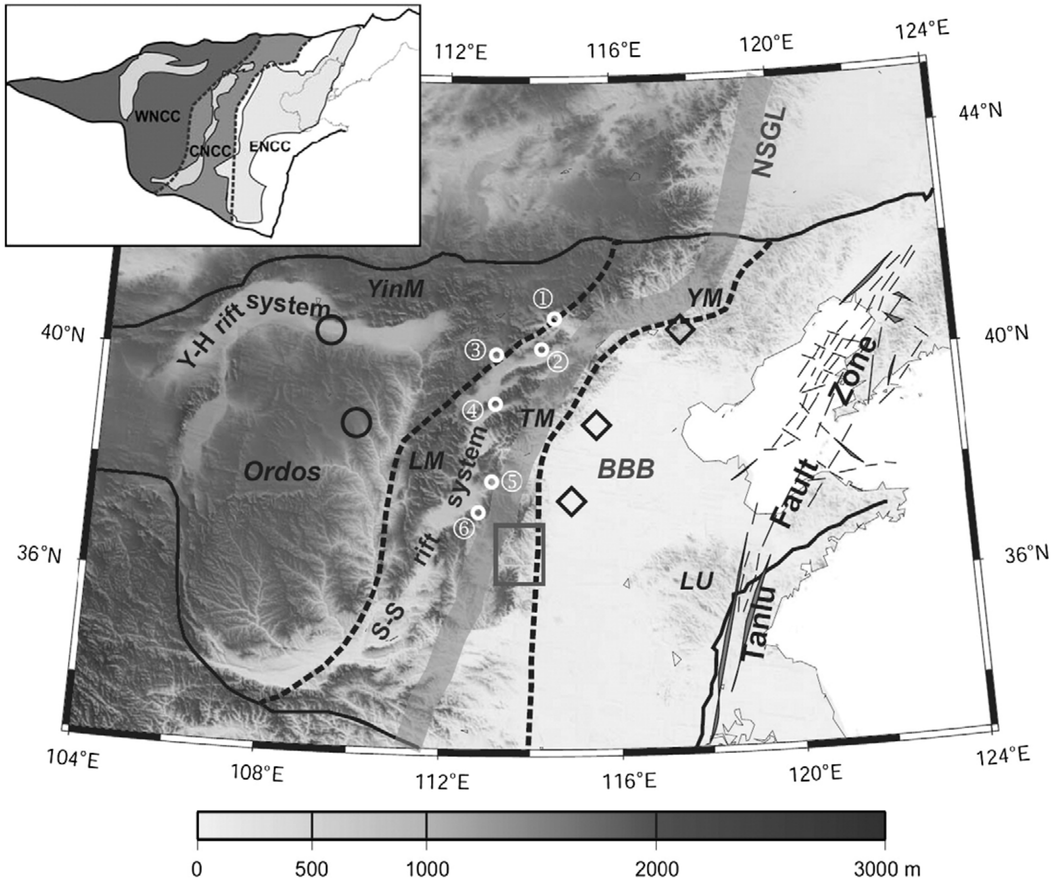

Fig. 1. Topographic map of the study region. Solid lines represent the boundary of the North China Craton (NCC), and two dashed lines outline the Trans-North China Orogen (the central NCC). White circles denote mantle xenolith localities (① Hannuoba; ② Yangyuan; ③ Datong; ④ Fanshi; ⑤ Xiyang–Pingding; ⑥ Zuoquan) and the gray rectangle shows Cretaceous intrusions under which lithospheric modification and thinning may have taken place as suggested by petrological and geochemical studies (e.g., Xu et al., 2004; Wang et al., 2006; Xu, 2007; Tang et al., 2008). Black circles mark places where the thickest (south, >200 km) and thinnest lithosphere (north, ~80 km) in the western NCC were imaged and diamonds show places where sharp changes in lithospheric thickness were observed near the boundary between the eastern and central NCC from S-receiver function (S-RF) migration (see Figs. 4 and 9). Thick gray line represents the North–South Gravity Lineament (NSGL). Major tectonic units in the NCC are also labeled, including the Tanlu Fault Zone, Luxi Uplift (LU), Bohai Bay Basin (BBB), Taihang Mountains (TM), Lüliang Mountains (LM), Yan Mountains (YM), Yin Mountains (YinM), Ordos Plateau, Yinchuan–Hetao (Y-H) and Shaanxi–Shanxi (S-S) rift systems. Map inset is a simplified geological map of the NCC showing the three-fold subdivision of the cratonic basement (Zhao et al., 2001) with Mesozoic–Cenozoic rift systems outlined in light gray.

field, as marked by the NNE-trending North–South Gravity Lineament (NSGL), roughly coincide with the boundary between the eastern and central NCC (Fig. 1). These observations have led to the idea that the central and western NCC have remained relatively stable and retained the characteristics of a typical craton.

However, recent petrological and geochemical studies (e.g., Xu et al., 2004; Wang et al., 2006; Xu, 2007; Tang et al., 2008) suggest that lithospheric remobilization and thinning may also have taken place around the rift areas or near the southeastern margin of the central NCC (see Fig. 1 for locations). In addition, lithosphere less than 100 km thick has been imaged along a NW–SE profile across the boundary between the eastern and central NCC (green line in Fig. 2, Chen, in press). Because of the paucity of data, however, the detailed lithospheric structural features beneath most of the central NCC and the western NCC, which are important for better understanding the tectonic evolution of the entire craton, have not been well understood.

In this study, we investigate the lithospheric structure of the three parts of the NCC by analyzing the new data collected at a dense broadband seismic station array in the western NCC and combining them with two previous data sets from stations in the eastern and central NCC (Fig. 2). We focus mainly on the lateral variations in the lithospheric thickness, particularly beneath the western and central NCC, and their correlations with the surface topography and the tectonic divisions of the region. We also discuss the implications of our observations for the destruction of the NCC's cratonic root.

2. Geological setting

The eastern NCC is dominated by lowlands with altitudes generally less than 200 m (Fig. 1). A large part of this region is covered by thick sedimentary basins including the Bohai Bay Basin in the north and the South North China Basin in the south. These basins are collectively called the North China rift system (light gray area within the eastern NCC in the map insert in Fig. 1) which has formed as a direct consequence of the widespread lithospheric extension during the late Mesozoic and early Cenozoic (Ren et al., 2002). The Tanlu Fault Zone, a large translithospheric strike-slip fault zone bounding the North China rift system to the east, developed during the collision between the NCC and the Yangtze Craton in the early Mesozoic (Yin and Nie, 1993; Zhang, 1997; Faure et al., 2001) and played an important role in the Mesozoic–Cenozoic lithospheric reactivation of the eastern NCC (Zheng et al., 1998; Xu, 2001; Xu et al., 2004). Highlands appear only locally in the eastern NCC, including the Luxi Uplift in the southeast, the eastern part of the Yan Mountains and the highland of Liaodong peninsula in the north and northeast. In contrast, the central and western NCC including the Taihang Mountains, Lüliang Mountains, the western part of the Yan Mountains, the Yin Mountains and the Ordos Plateau (Fig. 1) are characterized by high altitudes of >500 m, and up to 3500 m. Bordering the eastern NCC in the west and roughly coinciding with the NSGL, the Taihang Mountains formed as an extensional orogen in the late Mesozoic, the evolution of which has been tectonically coupled with