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# Crustal structure and extensional deformation of thinned lithosphere in Northern China

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ABSTRACT

We herein present an interpretation of a 320 km-long wide-angle seismic profile between Anxin and Kuancheng, which was obtained in 2002. The profile runs from the North China Plain (NCP), where the lithosphere is just 70 km thick; to the Yanshan Mountain Folded Belt (YMFB), where the lithosphere is180 km thick. Our model shows a crustal thickness that varies from 31 km under the NCP to 36 km under the YMFB. The observed thinning of the crust in the NCP is about 14%, which compares with an average extension of 24–41% at basin-scale and 25% at lithosphere-scale. This finding suggests that the extensional deformation of the lithosphere in the North China block depends on depth. The thin, high-velocity crust–mantle transition zone has most likely originated after a delamination of the bottom of the crust and a concomitant intrusion of materials from the mantle. The lower velocity of the lower crust may be attributed to the destruction of the lithosphere, which permitted the lateral flow of melting materials above the Moho from the NCP to the YMFB. The differences found between the crust and the lithospheric mantle help to dispel any of the remaining uncertainty in the extensional factors, and they may be attributed to detachment of middle crust and an intrusion of magma that originated in either lithosphere or asthenosphere. We infer that the detachment of the middle crust, lower-crustal flow and magma intrusion probably lead to the underestimation of the crustal-scale extensional factor, and may represent the crustal response to the thinning of the lithosphere.



## 1. Introduction

The North China block is one of the oldest continental nuclei in the world (Jahn and Nyquist, 1976), and consists of two Archean blocks, namely the western and the eastern, which have reported crustal ages of 3.8 Ga (Liu, 1992), separated by a Proterozoic orogenic belt of 1.8 Ga (Zhao et al., 2000). The thickness of the lithosphere beneath the Precambrian shield is generally considered to be 185 km, with mechanical and thermal boundary layer thicknesses of about 165 and 36 km, respectively (White and McKenzie, 1988; McKenzie and Nimmo, 1997). Ever since the Cenozoic, the North China Craton has been fragmented by intensive intracontinental rifting and extensional tectonics, which have resulted in the formation of two extensional domains, namely the western domain, characterised by graben systems around the Ordos basin, and the eastern domain, represented by the North China Plain (NCP; Zhang et al., 2003). The rifting and extensional tectonics have worked to induce thinning of the lithosphere in the eastern domain, while thicker lithosphere has been preserved in the older western domain.

It has been estimated from geochemical data that the lithosphere is as much as 200 km thick in the western block, but only 80 km thick in the eastern block (Fan et al., 2000). Apart from the thickness, also the lateral heterogeneity (Ma, 1987) and the composition (Zhang et al., 2003) of the lithosphere differ between the two blocks. Gravity data inversion (Ma, 1987; Yuan, 1996) indicates that the lithosphere is around 100 km thick in the western domain, but shows large variations in thickness of 60–100 km in the eastern domain (Fig. 1). It has been suggested that the original cratonic lithosphere is well preserved in the western domain, and that pronounced thinning of the lithosphere occurred in the eastern domain (Zhai et al., 2007).

Seismic data acquired from passive seismogenic sources show that the thickness of the lithosphere varies considerably in the eastern domain (Ma, 1987; Yuan, 1996; Li and Mooney, 1998; Deng et al., 2004; Huang and Zhao, 2004). For example, surface wave modelling has shown that the thickness is almost 80 km at the southwestern end (38.5°N) of the Anxin–Kuancheng wide-angle seismic profile (Fig. 1), and approximately 180 km at the northeastern end (41.5°N) of the profile in the eastern block of the North China Craton (Griffin et al., 1998; Lebedev and Nolet, 2003; Deng et al., 2004; Huang and Zhao,

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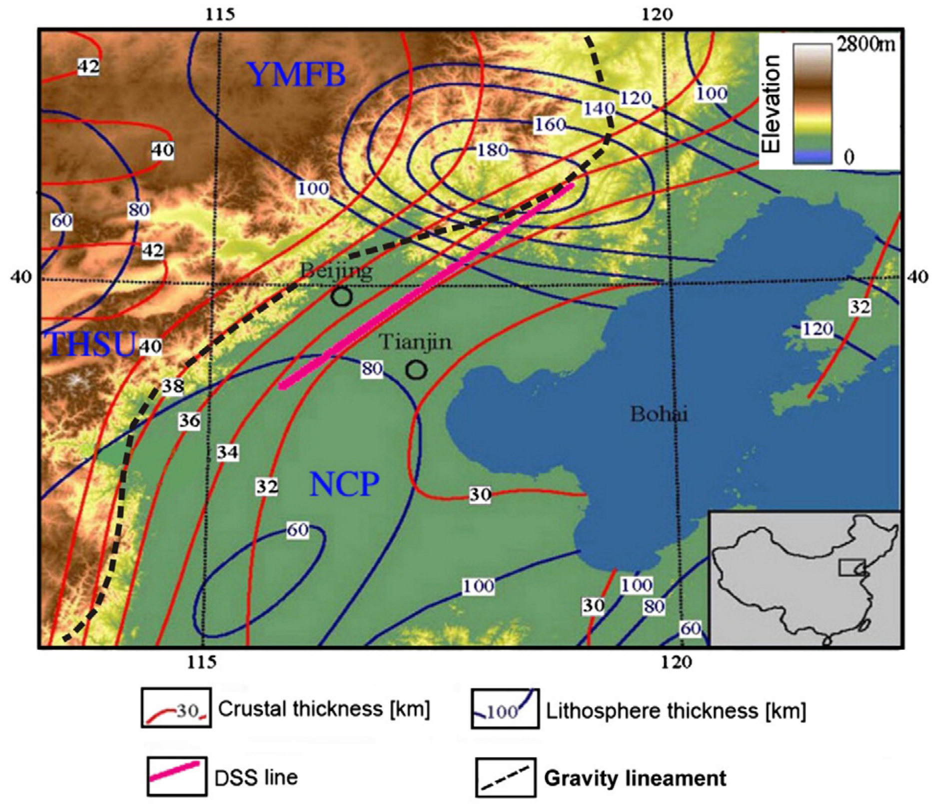


**Fig. 1.** Thickness of the crust (red isolines) and lithosphere (blue isolines) on an elevation map (Yuan, 1996; Li and Mooney, 1998). The straight line running in a NE–SW direction (green line) marks the deep seismic sounding profile studied herein. YMFB is the Yanshan Mountain Folded Belt, THSU is the Taihangshan uplift, and NCP is the North China Plain. The inset in the lower right-hand corner indicates the location of the study area with respect to the rest of China. The small box indicates the location of the study area.

2004; Kusky et al., 2007). However, it should be noted that the thickness of the crust along the Anxin–Kuancheng profile barely changes, even though the topography drops from an average surface elevation of 1 km above sea level in the northeastern region to less than 500 m in the southwestern region (Li and Mooney, 1998; Li et al., 2004; Zheng et al., 2006).

By taking the top of the high-conductivity layer as the bottom of the lithosphere (Wei et al., 2006), the magnetotelluric data suggest that the thickness of the lithosphere along the Anxin–Kuancheng profile changes very little, from 60 km under the southwest end to almost 55 km under the northeast end, which contradicts previous findings. Later on, we will assume that the high-conductivity zone represents a huge intrusion that originates from the asthenosphere.

Using geophysical data, Ma (1987) identified a northeast–southwest gravity lineament (Fig. 1) between the Taihangshan uplift (THSU) and the North China Plain (NCP) that divides the North China Craton into different tectonic domains (Fig. 1). The region to the west of this gravity lineament is characterised by large negative Bouguer anomalies and a lithospheric thickness of 150–220 km. The region to the east of the lineament is characterised by weak negative/positive gravity anomalies, a high heat flow, and a lithospheric thickness of 60–120 km. These Bouguer gravity anomalies show a rapid increase from −100 to −40 and −20 mGal, over a narrow band in the west–east direction. Mesozoic magmatism occurs mainly to the east of the gravity lineament. It is characterised by voluminous felsic to-intermediate intrusion (predominantly monzonitic) and associated mafic bodies, together with widespread volcanic counterparts. To the west, the magmatism and basin development are less pronounced (Ma, 1987; Ai and Zheng, 2003; Ai et al., 2003, 2008; Chen et al., 2008).

Spatial (and temporal) variations in lithospheric thickness can provide significant constraints on the evolution of the lithosphere. The seismic survey line that follows the Anxin–Kuancheng transect (Fig. 1) crosses the study area, and offers one of the best opportunities for investigating the seismic velocity structure of the crust and the evolution of the lithosphere in Northern China. In this paper, we present our interpretation of the velocities in the Anxin–Kuancheng seismic profile. Below, we discuss the structural response to lithospheric thinning at different scales, namely those of the basin, crust and deep lithosphere. We also describe the related coupling–decoupling deformation as the key geodynamic mechanism in the NCP.

## 2. Tectonic setting

The Anxin–Kuancheng profile is situated to the east of the gravity lineament and crosses two tectonic subunits in a SW–NE direction, namely the NCP to the southwest and the Yanshan Mountain Folded Belt (YMFB) to the northeast (Fig. 2). Within the NCP, various Cenozoic basins of different thicknesses lie along the profile from SW to NE, namely the Jizhong depression, the Baoding depression, the Niutuozhen uplift, the Guan depression, and the Beijing–Tianjing depression (Li, 1981; Ye et al., 1985, 1987; Liu, 1988). The North China basins endured NW–SE shear-compression during the Early Cenozoic, forming incipient faults (Li, 1981; Ye et al., 1985, 1987; Liu, 1988). A number of active faults exist in the North China basin (Fig. 2); all the tectonic structures are oriented in the NE–SW direction. Since the Mid-Cenozoic, the region has experienced extension, crustal rise and faulting, and widespread extension of the upper and middle crust took place during right-lateral extensional shearing. The delamination of the lithosphere occurred during the Late Tertiary, and resulted in a thinner lithosphere and the present tectonic setting of the NCP. The NCP is surrounded by large-scale normal faults that cross the interior of the block and stretch in a NE direction. To the north of the Baodi–