Earth and Planetary Science Letters 369–370 (2013) 129–137

Contents lists available at SciVerse ScienceDirect

Earth and Planetary Science Letters

journal homepage: www.elsevier.com/locate/epsl

Crust and upper mantle structure of the North China Craton and the NE Tibetan Plateau and its tectonic implications

Xuewei Bao [a], Xiaodong Song [a,b,*], Mingjie Xu [a], Liangshu Wang [a], Xiaoxiao Sun [a], Ning Mi [a], Dayong Yu [a], Hua Li [a]

[a] Institute of Geophysics and Geodynamics, School of Earth Sciences and Engineering, Nanjing University, Nanjing, 210093, China
[b] Department of Geology, University of Illinois at Urbana-Champaign, IL 61801, USA

ARTICLE INFO

Article history:
Received 11 December 2012
Received in revised form
15 March 2013
Accepted 15 March 2013
Editor: T.M. Harrison
Available online 20 April 2013

Keywords:
North China Craton
Tibetan Plateau
ambient noise tomography
lithospheric structure

ABSTRACT

Understanding the Mesozoic–Cenozoic tectonic evolution of the North China Craton (NCC) and the NE Tibetan Plateau (TP) requires detailed knowledge of the lithospheric structure. Using dense regional networks and temporary deployments as well as updated reference models, we obtain the crust and upper mantle structure to 120 km depth. Our tomographic results show several major features, which have particular implications for the Weihe–Shanxi rift system (WSRS), deformation of the NE TP, and lithospheric evolution of the NCC. Beneath the WSRS, the crust gradually thickens from south to north, the lithospheric mantle gradually becomes slower, and the mid-lower crustal velocities are lower in the Weihe Rift, where rifting of the WSRS initiated. We suggest that along-strike variations of the lithospheric structures of the WSRS have played an important role in its multistage evolution. A low-velocity zone (LVZ) in the mid-crust beneath the Qilian Orogen is characterized by relatively higher velocities compared to LVZs in other parts of the TP. Thus, coherent lithospheric deformation may occur due to the high viscosity of the LVZ during early plateau growth, causing strong anisotropy to develop. The western NCC (including the Ordos Block and part of the Alashan Block) shows a high-velocity cratonic root extending to the base of our model. In contrast, the lithosphere of the eastern NCC appears to have been completely modified during the Mesozoic through Cenozoic and presents a thin lithosphere of relatively low velocities underlain by hot asthenosphere. We observed significant upper-mantle heterogeneities in the NCC, which may reflect its diachronous lithospheric modification.

1. Introduction

The North China Craton (NCC), one of the world's oldest Archean continental nuclei, is the Chinese part of the Sino-Korea Craton (Liu et al., 1992). Based on petrologic, geochemical, geochronological, structural and metamorphic P–T path studies, the NCC can be divided into three parts (Fig. 1): the Archean eastern NCC, the Archean western NCC, and the Trans-North China Orogen (TNCO), an intervening orogenic belt along which the eastern and western NCC were amalgamated to form the NCC at ~1.85 Ga (Zhao et al., 2005). The NCC is unique among the world's cratons due to its complex and contrasting evolution during the Phanerozoic: the eastern NCC (mainly the North China Basin) experienced dramatic thermotectonic reactivation that led to significant lithospheric modification and widespread rifting and volcanism during the Late Mesozoic–Cenozoic, while the western NCC (mainly the Ordos Block) was much less involved in this process and most likely preserves the old cratonic root (Griffin et al., 1998; Menzies et al., 2007).

The Ordos Block is located in a transition from compression of the NE Tibetan Plateau (TP) to extension of the NCC (Fig. 1). The intracratonic Ordos basin developed during the middle-late Triassic and early Cretaceous, with subsidence in its western part and uplift in its eastern part for nearly 200 million years (Liu et al., 2006). Cenozoic rifting in central and western NCC is localized along two rift systems surrounding the Ordos Block, namely the Yinchuan–Hetao rift system (YHRS) to the north and west and the Weihe–Shanxi rift system (WSRS) to the south and east (Fig. 1). Magmatism is localized around Datong Volcano in the northernmost part of the WSRS.

The WSRS extends from the southeast margin of the Ordos Block north-northeastward to the northern part of the TNCO over a distance of approximately 1200 km, making a roughly S-shaped curve. It is one of the largest Cenozoic intracontinental rift systems in the world, consisting of a series of fault-controlled asymmetrical half-grabens ranging from 40 to 100 km wide (Xu and Ma, 1992; Ye et al., 1987). The northeast- or north-northeast-trending major faults that bound the grabens are mostly normal faults with varying degrees of right-lateral strike-slip motion and dip angles

* Corresponding author.
E-mail address: xiao.d.song@gmail.com (X. Song).

0012-821X/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.epsl.2013.03.015

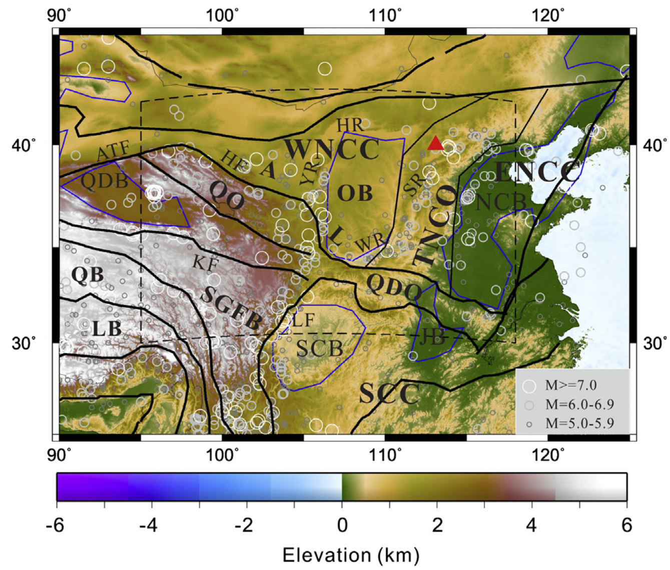

Fig. 1. Tectonic map of the study region. Our region of focus (dashed box) covers Ordos Block and parts of NE Tibetan Plateau and North China Craton to the west and the east, respectively. Plotted are topography in the background (color), major tectonic and geologic boundaries (lines), seismicity since 780 B.C. (circles), and the Datong Volcano (red triangle). The abbreviations are eastern North China Craton, ENCC; North China Basin, NCB; Trans North-China Orogen, TNCO; Weihe Rift, WR; Shanxi Rift, SR; Ordos Block, OB; the western North China Craton, WNCC; Yinchuan Rift, YR; Hetao Rift, HR; Alashan Block, A; Liupanshan Fold Belt, L; Qilian Orogen, QO; Qinling–Dabie Orogen, QDO; Songpan–Ganzi Fold Belt, SGFB; Sichuan Basin, SCB; Jianghan Basin, JB; South China Craton, SCC; Qiangtang Block, QB; Lhasa Block, LB; Qaidamu Basin, QDB; Altyn-Tagh Fault, ATF; Haiyuan Fault, HF; Kunlun Fault, KF; Longmenshan Fault, LF. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

ranging from 40° to 75°. Accompanying the mainly vertical displacement of the marginal fault zones, the crustal extension of the rift system was estimated to be several tens of km (largest in the Weihe Rift) and decreases from south to north (Zhang et al., 1998). Geological data show that the highest Pliocene–Quaternary northwest–southeast extension rate is in the order of 1.6 mm yr^{-1} across the Weihe Rift and 0.5 mm yr^{-1} across the southern Shanxi Rift (Zhang et al., 1998). Although rifting started to develop in the Weihe Rift and the YHRS in the early Oligocene or late Eocene, the major extension and rapid subsidence of the WSRS and the YHRS occurred in the Neogene and Quaternary. The development of the fault basins peaked in the Pliocene (Chen, 1987). To further understand the variable rifting process of the WSRS and evolution of the NCC, more detailed information on the crustal and lithospheric structure beneath a broad region is required.

Nearly coeval with the peak rifting of the WSRS, the NE TP experienced shortening and rapid uplift during the Late-Cenozoic. Cumulative regional shortening perpendicular to thrust faults (N30°E) appears to have been more than 1.5 cm yr^{-1} since the late Neogene (Meyer et al., 1998), only slightly less than that across the Himalayas (Bilham et al., 1997). The growing NE TP has a series of parallel NW–SE-trending mountain ranges that are bounded by active thrusts and sinistral faults and are separated by inter-mountain basins with elevations between 2000 and 4000 m. Active overthrusting is observed over a broad region in NE Tibet, which is bounded by the Altyn-Tagh–Haiyuan fault system to the north and the Kunlun fault system to the south. The growth of the TP, which began approximately 55 Ma, is considered to have begun in the south and progressed north (Tapponnier et al., 2001). The NE margin of the collisional highlands may be viewed as a small, actively growing TP. The structure and deformation of the crust and lithosphere of this region might reflect deformation during the formation of the TP.

In recent years, high-resolution surface wave tomography using Green functions estimated from ambient noise interferometry has become a particularly useful tool to image the crustal and upper-mantle velocity structure of the earth (Shapiro et al., 2005; Yang et al., 2012; Yao et al., 2008; Zheng et al., 2008). We use seismic data from several data sources to significantly increase the resolution of ambient noise tomography in the NCC and NE TP. We use fundamental-mode Rayleigh waves recovered from ambient noise cross-correlation to measure dispersion at periods of 8–50 s, and combine these data with longer-period earthquake dispersion data to study the crust and uppermost mantle structure from NE TP across the Ordos Block to North China.

2. Data and ambient noise tomography method

The original data we used in this study include continuous vertical-component seismic records, which come from two sources (Fig. 2): (1) Chinese regional digital seismic networks (Zheng et al., 2010) (about 400 broadband stations during the time period from Jan., 2008 to Mar., 2008 and from Jan., 2009 to Dec., 2009), and (2) temporary seismic arrays deployed by Nanjing University (in the period from Jan., 2008 to Mar., 2008 and from Jan., 2009 to Oct., 2009) (Lu et al., 2011; Wang et al., 2013). The overlapping times between different pairs of stations range from three to twelve months, which generally results in cross-correlations of sufficiently high signal-to-noise ratios (SNRs). In addition, we use Rayleigh wave dispersion maps (8–120 s) of China by Xu (2011) as the background models, which were derived from a tremendous data set (including Chinese backbone stations, temporary PASSCAL deployments, and permanent global stations over about two decades with variable station overlapping periods, as well as traditional earthquake data).

We extract Rayleigh wave empirical Green functions from ambient noise using the data processing procedures described by Bensen et al. (2007). The pre-processing procedure involves removing the instrument response, band-pass filtering (5–100 s), and applying temporal normalization and spectral whitening. Using these corrected waveforms, we perform cross-correlations for all simultaneously recorded station pairs using day-long windows. We stack all available cross-correlations for a given station pair to produce the estimated Green functions. The symmetric component is then calculated by averaging the positive-lag and negative-lag parts of the cross-correlation.

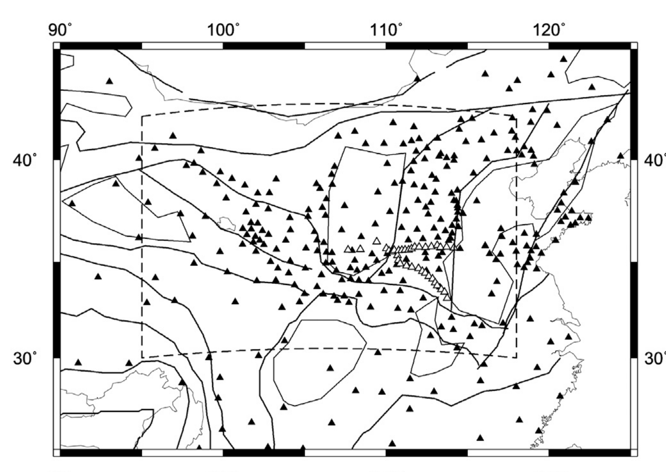

Fig. 2. Map of seismic stations used in this study. The stations include regional networks operated by China Earthquake Administration (black triangles), and two temporal arrays deployed by Nanjing University (white triangles).