Earth and Planetary Science Letters 417 (2015) 132–141

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

www.elsevier.com/locate/epsl

High-resolution lithospheric structure beneath Mainland China from ambient noise and earthquake surface-wave tomography

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ARTICLE INFO

Article history:
Received 23 November 2014
Received in revised form 11 February 2015
Accepted 13 February 2015
Available online 6 March 2015
Editor: P. Shearer

Keywords:
Rayleigh wave tomography
ambient noise correlation
lithosphere
North China Craton
Tibetan Plateau

ABSTRACT

We present a new high-resolution shear-velocity model of the lithosphere (down to about 160 km) beneath China using Rayleigh-wave tomography. We combined ambient noise and earthquake data recorded at 1316 seismic stations, the largest number used for the region to date. More than 700,000 dispersion curves were measured to generate group and phase velocity maps at periods of 10–140 s. The resolution of our model is significantly improved over previous models with about 1–2° in eastern China and 2–3° in western China. We also derived models of the study region for crustal thickness and averaged S velocities for upper and mid-lower crust and uppermost mantle. These models reveal important lithospheric features beneath China and provide a fundamental data set for understanding continental dynamics and evolution. Different geological units show distinct features in the Moho depth, lithospheric thickness, and shear velocity. In particular, the North China Craton (NCC) lithosphere shows strong east–west structural variations with thin and low-velocity lithosphere in eastern NCC and thick and high-velocity lithosphere beneath western NCC and the lithosphere of the Ordos Block seems to have undergone strong erosion. The results support the progressive destruction of the NCC lithosphere from east to west at least partly caused by the thermal–chemical erosion of the cratonic lithosphere from the asthenosphere. Another pronounced feature of our model is the strong lateral variations of the mantle lithosphere beneath the Tibetan Plateau (TP). The Indian lithosphere beneath the TP shows variable northward advancement with nearly flat subduction in western and eastern TP and steep subduction in central TP with evidence for the tearing of Indian lithosphere beneath central TP, which may be important for the riftings at the surface in Himalayas and southern TP. The low-velocity zone in northern TP shows strong correlation with the region of the mid-Miocene to Quaternary potassic magmatism, suggesting that delamination of lithosphere may have played an important role in the rise of the TP.

1. Introduction

The Chinese continent is composed of several Precambrian cratonic blocks and large Phanerozoic orogenic belts, such as the North China Craton (NCC) in the north, the Yangtze Craton (YZC) in the center, the Tarim Block in the northwest, the Central Asian Orogenic Belt (CAOB) to the north of the NCC, the Qinling-Dabie orogenic Belt between North China and South China, the Cathaysia fold-belt (CFB) in the southeast, and the Tibetan–Himalayan orogenic system in the west (Fig. 1). Mainland China and its neighboring region are located in a unique tectonic setting where the Paleo-Asian Ocean Domain, the Tethyan Domain, and Western Pacific Domain meet in a triangular framework (Zheng et al., 2013), forming one of the most geologically complex and tectonically active regions on Earth. The present-day tectonics of the Chinese Mainland has been mainly affected by the India–Eurasian collision (Molnar and Tapponnier, 1975; Yin and Harrison, 2000) in the southwest and the subduction of the Pacific and Philippine plates (Northrup et al., 1995) to the east, making this region an ideal natural laboratory to investigate the evolution of complex continental lithosphere in response to the dynamic interactions of diverse plates. The Mesozoic–Cenozoic destruction of the NCC (Menzies et al., 2007; Xu, 2007) and the Cenozoic rise of the Tibetan Plateau (TP) (Yin and Harrison, 2000) are the two most significant tectonic events in relatively recent past. Detailed knowledge about the structural heterogeneities of the lithosphere beneath China is key to the understanding of these intensive geodynamic processes.

Seismic tomography has been widely applied to explore the three-dimensional (3D) heterogeneity beneath Mainland China

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http://dx.doi.org/10.1016/j.epsl.2015.02.024
0012-821X/

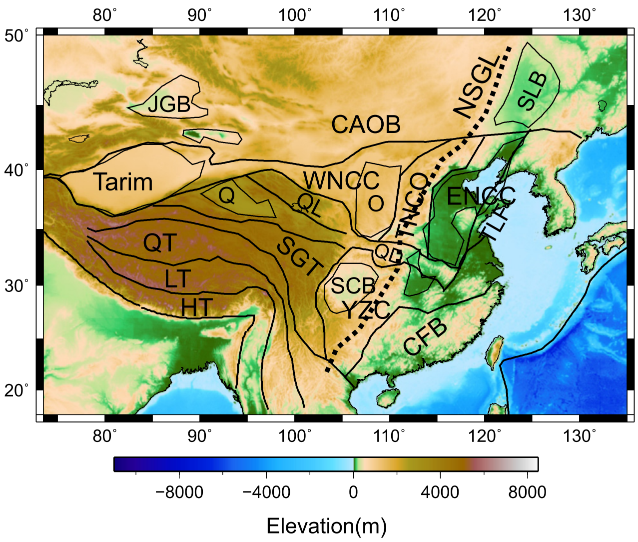

Fig. 1. Topographic map of the study region showing the main tectonic units. Thick black lines are geologic boundaries. The abbreviations are: Junggar Basin (JGB), Qaidam Basin (Q), Qilian Orogenic Belt (QL), Songpan-Ganzi Terrane (SGT), Qiangtang Terrane (QT), Lhasa Terrane (LT), Himalaya Terrane (HT), Sichuan Basin (SCB), Yangtze Craton (YZC), Cathaysia Fold Belt (CFB), Central Asian Orogenic Belt (CAOB), Songliao Basin (SLB), Eastern North China Craton (ENCC), Trans North-China Orogen (TNCO), Western North China Craton (WNCC), Ordos Block (O), Qinling–Dabie Orogen (QD), TLF (Tanlu Fault), NSGL (North-South Gravity Lineament).

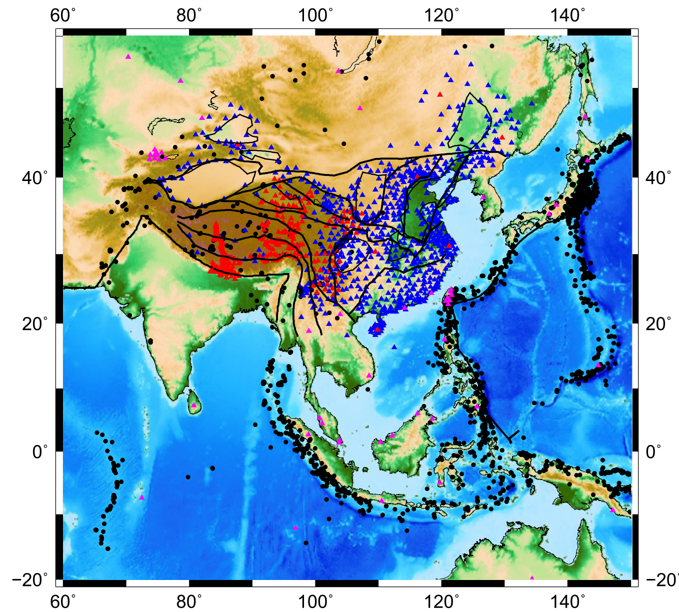

Fig. 2. Distributions of seismic stations (color triangles) and earthquakes (black dots) used in this study. The stations are from Chinese Regional Seismic Networks (blue), temporary arrays (red) in and around Tibet, and global permanent stations (magenta). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

using different data sets, including continent-scale body-wave (Huang and Zhao, 2006; Liang et al., 2004; and references therein) and surface-wave (Feng and An, 2010; Li et al., 2013; Pandey et al., 2014; Xu et al., 2013a; and references therein) tomography, and numerous regional-scale tomographic studies (Bao et al., 2013, 2011; Ceylan et al., 2012; Chen et al., 2009; Liang and Song, 2006; Sun et al., 2014; Yang et al., 2012; Yao et al., 2010; and references therein). These studies show consistent features as well as inconsistency and limitation in resolution. For example, the lithospheric thickness of the Ordos Block, which is essential to studying the destruction of the NCC lithosphere, ranges from 100 km to >200 km in previous models (Bao et al., 2011; Chen et al., 2009; Feng and An, 2010; Huang and Zhao, 2006). Another example is that the mode of the Indian-Eurasian lithosphere collision, which is essential to understand the mechanisms of mountain building and plateau growth, remains controversial (Ceylan et al., 2012; Li et al., 2008; Liang et al., 2012; Zhao et al., 2010). Essentially, the resolution of these earthquake-based studies is controlled by the uneven distribution of earthquakes and stations.

The recent revolutionary method for retrieving the empirical Green function (EGF) from ambient noise correlation has provided new data coverage (Shapiro et al., 2005), especially at shorter periods, complementary to traditional surface-wave tomography using earthquakes. Therefore, combining both ambient noise correlation and earthquake data can improve resolution of the lithospheric structure (Xu et al., 2013a; Yao et al., 2010), for which teleseismic body-wave tomography usually loses vertical resolution because of steep ray paths used. On the other hand, with the deployments of ever increasing temporary seismic arrays and the continuous upgrade of the dense China Regional Seismic Networks (CRSNs) (Zheng et al., 2010), the accumulated massive seismic data sets over the past decade make it feasible to construct a high-resolution lithospheric shear-velocity model for Mainland China and adjacent regions through the combination of ambient noise and earthquake data.

Building on our previous surface-wave tomographic studies of China (Sun et al., 2010; Xu et al., 2013a; Zheng et al., 2008), here we present a new high-resolution 3D shear-velocity model of the Chinese Mainland and neighboring regions by Rayleigh-wave tomography using both earthquake data and inter-station EGFs from ambient-noise correlation. The model improves resolution of major features and reveals new features that correlate with surface geology. We discuss in particular the implications of the new images for the destruction of the NCC lithosphere and the Indian-Eurasian collision.

2. Data and methods

Seismic data used in this study came from three sources: the updated CRSNs (Zheng et al., 2010), temporary deployments in the TP, and permanent global seismic stations within or around the study region (Fig. 2). The largest data set is from four years of continuous data at 864 stations of the CRSNs from 2008 to 2011. The temporary deployments (a total of 401 stations) included HIMNT (de la Torre and Sheehan, 2005), HI-CLIMB (Nábělek et al., 2009), MIT-CHINA (Yao et al., 2010), Namche Barwa (Sol et al., 2007), and INDEPTH IV (Ceylan et al., 2012) experiments. We also collected continuous data from other permanent stations (a total number of 51) available from the IRIS DMC (Incorporated Research Institutions for Seismology Data Management Center) for the same time period as the data from the CRSNs and the temporary deployments. Both EGFs from ambient-noise correlation and earthquake-generated Rayleigh waves were used to measure Rayleigh-wave dispersions. Group velocities were measured at 10–70 s from the EGFs and 10–140 s from the earthquakes and phase velocities were measured at 10–70 s from the EGFs only. The dispersion measurements were based on a frequency-time analysis method (Ritzwoller and Levshin, 1998).

We extracted Rayleigh-wave EGFs from continuous vertical-component seismic recordings following the basic data processing scheme similar to Bensen et al. (2007) and Zheng et al. (2008). In this study, we implemented a parallelization scheme to accelerate the computation of the large quantity of data, which increased our data processing capacity by an order of magnitude. In the meantime, we selected shallow teleseismic Rayleigh waves with magnitudes larger than 5.0 and with distances greater than