A Broadband Seismic Network in the Middle–Lower Yangtze Metallogenic Belt, China

by Xinfu Li, Longbin Ouyang, Hongyi Li, Yingjie Yang, Dan Zheng, Qingtian Lü, Ming Zhou, Jing Tan, Sanjian Sun, and Guibin Zhang

INTRODUCTION

The middle–lower Yangtze Metallogenic belt (MLYMB) is surrounded by the North China Block in the northwest, the Dabie Orogen in the west, and the Yangtze Block in the south (Fig. 1a). The MLYMB experienced tectonic adjustment from south–north compression in the late Jurassic period to extension in the Cretaceous period (Ren et al., 1997), as indicated by the extensive Cretaceous calc-alkaline to alkaline volcanism, granitoid magmatism, and synchronously rift volcanic basins. Major geologic features observed today, including the extensional tectonic settings in eastern China and the MLYMB, were basically formed in this transitional period.

Seven large ore-concentration districts with more than 200 kinds of polymetallic (Cu, Au, Mo, and so on) deposits are clustered in the narrow mineralization zone of the MLYMB. It is still unclear how such rich mineral resources are concentrated in such a narrow zone and what deep geodynamic processes and magmatic activities are responsible for forming the massive metallogenic belt. Many different models have been proposed, such as lower-crust melting (Wang et al., 2001; Zhang et al., 2001, 2002; Shi et al., 2013), thickening and delamination of lower continental crust (Wang et al., 2004; Hou et al., 2007), and subduction of the paleo-Pacific plate (Ling et al., 2009). A comprehensive seismological investigation can provide useful constraints on the structure and dynamics of the crust and upper mantle in this region and can help to evaluate candidate models for the MLYMB formation.

Although there are many geophysical surveys in this region (e.g., Chang et al., 1991; Lü et al., 2003, 2004, 2010, 2013; Shi et al., 2013), these surveys mostly focused on imaging shallow depths, and only a few geophysical investigations for deep-seated structures have been carried out (e.g., Shi et al., 2012, 2013; Jiang et al., 2013). In 2011, the SinoProbe program conducted a 450 km long active source seismic experiment along the profile from Lixing to Yixing (Fig. 2), and a linear broadband seismic array along the same profile were also deployed from November 2009 to August 2011 by the Chinese Academy of Geological Sciences in the middle–lower Yangtze River to study the Moho discontinuity (Shi et al., 2013). These studies focused on imaging structures along a linear seismic profile, unable to provide a 3D perspective on regional tectonics.

Because of low seismic activity in the middle–lower Yangtze region and sparse seismic station coverage in the past, only a few surface-wave tomographic studies have been carried out in this area (Song et al., 1993; Xu et al., 2000; Huang et al., 2003, 2009). Song et al. (1993) and Xu et al. (2000) obtained 3D shear-wave velocity structures in the crust and upper mantle beneath east continental China, and their lateral resolutions are about $4^\circ \times 4^\circ$ and $5^\circ \times 5^\circ$, respectively. Huang et al. (2003) conducted Rayleigh-wave tomography of China and adjacent regions, and the resolution is about $4^\circ \times 4^\circ$ for short periods and $6^\circ \times 6^\circ$ for long periods. Recently, several researchers conducted ambient noise tomography in the Dabie Orogen (Luo et al., 2012) and South China (Zhou et al., 2012). Their lateral resolutions at short-to-intermediate periods are about $0.3^\circ \times 0.3^\circ$, and $0.5^\circ \times 0.5^\circ$, respectively.

To explore the crustal and upper-mantle structure of the MLYMB and better understand the genesis of metallic deposits, China University of Geosciences (Beijing) (CUGB) deployed a temporary broadband seismic network from May 2012. In this paper, we first describe the middle–lower Yangtze broadband seismic Network (MLYN) (Fig. 2) and then present some data examples and preliminary results.

STATION DISTRIBUTION

Our seismic network extends and complements previous seismic experiments in this region (e.g., Lü et al., 2004; Liu et al., 2010; Shi et al., 2013; Xu et al., 2014). The first phase of MLYN consists of 20 stations operating from May 2012 to May 2014. All the 20 stations were deployed in the southwest part of the MLYMB with an average station spacing of about 50 km (Fig. 2). Our field deployment setup generally follows that for the USAArray deployment (http://www.usarray.org/public/about/how#3; last accessed February 2015; Fig. 1b). Each station includes a three-component Guralp CMG-3ESP broadband sensor with a response from 60 s to 50 Hz and a RefTek 24-bit 130-1 digitizer. The field stations are powered by solar panels. The second phase of MLYN began in June 2014 and is expected to finish in December 2015. The 20 seismometers in the first phase were redeployed to the northeast part of the MLYMB along with 15 additional CMG-3ESP2CD seismometers, with the total number of stations reaching 35. As shown in Figure 2, the distribution of
the provincial stations (black triangles) in the northeastern part of the study area is relatively dense with a station spacing about 60–70 km. However, in the rest area the average station spacing is about 150–200 km. Especially in the central and southwest part of the MLYMB, the station coverage is sparse and only a few stations are available. Our deployment added many temporary stations in the central and southwest part of the MLYMB, and the average station spacing can reach \( \sim 50 \) km in the entire region. With such station spacing, we expect to obtain a reasonably high-resolution crustal and upper-mantle velocity structure in the MLYMB.

**EXAMPLE DATA AND NOISE LEVEL**

Figure 3a,b shows waveform examples (instrument-corrected displacement) from a teleseismic event and a local event recorded by station AQ10 in the first phase. The parameters of these two events are shown in Table 1. We also compute power spectrum density levels of background noise in seismograms following Bendat and Piersol (1971) and Otnes and Enouchson (1972) and compare them with the new low noise level models and the new high noise level models (NHNM) (Peterson, 1993). As shown in Figure 4a, the background noise levels at the station AQ04 is low, especially at periods longer...
than 1 s. Because the seismometers have a sharp response frequency cutoff at 0.0167 Hz (60 s), the actual noise levels at frequencies lower than 0.0167 Hz are not well constrained. At periods shorter than 0.5 s (or frequency above 2 Hz), the noise levels become slightly higher but still reasonable considering that this and many other stations are located near cities. The relatively low background noise level guarantees that high-quality waveforms (from local to teleseismic earthquakes) can be recorded. In comparison, the background noise level at the station AQ20 is relatively higher, especially at period shorter than 2 s (Fig. 4b). This is because a quarry was developed after our instrument installation at this station, raising the high-frequency noise levels.

**PRELIMINARY RESULTS**

During the first phase deployment period (May 2012–June 2014), several hundreds of teleseismic earthquakes with mag-

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### Table 1

<table>
<thead>
<tr>
<th>Event</th>
<th>Date (yyyy/mm/dd)</th>
<th>Origin Time (hh:mm:ss)</th>
<th>Latitude (°)</th>
<th>Longitude (°)</th>
<th>Depth (km)</th>
<th>Epicentral Distance (°)</th>
<th>$m_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>2012/07/25</td>
<td>19:01:36</td>
<td>−19.297</td>
<td>167.728</td>
<td>35</td>
<td>69.47</td>
<td>5.5</td>
</tr>
<tr>
<td>b</td>
<td>2012/07/20</td>
<td>12:11:52</td>
<td>32.978</td>
<td>119.593</td>
<td>10</td>
<td>4.45</td>
<td>4.9</td>
</tr>
</tbody>
</table>
nitude greater than 5.0 were recorded by our array. The number of earthquakes is sufficient to perform several start-of-art seismic analyses that are described in the following sections. Although these methods provide constraints on different aspects of the Earth’s structure, our ultimate goal is to integrate results from different seismic methods to improve our understanding of the deep geodynamic processes and the mechanism of magmatic activities contributing to the formation of the metallogenic belt. Specifically, we plan to explore whether lithosphere detachment and asthenosphere upwelling exists, whether there is substantial evidence for lower-crustal magma injection, and what is the pattern of lithosphere deformation and asthenosphere flow beneath the MLYMB.

Below, we briefly describe preliminary results from cross correlation of ambient noise and receiver functions. A detailed analysis on each topic will be performed and reported elsewhere.

Cross Correlation of Ambient Noise Data
In ambient noise tomography, interstation Green’s function (primarily surface waves) is extracted from cross correlations of continuous noise recording (e.g., Shapiro et al., 2005). The interstation distances are typically required to be longer than 3 wavelengths of interest to ensure that measured dispersion curves from cross correlations are stable and accurate (Bensen et al., 2007). Here, we perform ambient noise cross correlations by using the data from the first phase deployment (Fig. 5a). The processing procedures generally follow those of Bensen et al. (2007) and are briefly described below. First, trend, mean value, and instrument response are removed from raw seismograms. Then, the seismograms are band-pass filtered at 0.2–0.01 Hz and decimated to 1 sample/s and cut into a series of one-hour-long segments. Any segment with spikes 10 times larger than the root mean square of the entire time series is discarded. Finally, spectral whitening is applied to the retained segments. The one-hour-long time series between all station pairs are cross correlated and then stacked together to form the stacked cross correlations. Only those stacked cross correlations with signal-to-noise ratio (SNR) greater than 8 and interstation distances larger than three wavelengths of the interested surface waves are retained. Figure 5b shows clear surface-wave signals at both negative and positive time lags by stacking 14-month cross-correlation functions.

Surface-wave tomography (either based on natural earthquakes or ambient noise) complements body-wave tomography in two aspects: (1) surface-wave tomography can provide better resolution in imaging the crustal and shallow uppermost-mantle structure, and (2) it constrains absolute velocities of the Earth, which is important for directly interpreting the origins of velocity features. Considering the aperture of our deployed array, we expect to obtain phase velocities at 5–50 s periods from ambient noise tomography. On the other hand, using teleseismic two-plane-wave tomography (Forsyth and Li, 2005; Yang and Forsyth, 2006), we are able to obtain phase velocity maps at periods from 20 to 150 s. Hence, both phase velocity and azimuthal anisotropy maps can be obtained by applying these methods to data from the two-year deployment.

In a recent study (Ouyang et al., 2014), both ambient noise tomography and teleseismic two-plane-wave tomography are used to obtain phase velocities, and image the 3D shear structures of the lithosphere and underlying asthenosphere.
in this region. By including those stations from our first phase deployment in the inversion (Ouyang et al., 2014), the lateral resolutions for ambient noise tomography and two-plane-wave tomography can reach \(~0.2^\circ\) and \(1^\circ\), respectively. Their high-resolution images showed a clear low-velocity zone in the upper mantle (\(~100–200\) km) beneath the MLYMB, which may be caused by partial melting of an enriched mantle source associated with subduction of ancient Pacific plate (Ouyang et al., 2014). Their results suggest that surface-wave tomography could provide useful information for better understanding of deep seismological structures and geodynamic processes beneath the MLYMB.

Receiver Function Analysis
The two-year recordings make it possible to obtain reliable receiver functions and quantify lateral variations of crustal thickness and \(V_p/V_s\) ratio in the MLYMB and the surrounding regions. These parameters in turn would help to understand the mechanism of magmatic activities and rock compositions in the study area.

We adopt a modified receiver function method (Zhu and Kanamori, 2000) to measure crustal thickness and \(V_p/V_s\) ratio in this region. To obtain receiver functions, we first visually examine all seismograms from 80 earthquakes occurred between June 2012 and August 2013 with magnitude greater than 5.4 and epicentral distances between 30° and 90°. Next, we only picked 72 earthquakes with high SNR. The earthquake distribution generally shows a reasonable distance and azimuthal coverage (Fig. 6a). A 65 s time window (5 s before and 60 s after the \(P\) arrival) is then used to isolate the interested body waves and calculate receiver functions. Figure 6b shows an example of receiver functions recorded at station AQ10. The
primary $P$ to $S$ conversions and the Moho multiples are clearly visible in the receiver functions as seen in Figure 6b. With the obtained receiver functions, we then perform a joint inversion to measure the Moho depth and $V_P/V_S$ ratio at this station (Fig. 6c). We plan to apply the same procedure to the rest of the stations and obtain a spatial variation of Moho depth and $V_P/V_S$ ratio in this region. These results can be used to test the existence of lower-crustal delamination and partial melting.

**SUMMARY**

A temporary seismic network was deployed to record seismic data for studying the crustal and upper-mantle structure in the MLYMB. The first phase of the network consists of 20 broadband stations covering the south part of the MLYMB, and the second phase covers the northeast part of the MLYMB with a total of 35 stations including the redeployed 20 stations from the first phase. The installation method adopted for these seismic stations generally follows that for the USArray deployment. This network significantly increases the station coverage of deep geodynamic processes and shallow ore formation.

**DATA AND RESOURCES**

The project is expected to finish in December 2015. The expected total volume of data is ~900 GB. The data will be analyzed by the Principal Investigators (PIs) of this project (Qingtian Lü, Guibin Zhang, Xinfu Li, Hongyi Li, and Guoming Jiang) and are also available for collaborative work at this stage. Our data will be open to the public after two years of this project and also will be available from the data management center for the Deep Exploration in China (http://www.sinoprobe.org/DataShare.aspx; last accessed December 2014, currently under construction).

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**REFERENCES**


Xinfu Li

Key Laboratory of Geo-detection
China University of Geosciences, Beijing
Ministry of Education
Beijing 100083, China

xinfuli@cugb.edu.cn

Longbin Ouyang
Hongyi Li
Dan Zheng
Ming Zhou
Jing Tan
Sanjian Sun
Guibin Zhang

School of Geophysics and Information Technology
China University of Geosciences
Beijing 100083, China

Yingjie Yang

CCFS, GEMOC ARC National Key Centre
Department of Earth and Planetary Sciences
Macquarie University
North Ryde, New South Wales 2109, Australia

Qingtian Lü

MLR Key Laboratory of Metallogeny and Mineral Assessment
Institute of Mineral Resources
Chinese Academy of Geological Sciences
Beijing 100037, China

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1 Also at School of Geophysics and Information Technology, China University of Geosciences, Beijing 100083, China.