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Group velocity tomography of the upper crust in the eastern Tennessee seismic zone from ambient noise data

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ABSTRACT

The eastern Tennessee seismic zone (ETSZ) is the second most seismically active area in the central and eastern United States after the New Madrid seismic zone, but the relatively weak seismicity and the absence of correlation between the seismicity distribution and the surface geology make its seismogenic potential controversial. In this work we investigate the structure of the upper crust in the ETSZ by means of group velocity tomography maps from seismic noise data. Results show that the seismic activity is associated with a relatively low velocity anomaly mainly located in one or more basement blocks. These blocks, bounded to the NW by the NY–AL lineament and to the SE by the Clingman lineaments, are buried beneath low velocity strata consistent with the presence of a relatively thick sedimentary cover. The imaged low velocity anomaly migrates towards the SE at increasing periods, suggesting a possible SE dipping weak structure where most of the seismic activity takes place.
The correlation between the NY–AL magnetic signature and the position of the seismic velocity anomalies supports the interpretation of the low velocity zone as a major basement fault projected to the surface as the NY–AL magnetic lineaments. The fault juxtaposes Granite–Rhyolite basement to the NW with Grenville southern Appalachian basement to the SE.

1. Introduction

The ETSZ is an area of increased seismicity approximately 300 × 50 km located in the Valley and Ridge province of the southern Appalachians (Fig. 1). The two largest events recorded within the zone, both Mw 4.6, occurred on 30 November 1974 near Maryville, Tennessee (Bollinger et al., 1976) and on 29 April 2003 near Fort Payne, Alabama (Dunn and Chapman, 2006). However the ETSZ generated damaging earthquakes in historical time (Bollinger, 1973) thus its seismogenic potential, although widely debated, is of primary importance. Also, the well-known low attenuation of the central and eastern United States crust (Nuttli et al., 1979), that causes even moderate earthquakes to be felt and potentially cause damage at far distance, makes it significant.

The Grenville orogeny is the oldest known episode of continental accretion in the eastern United States (~1 Ga). The opening of Iapetus Ocean (~530 Ma) that followed the break-up of Rodinia was accompanied by several rifting episodes (e.g. Reelfoot rift) within the Grenville terrain but according to palinspastic reconstruction rifting did not affect the ETSZ (Thomas, 2006). The Paleozoic saw a sequence of several orogenic processes accreting the Greenville terrain, the last of which, the Alleghanian orogeny (~330 Ma), represents the most recent episode of mountain building in the area.

Cambrian to Lower Ordovician rocks deposited in a passive margin setting and Middle Ordovician to Pennsylvanian rocks were emplaced during the Taconic and Alleghanian orogenic phases on the Appalachian forehand. The rocks compose of the strongly folded sedimentary cover beneath the Valley and Ridge province and beneath the ETSZ in particular. Thickness of the sediments overlaying the basement has been recently estimated by means of magnetic data inversion and ranges from 4 to 12 km, [Brandmayr and Vlahovic, 2016) thus locally thicker than previous results (Laske and Masters, 1997; Mooney and Kaban, 2010).

The Cumberland Plateau, which lies west of the Valley and Ridge, is widely agreed to represent the boundary between the stable North American craton and the continental margin, roughly marking the western Grenville deformation front (Thomas, 1982; Tesauro et al., 2015). The location of the Grenville front to the east and the westward extension of the Appalachians terrains at depth still remains uncertain but

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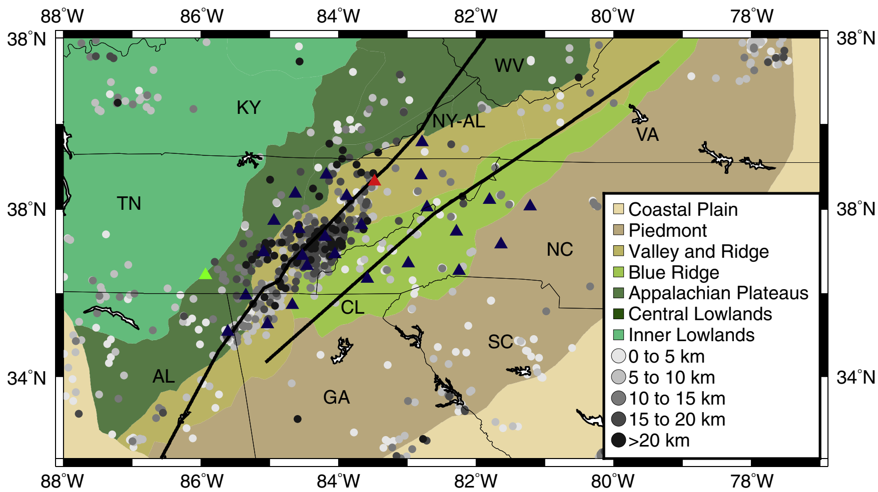

Fig. 1. The tectonic setting of the ETSZ: colors indicate geological provinces and black lines the NY–AL and Clingman (CL) magnetic lineaments. Triangles denote ET network seismic stations, with ASTN and SWET stations marked in red and green, respectively. Hypocenters are from the CERI catalogue (1974–2014, gray dots, http://www.memphis.edu/ceri/seismic/catalog.php last accessed 11/28/2015). For color legend please refer to the digital version of the paper.

basement rocks beneath the ETSZ are presumed to be of Grenville age (Powell et al., 2014 and references therein; Brandmayr and Vlahovic, 2016).

In the ETSZ, earthquakes occur at depths between 5 and 26 km (Vlahovic et al., 1998) and faulting does not seem to involve Appalachian structures (Thomas, 2006).Thus, the hypocenters do not correlate with surface geological features but mainly occur in a basement block known as Ocoee block (Johnston et al., 1985). This features are delimited by two NE–SW trending magnetic lineaments, namely the NY–AL lineament on the NW side and the less prominent Clingman lineament on the SE side.

In seismology, spurious signals contaminating the quality of any seismic data have been traditionally referred to as a noise. However, this notion changed over the years as it became widely accepted that ambient noise can bear important information about the Earth's structure, i.e. the Green's Function (GF). In active tectonic settings ambient noise serves as complementary seismic data; in other instances, where no or weak seismic activity is recorded, as is the case of the ETSZ, ambient noise can provide better resolution for crustal structures than most active source methods.

The cross correlation of continuous waveform signals (ambient noise) arriving at a pair of seismic stations gives an estimate of the GF of the medium between the stations (Aki, 1965; Sabra et al., 2005; Campillo and Paul, 2003; Bensen et al., 2007). Although the resulting signal should represent the full GF, thus should include body and surface waves, however, only the latter usually dominates ambient noise correlation, presumably due to attenuation and scattering. Surface waves emerge prominently provided that data have been collected for a sufficiently long time in order to improve the signal-to-noise ratio. Then, once dispersion curves have been extracted for the medium between each pair of stations, surface wave tomography algorithms can be applied to map the lateral variations of group velocity at relevant periods, i.e. at different depths. Tomography results can be further inverted to determine a three-dimensional shear wave velocity structure of the area (Pontevivo and Panza, 2006; Panza et al., 2007a; Costanzo and Nunziata, 2014).

Liang and Langston (2008) investigated the crust in eastern North America by means of tomography from noise data, imaging ETSZ with a variable resolution between 2° × 2° and 1° × 1°. Powell et al. (2014) used local earthquake tomography to study the same area providing a P and S wave velocity structure down to a depth of 24 km.

Both papers delineate the ETSZ as a transition zone between low velocity to the west and high velocity to the east. With improved resolution, we will show that the results of this study are in general consistent with their findings and spotlight some features that deserve further investigation.

2. Data and method

The data used in this study are obtained from 24 short period stations that are part of the eastern Tennessee (ET) seismic network deployed and managed by the Center for Earthquake Research and Information (CERI) at the University of Memphis, Tennessee. The network covers the ETSZ, an area about 300 km long and 50 km wide (Fig. 1).

Although broad band data are more frequently used for ambient noise tomography, several authors showed that short period data are suitable as well to investigate the upper crustal structure (e.g. Arroucau et al., 2010; Young et al., 2011; Rawlinson et al., 2014). In fact, the ET network is composed by high gain short period sensors (mainly L4C and S13) with corner frequency usually at ~1 Hz. Self-noise of 1 Hz seismometers is well below the New Low Noise Model (NLNM) until 0.1 Hz.

This means that with adequate amplification, a short period seismometer should be able to record low amplitude 20 s surface waves (Havskov and Alguacil, 2004).

Continuous waveform ambient noise data for 110 days from August to December 2011 were spooled, processed and analyzed in this study. Most of the processing steps adopted in this work are those described in Bensen et al. (2007), which has become the standard for processing ambient noise data (e.g. Idowu et al., 2011; Nunziata et al., 2009; Arroucau et al., 2010), with few modifications.

Following Saygin and Kennett (2009), we did not apply any normalization prior to the correlation process. This is because both time and frequency domain normalization are non-linear operations which could introduce artifacts, thus alter the spectral content of the data. The primary purpose of normalization is in fact to remove transients caused by seismic activities, however normalization and spectral whitening may alter the amplitude content of the signal leading to biased group velocity measurements (Lin et al., 2011).

In this study, each simultaneously recorded seismogram for all station pairs was cross-correlated over overlapping 1-hour segments. We use normalized cross-correlation (Cox, 1973), that means the