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The upper crust of the Eastern Tennessee Seismic Zone: Insights from potential fields inversion

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ABSTRACT

The study investigates the crustal structure of the eastern Tennessee seismic zone (ETSZ) by means of potential field inversion through the located Euler deconvolution method. Inversion of magnetic field data shows that the top of the magnetic basement ranges between 6 and 12 km depth in the Valley and Ridge physiographic province while it is shallower (<2 km depth) and locally outcropping in the Blue Ridge and Cumberland Plateau provinces. The estimated depth to the top of the magnetic basement is in general agreement with existing sedimentary cover maps of the broad study area. The inversion of gravity data is much more ambiguous, pointing to a generally deeper source, than magnetic data inversion. The findings support the interpretation of ETSZ seismicity as originating in basement structures not related to Appalachian orogeny and likely dating to Grenville age.

1. Introduction

The ETSZ, located mainly in the Valley and Ridge province of the southern Appalachians (Fig. 1), is the second-most seismically active area in the eastern United States, after the New Madrid seismic zone, on the basis of energy release (Powell et al., 1994). The ETSZ does not exhibit surface faulting, and the largest instrumentally recorded events, which 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), are of moderate magnitude (4.6 Mw), although the area generated damaging earthquakes in historical time (Bollinger, 1973). These factors significantly hamper our ability in determining the seismogenic potential of the ETSZ.

Earthquakes occur at depths between 5 and 26 km (Vlahovic et al., 1998), concentrated between 8 and 15 km, beneath the Paleozoic decollement. Thus, they are poorly related to surface geological features and have been attributed to basement faults not linked to any of the four stages of the Appalachian orogeny (e.g. Thomas, 2006).

The sedimentary cover is composed mainly of Cambrian to Lower Ordovician rocks deposited in a passive margin setting, as well as Middle Ordovician to Pennsylvanian rocks deposited on the Appalachian foreland during the Taconic and Alleghanian orogenic phases. Basement rocks are supposed to date back to Grenville age, although the position of the Grenville front in the region is unknown (Powell et al., 2014).

In addition to its complicated geology, the ETSZ is associated with a major magnetic lineament known as the NY-AL lineament, the tectonic significance of which remains controversial. This lineament marks the boundary between a spotty pattern of low and high anomalies associated with a granite-rhyolite province and Neoproterozoic mafic bodies to the northwest, and NE-trending magnetic lineaments of the Appalachian orogeny to the southeast. Interpretations about the tectonic role of the NY-AL lineament favor two options: 1) a collisional (King and Zietz, 1978) or post-collisional (Steltenpohl et al., 2010) intra-Grenville strike-slip fault, likely representing an age boundary within the Grenville tectonic province (Powell et al., 2014), or 2) the axis of anatectic melting following continental collision (Hopkins, 1995) during the Grenville orogeny. However, the hypocenters in the ETSZ are mainly located in a basement block, the Ocoee block (Johnston et al., 1985), which is delimited to the northwest by the NY-AL magnetic lineament and to the southeast by the less prominent Clingman magnetic lineament. Steltenpohl et al. (2010) suggest that the Ocoee block could be composed of relatively nonmagnetic meta-sedimentary gneisses, similar to the Amish anomaly, of which it would represent a southward continuation.

Seismological and potential field data offer complementary information about the structure of the earth's interior. The intrinsic non-uniqueness of the inverse problem in geophysics makes their joint analysis and interpretation a very useful tool, especially in low-seismicity continental areas like the ETSZ. The present work focuses on potential field analyses using 3D Euler deconvolution, obtaining results consistent

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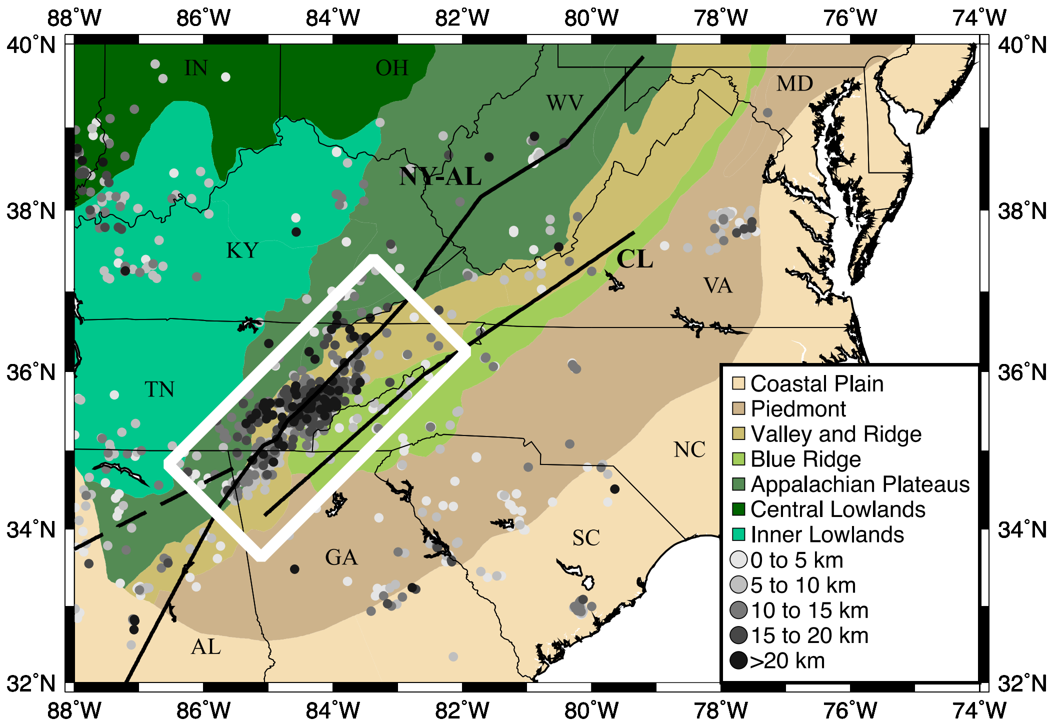

Fig. 1. Map of the study area with geological provinces after Fenneman and Johnson (1946). Gray dots are hypocenters reported in the CERI-University of Memphis catalogue from 1974 to 2014. Black lines denote New York–Alabama (NY-AL) and Clingman (CL) magnetic lineaments. Dashed black line denotes NY-AL lineament southern segment after Steltenpohl et al. (2010). White rectangle encloses ETSZ.

with some of the interpretations previously proposed. A companion paper describes the results of seismic noise tomography of the upper crust in the same study area.

2. Methods

The depth and the location of source rocks causing magnetic and gravity anomalies in the study area are estimated through 3D Euler deconvolution. We use a commercial software package based on the algorithm proposed by Reid et al. (1990), which is the three-dimensional implementation of the Euler's homogeneity equation described by Thompson (1982) for a two-dimensional profile. The solution of the Euler's homogeneity equation for a certain potential field (F) is the linearization of a strongly non-linear problem that requires independent a priori assumptions on the geometry of the causative bodies. Its formulation in Cartesian coordinates is

$$(x-x_0)\frac{\partial F}{\partial x}+(y-y_0)\frac{\partial F}{\partial y}+(z-z_0)\frac{\partial F}{\partial z}=N(B-F),$$

where N is the structural index (SI, assuming integer values ranging from 0 to 3); x, y, and z are the coordinates of the observed anomaly; x_0, y_0, and z_0 are the coordinates of the edge of the source body; and B is the background value.

The total gradient vector of the potential field F is called the analytic signal and, in its general formulation (Nabighian, 1972), is a complex number. In the Euler deconvolution method only the real part is used, i.e. the absolute value of the total gradient. For the sake of simplicity, we will henceforth use the term analytic signal to refer to only the real part. The analytic signal provides information about the horizontal location of the anomaly source.

Source depth information basically depends on the field curvature, i.e. on the geometry of the source. This information is encapsulated in the SI, which is, in the linear formulation of the problem, an integer number that describes different simplified geometries of the causative body. Although technical manuals distributed with the commercial software suggest the feasibility of non-integer values for the SI, and some authors have applied such values to real data problems (see Reid and Thurston, 2014, for a review), the use of non-integer SI values is considered correct only in the non-linear extension of the Euler's formulation (Stavrev and Reid, 2007). This is because a non-integer SI is dependent on the distance from the source, while the homogeneity equation requires it to be constant. With this in mind, although the body geometries corresponding to the integer SI are far from being the real geological structures expected in the study area, we adhere to the recommendation of using an integer SI.

In this study are used magnetic anomaly (Bankey et al., 2002) and Bouguer gravity anomaly (Kucks, 1999) data available from the USGS for the continental United States. The spatial resolution of the data is 1 km and 4 km, respectively. The data have been preprocessed in Cartesian coordinates and upward-continued to an elevation equal to the grid resolution. This operation is effective in suppressing noise and short wavelength contributions, without distortion that could possibly arise from arbitrary bandpass filtering (Lyatsky et al., 2005). The window size used in the search for the source location is kept greater than twice the spatial resolution of the respective dataset and greater than half the desired depth range of investigation, following Reid and Thurston (2014). Thus, the analytic signal of the field is computed and processed through Euler deconvolution. Being originally formulated for magnetic anomalies, there are few examples of the application of Euler deconvolution to gravity data. The inversion of the gravity anomaly is usually better constrained using the first derivative of the field in place of the field itself (Klingele et al., 1991); therefore, we also use this approach.

3. Results and discussion

In this section the results of Euler deconvolution of the magnetic anomaly (Fig. 2a) are first described. As explained in the previous section, the depth of the source retrieved by the inversion is strongly