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Crustal signatures of the tectonic development of the North American midcontinent

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A R T I C L E I N F O

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A B S T R A C T

The stable eastern portion of the North American continent offers an excellent environment to study the tectonic development of intra-continental structures. The midcontinent of North America formed by the accretion of Proterozoic terranes, and has since experienced episodes of deformation during the subsidence of the Illinois Basin and uplift of the Ozark Plateau. Rifting also initiated in eastern North America, but extension did not continue and arms of failed rifts extend across the region. The New Madrid Seismic Zone, situated within a portion of the failed Reelfoot Rift, represents an active zone of intraplate seismicity. Analyzing the structure of the crust and upper mantle within the midcontinent will therefore provide insight into the factors that lead to intraplate deformation. Using data from over 180 Transportable Array seismic stations, we calculate receiver functions to investigate the crust and upper mantle of the midcontinent. At close to 40 km thick, the crust of the New Madrid Seismic Zone is thinner than in the surrounding areas outside of the Reelfoot Rift and Rough Creek Graben. The Illinois Basin cannot be characterized by a single crustal structure, as crust near 50 km thick in the central portion of the basin thins to between 40 and 45 km thick towards the northern and southern portions of the basin. Discontinuities within the crust and upper mantle are prominent in and around the New Madrid Seismic Zone and mark locations of crustal modification and underplating. Comparing changes in crustal structure to the distribution of Bouguer gravity anomalies, the presence of positive gravity anomalies suggests that higher density crust plays a role in maintaining low surface elevations within the Reelfoot Rift. Conversely, a negative gravity anomaly in an area of thinner crust within the Ozark Plateau supports the need for low-density crustal material to influence the uplift of the plateau.

1. Introduction

Investigating crustal structure over continental scales has proven useful for determining the manner in which the crust records continental evolution through terrane accretion and modification by subsequent tectonic events. Continental-scale crustal thickness variations coincide with both the boundaries of terranes that accreted together and physiographic boundaries that mark the limits of particular styles, or episodes, of deformation. Crustal structure observations within North America using EarthScope USArray Transportable Array data have been generated through a variety of techniques that identified changes in crustal structure that align with physiographic boundaries. These changes in crustal thickness occur over distances that range from localized variations that align with specific tectonic features to broad-scale trends that extend over 1000's of km. The EarthScope Automated Receiver Survey (EARS; Crotwell and Owens, 2005) displays areas of thin crust between 30 and 40 km thick in the tectonically active western portion of North America, while thicker crust that is mostly greater than 40 km thick lies within the more stable eastern North America (Fig. 1). Additionally, thickened crust along the Grenville Front and Appalachian fold-thrust belt (Fig. 1) illustrate patterns of crustal modification during earlier episodes of shortening within the eastern half of North America.

The amplitudes of azimuthally dependent receiver function arrivals recorded by USArray stations also exhibit differences between tectonic provinces (Schulte-Pelkum and Mahan, 2014). By relating these azimuthally variable receiver function arrivals to the presence of either crustal anisotropy or dipping interfaces, the alignment of their spatial variability with province boundaries suggests changes in the strain history of the crust between provinces. Areas of the crust that experienced greater amounts of strain that produced an anisotropic crustal fabric would be expected to pos-

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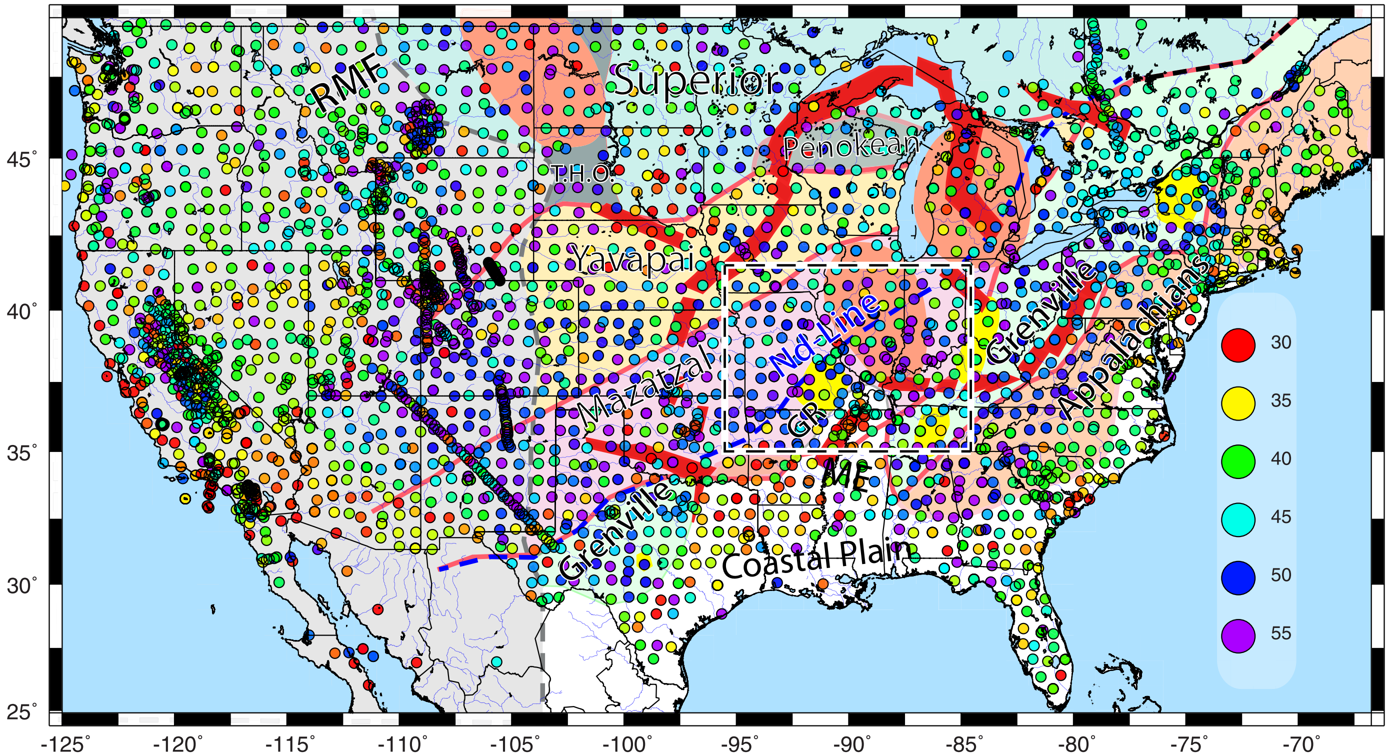

Fig. 1. Map of crustal thickness estimates for the contiguous United States from the EARS dataset. (http://ears.iris.washington.edu/stationLatLonBox.csv?minLat=28.0&maxLat=52.0&minLon=-125.0&maxLon=-65.0, accessed June 24th, 2015). Filled circles mark station locations with their color corresponding to crustal thickness values ranging from values of 30 km or less shown as red, to 55 km or greater, shown as purple. Locations of terrane boundaries and other structures (after Whitmeyer and Karlstrom, 2007) to the east of the Rocky Mountain Front (RMF labeled gray dashed line) are presented as thick red lines with terrane names noted. The location of the Nd-Line, discussed in text, is labeled and shown as a dashed blue line striking from the northeastern to the southwestern portion of the map. Locations of the Midcontinental Rift and other failed rifts are presented as filled red polygons stretching across the central portion of the United States. Abbreviations include T.H.O. – Trans Hudson Orogeny; GR – Granite Rhyolite Province; ME – Mississippi Embayment. Maps shown in Figs. 3–5 correspond to the focused study area in the box outlined by the white and black dashed line. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

sess receiver functions with larger azimuthally varying amplitudes. Clear differences in the amplitudes of azimuthally varying receiver function signals align with tectonic boundaries, such as the Rocky Mountain Front and the Appalachian–Ouachita belt (Fig. 2), which also correspond to locations of dramatic changes in crustal thickness (compare Figs. 1 and 2).

A smaller scale of heterogeneity can also be identified based on changes in the relative amplitude of the azimuthally varying receiver function signal between the Illinois Basin, Ozark Plateau, and Reelfoot Rift (Fig. 2; Schulte-Pelkum and Mahan, 2014), which appears to relate to intracontinental deformation and the formation of these epiorogenic features. Although the lateral extent of domes and basins within the midcontinent is sufficient for them to exhibit differing signatures in large-scale crustal structure maps, additional insights into the processes responsible for the evolution of these structures can be gained by investigating their lithosphere structure at a more focused scale (e.g. Hopper et al., 2014). The tectonically stable North American midcontinent provides an excellent setting to study how extension and mafic intrusions associated with the Reelfoot Rift, the formation of the Ozark Plateau, and subsidence of the Illinois Basin, changed the crust (Figs. 1 and 2).

The Nd- (Neodymium) line (Figs. 1 and 3) marks the eastern limit between the Paleoproterozoic Mazatzal province (>1.55 Ga) and the Mesoproterozoic Granite Rhyolite province (<1.55 Ga) (Whitmeyer and Karlstrom, 2007). This midcontinent structural boundary allows for investigating terrane accretion and the response of terranes to later episodes of deformation. A sharp transition in long-wavelength depth integrated magnetic susceptibility aligns with the Nd-Line, where the Mazatzal Province is characterized by higher susceptibility while the Mesoproterozoic province possesses lower susceptibility (Ravat, 2007). However, the magnetic signal at shorter wavelengths indicates no contrast between the terranes (Ravat et al., 2009) and instead reflects near-surface features such as plutons, the depth to basement, and faulting in the crystalline basement (Hildenbrand et al., 2002). While the contrast in long wavelength magnetic susceptibility suggests differing structural characteristics between these two Proterozoic crustal blocks at depth, the lack of a contrast in the short wavelength magnetization suggests that whatever contrast these blocks possess at depth does not extend to the shallower crust (Ravat et al., 2009).

The extensive and regular sampling of the Transportable Array, facilitates measuring changes in crustal structure across the midcontinent of North America (Figs. 1 and 3). Constructing cross sections by common conversion point (CCP) stacking receiver function waveforms, as presented here, facilities identifying discontinuities within and beneath the crust. Heterogeneous structures in the crust and upper mantle provide insight into the tectonic development of the region, and can be identified viewing receiver function waveforms in this manner even though such variations may not be apparent in crustal thickness maps. The sampling of the Transportable Array is well suited for investigating changes in crustal structure across terrane boundaries or between physiographic provinces with dimensions that exceed 100's of km.

Understanding the crustal characteristics and dynamics that allow for the formation of intracratonic structures also contributes to our understanding of seismic hazards and the conditions responsible for creating economic resources in a continental interior. Ore deposits in the Ozark Dome and the oil trapped in anticlines and domes within the Illinois Basin both serve as examples of