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Seismic Vp & Vs tomography of Texas & Oklahoma with a focus on the Gulf Coast margin

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ABSTRACT

The northwestern Gulf of Mexico passive margin contains an extensive record of continental collision and rifting, as well as deformation associated with orogenic events and heavy sedimentation. Seismic traveltime tomography that incorporates new data from 328 broadband seismic stations deployed throughout the region reveals features that correlate well with expected mantle structures, as well as features that have no obvious expression at the surface. Among the former are a large fast anomaly that corresponds to the southern extent of the Laurentia craton and a large slow anomaly associated with the Southern Oklahoma Aulacogen. Among the latter are a slow layer that we interpret to be a shear zone at the base of the cratonic and transitional continental lithosphere, a zone that is bounded at its top and bottom by discontinuities and high levels of seismic anisotropy identified in companion receiver function and shear wave splitting studies, respectively. A high velocity body underlying the Gulf Coastal Plain may mark delaminating lower crust. If this is true it could provide indirect evidence for an elevated geotherm during the rifting process that created the Gulf of Mexico.

1. Introduction

1.1. Geological background

The region that now comprises the northern Gulf of Mexico (GoM) and Texas's continental margin underwent several complete cycles of continental rifting and suturing before the opening of the modern GoM (Harry and Londono, 2004). These pre-GoM events include the southwest-northeast trending Grenville orogeny, which deformed Laurentia's southern margin during the late Precambrian and the Ouachita orogeny, which led to the formation of Pangea ∼300 Ma (Stern et al., 2010). Rifting in the region began approximately 160–140 Ma, ultimately separating what is now Texas from the Yucatan peninsula and creating of the Gulf of Mexico (Bird et al., 2005). This sequence of tectonic events resulted in the development of several significant geological features, including the Southern Oklahoma Aulacogen (SOA), the Rio Grande Rift (RGR), the Llano Uplift (LU), and post rift features such as the Balcones Fault Zone (BFZ) and the Gulf Coastal Plain (GCP) (Fig. 1).

The SOA is thought to be a failed rift, likely an arm of a triple junction that formed during continental break up in the Precambrian/early Paleozoic (Brewer, 1982). The current structure of the SOA is the result of deformation during the Ouachita orogeny (Baldridge et al., 1995). The RGR trends northward from Mexico through New Mexico and into Colorado. It consists of two distinct provinces: the north, which comprises a single rift valley between the Colorado Plateau and the Great Plains, and the south, where greater extension occurred and is physiogeographically identical to the Basin and Range (Keller and Baldridge, 1999).

The Llano Uplift (LU) exposes the deformed core of the Grenville orogenic belt (Mosher, 1998) in central Texas, marking the terminus of the Edwards Plateau. The LU is comprised of metavolcanic, metaplutonic, and metasedimentary rocks, aged 1303–1232 Ma (Walker, 1992). The Balcones Fault Zone (BFZ) is an extensional feature, consisting of normal faults that are located between the Edwards Plateau/Llano Uplift and the GCP (Weeks, 1945). The GCP is a passive margin that resulted from the rifting that opened the GoM. The creation of the GoM has been attributed to volcanic rifting, in which an anomalously hot mantle is invoked (Mickus et al., 2009) as well as to lithospheric extension in the absence of a mantle thermal anomaly (Marton and Buffler, 1993); its true origin is therefore uncertain. The style of rifting is poorly constrained, in part, because the crust is overlain by ∼15 km of sediments (Mickus et al., 2009) that were deposited between the Late Cretaceous and the Quaternary (Harry and Londono, 2004; Galloway et al., 2001; Galloway, 2008).

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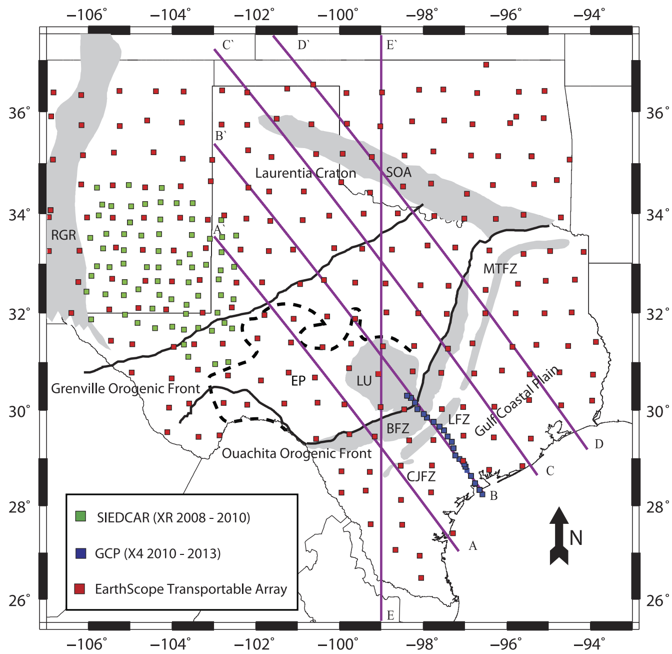

Fig. 1. Map of Texas and Oklahoma including seismic stations whose data were used in this study, a summary of tectonic features, and locations of 2D great-circle cross-sections shown in later figures. Regions of deformation and/or uplift (shaded) include: the Rio Grande Rift (RGR), Southern Oklahoma Aulacogen (SOA), Llano Uplift (LU), Edwards Plateau (EP), Balcones Fault Zone (BFZ), Mexia–Talco Fault Zone (MTFZ), Luling Fault Zone (LFZ) and the Charlotte–Jourdanton Fault Zone (CJFZ). Orogenic fronts (solid lines) include the Grenville orogenic front and the Ouachita orogenic front. The temporary broadband (X4) stations deployed across the Texas Gulf Coast from 2010-13 are shown in blue; stations deployed during the SIEDCAR project (XR 2008-10) are shown in green; Transportable Array (TA) stations deployed by EarthScope are shown in red. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

1.2. Previous geophysical studies

Few seismic body wave tomography studies have been performed in the Texas/Oklahoma region, due primarily to the small number of seismic stations that have been located in the region historically. The North American surface wave tomography model by Van der Lee (2002) appears to be the highest resolution velocity model that covers all of Texas and Oklahoma prior to the present work. Two seismic tomography studies have been conducted recently that focus on different properties of the Rio Grande Rift, which borders the western edge of our study area. These previous studies include the La Ristra (Colorado Plateau/Rio Grande Rift Seismic Transect Experiment) deployment, which traversed the rift from the Colorado Plateau in southeast Utah to the Great Plains in west Texas (Gao et al., 2004), and the SIEDCAR (Seismic Investigation of Edge-Driven Convection Associated with the Rio Grande Rift) deployment, which focused on possible lithospheric erosion beneath western Texas and eastern New Mexico (Rockett et al., in preparation). A potential field study of subsurface structure in the same region of the Texas/Gulf of Mexico transition zone found the gravity and magnetic data to be consistent with a deeply buried volcanic rifted margin (Mickus et al., 2009).

Traveltime tomography exploits information contained within a seismic record in order to constrain 2D or 3D seismic velocity variations within the Earth (Rawlinson et al., 2010). Seismic velocity perturbations can result from variations in temperature, partial melt, and seismic anisotropy, as well as variations in chemical composition (Schmandt and Humphreys, 2010). As has been shown by numerous previous studies, seismic tomography has the capacity to reveal a wide range of mantle structures and should therefore serve as a useful basis for inference concerning the state of the mantle beneath the Texas Gulf Coast passive margin (e.g., Rawlinson et al., 2006; Rawlinson and Kennett, 2008; Schmandt and Humphreys, 2010; Ping et al., 2006; Benoit et al., 2006; Schmandt et al., 2012; Cheng et al., 2012).

2. Data

We use earthquakes that occurred between July 2008 and March 2013 and were recorded by twenty or more of 328 broadband, three-component stations in Texas, Oklahoma and New Mexico. Earthquakes were required to have magnitudes ranging from 5.0 to 7.0 and located at epicentral distances of 30°–95° from recording stations. Of the 328 stations, 234 were from the Earthscope Transportable Array (TA), distributed throughout Texas, Oklahoma, and New Mexico (see http://www.earthscope.org); 71 stations were part of the SIEDCAR deployment (Pulliam et al., 2009), and 23 stations were from the GCP deployment that transverses the Gulf Coastal Plain (Fig. 1). All stations consisted of a broadband, three-component seismometer, a 24-bit digitizer/recorder, a battery and a solar panel. Precise information about each station's complement of instruments is available from the IRIS Data Management Center (X4 2010–2013 deployment).

The GCP broadband stations were distributed from Matagorda Island, a barrier island in the Gulf of Mexico, to Johnson City, TX, at 15–20 km spacing. The location of the transect was chosen because it is the shortest distance from the Gulf Coast shoreline to the Laurentia craton, so any remnants of suturing, deformation, and break-up might be imaged with a minimum number of stations. The GCP stations were installed in July 2010 and demobilized in March 2013; the transect was intended to provide a high-resolution 2D tomographic image of mantle structure across the transitional crust of the GCP that would, in turn, allow inferences concerning the tectonic history of Laurentia's southern margin. EarthScope's TA stations have a nominal spacing of 70 km, so images obtained from the 3D tomographic inversion will generally have lower resolution than the GCP transect (which is embedded in the TA footprint).

Data were retrieved from the GCP stations approximately every three months. The data were then preprocessed using *Antelope*™ and *PASSCAL* seismic software. First arriving P- and S-waves were manually picked on the preprocessed data, which were recovered from the GCP deployment, as well as on the TA data downloaded from the IRIS DMC. The program *xcorrelate* (Brandon Schmandt, personal communication, 2009), was used to find relative delay times of first arriving P- and S-waves across the array of stations via cross-correlation (refer to supplementary files). Data incorporated into this study from the SIEDCAR deployment were retrieved from the database at the Baylor University Geophysics Laboratory. Delay times produced from the GCP, Earthscope TA, and SIEDCAR waveform data were then used as inputs for 3D tomography. P arrivals were measured from 406 events, producing a total of 50 102 source–receiver pairs. S arrivals were analyzed from 131 events, for a total of 14 187 source–receiver pairs (Fig. 2). The difference in numbers between P- and S-wave data sets is largely due to the fact that scattered P energy creates higher noise levels for the later-arriving S waves.

3. Tomographic inversions

FMTOMO, a Fortran software package, performs 3D traveltime tomography, using the fast marching method (FMM) (de Kool et al., 2006) to compute traveltime predictions and a subspace inversion to adjust model parameters to satisfy observed seismic data (Rawlinson and Sambridge, 2004). FMTOMO employs an iterative non-linear scheme in which each inversion assumes local linearity