2000 AGU posterA Crustal Low Velocity Zone Under the Colorado Plateau - Rio Grande Rift Transition Zone

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Abstract

Project LA RISTRA (Colorado Plateau Rio Grande Rift Great Plains Seismic Transect) has completed one year of deployment of a broadband seismic array across the central Rio Grande Rift. The NW-SE trending, 950 km long linear array extends approximately from Lake Powell, Utah to Pecos, Texas. We have calculated receiver functions from teleseismic arrivals at the array to gain new insights into the seismic structure of the crust and upper mantle and hence the tectonics beneath this part of the western U.S. A preliminary analysis of the receiver functions reveals a number of crustal features. First, we observe a 200-km-wide crustal low velocity zone beneath the southeastern Colorado Plateau (from the southern Chuska Mountains to Mt. Taylor), which may extend into the central Rio Grande Rift in the vicinity of the Socorro magma body. Second, there are significant differences in the depth and character of the Moho on either side of the Rio Grande Rift. While the P-to-S conversion from the Moho beneath the Four-Corners region of the Colorado Plateau is rather weak, it appears as a dominant phase at the stations within the Rio Grande Rift and the Great Plains. The Moho is shallowest at the center of the rift and deepens gradually away from it. Third, sharp conversions from a mid-crustal, southeastward-dipping horizon, indicative of a sudden increase in velocity, are observed in western Texas and southeastern New Mexico. This feature may represent the northwestern edge of the Grenville basement - a buried continental margin.

Introduction

Project LA RISTRA is a collaborative geoscience project aimed at elucidating the structure of the lithosphere and upper mantle beneath the southeastern Colorado Plateau, central Rio Grande Rift, and western edge of the Great Plains (Figure 1). A 54 stations NW-SE trending, 950 km long linear array was completely deployed by November, 1999 (Figure 2). We have collected about one year of data and the array has recorded many large earthquakes around the world (Figure 3). Some of the scientific questions we would like to address are:
(1) What is the extent and cause of the crustal low velocity zone in the central Rio Grande Rift and its significance in the development of the rift?
(2) What is the relationship between mantle flow and crustal rifting? Are continents coupled to general mantle circulation?
(3) What is the cause of the uplift and relative tectonic stability of the Colorado Plateau?
(4) Where in the mantle is the most recently subducted Farallon plate and any thickened or detached continental lithosphere located?

Preliminary Results

Analysis of signal and noise levels (Figures 4 and 5) shows that the array has recorded high quality teleseismic data in the 0-3 Hz range.
We observe a 200-km-wide mid-crustal low velocity zone beneath the southeastern Colorado Plateau and the Rio Grande rift (Figure 6), possibly an extension of the Socorro magma body
The moho is readily visible in the receiver functions and shows thin crust beneath the rift with crust a little more than 50 km thick beneath the

Four-Corners region of the Colorado Plateau (Figures 6 and 7).
A sharp conversion (indicative of a sudden increase in velocity) from a mid-crustal, southeastward-dipping horizon, is observed in southeastern New Mexico and western Texas (Figures 6 and 7). This feature probably represents the southern edge of the Grenville basement.
Receiver functions for Ps conversions have been generated and stacked in geographical bins about depth nodes. Arrivals from the 410 and 660 km discontinuities (Figure 7) are visible but at present we can not make a strong conclusion about the width of the transition zone across the array.
Teleseismic P wave delays vary by about 1 sec across the array, and the S wave delays vary by up to 4 sec (Figure 8). Strong variations in residuals with azimuth are also apparent indicating strong lateral heterogeneity and anisotropy at depth beneath the array.

Figure 1
Figure 3: Generalized geological map of the study area. The RISTRA array crosses many tectonic regimes, from the Colorado Plateau in the northwest, across the Rio Grande Rift, into the Great Plains in the southeast. The Rio Grande rift is the zone of Cenozoic extension resulting from the separation of the Colorado Plateau block from the Great Plains of the Northa American craton (from Russel and Snelson, 1994).

Figure 2
Figure 1: Topographic map showing the 57 RISTRA stations (stars). Station spacing is approximately 18 km. Triangles: Previously deployed short/intermediate period stations. Black Circles: NM Tech Earthworm System broadband and short period stations. Black Squares: NM Tech/UW short-period teleseismic stations (1993-1994; Schlue et al., 1996). Yellow Circles: Earthquakes (M >= 1.3; 1962-1998; Sanford et al., 1999).

Figure 3
Figure 2: 183 Teleseismic events recorded by the RISTRA array between August 1999 and November 2000

Signal and Noise Analysis

Signal to noise ratios are shown in Figure 4 for all events recorded to date by the RISTRA array. The median values (Figure 4d) show that for all components the array has recorded good quality teleseismic data in the 0-3 Hz range.
Background noise analysis (Figure 5) shows that the array stations lie within the expected bounds for background noise models. The horizontal component data have slightly higher noise levels than the vertical component data at lower frequencies.
Figure 4
Figure 4: Event signal to noise ratios for all stations (a) vertical component (b) east component (c) north component, and (d) all components. In a,b,c the black line is the median signal to noise ratio for all events, also plotted in d. Signal to noise ratios are calculated using the ratio of spectra from a 30 second window immediately after event arrival, and a 30 second window immediately before event arrival.
Figure 5
Figure 5: Median background noise spectra for the RISTRA array stations. The black lines are low-noise and high-noise models (Peterson, 1993). Solid lines are the median spectra for each component, and dashed lines are the standard deviation. Background noise spectra are calculated using 24 hour time windows containing no events.

Receiver Function Analysis

Receiver functions were calculated using the deconvolution technique proposed by Langston (1979) which supresses the earthquake source and path effects, isolating the Ps phases and reverberations generated in the upper mantle and crust. The radial receiver function is given by

where Dr(w) and Dz(w) are the radial and vertical components of displacement, and A(w) is the deconvolution smoothing function given by

where

and

c is the water-level parameter, expressed as a fraction of the maximum vertical component power spectra, and a controls the width of the Gaussian filter used to remove high-frequency noise.

In southeastern New Mexico and western Texas (Figure 6a-d, A1 through A10), the receiver functions show a sharp, southeastward-dipping, mid-crustal conversion, this feature probably represents the northwestern edge of the Grenville basement (e.g. Bowring and Karlstrom, 1990).

Along the southeastern flank of the Colorado Plateau, and into the Rio Grande Rift (A43 through A28) there is a strong negatively polarized mid-crustal conversion, indicative of a low velocity layer. This layer is possibly an extension of the Socorro magma body (e.g. Sheetz and Schlue, 1992), a buoyancy-controlled mid-crustal sill at approximately 19km depth. This suggests that there is a regional (over 200km in extent), mid-crustal density barrier against which magma is ponding.

Figure 6

Figure 6: Receiver functions for earthquakes from a range of azimuths. (a) A Dec. 6, 1999 earthquake from the Aleutians, Mb 6.8, depth 66km, azimuth 321.2 (b) An April 23, 2000 earthquake from Bolivia, Mb 6.6, depth 609km, azimuth 140.5, (c) A March 28, 2000 earthquake from the Mariana trench, Mb 6.8, depth 127km, azimuth 299.0, (d) A January 8, 2000 earthquake from the Tonga region, Mb 6.5, depth 183km, azimuth 243.2.

Figure 7

Figure 7: Cross-section of stacked receiver functions along the line of stations showing discontinuities near 400 and 700 km depths. To produce this stack nearly 700 individual receiver functions were placed into depth and geographical bins by back ray tracing using the IASP91 spherically-symmetric Earth model. The Moho (near 45 km) can readily be seen in this figure as well, with about 15 km of topography and shallowing in the rift region. Although the 400 and 700 km discontinuities are visible, they cannot be interpreted with any certainty at this time. These features are expected to sharpen and become laterally coherent with the addition of data presently being recorded. The black circles at the surface are stations used in this analysis.

Travel Time Delays

Figure 8

Figure 8. (a) The average teleseismic P-wave residuals across the array from earthquakes to the south east of the array. (b) Average S-wave teleseimic residuals for earthquakes to the south east of the array. (c) The average P-wave residuals from earthquakes to the northwest of the array. (d) Average S-wave residuals for earthquakes to the northwest of the array.

For each earthquake used in the time analysis, the average P and S wave residuals were removed to account for near source structure and origin time errors. The station residuals were then calculated from an average of the mean removed residuals. Negative residuals indicate fast arrival times and positive slow. The delays are slowest in the rift with comparable travel time delays to Plateau and Great Plains stations. The patterns from NW and SE earthquakes vary considerably indicating significant deep heterogeneity beneath the array. A particularly striking feature is the narrow zone of fast arrivals from earthquakes to the SE at stations 10-15. This indicates a rather strong, narrow fast structure exists on the east flank of the Rio Grande Rift. Further residuals will be measured and a tomographic inversion will be performed for both P and S waves in the near future.

Future Work

Further receiver function analysis, including inversion for velocity structure and migration of receiver function data to produce a high resolution image of the upper mantle and crustal structure across the array.
Analysis of surface waves, and inversion for velocity structure.
Further delay time analysis, including tomographic inversion for P and S wave velocities. The resulting velocity profiles will be used for receiver function migration.
Study of seismic anisotropy by analysis of shear wave splitting, in order to understand the relationship between mantle flow and surface tectonics.

References

Ammon, C.J. (1991), The isolation of receiver effects from teleseismic P waveforms, Bull. Seism. Soc. Am. 81, pp 2504-2510
Bowring, S.A. and K.E. Karlstrom (1990), Growth, stabilization, and reactivation of Proterozoic lithosphere in the southwestern United States, Geology v.18, pp 1203-1206
Langston, C.A. (1979), Structure under Mount Rainier, Washington, inferred from teleseismic body waves, J. Geophys. Res. 84, pp 4749-4762
Peterson, J. (1993), Observations and Modeling of Seismic Background Noise, U.S Department of Interior Geological Survey, Open-File Report, pp 93-322
Russel, L.R. and S. Snelson (1993), Structural Style and Tectonic Evolution of the Albuquerque Basin Segment of the Rio Grande Rift, New Mexico, U.S.A., AAPG memoir 59, pp 205-258
Sheetz, K.E. and J.W. Schlue (1992), Inferences for the Socorro magma body from teleseismic receiver functions, Geophy. Res. Letts., 19, pp 1867-1870

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