An upwelling of basaltic magma 29 million years ago caused the earth’s crust to spread apart and create a region known today as the Rio Grande Rift (RGR). The RGR extends from central Colorado through New Mexico to northern Mexico, near El Paso. The RGR has different geologic features that distinguish it from most other valleys (e.g., RGR was not cut by a river nor does a river branch upstream). A growing body of evidence shows that geologic activity still occurs in the RGR, with a continuation of faulting, seismicity and widening at a small rate. The Southern Rio Grande Rift (SRGR) was the area of focus for this summer research. The goal of this research study will be to develop a contour map of velocity structures and moho depth using data from seismograms that have been installed around the region. The topographic mapping, Vp/Vs ratio, and the crustal thickness of the SRGR will define the crustal structure and the tectonic evolution of the region. The results will assist in understanding the crustal structure of not only the SRGR, but the RGR in general. Results have been obtained for the SRGR using GMT which includes a contour plot of the Vp/Vs ratio and crustal thickness in that region.
1. Introduction:

Understanding earth’s interior has been a curiosity for decades. Since nobody was able to put instrumentation in earth’s interior, the way that geoscientist gathered information about the interior processes of earth is by seismic waves propagating below the surface. Earthquake helps geoscientist to understand the earth’s structure. There are two types of body waves, P-waves (which are longitudinal pressure waves that propagate in both solids and fluids) and the S-waves (which are transverse waves that can propagate in solids but not in fluid). Seismic waves have their direction of motion changed (refracted) by vibrations in the interior density. Geoscientists have found that by studying the way such waves propagate in the earth (e.g. S-waves and P-waves) they can learn about density variations. Geoscientist have also found that the P-waves that propagate in fluids but the S-waves that do not allowed the geoscientist to conjecture that portions of the earth’s interior are liquid. The geosciences community understands that by looking at the way that seismic waves reflect off boundaries, or change in velocity as they enter new material, geoscientist are able to build up images of the interior inter processes of the solid earth.

I will focus on using data from seismograms that were installed in the southern Rio Grande Rift (RGR) that monitored seismic wave activity in that region and filter that data through a Unix C-Shell script program in order to understand the crustal structure of the southern RGR. The technique that I will be implementing is the teleseismic receiver function technique that enables me to decompose the harmonic waves recorded using a mathematical method called deconvolution to calculate the Vp/Vs ratio (Velocity of P-wave divided Velocity of S-wave) along with the moho depth (crustal-mantle boundary) in the southern RGR. There are several different techniques used by geoscientist in the past to better understand the crustal structure of the RGR and various other regions that have been found to have sources of seismic activity.

Geoscientists have found the topography of the western region of North America exhibits a tectonic history of uplift, extension, shortening, and volcanism during the Cenozoic. One province in particular in the southwest region of North America, the Colorado Plateau, has escaped much of the intense deformation and magmatism that has affected the rest of the southwestern region (H. Gilbert et al., 2007). Geoscientists were curious about why the Colorado Plateau was excluded from deformation during the Cenozoic. They were trying to determine the factors responsible for the elevation and lack of significant Cenozoic activity within the Colorado Plateau. The researchers involved in this study conjecture that the mantle is the possible source of strength that had provided the support needed for the plateau to resist deformation while the other bordering regions failed (H. Gilbert et al., 2007). The goal of this research study of the Colorado Plateau and RGR was to better characterize the crustal and mantle structure. The Rio Grande rift is geologically young and resulted from a process of regional extension and mantle upwelling in Neogene times. The RGR continues to widen today, geoscientist have found that ongoing geologic activity is evident through high heat flow, hot springs, continued seismicity, geodetic observations, and some of North America’s
most recent lava flows. My summer research on southern portion of RGR could assist in better understanding the crustal structure of RGR and the tectonic evolution of the southern RGR region.

A technique used by geoscientist in the past to better understand the use of receiver functions were calculations using the teleseismic arrivals recorded in Colorado Plateau-Rio Grande Rift-Great Plains Seismic Transect (LA RISTRA) experiment (Wilson et al., 2005). The purpose of the LA RISTRA experiment was to study the crust and mantle beneath surface of the southwestern portion of U.S by utilizing the 18-20 months of collective data samples, and continuous broadband data (Wilson et al., 2005). They have used receiver functions to obtain information about reflections, refractions, and conversions of P and S waves as they were dispersed across boundaries and between regions (Wilson et al., 2005). For a more explanation of how they used the receiver functions and the LA RISTRA in order to better understand the crustal structure, refer to (Wilson et al., 2005).

In the southwestern portion of U.S, the Rocky Mountains was another region where geoscientist investigated the crustal structure with the goal of using geophysical instrumentation and receiver function estimations to extract information on the lithosphere in the vicinity of the recording station (Rumpfhuber et al., 5). The scientists setup a series of recording stations for the purpose of analyzing the P-to-S converted energy from major velocity discontinuities in the crust and upper mantle (Rumpfhuber et al., 6). This research study of the Rocky Mountains has some similarities to the approach they used on understanding the seismic waves propagating in the solid earth. The only difference between the research study in Rocky Mountain region and the LA RISTRA experiment is the use of geophysical instrumentation (e.g recording stations, IRIS/PASSCAL seismographs,etc) along with receiver function estimation of seismic waves in order to better understand the crustal structure of Rocky Mountains. These are some of the techniques that were used by geoscientist in the past to understand the unknown phenomena of the crustal structure of the earth and the interior of the earth by analyzing seismic waves (P-waves and S-waves) when an earthquake occurs. As I move further into my research, the teleseismic receiver function technique that was mentioned would help to enable the geoscience community to better understand the crustal structure of a particular region which is the Rio Grande Rift in southwestern U.S.
2. Methods

There is a program called GMT (Generic Mapping Tools) that will be used to obtain information about the crustal structure of the southern tools for manipulating geographic and Cartesian data sets (including filtering, trend fitting, gridding, projecting, etc). GMT has the capability to produce x-y plots via contour maps to 3-D perspective views of any particular region in the world. GMT will be used this summer for the purpose of modeling the southern RGR in order to interpret the crustal structure. Before proceeding with modeling, the US Array files must be updated for the GMT program to provide an efficient topographic mapping of the southern RGR for this research study. To update the US Array files for the GMT program, the necessary data needed for the GMT program to function properly comes from Earthscope Automated Receiver Survey (EARS) database. The EARS website contains the data sets of all frequent seismic activity and a database of all the recording stations that monitor seismic events. Once the US Array is updated by data from the EARS website then the next step is to modify a particular c-shell script r_rgr_basemap.csh* in order to provide a 2-D model of the southern RGR. When the 2-D model is up and functional, the model will be able to not only display a contour map of the southern RGR it will be able to contour the Vp/Vs ratio and the moho depth.

The deconvolution technique is the technique that will be implemented in order for the Vp/Vs ratio and moho depth to be calculated before that information is filtered into the C-shell script program (e.g r_rgr_basemap.csh*). Deconvolution is a mathematical method used to filter a signal and isolate the superimposed harmonic waves. For example, when given a convolved signal \( u(t) = s(t) \ast g(t) \ast i(t) \), the system should isolate the components \( s(t) \) the source, \( g(t) \) the earth structure, and \( i(t) \) the instrumentation so that they can be analyzed individually from the seismogram \( u(t) \).

**Ideal deconvolution**

\[
\begin{align*}
\text{Ideal deconvolution} \\
\text{s(t) \ast g(t) \ast i(t)} \\
\text{D} \\
\text{s(t)} \\
\text{g(t)} \\
\text{i(t)}
\end{align*}
\]

Convolution is a mathematical way of combining three signals to form a fourth signal (e.g \( u(t) = s(t) \ast g(t) \ast i(t) \)) by the point-wise product. The point-wise product of three time domain functions is another function. The point-wise product is obtained by multiplying the image of the three functions at each value in the domain. Once the point-wise product is computed and taking the fourier transform of the fourth signal, it will produce the frequency domain. The fourier transform of the point-wise product of the three functions is a mathematical way to convert to the frequency domain.

RESESS 2008, Lennox Thompson, 4
(e.g. \( F[s(t) * g(t) * i(t)] = S(w)G(w)I(w) \)). The frequency domain relates to the Fourier transform by decomposing a function into an infinite or finite number of frequencies. This is based on the concept of Fourier series that any waveform can be expressed as a sum of sinusoids. To perform deconvolution of signals, \( s(t), p(t), i(t) \) is by the following:

\[
F[u_z(t) = S(t) * p_z(t) * i(t)] = u_z(w) = S(w)p_z(w)I(w)
\]

\[
F[u_r(t) = S(t) * p_r(t) * i(t)] = u_r(w) = S(w)p_r(w)I(w)
\]

\[
u_r(w) = S(w)p_r(w)I(w) ÷ u_z(w) = S(w)p_z(w)I(w)
\]

\[→ u_r(w) ÷ u_z(w) = p_r(w) ÷ p_z(w)\]

This is the whole conceptual understanding of how to apply the deconvolution technique in order to filter signals and isolate them separately for analysis.

3. Results

The results that I was able to acquire were a contour plot of the SRGR (Southern Rio Grande Rift). Once the exact coordinates were known, the grid data had to be filtered into a UNIX c-shell script program in order for the topography to be displayed. When the grid data were initially used in the post script program, the contour plot had the topography but did not have the color features that displayed the various elevation levels (meaning the steepness of the terrain) of the SRGR region (e.g., figure 1 is a contour map of US without any color added to the plot). The missing component in the post script program was the file temp.cpt. The temp.cpt file provides the color features necessary for the contour plot. When the temp.cpt file was added to the GMT commands in the script program, the program displayed a detailed contour map of the North America (e.g., in figure 2 is a display of North America with the color features which deciphers what is the coastlines, rivers, lakes, mountain ranges, etc). After the color features were added into the c-shell script program, the next factor to be added was the state boundaries along with the receiver function data. The psxy GMT command had to be implemented in order for the state boundaries to appear on the contour plot. The state boundaries help to see exactly where I zoom in on the contour plot. It is rather difficult to know exactly where the SRGR is located without some kind of state boundaries to indicate the state borders of US like in fig 3 where there are no state boundaries on the contour map. A miniature map of the US and a star on the map was added to avoid confusion of the location of the SRGR in US. After the state boundaries were factored in, the receiver function data was the next component to be added in the postscript program. The receiver function data is the locations of the US array stations relative to the epicenter of an earthquake. The US array stations were deployed by EarthScope to record seismicity in the US. The receiver functions were collected from the Earthscope Automated Receiver Survey (EARS) EarthScope website where they have a database of all the US array stations deployed in
the US. EarthScope explores the 4-dimensional structure of the North American continent. EarthScope provides a framework for broad, integrated studies in the earth sciences (e.g., research on fault properties, earthquake process, plate boundary process, large-scale continental deformation, etc). The receiver function data was plotted with black triangles to represent the US array stations surrounding the SRGR in figure 4.

Fig1: A contour map of US with the boundaries of the map around the plot.
Fig 2: A colored contour map of North America in GMT using a Unix-csh shell script program.
Fig 3: A zoomed in view of the SRGR region.
Fig 4: The topography of the SRGR with the color features indicating Elevation levels. Above the contour plot is a color scale of the elevations in meters. The black triangles signify the receiver function relative to the epicenter of the earthquake below the seismogram.
Fig 5: A plot of the Vp/Vs and the crustal thickness of the receiver function NM35 provided by EarthScope.
Fig 6: A contour plot of Vp/Vs structure of SRGR. From blue to red colors represent higher Vp/Vs ratio in some areas. The black triangles represent the receiver functions around the SRGR.
Fig 7: A contour plot of the crustal thickness of the SRGR. The color scheme used represents the crustal thickness in kilometers. The black triangles represent the receiver functions around the SRGR.
4. Discussion

All the figures represent the topography of SRGR. From Fig 1-4 have various features that describe the topography, lat/lon, Vp/Vs ratio, and receiver function data of SRGR. The reason the receiver function data helps with understanding the crustal structure of the SRGR, it records the relative response of the earth structure when seismic waves reverberate near the receiver. As shown on fig 4, all the receiver functions were deployed in the surrounding area of the SRGR represented by the black triangles in the contour plot. From fig 1-3 are general topographic maps that supply a general image of the earth’s surface. In fig 2-4 contain color variations from temp.cpt file that represents the elevation levels. In the color scale in fig 4, the terrain gets steeper as you move from dark to lighter colors on the contour plot. In fig 5, the plot represents the Vp/Vs velocity structure and crustal thickness in the SRGR provided by EarthScope from station NM35. As shown on fig 5, approximately between 46 – 50 kilometer depth the crustal thickness is higher. In fig 6, the contour plot represents the Vp/Vs velocity structure of the SRGR. The black triangles plotted on the figure represent the receiver function data. In fig 7, the plot is similar to the plot in fig 6 except that the contour plot represents the crustal thickness of the SRGR with a scale measured in kilometers. The same color scheme was used in both fig 6 and fig 7, however, the color patterns are different in some areas around the receiver function data.

5. Conclusion

Past research done on the crustal structure of RGR has assisted with this summer research. Some of the methods used by geoscientist has led to new insights and discoveries about the RGR. The approach used for this research was different from the approaches used before (e.g., the LA RISTRA experiment). The method that was used in this research, the teleseismic receiver function technique. The teleseismic receiver function technique enables the decomposing of superimposed harmonic waves recorded using a numerical mathematical method called deconvolution. The deconvolution technique is the technique that was implemented in order to compute the receiver functions which includes the calculation of the Vp/Vs ratio (Velocity of P-wave divided by Velocity of S-wave) along with moho depth (crustal-mantle boundary). The deconvolution technique was implemented so the receiver functions could be filtered through the Unix c-shell script program for the purpose of plotting the receiver functions on the contour map of SRGR and contouring the Vp/Vs along with the crustal thickness. Past research done in the Colorado Plateau and researching why the province has escaped much of the intense deformation and magmatism that has affected the rest of the southwestern region is an example of the types of previous work done related to understanding the tectonic evolution and crustal thickness of a particular province like the Colorado Plateau. The previous work done by geoscientist on Colorado Plateau has helped with the results that were obtained in this summer research. The reason is the results that were obtained in that particular research study has helped with thinking about new approaches to interpreting the tectonic evolution and crustal structure of a seismically active province, the SRGR.
There were three preliminary results that were obtained this summer. The three preliminary results were, the topography of SRGR, contouring of Vp/Vs ratio, and contouring of the crustal thickness of the SRGR. In figures 6 and 7, the color scheme was the same but the color patterns in different portions of the plot vary. Questions were raised about the results that were acquired, for instance, in figure 6, there are some areas in the plot that are red which indicates a decrease in Vs which in turn enlarges the fraction Vp/Vs. This is caused by an upwelling of the earth’s mantle which results in a higher Vp/Vs. Overall, the research done this summer helped with understanding the crustal structure and what unknown processes of the crustal structure that is not yet well understood.
References


