

Gravity and Magnetic Anomalies Compared to Moho Depth throughout the State of Texas

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Introduction

My Master's thesis is to improve and create additional crustal seismic velocity models of Texas. A crucial step in creating the 1D and initial 3D model is to know where major units lie in the subsurface. The Ellenburger formation, a karstic limestone, and the Precambrian igneous basement are the most widespread units in Texas and extend, generally, from the Panhandle to Balcones Fault. By importing surfaces of both units, I can find the thickness of the Ellenburger Formation to use in the velocity models. Because the Moho is such a large velocity contrast in comparison to the crust above, mapping the surface of the Moho is a crucial step. I used this project as an opportunity to create the best Moho surface from receiver function data, comparing multiple tools in ArcMap.

Aside from my thesis work, I nor Dr. Helper were aware of any basic studies analyzing general tectonic structures represented in the gravity and magnetic anomaly studies that covered Texas. In this project, I conduct a general observational study mapping out highs and lows in the gravity maps in relation to tectonic regimes and geologic units.

Data Collection

Working from the surface down, I downloaded and collected the data sets from various sources. I downloaded the geologic units shapefile from the USGS Mineral Resources On-Line Spatial Data page for Texas (<https://mrdata.usgs.gov/geology/state/state.php?state=TX>). I also downloaded the ArcMap style file for the lithology colors. The hillshade DEM shapefile for the state of Texas was available on the Texas Water Development Board's GIS Data site (<http://www.twdb.texas.gov/mapping/gisdata.asp>). Cari Breton at the BEG gave me access to the digitized files for the "Tectonic Framework of Texas" by T. E. Ewing.

I received the files for depth to top of the Ellenburger formation from Eric Potter and colleagues at the BEG who various studies to create a statewide surface map of the formation. The contours were originally created in regional studies by the Texas Water Development Board, ISPB, BEG and Ruppel. The files were in the NAD 1927 Texas Statewide Mapping System projected coordinate system and North American 1927 geographic coordinate system.

For the Precambrian basement, Cari Breton digitized Peter Flawn's "Basement Rocks of Texas and Southeast New Mexico" (Flawn, 1956) maps of depth to basement and rock samples. The files were originally in the North American 1983 geographic coordinate system.

Moving to the Moho, I downloaded the EarthScope Automated Receiver Survey (EARS) data (<http://ds.iris.edu/ds/products/ears/>) for all of the US Transportable Array stations in Texas when the USArray rolled across Texas from 2008 to 2011. EARS calculates the receiver functions for

each TA station using teleseismic earthquake data to measure the thickness of the crust above the Moho.

I downloaded the gravity and magnetic anomaly maps from the USGS (<http://pubs.usgs.gov/ds/2006/232/data/>), which were in .e00 format and covered Texas and parts of surrounding states (Fig. 1).

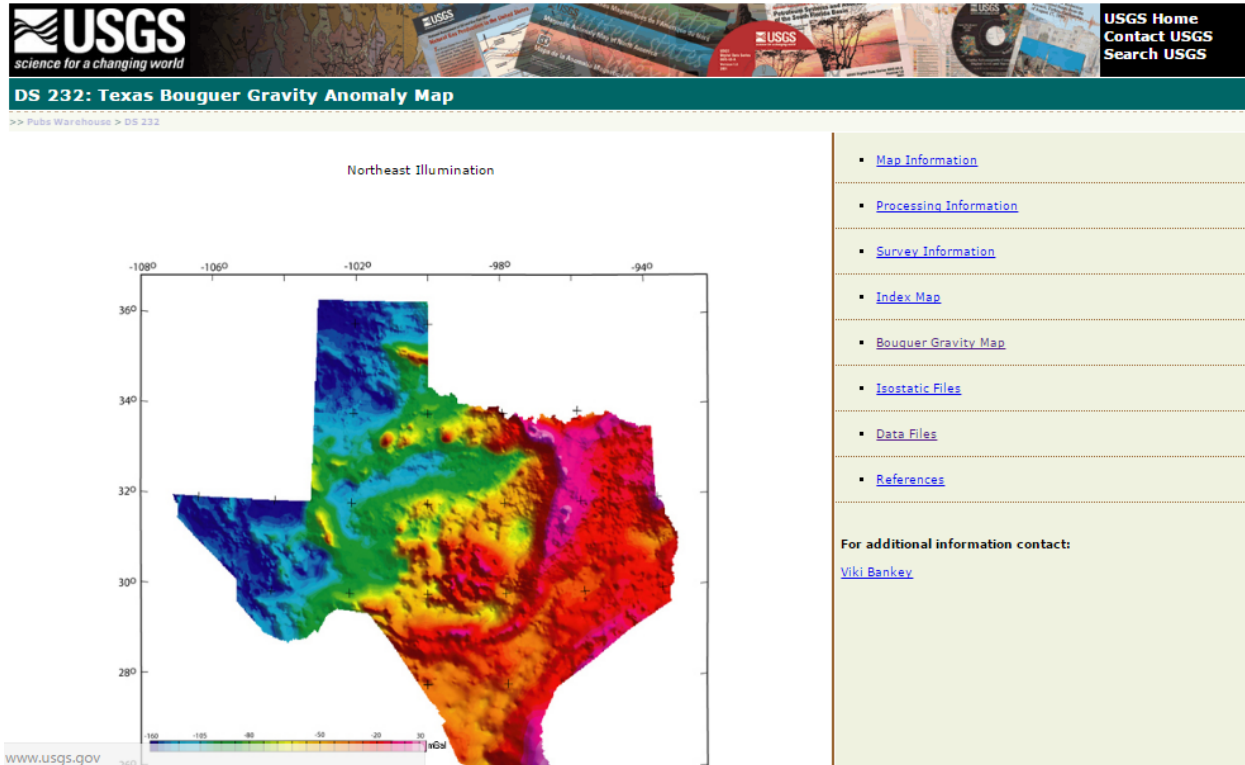


Figure 1: Image of USGS site with gravity and magnetic data

The state boundary was downloaded from TIGER shapefile page on Data.gov (<https://catalog.data.gov/dataset/tiger-line-shapefile-2013-state-texas-current-county-subdivision-state-based>). Original projected coordinate system is NAD 1983 Albers.

Data Pre-processing

Geologic Units, Faults and Tectonics

I used 'Project' to transform from NAD27 to NAD 1983 UTM Zone 14N for both faults and geology. For geologic units, I had to 'Match to Symbols in a Style' in the symbology and used the style file from USGS to color the units properly.

Ellenburger

To create a single surface for the Ellenburger, I began by importing all the shapefiles and related files for each study of the Ellenburger into ArcMap (Fig. 2).

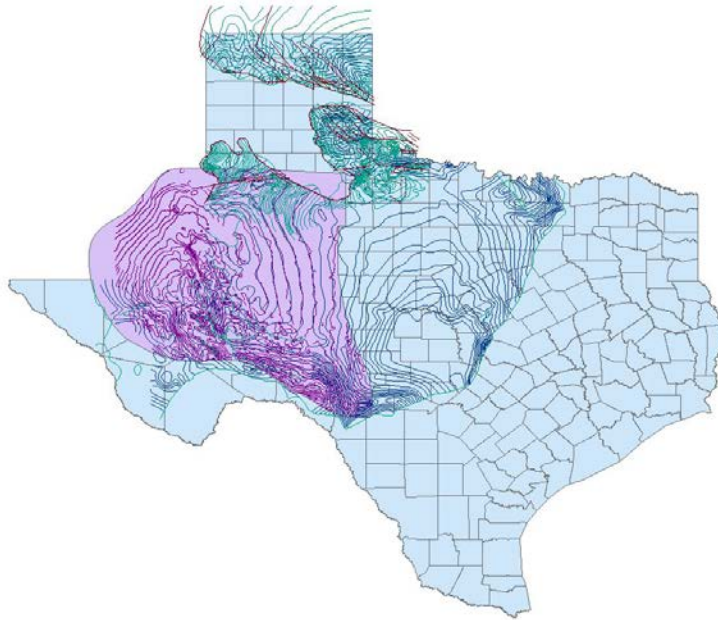


Figure 2: Screenshot of original contours, breaks and polygons for all Ellenburger studies

I then individually converted each set of contours to rasters using 'Topo to Raster' with the Field set to 'value' and Type set to 'contour' (Fig. 3).

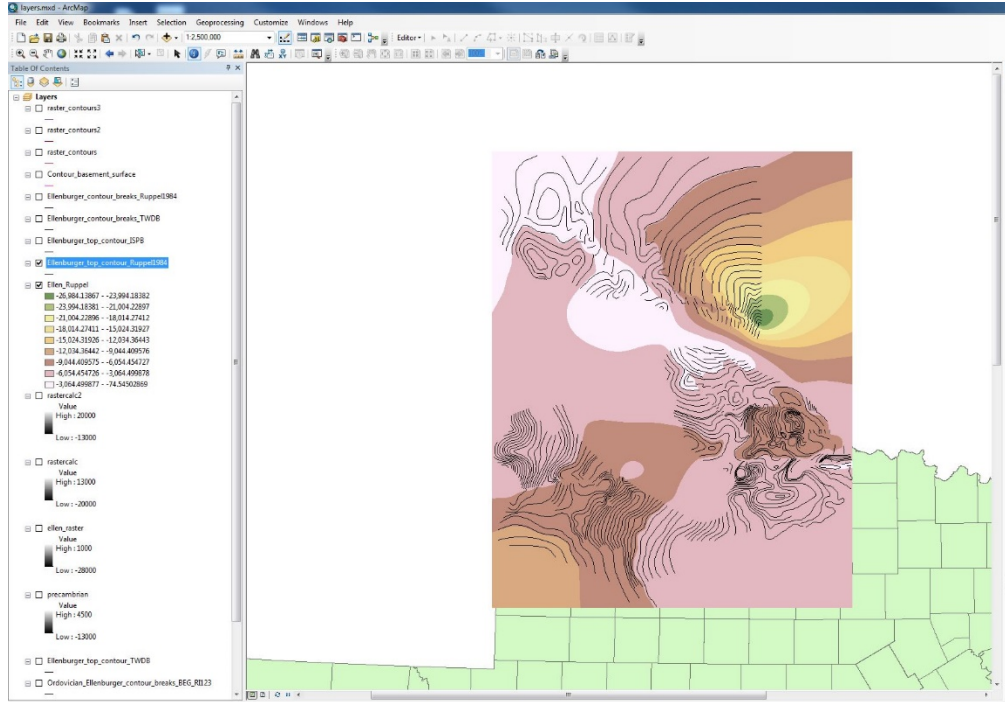


Figure 3: Screenshot of contours converted to raster but not clipped

I also added the boundary file for each set of contours and set their Type to 'cliff'. This stopped the interpolation of the raster at the boundaries of each study area (Fig. 4).

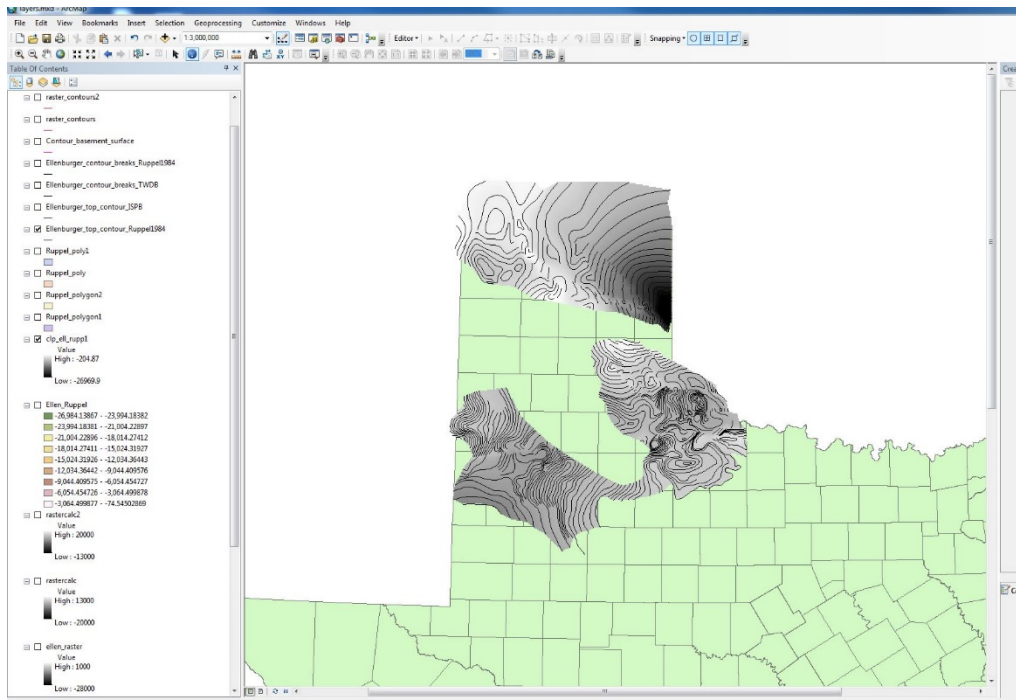


Figure 4: Screenshot of Ellenburger raster clipped at boundaries with contours overlaying raster

At this point, I had 4 rasters that overlapped and covered various parts of Texas but all represented the same geologic unit. To merge the rasters, I used 'Mosaic to New Raster' with the Mosaic Operator set to MEAN to average the value of cells that have overlapping rasters (Fig. 5).

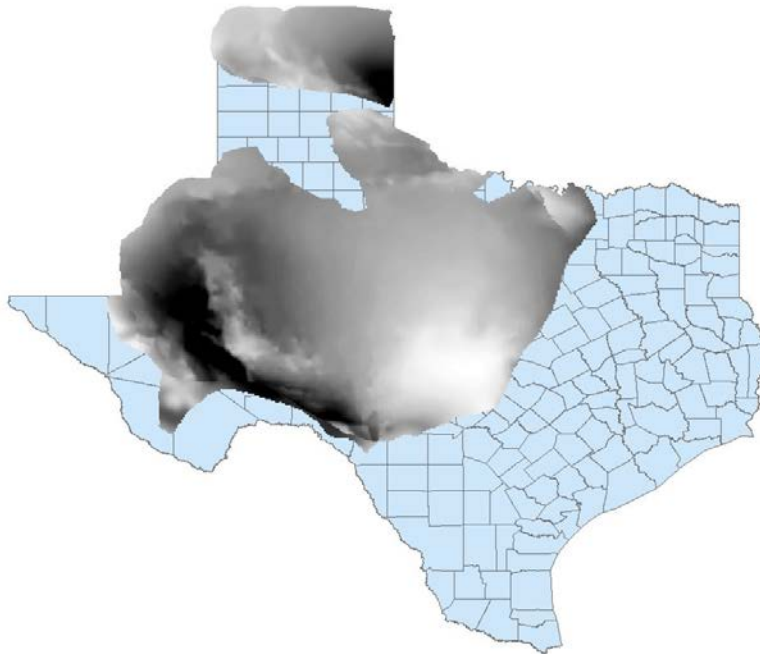


Figure 5: Raster of complete Ellenburger surface

Precambrian Basement

I repeated the same process for the Precambrian igneous basement in Texas with the only difference that I had only one set of contours, so I did not have to merge or average cell values. As part of my thesis work, I need to know the thickness of the Ellenburger formation. To calculate the thickness, I used the Raster Calculator to subtract the Ellenburger mosaic raster from the Precambrian raster (reversed because of negative depths) to find the thickness of the Ellenburger everywhere the Precambrian underlies it.

Moho

To create a shapefile of the top of the Moho boundary, I first had to export the data from the EARS site for all TA stations within the latitude and longitude limits (-107°W to -93°W and 26°N to 36°N) of Texas. This included stations in surrounding states, but I will later fix that by clipping the Moho shapefile (Fig. 6). I used a Bash shell script to remove the latitude, longitude and depth (km) from the downloaded data, and then imported it into Excel. I then added the Excel file to ArcMap, selected 'Display XY Data', set X Field to Longitude, Y Field to Latitude, Z Field to Depth (km) and set the coordinate system to the geographic coordinate system NAD 1983. I then exported the data to a shapefile and set the Data Frame Properties to NAD 1983

UTM Zone 14N. To ensure the XYZ points overlapped other rasters and shapefiles, I used the 'Project' tool to change from GCS NAD 1983 to projected coordinate system NAD 1983 UTM Zone 14N to match the data frame.

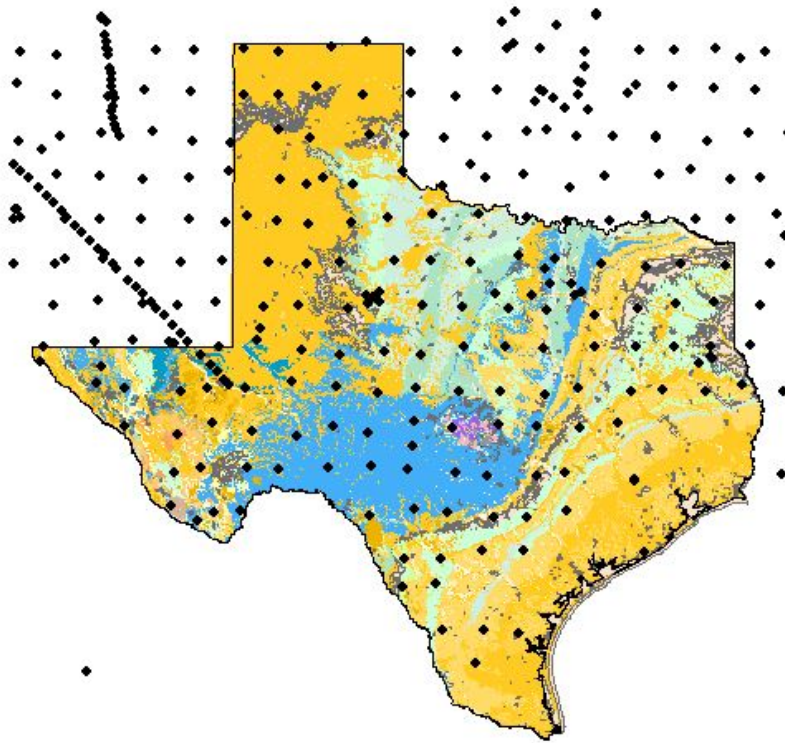


Figure 6: All EARS stations plotted on top of the geology shapefile as reference for viewer

Gravity and Magnetic

I downloaded the isostatic and Bouguer gravity maps and the magnetic anomaly map in the .e00 format and used the 'Import from E00' tool.

ArcGIS Processing

Geology, Faults, and Tectonic Boundaries

I 'clipped' the tectonic boundary shapefile to the state boundary shapefile.

Hillshade

There was a discrepancy between the outline for the hillshade and the state boundary along the Gulf. I believe the difference is due to the state boundary inlet traces while the hillshade is a smooth and constant trace of the coastline. I therefore used 'Extract by Mask' to clip the hillshade to the state boundary to keep all files consistent.

Ellenburger and Precambrian basement

Processing was completed in pre-processing.

Moho

- Used IDW, Spline, Tin, Topo to Raster, Trend to interpolate the surface (Fig. 7-12)
- Used 'Extract by Mask' after each tool with the state boundary
- Changed Symbology to inverted partial spectrum

To interpolate a surface from the EARS data points, I used various tools (IDW, Spline, Tin, Topo to Raster, Trend) to see the differences in the interpolated surfaces created. For all surfaces created, the interpolation can only reach as far as the furthest data point in each direction. Therefore, the surfaces do not extend to the southernmost part of Texas.

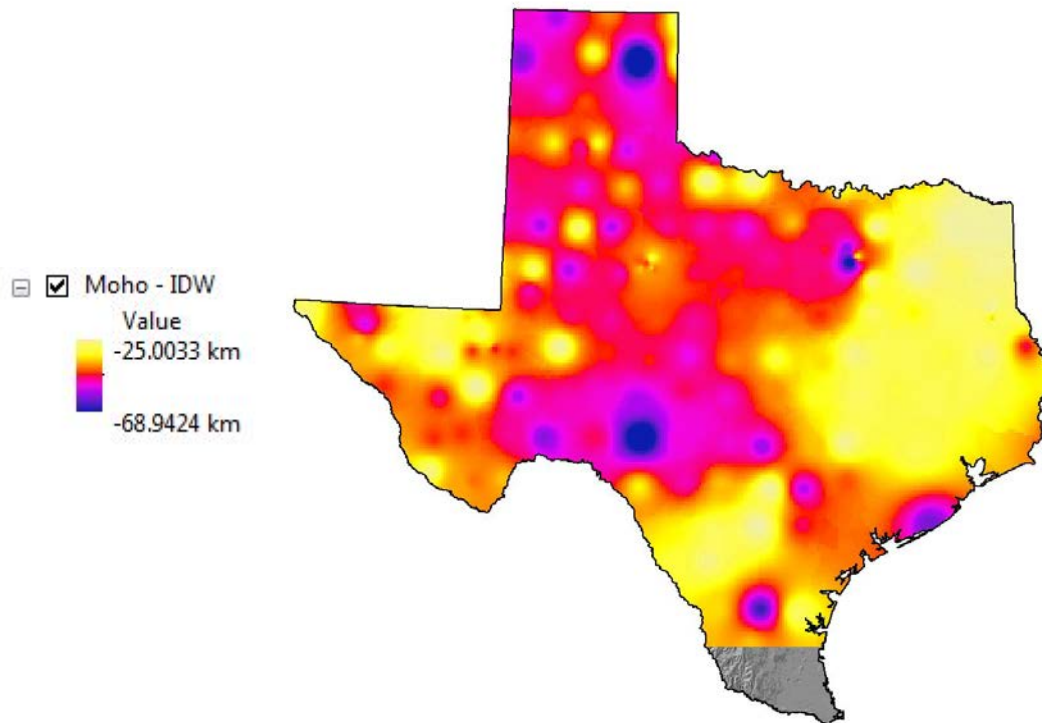


Figure 7: Moho surface using IDW tool

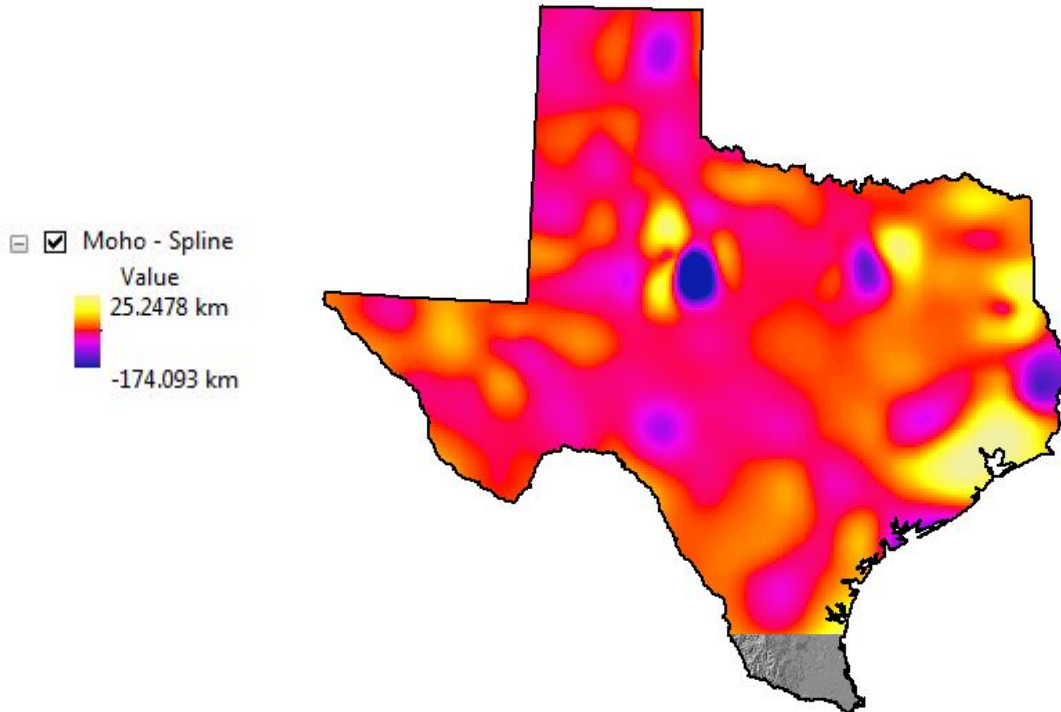


Figure 8: Moho surface using Spline tool and 8 points per region

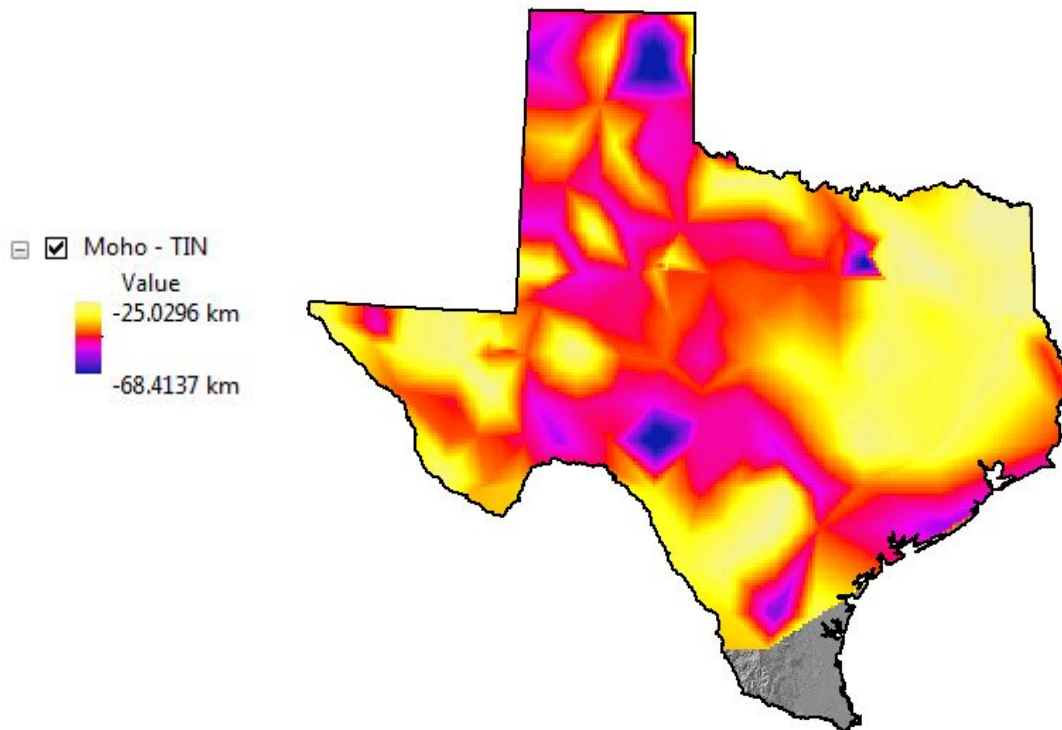


Figure 9: Moho surface using TIN tool with linear method

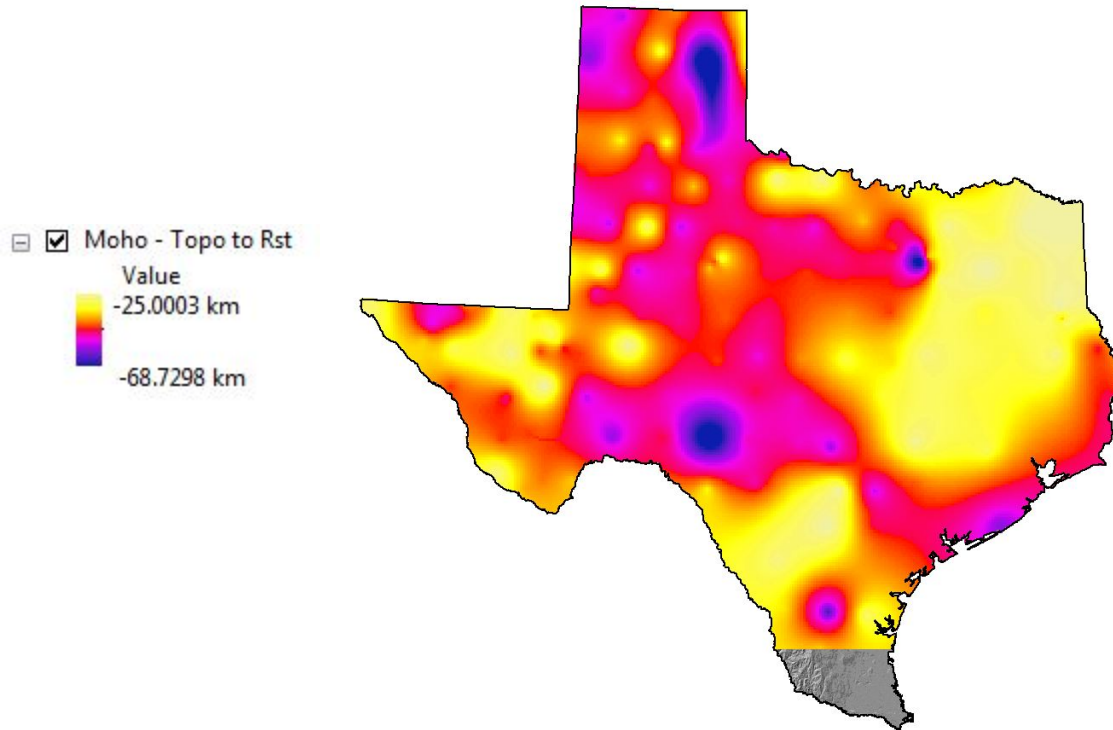


Figure 10: Moho surface using Topo to Raster tool

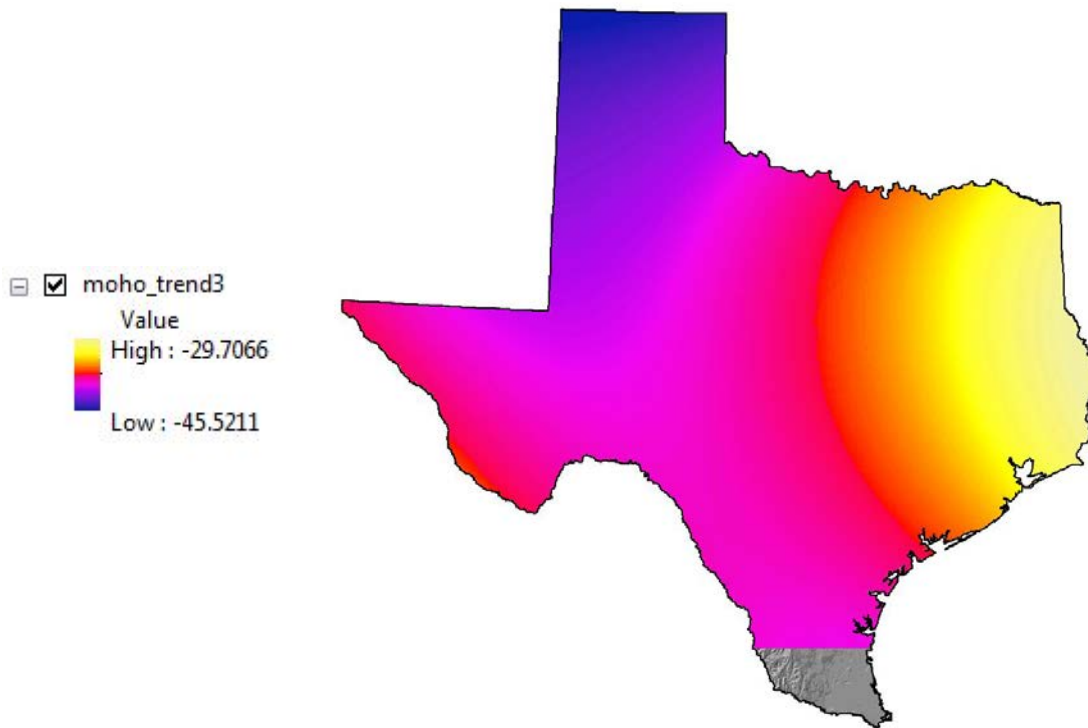


Figure 11: Moho surface using Trend tool with polynomial order of 3

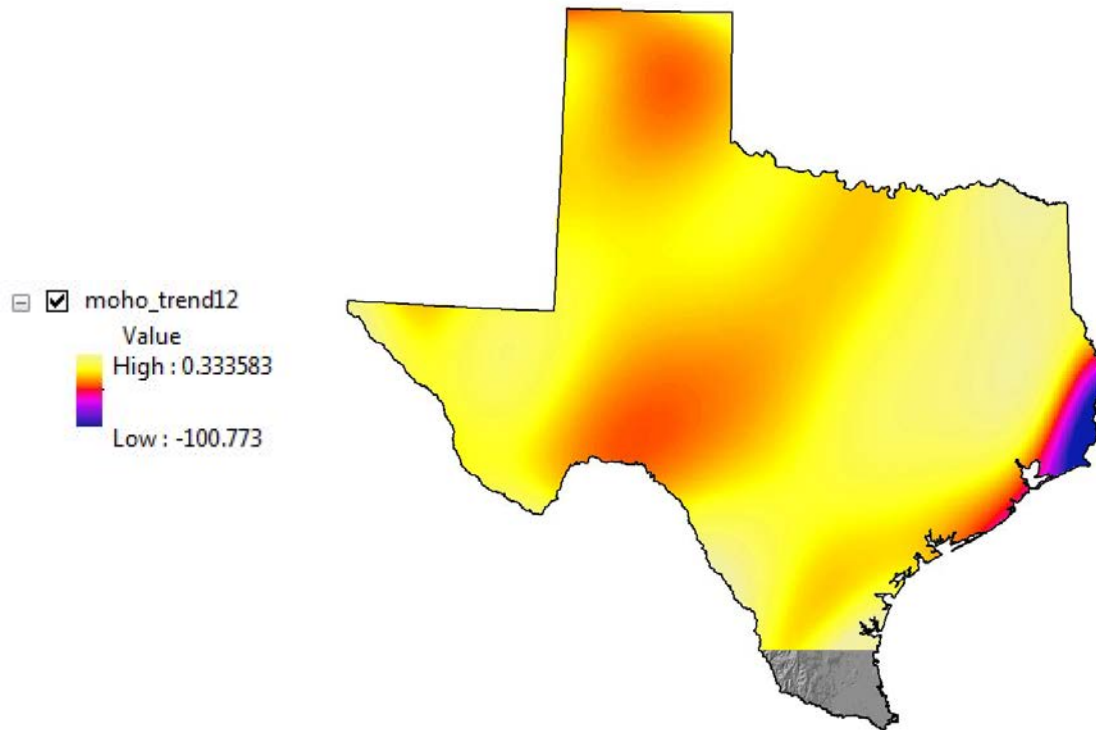


Figure 12: Moho surface using Trend tool with polynomial order of 12

Gravity and Magnetic

After the files were imported with the 'Import from E00' tool, the individual maps covered Texas and part of surrounding states. I then used the correctly projected Texas boundary shapefile in 'Extract by Mask' to clip the three files to Texas (Fig. 13-15).

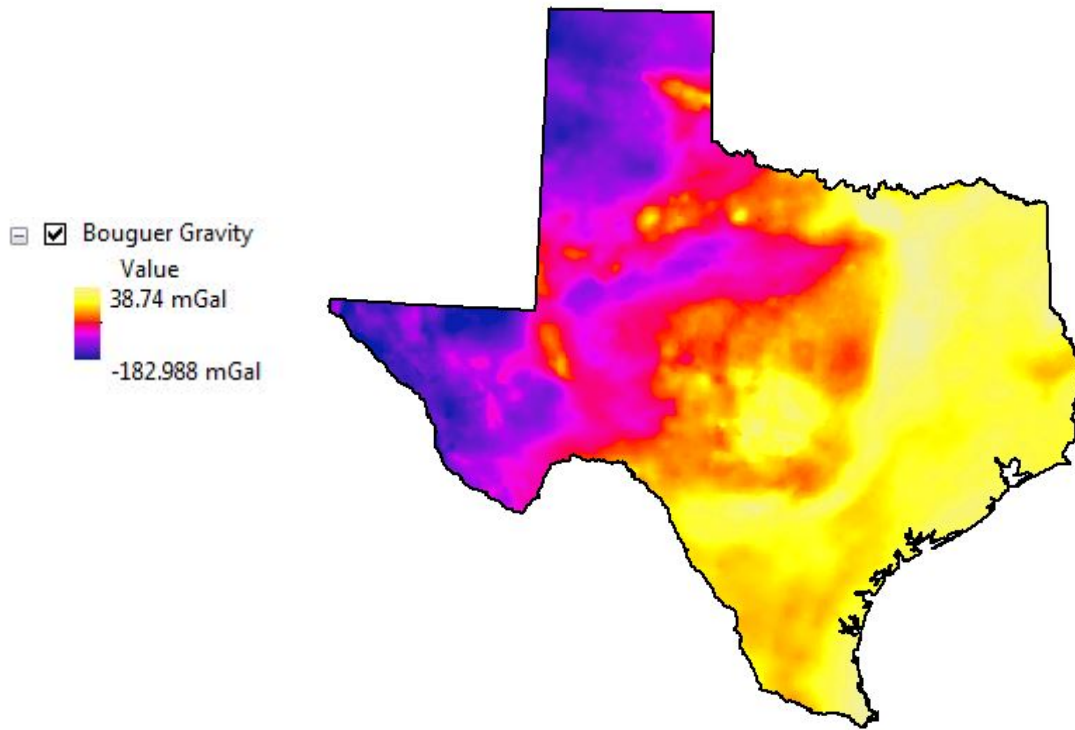


Figure 13: Screenshot of clipped Bouguer anomaly raster

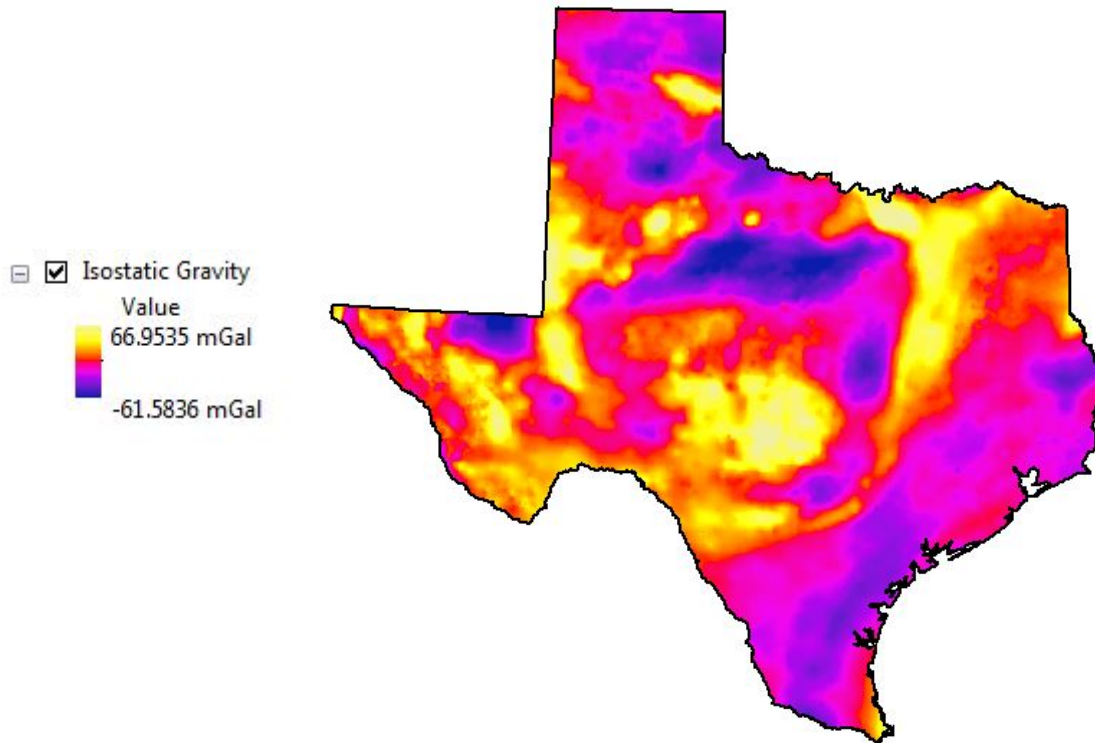


Figure 14: Screenshot of isostatic gravity anomaly raster

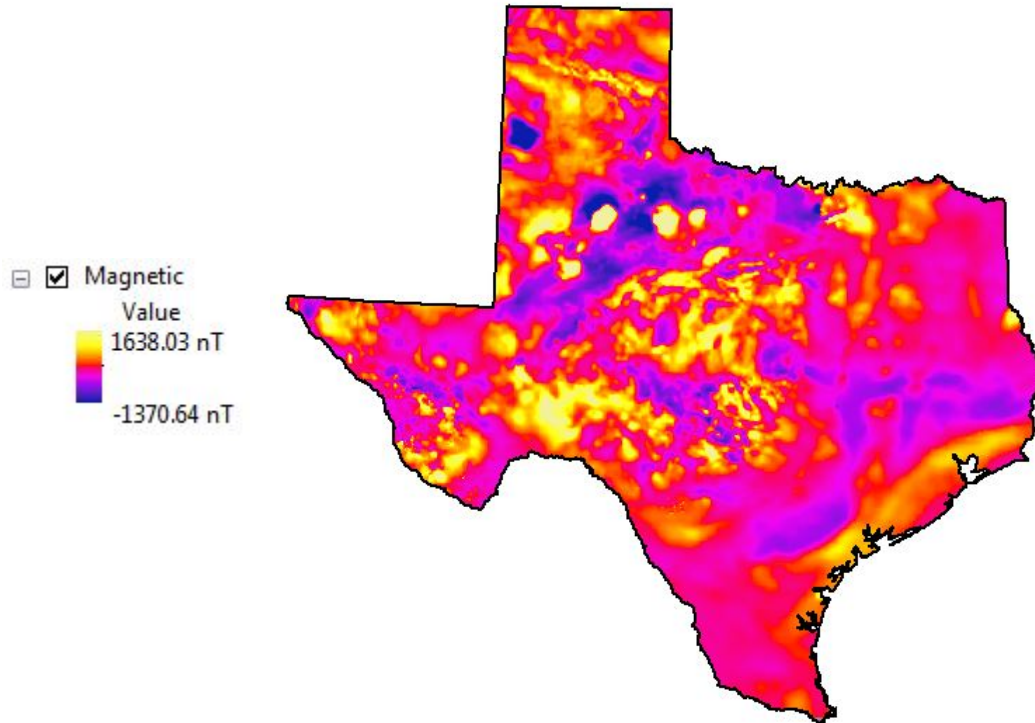


Figure 15: Screenshot of clipped magnetic anomaly raster

Discussion

This project initially began as a step toward creating surfaces that are indicative of seismic velocity contrasts in the subsurface of Texas. As I began working with the data points from the EARS receiver functions, I realized the Moho topography is highly dependent on the tools used to interpolate the XYZ points. Therefore, I conducted a qualitative analysis on the surfaces produced from various interpolation tools in Arc. I then compared the topography of the Moho to the Bouguer and Isostatic Anomaly. The surfaces created for Ellenburger and Precambrian basement did not have any similarities to the Bouguer, isostatic or magnetic anomalies.

- Inverse Distance Weighting (IDW) (Fig. 7)

IDW is an exact, deterministic method of interpolation, so the surface passes through measured data points. No values of the surface exceed the minimum or maximum measured values, but the IDW surface is considered rough and not the best method for data sets that do not decrease as a function of distance. The surface created with the IDW tool has quite a few (>10) peaks and pits. Because this is supposed to be representative of the Moho, I determined this tool to be unfit for Moho surface interpolation with the given data set.

- Spline (Fig. 8)

The spline tool creates a minimum curvature surface that passes through data points but can exceed maximum and minimum measured values. It is supposed to create a smoother surface than IDW and be a better fit for topography. A parameter that is able to be set in the spline tool is

the number of points per region used for local approximation. The most ‘realistic’ (smooth with enough representation of topography changes) surface I could create was with 8 points per region (Fig. 8). The EARS Moho depths range from -69 km to -25 km, but the spline surface extends from -174 to +25 km. Obviously, the Moho is not above the earth’s surface and does not have pits of -174 km in isolated areas. However, compared to the gravity anomalies, some of the same general trends are found in highs and lows. Therefore, the spline tool is also an inaccurate representation of the Moho in regards to accurate depths, but can be a good smooth surface to examine gross trends in the surface.

- Triangular Irregular Network (TIN) (Fig. 9)

I used ‘Create Tin’ and then ‘TIN to Raster’ to create a TIN surface from the EARS data. I used a ‘float’ output data type, ‘linear’ method, and ‘OBSERVATIONS250’ sampling distance. This tool does not create an interpolated surface that exceeds the minimum and maximum measured data points. It uses Delaunay triangles (vertices are data points with the goal of creating the most equilateral triangles), which takes advantage of non-gridded data points with variable levels of detail across the study area. The surface rendered is reasonably variable without peaks or pits, follows similar trends to the isostatic gravity anomaly and does not exceed measured data points; therefore, it is the best tool available to create a surface from variably spaced XYZ points that represent a smooth topography.

- Topo to Raster (Fig. 10)

This tool is recommended “for the creation of hydrologically correct digital elevation models (DEMs).”¹ The tool ensures connected drainages and accurate representation of ridges and streams. It “has been modified to allow the fitted DEM to follow abrupt changes in terrain, such as streams, ridges and cliffs”¹. This surface does not exceed the measured data points and is reasonably smooth. But, due to the hydrology application, the tools appears to interpolate more trenches than possibly exist between higher values. The interpolated surface is very similar to the TIN surface (Fig. 9), but I think TIN is still more appropriate.

- Trend (Fig. 11 and 12)

The Trend tool is an inexact, deterministic method of interpolation. Because it is inexact, the surface does not need to pass through measured data points. This allowed one surface to start just below the surface (unrealistic) and extend to -100 km depth (unrealistic). The surface is created by setting the order of polynomial to increase complexity of the surface. I used a polynomial order of 3 and 12 (Fig. 11 and 12) to compare the possible surfaces, but neither appear to be similar to the gravity surfaces, or any other interpolated surfaces. I do not think trend is a reasonable tool to use.

- Structure and Tectonics in the Moho, Gravity, Magnetism

The final maps show a few plots of the Moho surface interpolated by various tools and the gravity and magnetic anomalies. Some of the figures have the tectonic boundary shapefile

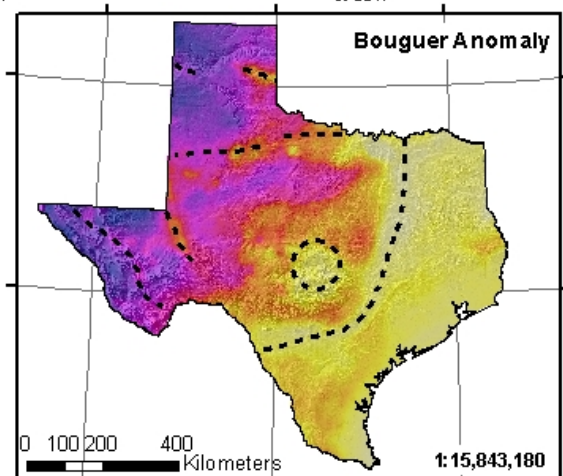
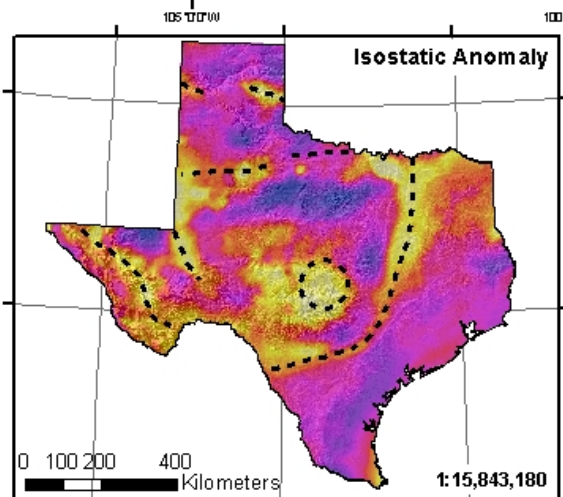
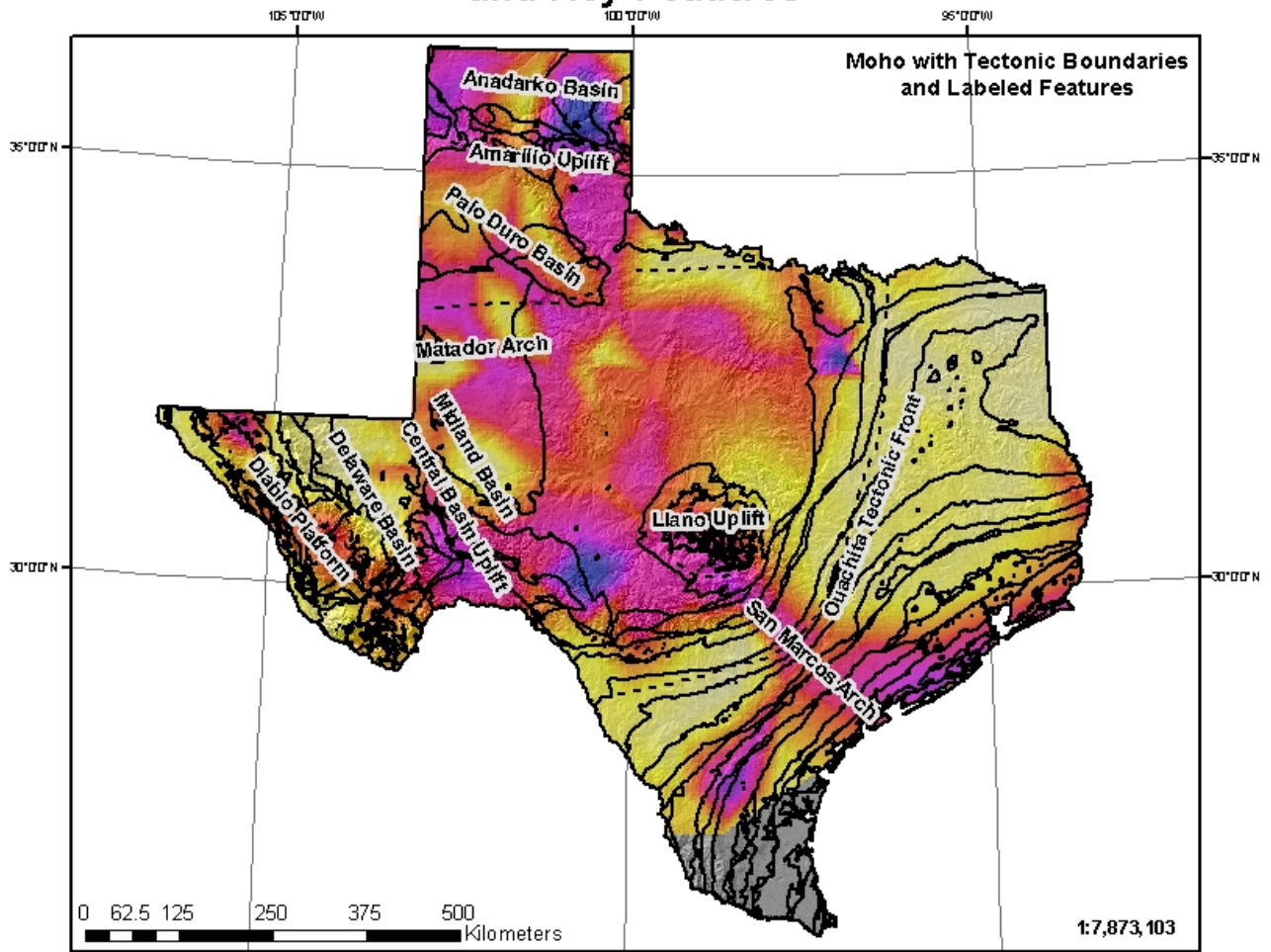
¹ <http://pro.arcgis.com/en/pro-app/tool-reference/3d-analyst/how-topo-to-raster-works.htm>

overlaying the surface (Moho, anomaly) and others have polylines drawn to show where key features plot on the various figures. Overall, large tectonic features are visible in the Moho TIN surface, Bouguer and isostatic gravity anomalies and the magnetic anomaly. As seen in the 'Map of Moho Topography, Isostatic Gravity, Bouguer Gravity and Key Features', the San Marcos Arch, Ouachita Tectonic Front, Llano Uplift, Midland Basin, Central Basin Uplift, Delaware Basin, Diablo Platform, Anadarko Basin, Amarillo Uplift and Matador Arch are all topographic and/or gravity highs or lows. Because there is strong correlation between tectonic features in the gravity anomaly maps with the TIN surface, I will continue to use TIN as the tool to create interpolated surfaces from EARS data.

In the future, I need to incorporate station elevation into the EARS Moho depths and investigate other studies to increase the data set. The station elevations are already available, but I did not include them in order to create a simpler, smoother surface that would be easier to test.

Taylor Borgfeldt, Dec. 1, 2016

Map of Moho Topography, Isostatic Gravity, Bouguer Gravity and Key Features



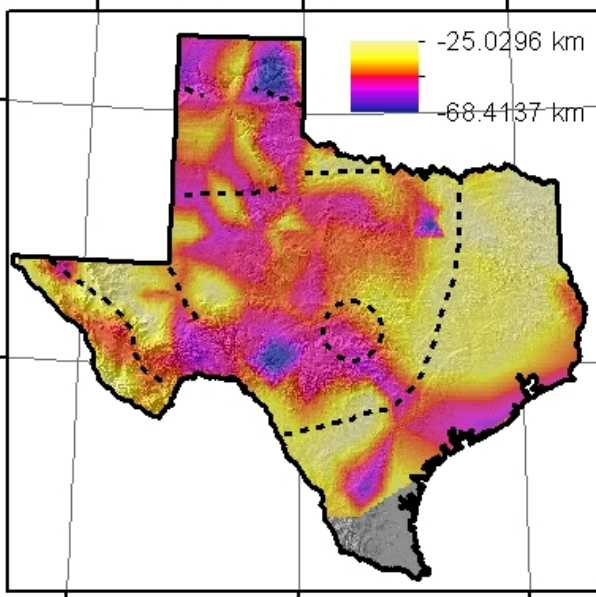
Legend

- Features
- Tectonic Boundaries

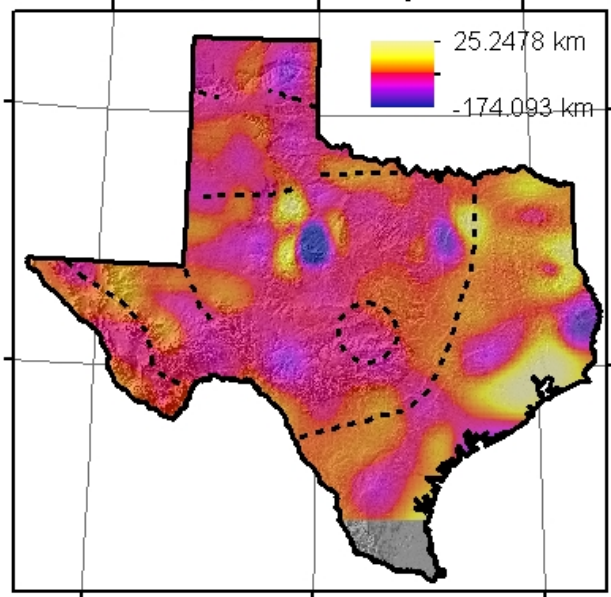
Moho	Isostatic	Bouguer	
High: -25.0296	High: 66.9535	High: 38.74	NAD 1983 UTM Zone 14N
Low: -68.4137	Low: -61.5836	Low: -182.988	

Maps of Moho Topography, Magnetic and Isostatic Gravity Anomalies

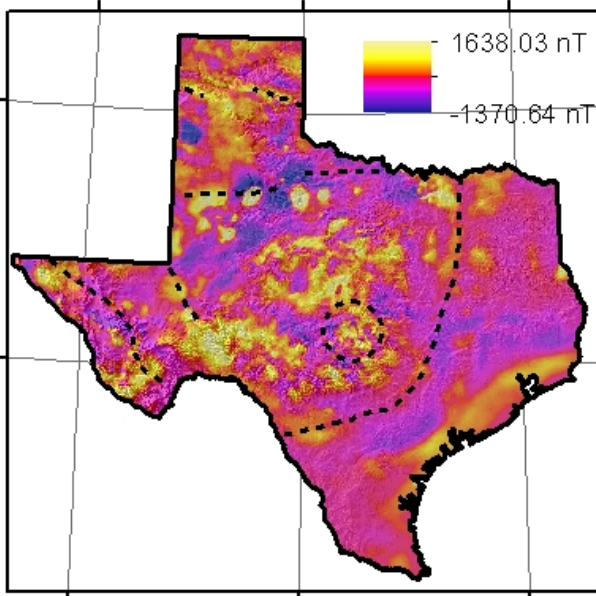
Moho with TIN



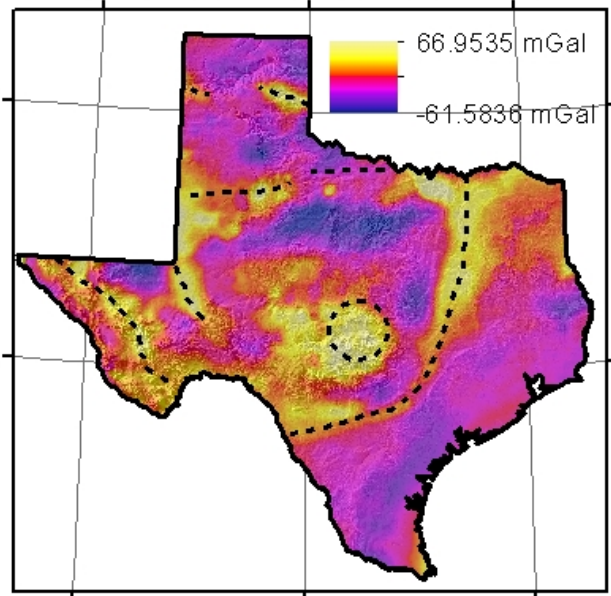
Moho with Spline



Magnetic Anomaly



Isostatic Gravity Anomaly



Projection: NAD 1983 UTM Zone 14N
Datum: NAD 1983
Map Scale: 1:13,000,000

Major tectonic features visible in one or more map are mapped by tracing with: - - - -
0 125 250 500 Kilometers

