USING LANDSAT 8 TO MAP THE GEOMORPHOLOGY AND STRUCTURAL GEOLOGY OF NORTHWESTERN VENEZUELA

Tyler Ricketts, Graduate Student
Lance D. Yarbrough, Assistant Professor
Department of Geology & Geological Engineering
University of Mississippi
Oxford, MS 38655
tericket@go.olemiss.edu
ldyarbro@olemiss.edu

Greg Easson, Director
Allison Innman, GIS Analyst
Mississippi Mineral Resource Institute
University of Mississippi
Oxford, MS 38655
geasson@olemiss.edu
asinnman@olemiss.edu

ABSTRACT

The goals of the investigation were to characterize the regional geomorphology and related structural controls of a tectonically active region in Northwestern Venezuela as part of a regional petroleum exploration study. The study area is approximately 427,000 hectares (1,640 mi^2) and covers portions of the northern extent of the Barinas Basin and the foothills of the Mérida Andes in Guarumen area. Large structural features influencing the study area include the Maracaibo block against the Guyana Shield of the South American Plate. The results of this oblique boundary give rise to the fold-and-thrust belt of the Mérida Andes and the general right-lateral shearing as evidence by the Boconó fault system. Several studies have addressed the more apparent geologic structures in this region however they have not investigated the alluvial plains associated with the fault zone. This is due primarily to the urban development and agriculture in an alluvium depositional area that mask the underlying lineaments. The main goal of this research is to make structural and geomorphological interpretations in these less visible areas using geospatial data available from the region, and imagery data collected from Landsat8, ASTER DEM, and hyperspectral images. However, due to covered geology by the alluvial plains, a new method has to be conducted to formally hypothesize this area of interest. The methods used include an automatic lineament extraction model that showed possible trends in the geologic structure. This will improve the use of remote sensing for geologic investigations with significant deposition characteristics while enhancing the understanding of these areas structurally for future field campaigns.

INTRODUCTION

In this project we characterize the regional geomorphology and related structural controls of a tectonically active region in northwestern Venezuela. The study area is approximately 427,000 hectares (1,640 mi^2) and extends across northern portions of the Barinas Basin and the foothills of the Mérida Andes. The Maracaibo block acts against the Guyana Shield of the South American Plate to create the dominate structural features found in the region. The results of this oblique boundary give rise to the fold-and-thrust belt of the Mérida Andes and the general right-lateral shearing as evidenced by the Boconó fault system. Within the study area, the Barinas Basin covers the entirety of the alluvial plain in its northern region. Several studies have addressed the more apparent geologic structures in this region, however we have undertaken a more detailed investigation of the alluvial plains associated with the fault zone. The basin has an asymmetric shape that deepens in elevation to the northwest from the Guyana Shield towards the SE border of the Venezuelan Andes while the basin is restricted to the north by the northwest trending El Baúl uplift (James, 2000). The Barinas foreland is missing a key regional gravimetric Bouguer anomaly along with a consistent flexural subsidence. This prevents any sort of underthrusting to happen within the lithosphere in the area (Colletta and Roure, 1997).

DATA ACQUISITION

After review of literature and knowledge of the land cover phenomenology of interest, data acquisition for this research project focused on Landsat 8, a digital elevation model (DEM) of the region, and SpecTIR hyperspectral data as the primary data used for the Guarumen area of interest. These data were accessed through EarthExplorer, GloVis, and supplied by SpecTIR respectively. The DEM data utilized in this project was created via stereo images from the NASA TERRA satellite using an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) sensor system which has nadir and backward-looking cameras that, when processed, yield a gridded DEM at approximately 20 meters vertical accuracy at 95% accuracy without the use of ground control points for individual scenes (Fujisada *et al.*, 2005). The Landsat 8 data was used due to its 30-meter spatial resolution with 9 different bands for multispectral analysis, while the ASTER DEM data was primarily used for creating a topographic survey of the study area's surface to help identify elevation change. The hyperspectral imagery provided a means for in-depth analysis of the study area due to the significantly greater spectral resolution and the 3-meter spatial resolution. The ERDAS Imagine software toolkit has specific hyperspectral analytical functions that are optimized for these data, and it was possible to use its functions to highlight features within the data both spatially and spectrally.

DATA PROCESSING AND ANALYSIS

The goal for the processing phase of this research was to identify geomorphological features within the image data that have a high correlation with the structural geology of the area. Multiple image processing techniques were used to achieve this goal, including: Histogram equalization, Normalized Difference Vegetation Index (NDVI), Principal Component Analysis (PCA), unsupervised classification, Sobel filtering, hydro flow mapping, painted relief DEM mapping, and lineament extraction. Each of these techniques highlighted different geomorphological features within the research area, and will be described in greater detail later.

SpecTIR Corporation provided baseline data of the research area in the form of ArcGIS files and tables which contained valuable information to help conduct the analysis. These data contained general geomorphology, hydrology, vegetation, and structural geology information, as well as others. The combination of image data and baseline data helped address questions concerning specific trends within the regional geology that supported a greater understanding of the structure and geomorphology within the study area, a better understanding of the agricultural land use within the alluvial plain, and how the elevation plays an important role as an expression of the overall geology.

The processing techniques performed on the remote sensing data were used to enhance different features spatially and spectrally to identify key features that would enhance the geologic interpretation. Each processing technique highlights different aspects of the image data that would not be apparent through visual inspection of the images in their native form. Using multiple processing techniques during this research made it possible to identify specific features that contributed to a better overall understanding of the data. The following are the processing techniques used to emphasize selected features within the imagery.

Histogram equalization was conducted on the ASTER DEM to create a contrasted enhancement of the topography of the study area. The area of interest lies within the Barinas basin with the Andes mountains located to the West. There was a large elevation change within the DEM data, causing the alluvial plain of the basin to look as if it were void. When applying the histogram equalization technique, pixel values in the lower range of the DEM became apparent and subtle differences were observed. However, an optimized rendering of these data for comparison with other data was achieved using a shaded relief cartographic technique. This produced a sun-angle shaded representation of the DEM data which could be manipulated in concert with a variety of other data for visual as well as statistical analysis. The resulting shaded relief map using the DEM is Figure 1. The shaded relief map allowed geomorphic changes in the environment to become more apparent based on elevation of the study area. When using this DEM with hydrology shapefiles overlain on the imagery, it was possible to trace out valleys and identify them as either mountain valleys, river valleys, or foothill valleys based on the elevation of the area of interest. To make this cartographic exercise more accurate when mapping the geomorphology, the DEM was imported into ArcGIS. With the help of the Arc Hydro toolbox, it was possible to calculate flow direction from the DEM by creating a hydroflow direction shapefile. This gave a more accurate representation of where to draw the geomorphic boundaries for the specific valleys. The geomorphology is shown in Figure 2.

Normalized Difference Vegetation Index (NDVI) was used to differentiate vegetation health within the study area and to identify geological structure based on vegetation trends. Due to a large amount of agricultural land use in the study area, it was difficult to make any correlation between the vegetation and the geologic structure within the alluvial plain, which had a diverse and complex agricultural land use pattern. However, the NDVI product aided in geologic interpretation outside of the agricultural areas. It improved the identification of different geologic types based on the biophysical parameters described via the NDVI of the vegetation in the area. This vegetation-aided interpretation was only effective in the western and northwestern regions where no agriculture was present. The NDVI would be beneficial with future field campaigns because it is now possible to identify different types of geologic units with different types of soils and vegetation. For example, the Cerro Pelón ultramafics give different NDVI values than the Mamey, Yacambú, and Volcancito Formations in the northern Andes region. Utilizing NDVI when conducting structural and geomorphological mapping within the region can aid in producing a more accurate interpretation of the area.

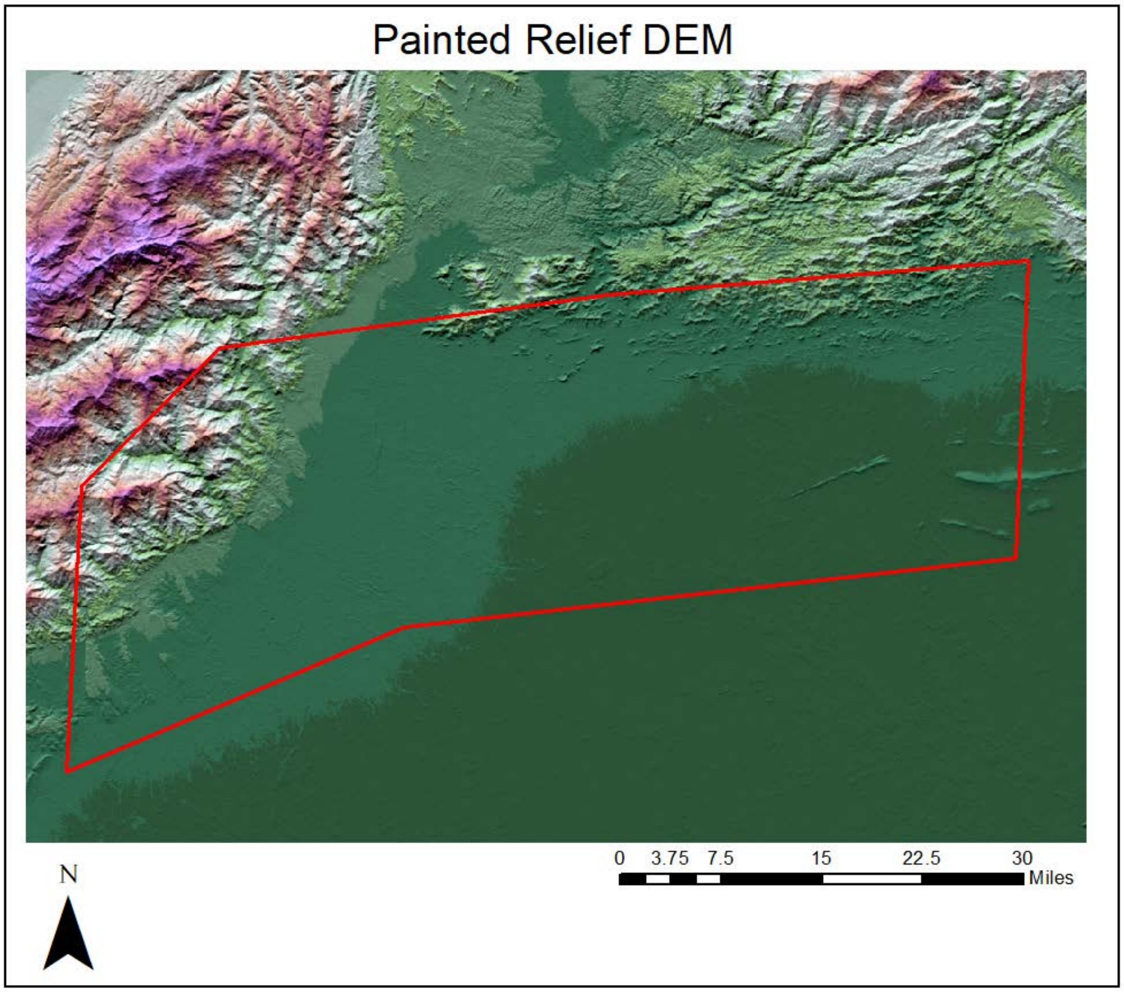

Figure 1. Painted Relief DEM produced by generating a sun-angle shaded representation of the DEM data, which visually emphasized elevation change throughout the study area (indicated by the red boundary). The Elevation of DEM ranges from -26 feet to 6544 feet based on dark green being the lowest in elevation, and violet being highest in elevation.

Within the study area there is an exceptionally large alluvial plain, as previously mentioned, that covers most of the study area, Figures 2 and 3. Mountainous features surround this plain with the Andes Mountains to the west and a smaller range of hills and mountains to the north. The structural features of these ranges are predominantly trending in a NE-SW orientation with less than half of the faults structurally trending in a NW-SE orientation of the study area. Most of the NE-SW orientated faults are thrust faults that are thrusting upward to the NW direction due to horizontal compressional stresses. Thrust faulting commonly results in older geology physically above the younger geology. This is important for future field campaigns to take this into consideration when conducting a field analysis.

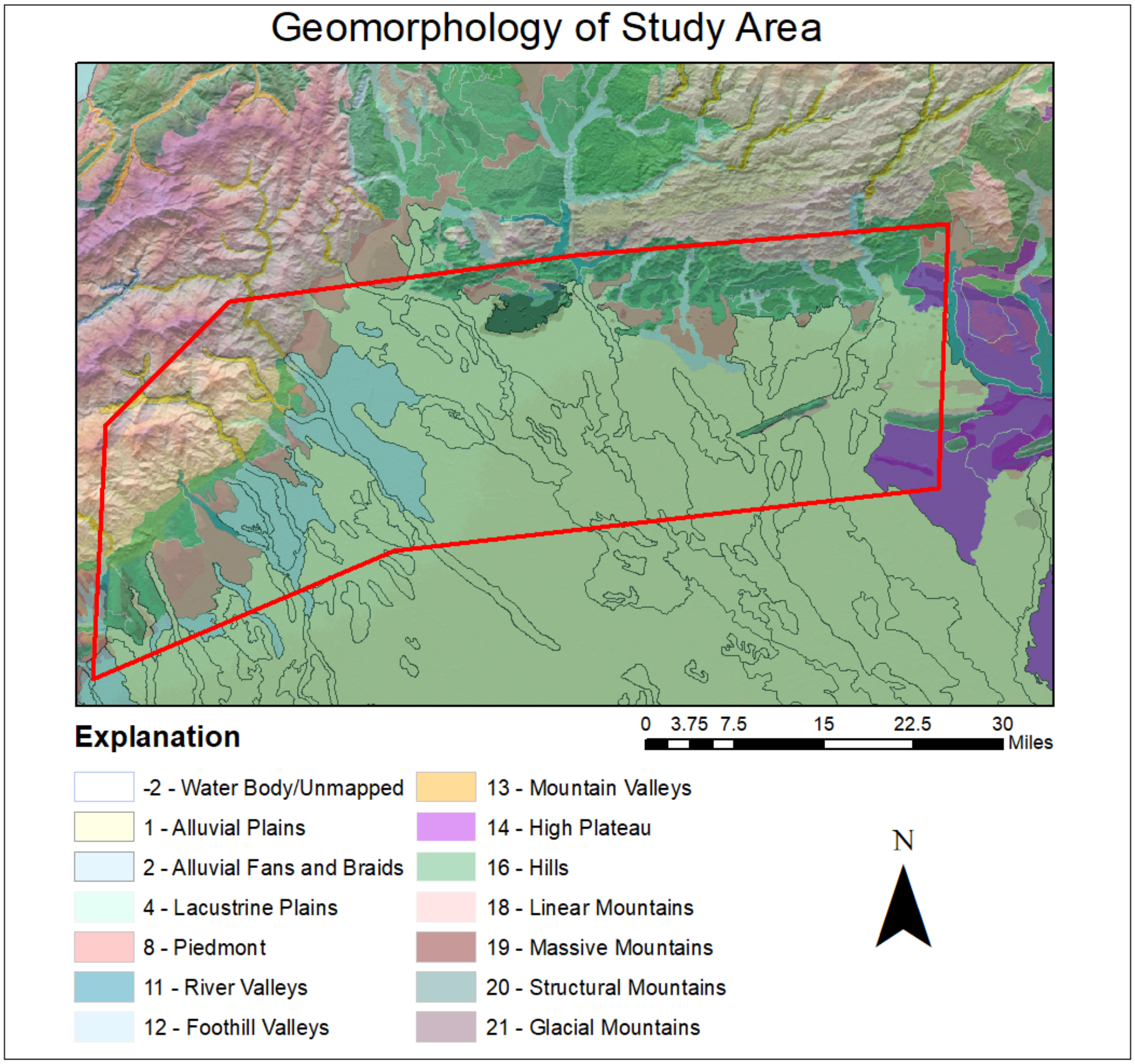

Figure 2. Geomorphologic map draped over the painted relief DEM image representing the key features of the study area with an elevated view of the geomorphology.

The urban development and large amount of agriculture within the alluvial plain made identification of lineaments that would be suggestive of underlying geologic structure difficult. Lineaments can reveal regional tectonic trends, faulting patterns, major relief, structural displacement, and fracture zones in areas that are highly covered by soil (Thannoun, 2013). Therefore, an image-based lineament extraction method was conducted to locate these lineaments within the imagery. A mosaicked image of two Landsat 8 scenes was imported into the Geomatica PCI image processing toolkit. The Lineament Extraction tool within PCI was used to calculate an accurate lineament map for the mosaicked study area. Once the extraction was accomplished, the file was saved and then input into the ERDAS toolkit so it could be overlain by multiple image products that were developed previously to identify correlations.

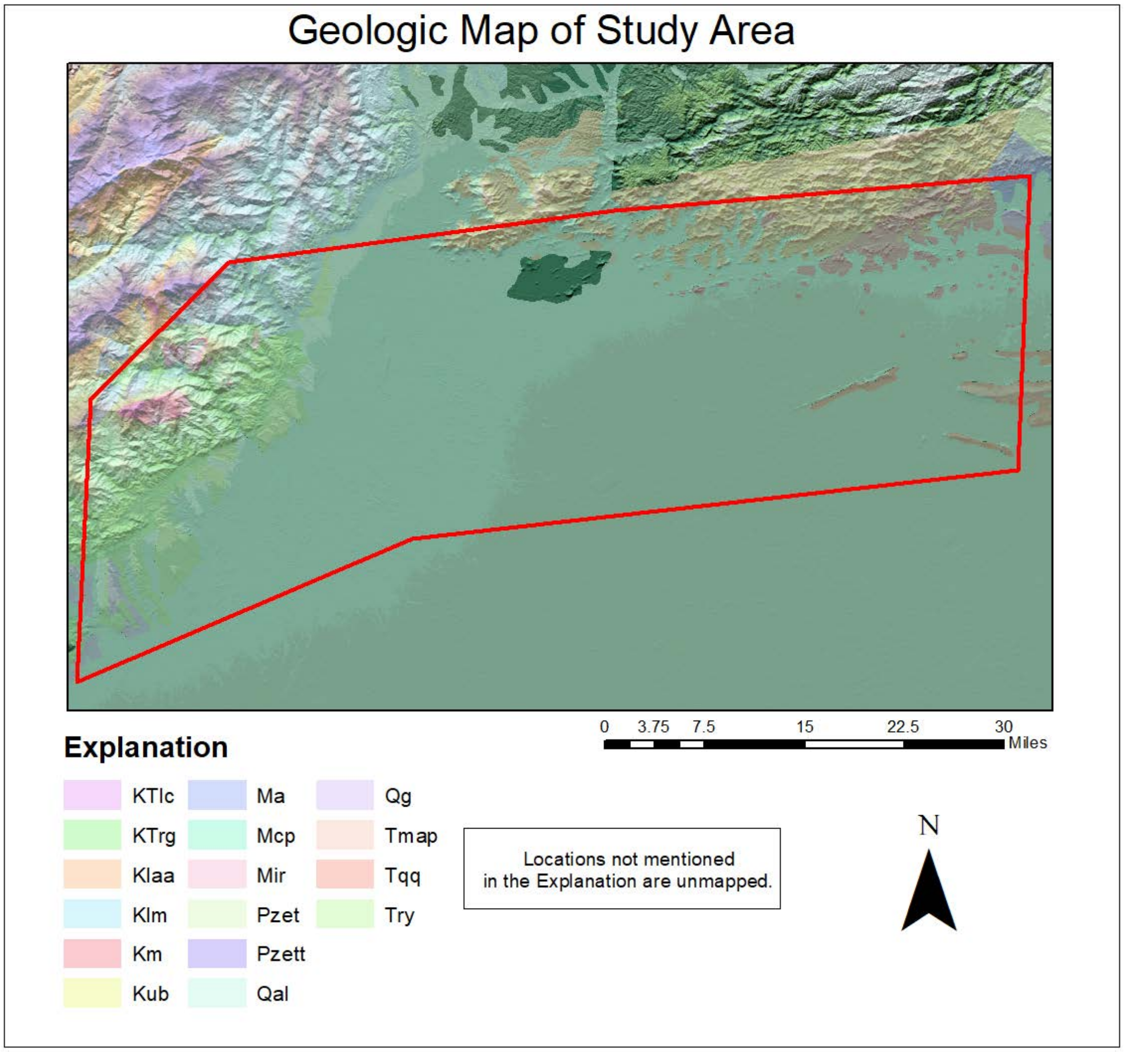

Figure 3. Geologic map of the study area draped over the painted relief DEM image to create an elevated view of the geology.

From the lineament analysis of the imagery, artifacts that were a result of rivers, roads and other man-made features were removed. Because a majority of the study area contains channelized waterways used in agricultural irrigation and roads, the lineament analysis understandably identified these features as lineaments. Using the imagery from the analysis, lineaments were visually inspected and removed if the lineament was indeed the result of a man-made feature captured in the imagery. This removal process was not a strict threshold and left many questionable lineaments in the candidate database. Future work could compare sensitivity of lineament search radius and those observed in the imagery.

Review of the imagery with the overlying lineament extraction shapefile clearly shows major lineaments of the visible structural features, as well as patterns within the alluvial plains that indicate structure (Figure 4). There are image features within the alluvial plain that are trending both in the NE-SW and the NW-SE directions that follow the orthogonal orientations of the visible faults. These features also marginally line up with certain visible faults in the study area, but there is not enough evidence to prove this in certainty. Figure 5 illustrates the results of lineament analysis in a rose diagram. Field work should be conducted in these specific areas, as seen in Figure 6, to determine if the pattern suggested by the image is accurate and represent structure within the alluvial plain.

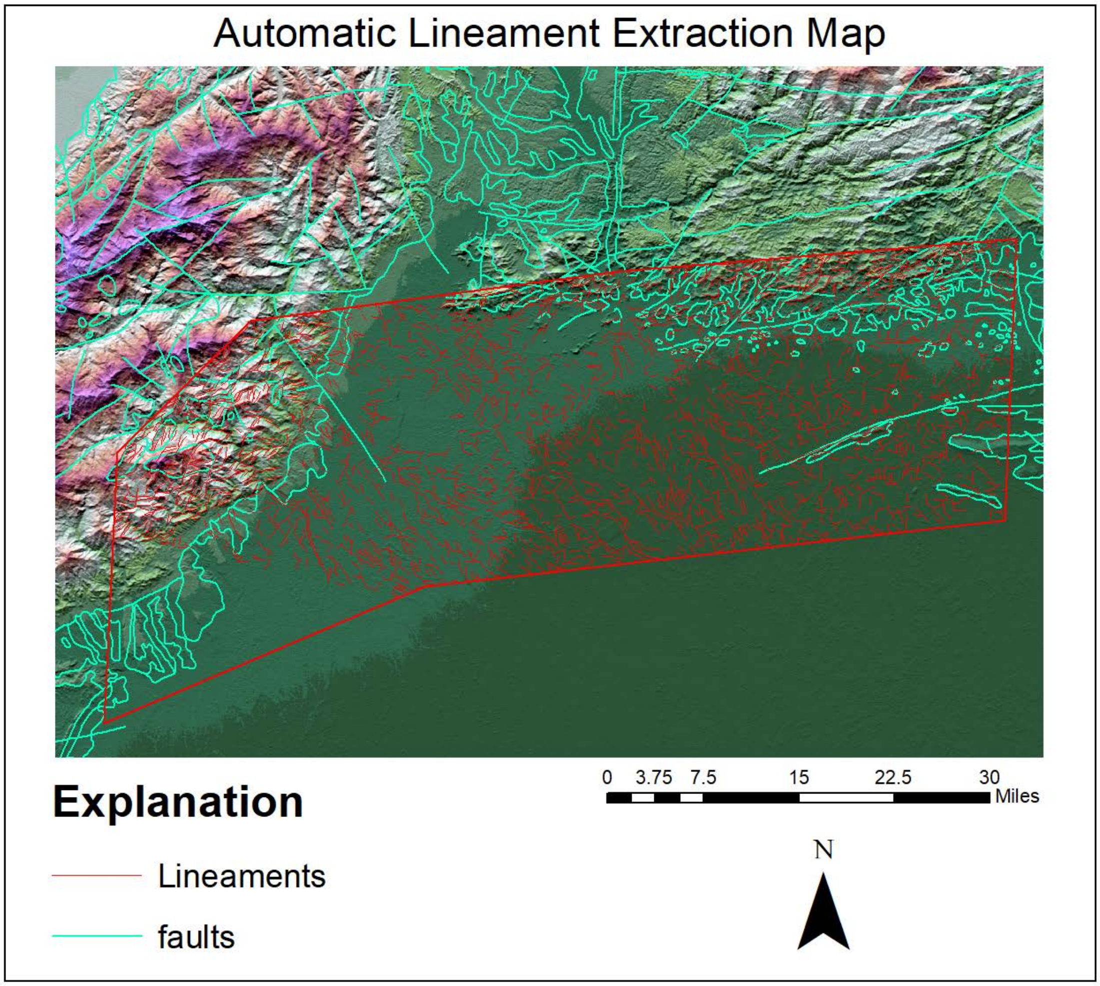

Figure 4. The automatic lineament extraction method was conducted with Geomatica PCI. As seen in the lower left-hand corner of the study area, a lineament extraction process could not be fulfilled due to the software's problems with extracting lineaments from a mosaicked image.

In addition to the PCI tool, a Sobel convolution filter was used to determine if additional lineaments could be defined from the spectral data within the image. This process involved the use of both 3x3 and 5x5 convolution filters to identify linear features within the Landsat image. Normally this would be conducted on an ASTER DEM image because it has better spatial resolution across more spectral channels, but due to the large gradient for elevation change, the DEM created a large void space in the alluvial plain. This made the use of Landsat 8 more beneficial due to the visibility of the imagery. This process resulted in the definition of linear features with similar orientation and location to the PCI linear extraction but also included linear features that reflected land use patterns.

Due to the political climate of the country of Venezuela, the field campaign has been postponed. This was mutually decided by SpecTIR and MMRI due to the safety of its consultants that would be conducting the field campaign. With this circumstance, extra measures were taken to ensure that data and analysis could be provided. Future field work locations have been compiled and a proposed thrust fault buffer going through the alluvial plain which could be of use with hydrocarbon exploration.

By using provided data and data products, sites are being recommended for follow-up which could help supplement future field campaigns.

FINDINGS

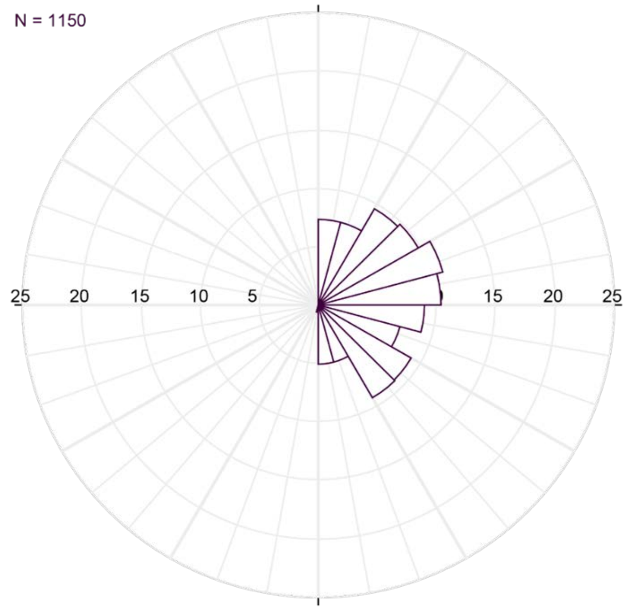

Figure 5. Rose diagram of lineament trends from Geomatica PCI analysis method. Outer ring represents 25% of total population of identified lineaments. Only one-half of the plot is shown for clarity. The data was normalized to east side.

With a large portion of the study area being alluvial and highly agricultural, it is believed that the complex and highly altered land cover on this area has hidden crucial geological and structural features that could be of great interest for exploration. A review of the preliminary structural data indicates a thrust fault that orientates in the NE to SW directions in two locations. One of these faults is located at 9˚ 12' 2.29" N, 69˚ 32' 20.330" W, and the other running through the 9° 31' 24.68" N, 68° 43' 23.29" W (as shown in Figure 6) with the anomaly overall running SW to NE. It is proposed that these two thrust faults are part of a larger single fault that is partially hidden beneath the alluvial plain. By use of a simple spatial model, a buffer zone was created to represent the most likely location of the hidden portion of the larger thrust fault. This approach to thrust fault mapping is supported by Colletta *et al*., (1997) where the authors compose a map with a similar inferred thrust fault through their study area. Along with the buffer that was composed, suggested field locations have been added to the map that should be investigated during future field work. Since it is difficult to visibly see the geology within the majority of the alluvial plain in the image data, it is believed that field investigation of the river and stream cuts will offer better results.

SUMMARY

Numerous image processing techniques were used to improve the characterization of geomorphological features and provide insight into the underlying geologic structure of the region and more specifically the study area. Utilizing medium resolution satellite imagery, processing methods such as NDVI, Principal Component Analysis (PCA), Sobel filtering, Hydro Flow mapping, and lineament extraction were preformed, and results analyzed. Each of these techniques highlighted different geomorphological features (both verified and potential) within the study area and region. These features were used to augment the current structural dataset. These datasets are deliverables with this report. In addition to the results of the image processing, we have documented the techniques to help benefit processing efficiency of a future field campaign.

ACKNOWLEDGEMENTS

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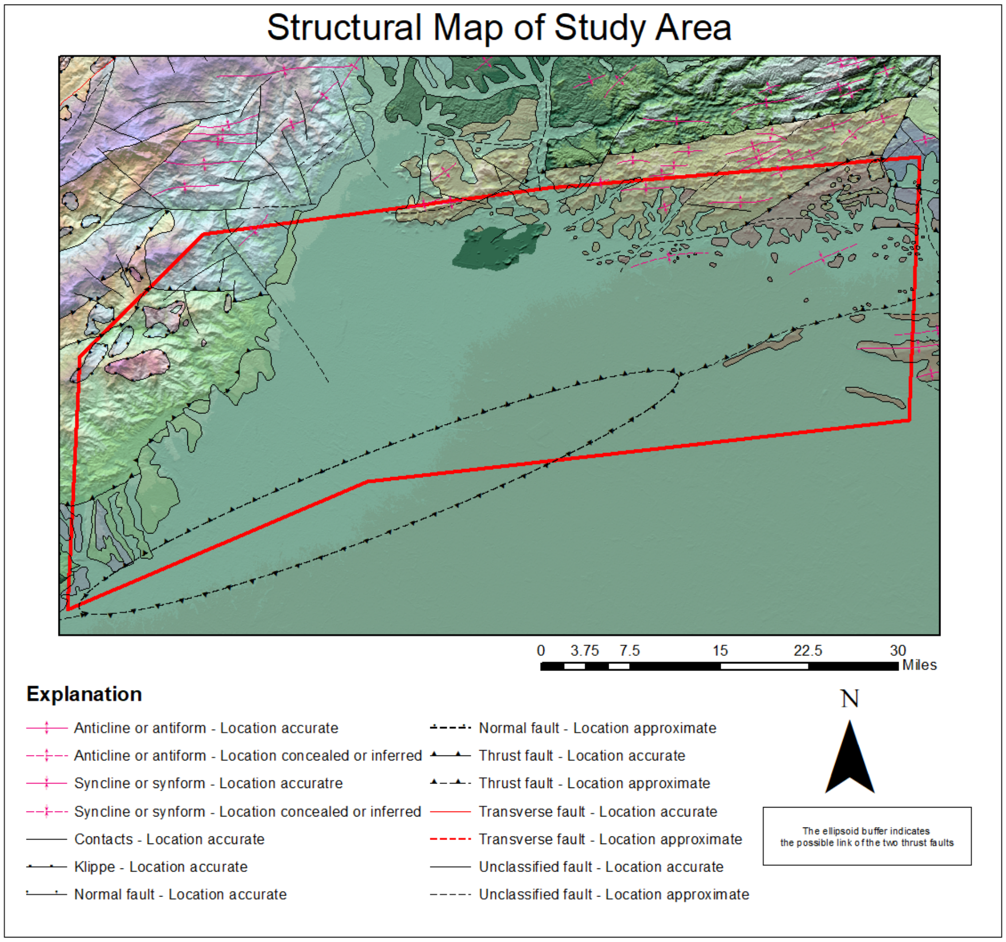

Figure 6. Structural map of the study area representing the different types of faults, folds, and buffer of the proposed location of the possible link between the two thrust faults.

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