Landsat TM processing in the investigation of active fault zones, South Lajas Valley Fault Zone and Cerro Goden Fault Zone as an example

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ABSTRACT – Landsat Thematic Mapper (TM) images of western Puerto Rico were used, supplemented by seismic and geophysical data, to delineate the lateral extent of two fault zones, the South Lajas Valley Fault Zone (SLVFZ) and the Cerro Goden Fault Zone (CGFZ). Application of different bands to the imagery data has been used as the basis for determining geomorphic structures in order to determine the geometry and surface patterns across the fault zones. Color variations in the Quaternary sediments reflect roughly east-west trending scarps crossing alluvial fans on the southern edge of the Lajas Valley and the middle of the Añasco Valley near the Río Grande de Añasco. We inferred that the South Lajas Valley Fault Zone extends 10 km east of Boquerón Bay. Furthermore, we also inferred that Holocene faulting mapped and trenched by Prentice (2000) trends SSW-NNE for about 5 kms. Meanwhile, preliminary results indicate that the CGFZ near the Añasco Valley is approximately 19 km long. Other short segments were inferred within the Valley, but the location still unknown at this time.

Keywords. - Lajas Valley, Añasco Valley, Cerro Goden, Landsat TM, fault zones

INTRODUCTION

New mapping and trenching studies (Prentice et al, 2000; Prentice et al, 2003; Prentice et al, 2004) has demonstrated that repeat Holocene surface rupture has occurred on a previously unrecognized east-west trending fault crossing an alluvial fan on the southern side of the Lajas Valley, SW, Puerto Rico. Meanwhile, existing multichannel seismic profiles offshore western Puerto Rico (PR), collected by Western Geophysical in 1972, show numerous east-west trending normal and strike slip faults offsetting Oligocene-Pliocene age carbonates and the underlying Cretaceous basement. Preliminary analyses of these data identify zones of active deformation within the survey area: 1) extensions of the Cerro Goden and Algarobo faults zones which lie offshore the Río Grande de Añasco and Mayagüez Bay of western Puerto Rico (Del Greco et al., 2000); and 2) a half-graben structure in Boquerón Bay and east-west trending lineaments offshore Cabo Rojo of southwestern PR that may be part of a system of faults that extend onshore to the tectonically controlled Lajas Valley (Prentice et al., 2000).

The Lajas Valley is an E – W trending, 30 km long, 1.5-9.0 km wide, linear depression bounded by abrupt mountains fronts on its northern and southern edges and characterized by closed drainage depressions of the former Laguna Cartagena, Laguna de Guánica, and Ciénaga El Anegado (Figure 1).

Cerro Goden Fault Zone coincides with an abrupt, linear mountains front separating the 270 to 361 m high La Cadena de San Francisco from the alluvium floored

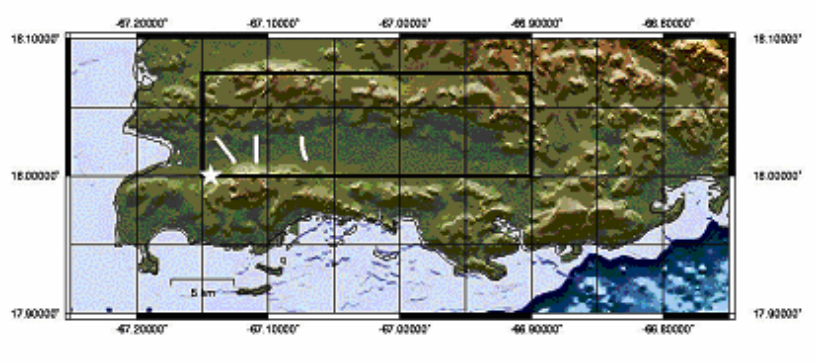

Figure 1: Study Area of the Lajas Valley, SW, Puerto Rico (thick black rectangle).

Añasco Valley. Previous workers have postulated that the Cerro Goden fault continues to the southeast of the Añasco Valley and merges with the Great Southern Fault Zone of south-central PR (Figure 2).

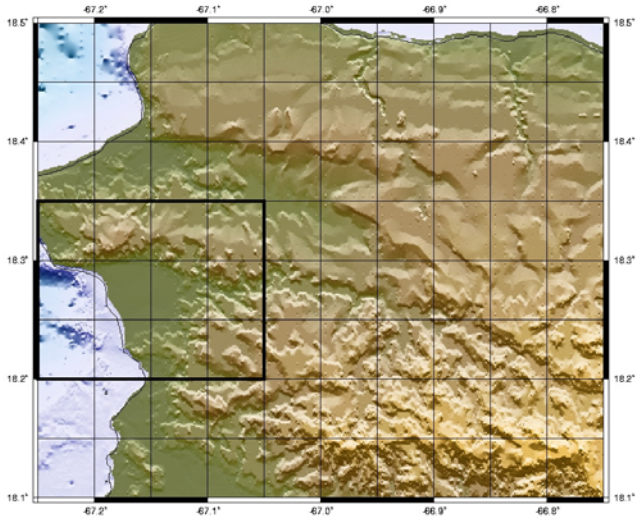

Figure 2: Study area of the Añasco Valley, western Puerto Rico (thick black rectangle).

The former study use, as a tool, the satellite remote sensing in order to corroborate, delineate, and demonstrate the existence of lineaments that can be associated to active fault zones in western PR. The term "lineaments" is the name given by geologists to lines or edges, of presumed geologic origin, visible on remotely sensed images. Applied correctly, it may lead to identify and understand better the patterns that dominate in both fault zones.

MATERIALS AND METHODS

Study Site

The island of Puerto Rico sits within the plate boundary zone between the North American and Caribbean lithospheric plates (Figure 3) where subduction beneath the Antilles Arc gives way to left lateral strike-slip (Meltzer and Almy, 2000). Active oblique slip faults accommodating deformation on the island are difficult to map due to the lack of good surface exposures. The distribution of small earthquakes recorded by the Puerto Rico Seismic Network (PRSN), suggest that deformation is occurring along the south Lajas Valley Fault toward the Boquerón Bay and the CGFZ (Figure 4).

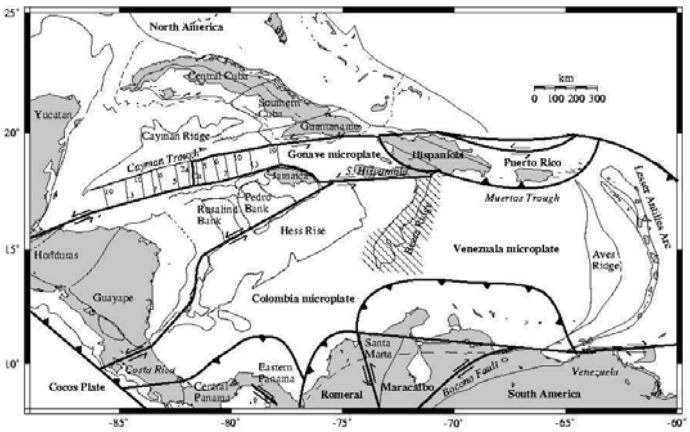

Figure 3: Tectonic map of the Caribbean.

Both fault zones (SLVFZ and CGFZ) coincide in regions where Quaternary sediments were deposited above a Cretaceous basement.

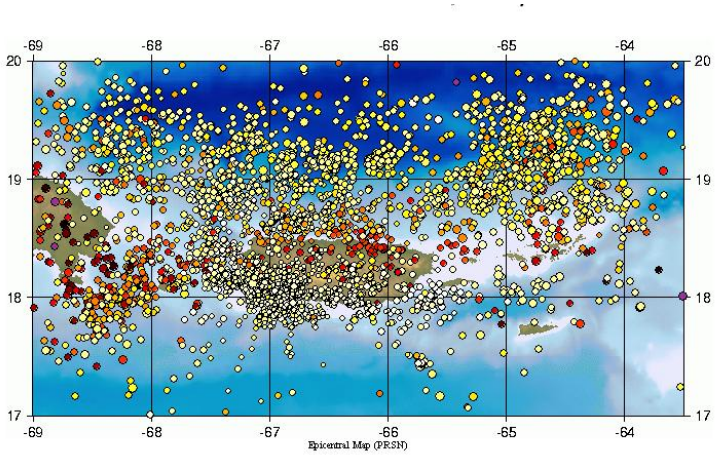

Figure 4: Standard PRSN locations for events in PR region 1999-2003.

Objectives

The present study proposed the use of Landsat Thematic Mapper images of western PR to analyzed active faults using the Environment for Visualizing Images (ENVI) software, and involved 3 different tasks:

- **TASK #1:** A preliminary search of a Landsat TM image of western Puerto Rico. The image will be taken at the Research and Development Center, located in the UPRM.
- **TASK #2:** Processing of the TM image using the ENVI software.
- **TASK #3:** Theoretical estimation of the lateral extension across- the Lajas Valley Fault and Cerro Goden Fault, using supervised and unsupervised classifications.

Specific goals of the study were to:

- Determine the location and the lateral extent of Lajas Valley Fault.
- Correlates the remote signature as reflectance of those lineaments with the known faulted structures.

Summary of Approach

Our principal satellite imagery consisted of two Landsat TM images: a full scene of western Puerto Rico showing the Añasco Valley (Figure 5) and a southwest scene showing the Lajas Valley (Figure 6), due to the availability of a large spectrum of bands.

Figure 5: Landsat TM image of west PR.

Figure 6: Landsat TM image of southwest PR.

Remote sensing data were essentially used for the location of the fractures occurring in the area. As the greatest portion of the area is flat to gentle rolling with a few clear morphological expressions of fracturing, fracture zones may be observed indirectly through increased soil moisture along them, or evidence of fault scarps (lineaments).

Multispectral analyses of lineaments on the TM images were performed visually

using the software called ENVI version 4.0. Linear fractures that are clearly of structural origin are significant because they indicate zones of fracturing and faulting. True color images (band1 (blue), band 2 (green), band 3 (red) were generated for both images, to analyze the area prior to generate false color images. In other hand, false color images were generated using bands 7, 4, 1 and bands 6, 5, 4. With the application of these bands (false color), lineaments on both fault zones were easy to observe.

RESULTS & DISCUSSION

False color images of the bands 6-5-4 and 7-4-1 (R,G,B), provide us the capability to clearly distinguish geomorphic structures associated to fault scarps and/or lineaments for both fault zones. Examination of geomorphic features in the SLVFZ image demonstrates the existence of truncated spurs, and an anomalous drainage pattern (Figure 7 & 8).

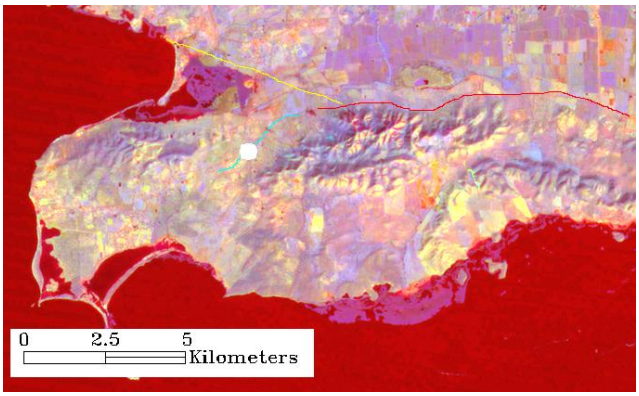

Figure 7: False color (bands 6, 5, 4) Landsat TM image of southwest PR. Showing ROI, SLVFZ (red line), trench (white point), lineament (yellow line).

Base on magnetic data collected offshore western PR, suggests that exists a fault toward north Boquerón Bay (Ocasio, 2004). Viewing both false color images, a short segment (yellow line) can be appreciated. Our interpretation suggests a possible relation between the SLVFZ

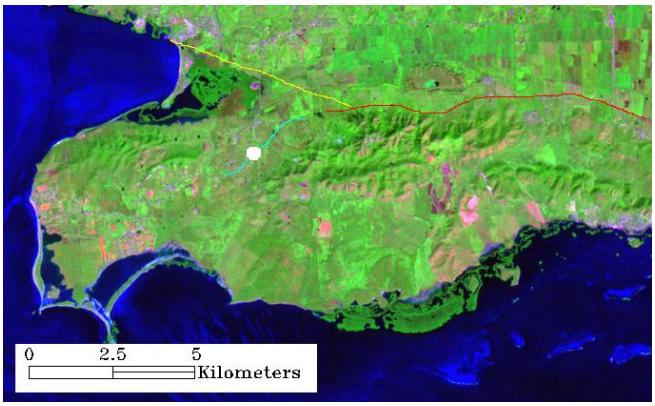

Figure 8: False color (bands 7, 4, 1) Landsat TM image of southwest PR. Showing ROI, SLVFZ (red line), trench (white point), lineament (yellow line).

and the fault founded offshore Boquerón Bay. Talking about Holocene faulting at the SLVFZ, we appreciate a lineament exactly were the trench excavated by Prentice (2003) was made it (white point figures 7 & 8).

The Lajas Valley is a seismically active west-northwest trending basin (Figure 4), and the reconnaissance of these lineaments appreciated on the TM images confirms the possible location and lateral extent (Table 1).

Table 1: Comparison on location and lateral extent of different lineaments at the SLVFZ.

STRUCTURE	LOCATION	LAT. EXTENT
SLVFZ	east-northwest	10.53 km
Carol's Fault	wsw-ene	4.3 km
Unknown Fault	wnw-ese	6.69 km
trench	-67° 8' 37.99'' W 18° 0' 2.49'' N	------

Observations of linear offsets in seafloor features and a unsedimented submarine ridge immediately south of the

mountains of La Cadena de San Francisco are consistent with recent activity along the CGFZ (Del Greco et. al, 2000). Meanwhile, do to the lack of geophysical data, the recognition of lineaments on the Añasco Valley was not very accurate.

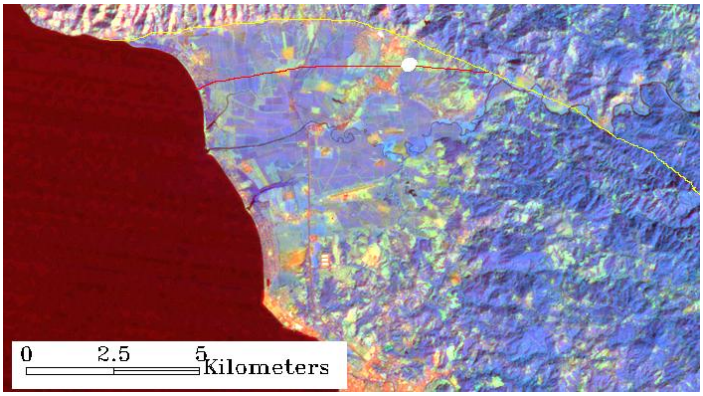

Figure 9: False color (bands 6, 5, 4) Landsat TM image of southwest PR. Showing ROI, PRGSFZ (yellow line), trench (white point), Añasco Valley "fault" (red line).

Both TM images (6, 5, 4 & 7, 4, 1) show very easy the PRGSFZ (yellow line, figures 9 & 10), but the geomorphic expression of the Añasco Valley fault is not easy to observe do to the high population density, vegetation cover and sediment deposition. The area offshore Añasco Valley was targeted as a likely location to image recent faults because of the evidence of faults identified by multichannel seismic data collected by Western Geophysical in 1972 and the presence of a relatively thick covering of recent deltaic sediments deposited by the Río Grande de Añasco.

As was mention before, geophysical data inland Añasco Valley is not abundant, but with the implement of the ENVI software, the location and lateral extent of Añasco Valley fault was estimated (Table 2).

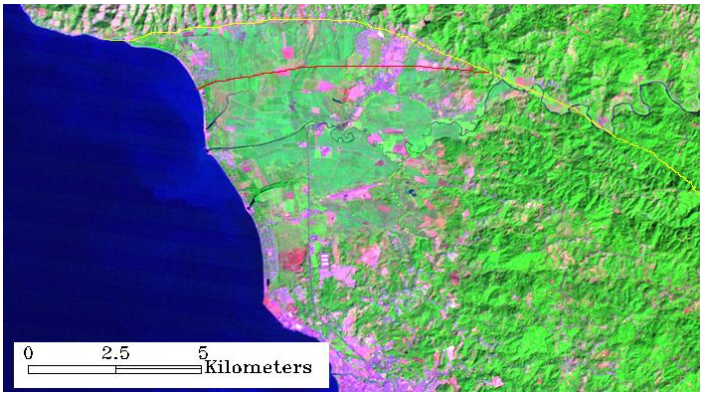

Figure 9: False color (bands 7, 4, 1) Landsat TM image of southwest PR. Showing ROI, PRGSFZ (yellow line), trench (white point), Añasco Valley "fault" (red line).

Table 2: Comparison on location and lateral extent of different lineaments at the CGFZ.

STRUCTURE	LOCATION	LAT. EXTENT
PRGSFZ	wnw-ese	18.92 km
Añasco Valley fault	east-west	8.92 km
trench	-67° 7' 37.07'' W 18° 16' 36.00'' N	------

Field observations suggest that this region is seismically active too, averaging one event per day, and there are 40 documented historical events in the last 500 years (Del Greco et al., 2000). These interpretations are very useful at the moment when events can be correlated to geomorphic structures such as faults and/or lineaments.

CONCLUSIONS

Do to the differences in spectral reflectance using combinations of various bands resulting from the effects of vegetation, land cover and other patterns; the application of remote sensing TM imagery, to geophysical studies was very useful. Evidence of lineaments on the SLVFZ images confirms to us the existence of deformation in the region. Also, the

correlation of the maximum horizontal gradient method (edge detector scheme) to the region, demonstrate that fault blocks are correlated in the same location as the ENVI software determined (Figure 10).

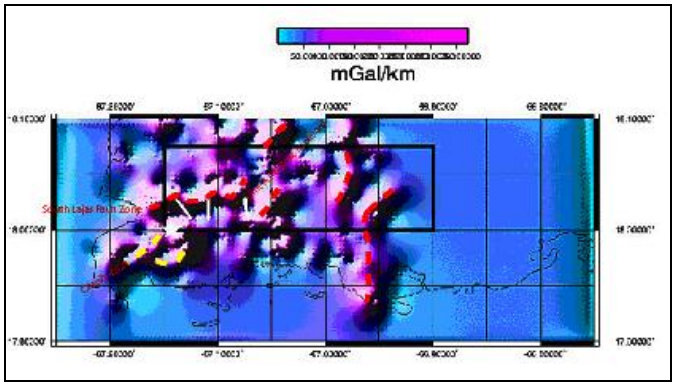

Figure 10: Maximum Horizontal Gradient of the residual gravity signature of SW Puerto Rico.

Our study suggests that the SLVFZ is approximately 10 km long. Other short segments of faulted blocks are also inferred within the Lajas Valley, but their relationship to the main fault is uncertain at this time. We also infer that Holocene faulting mapped and trenched by Prentice, (2000) ("Carol's-fault") is approximately 5 km long, generally trending WSW-ENE.

We need more field data on the CGFZ for better approximations. Geophysical work in the region is not sufficient, and interpretations using remote sensing imagery can be erroneous. Meanwhile, preliminary results indicate that the CGFZ near the Añasco Valley is approximately 19 km long. And other short segments are inferred within the Añasco Valley. But, the location is uncertain at this time.

FUTURE WORK RECOMMENDATIONS

We recommend the implementation of Normalized Difference Vegetation Index to both fault zones (NDVI). Do to the geometry of faults scarps and lineaments, vegetation grew up in the same direction of the fault planes. Differences in vegetation can be observed, if the conditions are appropriated.

More geophysical studies, such as gravity data, magnetic anomaly, and seismic reflection are required to both regions. And finally, we recommend the use of another remote sensor. Ikonos imagery can be appropriated, because it has more spatial resolution than the TM.

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