3-D IMAGING OF THE SOLITARIO, TEXAS

Christian Curtis
Pomona College
Claremont, CA 91711

Amy Fisher
Colorado College
Colorado Springs, CO 80904

Introduction

The purpose of this project was to produce a 3-D image which would give a view of the geomorphology of the Solitario laccolith in the Trans-Pecos region of Texas. Traditionally, maps have shown 3-D features on a 2-D surface. Image processing can accent the 3-D features of an area allowing an observer to see a clearer and more realistic view of geologic features. We used a variety of processing techniques, including Principal Components analysis, Dark Pixel Enhancement, and Band Normalizing to create a processed 2-D color image from Landsat Thematic Mapper data. Combining this new processed image with a Digital Elevation Model from the USGS produced the final 3-D image.

Geologic Setting

Solitario stands today as unique laccolith above a carbonate plain just west of Big Bend National Park. The Ouachita Orogeny in the mid-Pennsylvanian created folds in the Cambrian and Ordovician limestones. During this orogeny the region experienced an estimated 24 km of crustal shortening. These oldest layers are exposed in the top half of the circular laccolith structure. The folds were eroded down and thick layers of limestone were deposited during the Cretaceous. The Cretaceous Glen Rose formation, as seen today, encircles the older folded beds in the center of Solitario. The Santa Elena limestone forms the foot-like fan area surrounding the circular laccolith structure and stretches to the south. During the Laramide orogeny the Cretaceous and Paleozoic limestones were uplifted as the laccolith came near the surface. After the laccolith cooled, the layers above it were eroded revealing Solitario as we know it today. The modern arid climate leaves the geology highly visible and makes it an excellent candidate for remote sensing work (see the geologic map and stratigraphic column in figure 1).

Methods

The first step in creating the 3-D geological image was to create a 2-D image using NASA's Landsat 5 data obtained through EOSAT. Landsat satellites have a Thematic Mapper (TM) device which records electromagnetic radiation reflected from the earth's surface as a series of digital numbers (DN). Image processors display each DN as a pixel which represents the average amount of radiation coming from a 30m by 30m area on the surface of the earth. The processed display uses a grayscale format which shows any of 256 grays (from 0 = black to 255 = white) for each 30mx30m pixel (see figure 2). Landsat images come in 7 TM bands or channels each covering a segment of the spectrum from visible light (wavelengths 0.42-0.69μm; TM bands 1,2, and 3), to the near infrared (0.76-0.90μm; TM band 4) through the mid-infrared (1.55-1.75μm and 2.08-2.35μm; TM bands 5, 7) to the far infrared (10.4-12.5μm; TM band 6). Overlaying images from different bands and assigning each band a different color produces a color image of an area. Plate 6 shows a color composite image of the Solatario, with band 7 assigned to red, band 5 assigned to green and band 1 assigned to blue. Commonly, TM band 6 isn't used for geological purposes as it is designed mostly to measure surface temperatures and gives comparatively poor resolution. The Landsat data used in this project covers an area approximately $24km^2$, or 800x799 pixels from each band, showing the Solitario and the surrounding area.

The processing of the images began with a Principal Component (PC) analysis (see figure 3). An image processing program such as MultiSpec runs a statistical analysis of the 6 bands. The respective pixels in the bands showing the most variance are weighted to produce a new image. PC band 1 accents topography and the other PC bands emphasize differences in rock types or vegetation. Combining PC bands with other PC bands or TM bands and brings out geologic features for easier study.

Our 3-D image uses PC band 2 and normalized TM bands 5 and 7. Normalizing bands begins with a dark pixel enhancement (see figure 4). Though most of the image shows radiation reflected off the earth's surface, some of the data seen in the image are from scattered radiation in the atmosphere. Dark pixel enhancement assumes that the darkest pixel in the image contains only light scattered by the atmosphere. Subtracting the DN value of the darkest pixel from the rest of the image is a simple way to remove some of

Figure 1: Geologic map of
The Solitario

Stratigraphic Column:

Tertiary
Ti Tertiary intrusive felsics
Tivb Tertiary extrusive
Tf *Fresno Formation*-Undifferentiated tuff, ash-flow tuff (nonwelded) trachyandesite, latite prophyry, and rhyolite breccia, with some associated sandstone and conglomerate. About 100 ft.
Tc *Chisos Formation*-Undifferentiated tuffs and basalt with associated sandstone, conglomerate, mudstone, and non marine limestone. 150-250 ft.

Cretaceous
Kbo *Boquillas Formation*-Flaggy, sandy, light brown limestone with wavy bedding. About 60 ft.
Kbd *Buda Limestone and Del Rio Clay undivided*-Bluish white, thick bedded limestone with marly partings. *Del Rio*- Black to green marl and shale with ubiquitous pyrite and gypsum. Weathers gray. Total 68 ft.+
Ks-t *Undifferentiated limestone* -including these formations: *Santa Elena*- massive limestone with abundant bedded chert. *Sue Peaks*-Marly limestone and platy-nodular biomicrite. *Del Carmen*-Resistant, massive gray limestone. *Telephone Canyon*-fossiliferous gray limestone and gray marly limestone. 534 ft.+
Kgr *Glen Rose Formation*-Alternating beds of massive limestone and more thickly bedded, marly limestone. Generally fossiliferous, with common coquinoid limestone and coquina beds. 353 ft.

Lower Pennsylvanian
Pt *Tesnues Formation*- Thick alternating beds of dark green siliceous shale and massive brown siltstone and very fine sandstone. Characteristically dark green and weathers brown. 1,410ft.+

Mississippian
MDc *Caballos Novaculite* - White banded chert and novaculite with some dark chert. 84 ft.

Ordovician
Om *Marathon Formation* - Black siliceous shales, sandstone, sandy limestone, dark chert, and some flaggy blue limestone. Graywackes and subgraywackes are common. Limestone-pebble conglomerates and olistostromes are also found. 530-685 ft.

Cambrian
Cd *Dagger Flat Sandstone*-Massive, impure light brown sandstone, weathering gray, and sandy limestone. 183 ft.

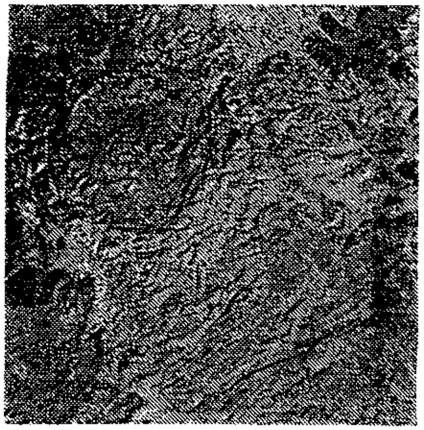

Figure 2: LandSat 5 TM band 5 raw data

Figure 3: Principal Components analysis band 2

Figure 4: TM band 5 after dark pixel enhancement

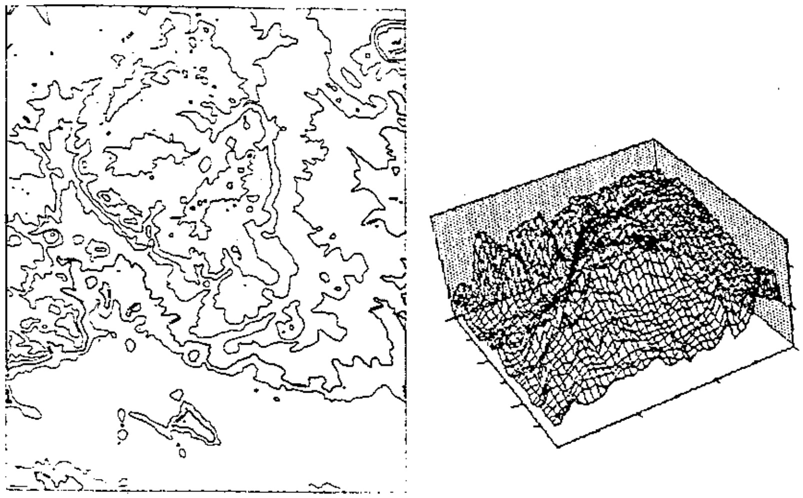

Figure 5: Digital Elevation Map as a 2-d map view and as a 3-d wire frame

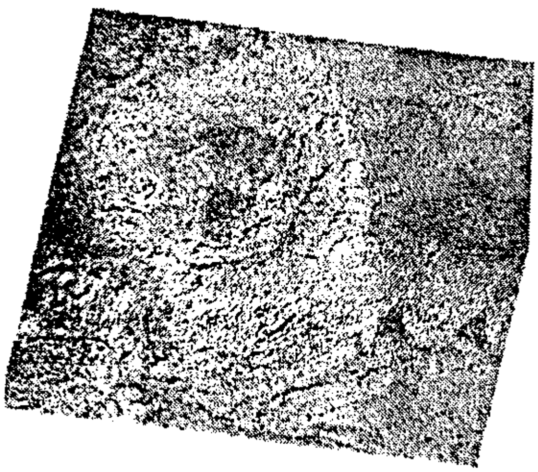

Figure 6: TM band 5 after registration with DEM

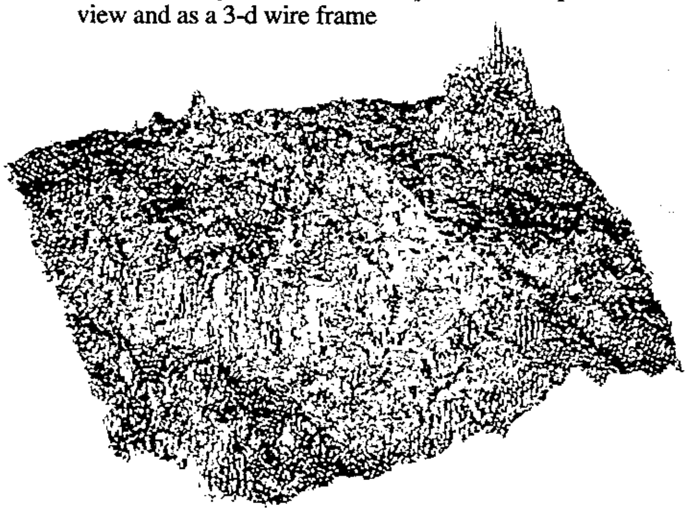

Figure 7: Final 3-d view of TM 5 overlain on a wire frame of DEM

the atmospheric scattered light from the image. Images from TM Bands 1, 2, and 3, the bands which cover the visible part of the electromagnetic spectrum, are most susceptible to showing shadows resulting from topography. Removing the components of the average of these 3 bands from all 6 bands removes most of the topography and allows the different rock types to be seen more clearly in non-PC bands. The topography comes back into the image later when it is combined with the Digital Elevation Model to produce the 3-D image.

After some experimenting with different combinations of processed images, we decided that a combination of PC Band 2, normalized band 5, and normalized band 7 showed the greatest amount of geologic detail. To produce a color image, we assigned the color red to PC Band 2, the color green to band 5, and the color blue to band 7. Combining these bands in a computer program such as Adobe Photoshop™ or MultiSpec produces a full color image known as an RGB image.

Taking the 2-D PC2, 5, 7 image and producing a 3-D image requires the elevation information or a Digital Elevation Model (DEM) (see figure 5). The Solitario DEM came from the USGS over the Internet. The information comes as a set of 16-bit numbers containing elevations in meters, with each elevation representing a ground area of $100m^2$. More image processing programs such as Spyglass Transform and Dimple can represent these numbers as a greyscale image.

Pixels in the DEM image cover 3 times the area that the pixels in PC 2, 5, 7 image represent. Dimple can compensate for this by allowing several points in one image to be registered with corresponding points in the other image and re-sampling the PC 2, 5,7 image and stretching it to fit the DEM image (see figure 6). Dimple then produces a 3-D plot of the DEM information and uses the PC 2, 5, 7 image as the color scheme overlain on top. Thus, voila!! A color 3-D geologic image of Solitario.(see figure 7 and plate 7). By combining a series of these 3-D images with different inclinations and displaying them in rapid sucsession we can create a video "fly-by" simulation of The Solitario.

Conclusion

The most obvious characteristic of the map combining the topographic data and the LandSat images is the correlation between the topography and the geology of the area. The more resistant geologic features can be clearly seen on the processed LandSat images and are accentuated when draped over the topographic data. This can easily lend itself to modeling trends in erosion patterns as well as various other types of geological modeling studies and electronic "walk-throughs" to better study the geology.

Bibliography

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