GEOLOGIC MAPPING OF THE MARATHON BASIN, WEST TEXAS, FROM SATELLITE IMAGES

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INTRODUCTION

The Marathon region is a topographic basin lying in northern Brewster county in west Texas. Outcrop within the Marathon Basin consists of Paleozoic and Mesozoic sedimentary rocks and Tertiary intrusives. The area is especially conducive to geologic mapping from space because the outcrop is not obscured by vegetation. The goals of this study are to explore image processing techniques to see which are most useful in differentiating the rock units and to explore the differences between the map arrived at through image processing and a preexisting geologic map produced from traditional ground based geological fieldwork. (1)

METHODS

The study area is underlain by a thick suite of Paleozoic sedimentary rocks. From the base upwards the sequence consists of the Marathon Limestone, a massive limestone; Alsate Shale, Fort Pena Fm., and Woods Hollow Shale, a limestone and shale sequence; Maravillas Chert and Caballos Novaculite; Tesnus Formation, a sandstone, shale, and quartzite sequence; Dimple Limestone, a clastic carbonate; and Haymond Formation, interbedded sandstone and carbonaceous shale. Volcanism during the Tertiary produced stocks and dikes as well as layered units of tuff and breccia.

Satellite images were a quarter-scene taken by the Landsat 5 Thematic Mapper Satellite. Data is in six bands or wavelengths: Bands 1-3 are images of blue, green, and red visible light, resepctively; band 4 is near-infrared (.76-.90 μm), band 5 is mid-infrared (1.55-1.75 μm), and band 7 is longer-wavelength mid-infrared (207-236 μm). Band 6 is much longer-wavelength thermal infrared and was not used in this study. Each pixel represents an approximately 30 by 30 meter area.

Image processing was performed on a Macintosh Quadra 610 using Adobe Photoshop 2.5.1, MultiSpec 2.15.94, and BandAid 2.1. Image processing was performed to enhance geologic features using standard methods such as histogram stretching.

Image analysis techniques included principal component analysis (PC analysis), in which the computer calculates principal components and then uses them to recalculate a new set of six images; PC band 1 shows the variation due to the most significant component, PC band 2 the next most significant component, and so forth. Dark pixel subtraction (DPS) was performed to normalize the image data so that the darkest pixel in every image had a digital number (DN) of 2. DPS effectively removes most of the effect of the atmoshpere's scattering of the light received by the satellite. In band ratioing, the DN for a pixel in one image (the numerator) is divided by the DN for the corresponding pixel in the second image (the denominator).

OBSERVATIONS

We recognized two separate problems in mapping the Marathon Basin: the first, to differentiate the Paleozoic sedimentary units, and the second, separating the Tertiary intrusives from the Paleozoic rocks. For this purpose we cropped two smaller areas from the original large image. The first (the "novaculite crop") was used to attempt to differentiate the Paleozoic sediments. This area contained a large area of folded and thrusted Caballos Novaculite and a synform in the Tesnus Fm., Dimple Ls., and Haymond Fm. The second (the "spot crop") was used to separate the Tertiary volcanics from the surrounding sediments. This contained five large igneous intrusions into Cretaceous limestone. Only the novaculite crop will be discussed here.

In principal component analysis of the novaculite crop, band 1, which accounts for 92% of the variation in pixel values, attenuates the contrast in light intensity due to topography. PC band 1 also separates the Fort Pena Formation and Alsate Shale from the rocks surrounding them. PC band 2 differentiates the Caballos novaculite and a large quantity of alluvium from the other rocks. In addition band 2 clearly subdivides the Dimple Limestone and Tesnus Formation into three mappable subunits. The Caballos Novaculite is quite dark and distinguished from the alluvium in PC band 3. Band 4 brings out the basin's drainage system; in addition, the lower Tesnus Formation is shown to be made up of distinct layers. PC band 5, though it only accounts for .05% of the original variation between the pixels, separates the whole Dimple limestone from the Haymond and Tesnus formations and also the Alsate Shale and Fort Pena Formation from the Woods Hollow shale. Band 6 is noise.

In the PC images of the novaculite crop, we noticed that there might be separate mappable units in the Caballos Novaculite. However, the novaculite is a highly resistant rock and throws dark shadows, and we were concerned that the variation in color we were seeing in the PC images acros the ridges of novaculite may

It is difficult to obtain detailed spectra that are representative of the average over a large area since the spectroradiometer takes readings over such a small area (~6 in^2). It should also be noted that the two basalt spectra have the greatest discrepancy in the infrared portion of the spectrum. We performed no precise atmospheric correction in this portion of the spectrum.

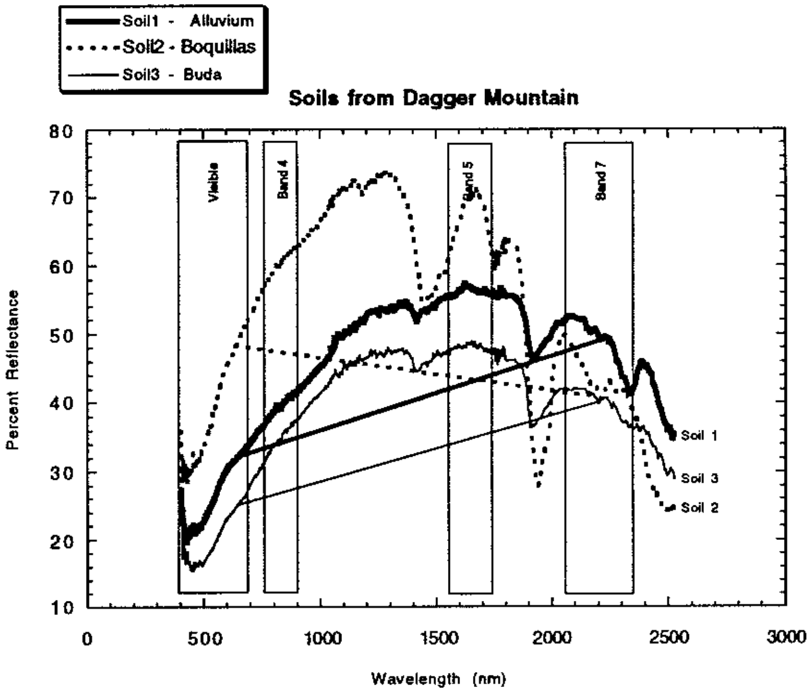

Figure 4. The spectral slopes for each soil from Band 3 to Band 7. Notice that the slope for Soil 2 is opposite in sign from the slopes for the other two soils.

Absolute radiometric calibration of TM data is very difficult, but our results show that such calibration is not essential in order to use the spectral information for geologic mapping purposes. Despite the variations between TM spectra and radiometer spectra, the use of band ratios 4/7 and 3/7 did show contrasts between the different rock units (see Plate 1). In addition, weathered basalt shows up remarkably well probably due to its high iron content. Although the traverse to gather field observations was small, the separation of rock units using the band ratios can be extrapolated over a much larger area. Our images reveal large areas of the weathered basalt which were incorrectly mapped as Boquillas formation on the geologic map of Big Bend National Park.

Color Plates

Plate 1. A 3/7,1,5 (RGB) composite image of Dagger Mountain. Notice the limestone units are effectively separated with this particular band ratioed image. Also, the weathered basalt around the basalt unit shows up well. The Buda limestone is the pink unit; the basalt is the black unit; the weathered basalt shows up in orange around the basalt; the Boquillas limestone is light green; and the quaternary alluvium is light blue.

Works Cited

Hunt, G.R., 1977, Spectral signatures of particulate minerals in the visible and near infrared: Geophysics, v. 2, p. 501-513.

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only be the effects of light and shadow and not of any true difference in rock type. We corrected for this effect by normalizing each original band for the light-and-shadow effects of topography. Since every band should show similar variation in intensity between sunlit and shadowed areas, we reasoned that dividing every band by an averaged visible light band would even out the intensity variation due to shadows.

The resultant images split the Caballos Novaculite into three distinct layers. In addition, the subunits within the Tesnus Formation and Dimple Limestone show up quite clearly, with the Dimple subunits being better differentiated than they were in the PC images.

Band ratioing was performed on the images after DPS. While several different band ratios easily separate the novaculite from the rest of the rocks in the area, only 5/7 separates the central member well from its alluvium. None does a very good job of separating any of the units older than the Novaculite. Band ratio 7/1 separates out some of the geology reasonably well and distinguishes the Dimple, Tesnus, and Novaculite subunits.

CONCLUSIONS

DPS, PC analysis, and band ratioing all proved to be very effective in differentiating the rock types in the Marathon Basin. They were especially effective in separating markedly different rock types, such as the igneous intrusions from the limestone and the novaculite from the limestone and sandstone surrounding it. However, both analysis methods also were useable for making finer distinctions between subunits in some formations. PC analysis also was successful in separating the very similar lower Paleozoic limestone/shale units from each other. It should be noted, however, that in most PC Analyses we attempted for this study, the majority of the variation between pixel values proved to be caused by light-and-dark variation due to topography, and some PC images that we found useful in separating mapped units accounted for significantly less that 1% of the variation.

Some areas mapped on the extant geologic map as bedrock appear to be covered by alluvium in our images. More than likely this means that the alluvial cover is thin and that ground-based mappers were able to find outcrop there, but from space it is impossible to say except by extrapolation what underlies the alluvial cover.

While PC Analysis was more effective than DPS/Normalization and band ratioing in differentiating some of the rock types, it has the disadvantage that the components found for the small area we picked are not necessarily the same components that the would be found for a different image, or even a different section of the same image, so we cannot make any generalizations about what individual bands show. This is especially true if PC Analysis were to be attempted on a very large image: subtle variations between rock units would be obscured by regional variation in pixel values. The other two methods, however, can be applied to any image, and the results should be similar as those arrived at in this study. A ratio of bands 7 to 1, for instance, should always be as good at separating limestone from sandstone, shale from limestone, and even thickly- from thinly-bedded sandstone as it is in these images.

COLOR IMAGES

Color plates were produced in Photoshop 3.0. The color balance in plates 9-11 was adjusted to increase the contrast between adjacent colors.

Plate 8 is a true color composite image generated from the Landsat TM bands: TM band 3 is assigned to red, band 2 to green, and band 1 to blue. This approximates the appearance of a color aerial photograph.

Plate 9 is a composite of principal component bands. PC band 2 is assigned to red, PC band 4 to green, and PC band 5 to blue. Note how strongly the central novaculite member separates from the other rocks--it is bright white, indicating high intensity in all three bands. The other novaculite members show up as markedly different colors (blue on the Tesnus side, green on the Woods Hollow side), indicating that perhaps there are separate mappable members in the Caballos Novaculite.

Plate 10 shows the effectiveness of normalizing the TM bands with an averaged band to remove the highlights and shadows caused by topography. TM band 7 is assigned to red, TM band 5 to green, and TM band 3 to blue. Dark pixel subtraction was performed on each TM band before normalization to correct for atmospheric scattering of light.

Plate 11 is a color composite with DPS/Normalized TM band 5 as red, band ratio 7/1 to green, and band ratio 5/7 to blue. The band ratios work very well at differentiating some rock units, especially the Paleozoic sediments in the western part of the image and the thin bands in the lower Tesnus Formation.

REFERENCES

(1) Geologic Atlas of Texas, Fort Stockton Sheet Virgil E. Barnes, Project Director UTAustin Bureau of Economic Geology 1:250,000

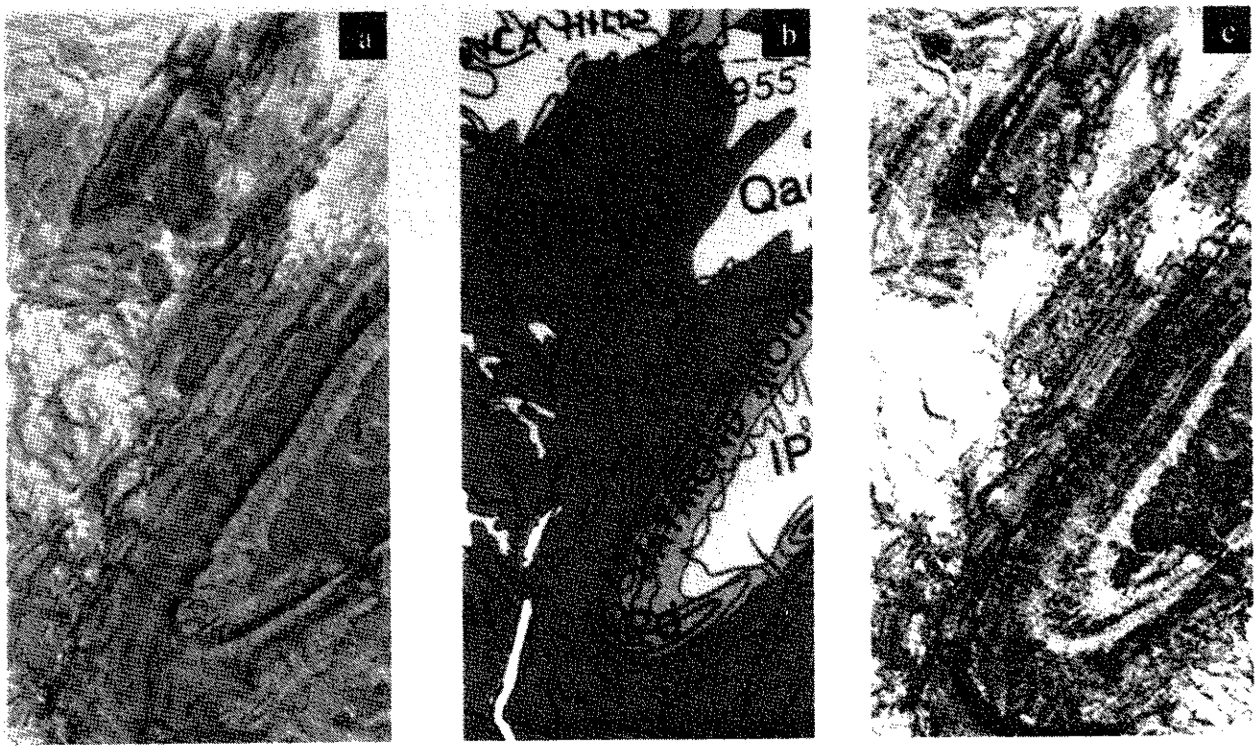

Figure 1. The western Haymond Mountains: a synform in the Tesnus Formation, Dimple Limestone, and Haymond Formation. Each image represents an approximately 5 by 10 km area. North is toward the top of the page.

a. Image created by composing the visible TM bands into an RGB image, then converting it to grayscale. This picture would be similar to low resolution aerial photographs of the area.

b. The geologic map of the area. The synform is expressed nicely by the Dimple formation (IPd); surrounding it to the west and north is undifferentiated Tesnus Formation (IPt).

c. Image composed of Principal Component bands 1, 2, and 4. Each rock unit showed up as a distinctly different color; we used Photoshop to alter the value of each color so thet the differences between them would show up in this grayscale image. Note how the Dimple Limestone splits into three subunits (a dark gray band surrounded by two lighter gray bands). Note also the very dark layer in the middle of the Tesnus Formation that brings out a feature not visible in the geologic map: another synform north of the first one.

d. Ratio of band 7 to band 1 after dark pixel subtraction had been performed on both. Note again how the Dimple Limestone splits into three subunits. Here, also, the lower Tesnus in clearly well layered and darker than the upper Tesnus.