LITHOLOGIC MAPPING WITH LANDSAT TM BAND RATIOED IMAGES, DAGGER MOUNTAIN, BIG BEND NATIONAL PARK, TEXAS

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Introduction

Dagger Mountain is an anticline in the north end of Big Bend National Park formed in the Laramide Orogeny. The units exposed on the west flank of the mountain are a series of Cretaceous and Tertiary carbonates and shales intruded by basalt sills. Our goal was to map these units with Landsat Thematic Mapper (TM) imagery. We wanted to distinguish the units on the basis of their spectral characteristics. Detailed reflectance spectra of these units were taken using a spectroradiometer. This spectral information along with results of a field traverse were used to determine how to process the TM spectra.

Stratigraphy and Field Observations

The Santa Elena limestone is the oldest unit exposed over most of the Dagger Mountain anticline. It is overlain by the Del Rio clay, which is in turn overlain by the younger Boquillas limestone. Basalt sills of Cretaceous to Tertiary age intrude these units (see figure 1). The Boquillas is a flaggy limestone mixed with some shales that supports little vegetation, while the Buda is a more massive limestone with noticeably more vegetation, much of which is the infamous lechuguilla, known for penetrating hikers' boots.

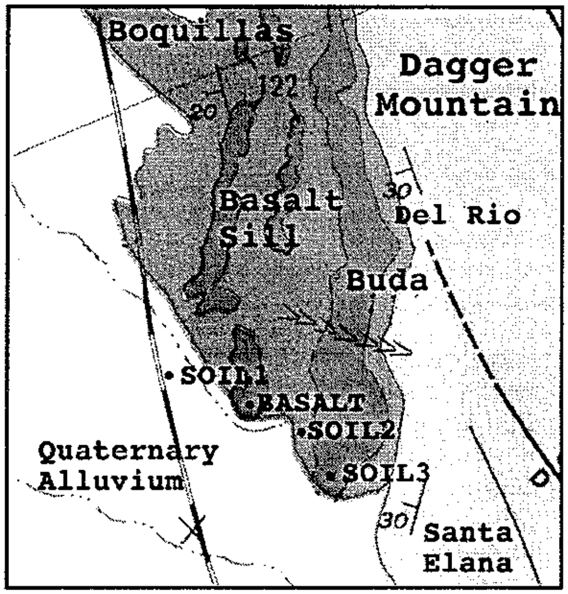

Figure 1. Map of Dagger Mountain, Big Bend National Park representing the area of the field traverse.

The major observed difference between the Buda and the Boquillas was vegetation cover. TM band 4 (760 to 900 nm) responds in the near infrared, and chlorophyll is highly reflective in this region, thus highlighting subtle differences in vegetation. Mineralogical differences are best seen in TM bands 5 (1550 to 1750 nm) and 7 (2050 to 2350 nm). Because of the properties of these bands, we found that a combination of TM 1,4,5 (RGB) displays the different rock units in distinguishable colors. It should be noted that the basalt unit has such a different reflectance from the other samples that virtually any band combination will highlight it.

Spectroradiometer Analyses

Detailed reflectance spectra of surface soils were taken using a GER IRIS MARK IV spectroradiometer. The units from which these spectra were taken are the Buda formation (soil 3), the Boquillas formation (soil 2 and an outcrop of dense limestone), a Quaternary alluvial fan (soil 1), and a porphyritic basalt sill.

The GER spectroradiometer takes reflectance readings at 900 different wavelengths between 400 and 2500 nm, covering the visible to near infrared portions of the spectrum. It uses a piece of Teflon as a reflectance reference. In

The Summer Project of '94

The first five days of the project consisted of a rapid and intensive introduction to multispectral remote sensing and image processing using desktop computers. The goal was to have students process imagery from the Slick Hills of southern Oklahoma prior to a field trip to the site. Students worked in groups of two or three to produce the most revealing images possible. Each group printed their best images before departing San Antonio. We traveled first to Texas Christian University (TCU) in Fort Worth. There we met Ken Morgan and Art Busbey who served as our guides into the Oklahoma wilderness. Ken and Art have conducted remote sensing workshops for NASA and industry and their expertise was invaluable. We spend most of the next day in the Wichita Mountains and Slick Hill. In the field students were able to compare images to ground observations of vegetation, lithology and geologic structures. We returned to Fort Worth in the evening and to San Antonio the next day. High temperatures coupled with vehicle air-conditioning failure complicated the return trip slightly.

After a needed day of rest, the students began to process images of Big Bend National Park. The experience of comparing imagery and ground observations in Oklahoma enabled them to generate much more useful images for the trip to Big Bend. We departed for Big Bend on Tuesday and stopped at the entrance of the park to view the geology at Persimmon Gap where Ouchita, Laramide and Basin and Range structures are superimposed. Wednesday was spent visiting the western half of the park and the Tertiary volcanic formations. Thursday morning we made observations in a Cretaceous section in the northern part of the park in unseasonably cool temperatures under a mercifully overcast sky. The afternoon was spent observing outcrops of Paleozoic shelf and turbidite deposits in the Ouchita fold and thrust belt exposed in the Marathon Basin. We returned to San Antonio late that night.

During the final 10 days of the project, students, working in groups of two or three chose their final project images and topics. The work included round–the–clock computer processing as well as laboratory measurements of collected rock and soil samples using a GER spectroradiometer. Students completed preliminary abstracts of their work before leaving, although the main thrust was the completion of images for color laser and dye–sublimation printing. One group worked on mapping shoreline changes at San Louis Pass, Texas. On the final Friday of the project, these two students and Bill Fox embarked on a one day field trip to the Texas coast at San Louis Pass, a round trip of over 400 miles. Combined with the trips to Oklahoma (about 800 miles round trip) and Big Bend (about 1000 miles round trip) this Keck project covered an enormous area!

Each of the six student project groups generated more than 100 MB of image data. Since it was impractical to store this amount of data on floppy disks, a set of CD-ROMS was generated. Each student received a CD-ROM containing the complete results of all projects. In addition, we produced a second CD-ROM containing all of the raw images used in the project. This CD-ROM will be distributed to each school in the consortium for use in teaching remote sensing and image processing.

The results of the students' work can best be appreciated in their own words, and for the first time in a Keck Symposium volume, their color images.

Acknowledgments

We all owe a great debt to Bill Fox and Richard Stenstrom. In addition to their invaluable scientific leadership, they were excellent chauffeurs. Although neither can ever be a native Texan, their cockpit time in Chevy Suburbans qualifies them for permanent Texas resident status. I personally thank them for helping me maintain my sanity during the times when hardware, software or both were behaving badly!

We thank Mary Savina and Andy deWet for their participation in the early days of the project. We only regret that they were unable to stay for any of our long distance field excursions.

We are greatly indebted to Ken Morgan and Art Busbey for their hospitality and expertise on our field trip to Oklahoma, and the working air-conditioning in the TCU van. Their generous loan of the GER spectroradiometer made much of our work possible and the use of their computer facilities, in Ft. Worth, simplified the transfer of several of our Landsat images.

Special thanks are due to Karen Kroeger, my wife. In addition to her patience, her shopping helped keep breakfast and lunch on the table.

Of course we thank the W. M. Keck Foundation and the National Science Foundation for their ongoing support of these projects. We believe that the science done, and the careers launched by this project are worthy of their generosity.

Finally, my thanks to the gang of 13 for an enjoyable, exciting and exhausting month. They braved the restaurants of south Texas and proved the wise old saying: "image processing is like a box of chocolates, you never know what you're gonna get!"

this same range of wavelengths, Thematic Mapper bands record data in only six locations, each representing an average over a span of wavelengths. Two readings were taken on each sample, and representative plots of the spectral reflectance readings are shown in figure 2.

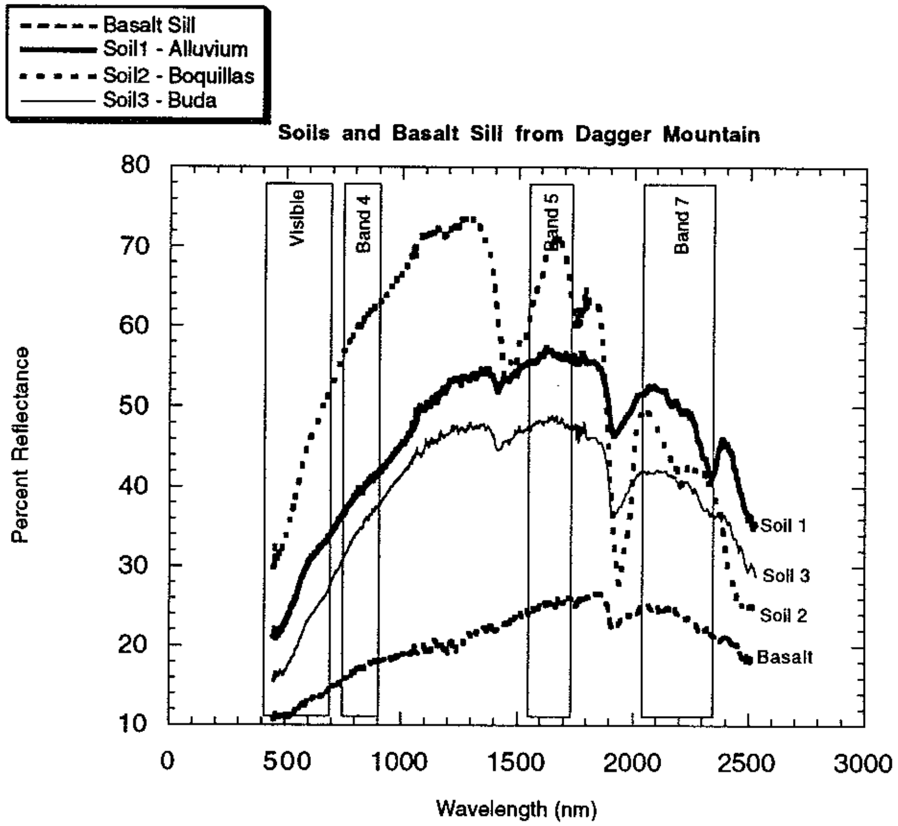

Figure 2. Spectroradiometer data for the basalt and the three soil types.

In analyzing the spectra, several trends appear. All three soils and the basalt display a distinct drop-off in overall reflectance in the visible and very near infrared wavelengths (<1000nm). This feature, common in many weathered rocks, is due to the presence of iron. The ferrous ion encounters a conduction band transition at around 1000 nm causing a decrease in spectral reflectivity (Hunt, 1977). Overtones of the H_2O molecular vibrational modes lead to peaks at 1400 nm and 1900 nm, and are present in all three soils. These peaks indicate the presence of molecular water, which may be held by expandable clays in the soil samples (Hunt, 1977). The peaks seen in soils 1 and 3 at approximately 2200 nm and 2300 nm may be caused by overtones of the stretching mode of the OH radical. Another possibility is that these peaks, coupled with the peaks seen at approximately 2500 nm in all three samples, may be due to the presence of the CO_3 radical. CO_3 has five absorbance bands between 1900 nm and 2550 nm (Hunt and Salisbury, 1971). Since we know these rocks are carbonate rich (calcite was found lying on the ground surface), it is possible that all the absorbance peaks in this region are due to CO_3 stretching.

These spectral characteristics are important in that they show how similar these units are. One important difference is how much stronger soil 2 reflects overall as compared to soils 1 and 3, and also how much more pronounced the absorption peaks are in soil 2. This stronger reflectance is especially noticeable in the peaks around 1400 nm and 1900 nm. This seems to indicate a higher presence of molecular water in soil 2. The higher reflectance is probably the result of soil 2 having an overall higher albedo than soils 1 and 3.

Landsat Thematic Mapper (TM) Spectral Analyses

Ideally, the TM bands would record the same or similar reflectance spectra as the spectroradiometer, however, this is not the case mainly due to atmospheric absorption and scatter. TM bands are positioned to avoid areas of the spectrum with high atmospheric absorption. One way to correct for atmospheric scatter is to do a dark pixel subtraction on the TM data. This correction involves the assumption that in every image there exists at least one pixel that should be black (0 DN). Therefore, any light seen in that pixel is a result of atmospheric scatter. By subtracting out the amount of light seen in the darkest pixel from all the other pixels, the broad band effects of atmospheric scatter can be removed. We performed this correction using Adobe Photoshop ™ 2.5.

The TM spectral shape of each pixel is a function of the reflectance of the material. The overall intensity of the pixle's spectra is also a function of topography and sun angle. To compare the shapes of spectra without the influence of topography and sun angle, all six bands were normalized. First, the bands in the visible range of the spectrum (bands 1, 2, and 3) were averaged, then each individual band was divided by the average. The Macintosh program MultiSpec (David Landgrebe, Purdue University) was used to extract the TM spectra from individual pixels as shown in figure 3.

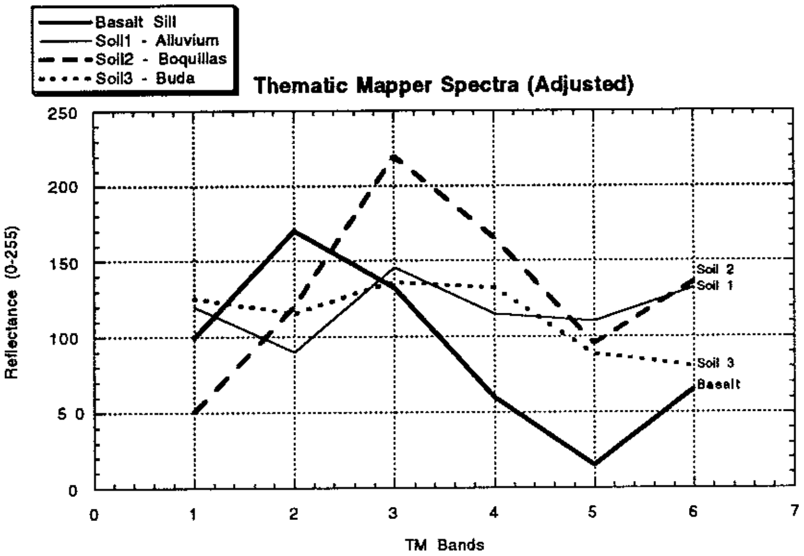

Figure 3. Thematic Mapper spectra of units.

Band Ratioed Images

Because we were able to find differences in the shape of the spectra, the use of band ratios was an appropriate method of mapping the units. The spectra obtained from the spectroradiometer were used to select the band ratios that best highlighted the different units. Band ratios are obtained by dividing each pixel in one band by the corresponding pixel in another band. The result is a new band that is sensitive to the slope of the spectrum between the two original bands. Like normalization, this division removes the effects of topography and sun angle. Often, in spectrally similar areas, slopes between bands will be markedly different resulting in a much greater image contrast after ratioing.

Since the basalt unit separates easily from the surrounding rocks due to its much lower overall reflectivity, only the three soil spectra were used to select band ratios that would emphasize the differences between the two carbonate units and the alluvium. Using the spectroradiometer data, the band ratios 3/7 and 4/7 were chosen because the resulting slopes were positive for soils 1 and 3 and negative or near zero for soil 2 (see figure 4). Band ratio images were computed using the Macintosh program BandAid (Trinity University).

Color Plate 1 shows a color composited image where the band ratio 3/7 is assigned to red, band 1 is assigned to green, and band 5 is assigned to blue. 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.

Discussion

The coarse spectra obtained from the TM data do not closely match the detailed spectra obtained from the spectroradiometer. The TM spectra incorporate vegetation and atmospheric influences, and also reflect the ground conditions, such as soil moisture content, at the time the Landsat image was acquired. The TM bands sample a large area per data point (30m x 30m) and represent the average spectral value over the wavelength range of the band.

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.

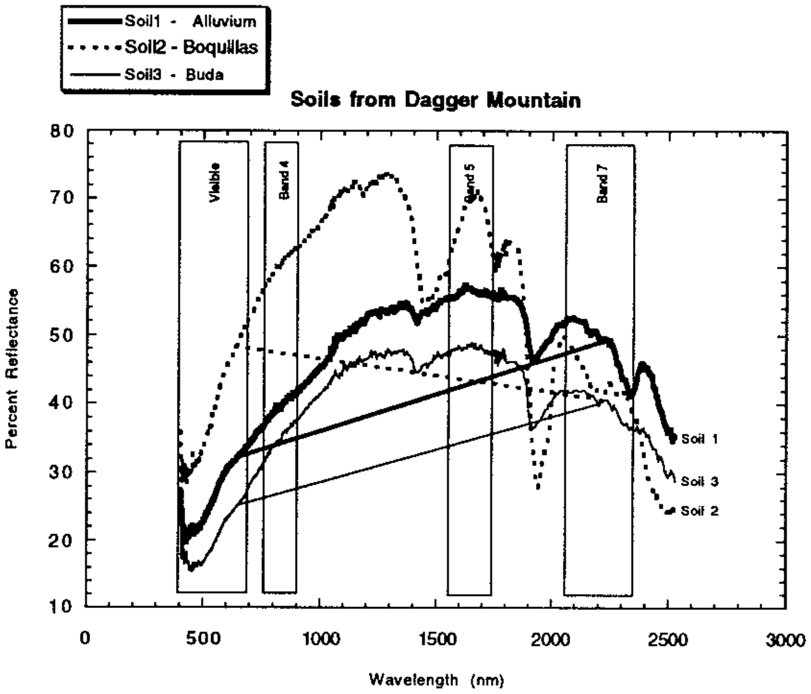

Figure 4. The spectral slopes for each soil from Band 3 to Band 7. Notice that the slope for Soil 2 is opposite in sign from the slopes for the other two soils.

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.

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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