GEOLOGIC REMOTE SENSING AND MULTISPECTRAL IMAGE PROCESSING

FACULTY

Glenn C. Kroeger, Trinity University
William T. Fox, Williams College
Richard C. Stenstrom, Beloit College

STUDENTS

Karen Bobbitt, Carleton College
Nova Clarke, Washington and Lee University
Christian Curtis, Pomona College
Kelley Doswell, Virginia State University
Amy Fisher, Colorado College
Veronica Francis, Pomona College
Tracy Knapp, Beloit College
Matthew Nwosu, Colgate University
Sarah Robinson, Franklin and Marshall College
Maryellen Sault, SUNY-College at Buffalo
Emily Stewart, Amherst College
Rebecca Thomas, Williams College
Kim Twining, Trinity University

VISITORS

Mary Savina, Carleton College
Andrew deWet, Franklin and Marshall College

FIELD TRIP HOSTS

Arthur B. Busbey, Texas Christian University
Ken M. Morgan, Texas Christian University

GEOLOGIC REMOTE SENSING AND MULTISPECTRAL IMAGE PROCESSING

Glenn C. Kroeger
Department of Geosciences
Trinity University
San Antonio, Texas 78212

Beyond the Visible

Every time we look at an outcrop we are remote sensing. Our eyes acquire data from reflected electromagnetic energy having wavelengths between 0.4 µm and 0.7 µm, a range of the spectrum that we call visible light. Our eyes do not do a spectral analysis of this energy. Rather, they are optimized to form sharp images from this light. In the grand scheme of evolution, it is more important to image the predator than to analyze its surface characteristics. Humans do see in color, and with this capability we crudely perceive variations in the spectral reflectivity of materials. Of course geologic materials also reflect electromagnetic energy outside of the visible spectrum, and it is the information contained in those wavelengths that we seek in instrumental multispectral remote sensing.

All objects with temperatures above absolute zero radiate electromagnetic energy. As an object's temperature increases, its radiance spectrum increases in intensity and shifts toward shorter wavelengths. A perfect radiating body, a **black body,** has a radiance spectrum governed by its temperature. The Sun's radiance closely approximates the radiation of a black body at 6000°K (Figure 1). It is no accident that we see in the 0.4 µm to 0.7 µm region of the spectrum. Solar radiance peaks at about 0.5 µm, right smack in the green wavelengths of visible light. The solar radiation reaching the Earth's surface, irradiance, is affected by the atmosphere which cuts absorption "holes" in the spectrum due primarily to absorption by H_2O, CO_2 and O_3 (figure 1). Solar irradiance drops off sharply in the shorter, ultraviolet wavelengths but extends well into the longer, infrared wavelengths.

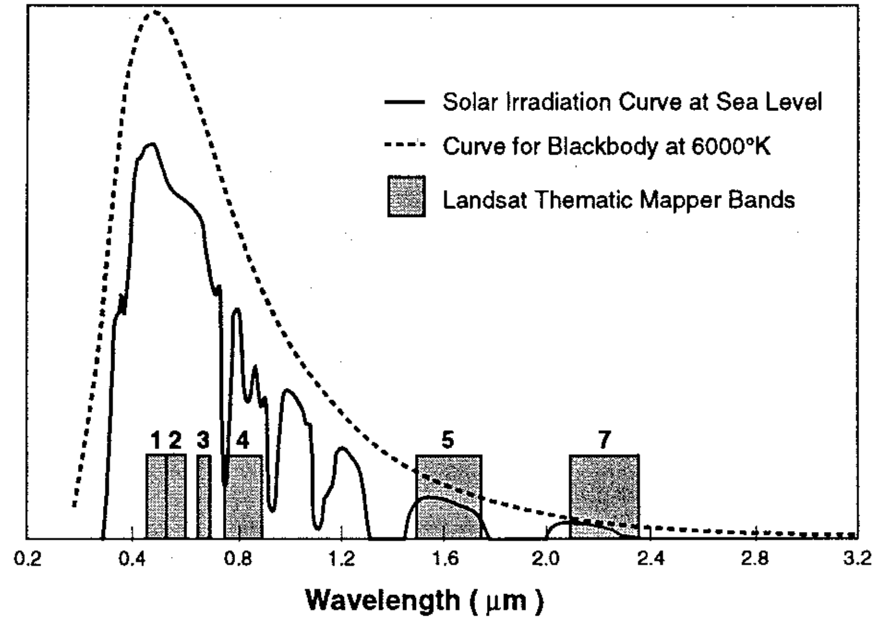

Figure 1. Visible to SWIR Spectrum

Because of the presence of significant solar radiation and the nature of the reflection and absorption of radiation by materials, the infrared portion of the spectrum is of particular interest. Infrared energy is reflected by geologic materials, but is also radiated by those materials. Since most materials are at surface temperatures around 300°K, they radiate only infrared energy. So do you! A black body at 300°K radiates at wavelengths longer than 2.5 µm with peak radiation at about 10 µm. We call this long wavelength portion of the infrared the thermal infrared.

At wavelengths shorter than about 2.5 µm, materials at surface temperatures only reflect infrared radiation. The near infrared (NIR) is the portion of the spectrum between 0.7 µm and 1.0 µm. Short-wavelength infrared (SWIR) consists of the portion of the spectrum between 1.0 µm and 2.5 µm. Electronic interactions such as crystal field effects involving Fe, and molecular vibrations and overtones, involving the OH^- ion and its bonds with Al and Mg, are important in controlling the reflectivity spectra of geologic materials in the NIR and SWIR.

Vegetation is either a subject of study, or an impediment, depending on goal of the remote sensing. This is, of course, why most *geologic* remote sensing studies are carried out in arid regions. Chlorophyll is the key factor in the reflectivity of vegetation. It absorbs strongly in the red, giving rise to our visible observation that healthy vegetation is green. But chlorophyll reflects most strongly in the very-near infrared (VNIR), just beyond the visible. To the multispectral observer, leaves are bright VNIR!

Multispectral Remote Sensing

Ideally, we would like to gather the complete visible–to–SWIR spectrum for every point in an image. We would also like a very detailed image, which in a digital world means many pixels. If we gathered a complete spectrum for each pixel we would have a wonderful, but enormous and expensive data set. In **multispectral** remote sensing we acquire a small number, usually less than a dozen, spectral measurements for each pixel. Each spectral sample is the average over a region of the spectrum greater than 0.1 μm wide.

We can think of a multispectral image as a set of grayscale images, called **bands**, each taken in a different region of the spectrum. We can study the data as a set of grayscale images, or more commonly we can generate a **color composite** of any three bands by coloring one band red, another green and the third blue, and combining the results into a single color image. Another way of looking at the data is to use the values of a pixel in each band as a (crude) spectrum of that point in the image.

Imaging spectroscopy, or hyperspectral remote sensing involves acquiring dozens to hundreds of spectral samples for each image pixel. This data is spectacular, but it is less readily available than multispectral data. Color composites, three bands out of hundreds, do not take advantage of the data. Other analysis techniques are available, but the shear volume of data (and these data sets are usually visualized as *volumes*) make this data more difficult to process and analyze.

Landsat and the Thematic Mapper

While multispectral images can be acquired by aircraft, the most familiar source of this imagery is the Landsat series of satellites. Early Landsats carried a multispectral instrument known as the Multispectral Scanner (MSS). Landsats 4 and 5 added a better instrument known as the Thematic Mapper (TM). In addition to better spectral sensitivity, TM images have pixels that are approximately 30m x 30m on the ground compared to 80m x 80m with MSS. Landsat 6 carried an enhanced Thematic Mapper which could acquire 15m x 15m pixels in the visible. Unfortunately it also carried the instrument to the bottom of the Pacific Ocean!

Landsat TM images sample seven spectral bands. Bands 1, 2 and 3 are in the visible, in the blue, green and red respectively. Thus a color composite image that maps TM band 1 to blue, TM band 2 to green and TM band 3 to red will approximate the image seen by the human eye, or color film. We denote this composite as a 3,2,1 RGB image and call this a **true-color** image.

Other composites are called **false-color** images. TM band 4 is in the VNIR and is specifically positioned to record the peak in chlorophyll reflectance. A 4,3,2 RGB composite is a false color image that mimics the response of color infrared films. This composite gives the familiar false color images with bright red areas representing healthy vegetation. Iron-bearing aluminosilicates also show strong absorption in the region sampled by TM band 4.

TM bands 5 and 7 sample the SWIR region. These bands are particularly useful in geologic interpretation due to mineralogically controlled absorption features in this region of the infrared. Magnetite and other opaque phases tend to have very low reflectivity in the region sampled by TM band 5 while hydroxyl-bearing minerals have strong absorption features in the region sampled by TM band 7.

TM band 6 is located, out of order, in the thermal portion of the infrared spectrum. It samples a region of the spectrum where materials, at surface temperatures, primarily radiate rather than reflect infrared energy. Use of band 6 requires simultaneous analysis of material emissivity and temperature. It also has a lower spatial resolution (120m x 120m) than the other bands, but it can be used at night. Figure 1 shows the location and spectral widths of all TM bands except band 6.

Multispectral Image Processing

Spatial image processing techniques, such as lineament detection and edge detection, are useful tools for geologic remote sensing but they do not make use of the spectral information contained in the data. Color composites are just a first step in using the spectral information content of the data. Dark pixel subtraction, band ratio images and principal component analysis are processing procedures which were used to extract additional spectral information.

While most of the light forming each pixel of an image is reflected from the Earth's surface, some of the light is scattered toward the instrument by the Earth's atmosphere. Detailed atmospheric corrections require modeling the temperature and moisture content of the atmosphere. For multispectral images, which sample only a few points in the spectrum, a simpler correction is usually adequate. We assume that at least one pixel in the image should be pure black, either because it reflects almost no light, or because it is in total shade. We find the "darkest" pixel in the image and assume that its value represents only scattered light. We subtract this "dark pixel" value from all pixels, removing most of the effects of atmospheric scatter.

A single pixel of a TM image can be thought of as a crude, six sample, spectrum. Figure 2 compares the reflectance spectrum of muscovite and kaolinite, densely sampled with a spectroradiometer, and the way that these spectra are "seen" by the TM instrument. The overall *amplitude* of the spectrum of a pixel is primarily controlled by how bright that spot on the Earth is, which is controlled mostly by topography and sun angle. The *shape* of the spectrum is controlled by the material. One way of analyzing the shape of the spectra is to form the ratio of two image bands. This is done by dividing the value of each pixel in one band by the value of the corresponding pixel in another band. The result of this operation is a new image band in which the brightness of each pixel represents the slope of the spectrum between the two original bands and thus an aspect of the shape of the reflectance spectrum of each pixel. Band ratioed images appear "flat" as most of the effects of topography are removed. Different band ratioed images can be composited with each other, or with original TM bands to form false-color images.

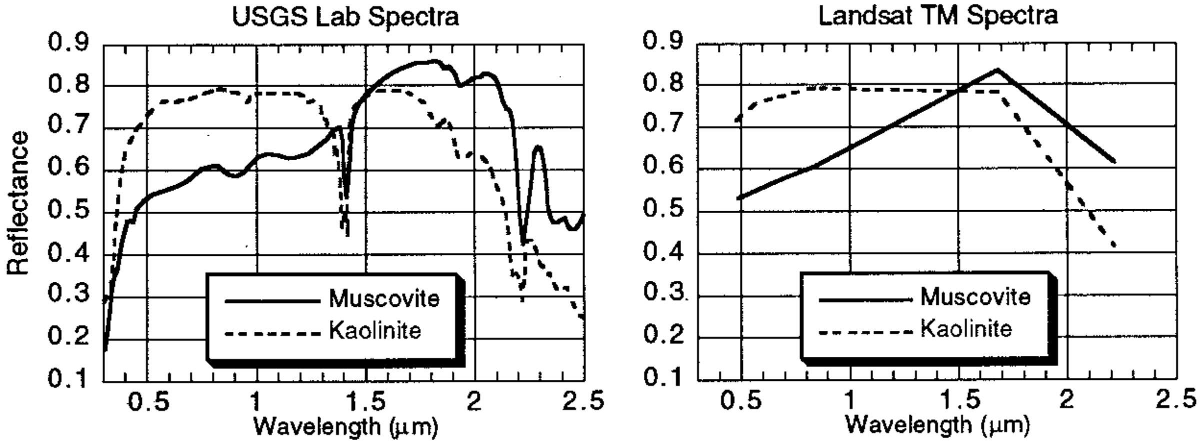

Figure 2. A comparison of densely sampled spectra acquired with a spectroradiometer and the six sample spectra "seen" by the Landsat Thematic Mapper

Another way of analyzing a multispectral image is to consider each pixel as an N dimensional data point, where N is the number of bands, and the intensity of the pixel in each band is the value along one dimension. This N dimensional space is called color space and the entire image is a distribution of points in color space. Principal component analysis is a rotation of the axes of this color space into directions which "best fit" this distribution of points. This is an eigenvalue/eigenvector problem identical to finding principal stresses and stress axes in structural geology. The coordinates of the pixels with respect to the rotated axes form N new principal component (PC) image bands which reflect inherent trends in the image. Pixel values in PC band 1 are usually controlled by topography while other PC bands display other natural variations in the spectral content of the data. As with ratioed bands, the PC bands can be composited with other PC bands, band ratios, or original TM bands to form false-color images.

Images and Thematic Maps

While images are often spectacular and revealing, they do not have the abstraction of a map. Consider an image of a corn field and a road. Each pixel of the corn field will have a slightly different value and each pixel of road will have a slightly different value. In a well behaved image, all road pixels will be very different from all corn pixels. If we set all road pixels equal to one value, and all corn pixels equal to a different value, we have created a **thematic map**. The process of creating thematic maps from images is know as classification. This process is messy in the real world where some road pixels are more similar to corn pixels than to other road pixels!

Classification algorithms fall into two general types. Unsupervised classification algorithms find natural spectral groupings of pixels. Supervised classification algorithms require the image analyst to define the groups by selecting "training" groups of pixels. The classification algorithm then attempts to assign each pixel to one of these groups based on some measure of goodness of fit.

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!"

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

Karen Bobbitt, Carleton College
Kelley Doswell, Virginia State University
Kim Twining, Trinity University

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.

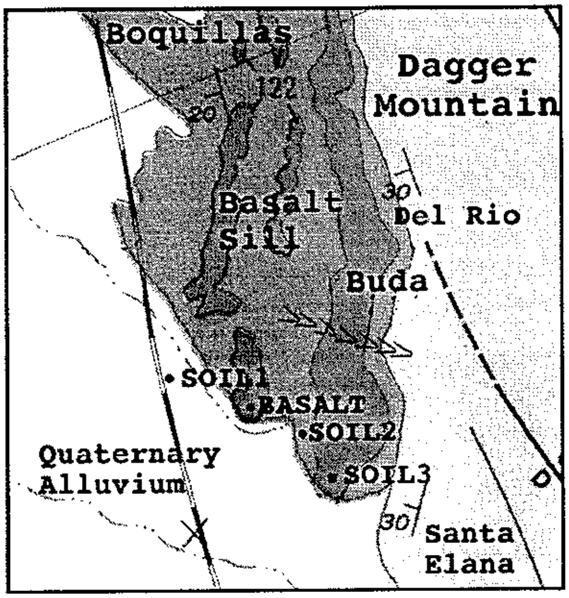

Figure 1. Map of Dagger Mountain, Big Bend National Park representing the area of the field traverse.

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