ANALYSIS OF AVIRIS DATA FOR SPECTRAL DISCRIMINATION OF GEOLOGIC MATERIALS IN THE DOLLY VARDEN MOUNTAINS, NEVADA

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ABSTRACT

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data were collected over the Dolly Varden Mountains and Currie Hills in northeastern Nevada in June of 1989. The study area contains a variety of sedimentary, plutonic and volcanic rock types as well as a contact metamorphic aureole around a large intrusion. The internal average relative (IAR) reflectance calibration method is compared with the empirical line calibration method. A binary encoding routine was used to match selected spectra and produce thematic scenes. These scenes provide geologists with evidence of previously unmapped faults and folds in the area.

INTRODUCTION

Five flight lines of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data were collected on June 2, 1989 over the Dolly Varden Mountains-Currie Hills area in northeast Nevada. AVIRIS collects radiance data in 224 bands using four spectrometers to cover a wavelength region from 0.4 to 2.45 µm. These data were collected to assist in our goal of determining the style of structural deformation prevalent in this region during Mesozoic time. Geologic mapping is essential in delineating structural elements such as faults and folds. Spectral signature mapping using imaging spectrometer data assists in correlating geologic units and helps identify places where rocks have been folded or faulted. It is then left to the geologist to measure the structures in the field. By studying information derived from imaging spectrometer data, time spent mapping in the field is reduced as the geologist is directed to specific areas where faults and folds may occur.

The Dolly Varden Mountains and Currie Hills are located in the semi-arid environment of the northeastern Great Basin. The area ranges in elevation from 1750 to 2600 meters. Other than some high relief areas of bare outcrop, vegetation cover typically ranges from about 20% to 50%. In some places along drainages and on high, north-facing slopes, vegetation cover approaches 100%. Sagebrush is present at lower elevations and piñon pine and juniper are prevalent at higher elevations from about 2000 meters.

GEOLOGY

The study area contains a variety of geologic materials exposed at the surface. A sequence of Late Paleozoic and Triassic sedimentary rocks includes limestone, dolomite, sandstone, siltstone and shale. Igneous rocks in the area include a two-phase monzogranite and quartz monzonite intrusion and volcanic rocks with compositions ranging from andesite to quartz latite to rhyolite. The igneous intrusion produced a calc-silicate contact metamorphic aureole in the sedimentary section. Minerals such as andradite, diopside, tremolite, epidote, serpentine, sepiolite and saponite resulted from this metamorphism.

DATA CHARACTERISTICS

The detectors on AVIRIS have an instantaneous field of view (IFOV) of 0.95 mrad (Vane et al., 1988). When flown on the ER-2 aircraft at 20,000 m, the pixel size at sea level would be 19 m. In the Dolly Varden area, using the median altitude of 2200 m, the pixel size would be 17 m. However, AVIRIS spatially oversamples by 17% (Vane et al., 1988) so that the actual pixel size should be 14.1 m at an elevation of 2200 m. Sections of road in the AVIRIS scenes were measured and scaled to maps, and pixel size at an elevation of 2200 m was found to be about 14.4 m in both cross-track and along-track directions. Over the whole area, where the relief is about 800 m, pixel size should vary by less than a meter. The measured flight line swath width at about 2200 m is approximately 9.5 km.

Signal-to-noise ratios were calculated for the AVIRIS data by dividing the average radiance of 9 pixels over homogeneous targets by the standard deviation of the radiance. A bright playa and a dark andesite flow were used to calculate signal-to-noise. Four spectrometers (A-D) sample wavelength intervals from 0.4-0.7, 0.68-1.28, 1.24-1.86 and 1.83-2.45 µm. Signal-to-noise ratio values for dark and light targets respectively are 50 and 180 for spectrometer A, 60 and 150 for B, 35 and 100 for C, and 15 and 45 for D (Table 1). The assumption of homogeneity of these targets is perhaps a generous one, so these values are probably somewhat lower than the actual signal-to-noise ratio. It can be assumed that signal-to-noise values over other materials in the area fall between the values obtained for these dark and bright targets.

Table 1. AVIRIS signal-to-noise over the Dolly Varden Mountains

midday June 2, 1989 latitude=40°22'				
spectrometer	A	B	C	D
bright target Albedo=0.53	180	150	100	45
dark target Albedo=0.24	50	60	35	15

CALIBRATION

Preprocessing of the data was done to convert the radiance values to reflectance. Two methods were used, the internal average relative (IAR) reflectance method (Kruse, 1988) and the empirical line method (Conel et al., 1987). The first step followed in each calibration method was to normalize the data to equal energy by calculating a multiplier for each pixel to scale the data to a total image average. By shifting each spectrum to the same relative level of brightness, this step removes albedo variations and topographic effects.

The conversion to IAR reflectance was done by dividing each pixel's spectrum by the average spectrum for that flight line segment. This method produces relative reflectance spectra that show features not common throughout the flight line segment. Thus, atmospheric absorption features common throughout are removed. The IAR conversion has an advantage in that no *a priori* knowledge of the geology of the area is required. However, this method can introduce peaks in reflectance if the average spectrum for the scene contains an absorption feature that some pixels do not have. For example, in a scene where vegetation coverage is sufficient to produce a chlorophyll absorption feature in the average spectrum, pixels that do not contain vegetation will show an "anti-vegetation" peak in their reflectance spectra that mirrors the absorption feature in the average spectrum (Figure 1). Consequently, if one is interested in features within that wavelength region, this calibration method might not prove satisfactory.

The empirical line method for conversion to reflectance involves calculating gain and offset values for each band based upon reflectance measurements taken from bright and dark targets under the same illumination conditions as the AVIRIS data. Radiance values from AVIRIS data are plotted against field reflectance measurements and a linear regression is performed to find the intercept and slope (offset and gain) for each band. These values are then used to convert the radiance spectra to reflectance spectra (Conel et al., 1987). This method corrects for the multiplicative effects of solar irradiance, atmospheric attenuation and instrument response, and the additive factor of path radiance. For this study, a dark andesite flow and a bright playa adjacent to the Dolly Varden Mountains were chosen as calibration targets. A Geophysical Environmental Research, Corp. Single FOV Infrared Intelligent Spectrometer (SIRIS) was used to take reflectance spectra of these targets concurrent with the AVIRIS flyover.

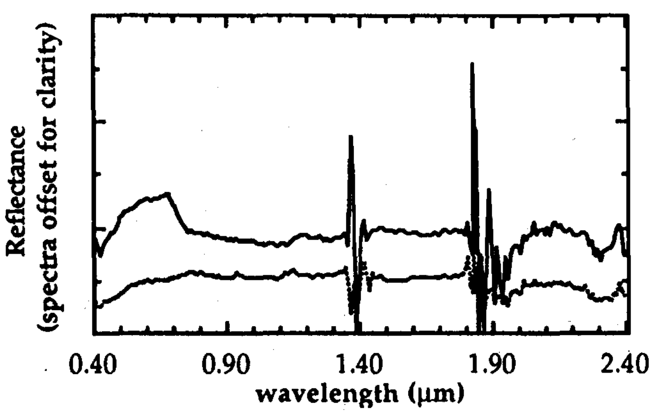

Figure 1. Comparison of the IAR reflectance calibration method (solid line) with the empirical line method (dashed line) for the same pixel.

Figure 1 compares reflectance spectra from the same pixel using the two calibration methods. Nonvegetated outcrops of a carbonate formation are exposed in this pixel, thus, the presence of an "anti-vegetation" peak at 0.68 µm in the IAR spectrum for reasons discussed previously. Both spectra show noise-dominated H_2O bands about 1.4 and 1.9 µm and both show the dominant CO_3 feature around 2.33 µm. A relatively noisy D spectrometer is evident in both spectra. The empirical line calibrated spectrum has two small peaks around 0.94 and 1.13 µm that are due to overcorrection for atmospheric H_2O vapor. This overcorrection results from the calibration targets being located about 500 m lower in elevation than the pixel sampled in figure 1. When using calibration targets over which there is greater atmospheric attenuation than over a particular pixel, the conversion to reflectance produces peaks in the spectrum at the atmospheric bands.

DATA ANALYSIS

Reflectance spectra for the same area taken from the AVIRIS data and the SIRIS field instrument are compared in figure 2. The AVIRIS spectrum is noisier and displays the same over-corrected atmospheric H_2O peaks as in figure 1. Both spectra show the dominant CO_3 feature at about 2.31 µm. This area also contains some iron oxide alteration. It is likely that AVIRIS sampled more of this alteration, as iron absorption bands are more pronounced in the AVIRIS spectrum.

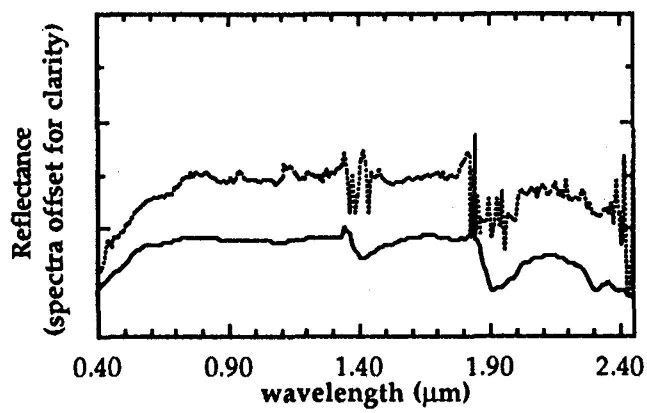

Figure 2. Comparison of an AVIRIS spectrum (dashed line) with a SIRIS field spectrum (solid line) over the same ground target.

The reflectance data were analyzed using the QL3 software developed by the U.S. Geological Survey at Flagstaff, Arizona and enhanced by the Center for the Study of Earth from Space at the University of Colorado. This software package enables the user to interactively examine a three-dimensional cube of imaging spectrometer data (two spatial and one spectral dimension) (Kieffer et al., 1988). QL3 can handle three million voxels (volume elements) at one time.

Pixels with spectra characteristics of various geologic materials were selected from the AVIRIS reflectance data and then, using a binary encoding algorithm, other pixels whose spectra matched closely were selected and color coded. These thematic images were then studied to locate geologic structures. On the east slope of the Dolly Varden Mountains, thematic images show lateral separation of a tuff-vitrophyre volcanic sequence. It is evident that faulting has offset the sequence. Recent field mapping has also provided clues to the existence of these faults which do not appear on a previous geologic map of the area (Snow, 1964). Unmapped folds and faults located on the southwest side of the range are also apparent in the AVIRIS data.

CONCLUSIONS AND FUTURE WORK

AVIRIS data are of sufficient quality to detect mineral absorption features. This study demonstrates the usefulness of imaging spectrometer data in helping to identify and map minerals and rock types. These data enable us to concentrate our field efforts to specific areas of faulting and folding. Future field work will involve the measurement of geologic structures detected in the AVIRIS data. Finally, a tectonic history of the area will be proposed and correlated to other ranges in the region.

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