EVALUATION OF AIRBORNE VISIBLE/INFRARED IMAGING SPECTROMETER DATA OF THE MOUNTAIN PASS, CALIFORNIA CARBONATITE COMPLEX

JAMES CROWLEY, LAWRENCE ROWAN, and MELVIN PODWYSOCKI, U.S. Geological Survey, MS 927, Reston, Virginia 22092, U.S.A.; DAVID MEYER, Eros Data Center, Sioux Falls, South Dakota 57198, U.S.A.

ABSTRACT

Airborne visible/infrared imaging spectrometer (AVIRIS) data of the Mountain Pass, California carbonatite complex have been examined to evaluate the AVIRIS instrument performance and to explore alternative methods of data calibration. Although signal to noise estimates derived from the data indicated that the A, B, and C spectrometers generally met the original instrument design objectives, the S/N performance of the D spectrometer was below expectations. Signal to noise values of 20 to 1 or lower were typical of the D spectrometer and several detectors in the D spectrometer array were shown to have poor electronic stability. The AVIRIS data also exhibited periodic noise, and were occasionally subject to abrupt dark current offsets. Despite these limitations, a number of mineral absorption bands, including CO_3, Al-OH, and unusual rare earth element bands, were observed for mine areas near the main carbonatite body. To discern these bands, two different calibration procedures were applied to remove atmospheric and solar components from the remote sensing data. The two procedures, referred to as the "single spectrum" and the "flat field" calibration methods gave distinctly different results. In principle, the single spectrum method should be more accurate; however, additional fieldwork is needed to rigorously determine the degree of calibration success.

INTRODUCTION

This report summarizes the initial evaluation of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data acquired in 1987 over the Mountain Pass, California alkalic igneous rock-carbonatite complex (Fig. 1). A detailed discussion of the Mountain Pass area geologic setting and a description of the carbonatite complex itself may be found in Olson et al., 1954. The carbonatite complex is noted for its extremely high rare earth element (REE) concentrations, and samples of the main carbonatite body have been shown to exhibit numerous REE absorption features in the 0.4 to 2.5 μm wavelength range (Fig. 2; Rowan et al., 1986). Because of the REE and other mineral absorption features, the complex provides an especially useful test area for assessing AVIRIS's spectral measurement capabilities. AVIRIS data have also been requested, but not obtained, for two additional carbonatite complexes, Iron Hill, Colorado, and Oka, Quebec, which contain lower rare earth concentrations and represent different exposure and weathering conditions. Emphasis in this evaluation is placed on characterizing the AVIRIS instrument behavior during the Mountain Pass overflight, and on describing various spectral observations and data calibration techniques.

DATA ACQUISITION

Three flightlines of AVIRIS data (Fig. 1) were acquired by the NASA ER-2 aircraft under clear sky conditions at approximately 11:00 A.M., July 28, 1987. Digital tapes of the raw data and the radiometrically corrected, spectrally resampled data with related calibration files were received from the Jet Propulsion Laboratory (JPL) during November, 1987. All of the data analysis discussed in this report was conducted for flight line 2, which covered five areas selected as ground calibration targets. The targets included: (1) an asphalt parking area approximately 1 km southwest of Mountain Pass, (2 & 3) an area of alluvium and a playground at the Mountain Pass school, (4) the Ivanpah playa located 20 km east of Mountain Pass, and (5) a plowed field near Valley Wells station located 15 km west of Mountain Pass (fig. 1). The JPL Portable Instant Display and Analysis Spectrometer (PIDAS) and the U.S. Geological Survey's IRIS spectrometer manufactured by Geophysical Environmental Research, Inc.,* were used to record in situ reflectance spectra for each of the calibration targets during the overflight. In addition, spectra for 27 field samples were remeasured in the laboratory using a Beckman UV 5240 spectrophotometer equipped with an integrating sphere. The AVIRIS image data were analyzed using the JPL Spectral Analysis Manager software package in conjunction with other image enhancement and statistical software programs developed at the U.S. Geological Survey.

RESULTS

Signal to Noise Analyses

Signal to noise estimates for the line 2 radiometrically corrected and spectrally resampled data were made by selecting a target area of 35 pixels within the Ivanpah playa, which provided a relatively bright target that was known from field and laboratory measurements to be very uniform spectrally. The average playa reflectance from 0.7 to 2.4 µm is 40 percent ± 6 percent. At shorter wavelengths the playa reflectance diminishes sharply due to iron oxide absorption. Using the block of 35 pixels, the mean digital number (DN) and the standard deviation were calculated for each of the 210 spectral channels. The mean DN divided by the standard deviation, a value known as the coefficient of variation, provides an empirical measure of signal to noise. Figure 3 plots coefficients of variation versus channel number for 84 representative AVIRIS channels.

The dark current (DC) data recorded after each image scanline were also analyzed statistically to help characterize the in-flight instrument behavior. Such an approach isolates the detectors and the related signal chain electronics from the complicating influences of atmospheric and ground target variations. Coefficients of variation were determined by summing 100 dark current values for each of the 224 detectors. This analysis showed that the detectors in all four AVIRIS spectrometers generally exhibited similar dark current behavior, with three exceptions. Three detectors in the D spectrometer array (raw channel nos.

---

* Brand names are for descriptive purposes only and do not represent an endorsement by the U.S. Geological Survey.

173, 181, and 210) gave anomalous coefficients of variation that were much lower than those calculated for other channels. Two of these channels (181 and 210) were known from previous reports to involve bad detector elements. However, channel 173 was not previously identified as having degraded performance.

To characterize periodic noise in the AVIRIS data, Fourier analysis of the Mountain Pass and Ivanpah image segments was done by forward transforming 64 bands for each segment (32 apiece from the B and D spectrometers), averaging the 32 transformed bands from each spectrometer, and then taking the logarithm of each average to identify noise peaks (Gonzalez and Wintz, 1979). The analysis identified two primary types of periodic noise common to both the B and D spectrometers. The first type exhibits strong horizontal frequency dependence, but only weak vertical frequency dependence (Table 1a). The frequencies in this noise group are related harmonically, characterized by a fundamental period of 28.4 pixels/cycle and missing even-numbered terms. This noise sequence is manifest as the "herringbone" pattern seen in some AVIRIS imagery. Although the Mountain Pass and Ivanpah images generally had similar noise characteristics, the Ivanpah vertical frequencies were somewhat shifted from those observed for the Mountain pass image (Table 1a). The second type of noise is localized horizontally but has no apparent vertical dependence (Table 1b). The highest frequency members of this noise class are responsible for an "odd-even" intensity modulation observed in some image data. This modulation intensifies and fades within each line of data, apparently due to constructive and destructive interference of these frequencies with each other and with the sampling frequency.

Calibration of AVIRIS Data

Despite the noise limitations described above, the AVIRIS data did permit the detection of a variety of spectral absorption features, including REE absorption bands, as well as bands caused by carbonate- and hydroxyl-bearing minerals. To make these observations, it was first necessary to remove atmospheric and solar irradiance effects from the AVIRIS data. Three methods to remove these effects were evaluated: (1) the flat field method, (2) the single spectrum method, and (3) the empirical line method. This report focuses on a comparison between the flat field and single spectrum methods. The empirical line method is discussed in a companion paper by Vane and Green elsewhere in this volume.

The flat field method of calibration has been widely applied in studies involving imaging spectrometer data. In this technique a small area within an image is used to normalize the entire image, i.e. the spectrum for the small area is divided into the spectrum for every other pixel in the scene. The method assumes that the small area contains no absorbing minerals or vegetation, in which case the shape of its remotely sensed spectrum is entirely determined by atmospheric transmission, scattering, and solar irradiance. If this assumption is true, then the normalization procedure will remove the atmospheric transmission, and solar irradiance components from the image data.

Unfortunately, few areas on the earth are spectrally featureless, and the effect of having a weak spectral feature in the normalization area is to remove an equivalent feature throughout the image, thereby changing the intensity and/or distorting other spectral bands of interest (Clark and King, 1987). The single spectrum method of calibration eliminates this major drawback of the flat field technique. The method requires a single spectrally well-characterized ground target, situated at about the average scene elevation. The spectrum for this ground target is divided by the radiometrically corrected, but otherwise uncalibrated, image DN's for the same area. The resulting quotients for each wavelength channel provide a set of scalars for calibrating the image data.

In this study, the flat field and the single spectrum methods were compared by using an area of alluvium as the calibration target for both procedures. Slide no. 10 depicts three curves including (1) an average IRIS spectrum for alluvium, shown in magenta, (2) the uncalibrated image spectrum for the alluvium calibration target, shown in red, and (3) the residual curve formed by dividing (1) into (2), shown in cyan. The subtle differences between curves (2) and (3) in the slide represent the differences between the flat field and the single spectrum calibration methods using the alluvium calibration target. Although these calibration curve differences appear at first to be minor, they produce substantial differences in the appearance of final image spectra. Two pairs of spectra that depict such calibration-related differences are shown in slide 11. The upper two spectra represent a 4 by 4 pixel area within a unit of mica-rich metamorphic rock; the lower two spectra were extracted from a 4 by 4 pixel area in a sedimentary carbonate unit. The top spectrum in each pair was calibrated using the flat field curve, the bottom spectrum using the single spectrum residual curve (refer back to slide 10). Notice the dissimilar shapes of the 2.2 μm absorption feature in the upper two spectra. In the lower two spectra notice the small relative displacement of the 2.3 μm carbonate absorption features. Although it is not presently known which curve in each pair gives the most accurate spectral representation, this calibration exercise does serve to emphasize the need for well-constrained calibration assumptions.

DISCUSSION AND CONCLUSIONS

Signal to noise estimates reported in this initial study of the Mountain Pass, California AVIRIS data generally agree with the pre-flight season estimates determined at JPL (Greg Vane memorandum dated 5/31/88). However, the anomalous behavior of the detector corresponding to raw channel 173 in the spectrometer D detector array apparently was not previously recognized. Although this detector is currently positioned at 1.947 μm, i.e. within an atmospheric water band, the detector behavior might present a problem if the array is swapped into a different spectrometer. One such possibility that has been suggested by others would involve trading detector arrays between spectrometers C and D in order to relocate the bad detectors corresponding to raw channels 181 and 210. This swap would place the questionable channel 173 detector within the water band at 1.36 μm and, therefore, should not raise any data quality concerns.

Our preliminary study of data calibration procedures indicates that the single spectrum calibration method shows considerable promise as an improvement over the flat field procedure. Remaining problems include the need to better characterize the field calibration targets and to define test areas for verifying the calibration results. Additional work is also needed to devise techniques for removing additive calibration terms, such as those related to detector to detector offsets, and atmospheric path irradiance variations with wavelength (R. Green, personal communication). In principle, additive terms can be removed as an initial step in the single spectrum calibration method, i.e., prior to applying the calibration scale factors. The difficulty lies in determining the proper shape of the scattering curve to subtract from the image data. Although atmospheric path irradiance due to Raleigh scattering is a relatively simple function for AVIRIS scenes, irradiance contributions from aerosols and dust are likely to be more complex. In the coming field season we plan to obtain additional field spectra of rock and soil units of the Mountain Pass study area. Using these spectra we will develop techniques for the removal of additive terms from AVIRIS data, and continue to test the single spectrum calibration method.

REFERENCES

Clark, R. N., and King, T. V. V. 1987. Causes of spurious features in spectral reflectance data: in Proceedings of the Third Airborne Imaging Spectrometer Data Analysis Workshop, June 2-4, 1987, Jet Propulsion Laboratory Publication 87-30.

Gonzalez, R. C., and Wintz, P. 1979. Digital Image Processing, Addison-Wesley Pub. Co., Reading, Mass.

Heinrich, E. W. 1980. The Geology of Carbonatites: Robert E. Krieger Pub. Co., Huntington, New York, 585 p.

Olson, J. C., Shawe, D. R., Pray, L. C., and Sharp, W. N. 1954. Rare-earth mineral deposits of the Mountain Pass District, San Bernardino County, California: U.S. Geological Survey Professional Paper 261, DC, 75 p.

Rowan, Lawrence C., Kingston, Marguerite J., and Crowley, James K. 1986. Spectral reflectance of carbonatites and related alkalic igneous rocks: Selected samples from four North American localities: Economic Geology, Vol. 81, p. 857-871.

Table 1a. AVIRIS periodic noises having strong horizontal and weak vertical frequency dependence.

Mountain Pass		Ivanpah
Horizontal norm. freq. (cycles/sample)	Vertical norm. freq. (cycles/line)	Vertical norm. freq. (cycles/line)
.035	.433	.437
.105	.297	.316
.175	.164	.213
.246	.017	.074
.316	.125	.062
.332	.209	.271
.402	.299	.293

Table 1b. AVIRIS periodic noises having horizontal frequency dependence only.

Horizontal norm. freq. (cycles/sample)	
.009	(cont.)
.017	.289
.027	.451
.045	.471
.084	.486
.201	.494

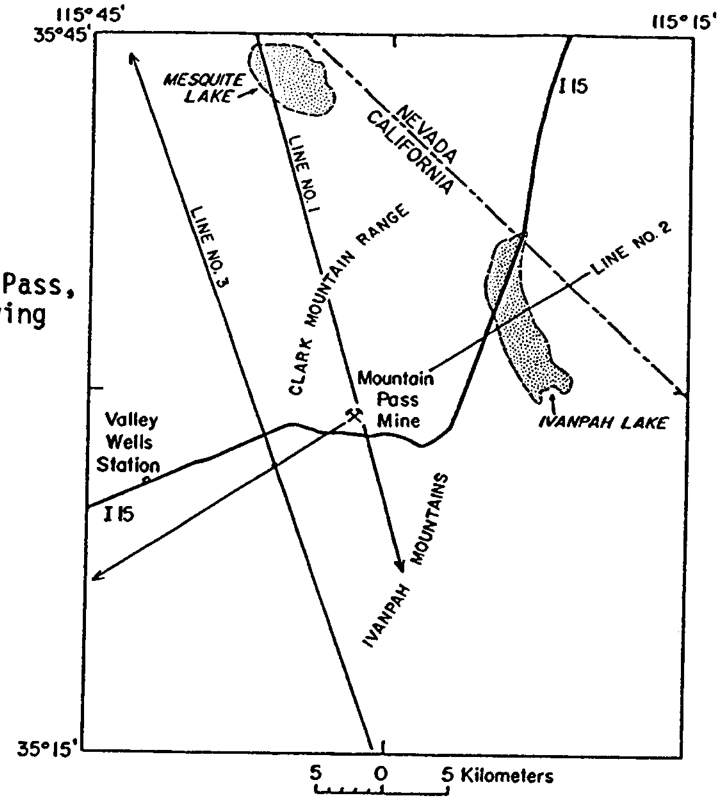

Figure 1. Map of Mountain Pass, California, study area showing locations of the AVIRIS flightlines.

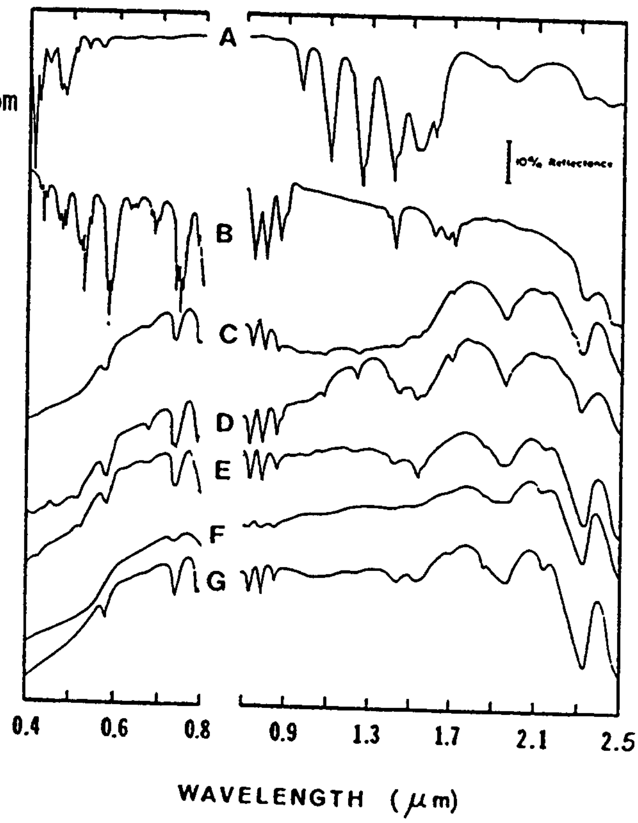

Figure 2. Reflectance spectra of sovite (D, E, F, G) and rauhaugite (C) rock samples from the Sulphide Queen mine and adjacent areas at the Mountain Pass carbonatite complex. Also shown for comparison purposes are spectra for reagent grade Nd_2O_3 (B) and Sm_2O_3 (A) standards. "Sovite" and "rauhaugite" are rock names applied to calcitic and dolomitic carbonatite materials, respectively (Heinrich, 1980). Figure adapted from Rowan et al., 1986.

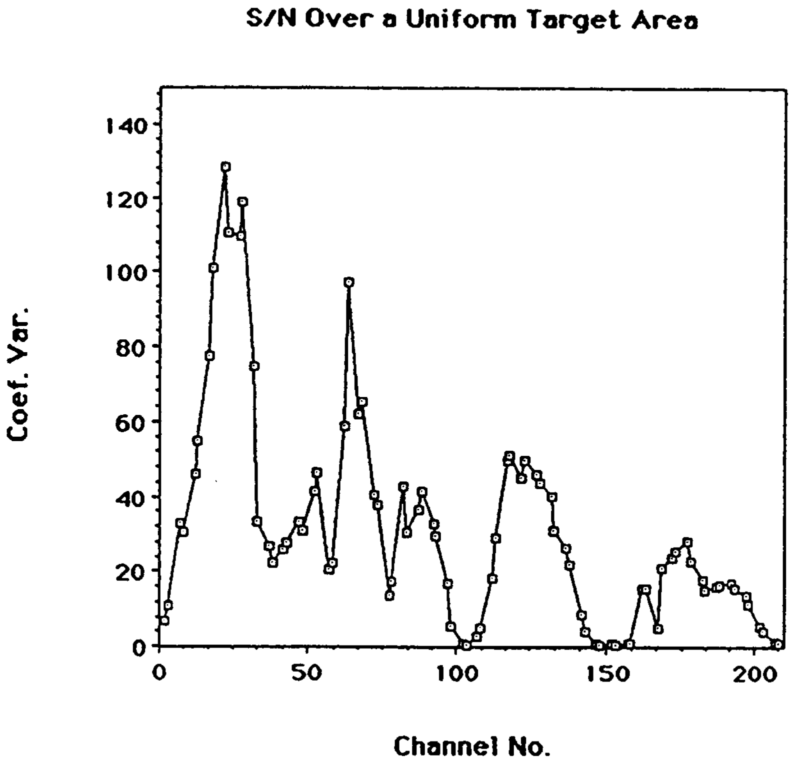

Figure 3. [Above] Signal to noise estimates for resampled AVIRIS data determined by the coefficient of variation method. A uniform area of the Ivanpah playa (35 pixels) was used to determine the coefficient values for each channel. Refer to text for details.

Slide 10 Single spectrum residual compared with original atmospheric curve for alluvium calibration target. Slide located in pocket at end of volume. Refer to text for discussion

Slide 11 Comparison between flat field corrected and single spectrum corrected data. Slide located in pocket at end of volume. Refer to text for discussion.