Preliminary analysis of Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) for mineralogic mapping at sites in Nevada and Colorado

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ABSTRACT

Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data for sites in Nevada and Colorado were evaluated to determine their utility for mineralogical mapping in support of geologic investigations. Initially, the bad data lines were removed by replacing them with the average of adjacent lines. Bad spectral bands were replaced by the average of adjacent bands. The dark signal was subtracted from the data and the data were normalized using an equal energy normalization; a technique commonly used with imaging spectrometer data to reduce albedo effects. Techniques previously used with the Airborne Imaging Spectrometer (AIS) were utilized to reduce the AVIRIS data to internal average relative (IAR) reflectance by dividing the spectrum for each pixel of the image by the global average spectrum for the image. Spectra, profiles, and stacked, color-coded spectra were extracted from the AVIRIS data using an interactive analysis program (QLook) and these derivative data were compared to AIS results, field and laboratory spectra, and geologic maps. Images showing the spatial distribution of specific minerals were made using three band color-composites in the QLook environment. A feature extraction algorithm was used to extract and characterize absorption features from AVIRIS and laboratory spectra, allowing direct comparison of the position and shape of absorption features.

Both muscovite and carbonate spectra were identified in the Nevada AVIRIS data by comparison with laboratory and AIS spectra, and an image was made that showed the distribution of these minerals for the entire site. However, severe signal-to noise problems degraded the quality of all spectra extracted from the AVIRIS data and differentiation between calcite and limestone, and muscovite and montmorillonite, previously demonstrated with AIS data, was not possible using the AVIRIS spectra. Additional, distinctive spectra were located for an unknown mineral. This mineral was also located with AIS data and it is likely a zeolite mineral, however, this has not yet been verified with field or laboratory measurements. For the two Colorado sites, the signal-to-noise problem was significantly worse and attempts to extract meaningful spectra were unsuccessful. Problems with the Colorado AVIRIS data were accentuated by the IAR reflectance technique because of moderate vegetation cover. Improved signal-to-noise and alternative calibration procedures will be required to produce satisfactory reflectance spectra from these data. Although the AVIRIS data were useful for mapping strong mineral absorption features and producing mineral maps at the Nevada site, it is clear that significant improvements to the instrument performance are required before AVIRIS will be an operational instrument.

INTRODUCTION

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) is the first of a second generation of imaging spectrometers. It is a 224-channel instrument measuring surface radiance over the spectral range 0.41 to 2.45 µm in approximately 10 nm-wide bands (Porter and Enmark, 1987). The AVIRIS is flown aboard the NASA U-2 and ER-2 aircraft at an altitude of 20 km, with an instantaneous field of view of 20 m and a swath width of 10 km. It utilizes a linear array of discrete detectors and four individual spectrometers to collect data simultaneously for the 224 bands in a 614 pixel-wide swath perpendicular to the the aircraft direction. The forward motion of the aircraft moves the ground field of view across the terrain.

AVIRIS was flown for two well characterized sites during 1987, one in Nevada and one near Cripple Creek and Canon City, Colorado. The primary objective of this study was to assess the AVIRIS data characteristics and quality and the usefulness of the data for detailed mapping of subtle lithological variation. The AVIRIS data are being evaluated using image and spectrum processing techniques based on known physical properties of geologic materials. The investigation utilizes laboratory, field, and aircraft spectral measurements and geologic data to evaluate selected characteristics of the AVIRIS data. AVIRIS data are calibrated to reflectance and their capability to detect subtle mineralogical variations in the rocks and soils at both test sites is being tested.

PREPROCESSING

Preprocessing of the AVIRIS data is required to obtain spectra that can be compared with laboratory spectra and to allow mineralogical mapping. The AVIRIS data for the sites used in this study were converted to internal average relative (IAR) reflectance (Kruse, 1988) using five preprocessing steps. This conversion has been successfully used with AIS data and does not require *a priori* knowledge of the site. One band of the raw AVIRIS data for each site was read from the tape to preview the data coverage. Because the AVIRIS data sets are very large, a 244 line by 192 sample subscene was selected from the raw band previewed for each site. Sixty four of the AVIRIS raw data bands from the D spectrometer (1.83 to 2.45μm) were used in the study.

The first preprocessing step was to locate bad bands in the AVIRIS data and replace them with the average of adjacent bands. The positions of the bad bands were recorded so interpretations would not be made using those particular bands. The next step in the data processing was the removal of bad data lines. The bad lines were replaced with the average of adjacent lines. The positions of the bad lines were also recorded so as not to be used in the interpretation. Next the dark current file was subtracted from the AVIRIS data set. Because of the high noise level in the dark current file, a running 7 line by 1 band box was used to filter the data. This filtered dark current file was subtracted from the AVIRIS data set. An equal energy normalization was performed next on the AVIRIS data. The normalization was done by calculating a multiplier for each pixel that scales the data to a total image average (Dykstra and Segal, 1985; Kruse, 1987, 1988). This normalization removes albedo differences and topography effects by shifting the spectra to the same relative brightness. The normalized data were finally converted to internal average relative (IAR) reflectance (Kruse, 1988). This method converts the data to a quantity approximating reflectance by dividing the spectrum for each pixel by the overall average spectrum for the image. This technique also removes the major atmospheric features because the average spectrum contains atmospheric features which are divided out of the resulting spectra. Caution must be used when applying the IAR reflectance technique because spurious features can be introduced into the converted spectra if the average contains strong absorption features related to the surface composition. The average spectrum for the Nevada site did not show any of these absorption features. The Cripple Creek average data, however, had strong vegetation features which produced unusual spectra not characteristic of geologic materials.

DATA ANALYSIS

A new software package called "QLook" developed by the United States Geological Survey in Flagstaff, Arizona and enhanced by CSES was used for the AVIRIS data analysis. QLook is a software package that allows interactive analysis of imaging spectrometer data. This software runs under the Transportable Applications Executive (TAE) on MicroVAXII computers utilizing GKS graphics and an IVAS 1024 display device. QLook can handle up to three million pixels at one time and needs 12 megabytes of address space. Using a subscene containing 244 lines and 192 pixels allows 64 bands to be viewed at once.

The IVAS display device has a 1024 by 1024 monitor which shows the AVIRIS subscene zoomed by four. This allows individual pixels to be selected for the spectral analysis. Part of the IVAS display shows a spatial image and the rest of the display shows a stacked, gray-scaled or color-coded spectral image (Marsh and McKeon, 1983; Kruse, 1987, 1988). The stacked spectra correspond to a slice through the spatial image which can be interactively selected in real time using the mouse. The mouse also controls the spatial location, band, and stretch being viewed. A movie stepping through all the bands of the spatial image can be displayed. A three band color composite can be selected and displayed as the spatial image or the stacked spectra and black and white image can be psuedocolored with four different look-up-tables.

The GKS graphics software is used to plot the spectrum for the pixel at the current cursor position. A window with information about the currently viewed bands is displayed along with a window containing the stretch plot. Individual spectra can be selected and saved in another window for comparison. An average spectrum from a group of pixels can be calculated and saved in a table along with the standard deviation and minimum and maximum values. The data in this table is used as input into the feature extraction routines.

One difficulty confronting researchers is that the immense volume of data collected by imaging spectrometers prohibit detailed manual analysis. CSES is developing automated techniques for analysis of imaging spectrometer data that emulate the analytical processes used by a human observer. Automatic absorption feature extraction algorithms have been developed that allow subjective characterization of absorption bands. A continuum is defined by identifying high points in the spectrum and fitting straight line segments between the high points. The continuum is removed from the data using division. The low points of the resulting spectrum are identified and the position, depth, and width of the absorption bands are determined (Kruse and Calvin, 1988). These results are input into an expert system which identifies the minerals based upon facts and rules derived from labatory spectra.

Northern Grapevine Mountains, Nevada

The Nevada study area in the northern Grapevine Mountains has been studied in detail using conventional geologic mapping, geochemistry, field and laboratory reflectance spectroscopy, and imaging spectrometers (Raines and others, 1984; Wrucke and others, 1984; Kruse, 1987, 1988). Precambrian bedrock in the area consists of sedimentary (limestone, dolomite) and metasedimentary rocks (marble, hornfels, skarn). Mesozoic plutonic rocks include quartz syenite, a quartz monzonite porphyry stock, and quartz monzonite dikes. Tertiary volcanic rocks (primarily Timber Mountain Tuff, Wrucke and others, 1984) are abundant around the periphery of the study area. Quaternary deposits include Holocene and Pleistocene fanglomerates, pediment gravels, and alluvium.

The Mesozoic rocks are cut by narrow north-trending mineralized shear zones containing sericite (fine grained muscovite) and iron oxide minerals. Slightly broader zones of disseminated quartz, pyrite, sericite, chalcopyrite, and fluorite mineralization occur in the quartz monzonite porphyry. This type of alteration is spatially associated with fine-grained quartz monzonite dikes. There are several small areas of quartz stockwork exposed at the surface in the center of the area. Skarn, composed mainly of brown andradite garnet intergrown with calcite, epidote, and tremolite, occurs around the perimeter of the quartz monzonite stock in Precambrian rocks.

The Nevada site has been studied in detail using Airborne Imaging Spectrometer (AIS) data (Kruse, 1987, 1988). Figure 1 shows a mosaic of 7 AIS flightlines obtained between 1984 and 1986. AVIRIS data have obvious advantages over AIS because of the 10 km swath width and excellent image geometry. Figure 2 shows part of an AVIRIS image for the Nevada site. The AVIRIS data for this site were reduced to IAR reflectance as described in the preprocessing section. The QLook program was used to extract spectra for areas of known mineralogy. Figure 3 shows an AVIRIS spectrum for sericite (fine grained muscovite) compared to a laboratory spectrum of muscovite. Figure 4 shows an AVIRIS carbonate spectrum compared to a laboratory spectrum of dolomite. Both AVIRIS spectra are very noisy, despite the fact that they are averages of several pixels. Sericite and dolomite have very strong absorption features and yet are only marginally identifiable using the AVIRIS data because of the noise. Additional spectra with a broad band near 2.4 µm were located in the AVIRIS data. Similar spectra for an unidentified mineral were also located with AIS data and the mineral is likely a zeolite, however, this has not yet been verified with field or laboratory measurements. Known occurrences of montmorillonite at this site were not identified using the AVIRIS data and it was not possible to distinguish between dolomite and calcite using the AVIRIS. These findings indicate that the AVIRIS data is not as useful as the AIS data for mapping subtle mineralogical variation, primarily because of signal-to-noise problems.

Cripple Creek/Canon City, Colorado

The Cripple Creek mining district is located 21 miles southwest of Colorado springs (Figure 5). The district is hosted by a silica-undersaturated alkalic intrusive complex (Thompson, 1986). The most voluminous rock within the intrusive complex is a phonolitic breccia. This breccia has a bimodal size distribution and contains Precambrian and Tertiary rock fragments. The texture, structure and composition of the suggest a diatreme-like origin showing several root centers and episodes of activity (Wobus and others, 1976). The Pikes Peak Granite borders the Cripple Creek district to the north and is a medium to coarsely crystalline hornblende-biotite granite, locally grading to quartz monzonite. Lode gold mineralization is hosted by the upper Oligocene age phonolitic breccia pipes which have produced over 21 million ounces of gold since discovery in 1891. The objective of the work at Cripple Creek is to identify and map lithological variation related to emplacement of the intrusive rocks and subtle lithological variation caused by hydrothermal alteration. It is expected that the AVIRIS data will contribute to a better understanding of the volcanic center and the processes that localized the gold deposits.

The Canon City Embayment lies 20 miles directly south of the Cripple Creek mining district. It is a large syncline which pitches to the southeast and contains long, continuous surface exposures of sedimentary rocks ranging from Ordovician to Tertiary age (Scott and others, 1978). The sedimentary units include limestones and dolomites, conglomerates, sandstones, siltstones, and shales. The embayment is bounded on the west side by Precambrian granites, gneisses and schists and to the north by Precambrian granodiorite. The Canon City oil field has produced over 14 million barrels of oil since its discovery in 1887. The objective of the work at Canon City is to identify and map lithological variation related to primary sedimentary deposition and subsequent changes produced by surface weathering. It is anticipated that the imaging spectrometer data will provide information about subtle lithological variation within mapped units that will lead to an improved understanding of the conditions of deposition of the sedimentary rock sequence.

The Cripple Creek/Canon City AVIRIS data were reduced to IAR reflectance using the procedures discussed in the preprocessing section. QLook was used to extract spectra from the data and to produce images and stacked, color-coded spectra. No meaningful spectra could be extracted from this data set because of severe signal-to-noise problems. Problems with the Colorado AVIRIS data were accentuated by the IAR reflectance technique because of moderate vegetation cover. Alternative calibration procedures will be required to produce satisfactory reflectance spectra even when the signal-to-noise problems are corrected.

CONCLUSIONS

Software has been developed to correct AVIRIS data for bad lines and bad bands. Additional procedures have been developed for dark subtraction, normalization and reduction to IAR reflectance. IAR reflectance images have been produced, spectra extracted, and minerals identified. Absorption features have been successfully extracted and characterized for AVIRIS spectra using automated feature extraction procedures. First results from the Nevada AVIRIS data for areas of known mineralogy show matches between extracted absorption features and laboratory measurements despite signal-to-noise problems. Initial evaluations of the Colorado AVIRIS data indicate that image geometry is excellent, however, severe signal-to-noise problems have hindered evaluation of spectral characteristics.

Evaluation of the 1987 data will continue, with additional laboratory analysis and field investigations planned for the remainder of 1988 and 1989. Analysis software will be refined and additional algorithms developed. Additional AVIRIS data has been requested for the 1988 flight season and if the improved signal-to-noise is adequate, the data will be re-evaluated for mapping subtle lithological variation.

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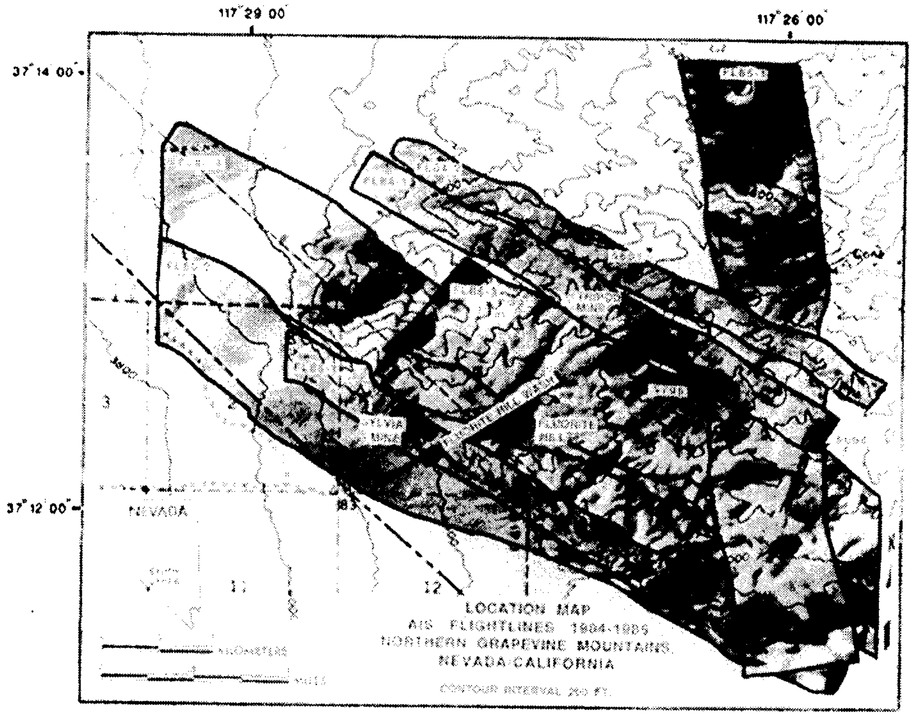

Figure 1 Nevada AIS single band mosaic, 2.0 μm.

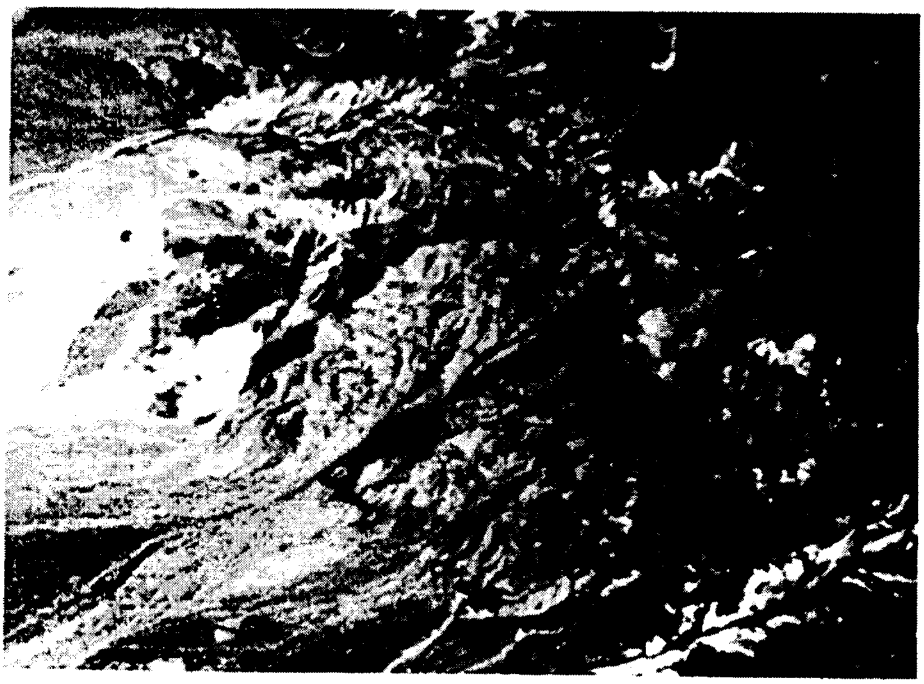

Figure 2 Nevada AVIRIS single band image, band 29, .67 μm.

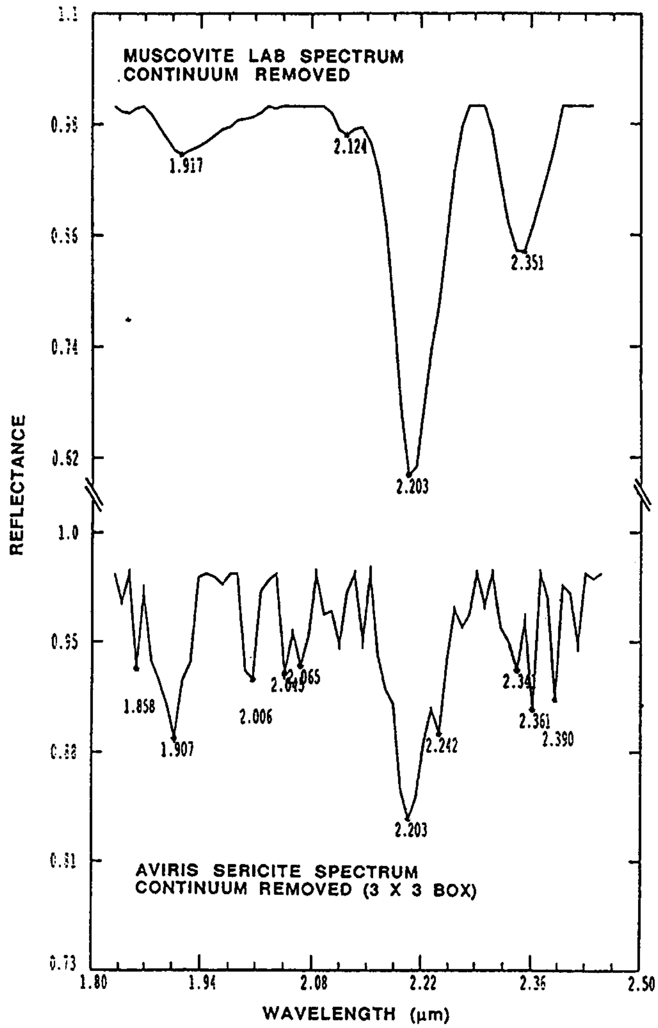

Figure 3. Nevada AVIRIS sericite compared to lab spectrum of muscovite.

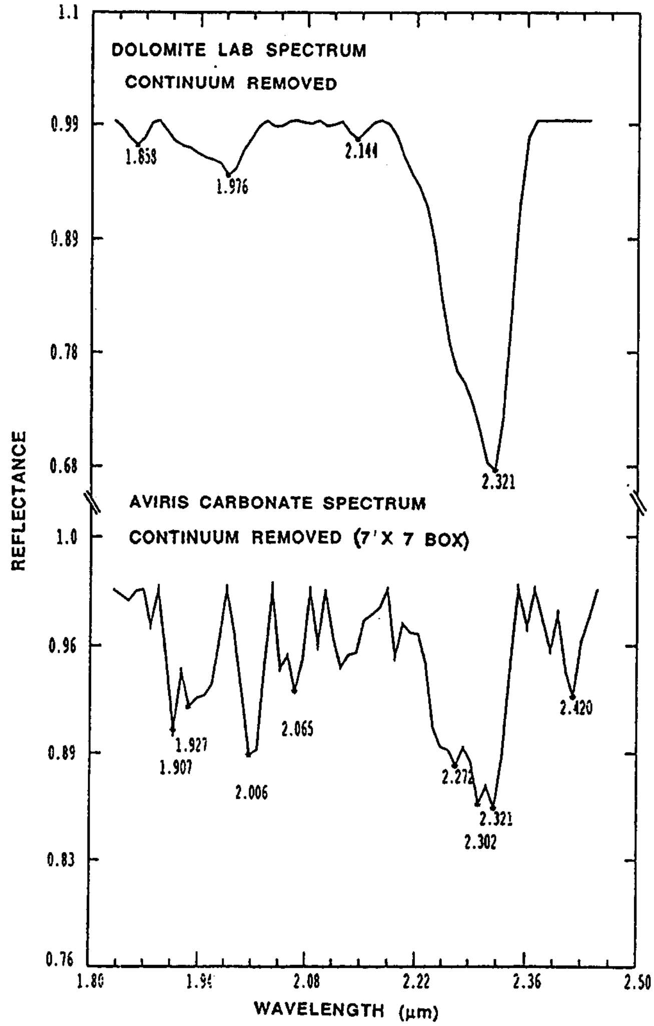

Figure 4. Nevada AVIRIS spectrum compared to lab spectrum of dolomite.

Figure 5. Location of Canon City and Cripple Creek AVIRIS study areas.