ANALYSIS OF AIRBORNE VISIBLE/INFRARED IMAGING SPECTROMETER (AVIRIS) DATA FOR THE NORTHERN DEATH VALLEY REGION, CALIFORNIA/NEVADA**

Fred A. Kruse, Center for the Study of Earth from Space (CSES), Cooperative Institute for Research in Environmental Sciences, (CIRES), University of Colorado, Boulder, CO 80309-0449

ABSTRACT

The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS), a 224-channel imaging spectrometer operating in the 0.41-2.45 μm range, was flown over portions of Death Valley during May 1989 as part of the AVIRIS evaluation program. The data were converted to reflectance using ground spectra and the "empirical line calibration" technique. Reflectance spectra were extracted from the images and compared with both field and laboratory spectra to identify the minerals sericite (fine grained muscovite), calcite, dolomite, hematite, and goethite. Binary encoding of the image spectra was used to produce an image map that showed the spatial distribution of these minerals and combinations of the iron oxides with the other minerals. The image map compared favorably with conventional geologic and alteration maps produced over several field seasons, however, it showed a few previously unmapped carbonate exposures and other areas that will require further field mapping.

INTRODUCTION

This paper summarizes recent results obtained using the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) in the northern Death Valley region, California and Nevada (Figure 1). AVIRIS is an imaging spectrometer measuring reflected light in 224 narrow (10-nm-wide) bands between approximately 0.41-2.45 μm (Porter and Enmark, 1987). Many minerals have diagnostic spectral features in this range (Hunt, 1977, 1979; Hunt and Ashley, 1979; Lee and Raines, 1984; Clark et al., 1990).

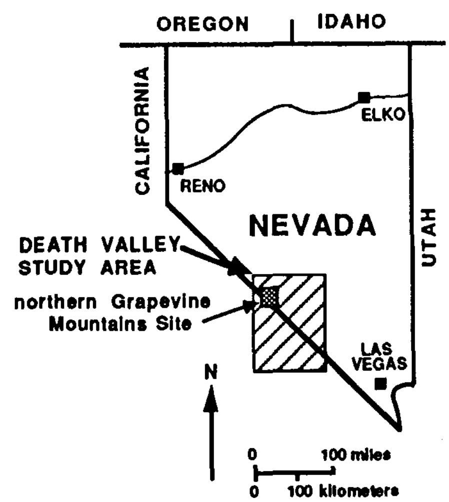


Figure 1. Location map for Death Valley Site.

AVIRIS is flown aboard the NASA ER-2 aircraft at an altitude of 20 km, with an instantaneous field of view of 20 m and a swath width of about 10 km. It utilizes four linear arrays and four individual spectrometers to

** Presented at the AVIRIS Workshop, JPL, 4 June 1990.

collect data simultaneously for the 224 bands in a scanned 614-pixel-wide swath perpendicular to the the aircraft direction (Porter and Enmark, 1987).

AVIRIS is one of several imaging sensors being used at the Center for the Study of Earth from Space (CSES) at the University of Colorado, Boulder, to develop a better understanding of the complex depositional and erosional processes that resulted in formation of the modern land surface in the Death Valley region (Figure 1). The spectral information derived from AVIRIS is being integrated with both thermal infrared and radar images to discriminate lithological variation and the effects of processes such as weathering, erosion, and soil development. The objectives of this research are 1) to use AVIRIS as a tool to assist in detailed lithological mapping, and 2) to evaluate the performance and utility of the AVIRIS sensor.

GEOLOGY

The extreme northern end of Death Valley (northern Grapevine Mountains) California and Nevada (Figure 1), has been studied in detail using conventional geologic mapping, geochemistry, field and laboratory reflectance spectroscopy, Landsat Multispectral Scanner (MSS), Thematic Mapper (TM), the Airborne Imaging Spectrometer (AIS) and detailed field mapping (Wrucke et al., 1984; Kruse, 1988). Precambrian bedrock in the area consists of limestones, dolomites, sandstones and their metamorphic equivalents. Mesozoic plutonic rocks include quartz syenite, a quartz monzonite porphyry stock, and quartz monzonite dikes. The Mesozoic rocks are cut by narrow north-trending mineralized shear zones containing sericite (fine-grained muscovite) and iron oxide minerals. Slightly broader northwest-trending zones of disseminated quartz, pyrite, sericite, chalcopyrite, and fluorite mineralization (QSP alteration) 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 (silica flooding of the rocks) 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. Tertiary volcanic rocks are abundant around the periphery of the study area (Wrucke et al., 1984). Quaternary deposits include Holocene and Pleistocene fanglomerates, pediment gravels, and alluvium.

AVIRIS ANALYSIS

AVIRIS data acquired during May 1989 were analyzed for the northern Grapevine Mountains site. Field spectra of known targets were used to calibrate the data to reflectance with the empirical line method (Roberts et al., 1985). Spectral signatures were extracted using interactive display and analysis software (Torson, 1989) allowing identification of individual minerals and mineral mixtures. Two wavelength ranges of the AVIRIS data were used to identify and map the distribution of minerals. The short-wave infrared data from 2.0 to 2.5 μm was used to identify and map the distribution of clay minerals, muscovite (sericite), and carbonate minerals. The visible and short-wavelength, infrared portions of the spectrum (0.4-1.2 μm) allowed identification and mapping of iron oxide minerals. Figure 2a shows spectra extracted from the AVIRIS data for known occurrences of sericite, calcite, and dolomite. Comparison of the shapes and positions of the absorption features to laboratory spectra makes positive identification of the three minerals possible (Figure 2b). The AVIRIS data not only allow identification of the carbonate-group-minerals, but allow identification of the individual species (calcite and dolomite) based upon a 20-nm (2 channel) difference between the position of the main absorption feature (2.34 vs 2.32 μm, Figure 2).

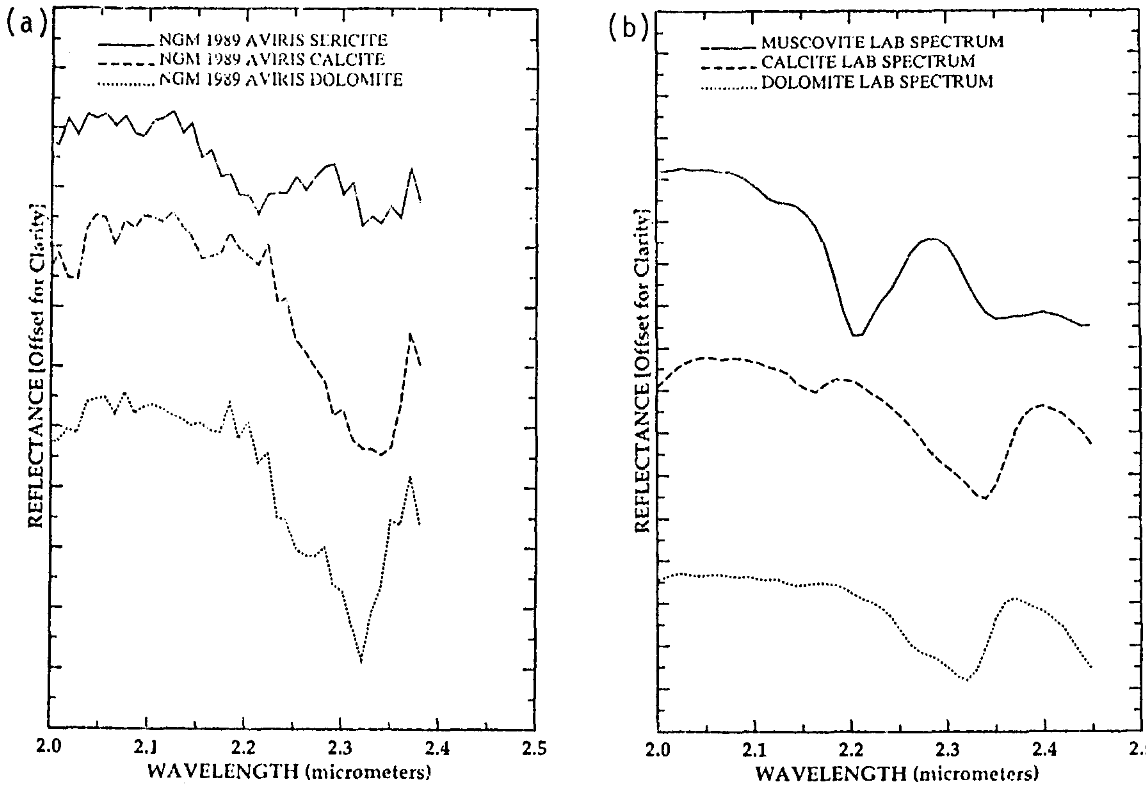
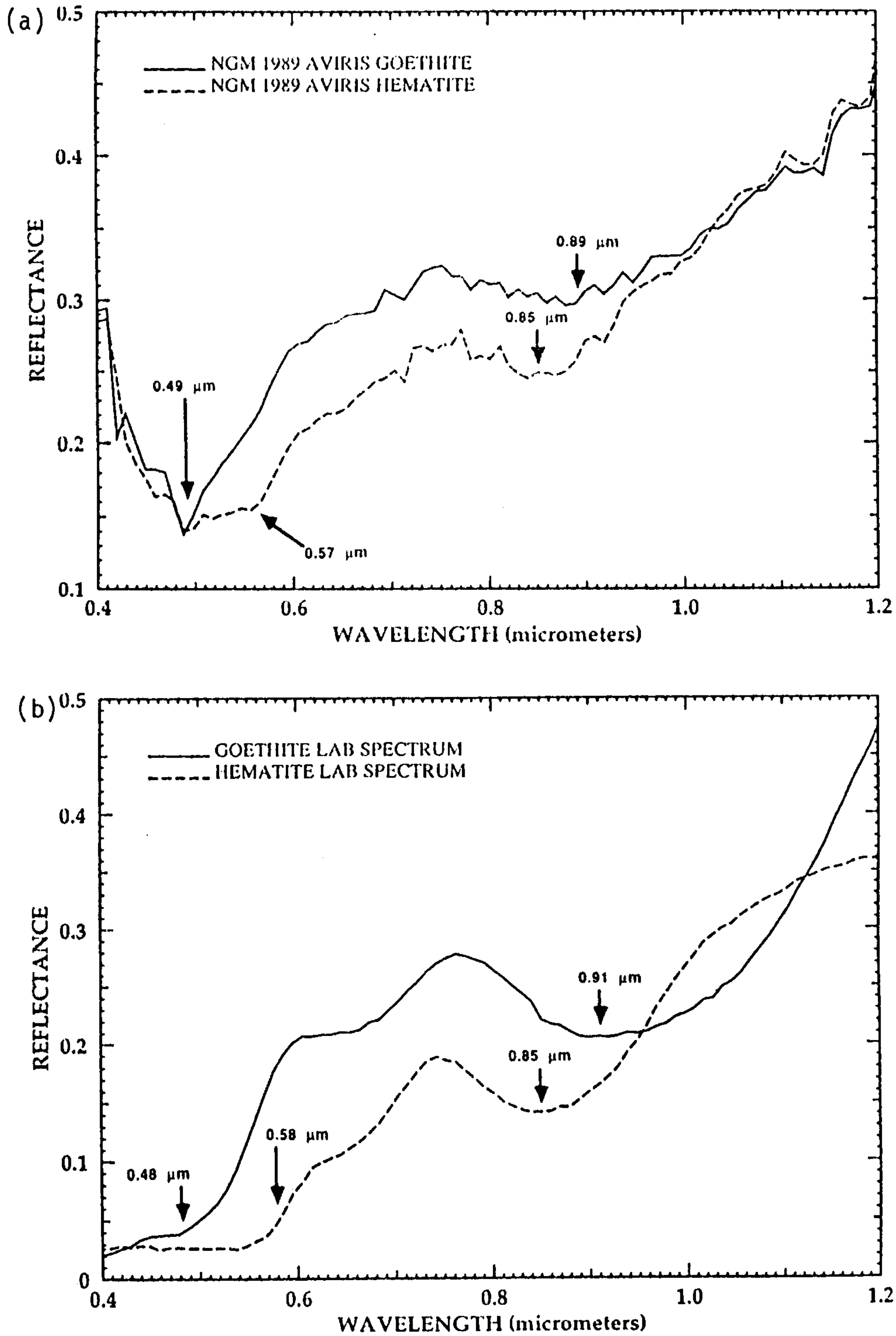


Figure 2. A. AVIRIS reflectance spectra for the minerals sericite (muscovite), calcite, and dolomite; B. Laboratory reflectance spectra convolved to AVIRIS bands for the minerals sericite (muscovite), calcite, and dolomite.

Figure 3a shows spectra extracted from the AVIRIS data for known occurrences of hematite and goethite. Comparison of these spectra to laboratory spectra for goethite and hematite permit positive identification of the two iron oxide minerals (Figure 3b). This distinction has not previously been demonstrated with imaging spectrometer data. Note the positions of the broad absorption feature near 0.9 μm for goethite and 0.85 μm for hema-

Figure 3. A. AVIRIS reflectance spectra for the minerals goethite and hematite. B. Laboratory reflectance spectra convolved to AVIRIS bands for the minerals goethite and hematite.



tite. Note also the position of the visible absorption shoulder near 0.48 μm for goethite and near 0.58 for hematite.

The final step in the analysis of the AVIRIS data was to map the spatial distribution of the minerals identified from interactive inspection of image spectra. The calcite, dolomite, sericite, goethite, and hematite spectra extracted from the image were used as a spectral library for image classification. Binary encoding of the spectrum for each pixel of the AVIRIS image was used to select those areas that closely matched the library spectra (Mazer et al., 1988). Areas that matched within specified tolerances were color coded and overlain on a gray scale image to produce a thematic image map. Mixtures were determined by identifying the individual minerals (using the SWIR to identify sericite and carbonates and the visible to identify the iron oxides) and using standard image processing techniques to combine the classifications where overlap occurred. The final thematic mineral maps provide detailed surface compositional information that can be used in developing geologic models. Color slide 6 is a color coded thematic image map showing the distribution of calcite (red) and dolomite (yellow), based upon the relative position of the ~2.3 μm absorption feature (2.32 μm for dolomite vs 2.34 μm for calcite). The basic distribution of carbonate mineralogy shown has been confirmed by field testing (acid test) and X-ray diffraction (XRD) (Kruse, 1987a, b). The lack of coherent distribution in the carbonate image is attributed to the similarity of the two mineral spectra which make the ~25/1 signal-to-noise of the AVIRIS data in the 2.3 μm region marginal for identification. Additionally, image speckle indicates that the tolerances chosen were probably slightly too high. Color slide 7 is a color coded thematic image map showing the distribution of sericite, carbonates (calcite and dolomite combined as a group), hematite, goethite, and mixtures of the iron oxides with the other minerals. Again, the basic mineralogical distribution has been confirmed by field mapping, spectral measurements, and XRD (Kruse, 1987a, b). The fracture-controlled nature of the quartz-sericite-pyrite (QSP) alteration can be seen as northwest-trending sericite (green) and sericite+goethite (yellow) in the bottom center of the image. This image also shows that goethite is mostly limited to the Jurassic-age intrusive rocks, while hematite is distributed primarily over the Tertiary volcanic rocks (Kruse, 1987a, b).

DISCUSSION

The results discussed above show the link between the physical properties of surface materials and remote sensing in the visible and infrared. Calibrated aircraft data allowed extraction of reflectance spectra that made direct compositional mapping possible. The AVIRIS data covering the 0.41-2.5 μm range permitted identification and mapping of both primary rock forming minerals (calcite and dolomite) and minerals principally associated with hydrothermal alteration (sericite, goethite, and hematite). Comparison of the AVIRIS mineral maps with conventional geologic and alteration maps showed generally good correspondence, however, the

AVIRIS data indicated several areas where further work is required. The AVIRIS analysis demonstrates that improved lithological mapping is possible even where extensive, detailed ground mapping has been completed.

The next step is to use other AVIRIS data collected during the Geologic Remote Sensing Field Experiment (GRSFE) during July 1990 to extend the analysis to a regional scale and to integrate AVIRIS with thermal infrared and radar sensors. We plan to use these data to produce detailed geologic maps that will allow development of regional geologic models for igneous processes such as emplacement of plutons, magma mixing and evolution, spatial variation of igneous phases, and hydrothermal alteration. Additional models will be developed for sediment accumulation, facies variation and migration, and shifting of sediment sources. By better understanding the nature and regional distribution of lithologies, alteration, and weathering products, a comprehensive model will be developed describing the interaction of processes that formed the modern surface in the Death Valley region.

ACKNOWLEDGMENTS

Analysis of the northern Grapevine Mountains AVIRIS data was funded by NASA grant NAGW-1143.

REFERENCES

Clark, R. N., King, T. V. V., Klejwa, M., and Swayze, G. A., 1990, High spectral resolution spectroscopy of minerals: Journal of Geophysical Research, (in press).

Hunt, G. R., 1977, Spectral signatures of particulate minerals in the visible and near-infrared: Geophysics, 42, 3, 501-513.

Hunt, G. R., 1979, Near-infrared (1.3-2.4 μm) spectra of alteration minerals - potential for use in remote sensing: Geophysics, 44, 1974-1986.

Hunt, G. R., and Ashley, R. P., 1979, Spectra of altered rocks in the visible and near infrared: Economic Geology, 74, 1613-1629.

Kruse, F. A., 1987a, Extracting spectral information from imaging spectrometer data: A case history from the northern Grapevine Mountains, Nevada/California: in Proceedings, 31st Annual International Technical Symposium, Society of Photo-Optical Instrumentation Engineers, 834, pp. 119-128.

Kruse, F. A., 1987b, Use of high spectral resolution remote sensing to characterize weathered surfaces of hydrothermally altered rocks:

Unpublished Ph. D. Thesis, Colorado School of Mines, Golden, Colorado, 139 p.

Kruse, F. A., 1988, Use of Airborne Imaging Spectrometer data to map minerals associated with hydrothermally altered rocks in the northern Grapevine Mountains, Nevada and California: Remote Sensing of Environment, 24, 1, 31-51.

Lee, K., and Raines, G. L., 1984, Reflectance spectra of some alteration minerals--a chart compiled from published data 0.4µm-2.5µm: U.S. Geological Survey Open-File Report 84-96, 6 pp., 1 chart.

Mazer, A. S.,Martin, M., Lee, M., and Solomon, J. E., 1988, Image processing software for imaging spectrometry data analysis: Remote Sensing of Environment, 24, 1, 201-210.

Porter, W. M., and Enmark, H. T., 1987, A system overview of the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS): in Proceedings, 31st Annual International Technical Symposium, Society of Photo-Optical Instrumentation Engineers, 834, pp. 22-31.

Roberts, D. A., Yamaguchi, Y., and Lyon, R. J. P., 1985, Calibration of Airborne Imaging Spectrometer Data to percent reflectance using field spectral measurements: in Proceedings, Nineteenth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, October 21-25, 1985.

Torson, J. M., 1989, Interactive image cube visualization and analysis: in Proceedings, Chapel Hill Workshop on Volume Visualization, 18-19 May, 1989, University of North Carolina at Chapel Hill.

Wrucke, C. T., Werschky, R. S., Raines, G. L., Blakely, R. J., Hoover, D. B., and Miller, M. S., 1984, Mineral resources and mineral resource potential of the Little Sand Spring Wilderness Study Area, Inyo County, California: U.S. Geological Survey Open File Report 84-557, 20 p.