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EXPERT SYSTEM-BASED MINERAL MAPPING USING AVIRIS

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1. INTRODUCTION

Integrated analysis of imaging spectrometer data and field spectral measurements were used in conjunction with conventional geologic field mapping to characterize bedrock and surficial geology at the northern end of Death Valley, California and Nevada. A knowledge-based expert system was used to automatically produce image maps from Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data showing the principal surface mineralogy. The imaging spectrometer data show the spatial distribution of spectrally distinct minerals occurring both as primary rock-forming minerals and as alteration and weathering products. Field spectral measurements have been used to verify the mineral maps and field mapping has been used to extend the remote sensing results. Geographically referenced image-maps produced from these data form new base maps from which to develop improved understanding of the processes of deposition and erosion affecting the present land surface.

The "northern Grapevine Mountains" (NGM) study area has been reported on in numerous papers (Kruse et al., 1992, and references therein). This area is an unnamed northwestward extension of the range. Most of the research here has concentrated on mapping of Jurassic-age plutons and associated hydrothermal alteration (Wrucke et al., 1984; Kruse, 1988), however, the nature and scope of these studies is much broader, pertaining to the geologic history and development of the entire Death Valley region.

AVIRIS data for the NGM site were obtained during May 1989. Additional AVIRIS data were acquired during September 1989 as part of the Geologic Remote Sensing Field Experiment (GRSFE) (Evans and Arvidson, 1990). The area covered by these data overlaps slightly with the May 1989 data. Three and one-half AVIRIS scenes total were analyzed.

2. MINERAL MAPPING WITH AN EXPERT SYSTEM

Many naturally occurring materials can be identified and characterized based on their reflected-light spectral characteristics. In geology, the exact positions and shapes of visible and infrared absorption bands are different for different minerals, and reflectance spectra allow direct identification. The objective of this work was to use an expert system approach based on known mineral absorption bands to perform automated mineral mapping using AVIRIS as the first step to detailed geologic mapping and analysis.

Because of the large volume of data that is generated by imaging spectrometers and its unique spectral/spatial nature, development of automated data reduction and analysis capabilities is required to allow extraction of useful information. As part of the research described here, an expert system was developed that allowed automated identification of Earth surface materials based on their spectral characteristics in imaging spectrometer data. A spectral library of laboratory spectral reflectance measurements was

used to develop a generalized knowledge base for analysis of visible and infrared reflectance spectra. Spectral features were digitally extracted from a spectral library containing a suite of 28 common minerals (Kruse, unpublished data) and both green and dry vegetation. Numerical analysis and characterization of the digital reflectance measurements were used to establish quantitative absorption band criteria (wavelength position, band depth, FWHM, and asymmetry) for identifying minerals, mineral mixtures, and vegetation. These procedures are described in detail in Kruse (1990).

The expert system was used to analyze the AVIRIS data to automatically identify minerals and to map their spatial distributions. The absorption feature positions and shapes of each reflectance spectrum for each pixel were characterized using the automated techniques. The features attributed to a specific mineral were assigned weighting factors between 0 and 1 depending upon whether they were required to identify the mineral (must-have, weight=1), were likely to occur in the specific mineral (should-have, weight=0.6) or might be present (may-have, weight=0.3). The weights chosen were arbitrary and have no direct physical meaning. The features found in a particular pixel were then compared to the expected features for each spectrum in the library. For example, if a specific mineral was expected to have three absorption features with respective weights of 1.0, 0.6, and 0.3 (must-have, should-have, and may-have) and it only had two of the features (say the 1.0 and the 0.3 features) then the probability of occurrence of that specific mineral could be represented as $(1.0+0.3)/(1.0 + 0.6 + 0.3) = 0.68$.

To help deal with some of the noise in the AVIRIS data, the results of the spectral features analysis were then assigned a weight of 0.67 in the final decision images while the results of binary encoding (Mazer et al., 1988) were assigned a weight of 0.33. The final products of the expert system analysis were a "continuum-removed" cube with 224 bands containing all of the continuum-removed spectra calculated from the reflectance data, a "feature" cube containing the wavelength positions, depths, FWHMs, and asymmetries for each pixel for the ten strongest absorption features, and an "analysis cube" showing the location and probability of occurrence of 30 minerals based on the weighted combination of binary encoding, and feature analysis in the expert system. Given calibrated data, automated analysis using the expert system described above can be used to produce a preliminary mineral map for the 30 endmembers in less than one hour for a standard 614 line by 512 pixel AVIRIS scene (on a 30 MIPS-class computer).

3. DISCUSSION OF RESULTS

The expert system and spectral unmixing were run on the NGM and the GRSFE AVIRIS data. In the one area of overlap (at the northern end of the flightlines) there is good agreement in the mineral identifications between the two flightlines. Minerals identified in this area include calcite, dolomite, goethite, hematite, and sericite. The middle one third of the GRSFE AVIRIS flightline consists primarily of Tertiary volcanic rocks (Wrucke et al., 1984). This area is dominated in the AVIRIS data by the mineral hematite, likely the result of surface weathering of mafic minerals in the volcanic rocks. The expert system also identified occurrences of montmorillonite, and jarosite in this region. One possible explanation for the montmorillonite concentrations, which appear oval in shape, is that they are associated with small intrusions. This still requires field verification. The southern one third of this area is dominated by Paleozoic sediments (Oakes, 1977; Wrucke et al., 1984). Detailed examination of the AVIRIS image spectra combined with the expert system, linear unmixing, and photointerpretation were used to subdivide these rocks into several different classes. The most obvious of these are nearly pure dolomite and pure calcite units. Alluvial fans derived from these units show similar spectral features. Several additional dolomite and calcite and mixed carbonate/iron oxide units were defined based on their spectral signatures in the AVIRIS data. The distribution of all these units is remarkably similar to lithologies mapped using classical techniques for a portion of the range (Oakes, 1977). The AVIRIS mapping, however, extends over a much larger region and resulted in high quality mineral maps with a minimum of field work.

4. CONCLUSIONS

An expert system has been developed that allows automated identification of Earth surface materials based on their spectral characteristics in imaging spectrometer data. Automated techniques were developed for the extraction and characterization of absorption features by analyzing a suite of laboratory spectra of some of the most common minerals. Critical absorption band characteristics for identification were defined and these were used to develop facts and rules defining a generalized knowledge base for analysis of reflectance spectra that allowed the computer to make decisions similar to those that would be made by an experienced analyst. The expert system produced image maps from AVIRIS data showing the predominant surface mineralogy. Analysis of the AVIRIS data using the expert system provides a rapid means of assessing surface mineralogy and the maps produced accurately represent the surficial geology.

5. ACKNOWLEDGMENTS

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