MINERAL MAPPING WITH 1995 AVIRIS DATA

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1. INTRODUCTION

This extended abstract outlines preliminary mineral mapping results obtained using 1995 AVIRIS data acquired over the Oatman area of northwestern Arizona. The data were acquired in the summer of 1995 as a part of a "group-shoot" organized by Analytical Imaging and Geophysics and CSIRO. The results reported here, in the workshop presentation and in the full manuscript demonstrate the dramatic improvement in AVIRIS data quality, analysis tools and the associated advancement of quantitative spectral remote sensing. The improved signal to noise of the AVIRIS data, complemented by new data reduction and processing techniques, permits unambiguous mineral identification and spectral unmixing of subpixel targets. Subtle spectral differences observed and enhanced in the data include: calcite/chlorite discrimination; spectral shifting of muscovite absorption features as a result of cation substitution in mineral chemistry; hematite/goethite discrimination and the unraveling of spectral mixtures of alunite, muscovite and kaolinte.

2. DATA PROCESSING

The processing and analysis are briefly outlined here. There are three main phases in the analysis: preprocessing; reduction to apparent reflectance; and partial unmixing for mineral mapping. More detailed descriptions of these methods will be included in the workshop presentation and full manuscript.

2.1 Noise Characterization and Data Quality Assessment

Noise level estimations were made using the spectral radiance data, and the associated dark current imagery. The signal to noise ratios are very high, and coincide with the predictions of AVIRIS performance after the recent numerous improvements. For a fifty percent reflectance target, the apparent reflectance signal to noise ratio is greater than 1000 in the A spectrometer, and more importantly for geological studies, greater than 400:1 in portions of the D spectrometer. We believe these dramatic improvements in instrument capabilities permit new applications of imaging spectrometry for subtle and detailed surficial composition mapping that have been previously infeasible.

While the overall quality of the data is much improved, several small problems were identified. Channels 13 and 35 exhibit apparent spatial misregistrations. These two spectral channels were dropped from all of our subsequent analyses. A small number of pixels exhibit spectral "spikes" caused by dropped bits in the data. These pixels were identified and dropped from subsequent processing.

2.2 Reduction of AVIRIS Radiance to Apparent Surface Reflectance

The stability and precision of the AVIRIS instrument now exceed the accuracy of radiative transfer models such as MODTRAN and 6S. We believe inherent uncertainty in solar irradiance models, atmospheric transmission calculations and instrument calibration techniques limit the ultimately accuracy of theory-based data

reduction schemes. To circumvent this limitation, we have developed a two stage data reduction scheme combining the best aspects of theory-based and ground target-based methods.

First the data are reduced to apparent surface reflectance using a traditional theory-based approach, for example the ATREM program available from the University of Colorado. This first step models and removes the gross effects of solar irradiance and atmospheric scattering and absorption. However, the ATREM-produced spectral exhibit systematic band-to-band errors. These errors appear as "saw-tooth" noise and give the spectra an unnaturally rough or noisy appearance. We suggest these coherent errors are cumulative gain errors, combining errors in the instrument calibration and the atmospheric and solar modeling.

The second stage of the processing employs an empirical method to estimate these cumulative gain errors and to remove them. Drawing on the ideas of ground target-based reduction methods, we seek to identify a set of pixels and to calculate a best-fit gain function that minimizes the RMS error between their spectra and our model of their desired spectral reflectance curves. However, we use only the AVIRIS data for this process, removing the onerous requirement of *a priori* knowledge of ground target reflectance. Using this method, pairs of observed and modeled spectra are developed for thousands of pixels, permitting a very accurate derivation of the ideal gain function that removes the cumulative calibration and model errors. The method is based wholly on the remotely sensed data and requires no ground spectra. After removal of the calculated gain errors the true fidelity of the 1995 AVIRIS data is revealed. The efficacy of analysis methods based upon direct comparison to spectral libraries is greatly improved. Subtle spectral features that were buried in the systematic errors are made visible.

2.3   Partial Unmixing for Mineral Mapping

Identification and mapping of mineral species and other scene components, such as vegetation, was done in two steps. First, the data were compared to reference, or library, spectra of the desired target materials. This comparison was done both manually, using visual spectral interpretation, and automatically, using comparison metrics including correlation coefficients and spectral angles. This first step resulted in sets of image pixels that best match the desired target spectra. The mean spectra of these best-match pixel sets were used as seeds for the second stage of mineral mapping, an iterative partial unmixing process.

Partial unmixing seeks to accurately map the apparent abundance of a known target material in the presence of a background composed of many unknown, and spatially varying, components. The method is related to matched filtering, but extends that technique by incorporating useful attributes of the mixed pixel model. In this application the partial unmixing was performed in an iterative fashion, with convergence to a final solution after two or three iterations. The final result of the process is an optimal spectral signature for the desired material and an apparent spectral abundance image, mapping the spatial distribution of the target material. Combining the results for various materials permits an examination of the mixing characteristics of the scene components and an improved understanding of the surface geology and processes.

3.   GEOLOGICAL RESULTS

The data were processed in two spectral ranges: visible and near infrared (0.4 to 1.0 micrometers) and short wave infrared (2.0 to 2.5 micrometers). Highlights of the results for each spectral region are outlined in this section. A post-analysis field trip is planned for February, 1995. Results of the field verification will be presented at the workshop and in the final manuscript.

3.1   0.4 to 1.0 Micrometer Spectral Range

Hematite, goethite, as well as dry and green vegetation, were mapped using the 0.4 to 1.0 micrometer spectral range. Partial unmixing results for each of these image endmembers were calculated independently using the methods described above. Initial comparison of the AVIRIS-derived mineral maps indicate agreement between the remotely sensed results and spectral measurement of previously acquired field samples. Verification and validation of these results, using field spectrometry and analysis of field samples, are planned for the February field trip.

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3.2   2.0 to 2.5 Micrometer Spectral Range

The dramatically increased signal to noise ratio in the D spectrometer of the 1995 data permits an unambiguous discrimination between calcite and chlorite. Both minerals have strong absorption features near 2.35 micrometers, and past AVIRIS studies have had difficulty separating these two similar minerals. In the 1995 data, a secondary feature, an absorption present in chlorite spectra at 2.26 micrometers, is clearly visible. With these high fidelity data, the spatial distributions of chlorite and calcite were independently mapped. The calcite occurs mainly in a vein system, important for mineral exploration in the area. We believe that subpixel-width calcite veins have been detected and will field check these results in February.

The distributions of three types of hydroxyl-bearing minerals (kaolinite, alunite and muscovite) were mapped. Furthermore, excellent examples of mixed pixels were discovered. Evidence for the accurate unraveling of these mixed pixels is found in the scatterplots of the partial unmixing results, color composite imagery of the apparent abundance images and the spectral signatures of the mixed pixels. The high quality of the 1995 data permits both visual and numerical assessment of the spectral mixing on a pixel-by-pixel basis. Field studies planned for February will investigate areas of relative purity as well as highly mixed areas, for validation of the remotely sensed results.

Within the muscovite results, significant spectra shifting of the main 2.2 micrometer spectral feature is apparent. Pixels dominated by muscovite were identified and examined for spectral feature shifting. The position of the muscovite absorption feature was determined by a nonlinear fitting procedure on each of the muscovite-dominated spectra. The spectral position of the feature ranges from 2.190 to 2.210. The spatial position of the shifted spectra shows a coherent pattern. Initial studies of previously collected field samples indicate a correlation of band position with cation chemistry of the phyllosilicates. Further field and laboratory studies are planned to confirm the chemistry controls and to understand the geological significance.

4.   CONCLUSIONS

The improvements made to the AVIRIS instrument have dramatically increased its capabilities as a tool for quantitative surface composition mapping. The high quality of the data demands new and innovative data reduction and analysis techniques. Subtle surface chemistry effects are now easily mapped. Subpixel targets are detected and identified. Complex spectrally mixed pixels are recognized and unraveled. The investment in improvement of the instrument capabilities has resulted in a dramatic and measurable advancement in the ability of AVIRIS to perform quantitative surface composition, chemistry and mineralogy studies. The incremental improvement in the D spectrometer appears to have crossed some threshold of data quality for mineral mapping uses, opening a wide range of previously infeasible applications.

5.   ACKNOWLEDGMENTS