MINERAL MAPPING USING PARTIAL UNMIXING AT RAY MINE, AZ

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1. Introduction

Imaging Spectroscopy enables the identification and mapping of surface mineralogy over large areas. This study focused on the use of Airborne Visible and Infrared Imaging Spectrometer (AVIRIS) data for environmental impact analysis over Ray Mine, AZ. Using the Spectral Angle Mapper (SAM) algorithm in conjunction with AVIRIS data makes it possible to classify surface materials that are indicative of acid generating minerals. The improved performance of the AVIRIS sensor since 1996 provides data with a high enough signal to noise ratio to characterize multiple image endmembers (>5). In this study we used SAM to map minerals associated with mine generated waste, namely jarosite, goethite, and hematite, in the presence of a complex mineralogical background.

2. Background

If left unmonitored waste products from the mineral extraction industry can create long term environmental problems for both government and industry. Currently the Environmental Protection Agency's (EPA) Advance Measurement Initiative (AMI) is using remote sensing instruments such as AVIRIS to collect data that can be used for detection of pollutants prior to their release by mining operations (EPA, 1997). These releases tend to be associated with natural disasters and/or processes, even though the mine operator has attempted to prevent release under normal conditions. Imaging spectroscopy could provide the mineral extraction industry a new synoptic tool for monitoring mining operations. Enhanced monitoring will allow for better understanding of the materials present within an open pit mine. The availability of spatial data of specific locations of high-risk materials could contribute to the prevention of future unnecessary accidents. Furthermore the synoptic view offered by remote sensing can provide the mining industry an improved understanding of the surface geology within a region of interest for exploration or mine development.

This type of AVIRIS-based target endmember determination was demonstrated by Swayze & Clark (1996) who documented a method for identifying and characterizing acid generating materials associated with hard rock mining. Pyrite is one of the main source minerals for acid drainage. The weathering of pyrite causes sulfide oxidization, which in turn release heavy metals such as Pb, As, Cd, Ag and Zn into the environment. Low pH water, created during the weathering process, reacts with pyrite to release the heavy metals. From these weathering processes the secondary mineral jarosite is created. Though it is not possible to identify pyrite with imaging spectroscopy it is possible to map this weathering product because of the crystal field absorption due to the presence of Fe^{++} in the jarosite crystal structure (Hunt, 1980). Using hyperspectral data analysis to identify and map the abundance of this mineral, it is possible to identify pyrite oxidation zones. Heavy metals can substitute for Fe in the secondary mineral and can be transported into watersheds down stream from mining operations. Once in the watershed the jarosite mixes with higher pH water and the heavy metals precipitate out.

3. Methods

AVIRIS data was acquired in April 1996 as part of an AMI pilot study of Ray Mine, AZ, a copper producing open pit mine. Located approximately 65 kilometers east of Phoenix, AZ, the mine is located within a valley cut by Mineral Creek, a tributary of the Gila River. Copper deposits are likely associated with a hydrothermal alteration zone, but the paucity of publicly available ancillary data makes it difficult to asses in detail the surface geology *a priori*. Ray Mine, a high priority site for EPA Region office 9, was selected as a demonstration site for AMI use of remote sensing instruments for characterizing and monitoring mine generated waste products. We used a scaled down version of the AIG standardized methodology of Kruse & Boardman (1997) for processing of AVIRIS data as summarized below:

3.1 Conversion to Apparent Reflectance

Initial radiance data was inverted to apparent reflectance using a set of radiative transfer spectral feature fitting algorithms and in situ field spectra (Green et al. 1996). Use of a radiative transfer model was necessary to correct for atmospheric effects, so the AVRIS data was comparable to the spectral library reflectance data.

3.2 Spatial Spectral Browsing

Once in apparent reflectance Spatial/Spectral Browsing of Image was possible to compare and contrast spectral differences within the spatial domain of the image. Of particular interest was the open pit and associated mine tailings at Ray Mine itself as well as the watersheds of Mineral Creek and the Gila River.

3.3 Spectral Library Rebuilding

Due to differences in spectral resolution between AVIRIS and the USGS spectral library it was necessary to convolve the spectral library from 420 bands to match the courser resolution of AVIRIS data at 224 bands. Furthermore AVIRIS spectral calibration data is in nanometers whereas the spectral library was in micrometers, so we chose to convert the spectral library to the same units as the AVIRIS data.

3.4 Target Endmember Selection

The following endmembers were selected in order to characterize minerals associated with a hydrothermal alteration zone. All reference endmember spectra were from the USGS mineral spectral library that is included with the ENVI software package. In addition, a SAM classification was done using only the jarosite endmembers.

Spectral Library File Name	Mineral Identification
Jarosit6.spc	Jarosite JR2501 K
Jarosit8.spc	Jarosite WS368 Pb
Chlorit4.spc	Chlorite SMR-13.c 45-60 μm
Dolomit2.spc	Dolomite COD2005
Hematit1.spc	Hematite 2% + 98% Qtz GDS76
Gypsum2.spc	Gypsum SU2202
Kaolini4.spc	Kaolinite KL502 (pxyl)
Montmor5.spc	Montmorillonite CM27

Table 1. Spectral Library Used For SAM Classification

3.5 SAM Classification

Mapping the spatial abundance of the jarosite endmembers was done using the SAM algorithm for a supervised classification. SAM is a vector-based approach to identifying pixels that have the best-matched spectra to the reference endmember spectra. It compares the "spectral angle" between the two spectra and classifies pixels that have the best match. As well as a classified image showing pixels that are the same spectrally, a rule image is created which shows the difference between the reference and image spectra in radians (Kruse and Huntington, 1997). Figure 1& 2 shows rule image for jarosite 8 endmember compared to band 150 of the original image. One limitation to the SAM algorithm is that it classifies only the spectrally pure pixels, and does not address the issue of mixed pixels.

4. Results

Initial analysis of the AVIRIS data set using the SAM supervised classification has mapped large quantities of jarosite within Ray Mine. In particular is a linear feature that runs along the eastern edge of the open pit in a north-south orientation. There are also extensive amounts along the edge of the large tailings pond at the southern end of the open pit. However, these areas are well within the controlled region

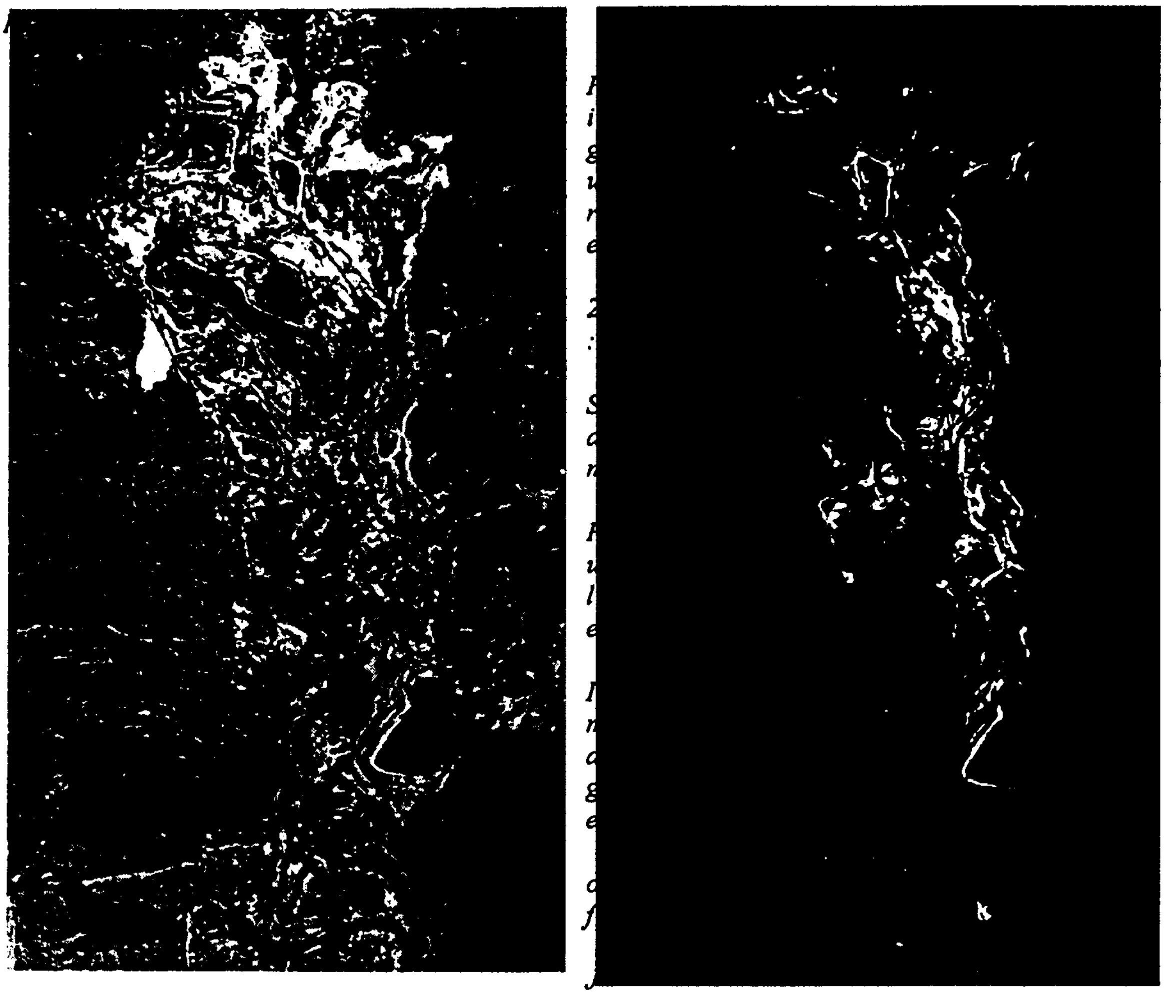

Figure 2: Sam Rule Image of Jarosite abundance within the scene. Lighter pixels are areas classified as jarosite.

of the mining operation and do not appear to be entering into the Gila River watershed. A small region has been mapped outside of Ray Mine (in the bottom right corner of figure 2). From past fieldwork this area was observed to be a defunct mining operation not associated with Ray Mine. Figure 2 shows quantities of jarosite between the abandoned operations and mineral creek, which may be entering the Gila River Watershed. Though the SAM algorithm allowed for identification of pixels that were predominately jarosite, the inability to classify mixed pixels is a drawback. Without mapping all pixels that may contain only a fraction of jarosite prevents a complete understanding of the spatial distribution of all possible zones of weathering pyrite. Future analysis of the Ray Mine data set using Boardman's (1995) Partial Unmixing technique may allow for identification of smaller quantities of jarosite within a pixel.

5. Conclusion

The SAM supervised classification coupled with the methodology put forth by Swayze and Clark (1996) for characterizing acid mine waste as allowed for identification of possible zones of pyrite oxidation within Ray Mine. Furthermore, preliminary results have show that within Ray Mine there are areas of high jarosite concentrations that suggest pyrite alteration. These areas are restricted to the mine confines indicating that acid-generating waste from Ray Mine is not entering Mineral Creek. These results show that Imaging Spectroscopy s a useful tool for the mining industry. It provides an efficient method for mapping open pit mine mineralogy. Understanding the spatial distribution of materials such as oxidizing pyrite helps mine operators prevent releases of environmental contaminants. Beyond the scope of environmental impact prevention and/or analysis, industry may see the use of remote sensing instruments, such as AVIRIS, as a cost saving technique for mineralogical mapping in exploration and mine development.

6. Acknowledgments

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