

MINERALOGIC VARIATIONS IN FLUVIAL SEDIMENTS CONTAMINATED BY MINE TAILINGS AS DETERMINED FROM AVIRIS DATA, COEUR D'ALENE RIVER VALLEY, IDAHO

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1.0 INTRODUCTION

The success of imaging spectrometry in mineralogic mapping of natural terrains (e.g., Clark et al., 1992) indicates that the technology can also be used to assess the environmental impact of human activities in certain instances. Specifically, this paper describes an investigation into the use of data from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) for mapping the spread of, and assessing changes in, the mineralogic character of tailings from a major silver and base metal mining district.

The area under investigation is the Coeur d'Alene river valley in northern Idaho. Mining has been going on in and around the towns of Kellogg and Wallace, Idaho since the 1880's. In the Kellogg-Smelterville Flats area, west of Kellogg, mine tailings were piled alongside the South Fork of the Coeur d'Alene River. Until the construction of tailings ponds in 1968 much of these waste materials were washed directly into the South Fork. The Kellogg-Smelterville area was declared an EPA Superfund site in 1983 and remediation efforts are currently underway. Recent studies (e.g., Horowitz et al., 1992) have demonstrated that sediments in the Coeur d'Alene River and in the northern part of Lake Coeur d'Alene, into which the river flows, are highly enriched in Ag, Cu, Pb, Zn, Cd, Hg, As, and Sb. These trace metals have become aggregated in iron oxide and oxyhydroxide minerals and/or mineraloids. Reflectance spectra of iron-rich tailing materials are shown in Figure 1. Also shown in Figure 1 are spectra of hematite and goethite. The broad bandwidth and long band center (near 1 μm) of the Fe^{3+} crystal-field band of the iron-rich sediment samples combined with the lack of features on the Fe^{3+} -O²⁻ charge transfer absorption edge indicates that the ferric oxide and/or oxyhydroxide in these sediments is poorly crystalline to amorphous in character. Similar features are seen in poorly crystalline basaltic weathering products (e.g., palagonites).

The problem of mapping and analyzing the downriver occurrences of iron rich tailings in the Coeur d'Alene (CDA) River Valley using remotely sensed data is complicated by the full vegetation cover present in the area. Because exposures of rock and soil were sparse, the data processing techniques used in this study were sensitive to detecting materials at subpixel scales. The methods used included spectral mixture analysis (Adams et al., 1993) and a constrained energy minimization technique (Farrand and Harsanyi, 1994a).

2.0 DATA

The CDA River Valley is currently under investigation by the Spokane field office of the USGS (C. Smith, pers. comm.). In a cooperative endeavor between the USGS, the EPA and the Naval Research Laboratory's HYDICE (Hyperspectral Digital Imagery Collection Experiment) Project Office an AVIRIS flight was scheduled over the

CDA River Valley. Data was collected on May 24, 1993 at 21:40 UTC. Incomplete coverage of the target area led to a reflight on September 17 at 19:40 UTC. An earlier paper (Farrand and Harsanyi, 1994b) presented a preliminary examination of two scenes from the May collection. The current paper considers three scenes from the September collection that cover an area extending down river from approximately Smelterville to Killarney Lake (see Figure 2).

The reflectance of samples collected in the field were measured in the laboratory. A subset of the samples were measured at Brown University's RELAB. The majority of the samples were measured on the USGS Reston Beckman (UV5240).

The AVIRIS data were analyzed in a radiometrically calibrated format and also in a format with DN equal to apparent surface reflectance. The conversion from radiance to reflectance was done using both surface reflectance data and the ATREM (Gao et al., 1993) radiative transfer based approach. First the data were converted to apparent surface reflectance through the use of ATREM which effectively removed atmospheric variability. This was followed by the application of a modified flat field (MFF) method (Farrand, 1992) applied to the ATREM corrected data which acted to remove instrumental noise that is retained in the ATREM correction.

3.0 ANALYSIS

The AVIRIS radiance data were initially examined with spectral mixture analysis. An iterative approach utilizing several runs and successive examination of the resulting RMS error images (Adams et al., 1993) suggested four endmembers: shade, vegetation, an agricultural soil, and an iron oxide or oxyhydroxide rich soil. As was discussed above, the iron-rich soil is the most likely candidate for bearing heavy metals leached from the mine tailings. In the fraction image for this endmember, other materials besides the ferruginous soil (for instance, the pavement on I-90) appeared bright on the fraction image.

In order to cut down on the false alarm rate, a recently developed detection algorithm that has already shown good success in detecting distributed subpixel target materials, the constrained energy minimization (CEM) technique (Farrand and Harsanyi, 1994b), was applied to the data. The key to the CEM technique is to determine a vector operator, w composed of weights ($w_1 \dots w_m$) that suppresses the unknown and undesired background spectra while enhancing the target spectrum d . The summed pixel energy can be represented by a scalar value y_i . The CEM operator is defined by two constraints. The first constraint, for any given pixel, is to minimize the energy summed across the wavelength range (e.g., minimize y_i). The second constraint is that when applied to the target spectrum, $y_i = 1$, e.g., $w^T d = 1$.

CEM was applied to subsections of the three AVIRIS scenes. The target spectrum for input to the CEM routine was derived from the data itself. Three pixels most like the BH-3 sample spectrum shown in Figure 1 were identified. The radiance spectra of these pixels were then extracted from a radiance data set that was subsectioned to 188 bands to exclude several of the shortest and longest wavelength bands, spectrometer overlap regions and atmospheric water absorptions at 1.4 and 1.9 μm . These radiance spectra were averaged and the average was used as input to the CEM routine. As might be expected, the resulting CEM component images showed that the iron-rich sediments are concentrated primarily along the CDA River. There were also known concentrations of tailings in a dump west of Smelterville. Weaker responses are returned from some fields in the CDA River Valley.

The CEM routine identified 159 pixels in the three scenes that were most like the iron-rich sediments at Cataldo Flats. These pixels were then extracted from the ATREM+MFF corrected data cube and transformed via a principal components analysis (PCA). The PCA was applied in two parts. 88 VNIR channels were analyzed separately

from 45 SWIR channels. This was done because iron bearing minerals primarily have features in the VNIR and clay minerals primarily have features in the SWIR. By separating the analyses, the resulting intrinsic dimensionality of the data set could be kept to a manageable number of endmembers (e.g., 3 to 4). For purposes of brevity only the VNIR analysis will be discussed here.

The first three principal components of the VNIR analysis were examined interactively using the "XGobi" data visualization program (Swayne et al., 1992). By rotating the data cloud, spectrally extreme endmember pixels could be identified. Two distinct linear trends revealed themselves outlining two ridges of a tetrahedron. Pixel spectra from the ends of these trends (i.e., the vertices of the tetrahedron) are shown in Figure 3. Although the PCA was done on only the first 88 channels, the full spectral range is shown in Figure 3 since, as it turns out, there is extra information to be gained from the SWIR region as well. Figure 3 reveals two similar appearing, but nonetheless distinct, sets of spectra. Both trends have one endmember with a strong "1 μm " Fe crystal field absorption feature and one with only a weak absorption at that wavelength. The spectra, t2em1 and t2em2 appear to be wetter with stronger 1.4 and 1.9 μm absorption features. These spectra also display absorptions indicative of gypsum at 1.48, 1.53 and longwards of 1.7 μm . The presence of the sulfate mineral, gypsum, lends further credence to the interpretation that the ferruginous sediments are contaminated by mine wastes.

4.0 CONCLUSIONS

These results provide encouragement that imaging spectrometer data can be used effectively both to track the spread of fluviially distributed mine tailings and to provide insight into changes in their mineralogic character. An enabling algorithm that aids significantly in this process is the constrained energy minimization technique which, in this instance, provided a unique identification of the ferruginous sediments associated with mine waste contamination.

5.0 REFERENCES

- Adams, J.B., M.O. Smith, and A.R. Gillespie, 1993, Imaging spectroscopy: Interpretation based on spectral mixture analysis. in *Remote Geochemical Analysis: Elemental and Mineralogical Composition*, (C.M. Pieters and P.A.J. Englert, ed.s), Cambridge University Press, New York, pp. 145-166.
- Clark, R.N., G.A. Swayze, and A.J. Gallagher, 1992, Mapping the mineralogy and lithology of Canyonlands, Utah with imaging spectrometer data and the multiple spectral feature matching algorithm. in *Summaries of the Third Annual JPL Airborne Geoscience Workshop: AVIRIS* JPL Publ. 92-14, 11-13.
- Farrand, W.H., 1992, A comparison of methods for retrieving apparent surface reflectance from hyperspectral data. *Proceedings of the International Symposium on Spectral Sensing Research*, pp.1154-1164.
- Farrand, W.H. and J.C. Harsanyi, 1994a, Mapping distributed geological and botanical targets through constrained energy minimization. *Proc. Thematic Conf. Geol. Remote Sens. 10th*, 419-429.
- Farrand, W.H. and J.C. Harsanyi, 1994b, An examination of mine waste contamination in the Coeur D'Alene River Valley, Idaho using imaging spectrometer data. in *Proc. ISSSR '94* (in press).
- Gao, B.-C., K.B. Heidebrecht, and A.F.H. Goetz, 1993, Derivation of scaled surface reflectances from AVIRIS data. *Rem. Sens. Env.* 44, 165-178.
- Horowitz, A., K.A. Elrick, and R.B. Cook, 1992, Effect of mining related activities on the sediment trace element geochemistry of Lake Coeur d'Alene, Idaho, USA: Part 1. Surface sediments, U.S. Geological Survey Open-file Report 92-109, 30 pp.
- Swayne, D.F., D. Cook and A. Buja, 1992, User's manual for XGobi, *Bellcore Technical Memorandum*

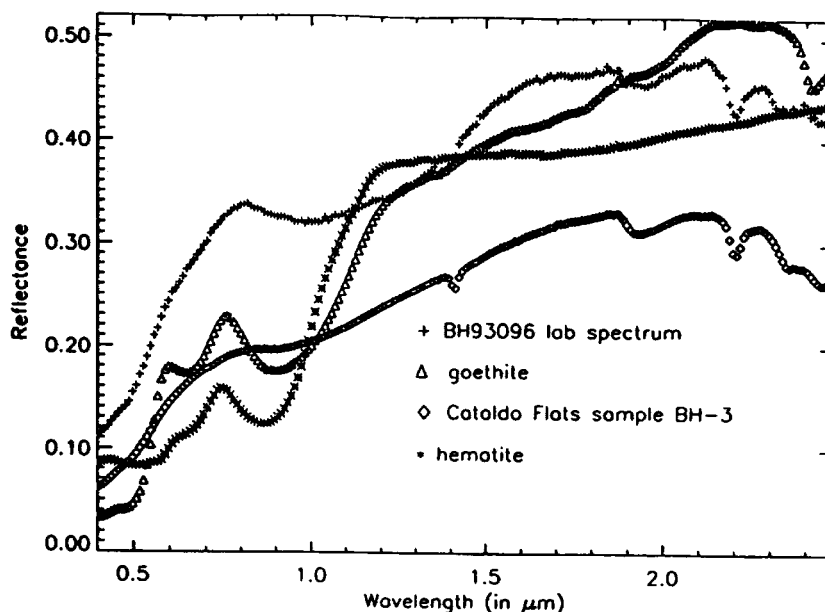


Figure 1. Laboratory reflectance spectra of iron-rich sediments collected near the Coeur d'Alene River compared against library spectra of goethite and hematite.

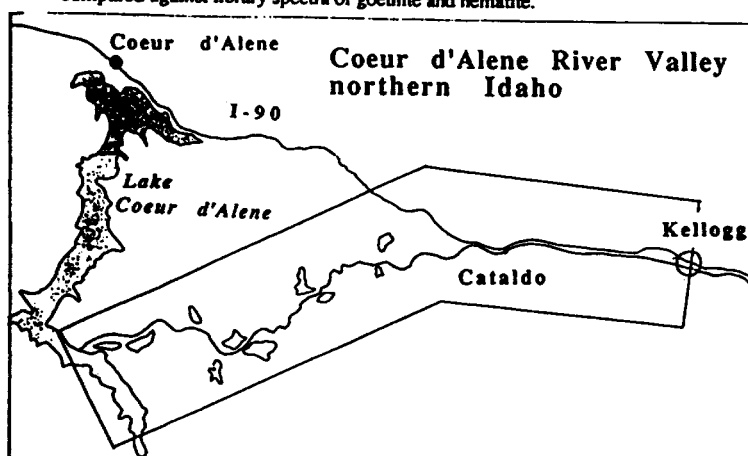


Figure 2. Sketch map of Coeur d'Alene River Valley in northern Idaho. The AVIRIS flightlines are outlined by the box.

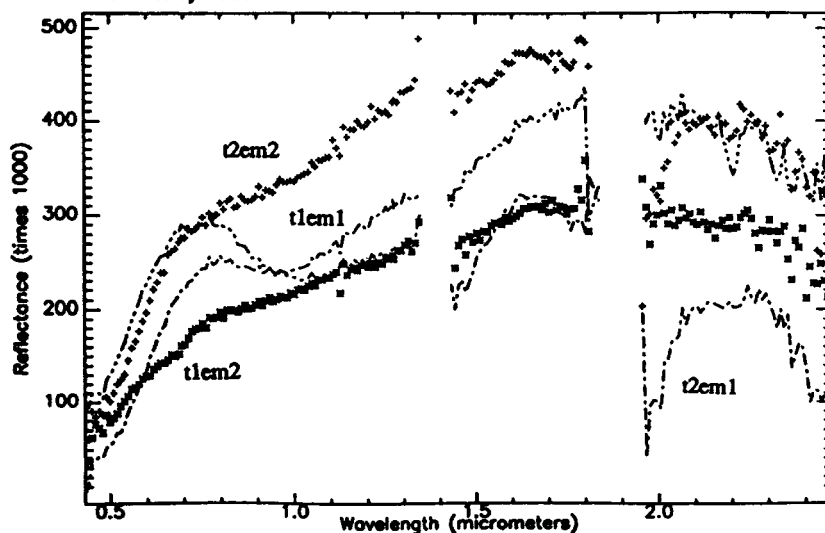


Figure 3. Iron-rich sediment endmembers determined from PCA of VNIR channels and interactive data analysis.