DISCRIMINATION OF POORLY EXPOSED LITHOLOGIES IN AVIRIS DATA

William H. Farrand and Joseph C. Harsanyi

HYDICE Project Office
Naval Research Laboratory, Code 9120
Washington, DC 20375

1. INTRODUCTION

One of the advantages afforded by imaging spectrometers such as AVIRIS is the capability to detect target materials at a sub-pixel scale. This paper presents several examples of the identification of poorly exposed geologic materials- materials which are either subpixel in scale or which, while having some surface expression over several pixels, are partially covered by vegetation or other materials.

Sabol et al. (1992) noted that a primary factor in the ability to distinguish sub-pixel targets is the spectral contrast between the target and its surroundings. In most cases, this contrast is best expressed as an absorption feature or features present in the target but absent in the surroundings. Under such circumstances, techniques such as band depth mapping (Clark et al., 1992) are feasible. However, the only difference between a target material and its surroundings is often expressed solely in the continuum. We define the "continuum" as the reflectance or radiance spanning spectral space between spectral features. Differences in continuum slope and shape can only be determined by reduction techniques which consider the entire spectral range; i.e., techniques such as spectral mixture analysis (Adams et al., 1989) and recently developed techniques which utilize an orthogonal subspace projection operator (Harsanyi, 1993). Two of the three examples considered herein deal with cases where the target material differs from its surroundings only by such a subtle continuum change.

2. LOW PROBABILITY DETECTION BASED ON ORTHOGONAL SUBSPACE PROJECTION

The goal of the investigations discussed herein is to discriminate a given lithology of spectral signature, d. Ideally, this goal could be accomplished by suppressing the spectra of background materials and maximizing the SNR of the signature of interest. Recent work by Harsanyi and Chang (1993) and Harsanyi et al. (1993) has outlined a method for achieving this goal through the technique of orthogonal subspace projection.

For greater detail, the reader is referred to the above references; however in brief, the equation for a mixed pixel composed of desired and undesired spectral signatures can be written as:

$$L = da + Ug + n \tag{1}$$

where d is the desired spectral signature of the lithology of interest, a is the desired signature abundance, U is a matrix whose columns are the undesired spectral signatures, and g is a vector containing the abundances of the undesired signatures. The vector n is assumed to be Gaussian noise which is independent and identically distributed.

In the case where the columns of U are known, an orthogonal subspace projection operator, P can be constructed:

$$P = (I - UU^{\#}) \tag{2}$$

where $U^{\#} = (U^T U)^{-1} U^T$ is the pseudoinverse of U. Multiplying this operator against every term in equation (1) has the effect of eliminating the Ug term thereby leaving only a transform of the desired target signature.

When the columns of U are not known, an estimate of their contribution can still be gleaned from the data. In this case, an estimate of the projection operator in equation 2 can be obtained from the first and second order statistics of the scene or scene subsection being processed. It is shown in Harsanyi (1993) and Harsanyi et al. (1993), that an operator:

$$w^T = d^T \tilde{P} \tag{3}$$

can be formed which will not only act to null the unknown, undesired background signatures, but also will maximize the SNR of the desired low probability target spectrum.

A drawback of the low probability detection algorithm is that the target material does, in fact, have to be a minor component in the scene. That is to say not present in enough pixels to be used as an endmember.

3. STUDY AREAS AND PRELIMINARY RESULTS

Three areas were examined in this study from three separate AVIRIS collections. These areas are: the Lunar Crater Volcanic Field (LCVF) of northern Nye County, Nevada; an area south of Mono Lake in Mono County, California; and a section along the Couer d'Alene river valley in Kootenai County, Idaho. The LCVF data were acquired on October 9, 1992, the Mono Lake data were acquired on August 20, 1992 and the Couer d'Alene data on May 24, 1993. All three data sets were acquired within an hour of solar noon.

The lithology being sought in the LCVF was a palagonite tuff exposed within the walls of the Easy Chair Crater tuff and cinder cone. Significant exposures of the palagonite tuff are restricted to two outcrops on the western rim of the crater. The exposures of tuff extend along the crater wall for as much as 100 m, with notable vertical exposure, but from an overhead perspective, the latitudinal extent of the tuff outcrop is only on the order of 5 to 8 m. The crest of the crater rim is covered by thinly bedded tuffs, cinders, grasses and scrub brush. In the area surrounding the crater are alluvial deposits derived from rhyolitic tuffs. Spectra of the palagonite tuff and several background materials are shown in Figure 1. Figure 2 compares a reflectance spectrum extracted from the AVIRIS data (the data were converted to reflectance via the empirical line method) over a tuff rich pixel with an average of several sample spectra measured on the RELAB laboratory spectroradiometer. The fact that the AVIRIS-derived spectrum is different from that of samples measured in the laboratory demonstrates that the tuff is present only at a subpixel scale.

In the area examined that was south of Mono Lake, the lithology of interest was the Bishop Tuff. South of the study area the Bishop Tuff becomes the dominant lithology; however, in the area of interest outcrops of Bishop Tuff are small and sporadic and occur generally on a subpixel scale although isolated exposures can fill the pixel. The Bishop Tuff reflectance spectrum closely resembles that of Quaternary aeolian and alluvial materials in the area; thereby complicating the detection problem.

Ferric oxide rich mine tailings spread along the Couer d'Alene river valley are the target of the third investigation. Downriver detection of these tailings becomes extremely difficult, because while the material is spectrally distinct from its surroundings, it is very poorly exposed due to the abundant vegetation in the area.

A routine written in IDL (RSI, 1992) that implements the low probability detection algorithm was applied to subsections of the aforementioned scenes including the LCVF subsection shown in Fig. 3. The low probability detection output image in Fig. 4, demonstrates an excellent discrimination of the palagonite tuff outcrops in the wall of Easy Chair Crater. Examples from the Mono Lake and Couer d'Alene scenes will also be shown.

4. ACKNOWLEDGMENTS

The authors are grateful to R.O. Green of JPL for providing the LCVF and Couer d'Alene AVIRIS data and to Chris Elvidge of DRI for the Mono Lake data. Thanks also to Steve Pratt of Brown University for the RELAB spectra.

5. REFERENCES

Adams, J.B., M.O. Smith, and A.R. Gillespie, 1989,"Simple models for complex natural surfaces: A strategy for the hyperspectral era of remote sensing". *Proc. IEEE Int. Geosci. Rem. Sens. Symp. '89*, I, 16-21.

Clark, R.N., G.A. Swayze, and A. Gallagher,1992, "Mapping the mineralogy and lithology of Canyonlands, Utah with imaging spectrometer data and the multiple spectral feature mapping algorithm". *Summaries of the 3rd JPL Airborne Geoscience Workshop*. (R.O. Green, ed.) JPL publ.92-14, vol. 1, 11-13.

Harsanyi, J.C., 1993, *Detection and Classification of Subpixel Spectral Signatures in Hyperspectral Image Sequences*, Ph.D. Dissertation, University of Maryland, Baltimore County, 112 pp.

Harsanyi, J.C. and C.Chang,1993, "Hyperspectral image classification and dimensionality reduction: An orthogonal subspace projection approach". (submitted to) *IEEE Trans. Geosci. Rem. Sens.*

Harsanyi, J.C., W.H. Farrand, and C.Chang,1993, "Detection of low probability, subpixel targets in hyperspectral images with unknown backgrounds". (in preparation for) *IEEE Trans. Geosci. Rem. Sens.*

Research Systems, Inc., 1993, IDL User's Guide Version 3.0, Boulder, CO.

Sabol, D.E., J.B. Adams, and M.O. Smith,1992, "Quantitative subpixel spectral detection of targets in multispectral images". *J. Geophys. Res.*, **97**, 2659-2672.

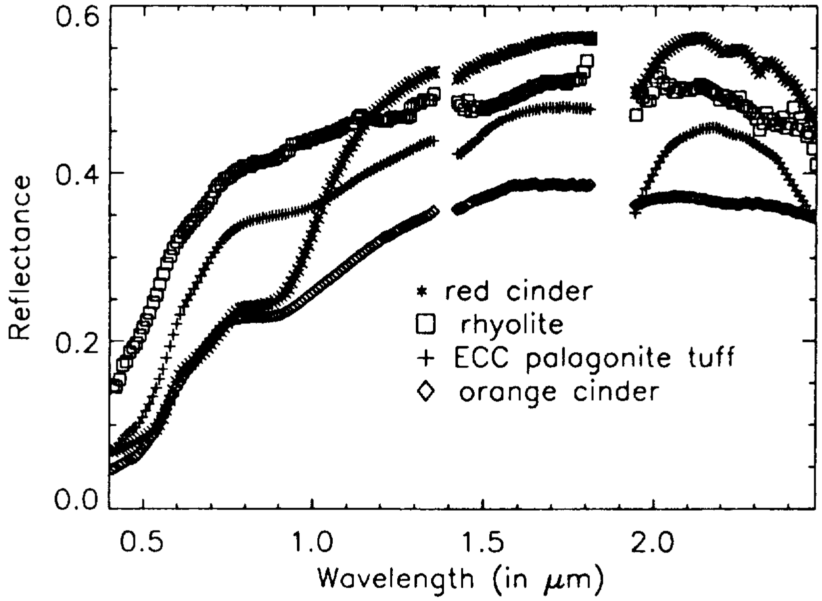

Figure 1. Reflectance spectra of geologic units at or near Easy Chair Crater. The greatest potential for confusion is between the tuff, rhyolite and orange cinder.

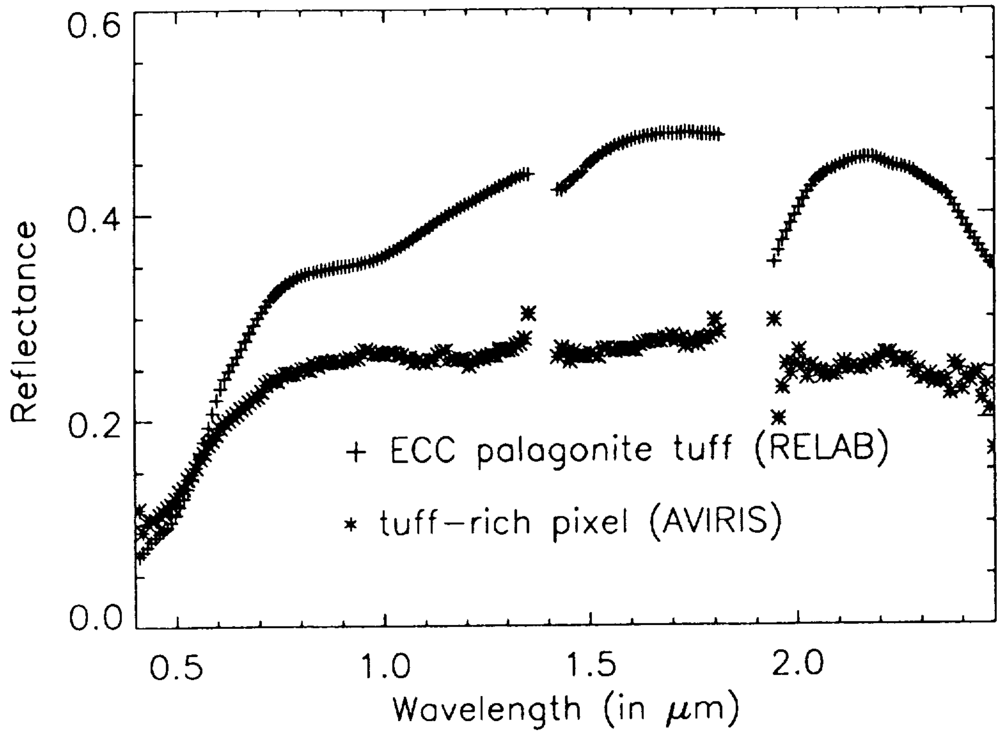

Figure 2. Average of 5 tuff sample spectra measured at RELAB compared with tuff-rich pixel spectrum extracted from AVIRIS data. The disparity demonstrates that the tuff is present at a subpixel scale.

Figure 3. 1.611 μm AVIRIS channel subsection containing Easy Chair Crater. Oxidized basaltic cinders are bright as are dry wash deposits. Arrows indicate subpixel scale tuff outcrops in crater walls.

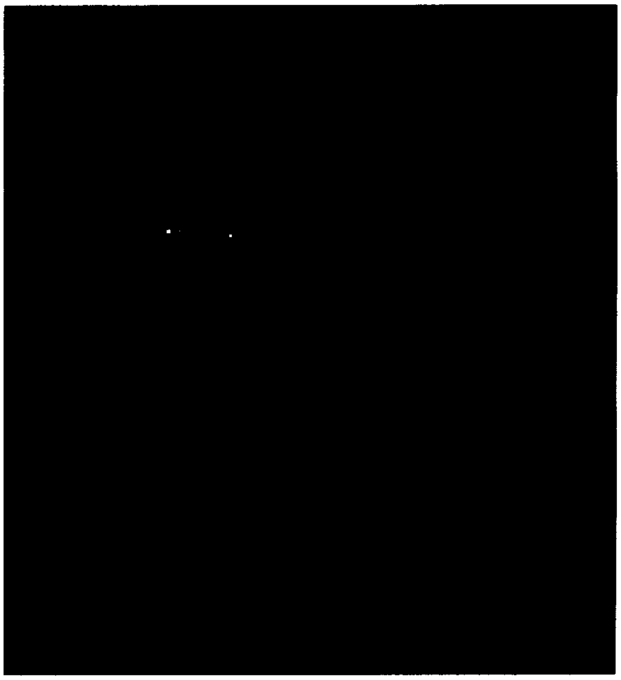

Figure 4. Low probability detection algorithm output image. The two tuff outcrops are accurately discriminated. The small playa at the crater's center is also highlighted since it contains a lesser fraction of palagonite.