HIGH-SPECTRAL RESOLUTION REMOTE SENSING FOR MINERAL MAPPING IN THE BODIE AND PARAMOUNT MINING DISTRICTS, CALIFORNIA

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ABSTRACT:

This paper examines and compares recently developed techniques for hyperspectral data processing in the context of mineral mapping and exploration for precious metals. Hyperspectral data comprises AVIRIS (Airborne Visible and Infrared Imaging Spectrometer) imagery acquired by NASA's ER-2 aircraft at an altitude of 25 km in August, 1992. The study area is the Bodie and Paramount mining districts, in California, USA, both containing hydrothermally altered Tertiary volcanic rocks.
Hyperspectral data were converted from radiance to apparent surface reflectance using a radiative transfer approach, based on atmospheric modelling using a modified MODTRAN method. The data were then processed for mineral identification using two techniques: spectral angle mapping (SAM) and the Tricorder algorithm. SAM is a supervised classification technique for mapping the similarity of image spectra to reference spectra. Tricorder uses an optimized least-square method to compare the spectrum for each pixel on the scene to library spectra.
The results obtained for the Bodie and Paramount districts show that alteration zones of different mineralogy can be separated using these methods without any knowledge of field spectra or any a priori field data, thus configuring a "true" remote sensing method. Applications of this kind of technology are likely to benefit mineral exploration programs for precious metals, particularly in frontier regions where little geological information is readily available.

1.   INTRODUCTION

Hyperspectral remote sensing has been under development since the first experimental sensor of this type, the Airborne Imaging Spectrometer (AIS), was first flown in 1983. Its successor, the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) was developed at JPL in 1987 and has continued to evolve since then. Data acquired by AVIRIS and also by some commercially operated imaging spectrometers developed during the 80's allowed a significant number of geological applications to be developed.   Among these applications is the discrimination of rocks and minerals important to mineral exploration, in particular, mapping hydrothermal alteration minerals.

However, the lack of routine availability of hyperspectral data covering diverse geological environments in different regions has restricted the full utilization of this type of data. Also, hyperspectral data required image processing algorithms specifically designed to take advantage of the high spectral resolution and to cope with the much larger amount of data than those used with conventional multispectral data.

With the continued deployment of AVIRIS in different regions of North America, Europe (1991) and South America (1995), and the continued operation of other airborne scanners, progressively more data have become available. New algorithms for processing hyperspectral data have also been developed and some of them algorithms have recently been incorporated into commercial image processing software.

This technology is currently under significant development, with several new imaging spectrometers being built and operated in recent years. In addition, spaceborne imaging spectrometers are planed for the near future. These developments, summarized by Taranik and Crósta (1996), indicate a clear trend toward operational use of hyperspectral data in geological remote sensing in the near future.

2. OBJECTIVES

This paper examines and compares two different algorithms, the Spectral Angle Mapper (SAM) and Tricorder, recently developed for identifying surface materials in imaging spectrometry data. The objective was to assess the performance of these algorithms and their ability to map alteration minerals important to precious metals exploration. Unlike previous

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mineral mapping studies such as those done at well known localities like Cuprite, Nevada, this exercise tried to simulate a operational situation often encountered in mineral exploration, in which remote sensing is used as the first tool for defining targets before the geologist sets foot on the ground. Therefore, techniques that do not require *a priori* input of ground data were favored and assessed in their ability to convert image data to ground reflectance and for identifying surface materials.

3. STUDY AREA

The area selected for this study is the Bodie mining district and part of the neighboring Paramount district located in Mono County, California, USA (Figure 1). AVIRIS data for this area were acquired in August 1992 by NASA's ER-2 aircraft. The scene used in this study consists of 614 x 512 pixels (10.44 x 9.70 km) in 224 bands, at 16-bit radiometric resolution, corresponding to approximately 141 MBytes of data. It covers the Bodie district almost entirely and the eastern portion of the Paramount district between Atastra and Rough creeks.
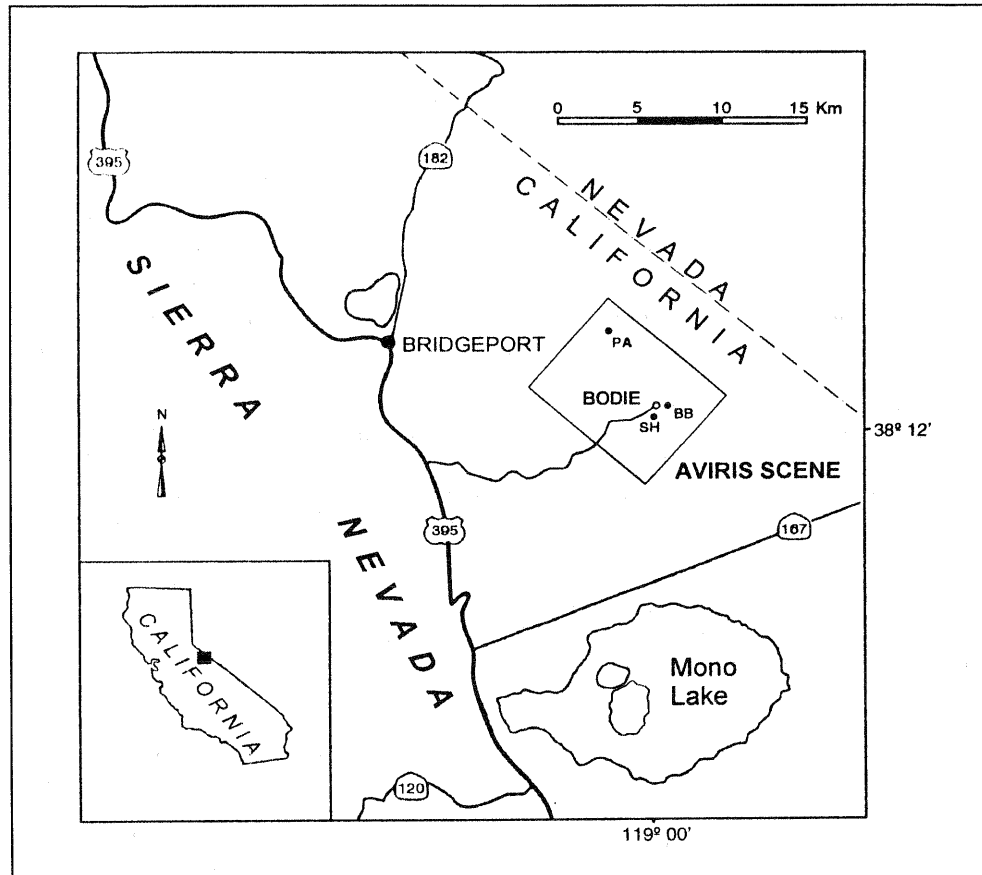
Figure 1 - Location of the study area. The rectangle around Bodie marks the outline of the AVIRIS scene and the locations marked as PA, SH and BB are refered in the text.

4. GEOLOGY AND MINERALIZATION OF THE BODIE AND PARAMOUNT DISTRICTS

Bodie was an important gold-silver mining district in the second half of the nineteenth century and a mercury mine was exploited in the Paramount district. Tertiary (7.8 to 9.4 Ma) intermediate to basic volcanic rocks (dacitic, andesitic and rhyolitic lavas, plugs, tuffs and breccias) underlie both districts. Hydrothermal alteration associated with precious metal concentration at Bodie is probably the result of intense thermal spring activity, some of which can still be found in this region along fault zones (Silberman et al., 1995).

Bodie has mixed characteristics of a bonanza-type lode quartz vein deposit and a large-scale stockwork system, with gold

occurring in quartz veins and quartz-adularia-chalcedony stockworks in the center of the district. Petrographic work by Herrera et al. (1993) showed vertical and lateral zoning in the alteration with silicification in the center surrounded by zones of potassic, argillic and sericitic alteration and an outer zone of propylitic alteration. Little information is available for the Paramount district due to the lack of important mineralization, but the district has recently been prospected for bulk tonnage precious metal mineralization (Herrera et al., 1993). Geological characteristics observed at Paramount are very similar to those in Bodie and the origin of the alteration is believed to be similar (Silberman et al., 1995).

5. DATA CALIBRATION TO SURFACE REFLECTANCE

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Identification of surface materials using hyperspectral data is based on quantitative comparisons between pixel and reference spectra. In order to make such comparisons, imaging spectrometer data must be pre-processed to retrieve ground reflectance values from radiance measurements. Several methods have been proposed for such conversion, some of which require the input of ground data preferentially collected simultaneously with the sensor's overflight. Radiative transfer methods rely on the use of atmospheric models and allow the retrieval of apparent ground reflectance from the radiance values provided by AVIRIS. A comparison of several methods by Clark et al. (1995) showed that a hybrid method which combines simultaneous ground-based data and the radiative transfer method developed by Green et al. (1993a), provides the best results for reflectance retrieval in hyperspectral data, followed by the sole use of Green's radiative transfer method.

We selected Green's radiative transfer method because it meets the requirements of this study that no independent ground or atmospheric measurement be utilized. This method uses the AVIRIS laboratory-calibrated radiance in conjunction with in-flight calibration data obtained over Rogers Dry Lake at the beginning of the 1992 AVIRIS data acquisition season, and the MODTRAN radiative transfer code (Green et al. 1993b). The method compensates for AVIRIS derived estimates of water vapor, aerosol and surface on a pixel by pixel basis. Compared to other radiative transfer methods, it provides a better correction for H_2O and other atmospheric gases, as a function of elevation throughout a scene (Clark et al., 1995). Disadvantages of this method include: (i) errors in the ground measurements during the in-flight calibration at the beginning of the season will propagate into the derived surface reflectance; (ii) computation time is considerable and (iii) the method is still under development at JPL and not yet available for general use.

6. IMAGE PROCESSING METHODS FOR MINERAL MAPPING

In this study we compared two different image processing techniques for mineral mapping at Bodie and Paramount: Spectral Angle Mapper (Kruse et al., 1993) and Tricorder (Clark et al, 1990; Clark and Swayze, 1995). Both methods compare spectra from pixels in the scene and reference spectra from a spectral library, using different algorithms to compare and measure spectral similarity. The two methods are relatively insensitive to illumination differences due to topography in areas of low to moderate relief and high sun angle. The library used for this assessment was the public domain USGS Spectral Library which contains nearly 500 reference spectra of minerals, vegetation and other surface materials (Clark et al., 1993).

6.1 Spectral Angle Mapper Classifier

Spectral Angle Mapper (SAM) is a supervised classification technique that measures the spectral similarity of image spectra to reference spectra which can be obtained either from a spectral library or from field and laboratory spectra. SAM defines spectral similarity by calculating the angle between the two spectra, treating them as vectors in n-dimensional space, with n being the number of bands used (Kruse et al., 1993).

Small values for the angle represent higher spectral similarity between pixel and reference spectra. This method is not affected by gain (solar illumination) factors, since the angle between two vectors is invariant with respect to the lengths of the vectors. SAM produces an image with the pixels it manages to classify assigned to the respective reference minerals, constrained by a user-specified threshold, together with a set of "rule images", one for each reference mineral used. DN values in these "rule images" are the expression of the angle itself (smaller DNs indicate greater similarity to the respective reference mineral), and these images can be used to assess individual results for each reference mineral.

The advantages of SAM are that it has already been implemented in commercial imaging processing packages, it is easy to use and it is computationally fast. SAM's implementation used for this study is part of ENVI image processing software (Research Systems, Inc, 1995).

6.2 USGS Tricorder Algorithm

Tricorder is still under development at the Spectroscopy Laboratory of the U.S. Geological Survey and is expected to be released soon for general use. It was designed to compare spectra of materials from the USGS Digital Spectral Library to image spectra acquired by hyperspectral sensors, analyzing simultaneously for multiple minerals, using multiple diagnostic spectral features for each mineral (Clark and Swayze, 1995).

Tricorder works by first removing a continuum from spectral features in the reference library spectra and also from each spectrum in the image data set. Both continuum-removed spectra are then compared using a modified least square procedure.

One of the strengths of Tricorder is that it considers several attributes in the analysis, such as the depth of particular absorption features, the "goodness of fit" and the reflectance level of the continuum at the center of the feature. By doing this, it can analyze feature shapes using all data points and therefore resolve even complex feature shapes such as doublets in minerals like kaolinite, dickite and halloysite. The method, like SAM, is also not affected by illumination differences in areas of low to moderate relief.

7. ALTERATION MAPPING AT BODIE AND PARAMOUNT

The results of alteration mapping discussed in this section uses the locations of Bodie Bluff (BB) and Silver Hill (SH), both in the Bodie district, and Paramount (PA) as references (see Figure 1).

7.1 SAM Results

Two spectral regions were processed separately in SAM: the visible/near-infrared (VNIR) region (0.4 to 1.3 mm) and the shortwave infrared (SWIR) region (2.0 to 2.4 mm). The VNIR bands were analyzed for minerals with diagnostic electronic transition features (hematite, goethite, jarosite, etc.) and the SWIR bands were analyzed for hydroxyl-bearing minerals and carbonates. Spectra used as reference were obtained from the

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USGS Digital Spectral Library and convolved to AVIRIS bandwidths prior to running the SAM classification.

In the SWIR, 46 AVIRIS bands were used with 15 reference spectra of common hydroxyl-bearing minerals. SAM classified most of the alteration at Bodie and Paramount as Na-montmorillonite, Ca-montmorillonite and a mixture of kaolinite+smectite. This mixture was concentrated predominantly at Paramount, with smaller occurrences at three locations at Bodie: Silver Hill, near the center of district, and Bodie Bluff. At Paramount, a clear zonation was revealed with most of the western part classified as a mixture of kaolinite+smectite, surrounded by pixels classified as Na-montmorillonite, and the eastern part classified as Na- and Ca-montmorillonite. SAM identified the two types of kaolinite used as references (well and poorly crystalline) in a very small number of pixels. Illite and Ca-montmorillonite were mapped mostly as isolated pixels scattered throughout the scene with no meaningful pattern. We treated these as misclassifications and removed them from the final result.

Computation time for the SWIR 15-mineral classification using 46 AVIRIS bands on a low-end Unix workstation (Sun IPX) was 8 minutes.

In the VNIR, 94 AVIRIS bands were used with 9 reference spectra of common Fe^{2+}- and Fe^{3+}-bearing minerals. Initial results were not satisfactory because it classified most pixels in the entire scene as a mixture of hematite and quartz. Even after experimenting with different values for the angle threshold and removing the hematite+quartz spectrum from the reference spectra, SAM classified most of the pixels in the scene as a single reference mineral. We then decided to use only three reference spectra: hematite, goethite and jarosite. Changes in the value of the threshold produced significant changes in the number of pixels classified as one of the reference minerals.

The results showed goethite in altered areas at Bodie Bluff and Silver Hill together with jarosite in mine dumps and in a tailings pond. A few pixels were mapped as hematite at Silver Hill and in an area to the north of the major alteration. SAM also mapped goethite in the Paramount district as well as jarosite which also appeared scattered throughout the western part of the scene and along dirt roads.

It took 15 minutes to run SAM using 94 AVIRIS bands and 3 reference spectra on a low-end Unix workstation (Sun IPX).

7.2 Tricorder Results

Tricorder is run through command files which are pre-set to analyze specific groups of minerals. The command file used in this study included 126 materials (minerals, vegetation and ice). Among the minerals analyzed were some of the most common alteration minerals. All the minerals analyzed using SAM were included in Tricorder's command file.

Tricorder also analyzes separately for multiple minerals in the VNIR and SWIR spectral regions. Therefore, the analysis of the whole spectrum for a single pixel may find two different minerals, one for each spectral region, showing that the pixel contains diagnostic features for two minerals in different spectral regions.

The output from Tricorder are individual "mineral maps" for the SWIR and VNIR respectively. Compared to results from SAM, these maps were found to be more detailed resulting in greater number of spectral classes relatively to mineral species.

In the SWIR region, Tricorder distinguished Na- and Ca-montmorillonite in most of the Bodie district and in the eastern part of Paramount, two types of kaolinite (well- and poorly-crystalline) in the western part of Paramount, a mixture of kaolinite+smectite in the central part of the Bodie district, halloysite in the western part of Paramount, plus a few pixels as Al-muscovite, mostly at Silver Hill and the center of the Bodie district, and illite in mine tailings at Silver Hill. Dolomite was given a good fit by Tricorder, and a fair number of pixels were mapped as such, but these pixels were isolated and scattered all over the image without any meaningful geological pattern. We treated these as misclassifications and removed them from the final result, together with a other minerals with low fits and small number of pixels: dolomite, phlogopite, hectorite, diaspore, clintonite, palygorskite, elbaite and nontronite.

In the VNIR, Tricorder mapped two different types of hematite. The first one, a fine-grained variety, was mapped scattered around hydrothermally altered areas in Bodie and Paramount and the other, a mixture of hematite and quartz, was distinctively associated with the alteration at Bodie Bluff, plus a few pixels in the western part of Paramount. It also mapped goethite in the center of the Bodie district and in a tailing pond nearby. A few pixels scattered across the Bodie district were mapped as K-jarosite, while some others were classified as Fe^{2+}-bearing minerals (mostly cummingtonite) in the center of district and at Silver Hill.

Tricorder took around 4 hours to process the 141 MBytes scene for 126 minerals in the VNIR and SWIR running on a medium-performance Unix workstation (HP 9000) at the USGS Spectroscopy Laboratory. Since then the hardware at the Laboratory has been upgraded to more powerful workstations and it is now taking 2 hours to process a similar scene.

7.3 Comparison of results obtained by SAM and Tricorder

A spatial comparison between the areas of major alteration identified by both methods reveals that Na-montmorillonite was identified by both methods at approximately the same locations in Bodie and the eastern part of Paramount. SAM, however, mapped a larger number of pixels as Ca-montmorillonite in both districts, particularly at eastern Paramount, in areas which Tricorder assigned to halloysite and both types of kaolinite. Also, an area in the northern extreme of Paramount located at the northern corner of the scene, which Tricorder did not map as any mineral, was assigned by SAM to Ca-montmorillonite. The mixture of kaolinite+smectite shows good correlation between both methods only at the center of the Bodie district, whereas another major area of occurrence for this mineral mapped by SAM at the western part of Paramount was mapped by Tricorder as both types of kaolinite and halloysite. The separation achieved by Tricorder between Na-montmorillonite, halloysite and poorly-crystalline kaolinite in the eastern part of Paramount, did not appear in the SAM results.

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In the VNIR , major differences show up in the comparison between results obtained by both methods for those minerals that could be mapped by SAM (hematite, goethite and jarosite). SAM did not find much hematite in the whole scene, whereas Tricorder mapped significant clusters of pixels as hematite in both districts. However, some of the pixels mapped as hematite by Tricorder were assigned to goethite by SAM. On the other hand, pixels that Tricorder mapped as goethite were assigned to jarosite by SAM.

8. SPECTRAL ANALYSIS

In order to assess the accuracy of the results, particularly those obtained by Tricorder which identified a greater number of minerals, we selected six sites for ground checking and collected samples for laboratory spectral analysis. These sites correspond to areas where one or more alteration minerals were mapped by Tricorder in the VNIR and SWIR. Rock samples from each site were analyzed using a Beckman UV-5240 spectrophotometer. The resulting spectra were then convolved to AVIRIS bandwidths for comparison with pixel spectra.

Table 1 shows these six sites with the sample number, their location on the scene and a comparison of the minerals assigned to them by both, Tricorder and SAM. For the location without a sample number in Table 1, only the pixel spectrum and a library spectrum were used, since it was not possible to collect a ground sample.

Sample	Pixel Location (row/line)	Tricorder Result	SAM Result
BO-17	481/435	Na-montmoril.	Na-montmoril.
BO-11a	161/352	Ca-montmoril.	Na-montmoril.
BO-14b	589/445	kaolinite(pxyl)	kaol./smectite
-	524/352	kaolinite	kaol./smectite
BO-14a	485/442	halloysite	Na-montmoril.
BO-05	78/344	Na-montmoril. & goethite	Na-montmoril. & jarosite

Table 1 - Comparison of results between SAM and Tricorder for
selected sites. Spectra for each site is shown in figures 9 to 14, respectively.

An overall coincidence of the most important spectral features for each mineral was observed. The vibrational absorption features located at approximately 2.20 mm, characteristic of hydroxyl-bearing alteration minerals such as those that occur in Bodie and Paramount, shows a good correlation in both position and shape between ground sample, AVIRIS pixel and library spectra for all these samples.

The spectra of the pixel which Tricorder mapped as kaolinite (sample without number) shows a remarkable coincidence for the doublet feature centered at approximately 2.20 mm. The same coincidence was observed for the sample, AVIRIS and library spectra of the pixel mapped as poorly-crystalline kaolinite (sample BO-14b), despite the fact that in this case the feature is more subtle than in well-crystalline kaolinite. Halloysite (sample BO-14a) was also mapped and differentiated from well- and poorly-crystalline kaolinite, despite having a even more subtle doublet in the same region. Apparently Tricorder can deal with even the most subtle spectral differences because on its ability to analyze for total shape, using the three or four most significant SWIR absorption features and weighting these features differently in the final steps of the fitting process.

A good correlation between position and total shape can be seen for the more obvious absorption features related to Na-montmorillonite and Ca-montmorillonite (samples BO-17 and BO-11a), particularly the single feature near 2.2 mm. Different depths of this feature for both minerals was one of the criteria used by Tricorder to discriminate between them.

Sample BO-05 corresponds to a location identified by Tricorder as containing Na-montmorillonite and goethite. Its spectrum clearly show the more obvious features due to these two minerals, the electronic absorption due to Fe^{3+} ion of goethite at 0.92 mm and the vibrational feature due to the OH ion of montmorillonite at approximately 2.20 mm. As these two spectral regions (VNIR and SWIR) are processed separately by Tricorder, this pixel has been assigned to both minerals. SAM, however, mapped this same pixel as jarosite using the VNIR bands.

9. CONCLUSIONS

We managed to recognize and map a variety of minerals associated with hydrothermal alteration processes using AVIRIS data at the Bodie and Paramount mining districts, California. The method selected for calibrating the data and for retrieving reflectance from radiance was precise enough to allow mineral mapping without the use of independent ground and atmospheric data. This represents a major advantage for mineral exploration activities in which ground data acquisition is usually not possible or desirable during the initial phases of an exploratory program.

In general, Tricorder was able to produce mineral maps with greater variety of alteration minerals than SAM. Results obtained for the SWIR region showed a relatively good coincidence between the two methods for alteration minerals of

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major occurrence in the study area, such as montmorillonite and kaolinite. Both methods showed an east-west zonation in the alteration at Paramount and also some zoning at Bodie. The zonation at Paramount is more clear and, as shown by Tricorder, has predominantly kaolinite (both types) and halloysite in the western and southwestern portions and predominantly Na-montmorillonite in the eastern portion, with a dividing line coinciding with Atastra Creek. SAM also showed the same zonation but mapped predominantly kaolinite/smectite in the western and southwestern portions and Na- and Ca-montmorillonite in the eastern portion. In addition, Tricorder was able to map two types of kaolinite, plus halloysite, muscovite and illite.

In the VNIR however, results from both methods were quite different. Pixels mapped by SAM as goethite were assigned by Tricorder to hematite, whereas others mapped as jarosite by SAM were assigned to goethite by Tricorder. Tricorder managed to map more pixels as minerals with diagnostic spectral features in the VNIR than SAM, including hematite, goethite, K-jarosite and cummingtonite.

Spectral analysis of samples from selected sites confirmed the Tricorder results in the SWIR region. There was a good coincidence of position and shape of the most important diagnostic features for Na- and Ca-montmorillonite, kaolinite (with different crystallinity), halloysite, kaolinite+smectite, muscovite and illite between spectral curves from ground samples, AVIRIS pixels assigned by Tricorder to these minerals and reference spectra from the USGS Spectral Library.

Some of the characteristics of SAM, such as its availability in commercial image processing packages, ease of use and speed make it a feasible operational option for mineral mapping in exploration activities. Tricorder on the other hand produced more detailed results than SAM, and will be available for general use in the near future, but its complexity will demand some training, basic knowledge of spectroscopy and considerably more computing time than SAM.

10. ACKNOWLEDGMENTS

11. REFERENCES

Clark, R.N., Swayze, G.A., Gallagher, A., King, T.V.V., and Calvin, W.M. (1993) *The U.S. Geological Survey Digital Spectral Library: Version 1: 0.2 to 3.0 mm.* U.S. Geological Survey, Open File Report 93-592, 1340 p.

Clark, R.N., Swayze, G.A., Heidebrecht, K., Green, R.O., and Goetz, A.F.H. (1995) Calibration to surface reflectance of terrestrial imaging spectrometry data: comparison of methods. *Summaries of the Fifth Annual JPL Airborne Earth Science Workshop*, Pasadena, CA, January 23-26, 1995. JPL Publ. 95-1, vol. 1, pp. 41-42.

Clark, R.N., and Swayze, G.A. (1995) Mapping minerals, amorphous materials, environmental materials, vegetation, water, ice and snow, and other materials: the USGS Tricorder algorithm". *Summaries of the Fifth Annual JPL Airborne Earth Science Workshop*, Pasadena, CA, January 23-26, 1995. JPL Publ. 95-1, vol. 1, pp. 39-40.

Clark, R.N., Gallagher, A.J., and Swayze, G.A. (1990) Material absorption band depth mapping of imaging spectrometer data using a complete band shape least-square fit with library reference spectra. *Proc. Second Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Workshop*, Pasadena, CA, June 4-5, 1990. JPL Publ. 90-54, pp. 176-186.

Green, R.O., Conel, J.E., and Roberts, D.A. (1993a) Estimation of aerosol optical depth, pressure elevation, water vapor and calculation of apparent surface reflectance from radiance measured by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) using a radiative transfer code. *SPIE*, vol. 1937, pp. 2-11.

Green, R.O., Conel, J.E., Helmlinger, M., Bosch, J., Chovit, C., and Chrien, T. (1993b) Inflight calibration of AVIRIS in 1992 and 1993. *Summaries of the Fourth Annual JPL Airborne Earth Science Workshop*, Pasadena, CA, October 25-29, 1993. JPL Publ. 93-26, vol. 1, pp. 69-72.

Herrera, P.A., Closs, L.G., and Silberman, M.L. (1993) Alteration and geochemical zoning in Bodie Bluff, Bodie mining district, eastern California. *Journal of Geochemical Exploration*, vol. 48, pp. 259-275.

Kruse, F.A., Lefkoff, A.B., Boardman, J.W., Heidebrecht K.B., Shapiro, A.T., Barloon, P.J. and Goetz, A.F.H. (1993) The Spectral Image Processing System (SIPS) - interactive visualization and analysis of imaging spectrometer data. *Remote Sensing of the Environment*, vol. 44, pp. 145-163.

Silberman M.L., Breit, F., and Lawrence, E.F. (1995) *Geology and Ore Deposits of Bodie Hills, Northern Mono Basin Region*. Geological Society of Nevada, Special Publ. 22, 49 p.

Taranik, J.V., and Crósta, A.P., 1996, Remote sensing for geology and mineral resources: an assessment of tools for geoscientists in the near future. *XVIII Congress of the International Society of Photogrammetry and Remote Sensing*, Vienna, Austria, July 9-19, 1996.

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