AVIRIS STUDY OF DEATH VALLEY EVAPORITE DEPOSITS USING LEAST-SQUARES BAND-FITTING METHODS

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1. INTRODUCTION

Minerals found in playa evaporite deposits reflect the chemically diverse origins of ground waters in arid regions. Recently, it has been discovered that many playa minerals exhibit diagnostic visible and near-infrared (0.4-2.5 μm) absorption bands that provide a remote sensing basis for observing important compositional details of desert ground water systems (Crowley, 1991). The study of such systems is relevant to understanding solute acquisition, transport, and fractionation processes that are active in the subsurface. Observations of playa evaporites may also be useful for monitoring the hydrologic response of desert basins to changing climatic conditions on regional and global scales. This paper describes ongoing work using Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data to map evaporite minerals in the Death Valley salt pan. The AVIRIS data point to differences in inflow water chemistry in different parts of the Death Valley playa system and have led to the discovery of at least two new North American mineral occurrences.

Seven segments of AVIRIS data were acquired over Death Valley on July 31, 1990, and were calibrated to reflectance by using the spectrum of a uniform area of alluvium near the salt pan. The calibrated data were subsequently analyzed by using least-squares spectral band-fitting methods, first described by Clark and others (1990). In the band-fitting procedure, AVIRIS spectra are fit compared over selected wavelength intervals to a series of library reference spectra. Output images showing the degree of fit, band depth, and fit times the band depth are generated for each reference spectrum. The reference spectra used in the study included laboratory data for 35 pure evaporite minerals (Crowley, 1991) as well as several vegetation and rock spectra extracted from the AVIRIS image cube. Additional details of the band-fitting technique are provided by Clark and others elsewhere in this volume.

2. RESULTS AND DISCUSSION

Playa minerals occur under a broad range of moisture conditions and accordingly present special remote sensing problems. In particular, it is necessary to distinguish water coatings on grain surfaces from water that is structurally bound in different mineral species. The band-fitting technique can be used to make this distinction for a number of strongly hydrated minerals by examining the shape and position of a reflectance maximum observed near 1.66 μm. Figure 1 shows laboratory spectra in the 1.5- to 1.8- μm wavelength interval for the hydrate minerals antarcticite ($CaCl_2.6H_2O$), bischofite ($MgCl_2.6H_2O$), and mirabilite ($Na_2SO_4.10H_2O$) and for anhydrous halite (NaCl). All the samples consist of coarse (~250 μm) powders, and a small amount of water was added to slightly dampen the halite (dry halite is spectrally featureless). The reflectance maximum in mirabilite and bischofite occurs at longer wavelengths and is narrower than the halite+water feature. The antarcticite reflectance peak lies near the halite+water feature position but again is somewhat narrower. At Death Valley, mirabilite has been mapped successfully by careful analysis of the 1.66 μm reflectance feature in the AVIRIS data. Antarcticite and bischofite were not expected to occur in Death Valley and do not appear to be present.

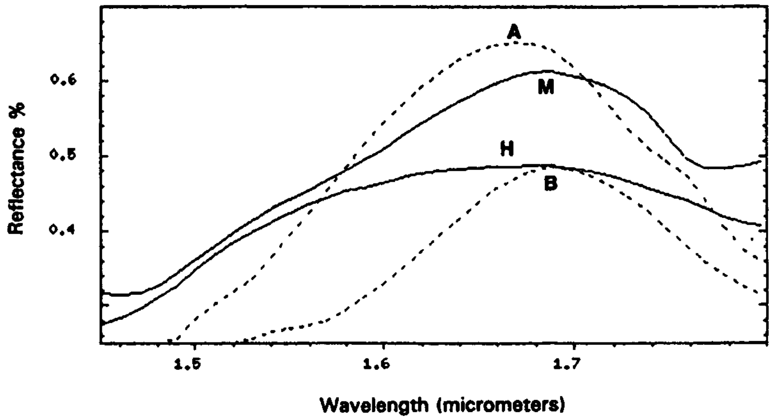

Figure 1. Laboratory reflectance spectra of antarcticite (A), bischofite (B), mirabilite (M), and damp halite (H).

Reflectance maxima and minima can also be used in combination to aid in identifying evaporite species. For example, owing to the signal-to-noise limitations of the AVIRIS "D" spectrometer, gypsum was not mapped accurately when using only the gypsum 2.2-μm absorption feature in the band-fitting procedure. However, good mapping results were obtained with the band-fitting method by using the 2.2-μm band minimum together with the reflectance maximum near 2.1 μm.

Six different evaporite minerals have been mapped in the Death Valley salt pan with a reasonable degree of confidence. The minerals are bloedite ($Na_2Mg(SO_4)_2.4H_2O$), gypsum ($CaSO_4.2H_2O$), halite, syngenite ($K_2Ca(SO_4)_2.H_2O$), rivadavite ($Na_6MgB_{24}O_{40}.22H_2O$), and mirabilite. X-ray diffraction analyses of efflorescent crust samples collected near the old Eagle Borax works indicate the occurrence of rivadavite and pinnoite ($MgB_2O_4.3H_2O$), two rare magnesium borate minerals. Both minerals are spectrally distinctive (Fig. 2), and neither has been previously reported to occur in North America.

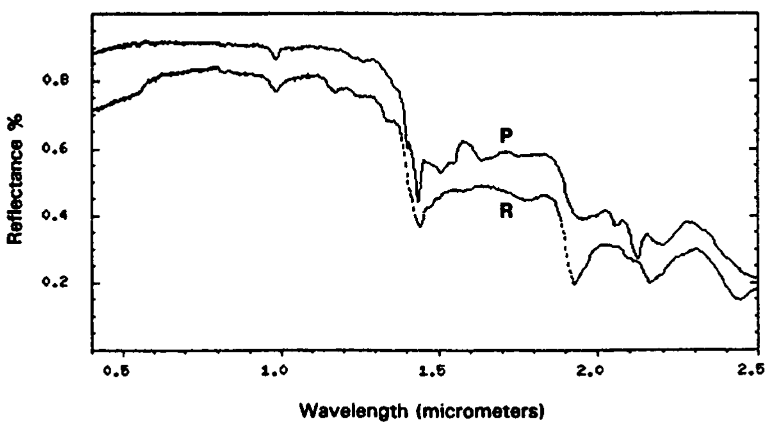

Figure 2. Laboratory spectra of rivadavite (R) and pinnoite (P).

The Eagle Borax area is one of several spring deposits located along the margins of the Death Valley salt pan. Active springs in Death Valley typically have well-developed efflorescent crusts and mineral assemblages that reflect the water compositions. For example, springs that are relatively low in calcium exhibit thenardite (Na_2SO_4) and mirabilite-rich efflorescent crusts, whereas higher calcium inflow waters generate gypsum-rich crusts. The evaporite assemblages at springs can be quite complex, as at Eagle Borax, where bloedite, gypsum, eugsterite ($Na_4Ca(SO_4)_3.2H_2O$), thenardite/mirabilite, rivadavite, and pinnoite occur in various combinations. All of these minerals exhibit diagnostic VNIR spectral bands, and a spectral unmixing study of this area may result in better definition of the mineral distributions. Given the difficulty in studying such deposits with traditional sampling techniques, we believe that the detailed spatial/spectral information provided by imaging spectrometry will improve understanding of evaporite minerals and associated ground water processes in Death Valley and in other arid regions.

3. REFERENCES

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-squares fit with library reference spectra, in Proceedings of the Second Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) Workshop, June 4-5, 1990: Jet Propulsion Laboratory Publication 90-54, p. 176-186.

Crowley, J.K., 1991, Visible and near-infrared (0.4-2.5 μm) reflectance spectra of playa evaporite minerals: Journal of Geophysical Research, v. 96, p. 16231-16240.