SPECTROSCOPY OF SULFATES, CLAYS, AND IRON OXIDES IN THE JURASSIC NAVAJO SANDSTONE

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1. INTRODUCTION

The Jurassic Navajo Sandstone unit in southern Utah is clearly exposed in many areas throughout the Grand Staircase-Escalante region, with relatively little vegetation to obscure its spectral response. It is also composed of approximately 90% quartz, which provides a spectrally-bland background against which to map secondary minerals using spectroscopy. Imaging spectroscopy is thus a useful tool to map the surface mineralogy of this area in order to describe patterns of diagenetic mineralogy resulting from past fluid flow within the unit. Improved understanding of past fluid flow and diagenesis in the Navajo Sandstone could potentially provide important insight into the role of the unit as a water, economic mineral, CO_2 sequestration, and hydrocarbon reservoir as well as adding to overall knowledge of basin evolution and burial history. One prominent geomorphic feature in this region is a jarosite-cemented butte of Navajo Sandstone. This feature, "Mollies Nipple" (MN), is a topographic and mineralogic anomaly in this region, since jarosite forms under extreme conditions requiring acidic and sulfate-rich fluids; an environment not common to the Jurassic Navajo Sandstone. We hypothesize that the unique suite of minerals at MN are related to possible hydrothermal fluids that traveled along previously unmapped structural conduits that converge at this site. Characterizing the mineralogic variability and how these variations relate to the geomorphology of MN may help to constrain the conditions under which the unusual assemblage of secondary minerals where formed. Jarosite and additional authegenic minerals, *i.e.* clays and iron oxides, are mapped and analyzed using field-based spectroscopy, and airborne HyMap and SEBASS data sets, which provide a combined spectral range covering the visible to shortwave infrared (VNIR-SWIR) and thermal range. This same suite of minerals has also been spectrally identified in sedimentary units on the surface of Mars, further illustrating the importance of understanding the occurrence and spectral variability within this terrestrial analog.

Figure 1: (Left to right) View of MN looking ~ east, close view of MN looking ~ north, and MN jarosite distribution.

2. STUDY SITE

The objectives of this study are: 1) to map the comprehensive suite of minerals at MN utilizing both airborne and field-based spectral datasets, 2) compare the spatial mineral distribution to the butte geomorphology, 3) combine the spectral data and spectrally identified assemblages with other types of geologic data, and 4) evaluate the spatial relationship between structural deformation and spectrally mapped mineralogy. MN (Figure 1) is located within the Jurassic Navajo Sandstone, an ancient erg deposit that is widespread throughout south-central Utah. Both groundwater and hydrocarbons have moved through regions of the fairly porous and permeable Jurassic Navajo Sandstone in the past, removing and forming authegenic materials that can make up approximately 15-42% of the rock volume [1-3]. MN has experienced several episodes of complex diagenetic processes, resulting in an intriguing suite of mineralogic materials. Spatially, the butte covers an area of approximately one square kilometer, and can be clearly seen from the surrounding areas with its approximate relief of 200 m.

3. SPECTRAL DATASETS

Identification and mapping of materials using imaging spectroscopy relies upon the presence of spectral absorption features diagnostic of the materials [4]. The spectral datasets used in this study range from the macro-scale of the HyMap data (~ 4m spatial resolution) and SEBASS (~ 3m spatial resolution), to the micro-scale data obtained with the ASD handheld spectrometer from field samples (~1 cm spot size). Intensive field campaigns have provided the advantage of 100's of field-based spectral measurements and allowed for numerous field samples to be collected and analyzed in the laboratory with the ASD, as well as supporting analytical tools. Building upon the rich data available, continuing analysis will build image cubes of the field and field sample spectral data which may then be used to determine spectral endmembers. Additional mineral maps of the clays and iron oxides will be completed using endmembers extracted from the HyMap, SEBASS, and field sample datasets.

4. SULFATES

Jarosite, an iron sulfate hydroxide mineral, is mapped using multiple methods in order to examine its distribution at MN. Two methods, Spectral Angle Mapper (SAM) and Spectral Feature Fitting (SFF), are applied using multiple spectral library inputs including jarosite spectra from the standard USGS library, spectra selected from a HyMap image, and spectra selected from the field sample data. Another mapping method uses the band ratio approach [5-6] to isolate the ~2.26 μm absorption feature, which is one of the diagnostic features of jarosite. Relative abundances of jarosite are mapped using Mixture Tuned Matched Filtering. All mapping methods return similar distributions of jarosite across the MN slopes, with the greatest distribution (loose or in-place) being concentrated on the southern slopes. Comparison of the USGS K and Na jarosite spectra with a field sample spectrum shows the field sample spectrum most closely resembles that of the K jarosite. Spectral and XRD analysis also indicates the presence of another sulfate hydroxide, alunite.

5. CLAYS

A variety of clay minerals are present in the sandstone at MN and their spectral absorption features can be seen in the airborne and field sample spectra. Both jarosite bearing and non-jarosite bearing samples reveal clay absorption features. Initial analysis shows these clays as potentially including kaolinite, kaosmectite (a combination of kaolinite and smectite), illite, dickite, and halloysite, all of which can be associated with hydrothermal alteration. Major diagnostic absorption features are found within a similar wavelength range so the spectral detail of the samples as measured by the ASD and the comparisons of the spectral data with other types of mineralogical, geochemical, and petrographic data are important inputs for distinguishing between subtle differences in the imaging spectrometry.

6. IRON OXIDES

Field observations confirm the presence of abundant iron oxide concretions with the sandstone at MN. Iron oxides exhibit a diagnostic absorption feature within the near infrared. Many of the areas that exhibit this iron oxide absorption feature also contain the ~2.26 μm jarosite absorption feature, and are used in conjunction to map the jarosite. However, examination of the spectral response of HyMap image and field samples within the spectral interval of ~0.85 – 1.10 μm reveals that the wavelength value of the minimum reflectance varies considerably. This minima shift is believed to be a result of mixture of iron oxides (hematite and goethite) and jarosite coexisting in the area being analyzed. Comparing spectral data with other observations helps to elucidate the occurrence and importance of iron in this system, and the influence of spectral mixing.

7. SPECTROSCOPY OF A MARS ANALOG

The plentiful hematite concretions that are found at MN [7-8] plus the presence of jarosite make MN a terrestrial analog for sedimentary rocks on Mars that contain some of the same sedimentological, diagenetic, and mineralogical features. As Mars research is currently limited to remotely acquired data, whether it be satellite of rover technology collecting the data, spectral analysis of sites on Earth that can be studied both remotely and *in-situ* may be an important part of piecing together potential mechanisms for Mars mineralogy. No analog is a perfect match to Mars, and there are some significant differences between MN and the sedimentary rocks on Mars, but investigating conditions at MN that may have resulted in the formation of jarosite cements and hematite concretions may still supply insight into the ways in which these same mineralogic features may have formed on Mars, and help to further stretch the interpretations that can be made from spectral analyses of these types of environments.

8. REFERENCES

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