

TERRESTRIAL ANALOG STUDIES OF MAWRTH VALLIS, MARS: THE PAINTED DESERT.

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Introduction: Mawrth Vallis, Mars, exhibits unique stratigraphy characterized by distinct phyllosilicate units across an expansive region [1,2]. A potential analog for this site is the Painted Desert in Arizona, where striking profiles of clay and iron oxide units color the landscape [3]. Both sites contain multiple phyllosilicate units in similar stratigraphy across wide regions. We have acquired near infrared hyperspectral AVIRIS images over the Painted Desert at resolutions of 3-20 meters per pixel. The objectives of this study are: 1) to compare the hyperspectral images of the Painted Desert in order to gain insights into the Mawrth Vallis region of Mars, and 2) to analyze the hyperspectral images of the Painted Desert in the context of planetary exploration, by attempting geological interpretation from remotely sensed-data, and subsequent ground-truthing to validate our interpretations [4].

Painted Desert analog site: The Painted Desert is the name of the desert region in northern Arizona, characterized by badland morphology and colorful layering [2]. It encompasses an area of approximately 400 km², and extends from the southeastern rim of the Grand Canyon to the Petrified Forest. It is a part of the Triassic Chinle Formation and consists of stratified layers of phyllosilicates of varying compositions [3]. Many of these layers were formed by the deposition of volcanic ashes in lacustrine and fluvial environments. The process of deposition and alteration of the ashes resulted in the formation of bentonite, and also in the burial of organics in an anoxic environment.

AVIRIS image processing: Two different hyperspectral image lines in the wavelength range of 0.36 – 2.5 μm were obtained at spatial resolutions of up to 3 meters per pixel using AVIRIS. Correction for atmospheric opacities was performed using commercially available radiative transfer software (ACORN) specifically written for use with AVIRIS data. Correction processing discards data in the 1.3-1.4 and 1.78-2.0 μm regions due to saturation by atmospheric water bands in these spectral regions. Spectral endmember extraction was performed using standard ENVI spectral analysis tools, including minimum noise fraction analysis, pixel purity index, and spectral angle mapper target finder. These tools have been developed in parallel with AVIRIS and are optimized for such datasets.

Results: Spectral and morphological analysis of the AVIRIS spectral cubes presents an astounding minera-

logical diversity that is also observed in the field [4]. Comparison between endmembers extracted via the spectral angle mapper and spectral libraries resampled to the bandpasses of the instruments shows absorptions in the 1-2.5 μm region consistent with the presence of montmorillonite (inferred from a sharp band at 2.21 μm), illite (inferred from a rounded band at 2.21- μm), kaolinite-group minerals (characterized by a doublet at 2.16 and 2.21 μm), nontronite (inferred from an absorption at 2.29 μm), and calcite (inferred from an absorption at 2.33 μm) (Fig. 1). Note, however, that there are variations in the center of the 2.21 μm feature, suggesting that compositional variations such as those that characterize the montmorillonite-beidellite series may be occurring. Additionally, the center of the 2.28 μm absorptions in the AVIRIS data is shifted towards slightly longer wavelengths (by one channel), suggesting that Mg-substitution is occurring in the octahedral sites of the nontronite. Finally, both chlorite and serpentine also exhibit an absorption near 2.33 μm . However, these two also have additional absorptions which are not observed in the data.

The distribution of the observed minerals is location-dependent, and there is significant compositional variability at scales of 10's of km. Montmorillonite and illite are the most pervasive, occurring in all observations of the Painted Desert, and in most layers. When present, calcite occurs in conjunction with montmorillonite. A combination of Fe/Mg smectite and kaolinite occurs only in one observation (western portion of the painted desert). Fe/Mg smectite can appear either alone or in conjunction with montmorillonite, and is usually concentrated on the tops of mesas. Finally, kaolinite-group minerals are found primarily in the western portion of the Painted Desert, and occur in a bright layer directly underneath the uppermost unit.

Comparison to CRISM: Spectral endmembers collected from AVIRIS data present broad similarities and differences from what CRISM observes in the region around Mawrth Vallis.

Similarities: Kaolinite, montmorillonite, and nontronite have been identified at both the Painted Desert and the Mawrth Vallis sites. In both cases, kaolinite is identified in a relatively thin (~10 m) layer, sometimes in association with montmorillonite. Both sites also exhibit similar phyllosilicate stratigraphy across large regions that have since been altered by other processes.

Differences: No illites or carbonates have been identified in the CRISM spectra of the region around Mawrth Vallis, although hydromagnesite has been detected on Mars using CRISM data in the Nili Fossae region [5]. Additionally, the montmorillonite-bearing rocks and the Fe/Mg smectite (nontronite)-bearing outcrops are stratigraphically segregated at Mawrth Vallis: they are found in separate units, and mixture spectra occur only at the interface between these units. Also, the Al phyllosilicates usually occur above the nontronites at Mawrth Vallis, whereas the opposite stratigraphy tends to be observed at the Painted Desert. Finally, interbedding (compositional layers may be repeated) and pinching off (layers terminate horizontally) are observed in the Painted Desert data, but not seen in any of the CRISM observations.

Insofar as spectral variability, the Painted Desert region displays significantly more spectral variability over smaller spatial scales: practically every scene observed with AVIRIS displays different layers and compositions, suggesting either large lateral variations in the depositional environment, or the exposure of layers from different depths for each observation. This appears in stark contrast with the Mawrth Vallis region, where the same composition, morphology, and stratigraphy are observed over length-scales of ~ 1000 km. However, many geological features on Mars are extrapolated to much larger spatial scales than observed on Earth, and this Painted Desert site may be one of the better analogs available for Mawrth Vallis.

Discussion: Ongoing analyses suggest that the Painted Desert has experienced a much more complex geological history than that observed in the Mawrth Vallis region. Despite this, there are compositional analogs that can be derived from coordinated analyses of the two data sets. One of the most relevant aspects of the Painted Desert is the fact that each compositional layer presents a different soil horizon. The detection of kaolinite in a relatively thin layer is of significant importance because it has been shown that it is a soil horizon, and has been used in field studies as evidence for warm and rainy conditions at the time of its formation (kaolinite is typically formed through extensive leaching of soils by a replenishing water table). The identification of similar thin kaolinite-bearing layers on Mars needs to be investigated further because of their significance for past environmental conditions and the implications for life.

References: [1] Bishop J. L. et al. (2008) *Science*, 321, DOI: 10.1126/science.1159699, pp. 830-833. [2] Noe Dobrea et al. (2009) *JGR* to be submitted. [3] Woody D. T., in *A Century of Research at Petrified Forest National Park: Geology and Paleontology* W. G. Parker et al., Eds. (Museum of Northern Arizona, Flagstaff, AZ, 2006) pp.

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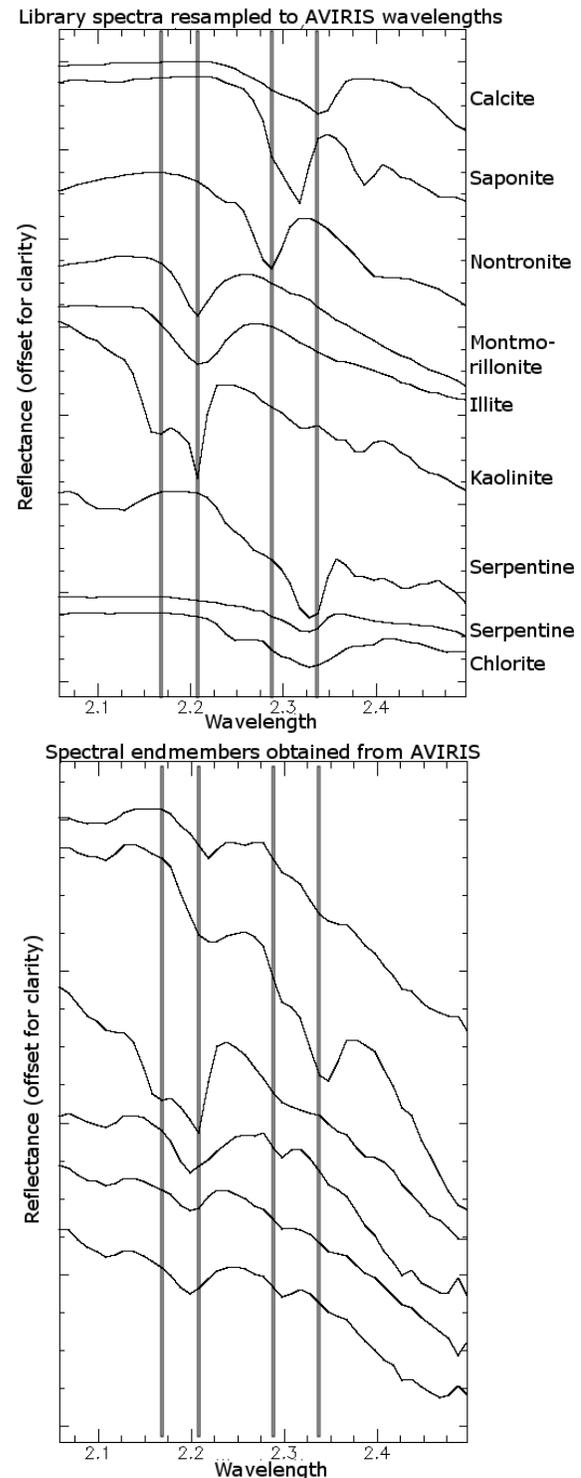


Figure 1. (top) library spectra of calcite and some phyllosilicates for comparison to (bottom) AVIRIS endmember spectra obtained for the Painted Desert.