AQUEOUS GEOLOGY IN VALLES MARINERIS: NEW INSIGHTS IN THE RELATIONSHIP OF HEMATITE AND SULFATES FROM CRISM AND HIRISE A. T. Knudson[1], R. E. Arvidson[1], P. R. Christensen[2], S. L. Murchie[3], J. F. Mustard[4], L. H. Roach[4], C. M. Weitz[5], S. M. Wiseman[1], and the CRISM Science Team. [1]Earth and Planetary Sciences, Washington University, Saint Louis, MO 63130 (knudson@wunder.wustl.edu), [2]Department of Geological Sciences, Brown University, Providence, RI 02912, [3]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, [4]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723, [5]Planetary Science Institute, Tucson, AZ 85719.

Introduction: Concentrations of coarsely-crystalline grey hematite have been identified by the Mars Global Surveyor Thermal Emission Spectrometer (TES) in three regions of Mars within 15° of the equator: Meridiani Planum, chaotic terrain near Ares Valles, and in Valles Marineris (Fig 1) [*1, 2*]. Light toned, layered deposits that contain sulfates detected by Mars Express hyperspectral visible/near-infrared imager, Observatoire pour la Minéralogie, l'Eau, les Glaces, et l'Activité (OMEGA) [*3*], are found in close association with hematite in all three areas. Extensive sulfate deposits have been identified without associated hematite [*4*] in other areas of Mars indicating that hematite formation within sulfate bearing deposits involves conditions that were not ubiquitous. Hypotheses surrounding the formation of hematite commonly involve persistent liquid water [e.g. *1, 5-8*]. In this case, hematite is an indicator of previous aqueous environments on Mars.

The purpose of this study is to further investigate the geologic and mineralogic context of hematite sulfates in Valles Marineris. Results obtained from spectral analysis of TES, Mars Odyssey Thermal Emission Imaging Spectrometer (THEMIS) [*9*], and OMEGA [*10, 11*] data are compared with newly acquired data from Mars Reconnaissance Orbiter Compact Reconnaissance Imaging Spectrometer for Mars (CRISM).

Datasets: The CRISM instrument operates in two modes, a targeted mode and a mapping mode. In this work we work with data collected in targeted modes with data at a spatial resolution of ~15 to 19 m/pixel in 544 visible to infrared channels from 0.362 to 3.92 μm [*12*].

CRISM data have been radiometricallly corrected and processed to cosine corrected I/F. Lambert Albedo is retrieved with a discrete ordinate radiative transfer model [*13*] of the atmosphere with customized interface for CRISM [*14*]. Atmospheric parameters for the model are derived from historical trends measured by the TES [*15*]. This produces spectra that are comparable to laboratory standards. Determination of atmospheric parameters from the EPF portions of targeted observations will improve this technique in the future.

Thermal infrared instruments (TES, THEMIS) are sensitive to molecular vibrations and these datasets are ideally suited for characterization of silicates and oxides. Visible to near infrared instruments (CRISM, OMEGA) are sensitive to molecular vibrations associated with hydrated materials and electronic features associated with transition metal bearing phases. With the thermal infrared providing bulk mineralogy and the VIS/IR identifying hydrated and iron-bearing phases, these datasets provide synergistic mineralogic context for the hematite deposits in Valles Marineris.

Background: Hematite and associated materials have been mapped in Valles Marineris using thermal infrared spectral data from TES and THEMIS with complementary data from the Mars Orbiter Laser Altimeter (MOLA) and high resolution images from the Mars Orbiter Camera (MOC) [*9*].

Hematite in Ophir and Candor Chasmata is generally located down-slope from sulfate-bearing layered materials with smooth, low albedo surfaces and few visible aeolian bedforms. Density driven separation of the hematite from the friable interior layered deposits (ILD) could produce lag deposits of hematite located in topographic lows and at benches in slopes below the source rocks.

A few of the hematite occurrences in Candor and Melas Chasmata exhibit layering within the unit, either as an underlying layer that could be a local source for the hematite, or as mesas and knobs that jut above the hematite and may indicate a previously thicker sequence of material that may have been a local source for the hematite (Fig. 2). The majority of hematite occurrences in Ophir and Candor Chasmata exhibit no evidence of layers, or only subtle indications, such as bright knobs, lineations, or splotchy textures with linear trends.

In two areas Valles Marineris there are examples of hematite associated with wall rock material: the spur and gully walls of southern Ophir Chasma and in a landslide scar of Coprates Chasma near a local mound of layered deposits,. In both cases, the hematite abundances are low, near the detection limits. They are locally correlated to bright, layered material upslope or coincident with the hematite. The interpretation of hematite in the majority of these localities was that it was a lag derived from the voluminous, bright, ILD, even if the hematite was located up to 10 km distant from these materials. [9]

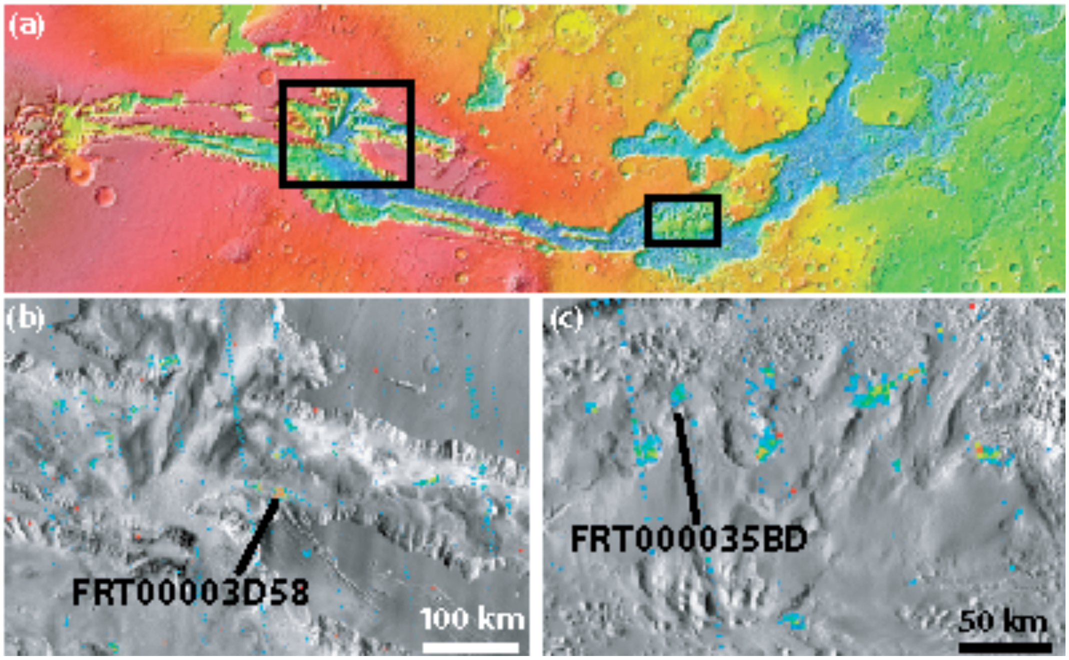


Figure 1. (a) Colorized MOLA map showing the Valles Marineris Region. Context of CRISM frames in (a) Candor Chasma and (b) Capri Chasma in eastern Valles Marineris. Both images are THEMIS daytime IR mosaics overlain with colors that represent the concentration of crystalline hematite from TES. Stars show approximate centers of CRISM targeted images.

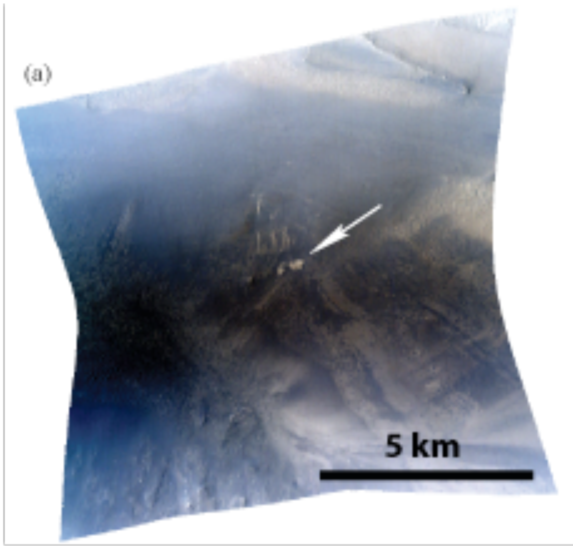
In Capri Chasma, on the northern slope of Capri Mensa, the hematite forms smooth, low albedo deposits that occur in apparently in-place layers situated near the base of the ILD. The hematite is often associated with positive relief features such as knobs or ridges, and may form a resistant cover that protects layers beneath from further erosion. Hematite may be concentrated in a local stratigraphic horizon. With the limited high resolution images available over contacts in this area, it appears that the hematite bearing layers are situated between the chaotic canyon floor deposits and the sulfate bearing ILD.

Composition: Materials intermixed with hematite throughout the Valles Marineris system are primarily basaltic in nature. Linear deconvolution [*16*] of TES data indicate that they consist of: 30-45% pyroxene, 15-20% plagioclase, 5-10% olivine, 5-20% glass or phyllosilicates, and 5-25% sulfates. Hematite-rich areas and surrounding surfaces without measurable hematite are spectrally indistinguishable in THEMIS data, with a consistently basaltic shape [*9*].

OMEGA data indicate that ILD in Candor Chasma contain both a polyhydrated sulfate and a monohydrated sulfate, identified as kieserite [*3, 10*]. Kieserite is preferentially associated with steeper slopes in West Candor Chasma and is likely to be a freshly exposed component of the interior layered deposit layers. Polyhydrated sulfates are found throughout sulfate-rich areas, and may have interacted with atmospheric water [*17*].

Initial results from CRISM: The high spatial and spectral resolution of CRISM data reveals complex layers of kieserite and polyhydrated sulfates in eastern Candor Chasma and Capri Chasma. Roach *et. al.* (this conference) describe the relationships of these sulfates in detail. The coarsely crystalline hematite has a bland, low albedo spectrum across the visible-near infrared wavelengths with a broad absorption centered near ~0.9 µm [*18*]. The presence of crystalline hematite can be inferred from a general decrease in spectral contrast of other materials mixed with it.

CRISM image FRT00003D58 covers a region in eastern Candor Chasma with the largest and highest concentration of hematite in the Valles Marineris system. In this frame (in the northest corner) is a mesa that was previously interpreted as an indication that layers of material have been eroded away to produce the current lag [9]. In the center of the image frame are some small bright materials with spectra that have weak absorptions at 1.4 and 1.9 µm, and a down turn at 2.4 µm that is consistent with hydrated



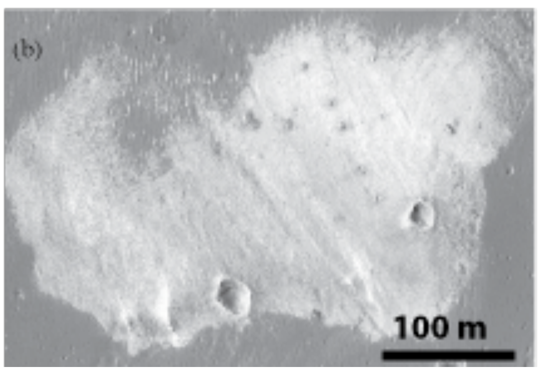


Figure 2. (a) CRISM image FRT00003D58 shown in a false color stretch of vis/nir bands at 592, 533, 442 nm as R, G, B. The whole scene is part of an area with high abundances of coarsely crystalline grey hematite as mapped by TES. Arrow indicates bright areas that are shown in (b) a subset of HiRISE image PSP_002142_1730 illustrating the characer of bright areas in CRISM image.

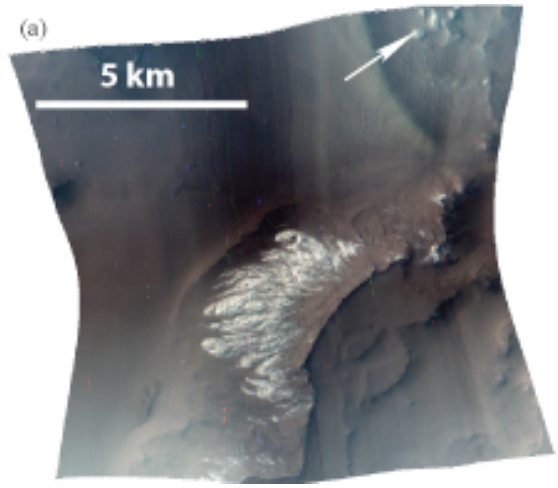


Figure 3. (a) CRISM image FRT000035BD shown in a false color stretch of infrared bands at 2.43, 1.47, 1.14 µm as R,G,B respectively. The northeast corner for the image covers an occurrence of coarsely crystalline grey hematite as mapped by TES. Arrow indicates bright areas with enhanced absorptions at 1.4 and 1.9 µm, along with a down turn at 2.4 µm that is consistent with hydrated sulfates. In this image, these small bright materials have stronger hydration features than the interior layered deposit bright material in the central portion of the image.

sulfates. In the HiRISE image of this area (Fig. 2b) it is evident that this bright material underlies the dark surficial materials, and is a window to the underlying unit.

In FRT00035BD taken in Capri Chasma (Fig. 3) there are similar bright materials with absorptions consistent with polyhydrated sulfates within the areas where hematite is concentrated. The spectral hydration features are stronger in the small exposed bright materials within the hematite than in the large, bright, exposure of interior layered deposit material in this location. The hematite and sulfate signatures here are more closely correlated than previously identified.

Discussion: Previous work has distinguished two distinct populations of hematite, the lag deposits without obvious source material, common in Candor and Ophir Chasmata, and the more apparently in-place deposits, which are still likely to be lags, that are common in Melas and Capri Chasmata [9]. These populations have grown less distinct as higher resolution images and spectra become available. There is growing evidence that there are local hydrated sulfate-rich outcrops associated with the hematite so far imaged with CRISM. Some of this material is visible in windows through the mixed surficial units of hematite and basaltic sand. The subtle layering and small bright materials that have been identified in many of the hematite occurrences in Valles Marineris that are distal to the ILD may prove to have similar mineral signatures.

The possibility that all of the hematite deposits are in-place lags cannot be ignored. All of the hematite exposures may be localized deposits that are relatively in-place with little down-slope transport. The subtle hints of layering observed in many of the hematite occurrences may indicate local underlying layers of sulfate-rich outcrop which serves as a source for the hematite surface lag.

If this is the case, then the Valles Marineris deposits are likely analogous to hematite in Meridiani Planum. The hematite occurrences may represent areas where near-neutral groundwaters were available to drive diagenesis of the parent, presumably iron-bearing, sulfate-bearing rocks [*19*]. The source of water in this region may have been upwellings of groundwater as driven by the growth of Tharsis and the subsequent stress in the area. Modeling of this process shows that the region from Meridiani to Valles Marinereis would have been likely to experience ground water upwellings [*20*].

The age of hematite bearing materials gets progressively younger from east to west with the Noachian Meridiani Planum deposits [*21*] to the Hesperian Aram Chaos [*22*], and to the Hesperian/Amazonian Valles Marineris interior deposits [*23*]. This may be an indication of a migration of groundwater upwelling or a change in chemistry from acidic to more neutral across this region through time.

The CRISM and HiRISE coverage acquired so far only samples a small fraction of the hematitic and sulfate-rich materials in Valles Marineris. These ini tial images have revealed significant details in the relationships between these minerals at the limit of the CRISM dataset. Further analysis of CRISM/CTX/HiRISE data are expected to provide insight into the relationships between the different sulfates associated with hematite, the nature of correlation of hematite with the sulfates, and the correlations of the sulfate bearing materials to the predominantly basaltic material surrounding the hematite, allowing further examination of the genetic relationship between the hematite and the sulfate-bearing layered materials and the history of water in Valles Marineris.

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