WATER AND HEMATITE: ON THE SPECTRAL PROPERTIES AND POSSIBLE ORIGINS OF ARAM, MERIDIANI, AND CANDOR.

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INTRODUCTION

The Terra Meridiani hematite area was recently selected as one of two final landing sites for the Mars Exploration Rovers. This selection was based in part on the spectral signature from the Mars Global Surveyor Thermal Emission Spectrometer experiment (MGS-TES) that shows a strong signature of bulk grey hematite in the region [1,2]. Both aqueous and non-aqueous processes have been used to account for the presence of this material [2,3,4,5]. Calvin [6,7,8] has long argued for the presence of alteration minerals in medium to low albedo regions and we have recently demonstrated the correlation between the TES hematite locations and those spectra from the Mariner 6 and 7 Infrared Spectrometer (IRS) that suggest increased water of hydration [9]. As the bulk hematite does not include hydration features it suggests the presence of other, associated hydrated minerals at the site and supports and aqueous formation mechanism. We here summarize the Mariner IRS evidence for increased water, explore the observations by the French Imaging Spectrometer for Mars (ISM) over these regions and consider possible scenarios for the concurrent deposition of bulk hematite and hydrated minerals.

TES HEMATITE REGIONS

Christensen et al. (2001) [2] found three regions of Mars that contained the spectral signature of bulk grey hematite.[1] The largest of the three deposits is in Meridiani exposed as a flat, layered deposit underlying etched and eroded terrain. The second largest deposit is in Aram Chaos, a large collapse zone at the source of the Ares outflow channel. The third region encompasses a number of small outcrops distributed primarily in East and West Candor Chasmae in the Valles Marineris, and the largest of these is approximately 50km wide at the base of a mesa in East Candor. There are number of other small outcrops in northern Melas, Coprates and Capri Chasmae. Christensen et al. [2] noted all occurrences are in association with layered sedimentary units and they favored an aqueous origin via chemical precipitation at either ambient or hydrothermal conditions.

Much of the ensuing discussion has focused on the largest Meridiani site. The even elevation and moderate surface roughness make it a possible landing site where the rugged terrain excludes both Aram Chaos and East Candor. Recent articles have studied in detail the morphology of the hematite outcrop and the surrounding terrain [3,10] noting that volcanic ash fall or volcanic material interacting with groundwater are possible sources of the deposit.

Our preference is to consider the spectral signatures in conjunction with each other, and as the identification is unique and spatially isolated the origins are probably related and must be consistent with the diverse morphologies of the sites. Even before the TES hematite identification, Calvin [6] noted that Aram Chaos appeared to have a spectral signature suggestive of more water in surface materials. This lead to the postulation of dark alteration analogs for Mars [7] and this scenario is consistent with the subsequent identification of bulk hematite.

MARINER 6/7 AND WATER

Calvin's [6] study focused on the region of overlap between IRS and ISM in Eos Chasma [11]. So, while the Mariner instruments covered the Meridiani site, they were not included in the original study. Baldridge and Calvin [9] revisited the analysis including a larger portion of the Mariner 6 ground track and previously unanalyzed Mariner 7 data. Figure 1 shows the locations of the Mariner and ISM data from Capri Chasma across Meridiani. Both Mariner 6 and 7 observed the TES Meridiani hematite region, Mariner 6 observed Aram Chaos and the ISM "Arabia" track just misses the northern most edge of small hematite outliers shown by Christensen et al. [2].

[1] We prefer to use the term "bulk" as opposed to crystalline or specular hematite as the latter can imply a high pressure or high temperature metamorphic regime considered unlikely for the surface of Mars. As we will show, bulk grey hematite can form as a chemical precipitate without either large crystals or specular nature.

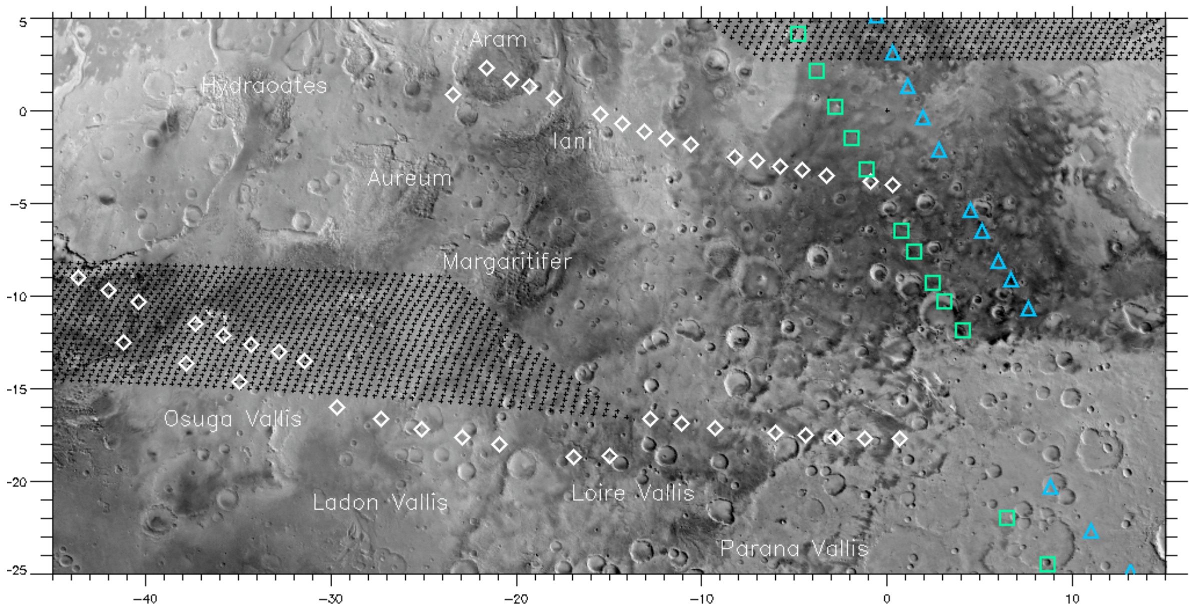

Figure 1: Location of Mariner 6/7 IRS and Phobos ISM spectral observations. White diamonds are Mariner 6, green squares are Mariner 7 short wavelength (2-6 μm), blue triangles are Mariner 7 long wavelength (5 to 15 μm). Small black points are ISM points of the Aurora and Arabia swaths.

Baldridge and Calvin [9] found there is a marked correlation between the Mariner spectra that have an increased integrated band depth for the entire water of hydration feature with regions identified by TES containing bulk hematite. Both Mariner 6 and 7 show increased water over Meridiani and Mariner 6 shows increased water in the spectra that correspond with the Aram Chaos hematite outcrop, consistent with the earlier study [6,9].

There are very few studies that quantify the amount of water in a sample and the reflectance shape of the 3-μm absorption feature. Yen et al. (1998) [12] used apparent absorbance to study water content. For soils of well characterized grain sizes, the apparent absorbance shows a near-linear trend with water content as determined by thermal gravimetry. However this band can be grain size dependent, and they also note that exceptionally fine-grained hydrated materials coating larger grains can lead to similar absorbance values with as little at 0.5% H_2O. More recently, Milliken and Mustard [13] have modeled dehydration of water adsorbed on montmorillonites using the optical constants of water relative to a dry sample.

The spatial footprint of the Mariner IRS instrument is quite large, ~ 100 x 200km. The viewing geometry is not strongly varying over the duration of the observations. The intermediate to low thermal inertia of the Meridiani site [3,10] suggests loose, sand size material. This and the albedo suggest there is not a strong component of fine-grained material. The integrated band depth is normalized so that the albedo of the surface is removed. Hence we have argued that the Mariner data are not likely sensitive to small scale variations in surface physical properties but are in fact recording a parameter sensitive to the hydration state of surface materials. Based on the apparent absorbance model, the Mariner data indicate an increase of water of 1 to 2 wt%. As the average soil is inferred to have only 1 to 2wt % water this is a significant local enhancement in hydrated minerals.

The marked spatial correlation of the two spectral properties suggests a genetic link, not just a coincidence, particularly given that both properties are atypical for the Martian surface. As the bulk oxide hematite is not hydrated, there must be an additional hydrated phase on the surface in these regions. Identification of the phase based strictly on the 3-μm absorption feature is unlikely.

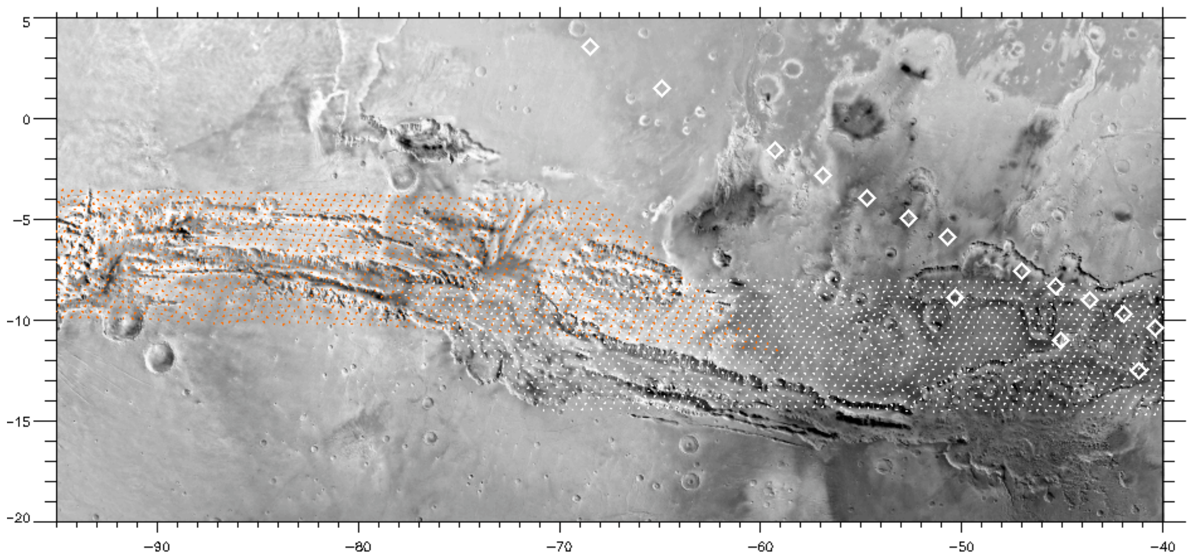

Figure 2: Locations of the VMC (Valles Marineris Center) and AUR (Aurora) swaths for ISM are shown as small points, red and white respectively. Mariner 6 IRS footprints overlapping AUR in Ganges and EOS Chasmae are shown as white diamonds.

ISM AND WATER

Only two orbiting spectrometers have observed Mars in the region sensitive to water of hydration. While many minerals have absorptions near 1.4 and 1.9 μm in addition to 3-μm, the shorter wavelengths are difficult to observe through abundant atmospheric absorptions and scattering. The Phobos ISM spectrometer also observed similar wavelengths to IRS, but at markedly reduced spectral sampling due to problems of calibration of the even and odd detectors [e.g. 14]. ISM also only observed to 3.1 μm, so that most analysis of that data set uses a simple ratio to albedo at shorter wavelengths to determine a 3-μm "band depth" [14,15]. The disadvantage of this approach relative to the integrated value determined by IRS is the strong correlation of the ratio method to albedo. Hence only among material of similar albedo can a 2.5/3.1 ratio appropriately be considered to reflect possible variations in surface hydration. Murchie et al. [15] recently summarized the ISM results noting increased hydration in intermediate albedo dark red soils and in layered terrains in the Valles Marineris.

Given the exciting correlation between integrated 3-μm band depth and the TES hematite regions we here revisit the ISM data set. Erard and Calvin [11] note good agreement between the IRS and ISM instruments overall and strong agreement in absolute value of 3-μm reflectance in low albedo regions. Also, while IRS did not observe the hematite sites in Candor in the Valles Marineris the ISM has three swaths over this region: VMC, HEB and AUR, for Valles Marineris Center, Hebes Chasma and Aurora Planum as shown in Figure 2.

In their summary paper, Murchie et al. [15] performed spatial averaging to smooth out calibration and other noise sources. We are looking for spatial properties that are 1 to 2 ISM pixels in Candor and hope to derive a method that is less sensitive to the overall albedo correlation. Figure 3 shows the apparent absorbance (-ln(r)) using a single wavelength channel for the calibrated data available on the ISM web page [14]. The apparent absorbance still has a strong correlation to albedo which makes this property somewhat suspect in determining hydration state. We are currently examining atmospherically corrected data as well as averaging a few channels for apparent absorbance. Figure 3 has been thresholded to map only the most extreme values of the 3-μm apparent absorbance. We are exploring various methods to remove the linear component of the hydration vs albedo fit in order to examine variations in band strength that deviate from the linear trend. Comparison to IRS values will be presented at the meeting.

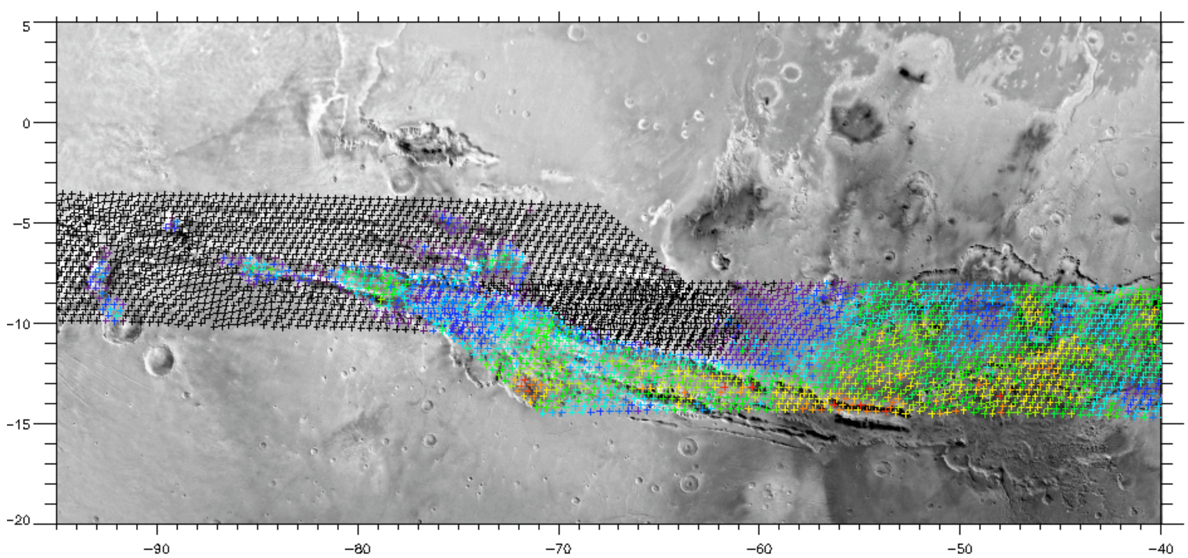

Figure 3: Apparent absorbance of ISM values at ~3.1 μm. Red indicates a higher strength due to the spectral features of water. The image has been thresholded so that brighter surfaces (albedos at 2.3 μm > ~ 0.25 have been set to zero.

POSSIBLE ORIGINS

The hydrated component of the hematite regions could be associated with carbonate, silicate or sulfate materials [9]. There are only a few natural environments where bulk oxides and hydrated minerals appear concurrently. These include terrestrial Archean iron formations and carbonaceous chondrites. An additional property is that both these environments lack abundant oxygen, similar to the present and inferred past state of the Martian atmosphere. A general similarity is seen between the alteration products in Archean Iron Formation (IF) and carbonaceous chondrites [8] and, in addition, both these assemblages are associated with organic materials or possible biological precipitation in the case of IF. Fallacaro and Calvin [16] describe spectral and chemical studies of Lake Superior Banded Iron Formation (BIF) associated with shallow sea precipitation. Previous work [7,8,17] has explored the silicate facies minerals similar in some detail. Here we expand on the work of Calvin [7] by considering the amount of silicate BIF spectral signatures that can be included in a mixture with oxides and still be compatible with TES observations in the 10-μm region. We will present linear mixtures models for thermal wavelengths at the conference.

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The rovers carry a suite of chemical and mineralogical instrumentation for determining the detailed nature of surface materials, including Moessbauer, APXS, thermal IR spectroscopy as well as color, panchromatic, and microscopic imagery. We look forward to the data returned by that mission and its ability to resolve the origins of the deposits and the nature of accessory minerals at the Meridiani site.

References: [1]Christensen et al. *JGR*, **105**, 9623, 2000. [2]Christensen et al. *JGR*, **106**, 23873, 2001. [3]Hynek et al. *JGR*, **107**, 5088, 2002. [4]Lane et al. *JGR*, **107**, 5126, 2002. [5]Kirkland et al. *LPSC XXXIV* abs 1944, 2003. [6]Calvin, *JGR*, **102**, 9097, 1997. [7]Calvin, *GRL*, **25**, 1597, 1998. [8]Calvin et al. LPSC XXXIII, abs 1154, 2002. [9]Baldridge and Calvin JGR submitted. [10]Arvidson et al JGR submitted. [11]Erard and Calvin *Icarus*, **130**, 449, 1997. [12]Yen et al. *JGR*, **103**, 11125, 1998. [13]Milliken and Mustard *LPSC XXXIV* abs 1345, 2003) [14]Erard et al. *Proc. Lun Planet. Sci.* **21**, 437, 1991, http://www.ias.fr [15]Murchie et al. *Icarus*, **147**, 444, 2000. [16]Fallacaro and Calvin, this conference. [17]Calvin and King, *Meteorit. Planet. Sci*., **32**, 693, 1997.