THE FORMS AND EVOLUTION OF WATER IN MARTIAN SOIL: EVIDENCE FROM ISM IMAGING SPECTROSCOPY. Scott Murchie1, Stephane Erard2, Janice Bishop1, John Mustard1, Jean-Pierre Bibring2, Yves Langevin2, James Head1, and Carle Pieters1. 1Brown University, Providence, RI, 02912; 2Institut d’Astrophysique Spatiale, University of Paris, Orsay, France.

Introduction. Compositional information on soil covering bright regions of Mars comes from direct Viking XRF and GCMS measurements and from remote sensing data. Viking found major-element compositions comparable to weathered basalts (e.g., a mixture dominated by montmorillonite and nontronite clays), with a total water content of 1-3% [1,2]. Soil composition was so similar at the landing sites that it was proposed to be globally homogenized by eolian mixing. Spectroscopic studies have provided evidence for hematite, mostly in nanocrystalline form [3,4,5]. No clear evidence for a 2.2-2.3 μm metal-OH absorption has emerged to indicate clays [6], though Hunt et al. [7] interpreted a 6-μm absorption in Mariner 6 IR spectra as indicating montmorillonite. Two major models for the composition of Martian bright regions have been proposed based on this evidence: (a) "Palagonite," a hydrated basaltic glass, formed when basaltic melt contacted ground ice or water and was distributed by winds [1,8]. (b) A montmorillonite-containing mineral mixture has formed by chemical weathering of basaltic glasses [9].

20-km resolution spectra of Mars were obtained by the ISM imaging spectrometer on Phobos 2. These spectra are comprised of two ranges, 1.63-3.16 μm (the 1st order) and 0.76-1.53 μm (the 2nd order). Initial calibration of these data and removal of a model atmosphere with CO2 absorptions at 1.44, 2.0, and 2.7 μm are described by Erard et al. [10]. The S/N ratio is ≥500 except at the ends of each spectral order. Calibration of the 2nd order was refined using gain and offset corrections based on low- and high-albedo standard areas and telescopic reference spectra [11]. Water-related absorptions in the spectral range of ISM include H2O at 1.9 and -3.0 μm; OH at -2.78 μm; H2O-OH absorptions at 1.4 μm; and metal-OH at 2.2-2.3 μm. Only the 3-μm feature was observed previously in ISM data [10].

Procedure. We used ISM spectra of Martian bright regions to investigate variability in the amount and form of water in soil, to determine relationships of these variations to surface geology and Fe mineralogy, and to assess possible compositional analogs. Our investigation included ISM images covering the Valles Marineris, Tharsis, Arabia, and Syrtis Major/Isidis regions. Surficial geology in each region was mapped using high-resolution Viking images [12]. Lateral variations in the strength of the 3-μm water absorption were determined using spectral parameter images, comparing regions of similar albedo to avoid introducing artifacts of possible band saturation. The strength and lateral variability of additional water absorptions were addressed similarly. Their identification was constrained to meet three criteria: (a) presence of a distinct absorption; (b) exhibition of spatially coherent variations; and (c) occurrence outside major atmospheric absorptions where calibration errors would be most likely. The last criterion is satisfied by the 1.9 μm H2O and 2.2-2.3 μm metal-OH absorptions, both occurring in the first spectral order. Calibration of the first order was therefore refined by dividing by a dark standard region, where the absorptions were assumed minimal, and multiplying by a telescopic reference spectrum. Representative spectra were also retrieved to examine Fe absorptions.

Occurrence and Variability of Water-Related Absorptions. The strength of the 3 μm water absorption exhibits significant variations within bright regions (Figs. 1 and 2). The variations are spatially coherent, independent of albedo, and correlated with surface geology. "Normal" bright areas, with less strong absorptions, correspond to surface morphologies indicative of only a thin cover of dust and soil (e.g., volcanic plains, cratered terrain). In contrast, "hydrated" bright areas have much stronger absorptions; these correspond to thick, unconformable deposits in Candor Chasma and western Arabia. The deposits in Candor Chasma consist of "layered materials," whose morphologic equivalents elsewhere in Valles Marineris exhibit strong pyroxene absorptions interpreted to indicate a basaltic lithology [13]. The deposits in Arabia consist of "stripped terrain," a partially eroded Hesperian mantling [14].

Representative spectra of bright regions are plotted in Fig. 3. There is no clear evidence for a water absorption at 1.9 μm; either it is absent or weak enough (<=1%) to be lost in noise. However many bright areas exhibit a weak metal-OH absorption at 2.2 μm with a depth of up to -1.5%. This is attributed to Al-OH in a phyllosilicate. Strength of this absorption also exhibits spatially coherent variations independent of albedo, atmospheric path length, and other factors that could lead to artifacts of calibration or processing. The absorption is present in "normal" bright regions, but weaker or absent in dark and "hydrated" bright regions. Within and around the two "hydrated" bright regions, the strengths of the 2.2 μm and the 3-μm water absorption are anticorrelated (r, -0.7) (Figs. 1 and 2). If strength of the 3-μm absorption is indicative of water content, then more hydrated bright regions have weaker Al-OH absorptions.

Variations in Fe Absorptions. The "hydrated" bright regions have similar ~0.9 μm Fe absorptions, distinct from those in "normal" bright regions except eastern Arabia. The "hydrated" regions' absorptions are centered at longer wavelengths, with evidence for two Fe-bearing components: Candor Chasma exhibits two minima, at ~0.86 μm and ~0.96 μm; western Arabia exhibits a minimum at ~0.95 μm and an inflection at 0.9 μm suggesting an additional shorter-wavelength absorption. Both regions exhibit broad, weak absorptions centered at 2.0-2.1 μm. These results suggest that "hydrated" regions contain ferric oxide like "normal" regions, and an additional phase, probably pyroxene.

Possible Compositional and Genetic Interpretations. The strong 3-μm water absorption, the ferric iron and possible pyroxene absorptions, and the lack of a 2.2 μm absorption in the "hydrated" unconformable deposits are all explicable by palagonite [4]. The weak 2.2 μm absorption in "normal" bright regions is suggestive instead of montmorillonite. Montmorillonite can contain a variety of exchangeable cations (Fe, Ca, Al, Na), the abundances of
which affect the relative strengths of the 1.9 and 2.2 μm absorptions. We have measured band strengths of a variety of partially dehydrated, cation-exchanged montmorillonites [15]. At water contents typical of Martian soil, a greater 2.2-
μm band strength like in "normal" bright regions is attained only if the exchanged cations are ferric-saturated. Two corroborating pieces of evidence also indicate that ferric montmorillonite can explain soil properties of Martian bright regions. First, laboratory simulations suggest that montmorillonite can account for results of the Viking PR experiment, but only if it is ferric-saturated [16]. Second, most montmorillonites are spectrally distinct from Mars at 0.4-1.0 μm, but ferric-saturated montmorillonite reproduces major elements Mars's spectrum at these wavelengths [15].

There are two possible genetic relations of "normal" and "hydrated" bright materials. (a) The "normal" regions represent globally homogenized dust, locally mixed with "hydrated" unconformable deposits. (b) "Normal" bright areas are regionally derived by chemical alteration of palagonitic glass in the unconformable deposits to montmorillonite [cf. 9]. Two tests may be applied to these models using our results. First, previous work [17] shows that water is more easily removed from montmorillonite than from amorphous palagonite by dehydration under Martian climatic conditions. If "normal" soil is derived by chemical alteration of the unconformable deposits, it should be less hydrated. This relationship is clearly observed (Figs. 1 and 2). Second, ferric oxide mineralogy may be unchanged by alteration of palagonitic glass. In this case, a distinctive ferric absorption in a "hydrated region would be retained in surrounding "normal" regions if the "hydrated" region is the source. Fig. 4 shows a transect of spectra across the "hydrated" and adjacent "normal" regions of Arabia. As 3-μm band depth ("H") decreases, the 2.2 μm band depth increases but the distinctive Fe absorption is largely unchanged. There is no evidence for mixing with a distinctive ferric mineralogy.

These results suggest as a working hypothesis that Martian soil contains ferric-rich montmorillonite, at least partly derived regionally by erosion, transport, and alteration of thick, unconformable deposits of palagonite.


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