NEW ANALYSES OF MRO CRISM, HIRISE, AND CTX DATA OVER LAYERED SEDIMENTARY DEPOSITS IN MERIDIANI.
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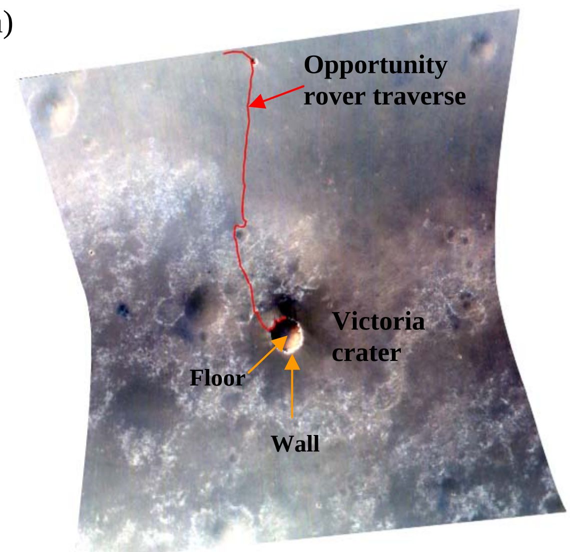
Introduction: The presence of vast sulfate bearing outcrops at Meridiani Planum was not anticipated prior to the landing of the MER Opportunity rover [1]. Thermal Emission Spectrometer and visible/near infrared (VNIR) OMEGA data are spectrally dominated by wind blown basaltic sand and hematite. In fact, hyrdrated sulfates were only identified by OMEGA VNIR data and those identifications are within a valley in the etched terrain located ~390 km to the northeast of the landing site. Several new occurrences of sulfates in Meridiani have been identified in high resolution Mars Reconnaissance Orbiter CRISM images and are reported in this abstract. In addition, a distinct sulfate signature is not detected in CRISM spectra extracted from the Opportunity traverse region and Victoria crater, despite the likely occurance of hydrated and hydroxolated sulfates based on the Opportunity rover's outcrop measurements.

HiRISE [3] images at resolutions up to ~28 cm/pixel and CRISM [4] targeted hyperspectral (544 bands between 0.362 and 3.92µm) images at up to 18m/pixel, as well as multispectral (72 band subset) mapping images at 100 and 200 m/pixel have been acquired in the Meridiani region. In this paper we map out the spatial distribution of new sulfate identifications with CRISM and examine the sedimentary sulfate deposits in northern Meridiani in concert with morphologic information derived from HiRISE to determine the relative timing of the deposition. The significance of the lack of sulfate detection along the Opportunity rover traverses and in Victoria crater will also be discussed.

CRISM Data Reduction: Surface Lambert albedos (i.e., atmospherically corrected spectra) were retrieved from CRISM I/F spectra using DISORT [5] based models of the Martian atmosphere [6] that were generated for the temporal and viewing conditions present at the time of acquisition of the CRISM image(s). Atmospheric carbon dioxide, water vapor and carbon monoxide as well as dust and ice aerosol contributions were modeled. Aerosol abundances and radiative properties based on historical trends from TES data [7] were used. In the future, the aerosol contribution will be determined from the emission phase function (EPF) measurements, or measurements at several different emission angles, that are acquired as a part of each CRISM targeted observation.

Opportunity Landing Site and Traverse: The Opportunity traverse region from Eagle to Victoria craters (fig. 1a) is dominated by aeolian basaltic sands, nanophase ferric iron oxides, and a lag deposit of hematitic concretions that cover light toned outcrops that are most likely dirty evaporate sandstones that formed in an acid sulfate environment [8,9].

a)



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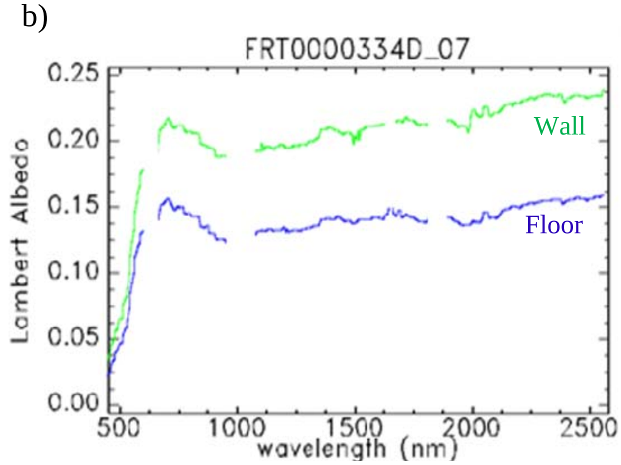

Figure 1. a) CRISM FRT0000334D (18m/pixel) false color composite (R=2.42, G=1.51, B=1.08µm) with the Opportunity rover traverse from Endurance to Victoria crater overlain. b) Lambert albedo spectra from the wall and floor of Victoria Crater are shown. Bands with known calibration artifacts have been omitted.

The hydroxolated sulfate mineral jarosite has been detected within the outcrop material by the Mössbauer (MB) spectrometer [10] and the presence of Mg and Ca bearing sulfates are inferred from analyses of Mini-TES data [11]. Interestingly, an enhanced ~6µm hydration feature is only present in Mini-TES data that include Rock Abrasion Tool generated fines [11]. This could result from the physical properties of the small particles generated during grinding. Alternatively, material with enhanced hydration may be present beneath the outermost surface of the outcrop. CRISM spectra extracted from Victoria crater are dominated by nanophase ferric oxide features and do not show evidence for enhanced hydration relative to the plains material or features related to hydroxolated or hydrated sulfates [12] (fig. 1b).

The lack of sulfate detection in the outcrop with orbital VNIR data my be explained by 1) the presence of iron oxide/dehydration coatings thick enough to obscure reflectance signatures of underlying sulfates, but thin enough to be transparent to the gamma radiation used by the MB, 2) the fine grain size or poor degree of crystallinity of the sulfates precludes detection using VNIR data, and/or 3) the textural characteristics of the outcrop trap nanophase ferric oxide dust that obscures the underlying spectral signature.

Meridiani Regional View: Extensive exposures of light-toned etched terrain material (~900m thick) that are largely interpreted to be sedimentary in nature [e.g., 13,14,15,16] occur in northern Meridiani. The hematite bearing plains on which the Opportunity rover landed are located to the southwest on Meridiani Planum (fig. 2a). The ~120km long northwest-southeast trending valley that contains exposures of hydrated sulfates [18] is centered at ~ 2°N, 0.5°W (fig 2a,b). A spectral and morphologic study of the valley and surrounding area, in which ~1km of relief is exposed, was carried out that incorporated data from OMEGA, MOC, MOLA, and THEMIS [17] (fig. 2b). The etched terrain materials were divided into two distinct units termed the upper etched plains (UEP) and the lower etched plains (LEP) [18]. UEP terrains are dominated spectrally by hydrated iron oxides, based on an enhanced 1.9µm hydration feature and sharp ferric absorption edge. LEP materials occupy the valley floor, and areas with OMEGA coverage exhibit spectral signatures consistent with kieserite ($MgSO_4 \cdot H_2O$) and polyhydrated sulfates [17,18]. The broad pixel size of OMEGA precluded the identification of distinct strata within the valley deposits. Absorption features at 1.9 and 2.4µm indicate the presence of polyhydrated sulfates. Minerals in the kieserite family have absorption features near 2.1 and 2.4µm.

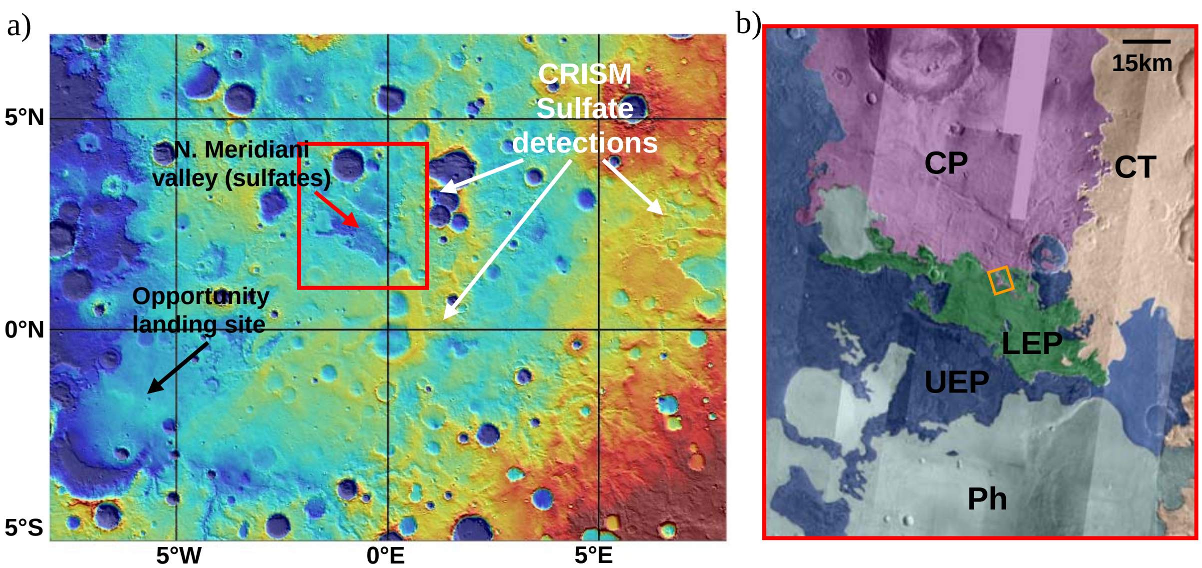

Figure 2. a) MOLA shaded relief map with color coded topography. The Opportunity rover landing site, sulfate bearing valley, and new sulfate detections with CRISM are shown. b) Geomorphic units map reproduced from [18] showing the valley. The location of this units map is shown on the MOLA basemap with a red box. Ph = hematite bearing plains, UEP = upper etched plains, LEP = lower etched plains, CP = cratered plains, CT = cratered terrain. The approximate location of CRISM FRT00004661_07 and HiRISE PSP_2680_1825 are indicated with a yellow box.

Spectral and Geomorphic Analyses: Analyses of high resolution CRISM, HiRISE, and CTX images show that several spectrally and geomorphically distinct layers occur within the valley at the 10s of meters scale. Variations in 1.9, 2.1, and 2.4µm band strengths among the layers reflect real variations in mineralogic and/or textural properties of the units. For example, CRISM FRT0004616_07 (fig. 3a) and HiRISE PSP_002680_1825 (fig 3b) were acquired as a coordinated pair of observations and show a contact between the valley deposits and the cratered plains to the north. Rampart ejecta from a ~15km wide crater located to the north of the valley is evident (fig. 3a,b). Areas that appear bluish in this false color CRISM image have a sulfate signature. A bright layer that has enhanced hydration but no 2.4µm sulfate band caps the hydrated sulfate layers (fig. 3c). The erosional texture of the material varies among the layers and ranges from relatively smooth to a scalloped appearance (fig. 3b). Examination of HiRISE image PSP_002680_1825 shows that windows occur within the ejecta deposits immediately to the north of the valley and expose an underlying older unit that appears geomorphically similar to etched terrain material. Spectral data from CRISM FRT0004616_07 suggest that the sulfate bearing materials cover the ejecta in some areas and are therefore younger than the ejecta. The sulfate deposits have been differentially eroded to expose multiple layers. MOLA [19] profile elevation data show that ~200m of relief is associated with the layers.

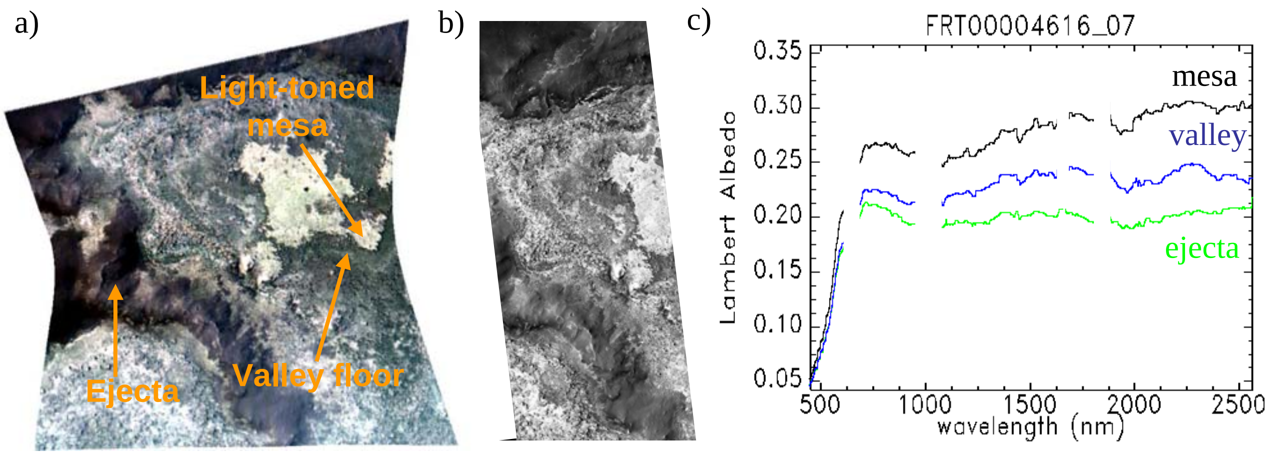

Figure 2. a) FRT00004616_07 false color composite (same band assignments as in fig. 1). b) A subset of HiRISE image PSP_002680_1825 (6km across) that overlaps with the CRISM images is shown. c) Spectra have been extracted from the locations on CRISM FRT00004616_07 that are indicated with yellow arrows.

New Sulfate Detections in Meridiani: Although CRISM coverage is still incomplete in Meridiani, three distinct locations have been identified that show spectral signatures for sulfates (fig 1a). A large cluster of craters centered at ~3.15°N, 1.5°E contains layered deposits [13] that are bright in THEMIS nighttime IR [20], which indicates indurated material. Hydrated material has been detected with OMEGA in these and numerous other craters in northern Meridiani [15]. CRISM multispectral mapping data show that areas within this cluster of craters exhibit both 1.9 and 2.4µm absorption features indicative of sulfates. The crater infilling material is clearly younger than this cluster of craters and may have formed contemporaneously with the sulfate deposits in the valley.

Additional sulfate exposures have been found in the CRISM multispectral mapping data near the contact between hematite bearing plains, etched terrain, and mantled crater terrain at ~0.24°S, 1.5°E. The third new sulfate identification is significantly further from the valley deposits, at ~2.2°N, 6.5°E. The sulfates occur in small exposures in CRISM FRT00003AA2 (fig. 4a, b) and show distinct 2.1 and 2.4µm bands (fig. 4c). Bright toned material that does not have a 2.4µm band is also present. At a resolution of 18m/pixel it is unclear if the sulfates occur as windblown deposits or small exposures of bedrock material. Multispectral data acquired proximal to FRT00003AA2 exhibit only a very subtle 2.4µm absorption features that would probably not have been identified if an FRT image at 18m/pixel had not been acquired.

Discussion: The rocks exposed in the walls of Victoria crater in Meridiani Planum are spectrally dominated by nanophase iron oxides, which is consistent with much of the upper etched terrain. Hydroxolated and hydrated sulfates are not seen in CRISM spectra of Victoria or along the Opportunity rover traverse. The lack of these spectral signatures may be

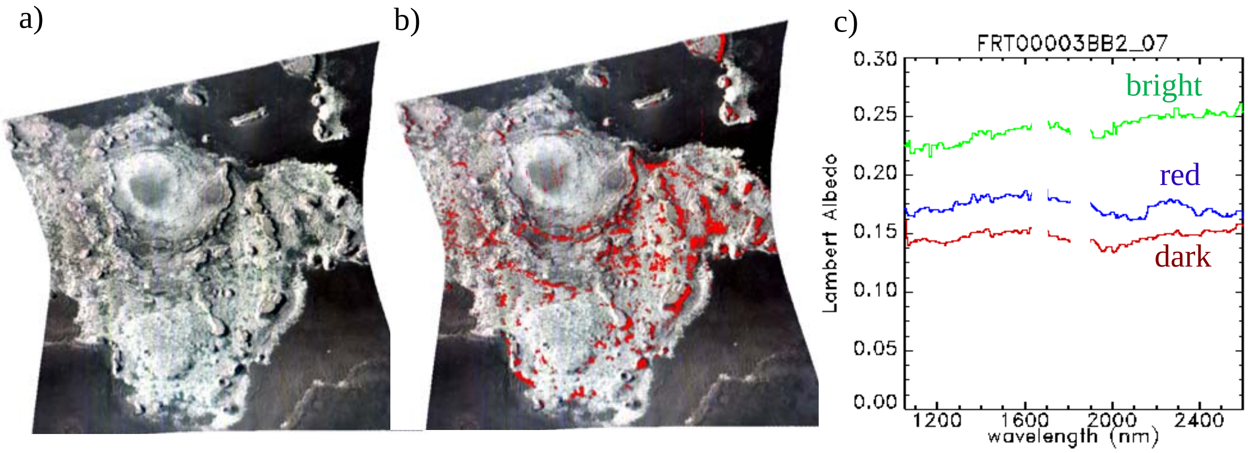

Figure 4. a) False color composite of CRISM FRT00003BB2. b) Areas with the strongest 2.4 micron feature are shown in red. c) Spectra were extracted from the dark material, the bright material, and the material highlighted in red that has the strongest 2.4micron feature.

due to the presence of coatings, surface dehydration, grain size, and/or textural effects. The rover ground data coupled with orbital analyses at Meridiani Planum suggests that other areas of the etched terrain most likely contain sulfates, even though they are not detected orbitally. Spectral and geomorphic analyses show that the sulfate deposits in the valley in northern Meridiani have distinct layers. These deposits overlay older etched terrain material and embay cratered terrain. New detections of sulfates with high resolution CRISM data show that sulfates are not restricted to the valley. With the current data set, it is unclear if these sulfate deposits are genetically related to the deposits in the valley, although future mapping will help address the stratigraphy.

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References: [1] Squyres S.W. et al. (2004) *Science, 306.* [2] Christensen P.R. et al. (2000) *JGR, 105.* [3] McEwen A. et al. (2006) *JGR, in press.* [4] Murchie S. et al. (2007) *JGR, in press.* [5] Stamnes et al. (1998) Appl Optics, 27. [6] Wolff M. [7] Smith M. (2004) Icarus, 167. [8] Arvidson R.E. et al. (2006) *JGR, 111.* [9] Grotzinger, J. et al. (2005) *E.P.S.L.*, 240. [10]Morris R.V.et al. (2003) *Science, 306.* [11] Glotch T. C. et al., (2006) *JGR*, 111.[12] Arvidson R. E. et al. (2007) *Science*, submitted. [13] Malin, M. and Edgett, K. (2000) *Science*, 288. [14] Christensen P. R. and Ruff S. W. (2004) *JGR* 107. [15] Poulet F. et al. (2007) *Icarus, submitted.* [16] Poulet F. et al. (2007) this conf. [17] Gendrin A. et al. (2005) *Science, 307.* [18] Griffes J.L.et al. (2006) *JGR, in press.* [19] Smith D.E. et al. (2001) JGR, 106. [20] Christensen P. R. et al. (2004) *S.S.R.*, 110.