

HYDRATED MINERAL EXPOSURES IN THE SOUTHERN HIGHLANDS. James J. Wray¹, Frank P. Seelos², Scott L. Murchie², and Steven W. Squyres¹, ¹Department of Astronomy, Cornell University, Ithaca, NY 14853 (jwray@astro.cornell.edu), ²JHU/Applied Physics Laboratory, Laurel, MD 20723.

Introduction: Orbital near-infrared spectroscopy has revolutionized our knowledge of the history of water on Mars. Sulfate minerals were first identified in Martian bedrock at Meridiani Planum by the Opportunity rover [1], but have since been found by OMEGA in numerous other light-toned layered deposits [2,3], where they are thought to reflect alteration by acidic solutions. Phyllosilicates, possibly indicative of more neutral-to-alkaline altering fluids [e.g., 4], have also been identified [2,5].

OMEGA global maps of hydrated minerals including phyllosilicates reveal that km-scale and larger surface exposures are scattered widely across low and mid-latitudes, but are relatively rare [6,7,8]. Sulfates at these latitudes are seen by OMEGA only in a narrow band surrounding the equator east of Tharsis [6], prompting the suggestion that they all may have formed via a single regional process [9]. But a more complex story is visible at higher spatial resolution. On the opposite side of Mars, ferric sulfates and opaline silica have been found in the Columbia Hills by the Spirit rover [10], while CRISM has found hundreds to thousands of Fe/Mg-clay exposures in the highlands of Terra Tyrrhena [11]. CRISM data now enable a reevaluation of the planetary-scale distribution of hydrated minerals.

Methods: We have undertaken a survey of publicly released CRISM observations in the Southern highlands. Using the online map of targeted observations (<http://crism-map.jhuapl.edu/>), we have examined the IR HYD and PHY browse products in search of spatially contiguous areas with absorptions characteristic of hydrated sulfate and phyllosilicate mineralogy. Promising observations are then processed using standard atmospheric and photometric corrections [11], and their spectra examined to confirm the presence of absorptions of interest. Regions currently under study by other investigators – including Terra Tyrrhena [11,12], Argyre basin [13], and Eridania basin [14] – have been omitted from our survey (Fig. 1).

We have focused initially on observations with the highest values of the summary parameters over many pixels. However, all web-released browse products were produced with a standard stretch, so future analysis of more subtle features on an image-by-image basis may reveal many additional hydrated mineral occurrences.

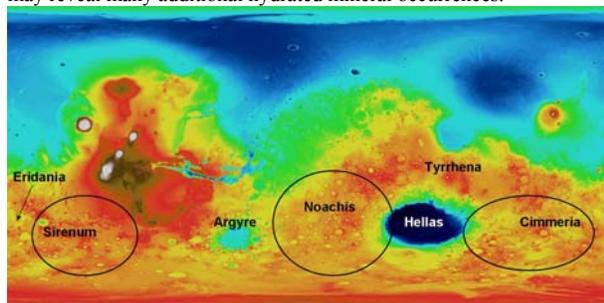


Figure 1. MOLA global topography with regions surveyed circled.

Results: Only a small subset of images exhibit strong hydrated mineral signatures. In Noachis, one image contains a broad exposure of a bright plains unit with a strong 2.3- μ m band diagnostic of Fe/Mg-phyllosilicates, while a small impact crater in the same scene has bright ejecta with a 2.2- μ m band indicative of Al-phyllosilicates. Two images south of Noachis contain strong evidence for hydrated sulfates. In one of these, at 63° S, polyhydrated sulfate is seen on top of a ~5-km wide hill; HiRISE images of this hilltop show a polygonally fractured surface with scattered ~10-m boulders.

In the Centauri Montes just East of Hellas, several spots on the hourglass-shaped glacier discussed by [15] exhibit absorptions at 1.5, 1.9, and 2.1 μ m, consistent with lab spectra of water ice but possibly also consistent with the monohydrated sulfate kieserite (Fig.

2). If water ice, this material may be frost, but could also be exposed glacial ice as predicted by [16]. Seasonal monitoring should distinguish between these possibilities.

In Terra Sirenum, several images of the D~100 km Columbus crater reveal a complex mineral assemblage. Polyhydrated sulfate is the spatially dominant hydrated phase, but both Fe/Mg- and Al-phyllosilicates are also seen. The latter is much more common, and spectrally most consistent with a kaolin group mineral (e.g., halloysite) with a strong 1.9 μ m band and doublet absorptions at 1.4 and 2.2 μ m (Fig. 2). The polyhydrated sulfate occurs in a finely layered light-toned unit that overlies both types of phyllosilicate-bearing units (Fig. 3). This assemblage of sulfates, kaolinite, and other minor phyllosilicates occurring in sedimentary layers inside a closed (crater) basin is reminiscent of terrestrial acid-saline lake deposits [19].

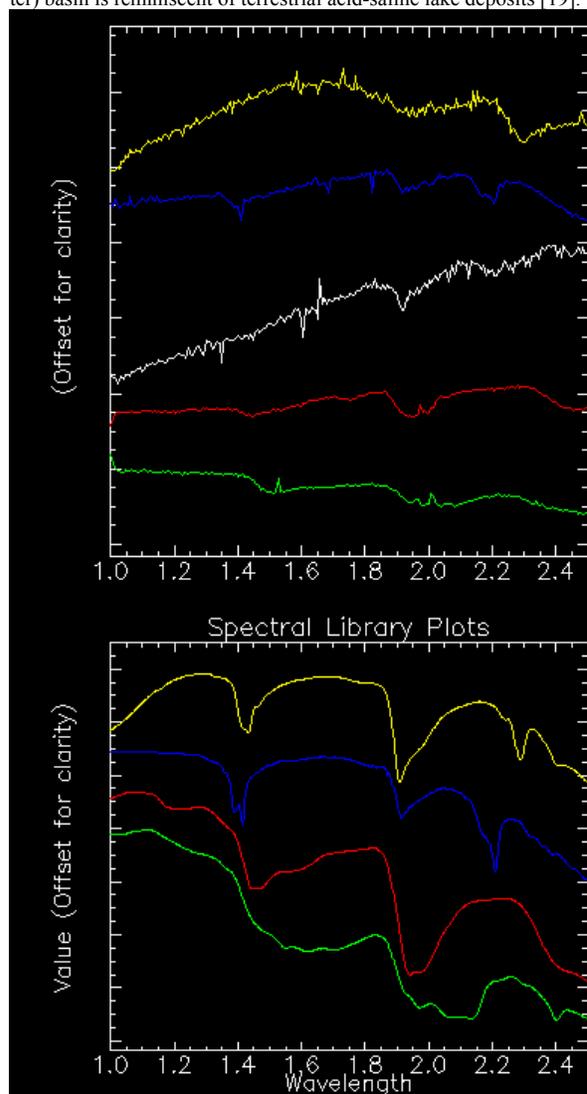


Figure 2. Top panel: CRISM ratio spectra (red, blue, and yellow from Columbus crater; green from Centauri Montes glacier; white from Icaria mound). Bottom panel: library spectra of nontronite (yellow), halloysite (blue), polyhydrated Mg-sulfate (red), and kieserite (green).

Elsewhere in Sirenum, several exposures of Fe/Mg-phyllosilicate occur immediately adjacent to exposures of the THEMIS “glowing” terrain interpreted to contain chloride salts [20]. In the three surveyed scenes containing both minerals, they occur in distinct light-toned units, with the glowing terrain relatively low-standing (either underlying or possibly embaying the clay-bearing unit). Farther East in Icaria Planum, a ~100 km-wide mound hosts an impact crater in which gullies have transported Fe/Mg-phyllosilicate downslope. Just outside the gully is a small exposure of material spectrally consistent with hydrated silica [e.g., 11], with a strong band at 1.9 μm and a broad, asymmetric band centered around 2.2 μm (Fig. 2).

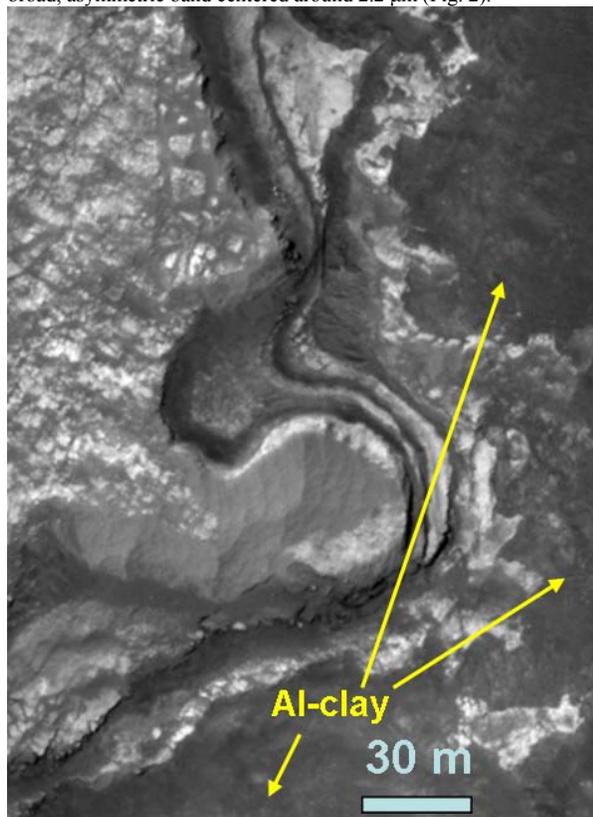


Figure 3. Portion of HiRISE PSP_005429_1510 in Columbus crater. Light-toned, layered unit contains polyhydrated sulfate, while underlying darker unit contains a kaolin group clay.

Discussion: One immediate conclusion from our survey is that sulfate minerals are more widespread than previously observed. OMEGA results have been used to infer a distinct period of sulfate formation during the early-to-mid Hesperian, coupled to Tharsis volcanic activity [6,9]. However, sulfates today are seen in locations far from Tharsis, and virtually all areas covered by our survey are mapped as Noachian in age (though the near-surface materials may be younger). Sulfate formation may have occurred locally or regionally at various times spanning a large fraction of Martian history.

We have observed hydrated silicates in a number of locations scattered throughout the Martian highlands. The various examples in Sirenum and Icaria do not occur near any of the large Martian impact basins, suggesting that phyllosilicate formation mechanisms related to hydrous basin impact melts [21] likely do not apply to these examples. Smaller impacts may have played a role, but we note that the phyllosilicates discussed above do not occur predominantly in association with impact craters as in Terra Tyrrhena [11,12].

Among the hydrated silicates observed, Fe/Mg-phyllosilicate appears to be most common overall, consistent with previous findings [5,11]. However, we note that the images we examined do not represent an unbiased sample of the highlands: while some images

were targets of opportunity or ride-along observations with other MRO instruments, much of CRISM’s targeting strategy is driven by previous discoveries of hydrated minerals at the lower resolution provided by OMEGA or CRISM multispectral data. Fig. 4 shows a small portion of Terra Sirenum in which multiple Fe/Mg-phyllosilicate exposures stand out in CRISM multispectral mapping strips. We are currently targeting these exposures for high-resolution CRISM and HiRISE observations.

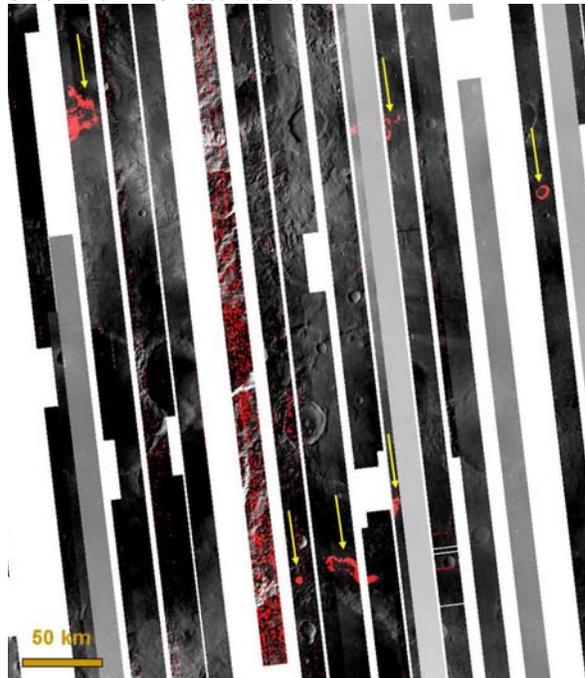


Figure 4. Mosaic of CRISM multispectral data in Terra Sirenum, (center ~30°S, 185°E). Background is IR albedo. The D2300 parameter, sensitive to Fe/Mg-OH absorption in phyllosilicates, is shown in red. Yellow arrows highlight exposures. Residual striping in some image strips is due to an uncorrected instrument artifact.

Our initial survey reveals the diversity of hydrated mineral occurrences in the ancient Southern highlands, and should precipitate several more focused studies of local areas of interest. Future work will also include analysis of high-resolution images to determine (where possible) the stratigraphic context of the hydrated mineral exposures, both relative to each other and to unaltered igneous units.

Acknowledgements: JJW thanks the Fannie & John Hertz Foundation and NSF Graduate Research Fellowship for support.

References: [1] Squyres S. W. et al. (2004) *Science* 306, 1709-1714. [2] Bibring J.-P. et al. (2005) *Science* 307, 1576-1581. [3] Gendrin A. et al. (2005) *Science* 307, 1587-1591. [4] Chevrier V. et al. (2007) *Nature* 448, 60-63. [5] Poulet F. et al. (2005) *Nature* 438, 623-627. [6] Bibring J.-P. et al. (2006) *Science* 312, 400-404. [7] Poulet F. et al. (2007) *Mars* 7, Abs. #3170. [8] Poulet F. et al. (2007) *JGR* 112, E08S02. [9] Bibring J.-P. et al. (2007) *Science* 317, 1206-1210. [10] Squyres S. W. et al. (2008) *Science* 320, 1063-1067. [11] Mustard J. F. et al. (2008) *Nature* 454, 305-309. [12] Pelkey S. M. et al. (2007) *LPS XXXVIII*, Abs. #1994. [13] Buczkowski D. L. et al. (2008) *LPS XXXIX*, Abs. #1030. [14] Noe E. (2007) *2nd MSL Landing Site Sel. Wkshp*, “Ariadnes Colles.” [15] Head J. W. et al. (2005) *Nature* 434, 346-351. [16] Gillespie A. R. et al. (2005) *Nature* 438, E9. [17] Malin M. C. et al. (2006) *Science* 314, 1573-1577. [18] McEwen A. S. et al. (2007) *Science* 317, 1706-1709. [19] Benison K. C. & Bowen B. B. (2006) *Icarus* 183, 225-229. [20] Osterloo M. M. et al. (2008) *Science* 319, 1651-1654. [21] Tornabene et al. (2007) *Mars* 7, Abs. #3288.