HYDRATED SULFATES IN THE SOUTHERN HIGH LATITUDES OF MARS. Sheridan E. Ackiss[1] and J. J. Wray[2], [1]School of Mathematics, Georgia Institute of Technology, Atlanta, GA 30332 (sackiss3@gatech.edu), [2]School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA.

Introduction: Sulfates figure prominently in the record of water and habitable environments on Mars. They are found in sedimentary rocks at equatorial and middle latitudes [1–3], in sand dunes around the north polar cap [4], and in the soils of every landing site to date [5,6]. They are hypothesized to reflect a transition from a wet, neutral-pH early Mars to an arid world where fluids are typically saline, acidic, and rare [7]. Yet they occur in rock units dating from the Early or Mid Noachian [8] through the Late Amazonian [9], so have likely formed throughout Martian history via multiple processes in diverse settings.

The high southern latitudes have received little attention to date in the search for sulfates and other hydrated minerals. Similar to the north, non-ice hydration is detected from ~60° latitude to the edge of the southern residual ice cap, with regional variations [10]. In some cases the orbital spectra are consistent with sulfates specifically [11], but no analog to the northern hemisphere's gypsum-rich (30–45%) dunes [12,13] has been reported. The gypsum ($CaSO_4$•$2H_2O$) in those dunes is inferred to derive from the polar layered deposits of dirty ice [13–16], where it may form when sunlight causes minor melting and resultant weathering of embedded dust [17]. The source(s) of sulfur and the reason for Ca-rich salts—in contrast to the Mg/Fe-rich sulfates that likely predominate at lower latitudes [2]—remain unknown. Regardless, similar processes could conceivably produce sulfates in the south.

Alternatively, some sulfates in the southern high latitudes appear localized to mountains of the Sisyphi Montes [3], which have been interpreted as volcanoes that erupted under a Hesperian ice sheet [18]. These sulfates might have formed via volcanic hydrothermal or acid fog alteration. We seek to find new examples of hydrated sulfates at high southern latitudes in order to test the volcanic vs. ice weathering hypotheses based on the mineralogy and spatial distribution of sulfates.

Methods: We searched for sulfates using the Mars Reconaissance Orbiter (MRO)'s Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). To date we have focused on the Sisyphi Montes region, whose putative volcanoes mapped in ref. 18 span 20°W to 40°E and 55°S to 75°S. This region has 163 targeted CRISM observations (Fig. 1). For each one we tabulated location, year and date, IR detector temperature, and any atmospheric hazes or surface frosts visible in browse images [19]. Images were sorted by detector temperature, and those above -148°C were neglected due to low signal-to-noise, as were images with widespread surface frosts or atmospheric hazes.

Images were then evaluated using standard procedures in the CRISM Analysis Toolkit (CAT), including the "volcano scan" atmospheric correction [19]. We worked with TRR3 data and used spectral summary parameters [19] to identify regions of interest, from which we extracted spectra, which we divided by spectrally neutral regions in the same scene to remove systematic artifacts, a common method in CRISM data analysis. The resulting ratio spectra were analyzed from 1.0 to 2.6 μm and visually compared to library spectra to identify possible hydrated mineral constituents. We analyzed all high-quality images of putative volcanoes and a similar number off the volcanoes.

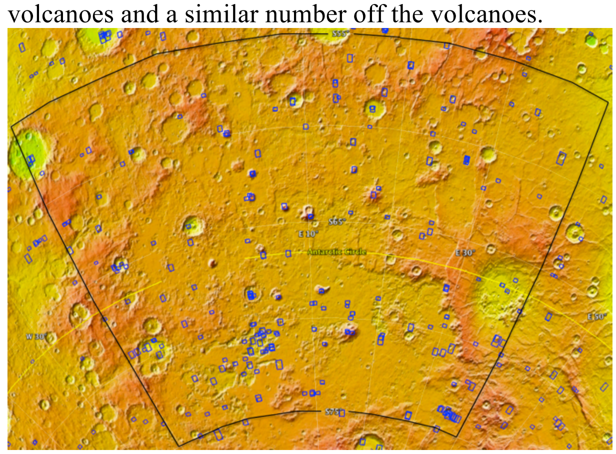

Figure 1. CRISM hyperspectral images (blue) on MOLA topography; black box spans 20°W to 40°E and 55° to 75°S.

	Yes Hydration	No Hydration
On Volcano	7	7
Off Volcano	8	8

Table 1. Number of analyzed images in each category.

Results: As Table 1 shows, exactly 50% of CRISM images on putative volcanoes have locations with a 1.9 μm absorption consistent with hydration. The percentage is identical for images on the plains between volcanoes; i.e., hydration is not unique to the volcanoes.

Nevertheless, the three locations at which we found the strongest absorptions (green, blue, and red spectra in top panel of Fig. 2) are all on volcanoes. The red spectrum is from the mountain shown in Fig. 4B of ref. 3, but all other spectra are from new locations. The green and red spectra each have broad bands around ~1.96 and 2.48 μm plus subtle features near 2.2 μm, consistent with gypsum (possibly mixed with bassanite, $CaSO_4$•½H_2O). The red spectrum additionally has a 1.44 µm band, as does gypsum. The blue spectrum is slightly different, with a narrower 1.9 µm band and a 2.52 µm band whose position is more consistent with the zeolite analcime than with library sulfates, although we note that the libraries may be incomplete.

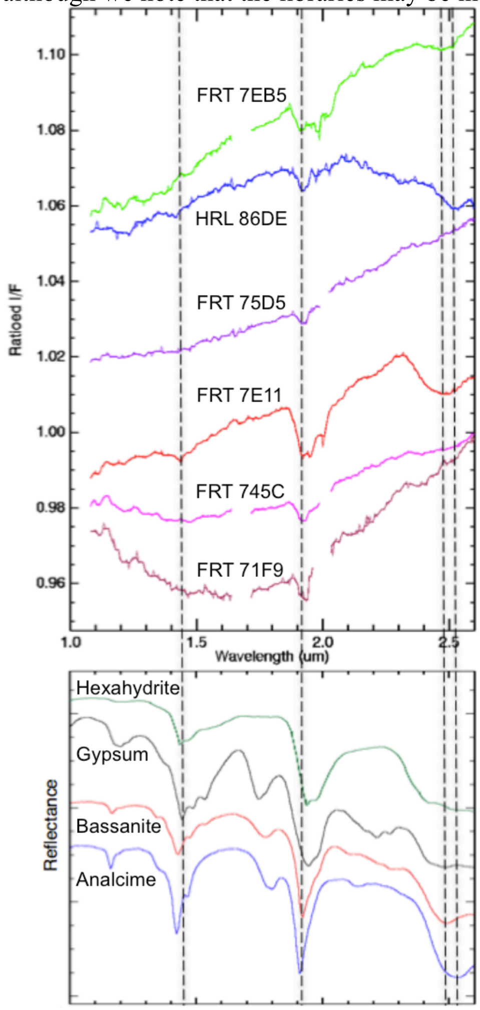

Figure 2. CRISM spectra (top) compared to library mineral spectra (bottom), vertically offset; see text for discussion.

The other three CRISM spectra in Fig. 2 (purple, magenta, and maroon) are from locations off volcanoes and have weaker absorptions. Their only clear absorptions are at 1.9 µm, but each also exhibits a very weak feature near 2.4 µm. This is consistent with polyhydrated Mg-sulfates such as hexahydrite, and in any case is distinct from the spectra shown from volcanoes.

Discussion: Our results expand the number of known areas in the southern high latitudes exhibiting hydration, and allow us to constrain the nature of this hydration. The fact that hydration is found equally often on vs. off the volcanoes suggests a more ubiquitous process for forming the hydrated minerals, possibly similar to the icy weathering processes proposed for the north polar region. It has been suggested that such processes may have contributed to sulfate formation at lower latitudes as well, during high-obliquity periods [17]; this can be tested by MSL/Curiosity when it lands at Gale crater this year [20]. Nevertheless, we should note that all but one (FRT 75D5) of the off-volcano CRISM images with hydration is either near a volcano or in/near a complex pit called Sisyphi Cavi (SC). SC exhibits esker-like features and its formation has been attributed to volcano-induced melting, similar to features on the Sisyphi mountains [21].

It is intriguing that the locations showing the strongest spectral features appear consistent with gypsum, similar to the north polar region. However, these locations are primarily on the putative volcanoes, whereas recent studies of the north polar sulfates do not invoke volcanism as a cause of alteration [14–16]. Perhaps a better analog for the Sisyphi mountains is the probable Ca-sulfate in Noctis Labyrinthus identified as a likely product of geologically recent volcanism [9]. Another caveat is that one of the Sisyphi mountains may have spectral features more consistent with zeolite than with sulfate (Fig. 2), which may imply a higher-pH alteration environment.

To further test these results and inferences, we will next explore lower-resolution CRISM multispectral mapping data to map hydration beyond the small areas of the high-resolution targeted images. We will also use images from the High Resolution Imaging Science Experiment (HiRISE), also on MRO, to examine the morphology of sulfates identified in various locations—e.g., ref. 3 suggested that sulfates correlate with boulders at the location of the red spectrum in Fig. 2.

References: [1] Squyres S. W. et al. (2004) *Science, 306,* 1709–1714. [2] Gendrin A. et al. (2005) *Science, 307,* 1587–1591. [3] Wray J. J. et al. (2009) *Geology, 37,* 1043–1046. [4] Langevin Y. et al. (2005) *Science, 307,* 1584–1586. [5] Vaniman D. T. et al. (2004) *Nature, 431,* 663–665. [6] Kounaves S. P. et al. (2010) *GRL, 37,* L09201. [7] Bibring J.-P. et al. (2006) *Science, 312,* 400–404. [8] Wray J. J. et al. (2010) *Icarus, 209,* 416–421. [9] Mangold N. et al. (2010) *Icarus, 207,* 265–276. [10] Poulet F. et al. (2008) *GRL, 35,* L20201. [11] Michalski J. R. et al. (2010) *LPS XLI,* Abstract #1959. [12] Fishbaugh K. E. et al. (2007) *JGR, 112,* E07002. [13] Horgan B. H. et al. (2009) *JGR, 114,* E01005. [14] Calvin W. M. et al. (2009) *JGR, 114,* E00D11. [15] Massé M. et al. (2010) *Icarus, 209,* 434–451. [16] Massé M. et al. (2012) *E&PSL, 317–318,* 44–55. [17] Niles P. B. and Michalski J. (2009) *Nature Geosci., 2,* 215–220. [18] Ghatan G. J. and Head J. W. (2002) *JGR, 107,* 5048. [19] Seelos F. P. et al. (2011) *LPS XLII,* Abstract #1438. [20] Grotzinger J. P. and Milliken R. E. (2012) *SEPM,* in press. [21] Ghatan G. J. and Head J. W. (2002) *Microsymposium 36,* Abstract #24.