SILICA-RICH DEPOSITS AND HYDRATED MINERALS AT GUSEV CRATER, MARS. M. S. Rice[1], J. F. Bell III[1], E. A. Cloutis[2], A. Wang[3], S. W. Ruff[4], M. A. Craig[5], D. T. Bailey[2], J. R. Johnson[6], P. A. de Souza, Jr.[7], W. H. Farrand[8], [1]Dept. of Astronomy, Cornell Univ., Ithaca, NY (mrice@astro.cornell.edu), [2]Dept. of Geography, Univ. of Winnipeg, Winnipeg, MB, Canada, [3]Dept. of Earth & Planetary Sciences, Washington Univ., St. Louis, MO, [4] School of Earth and Space Exploration, Arizona State Univ., Tempe, AZ , [5] Dept. of Earth Sciences, Univ. of Western Ontario, London, ON, Canada, [6] Astrogeology Team, USGS, Flagstaff, Arizona, [7] Tasmanian ICT Center, CSIRO, Hobart, Australia, [8] Space Sci. Institute, Boulder CO.

Introduction: In the Columbia Hills of Gusev Crater, the Mars Exploration Rover (MER) Spirit has recently made the only unequivocal detection of nearly pure silica on Mars [1]. Observations of the Gertrude Weise soil feature by the rover's Alpha Particle X-Ray Spectrometer (APXS) instrument show that its composition is ~98 wt.% SiO_2 when corrected for dust contamination [1], and measurements from Spirit's Miniature Thermal Emission Spectrometer (Mini-TES) are consistent with the presence of opaline silica [2]. Light-toned nodular outcrops in the Eastern Valley region are also Si-rich (63-73 wt.% SiO_2) [3]. In visible to near-infrared (Vis-NIR) Pancam data, all of the known high-silica soils and nodules show a distinct spectral downturn at 1009 nm [3,4].

In this work, we aim to link this specific Pancam spectral feature to specific mineralogical properties. We have also used a set of Vis-NIR spectral indices to remotely identify materials that are spectrally similar to the Si-rich soil and outcrop. The ultimate goal of our study is to map the distribution of potential alteration deposits within the Columbia Hills region and to constrain models for their formation and evolution.

Pancam Spectral Characteristics: Pancam's 13 narrowband geology filters cover 11 unique wavelengths from 434 to 1009 nm [5]. To characterize more generally the Pancam spectra of Si-rich targets (Fig. 1), we have examined a wide range of spectral parameters, including band depths at specific wavelengths, slopes between wavelength bands, and relative reflectance values. We find that the Si-rich soil and outcrops are spectrally distinct from other materials in the Columbia Hills, and we classify them with the following four spectral parameters: 1) 934 to 1009 nm slopes less than -2.0 x 10^{-4} nm^{-1}; 2) 754 to 864 nm slopes greater than 0.0 nm^{-1}; 3) 436 to 754 nm slopes greater than 4.0 x 10^{-4} nm^{-1}; and 4) 864 to 934 nm slopes between -1.0 and 1.0 x 10^{-4} nm^{-1}. Parameters (1) and (2) are indicated by the gray regions in Fig. 2, and spectral slope is defined as the difference between the relative reflectance (R*) values at two wavelengths divided by the wavelength difference.

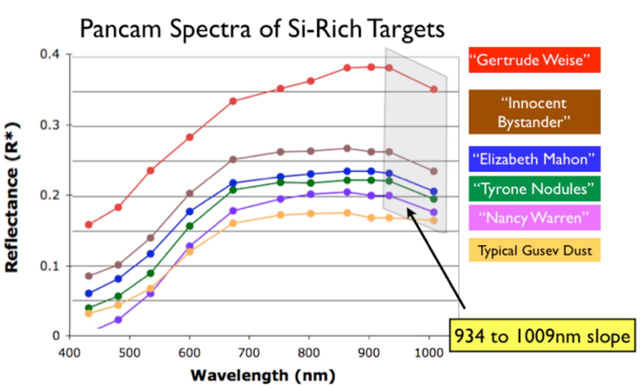


Fig. 1. Example spectra of materials confirmed as Si-rich by Mini-TES and/or APXS (plus typical Gusev dust for comparison).

The Origin of the Observed Vis-NIR features: As the 934 to 1009 nm negative slope is the most distinctive spectral feature of the Si-rich soil and nodular outcrops in the East Valley, it is important that we understand its chemical/mineralogical origin. It is unlikely that the 1009 nm downturn arises directly from the Si content of the soils and nodules because reflectance spectra of amorphous silica are typically featureless in Vis-NIR wavelengths [4]. The APXS detected Ti enrichments associated with the Si-rich soils [1], but TiO_2 is also spectrally featureless at the NIR Pancam wavelengths. No other elements were detected above 5 wt.%.

To identify other possible minor phases, we have performed comparisons of the Pancam spectra to a total of 1880 laboratory spectra of minerals from the USGS Digital Spectral Library [6], the CRISM Spectral Library [7], as well as spectra from other studies of sulfate minerals [8], playa evaporite minerals [9], and ices [10]. We have also acquired reflectance spectra of fresh snow and Si-rich materials. We have identified 18 spectra that exhibit a 934 to 1009 nm slope less than -2.0 x 10^{-4} nm^{-1} when convolved to Pancam bandpasses, the best matches being anarcticite ($CaCl_2{\cdot}6H_2O$), natron ($Na_2CO_3{\cdot}10H_2O$), sanderite ($MgSO_4{\cdot}2H_2O$), kainite ($MgSO_4{\cdot}KCl{\cdot}3H_2O$) [9], datolite ($CaBSiO_4(OH)$), alunite ($KAl_3(SO_4)_2(OH)_6$) [6], sodium metasilicate nonahydrate ($Na_2SiO_3{\cdot}9H_2O$) and fresh snow (H_2O) [our laboratory observations].

A common theme among these spectral matches is that they all possess structural or bound H_2O or OH. Thus, the 943 to 1009 nm slope may be due to an O-H stretch overtone feature (possibly the combinational mode $2\nu_1+\nu_3$) near ~1000 nm. We have observed a similar absorption band in our laboratory measurements of hydrated amorphous silica samples (silica sinters, opals, and silica gel; *Rice et al.*, submitted), but the band minimum occurs at wavelengths too short to be detected by Pancam's longest wavelength filter.

Regional Mapping: We argue that four slope parameters extracted from the Pancam Vis-NIR spectra of typical Si-rich species can be used as a "hydration index," based on our hypothesis that the 934 to 1009 nm slope is caused by an H_2O combination mode, and we have mapped pixels that meet the "hydration index" criteria over every 13-filter Pancam image sequence taken from the West Spur to Home Plate (sols 155-1400). We find that the "hydration index" is widespread along Spirit's path through the Columbia Hills and correlates with a wide variety of features, including: the edges of angular outcrops at Hank's Hollow; Clovis Class rocks across West Spur; Assemblee Class rocks at the Voltaire outcrop on Southwest Husband Hill; altered rocks across Husband Hill; dust-coated facets of massive basalts; light-toned nodular outcrops near S-rich soil deposits; scattered portions of the S-rich soil deposits at Paso Robles, Dead Sea, and the Tyrone "white" soil; platy, thinly-bedded, light-toned outcrops near Home Plate; and portions of the layered Home Plate outcrop.

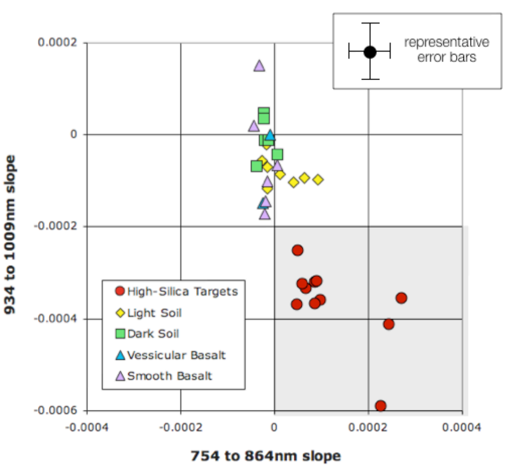
We have also performed this mapping over the 360^o McMurdo and Bonestell Panoramas. Because of their high resolution and wide spatial and spectral coverage, these observations allow us to map the regional distribution of the "hydration index" in the Inner Basin of the Columbia Hills (Fig. 3), which extend to regions where Spirit has not yet traversed (such as the Von Braun feature south of Home Plate).

Discussion: Based on comparisons with spectral databases, we hypothesize that the presence of H_2O or OH is responsible for the spectral feature observed by Pancam. Because the Gertrude Weise soil is nearly pure opaline silica [1], it is highly unlikely that additional hydrated mineral components are present in large enough quantities to produce the observed Pancam feature . Free water (as fine-grained water frost or fluid inclusions) could potentially create the negative slope from 934 to 1009 nm. Frost is unlikely to be stable at the surface of Gusev Crater under current Martian conditions [*e.g.*, 11,12], but water ice in fluid inclusions could be isolated from the Martian atmosphere and remain stable for extended periods [13]. Another hypothesis is that adsorbed water on mineral grains causes the observed ~1000 nm absorption feature in the Gertrude Weise soil. It is possible that Spirit's wheels exposed a water source at several centimeters depth below the surface that, as it sublimates and migrates towards the surface, gets cold-trapped on mineral grains.

The Si-rich nodular outcrops have different chemistries than the Gertrude Weise soil, and the presence of additional hydrated minerals could contribute to their spectra as well. Possible additional phases include sulfates, halides, chlorides, sodium silicates, carbonates, or borates. Because there are significant geochemical differences among the materials that exhibit the "hydration index" across Spirit's traverse, there could be several different mineralogic origins of the ~1009 nm hydration feature in the Columbia Hills.

The majority of our observed "hydration index" occurrences in the Columbia Hills correlate with materials that are suggested to have undergone aqueous alteration, and we find no overall correlation of these occurrences with topography. The variety of materials that exhibit the "hydration index" along Spirit's traverse, as well as their wide range of geomorphic settings and extended regional coverage, suggests a complicated history of alteration across the Columbia Hills.

References: [1] Squyres *et al.*, *Science, 320*, doi: doi:10.1126/science.1155429 (2008). [2] Ruff *et al.*, *LPSC 39*, 2213 (2008). [3] Wang *et al.*, *JGR, 113*, E12S40, doi:10.1029/2008JE003126. [4] Rice *et al.*, *LPSC 39*, 2138 (2008). [5] Bell *et al. JGR*, *108*, doi:10.1029/2003JE002070 (2003). [6] Clark *et al.*, http://speclab.cr.usgs.gov/spectral.lib06, *USGS Digit. Spec. Lib* (2007). [7] Murchie *et al.*, *JGR, 112*, E11, doi: 10.1029/2006JE002682 (2007). [8] Cloutis *et al.*, *Icarus, 184,* 121, (2006). [9] Crowley *et al.*, *JGR, 96*, 16231 (1991). [10] Roush *et al. Icarus, 86,* 335 (1990). [11] Clifford & Hillel, *JGR, 88,* 2456 (1983). [12] Mellon & Jakosky, *JGR, 98,* 3345 (1993). [13] Roeder, *Fluid Inclusions*, Min. Soc. Am., Washington, DC (1984).



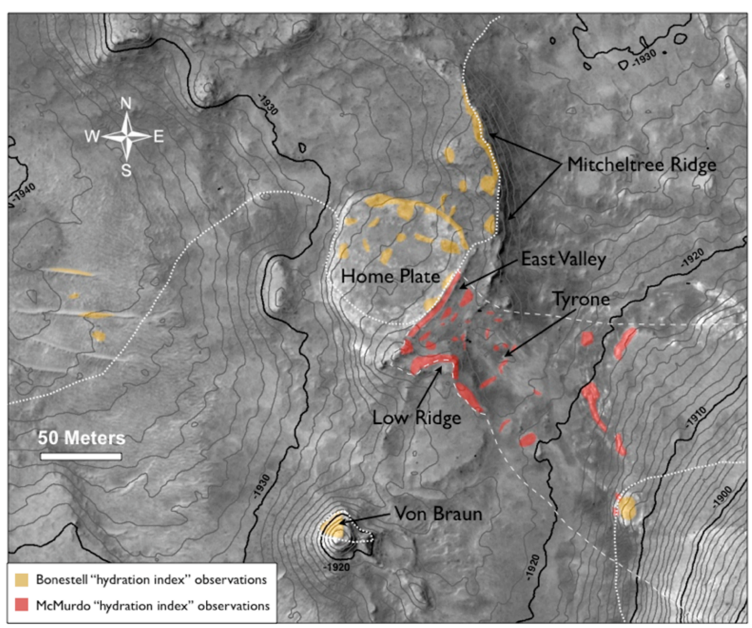


Fig. 2 (above). Parameter space plot indicating (in gray) two of the spectral parameters used to characterize Si-rich materials. **Fig. 3 (right).** Regions where the "hydration index" is seen in the McMurdo (red) and Bonestell (orange) panoramas over HiRISE image PSP_001513_1655_red. Contours are taken from the USGS HiRISE DTM.