

**CONTRASTING REGIONAL SOIL HYDRATION PROCESSES ACROSS THE TOPOGRAPHIC DICHOTOMY OF MARS.** D.R. Hood (dhood7@lsu.edu)<sup>1</sup>, S. Karunatillake<sup>1</sup>, O. Gasnault<sup>2</sup>, A. Williams<sup>3</sup>, B. Dutrow<sup>1</sup>, L. Ojha<sup>4</sup>, S. Kobs<sup>5</sup>, K. Kim<sup>6</sup>, J. L. Heldmann<sup>7</sup>, C. Fralick. 1: Louisiana State University, Baton Rouge, LA 2: L’Institut de Recherche en Astrophysique et Planetologie (IRAP), Toulouse, France 3: University of Florida, Gainesville, FL 4: Johns Hopkins University Baltimore, MD, 5: Idaho State University, Pocatello, ID, 6: Korea Institute of Geoscience and Mineral Resources, Daejeon, South Korea 7: NASA Ames Research Center, Mountain View, CA

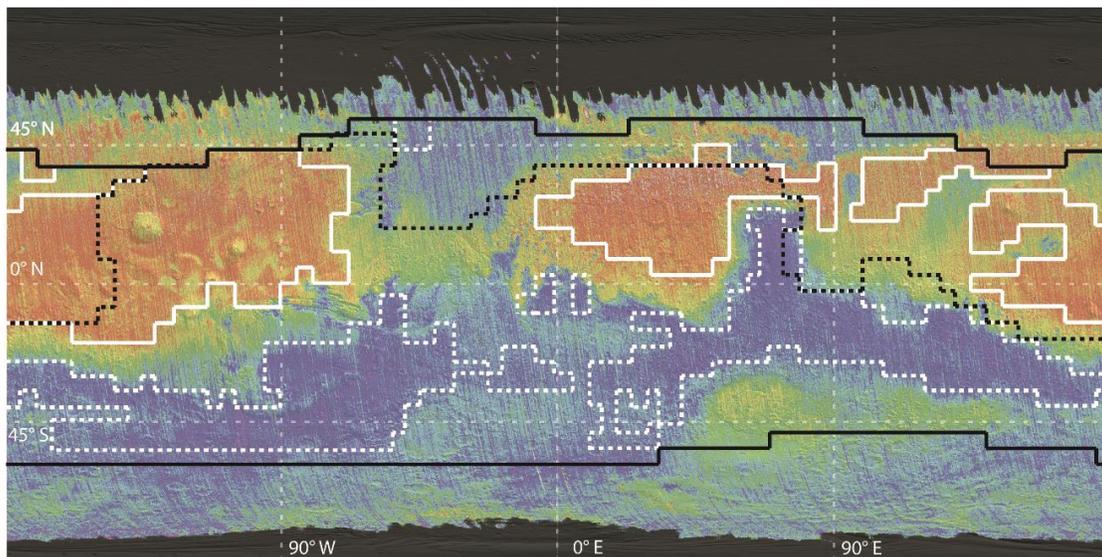
**Introduction:** The geochemistry of martian soil (e.g., as defined by Certini and Ugolini [1]) is known to vary at the global scale. However, correlative studies of global chemical data in multivariate space are lacking, and the contribution to soil geochemistry from surface dust (i.e., low-thermal inertia silicate particles finer than 30 micron grain size) is virtually unknown. Here, Gamma-Ray Spectrometer (GRS) maps of soil chemistry [2]–[4], combined with Thermal Emission Spectrometer (TES)-derived Dust Cover Index (DCI) [5] are used to examine the influence of dust on soil geochemistry and to determine the degree of alteration experienced by global soils

**Methods:** Principal Component Analysis (PCA) is the primary tool used to assess the spatial correlation among the data. This statistical method is selected in that it takes advantage of multiple chemical maps to derive chemical correlations that may help discriminate among geochemical processes. PCA is applied to the suite of chemical maps and DCI within the spatial extent of GRS data (figure 1), as well as on regional subsets of the data which examine more localized trends. Uncertainty is incorporated using t-scores

(eq 1, [6]) as input data. This improves the robustness of PCA results by normalizing with both the standard deviation of the dataset ( $\sigma$ ) and the uncertainty of each observation ( $s_i$ ).

$$\text{Eq. (1)} \quad t_i = (x_i - x_{avg}) / \sqrt{(\sigma^2 + s_i^2)}$$

The cosine similarity (CS) of vectors in Principal Component (PC)-space is used to measure correlation between variables [7]. Only the first two PCs (i.e. the directions of primary and secondary variance in the dataset) are used in this analysis. These PCs reveal the most significant soil chemistry variation (50-60% in 2 PCs) and reduce the influence of less significant variations in soil chemistry. CS serves as a proxy for correlation, while allowing comparisons across different data sets in PC1 and PC2 space. We compile CS across multiple regions to examine the cumulative distributions with two-tailed Kolmogorov-Smirnov (KS) tests. KS tests show if variables correlate with one another distinctly ( $p < 0.05$ ) relative to other variables (e.g. do S and H<sub>2</sub>O correlate stronger than H<sub>2</sub>O and Cl).



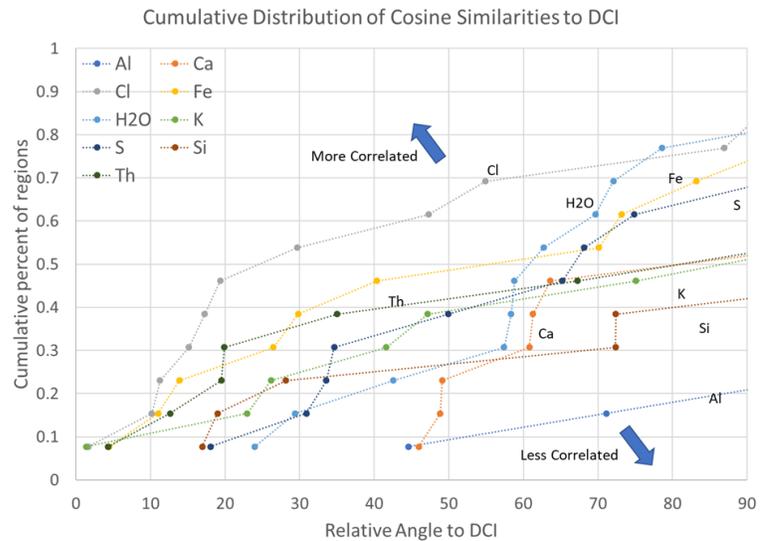
**Figure 1.** Map of the martian surface showing the extent of the GRS coverage for all elements (solid black lines) overlain on the map of Dust Cover Index (Red = high dust abundance, Blue = low dust abundance) at original resolution [5]. The black dotted line shows the boundary between the northern lowlands and southern highlands regions; the white boundaries show the extent of DCI-depleted (dashed) and enriched (solid) areas. Eight other regions were used for regional analysis, identified by terrain type (volcanic and non-volcanic) and anomalously high or low values in each of the variables Cl, S, and H<sub>2</sub>O.

**Results:** The results in Figure 2 show a key finding: the correlations of DCI with elements in which the dust is enriched relative to typical soil (S, H<sub>2</sub>O, Fe [8]) are indistinguishable from correlations with the remaining elements. Even Cl, an apparent outlier, is only distinct from Ca and Al, the two least correlated variables. Furthermore, regional analysis in the combined DCI-enriched and DCI-depleted regions (Figure 1) shows no enhanced correlation between DCI and the elements compared to analysis of the entire dataset.

Regional analyses on either side of the topographic dichotomy reveal chemical differences, and advance prior limited studies [9], [10]. In the southern highlands, H<sub>2</sub>O and S are strongly correlated (CS: 0.998) but S and Cl are weakly correlated (CS: 0.782). Such correlations are consistent with a preferential chemical association between S and H<sub>2</sub>O compared to S and Cl. By contrast, the northern lowlands show a weaker correlation between H<sub>2</sub>O and S (CS: 0.941) and a stronger correlation between S and Cl (CS: 0.999). While the S-H<sub>2</sub>O coupling is still present, the S-Cl coupling in the northern lowlands is stronger than in the southern highlands.

**Conclusions:** This multivariate analysis of chemical data demonstrates that DCI is poorly correlated with soil chemistry. Consequently, the chemical composition of the dust and volatiles physically adsorbed to dust particles may not contribute significantly to the bulk soil chemistry. Furthermore, proposed dust layers and duststones [11] are either not present at the suggested lateral (100s of km) and vertical scales (m-scale thickness), or they are chemically heterogeneous. Our observations are instead consistent with regional heterogeneity as the primary driver of volatile elemental trends (especially H<sub>2</sub>O and S) in the soil. Such trends likely represent the diversity of source materials [12] and distinct pedogenesis.

The mutual trends in S, Cl, and H<sub>2</sub>O correlation are indicative of widespread highly altered soils in the southern highlands, and relatively poorly altered soils in the northern lowlands. A geographically pervasive presence of aqueous alteration processes would be required to produce such soils. Such widespread soil alteration suggests that much of the southern highlands soil may have, at one point, contained chemical gradients relevant for habitability. The contrasting absence of such signatures in the northern lowlands supports a hypothesis of regionally pervasive mantling by generally basaltic, minimally weathered soil resembling the



**Figure 2.** Cumulative PCA results of variables vs. DCI. The x-axis shows relative angle, which is the angle between vectors in PC1-2 space, the cosine of the relative angle is the cosine similarity. As marked by the arrows, more correlated elements will plot towards the upper left side of the plot. Of the variables tested, Cl shows the strongest correlation with DCI. The remaining variables fall on a continuum of cumulative correlation.

surficial soil seen at several in situ locations (e.g. Gale Crater [13]). These findings motivate further work to refine the mineralogy of bulk soil at the regional scale, particularly regarding the phases that accommodate volatile elements. The volatile-rich amorphous phase observed in Gale [14] could reasonably cause much of the variation in volatile chemistry as a component of the soil. If this phase is responsible for soil hydration in much of the southern highlands akin to Paso Robles in Gusev Crater [15], it would indicate large-scale weathering that formed a hemispheric layer of altered soil. Therefore, the mineralogy and composition of this phase (e.g. volcanic glasses, sulfates, or clay minerals), as sampled in situ, locally, and regionally, may inform the nature of these global-scale events.

**References:** [1] G. Certini and F. C. Ugolini, *Geoderma*, 2013. [2] W. V. Boynton, et. al. *JGR*, 2007. [3] D. R. Hood, *JGR Planets*, 2016. [4] S. a. Nowicki and P. R. Christensen, *JGR*, 2007. [5] S. W. Ruff and P. R. Christensen, *JGR*, 2002. [6] S. Karunatillake, et. al. *JGR*, 2009. [7] G. Salton and M. J. McGill, 1983. [8] J. A. Berger, et. al. *GRL*, 2016. [9] S. Karunatillake, et. al. *JGR*, 2016. [10] S. Karunatillake, *GRL*, v 2014. [11] N. T. Bridges and D. R. Muhs, 2012. [12] H. E. Newsom, et. al. *JGR*, 2007. [13] A. Cousin, et. al. *Icarus*, 2015. [14] E. Dehouck, et. al. " *JGR. Planets*, , 2014. [15] A. S. Yen, et. al. *JGR*, 2008.