

**RELATIONSHIPS BETWEEN CHEMICAL TRENDS AND GRAIN SIZE IN GUSEV SOILS.** Suniti Karunatillake<sup>1</sup>, Scott M. McLennan<sup>1</sup>, and the Mars Exploration Rover Team. <sup>1</sup>Geosciences, SUNY-Stony Brook, Stony Brook, NY 11794 (wk43@cornell.edu).

**Introduction:** The Mars Exploration Rover (MER) science team has described the distribution of different soil particle size populations [1,2] over the Spirit rover's traverse at Gusev crater through sol 1512. Others have classified the soil in terms of composition [3,4]. We essentially combine the two approaches and seek to identify any chemical trends that may exist as a function of grain size, limited to the finest (less than pebble size) and most readily transported fraction. Consistent with earlier work, three broad groups may be defined according to grain size: sand, mix, and fines. The first is defined by the Wentworth scale. The latter includes all particles finer than 150 µm, the practical limit of resolution with the Microscopic Imager (MI). Remaining samples contain a mix of various grain sizes, typically of sand and fines, which we consequently termed "mix" (Table 1).

**Table 1 Soil classes as defined in this study, and the corresponding Wentworth classes. Those identifiable in MI samples are in boldface.**

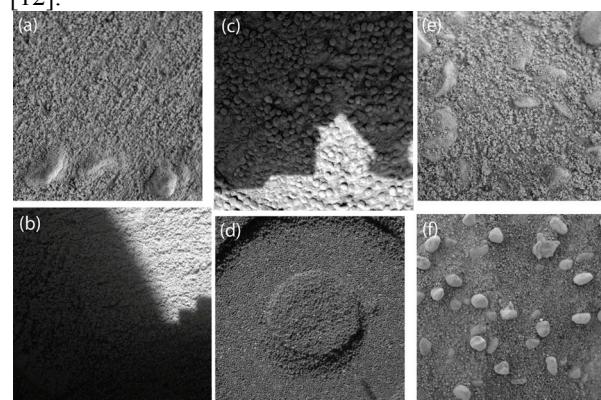
Class in this work	Particle size range	Wentworth class
Pebbles	4 – 31 mm	Pebbles
Granules	2 – 4 mm	Granules
<b>Sand</b>	<b>150 µm – 2 mm</b>	<b>Sand</b>
Fines	< 150 µm	Sand, silt, and clay
Mix	Two or more classes above	Inapplicable

In terrestrial settings, the dominance of particular grain sizes in association with specific minerals has provided insight into transport [5], chemical composition of shales has constrained provenance [6], and heavy mineral sorting has shed light on both provenance and transport [7,8]. While modeling the major media of sediment generation and transport on Mars has been difficult given the dramatic differences between terrestrial and Martian atmosphere-surface interactions, much progress has been made by recent work in the eolian context [9]. Additionally, potential end members have been identified for compositional mixing models based on recent characterizations of soil [1,9]. Lastly, soil is not only ubiquitous, but also areally dominant on Mars as epitomized by large swaths [10] of the planet where Visible/Near/Thermal-IR (V/N/T-IR) spectrometers are "blind" due to obscuration by fines. Consequently, characterizing Martian

soil simultaneously by grain size and composition as observed in situ can be an important contributor to advancing the understanding of the Martian surface in general.

We achieved several goals in the sedimentological context of this work. The first was to classify the soil at Gusev on the basis of grain size. Second, we characterized the chemical composition within each class. Third, we determined what inferences may be gained by differences and similarities across the classes, leading to our next goal of discussing the viability of binary (and/or ternary) mixing models to explain compositional variations.

**Synopsis of Methodology:** Given the compositional contrast between the Columbia Hills and the Gusev plains [11], we also bifurcated each class (Table 1) into a plains subclass and a hills subclass. All samples predating sol 156 [11] belonged in the former, and the rest in the latter. We identified a total of 54 samples as soil through sol 1512, with 39 classifiable as fines (19 plains subclass including 9 samples of dust by Yen et al. [12]; 20 hills subclass), 5 as sand (1 plains; 4 hills), and 10 as mix (2 plains; 8 hills). Examples in Figure 1 highlight the consistency of the classification system across the rover traverse, as well as the first-order visual similarity between fines and dust [12].

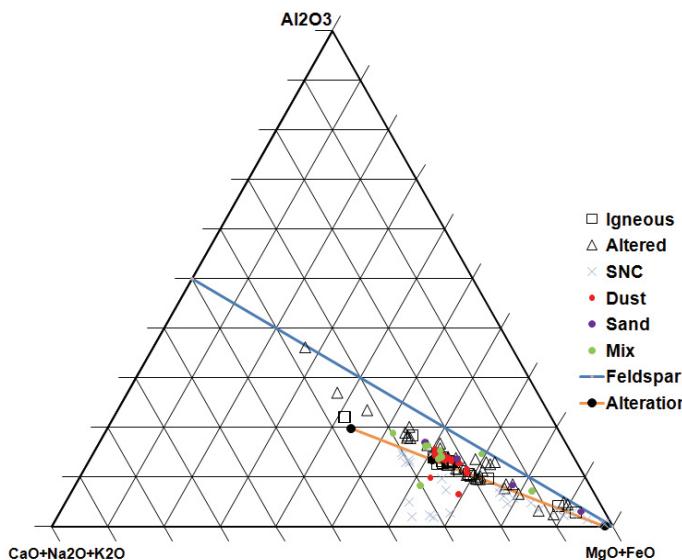


**Figure 1** MI examples of the different classes. Fines are labeled (a – sol 70 Gobi1 Deserts) and (b – 1510 ArthurCHarmon). (c – 41 Crest Arena) and (d – 709 ElDoradoScuff\_Shadow) are sand. (e – 105 Flats1 Bitterroot flats) and (f – 812 Enderbyland\_Mawson) are mix. Samples, such as (a) and (b), highlight the consistency of classification across the rover traverse. Sample (a) was also classified as dust by Yen et al. [12]. All images are at the same resolution, with the central imprint in (d) ~14 mm across for scale.

We utilized several statistical comparisons [13,14] among the grain size classes based on average, median, 25<sup>th</sup> percentile, 75<sup>th</sup> percentile, and standard deviation parameters. These identified the first order chemical trends in soils as a function of grain size.

Secondary trends were identified first by means of three distinct ternary diagrams of molar fractions: (1) MgO+CaO+FeO, SiO<sub>2</sub>+Al<sub>2</sub>O<sub>3</sub>, and SO<sub>3</sub>; (2) MgO, FeO, and SO<sub>3</sub>; (3) Al<sub>2</sub>O<sub>3</sub>, CaO+Na<sub>2</sub>O+K<sub>2</sub>O, and FeO+MgO. We also plotted abraded/brushed rock samples at Gusev and Meridiani to identify clusters and trends in the soil. SNCs served as supplementary data. The Al<sub>2</sub>O<sub>3</sub>, CaO+Na<sub>2</sub>O+K<sub>2</sub>O, and FeO+MgO ternary is shown in Figure 2 as an example [15]. Bivariate scatter plots among all elements within each class helped to identify additional secondary trends.

Second, we considered candidate binary mixing models and their ternary extensions as motivated by previous work [1,9] and the ternary diagrams. Some of the binary mixing models that we evaluated with oxide/element versus SiO<sub>2</sub>/SO<sub>3</sub> scatter plots include: Fines and C1 chondrites [12]; Fines and Ca-sulfate; Fines and Ilmenite [8]; Fines and Mg-sulfate.



**Figure 2** Ternary diagram including the anticipated low-pH open-system alteration trend of Martian basalt as determined experimentally (orange) by Hurowitz and McLennan[15]. The Mg-Fe and feldspar join is indicated in blue. Note that while the terrestrial moderate-pH alteration trend of Al enrichment is absent, many soil samples and rocks plot between the feldspar join (blue) and the predicted low-pH alteration line (orange).

**Discussion:** The key chemical observation is greater homogeneity in fines relative to the other two grain size classes. The mix class is generally more heterogeneous as are samples from the Columbia Hills within each class. The tentative evidence for binary mixes transcends classes and is consistent with significant non-mixing contributions, perhaps including loca-

lized chemical alteration. Optimal mixing models include: Typical fines with the opaline Si end member [16] identified at Home Plate; and typical fines with sulfates (bearing some mix of Ca, Fe, and Mg cations). Variations in Ni are consistent with a C1 contribution not exceeding 4%, while that of Ti is consistent with ilmenite enrichment not exceeding 4%. Such trends follow the mineralogic classification more than grain size groups, indicating that chemical processes coupling composition with grain size have been less significant. The sole exception is of elemental correlations Cl-Si, Cl-S, and Al-Si, which appear limited to the fines class.

### References:

- [1] Yingst R. A. et al. (2008) *J. Geophys. Res.* 113, E12S41. [2] Weitz C. M. et al. (2006) *J. Geophys. Res.* 111, E12S04. [3] Morris R. V. et al. (2008) *J. Geophys. Res.* 113, E12S42. [4] Morris R. V. et al. (2006) *J. Geophys. Res. Planets* 111, E02S13. [5] Xiao J. et al. (1995) *Quaternary Research* 43, 22-29. [6] Komuro K. et al. (2006) *Resource Geology* 56, 447-455. [7] Frihy O. E. et al. (1995) *Sedimentary Geology* 97, 33-41. [8] Garzanti E. et al. (2008) *Earth and Planetary Science Letters* 273, 138-151. [9] Sullivan R. et al. (2008) *J. Geophys. Res.* 113, E06S07. [10] Rogers A. D. et al. (2007) *J. Geophys. Res.* 112, E02004. [11] Squyres S. W. et al. (2006) *J. Geophys. Res.* 111, E02S11. [12] Yen A. S. et al. (2005) *Nature* 436, 49-54. [13] Karunatillake S. et al. (2009a, submitted) *Earth Moon Planets*. [14] Karunatillake S. et al. (2009b, submitted) *J. Sci. Comput.* [15] Hurowitz J. A. and McLennan S. M. (2007) *Earth Planet. Sci. Lett.* 260, 432-443. [16] Squyres S. W. et al. (2008) *Science* 320, 1063-1067.

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