

**PEDOGENETIC AND PALEO-ENVIRONMENTAL CONSTRAINTS FROM THE SOILS OF GALE CRATER.** Yutong Shi<sup>1</sup>, Siyuan Zhao<sup>1</sup>, Suniti Karunatillake<sup>2</sup>, and Long Xiao<sup>1\*</sup>, <sup>1</sup>Planetary Science Institute, School of Earth Sciences, China University of Geosciences, Wuhan, China (longxiao@cug.edu.cn), <sup>2</sup>Geology & Geophysics DEPT, Louisiana State University, USA.

**Introduction:** The physical, chemical and mineralogical properties of soils [1] on Mars effectively archive the history of Martian sedimentary processes and climate at the critical zone of interaction between the atmosphere and crust. Various sorting trends between mafic and felsic minerals have been identified through different methods in in-situ observed Martian soils, providing insights into the diverse pathways of Martian pedogenesis, e.g. the competing roles of physical sorting and chemical weathering [2-4]. Photo-analyzing of in-situ obtained images at both Gale and Gusev suggests an enrichment of felsic minerals in coarse sand (> 500  $\mu\text{m}$ ) [4-6]. Meanwhile, sieving analysis at Bagnold dunes have observed felsic enrichment in finer portions (< 150  $\mu\text{m}$ ) [7-8]. Integration of these separated and possibly contrasting sorting trends remains to be conducted. Accordingly, we aim to verify the sorting trends of soils at Gale crater through a grain size classification, and to further investigate the regional pedogenic processes and underlying paleoclimate through the geochemical and grain-morphometric variation across soil classes.

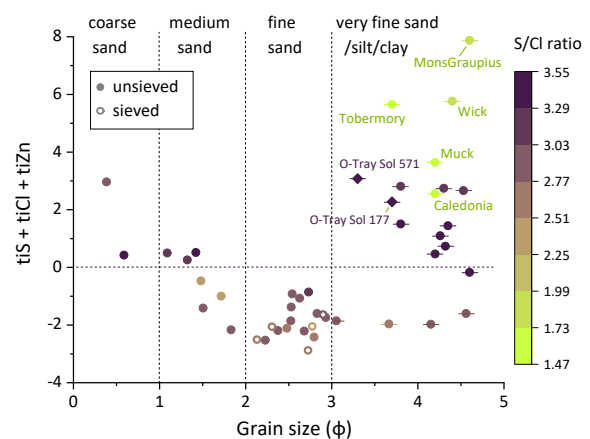
**Method:** Soil samples were selected from Sol 1-2700 based on the correlation of textural (MAHLI) and chemical (APXS) data. All selected MAHLI images were taken within 10 cm-distance from the target point. Our deterministic photoanalysis software suite semi-automated the measurement of grain size and morphometry [9-11]. To minimize conceptual bias from site expectations (e.g., dunes versus inactive sediment) and strengthen comparisons with terrestrial pedology, we define classes solely using the Wentworth scale [12]. Samples with mean grain size smaller than fine sand (125  $\mu\text{m}$ ,  $\phi > 3$ ) were grouped into the category of “Very fine sand/silt/clay”, considering the increasing inaccuracy in the measurements of particles smaller than 125  $\mu\text{m}$  (~ 9 pixel) relative to MAHLI’s point spread function.

The average composition of all selected Gale samples is used in the normalization of S, Cl, and Zn abundance (Fig. 1) and the analyzing of intra-class compositional trends, where log-log plots are used to compare the chemistry of each class versus Gale average. We used *notable* and *minor* to describe the enrichment/depletion of an element content relative to Gale average at better and worse than 2 standard error confidence level, respectively. The chemical index of

alteration (CIA) is calculated as  $[\text{Al}_2\text{O}_3/(\text{Al}_2\text{O}_3 + \text{CaO}^* + \text{Na}_2\text{O} + \text{K}_2\text{O})] \times 100$ , where  $\text{CaO}^*$  equals to the smaller of  $\text{CaO} - 10/3 \times \text{P}_2\text{O}_5$  versus  $\text{Na}_2\text{O}$  [13].

**Results and Discussion:** *Granulometry.* 49 soil targets chosen for collocated textural and chemistry data along the Curiosity traverse, classify as 18 very fine sand /silt/clay samples, 19 fine sand samples, 8 medium sand samples, and 4 coarse sand samples. Most soils are moderately well sorted. The skewness and kurtosis increase with grain size, suggesting a higher weathering state of finer grains.

*Dust Content.* 5 sieved fine sand samples are depleted in S, Cl, and Zn, which is likely a result of the mechanical disruption by sieving. For most of the samples that are unsieved, the abundance of S, Cl, and Zn increases from fine sand to coarse sand, suggesting a lower activity (e.g., transport by eolian saltation, suspension) level in coarser grains [8]. Samples with S, Cl, and Zn abundance below average also show S/Cl molar ratios below the range of Martian dust (3.0-4.4) [14], suggesting minimal atmospheric dust in the fine sand-dominated samples. In contrast, many very fine sand/silt/clay samples are enriched in S, Cl, and Zn relative to Gale average, and show S/Cl ratio within the range of the S/Cl ratio of Martian dust (Fig. 1). These chemical signatures can alternatively represent the composition of the sample itself or the volume of dust mantling surface soils. The former would suggest that these finest soils originate from the deposition of globally-circulated dust via atmospheric suspension.



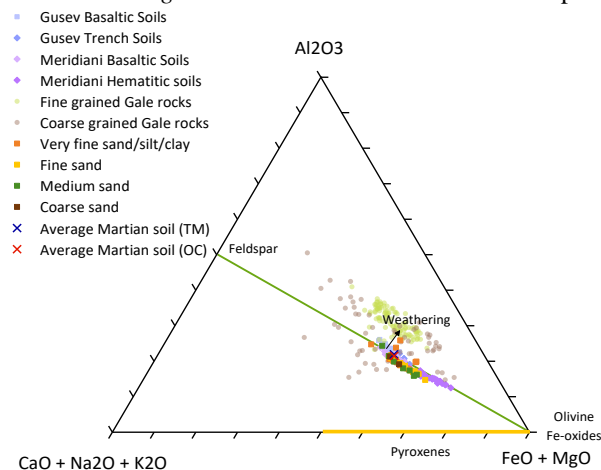
**Fig. 1.** Normalized S, Cl, and Zn abundance and S/Cl molar ratio of Gale soils grouped by grain size. Short bars on circles indicate grain ranges of above 3  $\phi$ .

Otherwise, these signatures of dust could also be explained by the cohesion of very small grains that raises the transport threshold and subdues the grain migration [15]. The 5 very fine sand/silt/clay samples with the highest S, Cl, and Zn abundance notably also show distinctively low S/Cl ratio, which may suggest the localized contribution of neutral chloride fluid [16] or atmospheric perchlorate [17].

**Intra-class compositional trends.** The very fine sand/silt/clay class shows minor enrichment of K and Br and minor depletion of Mn, Ca, Ni, and Mg. Notable depletion of Cl, S, Br, and Zn is observed in the fine sand class, along with minor depletion of K and minor enrichment of Mg. The medium sand class is characterized by notable depletion of Cr and Zn; and minor enrichment of Ni and P; while the coarse sand class is characterized by notable depletion of Mg and Cr, minor enrichment of Ni, Zn, S, Cl, and K; and minor depletion of Br, Ti, P, and Fe.

The depletion of Mg and Mn in the finest (< 125  $\mu\text{m}$ ) and coarsest (> 500  $\mu\text{m}$ ) class relative to other samples is consistent with the mafic sorting trend that has been reported in previous studies at Gale and Gusev [4-8], although the observed variation here is less profound. The enrichment of mafic compositions in coarser grains suggests enrichment of olivine minerals. While that may indicate the presence of heavy mineral sorting on a granulometric sense in Gale pedogenesis, the sorting effects seem to be dramatically subdued relative to Earth, indicating a distinct pedogenetic pathway for Martian soils. The enrichment of Ni in medium sand and coarse sand relative to finer soil classes suggests the contribution of chondritic meteorites [18], which may indicate the effect of meteoritic weathering more substantially than in terrestrial analogs.

**Weathering trends.** The CIA of Gale samples



**Fig. 2.** A-CNK-FM diagram of Gale soils in comparisons with other Martian references.

varies between 59.2 to 69.3, while 91% samples show CIA below 65, suggesting a weak chemical weathering degree that corresponds to a cold and arid climate [19]. Finer grains generally show higher chemical weathering than coarser grains, which is consistent with trends observed in terrestrial sites [20]. 4 samples (2 very fine sand/silt/clay and 2 fine sand) show CIA above 65, consistent with moderate weathering under a more clement climate condition, as is also shown on the  $\text{Al}_2\text{O}_3\text{-CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O-FeO} + \text{MgO}$  (A-CNK-FM) ternary (Fig. 2), where the finest portion of soil shows slight enrichment of Al, suggesting the effect of leaching and chemical alteration.

**Conclusion:** The finest portion of Gale soils (> 3  $\phi$ ) shows the largest compositional variability among all grain size classes, indicating the mixing of globally-sourced allochthonous sediment suspended in the atmosphere and autochthonous counterparts from the weathering of local rocks. The intra-grain size class variation of soil chemistry suggests that the effect of heavy mineral sorting, although subdued, is present in Gale pedogenesis. Gale soils overall show limited chemical weathering consistent with a predominantly water-limited low-temperature paleoenvironment [21]. Nevertheless, signs of moderate weathering in the finer grain size classes suggest the combined effect of provenance under more clement conditions, possibly at moderate pH.

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