GRAIN SIZE AND HYDRODYNAMIC SORTING CONTROLS ON THE COMPOSIITON OF SYNTHETIC BASALTIC SEDIMENT: IMPLICATIONS FOR INTERPRETING MARTIAN SOILS.

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Introduction: Lack of evidence for pervasive chemical weathering coupled with a growing recognition about the importance of physical processes in sediment formation on Mars [1-3] leads us to consider how we might address the extent to which such processes shaped sediment mineralogy and geochemistry. Here we report the results from analog experiments to explore whether compositional variations occur within sieved sediment fractions (0.5 ϕ increments) derived from two texturally and compositionally different crushed basaltic bedrock analogs. The analog experiment, though imperfectly, simulates impact-generated sediment and provides a starting point to consider redistribution of mineral grains from a basaltic source. After evaluating the compositional data from sieving, we model initial threshold velocity (u_{*t}) and grain-size relationships of relevant rocks and minerals with a range of densities to demonstrate that significant chemical changes in sediment may result from the redistribution of mineral species by sorting.

Results: The first examined rock is a trachybasalt (hawaiite) from the Cima volcanic field, Mojave Desert, CA. It contains rare phenocrysts of plagioclase, and microphenocrysts of olivine, plagioclase, and clinopyroxene set in a groundmass of olivine, clinopyroxene, plagioclase, and chromite. The second studied rock is a porphyritic vesicular basalt from Kilauea volcano, HI, with abundant euhedral olivine phenocrysts and a groundmass of olivine, clinopyroxene, plagioclase, and opaque minerals. Olivine grains make up the majority of phenocrysts present in the Kilauea basalt.

Crushed bedrocks, from which compositional data are derived, yield sediments that have a grain-size distributions similar to those generated from impact [3]. Modal mineralogy of each sieve fraction from both rocks varies as single-phase clasts break free of surrounding matrix (Fig. 1). Isolation of phenocrysts as individual clasts in Cima coarse sediment is rare due to the very fine sized phenocrysts in the source rock. As sediment approaches silt size grains, plagioclase, pyroxene and olivine microphenocrysts become increasingly more abundant in the resultant sediment (Fig 1A). By contrast, Kilauea sediments show a systematic increase in single-phase grains, particularly olivine, as grain size decreases, but the volume plateaus at about 2 ϕ because of the coarse size of the phenocrysts (Fig. 1B).

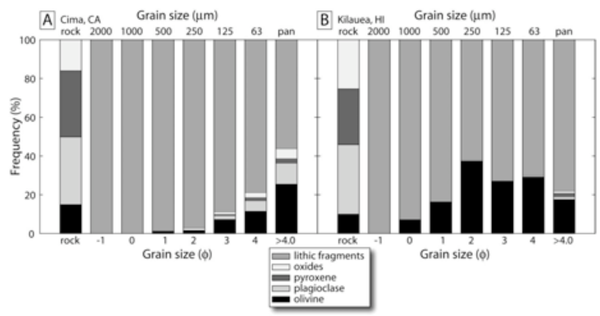

Fig. 1. Modal mineralogy per sieve fraction of synthetic basaltic sand from Cima and Kilauea basalts used in the study.

In terms of major-element geochemistry, sediments show a distinct concentration in MgO relative to original bedorocks, particularly in the Kilauea sample, where detrital olivine concentrates in certain sediment fractions (1-4 ϕ). Trace-element patterns for both sediment groups are very similar in high field strength and rare earth elements relative to bedrock. However, transition metals show marked enrichment in the sediments, particularly those from Kilauea where olivine grains are abundant. With all other processes held equal, we determine that sediments concentrated at different grain sizes regularly have different compositions relative to bedrocks, and that each grain size fraction may be different relative to each other. As a result, we should expect that as sediment enters transport systems further compositional modifications will occur.

Modeling: Density sorting of sediment on the surface of Mars is explored using threshold friction velocity (u_{*t};[4]), which represents the minimum friction velocity required to initiate movement of soil particles. Wind erosion is initiated when friction velocity (u_*) exceeds the threshold friction velocity (u_{*t}). We modeled particle sizes from 10 to 2000 μm (7 to -1.0 ϕ) across a range of compositions (fayalite, forsterite, Cima basalt, Kilauea basalt, plagioclase), that have particle densities ranging from ~ 2.6 to 4.4 gcm^{-3} (Fig. 2). Starting at a fixed u_{*t} of 2 ms^{-1}, there is about a 1 ϕ difference in grain size between between the most and least dense of the modeled phases that are in hydrodynamic equivalence (Fig. 2B). Conversely, for fixed grain size of 2 ϕ, there is a 0.35 difference in u_{*t} values needed to initiate sediment movement for materials of different densities (Fig. 2B).

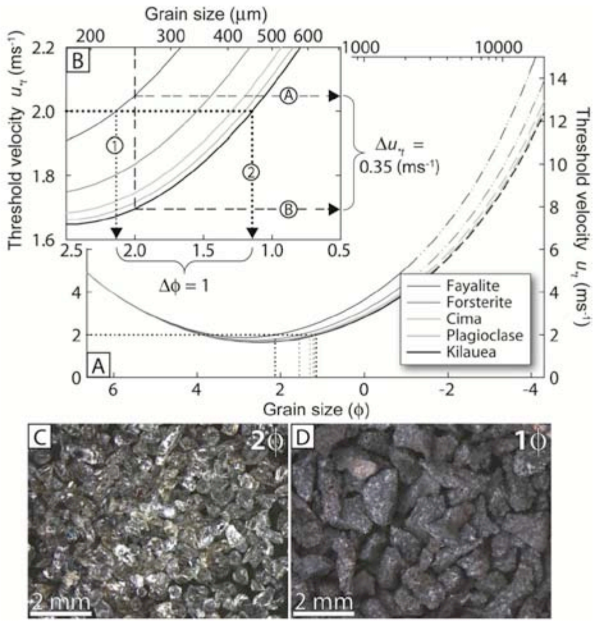

Fig. 2. (A) Plot of sediment grain size (ϕ) versus threshold velocity (u_{*t}) for rocks and minerals of different densities. Dotted horizontal line denotes hydrodynamic equivalence at $u_{*t} = 2$ ms^{-1} for sediment grains and minerals with different densities, and corresponding grain sizes. (B) Inset showing expanded part of plot in (A). At $u_{*t} = 2$ ms^{-1} the entrainment for medium sand (2 ϕ) olivine grains, modeled as fayalite (ρ_p = 4390 kg m^{-3}) shown by arrow 1 is equivalent to entrainment for Kilauea basalt derived coarse sand sediment (ρ_p = 2601 kg m^{-3}) shown by arrow 2. Differences in u_{*t} show potential for olivine (fayalite, arrow A) accumulation separated from Mars sand (Kilauea basalt, arrow B). (C) Olivine clasts separated from Kilauea basalt at grains size 2 ϕ. (D) Cima basalt clasts at grain size 1 ϕ.

Implications: This experimental approach demonstrates the capability of compositional modification of sediments by physical sorting, links igneous protolith mineralogies and textures with sediment compositions, and must be considered when interpreting the compositions and weathering pathways of martian sediments. Cima trachybasalt and Kilauea basalt represent high- and low-alkali compositions, bracketing the compositions of most rocks and soils in Gusev Crater. In A-CNK-FM compositional space (Fig. 3), the sieved sediment fractions for both basalts lie along a trend sub-parallel to a line connecting the FM pole and the A-CNK join at 50%. Gusev bedrock and sediment data scatter along a trend that is close to that observed in the Kilauea data (Fig. 3). This observation is not to imply that the sieved data make a direct analog for the martian data, but rather that physical process acting on a compositionally heterogenous sediment mass would likely result in mixtures of phases that possess a range of compositions that scatter along such trajectories.

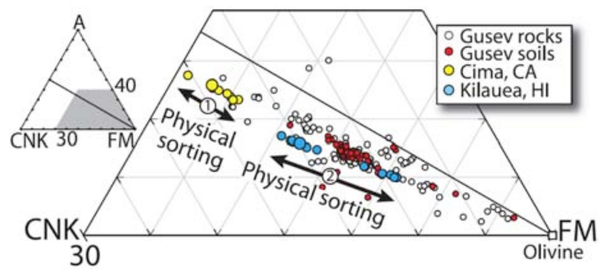

Fig. 3. A-CNK-FM plot showing the distribution of Gusev bedrocks and soils along with sieve fraction data from both Cima and Kilauea bedrocks and sieved sediment fractions. Modified from [3].

Aeolian transport modeling demonstrates the plausibility for density separation of minerals by selectively removing less-dense plagioclase and basalt clasts from denser grains of olivine, producing sedimentary deposits enriched in specific rock and/or mineral phases [e.g., 5]. Such a process would predict the martian surface could be covered by sediment with diverse compositions even in the absence of abundant chemical weathering, which would serve to enhance any compositional changes made during physical transport.

References: [1] Grotzinger J.P. et al. (2011) *Sed. Record, 9*, 4-8. [2] McGlynn I.O. et al. (2011) *JGR, 116,* E00F22. [3] McGlynn I.O. et al. (2012) *JGR, 117,* E01006. [4] Shao Y.P. and Lu H. (2000) *JGR, 105*, 22437-22443. [5] Chojnacki M. et al. (2014) *Icarus, 230,* 96-142.