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Introduction: If liquid water was once persistent on the surface of Mars, products of aqueous alteration in the form of phyllosilicate deposits should be abundant. Despite overwhelming geomorphic evidence that liquid water was once present [1,2], little evidence of chemical alteration resulting from liquid water has been found on the surface of Mars. The lack of substantial clay formations at Gusev Crater and Meridiani Planum indicate an arid environment that is void of significant hydrolysis [3].

Clues to the development and formation of soils on the surface of Mars can be found in the physical and chemical properties of unconsolidated sediments examined by the Mars Exploration Rover Spirit. The production of clays from the weathering of basaltic glass, olivine and feldspars can be an indication of aqueous alteration. Physical mechanisms of hydrodynamic alteration, selective sorting, and transport can be reflected in changes in soil composition, grain size, sphericity, and rounding. The purpose of this study is to evaluate the compositions of physically sorted and mixed sediments and evaluate the potential for weathering profiles and the extent of chemical weathering of basaltic soils in Gusev Crater. Major theories of weathering pathways are evaluated in the context of a chemical-textural relationship.

Data Sets: Undisturbed soils with corresponding compositional spectra from the Alpha Particle X-ray Spectrometer (APXS) and in-focus Microscopic Imager (MI) targets were selected to represent surface conditions in Gusev Crater. The chemical and textural correlation is possible from a database of textural measurements consisting of median grain size, grain size range, population modality, roundness, sphericity, and sorting developed from point counting high resolution (31 µm/pixel) MI targets with a minimum of 400 counts per analysis. This data set developed and already presented [4] provides a comprehensive set of parameters from which to evaluate chemical and physical weathering processes.

Textural Classifications: Four major soil types were originally identified [5]. These four classes are retained and broadened to include soils from Gusev Plains, Columbia Hills, Low Ridge, and Eastern Valley, and are expanded to include mixing of soil types (Fig. 1). Only grain size-frequency histograms are given in Fig. 1, although other soil characteristics have been quantified. Soil classes consist of a thin high-frequency band of grain sizes.

Figure 1. Six soil classes from mean grain size distributions for dark soil, bedform armour, mixtures of dark soil and bedform armour, and lithic fragments. Two distinct classes of bedform armour mixing with dark soil are combined. Bright dust soils are below the measurement resolution and not shown. The distinct populations indicate varying degrees of transport, mixing, and selective sorting in Gusev Crater.
albedo bright dust layer that is not directly measurable in MI images (<10μm), a very poorly sorted dark low-albedo soil with rounded to well rounded very fine to coarse sand grains, a very poorly sorted bedform-armour in the upper surface of subangular to well rounded fine sand to very fine pebbles, and very poorly sorted clasts of rounded to well rounded lithic fragments. Mixtures of dark soil with bedform armour are also present as two distinct classes, with very poorly sorted subangular to subrounded very fine sand to very fine pebbles.

Compositions and Alteration of Soils: Three major methods of chemical alteration have been suggested: palagonization, hydrothermal alteration, and acid fog. Devitrification of basaltic glass from palagonization [6] is not supported by CaO and MgO loss and Al₂O₃ gain relative to SiO₂ (Fig. 2). The dissolution of olivine in soils from acid fog alteration is not conclusive and has no apparent correlation with physical weathering, soil age, or dust mixture. Most soils have lower concentrations of olivine MgO+FeO in ACNK-FM plots relative to unaltered rocks in Gusev Crater that have been abraded by the rock abrasion tool (RAT) [3]. Soils with a higher abundance of smaller grains that are well rounded have experienced greater physical breakdown and transport and have larger surface areas for reaction. These sediments would be expected to show a greater degree of chemical weathering from acid fog. The lack of a clear weathering may be a result of soils developed from heterogeneous protoliths with varying compositions, or from dust and sediment mixing that homogenizes compositions.

In addition to alteration products, soils also contain admixed volcanic aerosols in the form of sulfur and chlorine additions and admixed chondrites in the form of nickel (~2%) additions [5]. Dust mixing is pronounced with grain size and soil type (Fig. 2).

Soil Formation in a Water-Limited Environment: Liquid water is required by most chemical weathering pathways on Earth, but little evidence of current water on the surface of Mars has lead to soil formation theories that require little or no liquid water. Soil compositions are likely to have been influenced by weathering processes acting on several different scales with localized impacts, regional volcanism, and global aeolian dust transport, with physical mixing of varying source materials and chemical alteration processes contributing to the complex provenance.

We suggest that soils on Mars are formed largely by physical processes with impact gardening and aeolian abrasion of basaltic rocks into lithic fragments, with locally derived pebble-sized grains, regionally derived sand-sized saltating grains, and globally homogenized silt-sized suspended dust. The physically pulverized grains are mixed with secondary components (sulfur and chlorine from volcanic outgassing, nickel from chondrites), and may be mixed with Noachian relic phyllosilicates that so far remain undetected in significant quantities in soils.

Figure 2. A) The addition of volcanic aerosols as Cl and SO₃ are apparent in soil classes with increasing dust compositions. B) Little indication of weathering from devitrification of basaltic components when grouped by soil type.