INTEGRATING PHYSICAL AND CHEMICAL ALTERATION MECHANISMS OF SOIL FORMATION ON MARS FROM THE MARS EXPLORATION ROVERS. I. O. McGlynn[1] , H. Y. McSween[1] and C. M. Fedo[1], [1]Department of Earth and Planetary Sciences and Planetary Geoscience Institute, University of Tennessee, Knoxville, TN 37996-1410 (imcglynn@utk.edu).

Introduction: Soils on the surface of Mars still require examination to determine how they formed. Aqueous conditions were once thought to have been prevalent with evidence of gullies [1], meandering rivers [2] and possible paleoflooding [3]. However the unconsolidated regolith, or soils, does not appear to be significantly altered by hydrolysis because of an absence of large quantities of highly aluminous phyllosilicates, such as kaolinite. Instead, more complex FeO_x+MgO-bearing phyllosilicates, including montmorillonite and nontronite [4,5] have been detected in limited quantities at the Mars Exploration Rovers (MER) landing sites of Gusev Crater and Meridiani Planum and elsewhere from orbit. Modal mineralogy estimates indicate that alteration components may account for up to 30% of soil compositions [6,7].

The prevailing concept of soil alteration accounts for olivine dissolution in S-rich acidic low water/rock conditions [8], which allows for FeO_T+MgO loss in soils without substantial Al_2O_3 enrichment from clay production. However, most soils are not significantly depleted in FeO_T+MgO relative to local rocks in Gusev Crater and Meridiani Planum.

In the arid wind-swept surface of Mars, physical processes must also play a significant role in soil comminution and modification, with observations of ripples, dust devils, yardings [9], and active dunes [10]. The purpose of the study is to present a new model of soil formation on Mars that incorporates physical in addition to chemical weathering processes linked to soil genesis.

Physical and Chemical Formation Mechanisms:

Bolide Comminution and Aeolian Reworking. Soil material originates as sediment from comminuted basaltic bedrock due to impact gardening. However, soil grain-size distributions differ from those formed by crushing alone, as would be the case with an impact-only origin [11], because exposed soils on the surface have been reworked by subsequent aeolian activity including sandblasting, which caused rounding of soil grins, and armoring of surface by deflation or aggregation [11]. Given that liquid water was apparently more important in the early history of Mars and leaves a distinct geochemical signature because of water-rock interactions, it is necessary to explore whether this was also an important process in soil formation.

Olivine Dissolution by Acid-S. The dissolution of olivine in soils [8] can be represented by the movement away from the FeO_T+MgO apex along a trend about parallel with the olivine-feldspar join in A-CNK-FM compositional space [arrow, Fig. 1A]. If soils are derived by acid-S olivine dissolution [8] of local basaltic rocks (represented by the Adirondack class mean composition [7,8]), then they should be depleted in olivine when compared to rocks. Instead, soils and rocks have similar compositions, with some soils showing the opposite trend being enriched in olivine relative to that bedrock composition.

While it is unclear if soils are entirely derived of local rock compositions, removing small amounts of olivine from some unaltered rocks can generally match current soil compositions [Fig. 1A]. From a starting composition of 23.4 wt. % olivine at Fo_{46} [12], 10 % increments of olivine is subtracted until is completely depleted. To match most soil compositions, 0 to 40 % olivine must be removed [Fig. 1A], in agreement with mineralogy estimates [12].

Olivine Redistribution by Hydrodynamic Sorting. With the dominance of aeolian reworking of surface sediments, hydrodynamic sorting [Fig. 1B] serves as a competing process to redistribute mineral concentrations including olivine. Continuous comminution of sedimentary grains by physical mechanisms such as impact gardening or aeolian sandblasting can separate grains of individual mineral constituents such as glass, olivine, plagioclase, and pyroxene. Subsequent aeolian transport may be capable of sorting minerals and glass components with different densities (e.g. ρ olivine > ρ plagioclase) resulting in soil lag deposits that are enriched in and transported soils that are depleted in olivine [arrows, Fig. 1B] relative to the original unsorted igneous mineral proportion.

If Adirondack class rocks are a meaningful source for soils in Gusev Crater, then soil compositions can be recreated from chemical weathering and physical sorting mechanisms. Some soil compositions towards the feldspar end member direction could be explained by acid-S [arrow, Fig. 1A] and or sorting [left arrow, Fig. 1B]. Acid-S has the possibility of driving soil compositions away from the Adirondack end member, but cannot explain the process of concentrating olivine necessary for soils towards the olivine end member. In totality, sorting can remove and also concentrate olivine and explain the compositional scatter of Gusev soils across the entire olivine-feldspar join [Fig. 1B].

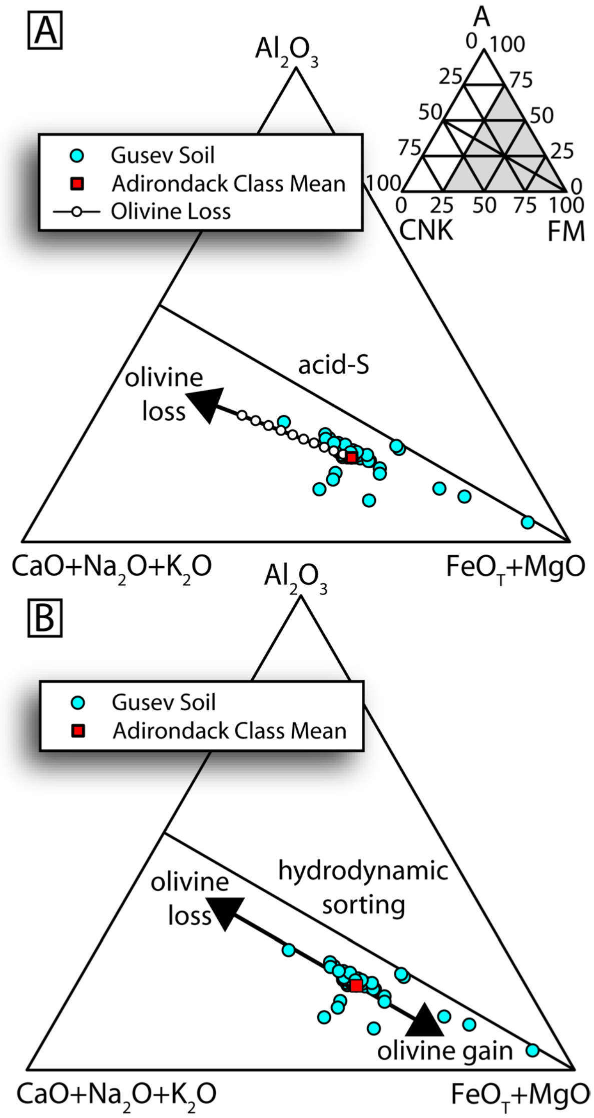

Figure 1. A) Olivine dissolution by acid-S alteration reduces the proportion of olivine in soils, which can be derived from the Adirondack class mean end member, by decreasing 10 % increments of olivine relative to the current 23.4 wt. % (Fo_{46}) estiamte. In contrast, B) hydrodynamic sorting concentrates olivine in lag deposits and removes olivine from transported soils as a competing mechanism to modify soil compositions.

Limited Chemical Weathering Chemical alteration of igneous material can be quantified by Al_2O_3 accumulation from clay production away from the olivine-feldspar join, as compared to a terrestrial basalt weathering profile [arrow, Fig. 2A]. Soils in Gusev Crater, plot on or below the olivine-feldspar join without significant quantities of alteration components.

Surface material imaged by the MER rovers represent aeolian transported and mixed sediment [11]. Physical processes may influence some compositional variations in surface soil types, when grouped by grain size. Soils with high dust cover (bright dust, lithic fragments) contain transported basaltic dust (<30 μm) and are deleted in olivine relative to other soils [Fig. 2B]. In comparison, saltation transported soils such as dark soils in ripples and bimodal mixed soils are slightly enriched in olivine. However bedform armored deflation surfaces are also depleted in olivine, indicating that sorting mechanisms are not the only control on soil compositions. Instead, soil types may be explained by variations in source material, alteration by acid-S, and modification and mixing by sorting.

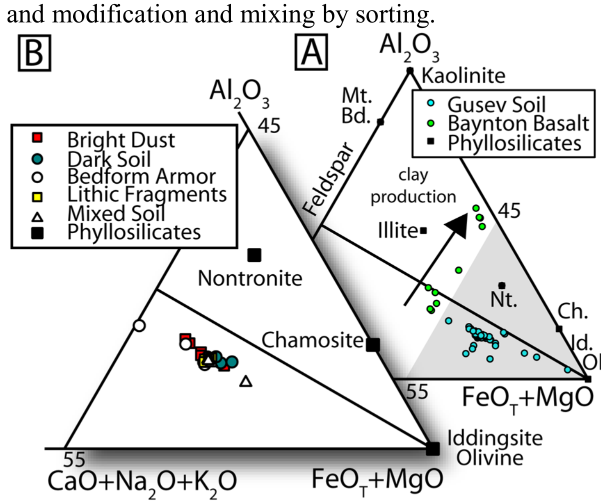

Figure 2. A) Gusev soils (blue) are not formed with significant clay production (black) typical in terrestrial profiles (green). B) Soils are not increasingly weathered with grain size. Mineral abbreviations are Bd.=beidellite Ch.=chamosite, Id.=iddingsite, Mt.= montmorillonite, and Ol.=olivine.

References:

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