PLANNING CONSIDERATIONS RELATED TO COLLECTING AND ANALYZING SAMPLES OF THE MARTIAN SOILS. Yang Liu[1], Mike T. Mellon[2], Douglas W. Ming[3], Richard V. Morris[3], Sarah K. Noble[4], Robert J. Sullivan[5], Lawrence A. Taylor[6], David W. Beaty[1]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA. (yang.liu@jpl.nasa.gov). [2]Dept. of Space Studies, Southwest Research Institute, Boulder, CO 80302, USA. [3]NASA JSC, Houston, TX 77058, USA. [4]NASA GSFC, Greenbelt, MD 20771, USA. [5]CRSR, Cornell University, Ithaca, NY 14853, USA. [6]Dept. of Earth & Planetary Sciences, University of Tennessee, Knoxville, TN 37996, USA.

Introduction: The Mars Sample Return (MSR) End-to-End International Science Analysis Group (E2E-iSAG [1]) established scientific objectives associated with Mars returned-sample science that require the return and investigation of one or more soil samples. Soil is defined here as loose, unconsolidated materials with no implication for the presence or absence of organic components.

The proposed Mars 2020 (M-2020) rover is likely to collect and cache soil in addition to rock samples [2], which could be followed by future sample retrieval and return missions. Here we discuss key scientific considerations for sampling and caching soil samples on the proposed M-2020 rover, as well as the state in which samples would need to be preserved when received by analysts on Earth. We are seeking feedback on these draft plans as input to mission requirement formulation. A related planning exercise on rocks is reported in an accompanying abstract [3].

Martian soils and MSR science goals:

***Knowledge of Martian soils from previous missions*:** From measurements by Mars exploration landers and rovers (Viking, Pathfinder, MER, Phoenix, and MSL) and orbital surveys, we have acquired initial knowledge of Martian soils.

Globally, Martian soils have some similar characteristics (e.g., [4]). The chemistry of Martian soils from different landing sites commonly reflects basaltic compositions [4-7], although there are sulfate- and silica-rich soils at Gusev [8-10]. Compared to basaltic rocks, anhydrous compositions of soils are enriched with salt components (e.g., Cl and S). Mineralogy of Martian basaltic soils, analyzed directly by MER and MSL, contains typical rock-forming silicates, Fe^{3+}-rich oxides, sulfates, and amorphous phases, the latter of which was suggested to contain water [6, 8, 11-16]. The Fe-rich minerals and possible volatile-rich amorphous phases in MER and MSL soils indicate that there have been *aqueous alterations at these sites* [6, 9]. Further, Martian basaltic soils at different sites display chemical and mineralogical features not necessarily derived from local rocks; this is indicative of global, regional, and local mixing [6]. These observations also point to chemical and physical weathering, at global, regional and local scales.

Soils including dust, in a broad sense, shows variation from the very surface to 10-20 cm depth. a) At the immediate interface between soil and atmosphere, there can be a thin, transient mantle of 'bright' dust ≤1 mm thick, except in areas scoured by the wind (e.g., [8, 14]) or 'mature' soils in the Gusev crater [11]. Also, aeolian 'bedform armour' sometimes covers the top layer of soil, and consists of ~1-2 mm grains (e.g., [4, 7]). b) Underneath the thin dust mantle is a layer of dark soils, observed down to 10-20 cm depth. Distinct stratification was not observed in the MER trenches, although elevated Mg, S, and Br concentrations were detected in the upper trench wall at one Gusev site (e.g., [11, 17]).

Martian soils display a wide range of grain size due to the presence of air-fall dust, sand-sized particles, spherules (sub-mm to several mm, hematite [4] or glassy [6]) and lithic fragments (e.g., [5]). However, it must be emphasized that our present knowledge of Martian soils only extends to ~10 cm depth in several MER trench locations, ~20 cm at the Phoenix site.

Martian soils as input for MSR science goals: The soil represents the boundary and interaction layer between the Martian atmosphere, and hydrosphere/lithosphere. Thus, returning well-chosen Martian soil samples is important to the following goals:

i. For assessing any extant life (priority 1 in [1]), the soil's contribution may not be as much as sedimentary rocks. Soils could contain biomarkers for assessing the presence of past life, if sampled to a depth that received minimum UV radiation and organic-destabilizing oxidants are lacking.
ii. For understanding the accretion and early differentiation of Mars (priority 2 in [1]), the soil may contain global and regional inputs from sources that will not be sampled by any rovers. For example, feldspar-rich igneous rocks as in [18-19] may provide complementary information on the early differentiation and magmatic history of Mars, as well as understanding of sources for volatiles on surface (e.g., Cl, S, H_2O).
iii. For assessing processes involving water (priority 3 in [1]), study of volatile-rich and amorphous phases and salts will help to understand the role of water in forming these phases.
iv. For constraining the planet-wide climate change (priority 4 in [1]), surface soils are more tightly coupled to the recent atmosphere, climate processes, and hydrological cycles; these are important for understanding climatic changes and surface-modifying processes, other than those simply involving water.

v. For other priorities such as environmental hazards and resource to future human exploration and surface-modifying processes (priority 5-7 [1]), they are also important soil-related objectives and require the knowledge of physical, chemical, and mineralogical properties of dust and soils.

Questions related to sampling and analyzing the soil: Significant prior thinking has gone into strategies and thresholds related to collecting Martian rocks for potential return to Earth. However, there are some important questions unique to acquiring soil samples. These questions have significant implications for how soil samples would be collected by the M-2020 rover, and how they might be transported back to Earth.

1) How important is collecting soil samples that preserve the stratigraphy? Is there a way to quantify "retention of stratigraphy"?
2) How many soil samples should M-2020 be capable of collecting, and why?
3) Must sampling start from a depth of 0 cm, or can it (or should it) start from a different depth?
4) Is it critical to collect equal amounts of sample from all depths penetrated?
5) What is the largest particle size normally expected in the soil? It is obvious that the sample container size is the limiting factor.

Discussion:

Preservation of soil stratigraphy: The group regards that sampling stratigraphy is of paramount importance, if it is present at the landing site. However, the retention of stratigraphy in a single sample will be difficult, if not impossible, to achieve. Rather, a similar approach might be sampling layers of significantly different characteristics.

Number of samples and sampling depth: E2E-iSAG recommended a minimum of one soil sample to be collected from the top 5 cm [1]. Similar to this recommendation, a surface sample is important for understanding the processes occurring at the immediate surface (UV, oxidation, etc.). In addition, because all of our current knowledge of Martian soils are from within the upper 10 cm (except at the Phoenix site), we recommend that a second sample representing the least dust-bearing soil be collected. In-situ investigation by the M-2020 rover would aid the identification and selection of such a sample.

Furthermore, similar to [1], the recommendation for the number of samples is to have the capability for collecting and caching additional soil samples if a peculiar/non-typical soil was encountered during the mission. The exact number of soil samples is difficult to predict, before the landing site of the proposed M-2020 rover is selected, and before the rover has a chance to interrogate the local geology.

Equal sampling from depth**:** If stratigraphy was observed at the landing site of the proposed M-2020 rover, soil samples sufficient for science investigations are needed from each interesting layer. But, there is no pre-request as to how much and how many samples to obtain. This decision will have to be made *ad hoc*.

Grain size of soil: As stated above, the grain size of soils can display a wide range from sub-10 μm through several mm, to even coarser material including pebbles. Returned pebbles could provide important information about as a diverse, "grab bag" sample, providing they can fit within the planned sample holders (a total volume of ~8 cc, [1]).

Factors that may affect the science value of returned samples: In planning for Mars sample return, 11 factors were evaluated and summarized that may affect the science value of a returned rock sample [3]. Relevant to soil, important factors to be considered include: Earth-sourced organic and biological contamination; Earth-sourced inorganic contamination; magnetization history; thermal history; volatile gain or loss; loss of drilled samples; radiation history; and exchange with non-Mars environment. Requirements to constrain the effects of these factors on rocks could be applied equally to soil samples.

Mechanical integrity (fracturing and relative movement of fragments) is one of the important factors for collecting and transporting rock samples. Investigations using the texture of rocks would require minimizing any damage caused by fracturing and relative movement. In contrast, soils have a wide size range and maintaining relative movement of fragments may not be feasible. However, selective comminution of soil particles by larger pieces 'rattling around' in the sample containers need to be minimized.

As with all previous sample-handling missions, there would be numerous *ad hoc* decisions that would have to be made, and the 'backroom' scientists must be assembled and ready to address the concerns in real time.

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