NEW HIGH FIDELITY MARTIAN AND PHOBOS REGOLITH SIMULANTS: ENABLING TOOLS FOR EXPLORING THE MARS SYSTEM AND ISRU DEVELOPMENT.

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Introduction: A large number of missions are slated to visit the Mars system in the coming decade with landed payloads, including NASA's InSight (Mars seismic station) and Mars 2020 (caching rover), ESA's ExoMars (astrobiology rover), China's Mars Global Remote Sensing Orbiter and Small Rover, an ISRO Mars rover, SpaceX's BFR cargo landings, and Japan's Martian Moons eXploration mission (Phobos sample return). All these missions, if successful, will interact with surface regolith on Mars or Phobos. In the absence of returned samples, simulated space materials, or simulants, are an important tool for testing engineering hardware and mission operability, and can also be used to address fundamental science and engineering questions [e.g., 1-3]. However, the current state of Mars and Phobos simulants is generally poor. JSC Mars-1(A) is no longer being produced, and the K-12 educational material produced by The Martian Garden company bears little resemblance to the original Mojave Mars Simulant described by [4]. A Phobos simulant made mostly of lunar simulant JSC-1A was recently described by [5].

Here, we report on ongoing efforts to develop and evaluate high fidelity, mineralogy-based simulants for Mars and Phobos. These efforts began as internal projects, but the simulants may have broad utility and to that end we seek community input during the development phase in order to maximize the usefulness of these materials.

Simulant design philosophy: Previous regolith simulants have been designed mostly based on spectral properties, bulk major element chemistry, or geotechnical characteristics. For example, JSC Mars-1(A) was sourced based on a spectral match of palagonitic tephra to dust-covered terrains on Mars [6], and the original Mojave Mars Simulant was mostly based on geotechnical properties [4]. These simulants tend to compare favorably to the target reference material (e.g., actual Mars soil) on one or two metrics, but are often strongly deficient on others. JSC Mars-1(A), for example, had high concentrations of organics and contained >20 wt.% H_2O [4].

In contrast, we design our asteroid and planetary simulants starting from the mineralogy. Minerals are the basic building blocks of planetary materials, and simulants designed to replicate the mineralogy of a reference material will tend to compare well on many different metrics, because the secondary properties (spectra, strength, etc.) are a result of the specific combination of minerals present in the regolith. Through our work creating asteroid simulants with Deep Space Industries, we have built up a library of source minerals that can be quickly combined to prototype new simulants, in this case those appropriate for Mars and Phobos.

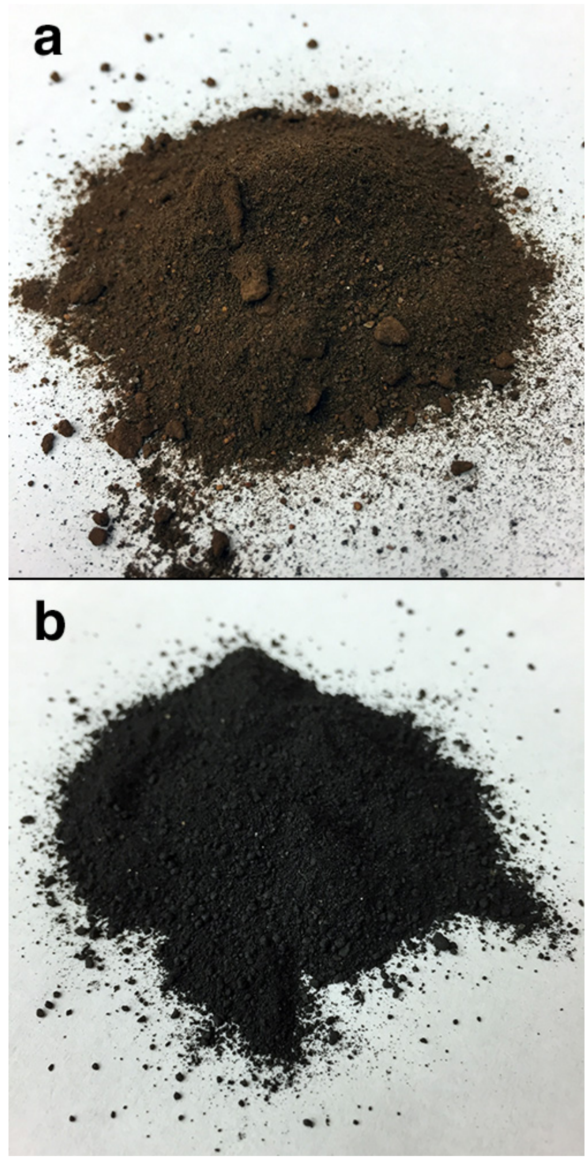

Figure 1. Photographs of the new (a) Mars MGS-1, and (b) Phobos PGI-1 regolith simulants.

Methods: Our general steps for creating regolith simulants involve: (1) choosing the appropriate reference material and deriving a mineral recipe, (2) sourcing and preparing the constituent minerals, (3) combining and binding the minerals together with water into coherent slabs, (4) microwaving out the water, then (5) grinding the dried slabs in a rock crusher to create a power-law size distribution of polymineralic grains.

Mars and Phobos recipes. For Mars, we chose to use the Rocknest windblown soil as a reference material, because it is the best-characterized Martian soil in terms of mineralogy and chemistry [7-9], and its bulk chemistry approximates other basaltic soils from disparate landing sites, evidence of a relatively homogenous global composition [10]. However, we note that all three of the landing sites compared in [10] are from relatively sulfur-rich terrains [11], such that there may be modest differences, particularly in sulfur mineralogy, elsewhere on Mars. The mineralogy of Phobos is woefully unconstrained, so we created two recipes based on the current leading hypotheses for the formation of this moon: one that is based on CI chondrites (captured asteroid scenario), and one that contains a mix of 57% CI material and 43% Martian mantle material (olivine and pyroxene) representing a giant impact scenario [12]. Keeping with tradition of short acronyms for simulants, we refer to these as Mars Global Simulant (MGS-1), Phobos Captured Asteroid (PCA-1), and Phobos Giant Impact (PGI-1).

Special considerations. For the Mars simulant, we added the highly soluble components to the already ground slabs to avoid unwanted chemical reactions upon wetting. Based on early feedback, we also intend to sterilize the mineral components in the future by heating them in an oven prior to mixing. For the Phobos simulants, we removed the <25 μm particle size fraction, which is believed to be winnowed from the surface due to the unique gravity environment of Phobos [13], and used a lunar-like upper bound for particle sizes (10% mass fraction >1 mm [14]).

Early characterization: Photos of the simulants are shown in Fig. 1, and visible/near-infrared spectra are shown in Fig. 2, compared with previous simulants and reference materials. We measured the grain density of all three simulants, with values of 2.72 g/cm^3 for MGS-1, 2.75 g/cm^3 for PCA-1, and 2.89 g/cm^3 for PGI-1.

Future work: For the Mars simulant MGS-1, future work will involve measuring geotechnical properties and refining the source minerals and manufacturing process to allow for consistent mass production. For the Phobos simulants, the immediate plans are for extensive physical properties measurements (described in this issue, [15]) in support of JAXA's MMX mission.

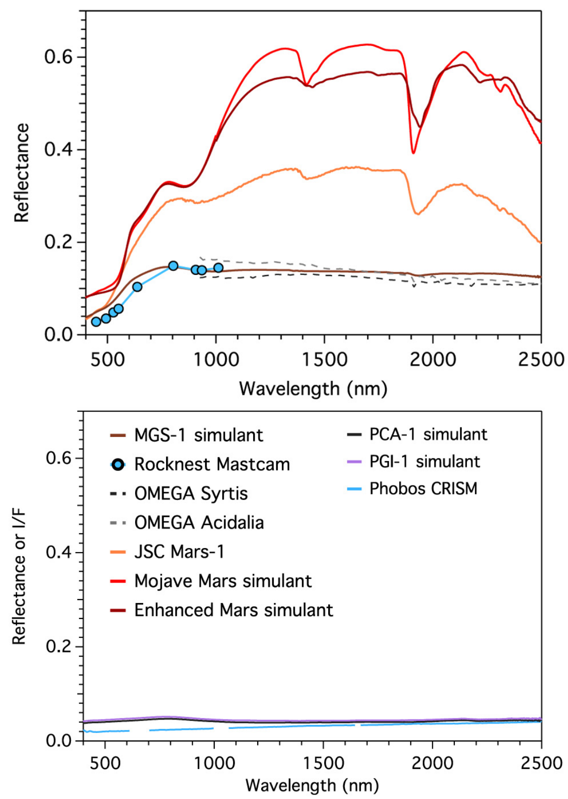

Figure 2. Visible/near-infrared spectra of our MGS-1, PCA-1 and PGI-1 simulants compared to previous simulants and remote sensing data.

Applications for ISRU. There is a growing need to develop and test ISRU hardware in highly realistic scenarios. This will involve using regolith simulants in environment chambers, and testing will benefit from the most realistic simulants available. We believe that MGS-1 is the highest fidelity Mars simulant ever produced, and the Phobos simulants may be useful for testing ISRU relevant to asteroids or for Phobos, should it be discovered that this moon contains significant volatiles appropriate for harvesting.

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