MARTIAN REGOLITH SIMULANT JSC MARS-1. Carlton C. Allen[1], Richard V. Morris[2], Karen M. Jager[3], D. C. Golden[1], David J. Lindstrom[2], Marilyn M. Lindstrom[2] and John P. Lockwood[4], [1]Lockheed Martin, Houston, TX 77258 carlton.c.allen1@jsc.nasa.gov [2]NASA Johnson Space Center, Houston, TX 77058 [3]Pomona College, Claremont, CA 91711, [4]Geohazards Consultants International, Volcano, HI 96785.

JSC Mars-1 is a Martian regolith simulant specifically developed to support scientific research, engineering studies and education. The simulant is the <1 mm fraction of weathered volcanic ash from Pu'u Nene, a cinder cone on the Island of Hawaii. Weathered ash from Pu'u Nene has been repeatedly cited as a close spectral analog to the bright regions of Mars [1-4]. We chose Pu'u Nene ash based on its spectral similarity to Martian material, extensive previous characterization and availability in quantity.

Characterization: JSC Mars-1 was characterized by a variety of techniques, and the results compared to our current knowledge of the regolith of Mars.

Reflectance Spectrum The simulant's VIS/NIR spectrum contains a relatively featureless ferric absorption edge through the visible, an indication of a ferric absorption band in the 800-1000 nm region and relatively flat absorption in the near-IR. Bands at 1400 and 1900 nm result from OH and H_2O.

The VIS/NIR reflectance spectra of bright regions on Mars closely approximate the simulant spectrum. Ferric iron features near 600, 750 and 860 nm in the Martian spectrum imply higher levels of well-crystallized red hematite on Mars than in the simulant [5,6]. The 1400 and 1900 nm bands, present in the simulant but not the Martian spectrum, imply that the simulant is much wetter than the Martian regolith.

Mineralogy XRD spectra of JSC Mars-1 are dominated by peaks corresponding to Ca-feldspar and minor magnetite. Spectra of the bulk sample and the non-magnetic altered split contain elevated backgrounds due to an amorphous component. None of the XRD spectra show evidence of phyllosilicates.

JSC Mars-1 is a mixture of ash particles with alteration rinds of various thicknesses and particles consisting entirely of altered ash. The ash is composed of finely crystalline and glassy particles of hawaiite composition. SEM images show that the crystalline magnetic grains are composed of feldspar and Ti-magnetite, along with minor olivine, pyroxene and glass. The non-magnetic fraction contains lesser concentrations of the same minerals in a highly weathered glassy matrix.

Electron microprobe analysis indicates that plagioclase in the simulant is anorthite ($An_{73}Ab_{21}Or_6$). The olivine composition is $Fa_{65}Fo_{35}$. Pyroxenes lie in the augite field ($En_{51}Wo_{32}Fs_{17}$). The Ti-magnetite contains 15-22 wt% TiO_2.

Iron Mössbauer spectroscopy demonstrates the presence of magnetite and olivine in the simulant, as well as traces of hematite and pyroxene and/or glass. The majority of iron (64%) is present as nanophase ferric oxide (np-Ox) particles.

The mineralogy in the bright regions of Mars is largely unknown, but is constrained by spectral data which indicate predominantly np-Ox. Subordinate minerals indicated by reflectance include hematite and other ferric-bearing phases, possibly geothite, maghemite, jarosite and schwertmannite [4,7].

Chemical Composition Table 1 compares the simulant composition to the Martian regolith at the Viking and Pathfinder landing sites. Data from these three locations are essentially identical, suggesting that the regolith has a component which is distributed planet-wide, probably by the wind. The simulant is similar to the regolith in some elements, but the simulant is significantly enriched in Al_2O_3 (from feldspar) and volatiles, mostly water. The simulant has a much closer match to the reflectance spectrum than to the regolith composition of Mars.

Volatile Content Martian regolith simulant JSC Mars-1 contains considerable water. Heating experiments in flowing argon demonstrate weight losses after one hour ranging from 7.8 wt% at 100°C to 21.1 wt% at 600°C. These losses are dominated by water but could also include SO_2.

The Martian regolith, by contrast, is extremely dry. Viking experiments released 0.1 to 1.0 wt% water from samples heated as high as 500°C [8].

Grain Size. We employed sieving and Stokes settling techniques to determine the simulant's grain size distribution (Table 2). Most of the simulant (75 wt%) is larger than 149 μm, while only 1 wt% is smaller than 5 μm.

The fine surface material clinging to the Viking sample arm magnets was in the 10 to 100 μm size range [9]. Pollack et al. [10] estimated that the mean radius of windblown Martian dust is < 2 μm.

Density and Porosity The particle density of JSC Mars-1 is 1.91 ± 0.02 g/cm^3. The bulk density is 0.87 ± 0.02 g/cm^3. This value can be increased to 1.07 ± 0.02 g/cm^3 by vibration. These data, compared to the particle density, infer an uncompacted porosity of 54% and a compacted value of 44%.

Drift material near the Viking 1 landing site has a bulk density of 1.2 ± 0.2 g/cm^3 while blocky material has a value of 1.6 ± 0.4 g/cm^3 [11]. The bulk density of <2 mm fines after delivery to the Viking x-ray fluorescence spectrometers was 1.10 ± 0.15 g/cm^3, implying a bulk regolith porosity of 60 ± 15 % [12]. Mars Pathfinder experiments indicate an average bulk soil density of 1.52 g/cm^3 [13].

Magnetic Properties JSC Mars-1 contains a highly magnetic component. Approximately 25 wt% of the sample can be lifted with a hand magnet. This split consists of large and small magnetic particles and adhering fine material. The magnetic phase is Ti-magnetite, concentrated within tephra particles.

The Viking and Pathfinder landers carried magnet arrays to characterize both the soil and windblown dust. Based on photographs of those magnets, the investigators concluded that the regolith contains between 1 and 7% magnetic material. While the magnetic mineral phase has not yet been determined, the preferred interpretations include maghemite (γ-Fe_2O_3) and Ti-magnetite [13,14].

Availability: JSC Mars-1 is now available for distribution to investigators and educators. This material will be supplied free in limited quantities, with recipients paying for shipping. Anyone desiring a sample should contact the Office of the Curator, NASA Johnson Space Center, Houston, TX 77058.

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Table 1. Chemical Compositions

	VL-1	**VL-2**	**Pathfinder**	**JSC Mars-1**	
Oxide	Wt%*	Wt%*	Wt%**	Wt%***	Wt%****
SiO_2	43	43	44.0	34.5	43.5
Al_2O_3	7.3	7	7.5	18.5	23.3
TiO_2	0.66	0.56	1.1	3.0	3.8
Fe_2O_3	18.5	17.8	16.5	12.4	15.6
MnO	n.a.	n.a.	n.a.	0.2	0.3
CaO	5.9	5.7	5.6	4.9	6.2
MgO	6	6	7.0	2.7	3.4
K_2O	<0.15	<0.15	0.3	0.5	0.6
Na_2O	n.a.	n.a.	2.1	1.9	2.4
P_2O_5	n.a.	n.a.	n.a.	0.7	0.9
SO_3	6.6	8.1	4.9	n.a.	n.a.
Cl	0.7	0.5	0.5	n.a.	n.a.
LOI	n.a.	n.a.	n.a.	21.8	n.a.
Total	89	89	89.5	101.1	100.0

n.a. not analyzed; all iron calculated as Fe_2O_3

LOI (loss on ignition) weight loss after heating 2 hrs at 900°C; includes H_2O and SO_2

* Viking landers 1 and 2 XRF (mean of 3) [15]

** Pathfinder APXS (mean of 5, normalized to 44 wt% SiO_2) [16]

*** XRF [17]

**** XRF (volatile-free, normalized) [17]

Table 2. Grain Size Distribution

Size (μm)	Wt%
1000-450	21
449-250	30
249-150	24
149-53	19
52-5	5
< 5	1