MOJAVE MARTIAN SIMULANT: A NEW MARTIAN SOIL SIMULANT. L. W. Beegle, G. H. Peters, G. S. Mungas, G. H. Bearman, J.A. Smith, R. C. Anderson, Jet Propulsion Laboratory, California Institute of Technology (M/S 183-601 4800 Oak Grove Dr., Pasadena, California 91109, Luther.Beegle@jpl.nasa.gov).

Introduction: The development of the next generation of Martian missions requires a suitable simulant that best represents dust and soils that exists on the Martian surface so engineering and scientific studies can be preformed in terrestrial laboratories. The current Mars simulant of choice is JSC MARS-1 soil simulant, developed in 1998, which is the <1mm size fraction of altered volcanic ash from a Hawaiian cinder cone. This simulant closely matches the reflectance spectra and some other properties of the martian soil [1], however, weathering processes have created a clay-like particle morphology that makes it very hygroscopic. It has a relatively large volatile composition (7.8 wt% at 100°C to 21.1 wt% at 600°C) compared to Viking data (0.1-1 wt% at 500°C). The chemical composition varies from recent MER APXS data [2, 3]. Finally, the grain size fraction is 5 wt% for sizes 52-5 µm and <1 wt% for <5µm is greater then what is expected on Mars.

MMS Description: We have developed the Mojave Martian Simulant (MMS). The bulk component of the MMS is found naturally as whole-rocks and processed into either finely crushed or sorted granular basalt with only slight surface weathering. The crushing process creates materials with coarse-angular particles, which along with the lack of extensive weathering makes it inert to hygroscopic reactivity. Dependent on the desired testing, researchers have the option of using the rock or mixing various chemical components of the crushed rock to mimic desired characteristics of Martian regolith and permafrost.

Geologic Setting: MMS originates from the Saddleback volcanic formation located in the Western Mojave Desert near the town of Boron, California. A series of Miocene era (~19my) flows originating from the Saddleback Mountain as well as various vents and fissures in the immediate area produced the basalt beds. At the collection area, pebbles to basaltic boulders, are found naturally bedded with the sedimentary rocks of the Miocene Tropico group and become dominant at the upper elevations of Saddleback Mountain and the surrounding buttes. A separate volcanic event produced a cinder cone feature just northwest of Saddleback Mountain. The red color of the cinder makes it distinguishable from the darker basalts in the area (Fig 1).

Fig 1 Image of the MMS Simulants.

Mineralogy We obtained XRD data of both the coarse and bag house dust material (Fig 2), as well as reflectance data (Fig 3).

Size fraction The particle size distribution in the Martian regolith has not been fully characterized as of yet. For particles above 100 microns, results from the MER MI indicate a distribution of soil sizes between 1 and 2 mm. During the Viking lander mission, drift of the very fine material on the surface indicates a size range between 0.1 to 10 micrometers while the blocky material that did not drift has a 0.1 microns to 1.5 mm size range [4, 5]. There is also a component of very fine grained dust which is suspended in the atmosphere that based on atmospheric observations is found to be on the order of 1.5 to 2 microns [6-9].

Two of the basalt products, the MMS Coarse and the MMS fine are graded materials. After crushing, the materials are processed to meet a particular particle size. The MMS dust and MMS Cinder are poorly sorted materials. We used the Wentworth Scale for determining the particle size definitions. While the shape of the MMS is jagged and less weathered, than the assumed platy-rounded and ellipsoidal shapes, modified by either aqueous or aeolian processes of martian material [10], the size distribution of the MMS Dust is a good match to the Martian dust (Fig 4)

Volatile content The volatile composition was determined by heating ~10 g of two different samples to 100°C and 500 °C for 1 hour. The MMS dust lost 2% of mass at 100°C and 7.3% at 500°C, while the cinder lost 0.6% and 3.3% respectively. This compares to the loss measured by Viking of 0.1% and 1% respec-

Table 1- Soil mechanical properties of MMS compared to martian soil

Pathfinder site [12]	*c* (kPa)	ϕ	% H_2O
Typical Range	*0.120 to 0.356*	*32° to 41°*	*0.1-1%*
Typical Mean	*0.238*	*36.6°*	
MMS Mixture	*1.149*	*41°*	*2.4%*
MMS Dust	*0.383*	*31°*	*4%*

Table 2- Major chemical composition of Mars, JSC-1 and MMS. Mars ave calculated from Viking, Pathfinder and MER missions.

Mission	Ave Mars	JSC-1	MMS Basalt	MMS Cinder
SiO_2	43.9%	43.5%	47.9%	57.1%
Fe_2O_3 and FeO	18.1%	15.6%	10.6%	8.3%
Al_2O_3	8.1%	23.3%	16.7%	15.2%
MgO	7.1%	3.4%	5.9%	2.9%
CaO	6.0%	6.2%	10.4%	5.3%
Na_2O	1.4%	2.4%	3.3%	4.1%
Cr_2O_3	0.2%		0.05%	0.02%

tively[11]. The volatile loss of the bag house dust was most likely dominated by H_2O.

Soil mechanical properties Martian soils mechanical properties were estimated at the Viking and Pathfinder landing sites. In general martian soils are similar to moderately dense terrestrial soils but have very low cohesion [12, 13]. At the Mars Pathfinder site, cohesion, c, and internal friction angle, ϕ, were estimated using the Sojourner rover wheel as a shear test device and observing the angle of repose for multiple deposits encountered by the rover. Table 1 summarizes existing MMS graded materials properties. While future MMS-derived simulants can be tailored to generate custom simulants, the simulants will also likely need to be baked out to minimize any additional contribution of cohesion associated with residual water higher than the observed Viking concentrations.

References: [1]. Allen, C.C., et al. (1998) in *Space 98*. [2] Rieder, R., et al., (2004) Sci. **306,** 1746-1749. [3] Gellert, R., et al., (2004) Sci. **305**, 829-832. [4] Ballou, E.V., et al., (1978) Nat. **271**, 644-645. [5] Christensen, P.R. and H.J. Moore, (1992) in *Mars*, M.S. Matthews, Editor., U. of Az Press: Tucson. p. 686-729. [6] Clancy, R.T., M.J. Wolff, and P.R. Christensen, (2003). JGR-P. **108**(E9). [7] Lemmon, M.T., et al., (2004) Sci, **306**,1753-1756. [8] Pollack, J.B., et al., (1979) JGR **84**, 2929-2945. [9] Smith, P.H. and M. Lemmon, (1999) JGR-P. **104**, 8975-8985. [10] Herkenhoff, K.E., et al., (2004) Sci. **305**, 824-826. [11] Banin, A., B.C. Clark, and H. Wanke, in *Mars*, H.H. Kieffer, et al., Editors. 1992, The U of Az Press: Tucson. [12] Matijevic, J.R., et al., (1997). Sci. **278**, 1765-1768. [13] Shibly, H., K. Iagnemma, and S. Dubowsky, (2005) J.of Terramechanics. **42**, 1-13.

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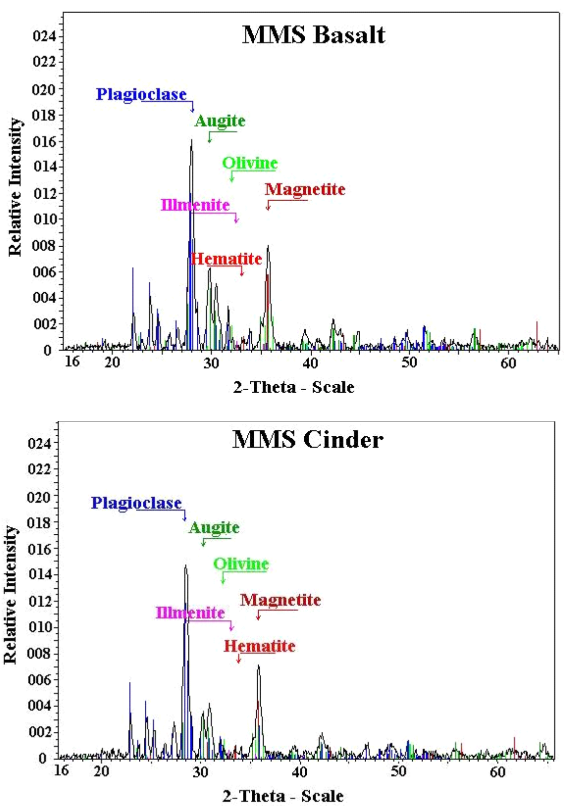

Fig 2- XRD spectra of the MMS Basalt (top) and Cinder (bottom). As expected the major mineral components are identical.

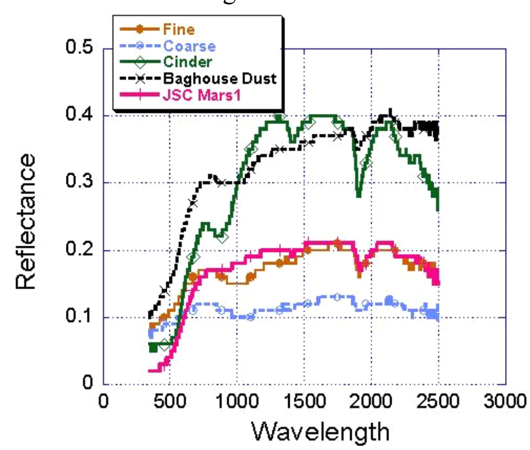

Fig 3 Reflectance spectra from the MMS in comparison to JSC-1.

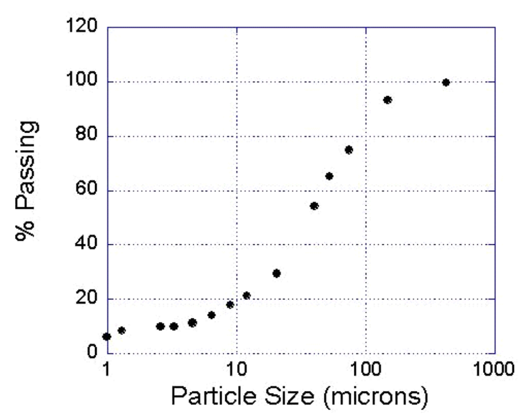

Fig 4 Baghouse Dust Particle size distribution