JSC Mars-1 SOIL MOISTURE CHARACTERISTIC AND SOIL FREEZING CHARACTERISTIC CURVES FOR MODELING BULK VAPOR FLOW AND SOIL FREEZING.

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Introduction: JSC Mars-1 is the <1 mm size fraction of a palagonite tephra from the Pu'u Nene cinder cone, Hawai'i [1,2]. *Hudson et al.* recently published several hydrologically relevant characteristics for this martian regolith simulant [3]. The published particle size data for JSC Mars-1 resolves the particle size distribution with 6 size fractions [2]. Recently, *Sizemore and Mellon* measured and reported bulk density, particle density, and porosity data associated with a sample of JSC Mars-1 [4]. Sizemore also sieved this sample into 22 size fractions >25 µm (Table 1). Particles <25 µm compose a 23rd size fraction. Some particles in the sample were larger than 1 mm, contrary to the JSC Mars-1 definition.

Table 1. JSC Mars-1 Particle Size Distribution.

Size (µm)	Mass (g)
25	3.92
32	0.33
45	0.76
53	0.59
63	0.98
75	1.07
90	2.10
106	2.20
125	4.19
150	4.89
180	6.61
212	8.45
250	9.34
300	8.38
355	8.13
425	8.23
500	8.84
600	8.34
710	6.54
850	3.90
1000	0.85
1180	0.06
1400	0.02

We use these new detailed particle size data to establish for the first time soil moisture characteristic and soil freezing characteristic curves for a Mars soil simulant. Such functional relationships between volumetric phase (i.e., gas, liquid, or solid) content within the pore space and capillary pressure head or soil temperature are required to model bulk (Darcy) vapor flow and soil freezing in the variably CO_2-, water-, and ice-saturated subsurface of Mars [5,6,7].

Derivation of Soil Moisture Characteristic: Experimental determination of the soil moisture characteristic curve can be time-consuming, there are uncertainties associated with repacking disaggregated samples, and no single laboratory method is capable of measuring soil water status over its full range [8]. Instead, we use the physicoempirical model of *Arya and Paris* [9] with improvements recommended by *Arya et al.* [10] to transform particle size (Table 1), bulk density (0.85 g/cm^3) [4], particle density (2.4 g/cm^3) [4], and porosity (0.646) [4] data into derived soil moisture characteristic data. The *Arya and Paris* model is based upon and capitalizes on the notable similarity between the extremely nonlinear shapes of particle size distribution data (Fig. 1) and soil moisture characteristic data (Fig. 2) [9]. Fig. 2 presents the derived soil moisture characteristic data for JSC Mars-1, given the data of *Sizemore and Mellon* [4] and that presented here in Table 1, as well as given the *Allen et al.* soil structural data [2].

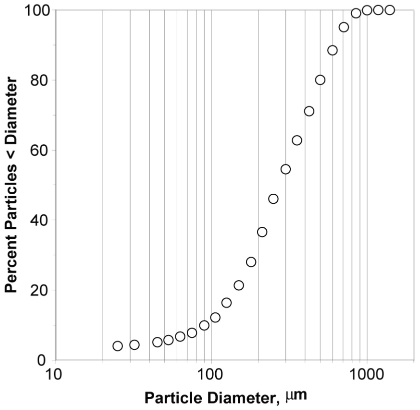

Fig. 1. JSC Mars-1 particle size distribution

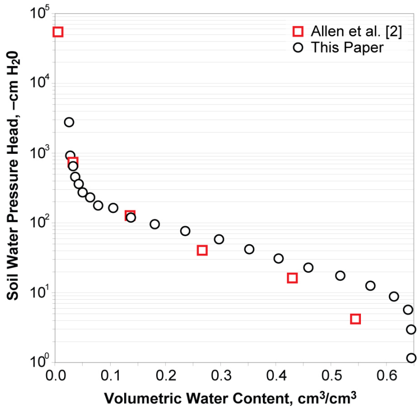

Fig. 2. Derived soil moisture characteristic data

The authors of computational modeling tools [e.g., 7] commonly select the *van Genuchten* [11] empirical model

$$S_{gl}(P_c) = \left[1 + (\alpha P_c)^n\right]^{-m} \quad for \quad P_c > 1 \qquad (1)$$

for the nonlinear curve-fitting of S, liquid water saturation, and P_c, capillary pressure (Pa), required to model soil moisture data. Using straightforward techniques described by *Wraith and Or* [12], we fitted the *van Genuchten* parameters α, n, and m with the solver add-in of *Microsoft® Excel* (Fig. 3); saturated and residual water content were assumed equal to porosity and 0.02 cm^3/cm^3, respectively, based on the data. Using a weighting scheme, we emphasized the low water content points when fitting the data.

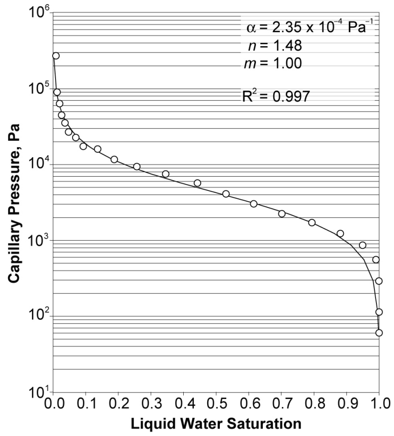

Fig. 3. Fitted soil moisture characteristic curve

Derivation of Soil Freezing Characteristic: In multiphase systems, the soil characteristic curve for any phase pair (e.g., gas–liquid water, denoted by subscript *gl*, water ice–liquid water, denoted by subscript *sl*) can be related to the soil characteristic curve for any other two-phase system by an interfacial tension-dependent rescaling of the capillary pressure head: i.e., $S_{sl} = (\sigma_{lg}/\sigma_{sl})*S_{lg}$ [e.g., 13]. At terrestrial pressures, this ratio is approximately 2.29 [14]. Due to limited data availability, further work is needed to approximate this ratio for Martian conditions. The soil freezing characteristic curve and model parameters are presented in Fig. 4a; using the relationship summarized by [13], Fig. 4b illustrates the unfrozen water fraction dependence on temperature for JSC Mars-1.

Discussion and Conclusions: During laboratory experiments, *Sizemore and Mellon* observed that pressure-driven bulk (Darcy) vapor flow became competitive with simple diffusion at pressure gradients as small as ~4 Pa/m in soils with permeability $>10^{-11}$ m^2 [2]. Pressure gradients of this magnitude or greater could be generated by barometric pumping, solar solid body tides, adsorption/desorption of CO_2, seismic pumping, and so on, thus demonstrating the importance of traditional terrestrial subsurface hydrology computational models for obtaining a complete picture of the hydrological cycle in the variably frozen subsurface and atmosphere of Mars. To this end, the general-purpose, coupled-process *MarsFlo®* code [5,6,7] continues to be developed to investigate numerous hydrological questions, including that of the long-term stability of water in Martian subsurface. *MarsFlo* is the first simulation tool to incorporate a wide range of relevant physical processes and Martian conditions [7], yet its soil characteristic and soil freezing curves lacked strong support in the absence of Mars-specific data. Our JSC Mars-1 curves can be implemented in MarsFlo for future simulations.

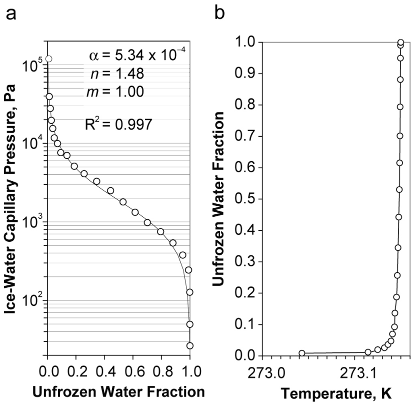

Fig. 4. Fitted soil freezing characteristic curve

Due to the aridity of the Martian climate, fitting the low liquid saturation data points is more important than fitting the high liquid saturation points. Unfortunately, we are unable to report particle size data for size bins <0.25 μm; this information would be useful for Mars applications because the smallest pores will be the last to drain or freeze. The JSC Mars-1 soil moisture characteristic curve is similar to that of a fine sand; there are, however, an unreported fine fraction [R.E. Grimm, pers. comm.] as well as intraparticle vesicles that increase the surface area and porosity relative to typical sand [4].

References: [1] Allen C. C. et al. (1997) *LPS XXVIII*, Abstract #1797. [2] Allen C. C. et al. (1998) *LPS XXIX*, Abstract #1690. [3] Hudson T. L. et al. (2007) *JGR, 112,* doi:10.1029/2006JE002815. [4] Sizemore H. G. and Mellon M. T. (2008) *Icarus*, in review. [5] Painter S. et al. (2002) *34th Ann. Mtg. of DPS of the AAS*, Birmingham, AL, 6–11 October. [6] Painter S. (2003) *6th Int'l. Conf. on Mars*, Pasadena, CA, 20–25 July, Abstract #3161. [7] Painter S. L. and Grimm R. E. (2007) *7th Int'l. Conf. on Mars,* Pasadena, CA, 9–13 July, Abstract #3272. [8] Bittelli M. et al. (2003) *WRR, 39,* doi:10.1029/2001/WR000930. [9] Arya L. M. and Paris J. F. (1981) *Soil Sci. Soc. Am. J., 45,* 1023–1030. [10] Arya L. M. et al. (1999) in *Characterization and Measurement of the Hydraulic Properties of Unsaturated Porous Media.* USDA, Riverside, California. [11] van Genuchten M. Th. (1980) *Soil Sci. Soc. Am. J.*, 44, 892–899. [12] Wraith J. M. and Or D. (1998) *J. Nat. Resour. Life Sci. Educ., 27,* 13–19. [13] Black P. B. and Tice A. R. (1989) *WRR, 25,* 2205–2210. [14] Grant S. A. (2000) *Physical and Chemical Factors Affecting Contaminant Hydrology in Cold Environments.* ERDC/CRREL TR-00-21.