ICE VISCOSITY REDUCTION RESULTING FROM REGOLITH INSULATION ON MARS. Reid A. Parsons[1] and H. Miyamoto[2], [1]Department of Museum Collection Utilization Studies, University of Tokyo, Japan (rparson4@fitchburgstate.edu), [2]Affiliation Department of Systems Innovation, School of Engineering, University of Tokyo, Japan.

Introduction: Thick deposits of ice covered by regolith debris are distributed throughout the Martian mid-latitudes. Determining the flow history of these ice deposits using numerical models furthers our understanding of the Amazonian glaciation events responsible for their formation. However, such models often assume the underlying ice isothermal and equal to the surface temperature. We test this assumption by using in-situ, remote, and analog measurements to constrain a plausible ice deposit stratigraphy. This stratigraphy is combined with an icy regolith thermal conductivity model to determine the change in temperature with depth due to a geothermal heat flux.

Prior investigations of the thermal conductivity of the Martian regolith have generally addressed either shallow(<3m) [1,2,3] or deep (~km) [4] scales. In this work we develop a granular regolith thermal conductivity model to study an intermediate depth scale (~100 m to ~1 km) in order to determine wether a surficial regolith debris layer can thermally insulate an underlying ice deposit and lower its viscosity.

Thermal Conductivity Model: Work focused specifically on regolith properties have shown that processes such as grain-emitted radiation [5] and gas conduction [6] play at least some role in influencing bulk thermal conductivity. We use a physics-based model [7] in which grain contact geometry and grain- emitted radiation are used to estimate the bulk thermal conductivity of regoliths in a vacuum. Since this model only applies to an ice-free regolith in the absence of an atmosphere, we have added gas conduction and ice mixture terms to derive a "best approximation" thermal conductivity model (λ_{BA}) (see Parsons and Miyamoto (submitted) [8] for details).

Fig. 1a plots the ice-free λ_{BA} for a regolith temperature of T=200 K (dash dot line) together with experimental and in-situ measurements (colored symbols). Symbol color indicates the temperature at which the measurement was taken - falling within the temperature range given by the scale to the left of the color bar (binned temperatures used for clarity). The dependance of λ_{BA} on the volume fractions of rock (V_r), ice (V_i), and gas (V_g) is given by the ternary diagram shown in Fig. 1c.

Model Validation: Empirical constraints on the thermal properties of the debris layer on Martian ice deposits come from in-situ (Phoenix Lander) and remote sensing (Thermal Emission Spectrometer - TES) spacecraft observations as well as laboratory experiments performed under Martian temperature and atmospheric conditions. Mars-like experiments (6.8 mbar CO_2) conducted by Fountain and West (1970) [5] using a basalt regolith with a grain size of 37 to 62 μm are given by the plus (+) symbols in Fig.1a. Their results suggest that λ is only weakly dependent upon porosity and temperature, but comparison to Mars-like experiments using Martian regolith simulant JSC Mars-1 (d_{80}=450 μm [9]) by Siegler et al. (2012) [12] (X symbols) indicates a

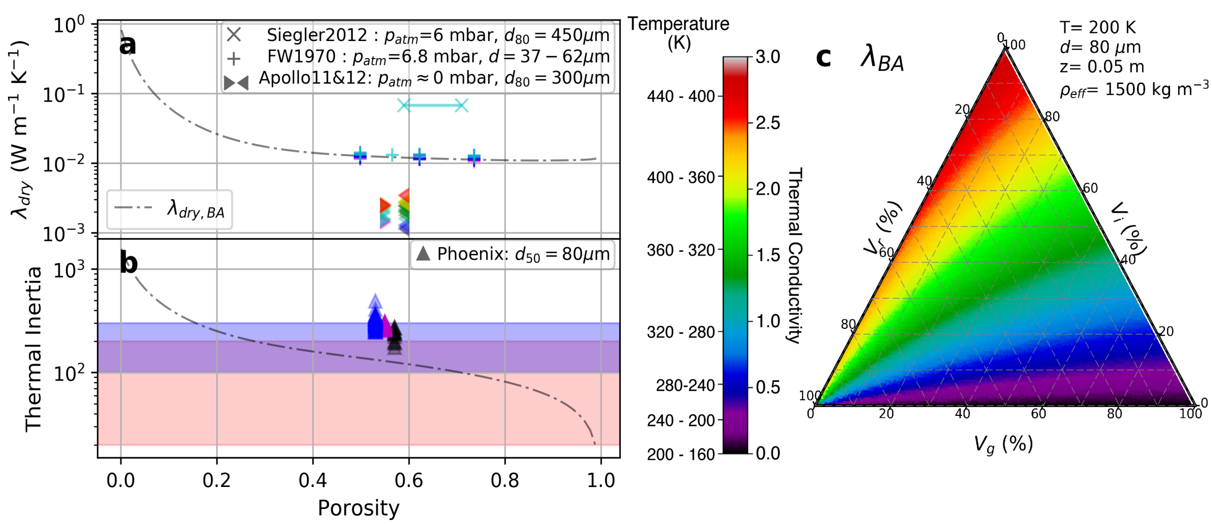

Figure 1: Comparison between the "best approximation" thermal conductivity model (λ_{BA}, dash-dot lines in (a) and (b) and ternary diagram (c)) for rock-ice-gas mixtures and experimental and in-situ measurements of Martian and Lunar regoliths (colored symbols).

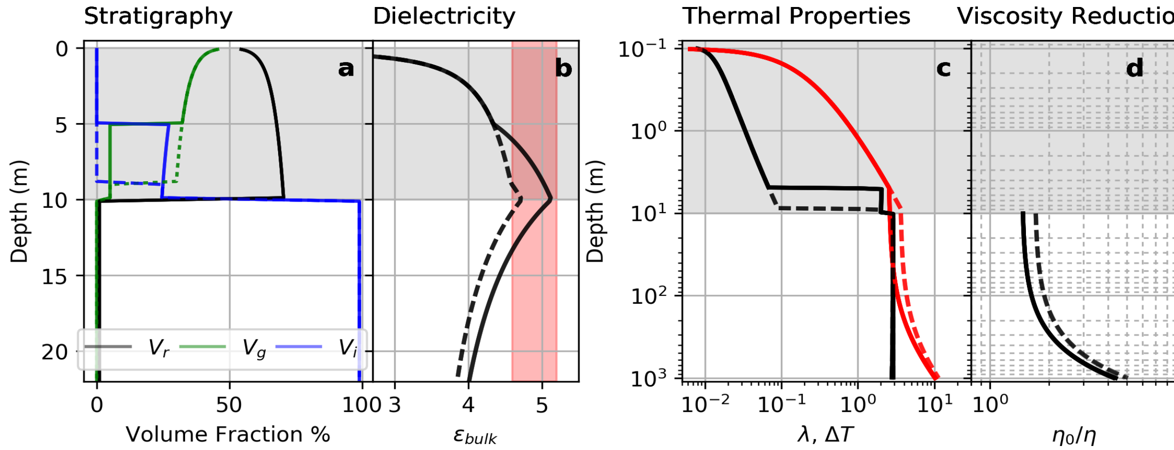

Figure 2: Debris covered ice deposit stratigraphy (a), dielectric profile (b), thermal conductivity and temperature change profile (c), and associated viscosity reduction (d) of the ice (white region) below the regolith layer (gray region).

strong dependance on regolith grain size. Gas conduction in even the tenuous martian atmosphere is also important as illustrated by Apollo 11 [11] and 12 [12] measurements (triangular symbols) at an assumed porosity of 0.57 [13] (symbols for the two missions offset by ±0.01 along x-axis for clarity). The lunar regolith grain size (d_{80} = 300 µm) was similar to JSC Mars-1, but comparing measurements made at similar temperatures (cyan Xs and triangles in Fig.1a), indicates a factor of 30 decrease in regolith thermal conductivity when measured in a vacuum [14].

Thermal intertia (I=λρc) measurements made by the Phoenix Lander in Vastitas Borealis are shown as triangles in Fig. 1b [15]. Apparent thermal inertia on ice deposits in Deuteronilus Mensae are given by the blue and red shaded regions in Fig. 1b corresponding to night, and day-side TES measurements [16], respectively and give slightly lower values than those measured by Phoenix, but are in agreement with the model results over a range of plausible regolith porosities.

Method: The model requires information about the porosity and pore ice content of the 10 m-thick [17] surficial debris layer in order to calculate the vertical thermal conductivity profile. V_r is prescribed using a scaled lunar porosity model based on Apollo data [18]:

$$V_r(z) = 0.6195z^{0.056} \qquad (1)$$

where z is depth in meters. We consider two pore ice table thicknesses in this stratigraphy: 1 m and 5 m.

In order to test the validity of our assumed stratigraphy and regolith ice content, we rely on observations of the relative dielectric constant (ε). We calculate the depth-integrated, bulk dielectric constant (ε_{bulk}) [19] for both ice table thicknesses and find that both cases comply with radar observations (ε_{bulk} = 4.9 ± 0.3 for the debris layer in the Deuteronilus Mensae region [20] - red region in Fig. 2b). The thermal conductivity can now be calculated at all depths in the model (Fig.2c) and then be used to determine the steady-state temperature profile resulting from conduction of geothermal heat.

Results: The ice temperature increase associated with insulation of geothermal heat (22 mW m^{-2} [21]) by a 10 m-thick debris cover (porosity given by Eq. 1) is 5 K to 9 K at 200 m and 700 m depths, respectively (Fig. 2c). These temperature changes result in the ice viscosity being reduced by a factor of 2.1 and 3.7, respectively based on the Arrhenius equation ($\eta_0/\eta = \exp(Q\Delta T/(RT(T+\Delta T)))$) in the flow law for ice (Fig. 2d). The magnitude of the temperature increase (and associated viscosity decrease) depends on the abundance of pore ice in the regolith debris layer and on our assumptions of a steady-state, conductive thermal profile with a sole, geothermal heat source.

References: [1] N. Schorghofer, et al. (2005) *JGR* 110:E05003. [2] A. P. Zent, et al. (1986) *Icarus* 67:19. [3] M. Mellon, et al. (1993) *JGR* 98:3345. [4] S. M. Clifford (1991) *GRL* 18:2055. [5] J. A. Fountain, et al. (1970) *JGR* 75:4063. [6] M. A. Presley, et al. (1997) *JGR* 102:6551. [7] N. Sakatani, et al. (2016) *Icarus* 267:1. [8] R. Parsons, et al. (2018) *JGR* Submitted. [9] C. C. Allen, et al. (1998) in *LPSC* vol. 29. [10] M. Siegler, et al. (2012) *JGR* 117:E03001. [11] C. J. Cremers, et al. (1970) *Geochimica et Cosmochimica Acta Supplement* 1:2045. [12] C. J. Cremers, et al. (1971) *Moon* 3:346. [13] B. Gundlach, et al. (2013) *Icarus* 223:479. [14] A. Wechsler, et al. (1972) in *Thermal characteristics of the moon* MIT Press. [15]A. P. Zent, et al. (2010) *JGR* 115:E00E14. [16] N. E. Putzig, et al. (2007) *Icarus* 191:68. [17] J. Holt, et al. (2008) *Science* 322:1235. [18] W. D. Carrier, et al. (1991) *Physical Properties of the Lunar Surface* 475–594 Cambridge University Press, Cambridge. [19] A. M. Bramson, et al. (2017) *JGR* 122. [20] E. I. Petersen (2017) private communication. [21] A.-C. Plesa, et al. (2016) *JGR* 121:2386.