THE INFLUENCE OF REGOLITH COMPACTOIN ON INSIGHT-HP^3 THERMAL CONDUCTIITY MEASUREMENTS,

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Introduction: The InSight [1] Discovery-class mission to study the martian interior landed in the Elysium Planita region [2] of Mars on November 26th, 2018, and will install the first geophysical station on the planet. A heat flow probe termed the Heat Flow and Physical Properties Package (HP^3) [3] is one of the mission's three geophysical instruments, and HP^3 will emplace a suite of temperature sensors to a depth of up to 5 m using a self-hammering mechanism called the HP^3-mole. During penetration, the regoltith's thermal conductivity will be measured using the mole's TEM-A sensors [3] as a modified line heat source [3,4]; measurements will be performed at depth intervals of 50 cm.

The principle of the mole relies on moving the regolith in front of the probe out of the mole path, thus reducing regolith porosity in the vicinity. Depending on regolith relative density, the volume affected extends to 2-3 mole diameters [5]. Such compaction can increase regolith thermal conductivity, and similar effects have been reported for the Apollo lunar heat flow experiments [6], resulting in a downward correction of the reported values by 30-50% [7]. While the higher Martian atmosphere pressure largely mitigates the influence of compaction on thermal conductivity, a quantitative analysis of the effect has so far not been performed.

Experimental Setup: We have used a flight-equivalent HP^3 mole model to perform compaction and thermal conductivity tests under representative environmental conditions. The general test setup is shown in the top panel of Fig.1 and schematics of the setup are given in the bottom panel. The test cylinder contains regolith simulant, mole, and a reference conductivity measurement using a Transient Hot Strip (THS) [4]. The test cylinder was placed inside a vacuum chamber, and air pressure was held constant to within 0.5 mbar during each experimental run. Depending on the experiment, background pressure was between 6 and 10 mbar using ambient air.

The experimental procedure was as follows: 1) The container was filled and the reference THS measurement strip was installed. Then, the mole was installed in its mounting fixure (compare top panel of Fig. 1) and the container was moved into the vacuum chamber. 2) A THS measurement was conducted to determine the pre-compaction thermal conductivity of the regolith simulant. The mole then penetrated to a 55 cm tip depth and another THS measurement was performed to verify that hammering does not influence the THS reference. 3) The chamber was closed and pumped down. 4) Another THS measurement and a TEM-A measurement were performed after the soil had thermally equilibrated.

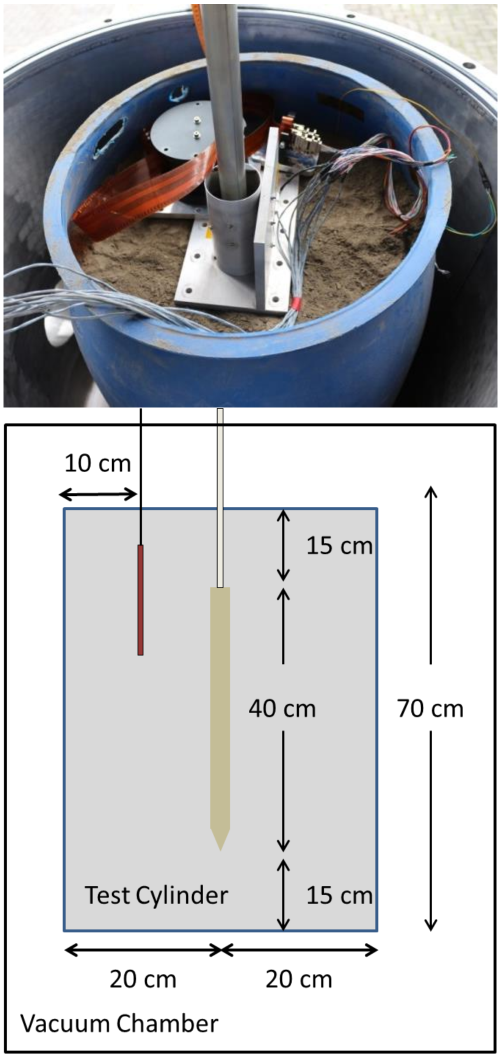

Figure 1. Top: *Experimental setup showing the HP^3 mole in the center prior to penetration. The THS reference measurement strip is buried on the right hand side of the test cylinder.* **Bottom**: *Schematic setup of the experiment showing the THS reference strip on the left and the HP^3 mole in the center of the test cylinder, fully buried.*

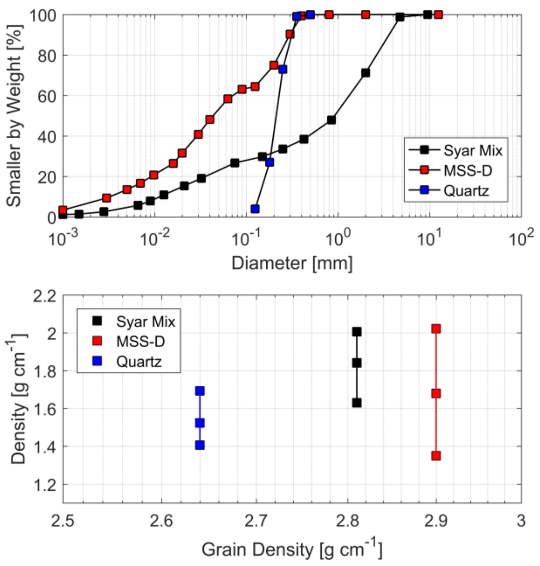

Figure 2. Top: *Grainsize distributions for the three different simulants tested.* **Bottom:** *Minimum, maximum, and average density as a function of grain density for the three simulants tested.*

Regolith simulants used in the tests were a broken up basalt mixed with 25% dust (Syar), quartz sand (Quartz), as well as a dunite powder (MSS-D). Grain-size distributions as well as the minimum (loose) and maximum (compacted) densities of the simulants are shown in Fig. 2. While the quartz sand has a very narrow grain-size distribution and is not very compactale, the MSS-D is highly compactable. Syar is in-between the two. During soil preparation, care was taken to place the soil in a loosely compacted state, as the influence of compaction is expected to be most pronounced in this setting [5].

Results: Results of the tests are summarized in Table 1, where conductivities determined using the THS reference as well as the HP^3-mole TEM-A measurements are shown. For all tests the influence of compaction at the location of the THS reference strip was below 2-3%, within the uncertainty of the method. Some TEM-A measurements suffer from increased background temperature drift, resulting in increased systematic uncertainties for the associated conductivity values.

During the tests, some soils inside container settled by a few cm, indicating soil compaction. For MSS-D, settling was ~3 cm during hammering, and pre- and post-hammering TEM-A thermal conductivities were 0.055 and 0.06 W/mK, respectively. This indicates a 10% increase of thermal conductivity due to the hammering action. For Quartz sand, no soil settling was observed and TEM-A results are indistinguishable between pre- and post-hammering in a first measurement, while a repetition of the experiement indicates a 9% increase of conductivity. However, the soil was not fully thermally equilibrated during the second test run, such that the apparent increase is likely due to systematic measurement errors. For Syar, soil settled by ~1.5 cm during hammering, and observed compaction amounts to a 7% increase in thermal conductivity. However, these results again suffer from background temperature drift, which makes them less reliable.

Soil	THS [W/mK]	TEM-A [W/mK]	Δk [%]
MSS-D	0.055	0.060	9
WF-34	0.094	0.092	-2
WF-34^{1}	0.089	0.098	10
Syar^{1}	0.142	0.167	18
Syar^{1,2}	0.142	0.152	7

Table 1 *Results using the THS reference method as compared to conductivity values determined using the HP^3 TEM-A after penetration. ^{1}Measurements suffer from background temperature drift. ^{2}Same measurement as above, but evaluated at shorter times to reduce the influence of background drift.*

Discussion: On Mars, we expect moderately compacted soil with a grain size distribution in-between that of Quartz and Syar, but without the dust fraction [2,8]. Therefore, some effect of compaction on thermal conductivity may be expected, but this should be less than the ~10% worst case conditions studied here. On Mars, results obtained using TEM-A will furthermore be compared to thermal inertia estimates using the HP^3 radiometer [3] as well as estimates derived from the attenuation of the annual temperature wave. These should be useful to verify/correct the TEM-A measurements.

References: [1] Banerdt, W.B., Russell, C.T., *Space Sci. Rev.*, 211, 1–4, 1–3 (2017). [2] Golombek, M., Kipp, D., Warner, N., et al., *Space Sci. Rev.*, 211, 1–4, 5–95 (2017). [3] Spohn, T., Grott, M., Smrekar, S.E., et al., *Space Sci. Rev.*, 214:96 (2018). [4] Hammerschmidt, U., Sabuga, W., *Int. J. of Thermophysics*, 21, 1, 217-248 (2000). [5] Marshall, J.P., Hudson, T.L., Andrade, J.E, *Space Sci. Rev.*, 211, 1–4, 239–258 (2017). [6] Grott, M. Knollenberg, J., Krause, C., *J. Geophys. Res.*, 115, E11005, (2010). [7] Langseth, M.G., Keihm, S.J., Peters, K., *Lunar Science Conference*, 3, 3143-3171 (1976). [8] Morgan, P., Grott, M., Knapmeyer-Endrun, B., et al., *Space Sci. Rev.*, 214:96, 2018.