THERMOPHYSICAL PROPERTIES OF MARTIAN DURICRUST ANALOGS,

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Introduction: Indurated surfaces on Mars, or martian duricrusts, are likely common surface types on Mars based on direct observations at spacecraft landing sites and remote-sensing data from orbit [1]. The crusted surfaces at the Viking lander sites were capable of supporting the spacecraft without significant deformation and showed discrete and coherent layers when subjected to stress [2]. Observations from the Mars Pathfinder rover showed crusty and cloddy material, which was interpreted to be an indurated material with lower density and degree of cementation than the surface at the Viking lander sites [3]. Both the Spirit and Opportunity rovers have observed examples of indurated surfaces, including crusty, hard driving surfaces and thick deposits of magnesium-sulfate salts [4, 5]. Soils at the Phoenix landing site were observed to be cloddy and showed significant variations in physical properties and cementation [6]. These observations suggest that indurated soils on Mars are highly variable in their physical and thermal properties.

Martian duricrusts have also been inferred from remotely-sensed observations from the MGS and Mars Odyssey spacecrafts. Thermal inertia and albedo measurements suggest that a large fraction of the Mars surface is composed of cemented materials [1, 7, 8]. Based on the range of indurated materials observed at the landing sites, it is also likely the duricrusts inferred from orbit vary in their degree of induration and other physical properties.

The purpose of this project is to compare the thermal properties of examples of indurated surfaces on Earth to the inferred duricrust surfaces on Mars. Samples from two field sites were examined in this study. The first sample is a gypsum duricrust from a deposit located near Las Cruces, NM. The second sample is playa material from Lunar Lake Playa, NV. Samples were collected from both sites and returned to the lab in their indurated form for laboratory analysis.

Site overviews: The New Mexico gypsum site is an exposed deposit of gypsum duricrust (Fig. 1). The material was likely transported to the location via aeolian processes and became cemented through fluvial activity at its current location. In recent history the deposit was exposed when the topsoil was removed by human activity. There has been no subsequent human development at the site since the topsoil was removed. The deposit contains both a softer, red-brown gypsum duricrust (hereafter gypsum A) and a harder, white gypsum duricrust (hereafter gypsum B). The deposit itself is heavily indurated with a bulk hardness similar to dry playas. The deposit showed no significant deformation when walking or driving on the material.

Lunar Lake Playa (LLP, Fig. 2) is a dry lakebed in central Nevada. We chose this playa because it has been well characterized by previous studies of planetary analog surfaces [9]. Shepard et al. [9] found the playa material to be cemented clay and silt sized particles dominated by smectites, and kaolinite. We obtained samples of the playa material at the surface and down to depths of ~30 cm, but analyses suggest little variation with depth.

Figure 1: *Photograph of the gypsum duricrust deposit*

Figure 2: *Photograph of Lunar Lake Playa*

Procedures: We analyzed the samples from the two field sites with a variety of laboratory measurements. These measurements include composition via X-ray diffraction analysis, intrinsic and bulk density, pore-size distribution via mercury porosimetry, and thin section analyses.

We measured the thermal conductivity (k) and volumetric heat capacity (VHC) of the samples using thermal probes from Decagon Devices Inc. We used a simple bell jar vacuum chamber apparatus in conjunction with the thermal probe to measure k and VHC for the samples for a range of gas pressures from ~0.05 mbar to ambient laboratory pressure (~840 mbar). We ground some of the samples to silt to sand-sized particle sizes and repeated the vacuum chamber measurements with these powdered samples. Samples of glass beads were used and the results compared to those of Presley and Christensen [10] to verify our method.

Results and Discussion: Table 1 is a summary of the thermal measurements at ~7 mbar atmospheric pressure. For all samples, the indurated case showed higher thermal conductivities and higher values of thermal inertia than the powdered samples. However, in the case of the gypsum A sample the powdered material exhibited a higher bulk density than the cemented material. For gypsum A the higher bulk density is also contributing to the higher VHC of the powdered material and a thermal inertia value closer to that of the cemented material than in either the gypsum B or LLP samples.

Sample	k [W/mK]	VHC [MJ/m^{3}K]	ρ bulk [kg/m3]	TI [J/m^{2}Ks$^{-1/2}$]
Gypsum A	0.069	1.08	1460	273
Gypsum A (powdered)	0.058	1.31	1590	250
Gypsum B	0.131	2.07	1720	513
Gypsum B (powdered)	0.056	1.39	1570	280
LL Playa	0.073	1.68	1710	352
LL Playa (powdered)	0.048	1.13	1620	232

Table 1: *Summarizes the measured thermal properties and bulk density properties at ~ 7 mbar atmospheric pressure.*

Thermal conductivity versus atmospheric pressure plots were generated for all samples. Figure 3 shows the case of the gypsum B sample. At very low pressures (< 1 mbar) the measured thermal conductivities cemented and powdered cases remain relatively similar, which may be an effect caused by the thermal conductivity approaching the lower limit of the probe. The cemented case begins to show significantly higher thermal conductivity by 1 mbar with an increasing difference with higher pressures. We used the same material for the cemented and powdered cases and so these differences are caused by the geometry and cementation of the granular material itself and not differences in composition.

Porosity can be measured from the mercury porosimetry data and comparing intrinsic versus bulk density. For both methods, gypsum A has the highest porosity with ~45%, gypsum B was slightly lower at ~40%, and LLP was significantly lower at ~25%. The porosity of the cemented samples does not appear to correlate with their thermal conductivity or thermal inertia in these samples. This suggests that the configurations of the grains and cementing agents are important factors for controlling the thermal conductivity of indurated materials. It is also likely that the composition of the indurated materials has a strong effect on their bulk thermal conductivity.

Thin section images (Figs. 4a and 4b) show the granular structure for the gypsum A and B, respectively. Despite originating in the same duricrust deposit, these two materials show extremely different granular structure. This is likely due to differences in the evolution of the materials, such as contact with water. These differences demonstrate the high dependence of the physical properties of indurated materials on environmental factors.

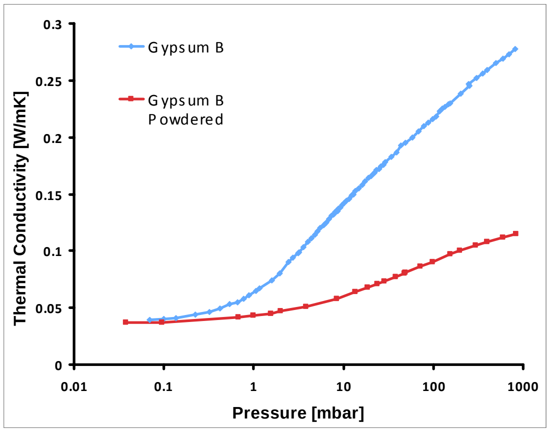

Figure 3: *A plot showing the thermal conductivity dependence on atmospheric pressure for the gypsum B sample.*

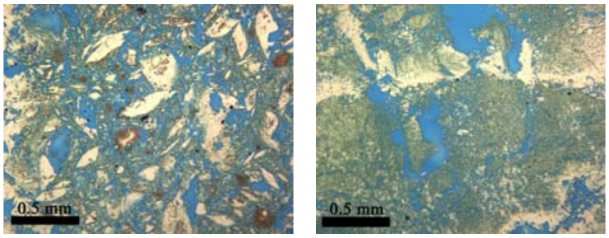

Figure 4: *Thin section images of the gypsum A (left) and gypsum B (right) samples. The pores appear blue due to the epoxy injected to create the thin sections.*

Conclusions: The thermal inertia values we measured at gas pressures typical at the Mars surface are commonly measured for the surface of Mars. The thermal inertia for the gypsum B and LLP samples are well within the range of thermal inertia commonly measured for the Mars surface. These values are also within the highest frequency of thermal inertia values for the major thermal inertia-albedo units B and C (see [1, 7, 8]). These results suggest that well-indurated materials, with aqueous or volcanic origins, may cover much of the Mars surface.

These measurements also show that the thermal properties of indurated material have complex dependencies on the granular structure and composition of the soil. Indurated materials have significant variability in their granular geometry, composition, and pore space distributions. This variability is likely the result of divergent evolution of these soils caused by differences in the environmental conditions present throughout their history.

References: [1] Mellon et al. (2000) *Icarus* 148, 437-455, [2] Moore et al. (1977) *Icarus* 81, 164-184 [3] Moore et al. (1999) *J. Geophys Res* 104, 8729-46 [4] Squyres et al. (2004) *Science* 305, 794-799 [5] Squyres et al. (2004) *Science* 306, 1698-1702, [6] Arvidson and Mellon (2008) AGU Fall Meeting, abstract #U14A-01 [7]Palluconi and Kieffer (1981) Icarus 45, 415-426, [8] Putzig et al. (2005) Icarus 173, 325-341 [9] Shepard et al. (1991) GRL 18, 2241-4, [10] Pressley and Christensen (1997) *JGR* 102, 6551-6566.