THERMOPHYSICAL PROPERTIES OF A POSSIBLE MARTIAN DURICRUST ANALOG,

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Introduction: Indurated surfaces on Mars, commonly referred to as martian duricrust, have been directly observed at all spacecraft landing sites. 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 [1]. Observations from the Mars Pathfinder rover showed crusty and cloddy material, which was believed to be an indurated material with a lower density and degree of cementation than the surfaces at the Viking lander sites [2]. More recently, both the Spirit and Opportunity rovers have observed examples of indurated surfaces, including crusty, hard driving surfaces and thick deposits of magnesium-sulfate salts [3, 4]. The range of density and degree of cementation of indurated materials suggests that these and other properties of martian duricrusts can vary significantly across the planet.

Martian duricrusts have also been inferred from remotely-sensed observations using instruments onboard the MGS and Mars Odyssey spacecrafts. Thermal inertia and albedo measurements suggest a large fraction of the Mars' surface is composed of a cemented surface [5, 6, 7]. Based on the range of indurated materials observed by previous landed missions on Mars, it is probable that these inferred duricrusts also show significant differences at the granular-scale despite showing relatively similar bulk properties from orbit.

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. The first terrestrial surface examined in this study is a gypsum duricrust deposit near Las Cruces, NM. This study includes field measurements of the thermal behavior of the duricrust, lab measurements of the thermal properties and composition of the duricrust, and modeling to extrapolate terrestrial duricrusts to martian duricrusts.

Site overview: A study site with an exposed deposit of gypsum duricrust was chosen for thermal measurements and sampling. The gypsum duricrust deposit was likely an aeolian deposit that formed a duricrust via post-deposition weathering. The site was cleared by human activity in recent decades, but has remained exposed and unused since it was cleared.

Methods

Lab Analysis: We conducted lab measurements on samples collected at the study site in order to conduct a detailed analysis of the properties of the gypsum duricrust. These measurements include composition via X-ray diffraction analysis, intrinsic and bulk density, porosity, and thin section analyses. Measurements in the thin sections include basic grain/pore geometric configurations, porosity, and relative abundances of the component materials.

Figure 1: *A view of the study site.*

We used a second numerical model to derive a bulk thermal conductivity of the duricrust based on the thin section images. We divided the image pixels into discrete components and assigned reasonable thermal conductivity values based on the composition of the component (typically gypsum or pore space). We use the method of Mellon et al. [8], which calculates effective thermal conductivities by combining components in series or parallel based on the path of heat flow through the medium. We assumed that heat transport was vertical within the deposit, which is also vertical in the thin section images, and so horizontal pixels were added in parallel and vertical pixels were combined in series.

Fieldwork: Subsurface temperatures were recorded using thermocouples placed in the duricrust deposit from the surface to a total depth of ~30 cm at ~5 cm intervals. Approximately five days of temperature data were recorded with measurements occurring once per minute with a mean temperature recorded at ten minute intervals. Samples of the duricrust deposit were collected for lab analyses.

We used a simple numerical model to estimate the thermal inertia of the deposit from the field temperature data. Modeled diurnal temperature curves were generated for a range of thermal inertia values. We then calculated the thermal inertia based on the best fit between the modeled temperature curves and field data.

Results

Lab analysis: There are two distinct colors of material within the collected sample. Some material appears nearly white (hereafter referred to as the white material), while other material exhibits a more reddish or pinkish hue (hereafter referred to as the red material). X-ray diffraction indicate that both materials are composed almost entirely gypsum with only traces of other compounds. Throughout the deposit these materials are found mixing at scales of a few to tens of centimeters. Figure 2 shows a thin section from the white material and Figure 3 shows a thin section image of the red material. Both images were taken within 2 cm of one another in the same sample. The sample was chosen for thin section analysis because it was located at the boundary between the red and white materials. The two different materials may represent slightly different states of duricrust evolution or indicate slightly different conditions (such as water content, permeability, or grain density) within the same deposit.

The gypsum lab samples have an intrinsic density of 2280 ± 50 kg/m^3 for both the white and red materials. The bulk density is 1600 ± 100 kg/m^3 for the white material and is 1360 ± 100 kg/m^3 for the red material. We calculated the porosity from the intrinsic and bulk densities and found values of 0.30 ± 0.05 for the white material and 0.40 ± 0.05 for the red material.

In Fig. 2, the gypsum appears to be a more uniform matrix with distinct large pores (0.2 – 0.5 mm) and smaller pores (<0.1 mm) abundant throughout the matrix. In Figure 3, gypsum crystals are more abundant and the cementing gypsum tends to form a loose matrix between the larger crystals. Pore sizes appear to be of similar size (~0.05 – 0.2 mm) throughout the image.

To model the effective thermal conductivity from the thin section images, we assigned thermal conductivity (k) values of 3.0 W m^{-1} K^{-1} to the gypsum and 0.012 W m^{-1} K^{-1} to the pore spaces to simulate atmospheric conditions on Earth. Based on the model, the white material (Fig. 2) has a porosity of 0.33 and k_{bulk} = 1.99 W m^{-1} K^{-1} in this thin section image. The red material (Fig. 3) has a porosity of 0.52 and k_{bulk} = 1.39 W m^{-1} K^{-1} in this thin section. These porosity values are generally consistent with those derived from the intrinsic and bulk density measurements.

Fieldwork: Based on the modeled temperature curves, the measured temperature curves best correspond to a thermal inertia value of 2200 J m^{-2} $s^{-1/2}$ K^{-1}. This value is significantly higher than typical values of thermal inertia of martian duricrusts (~200-600 J m^{-2} $s^{-1/2}$ K^{-1} [6, 7]) and better represents values of thermal inertia associate with solid rock. We estimated the thermal inertia of this deposit under Mars conditions by correcting for the different atmospheric conditions. This simple calculation suggests that the value of thermal inertia would only decrease by ~10-15% under martian conditions. This deposit would represent, at best, an extremely indurated duricrust on Mars.

Summary and Conclusions

The duricrust deposit shows similar composition throughout, but materials within the deposit show very different grain/pore geometries. The white material appears to be more densely indurated gypsum with a generally uniform matrix, while the red material appears to be composed primarily of gypsum crystals with cementing material found between the crystals. These differences imply slightly different evolutions for the materials within the deposit.

The differences between the white and red materials within the same deposit suggest that indurated materials on Mars may also show differences in grain/pore geometries. Understanding how these grain/pore geometries develop in terrestrial duricrusts can provide insight in to the origin and evolution of indurated surfaces on Mars.

Based on the temperature curves measured in the field, this deposit has a bulk thermal inertia significantly higher than typical martian duricrusts. As such, it is unlikely to directly represent the surfaces inferred to be duricrusts on Mars. Additional sampling of less indurated surfaces on Earth should provide better thermal comparisons to martian duricrusts.

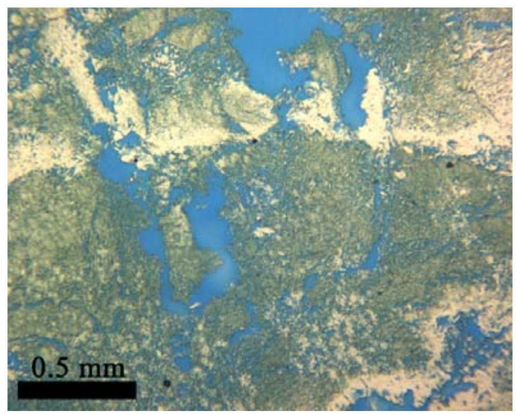

Figure 2: *Thin section of the bright sample. The gypsum grains are the yellow and green areas. The epoxy injected into the pore spaces turns the pore spaces blue.*

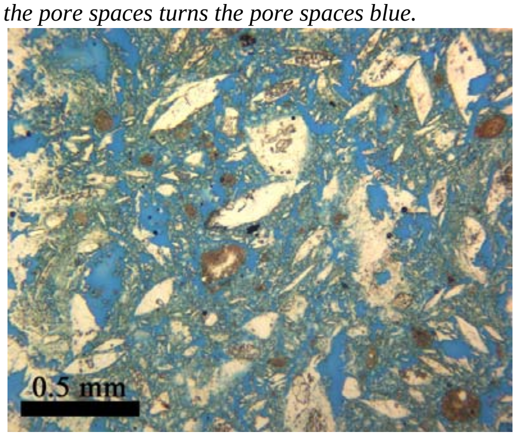

Figure 3: *The reddish sample. In addition the components present in Fig. 2, the red grains may represent iron granules.*

References: [1] Moore et al. (1977) *Icarus* 81, 164-184 [2] Moore et al. (1999) *J. Geophys Re*s 104, 8729-46 [3] Squyres et al. (2004) *Science* 305, 794-799 [4] Squyres et al. (2004) *Science* 306, 1698-1702 [5]Palluconi and Kieffer (1981) Icarus 45, 415-426 [6] Mellon et al. (2000) *Icarus* 148, 437-455 [7] Putzig et al. (2005) Icarus 173, 325-341 [8] Mellon et al. (1997) *J Geophys Res.* 102, 19,357-369.