

**THE EFFECT OF SALT ON THE THERMAL CONDUCTIVITY OF PARTICULATE MATERIALS UNDER MARTIAN ATMOSPHERIC PRESSURES.** *M. A. Presley<sup>1</sup>, R. A. Craddock<sup>2</sup>, and N. Zolotova<sup>3</sup>. <sup>1</sup>School of Earth and Space Exploration, Mars Space Flight Facility, Box 876305, Arizona State University, Tempe, AZ 85287-6305, mpresley@asu.edu, <sup>2</sup>Center for Earth and Planetary Studies, National Air & Space Museum, Smithsonian Institution, Washington, DC 20560-0315, [craddock@si.edu](mailto:craddock@si.edu). <sup>3</sup>School of Earth and Space Exploration, Box 871404, Arizona State University, Tempe, AZ 85287-1404, [nzolotova@asu.edu](mailto:nzolotova@asu.edu)*

**Introduction:** Salt crusts were observed at the Viking Lander sites [1,2], the Pathfinder landing site [3], and by both Mars Exploration Rovers (MER) [4,5]. Investigation of spacecraft data from the Viking Infrared Thermal Mapper (IRTM), and the Mars Global Surveyor Thermal Emission Spectrometer (TES) have revealed large regional areas of intermediate albedo and thermal inertia that have been interpreted to be indurated particulate materials [6-12].

Much of the surface of Mars can be classified as low albedo, high thermal inertia regions, such as Syrtis Major and Sinus Meridiani, or as high albedo, low thermal inertia regions, such as Arabia. The Oxia province is one example of a region that does not fit that bimodal classification. While its thermal inertia is intermediate between that of the bright areas and that of the dark areas, its violet reflectance is as low as the dark areas and its red reflectance is almost as bright as the bright areas [8]. Since the anomalous color does not fit within a coarse-grained, dark 'violet' (less red) to fine-grained, bright 'red' trend, one possibility is that the area may be composed of a crusted soil [6,7].

Mixing trends determined from the red and blue reflectances, as well as morphology interpreted from Viking Orbiter images, illustrate that the surface material in Oxia is relatively immobile [8]. Yet the thermal inertia of the material would correspond to a particle size in unindurated material of about 90  $\mu\text{m}$  [13], which is close to the particle diameter for which the threshold wind speed is at minimum [14]. As such, this material should be easily transported on Mars. Since the unit appears to be immobile, however, an alternative explanation is that the surface material of Oxia is composed of a finer grain size that is lightly indurated [8].

The color/albedo units characterized in the Oxia region also correspond to those observed in the Chryse region [12,15], which implies that this crusted soil could have formed over very wide areas of the planet.

If Oxia and similar regions are composed of a crusted material, logic suggests that the increased particle to particle cohesion must be balanced by an effective particle size that is much smaller than 90  $\mu\text{m}$  in order to be consistent with the thermal data. One possibility then, is that these regions have a similar effective particle size as the bright red dust, in which case these regions would be indurated dust deposits.

Most salts, however, are transparent in the visible. A transparent salt is unlikely to darken and to reduce the blue reflectance of the deposit. Iron sulfates such as quenstedtite [8] or jarosite [16,17] are trans-opaque and could explain both the darkening and the loss of blue reflectance. Abundant jarosite has indeed been identified by the MER Opportunity [4].

Another surficial unit has since been identified that has intermediate thermal inertia, but high albedo [11]. This unit has been interpreted as being a very thin deposit of dust that is thick enough to dominate the albedo, but thin enough that it cannot mask the effects of a higher thermal inertia surface underneath [11]. Alternatively, this region could also be an indurated surface, but with no trans-opaque salts present.

Although the induration theory seems to fit the data well, the problem is that the thermal conductivity of indurated materials has not yet been measured, which hinders accurate interpretation. The difficulties with such a project are numerous. The use of thermal conductivity probes would break the cement bonds upon insertion into the indurated soil and create a layer of disturbed soil around the probe. This effect would likely lower the thermal conductivity measured relative to the actual thermal conductivity. Creating uniform samples of lightly indurated samples is also not an easy task. With a line-heat source [13] there is a possibility that any salts grown in situ would preferentially grow around the line-heat source. Even if this effect is very small, it would nonetheless increase the measured thermal conductivity relative to the actual conductivity.

While a systematic study has yet to be implemented, a measure of the minimal effect of induration on thermal conductivity has been made for one fluvial sample. Although it is only one sample, the complete lack of data otherwise make presentation of the results, despite the limitations, worthwhile.

**Sample.** The sample was a cemented, but very friable deposit in the Ross River of the Simpson desert, Australia. The collection and transportation of the sample necessarily broke many of the cement bonds. When the sample was transferred into the sample holder it had already taken the form of a mostly loose particulate material. Some of the sample was more highly indurated than other parts and the cement retained some identity through the formation of more

durable clods. However, due to the small size of the sample holder, which is otherwise an advantage, and due to the fragility of the platinum heating wire, clods larger than about 3 mm were removed ahead of time and not allowed in the sample holder. Once the thermal conductivity of the sample in this condition was measured, the sample was removed from the sample holder and the remaining cement bonds were broken by (latex-gloved) hand.

**Experimental Procedures:** A particle size analysis was performed prior to the final bond breaking by a gentle sieving by hand, and a final particle size analysis was performed through a normal sieving procedure [13].

The line-heat source method was used to measure the thermal conductivity of sample materials, since the set up for such measurements was already available and was the only facility then being utilized to measure thermal conductivity under Martian atmospheric pressures. The laboratory set up was previously described in detail in [13], except for an upgrade in the computer and analog to digital circuit board, which provided better resolution in the temperature measurements.

A detailed error analysis of the thermal conductivities measured in this facility was presented in [13]. The typical precision of the thermal conductivity measurements is  $\pm 5\%$ . For low and high values of the thermal conductivities measured in this study, the precision errors reach  $\pm 15\%$ . The electronic upgrades did not significantly affect assessment of instrumental precision, as these upgrades were made primarily to improve the ease in data collection and precision improvements were minor.

Measurements produced in this lab were shown [12] to match those produced by Smoluchowski [18] and by Wechsler and Glaser [19], which are likely to be the most accurate thermal conductivity measurements previously obtained under Martian atmospheric pressures [12]. Additionally, particle size estimates based on this laboratory's results and MER Rover thermal measurements were demonstrated to match the particle size observed with the MER Rover Microscopic Imagers [20].

In order to assess the amount of salt in the sample, the major cations and anions were analyzed by ion chromatography in E. Shock's GEOPIG laboratory at Arizona State University.

Water was added to the sample in a 5:1 ratio and then filtered so that soluble, salt-forming ions were extracted from the sample [21]. The solution was divided into two parts and the soluble anions were analyzed by anion-exchange chromatography (Dionex DX-600) using suppressed conductivity detection and

a Dionex AS11 column. High-purity hydroxide eluent was generated by an on-line electrolytic eluent generator. Soluble cations were analyzed through suppressed conductivity detection using a Dionex Cation-Exchange CS12A column on a Dionex DX-120 chromatograph. Duplicates and blanks were also be run in both cases to insure accuracy. Estimated analytical uncertainties for this procedure, for all ions, are  $\pm 1\%$ . Carbonate ion content was determined through titration and the pH of the solution.

**Results.** The total salinity of the sample was determined to be 1.1 g/kg. The thermal conductivities of the sample with the cement bonds broken matched those of glass beads with a particle size of 70-75  $\mu\text{m}$ , although as much as 13% of the particles in the sample are larger than this [22]. The thermal conductivities of the sample before it was broken up are approximately 3x greater than the thermal conductivities of the sample with the cement bonds broken, which is equivalent to those of an unindurated particle size of 500  $\mu\text{m}$ . This result should be considered the minimum effect that this amount of salt would have on the thermal conductivity, as unbroken cement bonds would undoubtedly contribute to an actual thermal conductivity that would be higher than what was measured under these circumstances.

**References:** [1] Morris R. *et al.* (1978) *Icarus*, 34, 548-555. [2] Moore H.J. *et al.* (1982) *JGR*, 87, 10,043-10,050. [3] Rieder R. *et al.* (1997), *Science*, 278, 1771-1774. [4] Squyres S.W. *et al.* (2004), *Science*, 306, 1698-1703. [5] Gellert R. *et al.* (2004), *Science*, 305, 829-832. [6] Kieffer H.H. *et al.* (1981) *Proc Lunar Planet Conf*, 12B, 1395-1417. [7] Jakosky B.M. and Christensen P.R. (1986) *JGR*, 91, 3547-3559. [8] Presley M.A. and Arvidson R.E. (1988) *Icarus*, 75, 499-517. [9] Christensen P.R. and Moore H.J. (1992) in *Mars*, U of A press, 686-729. [10] Mellon M.M. *et al.* (2000) *Icarus*, 148, 437-455. [11] Putzig N.E. *et al.* (2005) *Icarus*, 173, 325-341. [12] Merényi, E. *et al.* (1996) *Icarus*, 124, 296. [13] Presley M.A. and Christensen P.R. (1997) *JGR*, 102, 6551-6566. [14] Iversen J.D. and White B.R. (1982), *Sedimentol*, 29, 111-119. [15] Arvidson R.E. *et al.* (1989) *JGR*, 94, 1573-1587. [16] Burns R.G. (1988) *Proc Lunar Planet Sci 18<sup>th</sup>*, 713-721. [17] Presley M.A. (1995) *PhD Diss.* ASU. [18] Smoluchowski, M.M. (1910) *Bull Int Acad Sci Cacovie*, 5A, 129-153. [19] Wechsler A.E. and Glaser P.E. (1965) *Icarus*, 4, 335-352. [20] Ferguson R.L. *et al.* (2006) *JGR*, 111, E02S21. [21] Agriculture Handbook 60, USDA [22] Presley M.A. and Craddock R.A. (2006) *JGR*, 111, E09013.