THERMAL CONDUCTIVITY MEASUREMENTS OF NATURAL EOLIAN AND FLUVIAL MATERIALS. M. A. Presley¹ and R. A. Craddock², ¹Dept. of Geological Sciences, Mars Space Flight Facility, Box 876305, Arizona State University, Tempe, AZ 85287-6305, mpresley@asu.edu, ²Center for Earth and Planetary Studies, Smithsonian Institution, MRC-315, 6th St & Independence Ave, SW, Washington, DC 20560-0315, craddockb@si.edu.

Introduction: The particle size of surficial materials may provide important clues about the history of erosion, transport, and depositional processes that have acted to form the deposit. Particle size may also provide a valuable clue about the genesis of those deposits. On Mars, most of the surface is covered with at least a thin coating of various particulate materials that tend to obscure direct evidence of bedrock [e.g., 1-3]. Thus, one of the primary goals of Martian studies and exploration [e.g., 4-5] has been to understand the nature of the Martian surface materials and to decipher their relationships with bedrock geology.

Global maps that present estimations of the thermal inertia of Martian surface materials have been created with surface temperature data gathered from the Viking Orbiter Infrared Thermal Mapper (IRTM) [1,6] and the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) [7,3]. Variations in thermal inertia primarily are due to variations in the thermal conductivity [8] under Martian atmospheric conditions. Laboratory measurements have shown that for Martian atmospheric pressures the thermal conductivity of particulate materials has a strong dependence on the particle size [9-11]. In particular, the log of thermal conductivity exhibits a linear relationship to the log of the particle size at any given atmospheric pressure, at least up to 100 torr [12]. A combination of these concepts should allow a reasonable estimate of an effective particle size of the Martian surficial deposits.

The most comprehensive study of the effects of particle size on thermal conductivity under Martian atmospheric conditions [12], however, used very narrow particle size ranges and spherical glass beads in order to establish an empirical relationship. Can this empirical relationship be applied to real surficial deposits, with non-spherical particle shapes and that consist of well- to poorly-sorted mixtures of particle sizes?

Samples: Eight samples were collected from various eolian and fluvial environments in the Simpson Desert, Australia [13]. At each site, a Model 3440 portable surface moisture density gauge manufactured by Troxler Electronic Laboratories was used to measure the bulk density of the sample in situ, before collection, so that the bulk density could be closely recreated in the laboratory. Particle size distributions for each sample were determined by sieving the samples through brass sieves at 1 mm size intervals (\(d = \log_{10} d\), where \(d\) is the particle diameter in millimeters). Two samples of basaltic dune sand from the San Francisco Volcanic Field had been previously analyzed [14] and are also included in this study, along with a sample of Mars simulant JSC Mars-1 [15].

Experimental Procedure: In this study, the line-source method is used to measure the thermal conductivity of sample materials, since it is relatively simple and has a proven reliability [16,12]. The line-source allows several measurements to be made over various atmospheric pressures under the same time frame generally required to reproduce one thermal probe experiment [e.g., 17]. Smaller samples may be used with the line-source technique [16], and thus the exchange of samples is easier and significantly faster than for most other methods of thermal conductivity measurement.

The laboratory set up was previously described in detail in [12]. The computer and analog to digital circuit board have been upgraded in order to obtain better resolution in the temperature measurements.

A detailed error analysis of the thermal conductivities measured in this laboratory was presented in [12]. Maximum instrumental errors of 10-15% were calculated for thermal conductivity values typical for this study. Maximum instrumental errors as high as 15-30% were calculated for the low (< 8 \(x 10^{-3}\) W m\(^{-1}\)K\(^{-1}\)) and high (> 0.1 W m\(^{-1}\)K\(^{-1}\)) values of thermal conductivities measured. These calculated errors were verified by examining both the reproducibility of the measurements and their internal consistency [12]. The typical precision of the thermal conductivity measurements in this study is ±5%. For low and high values of the thermal conductivities measured in this study, the precision errors reach ±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.

The lack of a low thermal conductivity standard continues to prohibit a true assessment of the accuracy of these measurements. In [12], measurements produced in this lab were shown to
match those produced by [10] and [11], which are likely to be the most accurate thermal conductivity measurements previously obtained under Martian atmospheric pressures [17].

**Results:** In 4 of the 11 samples, the thermal conductivity-derived particle size cannot be closely restrained, since the thermal conductivities measured were higher than those for 710-900 µm glass beads, which were the largest size previously investigated [12]. In order to evaluate the results from these 4 samples then, the particle size was calculated from the empirical relationship between thermal conductivity and particle size previously determined in [12], for 8 atmospheric pressures between 0.5 and 8 torr. The results were then averaged to produce a single effective particle size.

For 10 of the 11 samples, the thermal conductivity-derived particle size is larger than the median or mean particle sizes of the sample, but smaller than the absolute largest size present. In one of the basaltic dune sands, the derived particle size is essentially equal to the median and mean particle size values, as it is very well sorted and only ~1 wt. % of the sample is contained in the next larger particle size bin.

In all but one sample, the amount less than or equal to the derived particle size is at least 95 wt. % of the sample. Even when the “or equal to” phi bin is not considered, the thermal conductivity-derived particle size is still greater than 90 wt. % of the sample in all but 3 of them. In one of these 3 the value is at least greater than 80 wt. %. In another one of these 3, the sample is so well sorted that virtually the entire sample is contained in one phi bin, with very little of the sample in the next larger phi bin.

These results illustrate that virtually the entire sample is composed of particles that are equal to or smaller than the particle size that the thermal conductivity would suggest. When applied to thermal inertia-derived particle sizes for the Martian surface, the implication is that most of the particles may actually be much smaller than that derived size. How much smaller the average or median particle size is from the thermal inertia-derived particle size will depend on how well sorted the surficial deposit is.

**Discussion:** Thermal conductivities measured for natural mixtures of particle sizes tend to match those previously measured for the larger particle sizes within the mixture. Therefore, particle sizes predicted by thermal inertia should be considered to be a maximal particle size present, and not considered to be a mean or median value.

This result is an important one, as a number of researchers have been assuming that the “effective” particle size determined from thermal inertia measurements and the data in [12] is in effect an “average” or “modal” particle size. These results indicate that instead the thermal inertia-derived particle size is actually closer to a maximum.

The significance of this result is that it may allow scientists to distinguish geomorphologic processes acting on the Martian surface. For instance, sediments formed in an eolian environment tend to be much better sorted, and the size of dune particles is limited by the saltation threshold [18,19]. In contrast, sediments carried and deposited in a fluvial environment tend to be more poorly sorted and are likely to contain larger particles. Are the dunes visible in the Martian fluvial channels today derived from a simple reworking of fluvial deposits, or are they an eolian overprint? The results presented in this paper may provide an additional clue.