THERMAL INERTIA AND CONDUCTIVITY MEASUREMENTS OF MARS ANALOG ROCK SAMPLES.

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Introduction: Thermal inertia is an intrinsic property of a material that describes how efficiently that material can store, conduct, and re-radiate heat. It is given by:

\[ I = \sqrt{k \rho c} \] (1)

where \( k \) is the bulk thermal conductivity (W/cmK), \( \rho \) is the bulk density (g/cm³), and \( c \) is the specific heat (J/K); \( I \) has units of J/m²Ks¹/² or thermal inertia units (tiu, as defined by [1]). At Mars atmospheric pressure, thermal inertia is dominated by the effects of thermal conductivity, which is determined by the physical characteristics of the near subsurface (upper few cm) [2,3]. Such physical properties could include grain size (for unconsolidated sediment), degree of induration or cementation, vesicularity, porosity, or degree of fracturing.

Many laboratory studies have attempted to relate physical properties of materials to their associated thermal properties [1,4–9] to gain context for orbital thermal observations. However, methods have been inconsistent between laboratories and only a few studies have measured thermal properties in Mars-relevant pressures [e.g., 5]. Presley and Christensen conducted a number of studies [6–9] using a line-heat source apparatus in a Mars-like atmosphere and determined a quantitative relationship between unimodal and bimodal grain size samples and thermal properties. However, no thermal measurements under Mars-like conditions exist for solid samples, and questions still remain about the effects of porosity, rock mechanical strength [10], and density on the thermal inertia of non-particulate samples under Mars conditions. This work aims to close the gaps in our understanding of thermal properties as they relate to physical characteristics on both Earth and Mars. We also plan to quantify relationships between thermal properties on Earth and in Mars conditions for easier comparison of analog samples in the future.

Samples: We have gathered samples that span the chemical and physical range of rocks observed on Mars (e.g., volcanic vs. volcanioclastic, well-cemented vs. loosely consolidated sedimentary, effusive vs. pyroclastic) from a variety of sources. Select samples presented in this abstract are listed in Table 1. Some samples have already had uniaxial compressive strength and chemical composition measured [10].

Methods: Thermal measurements are being produced for the samples listed in Table 1 using two C-Therm thermal conductivity TCi analyzers (for the setup, see Fig. 1): one in ambient pressures and one in Mars-relevant pressures (1–9 mb). The sensors work as modified transient plane heat source systems by using interfacial heat reflectance, i.e., supplying the heat to the sample and then measuring the amount of heat reflected back to the sensor. C-Therm analyzers have been widely used in a number of industries (e.g., petroleum, pharmaceuticals, photovoltaics, textiles [11]) but this study represents the first time that they have been used in planetary thermal studies. At time of writing, measurements have only been acquired under ambient pressure.

Table 1. Terrestrial samples used in this study to span the range of martian sedimentary rocks.

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>Rock Type</th>
<th>Locality</th>
<th>Contributor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juniata Fm</td>
<td>Fine-grained sandstone</td>
<td>TN</td>
<td>R. Kronyak/L. Kah</td>
</tr>
<tr>
<td>Clinch Fm</td>
<td>Quartz sandstone</td>
<td>TN</td>
<td>R. Kronyak/L. Kah</td>
</tr>
<tr>
<td>Chapman Ridge Fm</td>
<td>Iron-rich sandstone</td>
<td>TN</td>
<td>R. Kronyak/L. Kah</td>
</tr>
<tr>
<td>Musseula Fm</td>
<td>Claystone</td>
<td>MT</td>
<td>R. Kronyak/L. Kah</td>
</tr>
<tr>
<td>Cutler Fm</td>
<td>Iron-rich arkosic sandstone</td>
<td>UT</td>
<td>R. Kronyak/L. Kah</td>
</tr>
<tr>
<td>Wingate Fm</td>
<td>Iron-rich quartz arenite</td>
<td>UT</td>
<td>R. Kronyak/L. Kah</td>
</tr>
<tr>
<td>Morrison Fm</td>
<td>Light-colored sandstone</td>
<td>UT</td>
<td>R. Kronyak/L. Kah</td>
</tr>
<tr>
<td>BT-DK-1</td>
<td>Basaltic tuff</td>
<td>ID</td>
<td>D. Moore</td>
</tr>
<tr>
<td>C-AKT-1</td>
<td>Basaltic sandstone</td>
<td>Antarctica</td>
<td>K. Cannon</td>
</tr>
<tr>
<td>SIL-1</td>
<td>Silicate</td>
<td>CA</td>
<td></td>
</tr>
<tr>
<td>OSJA-1</td>
<td>Carbonaceous shale</td>
<td>PA</td>
<td></td>
</tr>
<tr>
<td>Puna-3</td>
<td>Igneousite</td>
<td>Argentina</td>
<td>J. Radebaugh/D. McDougall</td>
</tr>
<tr>
<td>Puna-4</td>
<td>Pumice</td>
<td>Argentina</td>
<td>J. Radebaugh/D. McDougall</td>
</tr>
<tr>
<td>CRB-1</td>
<td>Loess</td>
<td>WA</td>
<td>D. Rogers</td>
</tr>
<tr>
<td>SS-01</td>
<td>Quartz arenite</td>
<td>UT</td>
<td>B. Thomson</td>
</tr>
<tr>
<td>LS-01-002</td>
<td>Fine-grained limestone</td>
<td>CA</td>
<td>B. Thomson</td>
</tr>
</tbody>
</table>

Each sample has been cut and smoothed to have two flat surfaces that can sit flush on the sensor. The thermal measurements themselves do not alter a sample in any way, given that the temperature of the sensor changes by 1-2 °C. For measurements, contact agents are needed between the sensor and sample for any solid samples. These contacts agents are normally distilled water for non-porous samples or Wakefield Thermal Joint Compound (a silicone oil-based grease) for porous samples. Individual thermal measurements take anywhere from 60-80 s and each sample has been measured in 3 different sessions of 10 measurements each.
Porosity measurements of selected samples have been and continue to be conducted at the Vatican Observatory. A Quantachrome Ultrapycnometer 1000 ideal-gas pycnometer is used with gaseous nitrogen, in which initial pressures in one chamber are compared with final pressures in the other sample-holding container to determine grain densities ($\rho_b$). Bulk densities ($\rho_b$) have been measured using the NextEngine model 2020i Scanner HD Pro laser scanner and Geomagic Verify software. Porosity ($P$) is then calculated according to Eq 2.

$$ P = 1 - \left( \frac{\rho_b}{\rho_g} \right) $$

A comparison of porosity and thermal properties is given in Fig. 2. Additional samples are being measured that will shed greater light on the relationship between porosity and thermal inertia and conductivity.

![Fig. 1. Laboratory setup at Stony Brook University in the Center for Planetary Exploration Spectroscopy Lab. Results from the ambient pressure sensor are presented in this abstract. Results from the Mars pressure measurements are in progress.](image)

**Results:** Thermal inertia and conductivity results are summarized in Table 2 for the samples listed in Table 1. Fig. 2 shows thermal inertia measurements with respect to porosity. Preliminary results show the trend with porosity as expected—that thermal inertia will decrease with increasing porosity. We will be working to develop the quantitative nature of that relationship with the addition of more porosity and thermal measurements. Variability within a single sample may add complication to thermal measurements. Work is ongoing to determine the relationships between uniaxial compressive strength and thermal inertia as a proxy for cementation quality.

![Fig 2. Preliminary porosity and ambient thermal measurement comparison from 9 of the samples described in Table 1. Where error bars cannot be seen, they are smaller than the symbol.](image)

**References:**


**Table 2.** Preliminary thermal results taken from the C-Therm ambient sensor of the samples listed in Table 1. Samples SS-01 and LS-01-002 are described for mechanical strength in [10].

<table>
<thead>
<tr>
<th>Sample Name</th>
<th>$k$ (W/mK)</th>
<th>TI (J/m2Ks1/2) at 1 bar</th>
<th>Porosity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juniata Fm</td>
<td>3.343 ± 0.026</td>
<td>2625.0 ± 11.5</td>
<td>3.9% ± 0.4%</td>
</tr>
<tr>
<td>Clinch Fm</td>
<td>2.697 ± 0.076</td>
<td>2324.0 ± 36.4</td>
<td>6.2% ± 0.3%</td>
</tr>
<tr>
<td>Chapman Ridge Fm</td>
<td>4.03 ± 0.076</td>
<td>2873 ± 171.7</td>
<td>2.0% ± 0.5%</td>
</tr>
<tr>
<td>Missoula Fm</td>
<td>1.975 ± 0.185</td>
<td>470.0 ± 1.5</td>
<td>47.3% ± 0.3%</td>
</tr>
<tr>
<td>Cutler Fm</td>
<td>2.068 ± 0.051</td>
<td>2128.3 ± 34.0</td>
<td>9.2% ± 0.6%</td>
</tr>
<tr>
<td>Wingate Fm</td>
<td>0.209 ± 0.006</td>
<td>545.2 ± 6.9</td>
<td>27.1% ± 0.3%</td>
</tr>
<tr>
<td>Morrison Fm</td>
<td>3.842 ± 0.078</td>
<td>2846.7 ± 33.9</td>
<td>4.5% ± 0.3%</td>
</tr>
<tr>
<td>BT-DR-1</td>
<td>0.053 ± 0.001</td>
<td>134.6 ± 0.9</td>
<td>pending</td>
</tr>
<tr>
<td>C-ANT-1</td>
<td>0.241 ± 0.001</td>
<td>579.9 ± 1.8</td>
<td>pending</td>
</tr>
<tr>
<td>SIL-1</td>
<td>1.681 ± 0.03</td>
<td>1813.8 ± 15.7</td>
<td>pending</td>
</tr>
<tr>
<td>CHSA-1</td>
<td>2.913 ± 0.11</td>
<td>242.4 ± 5.1</td>
<td>pending</td>
</tr>
<tr>
<td>Puna-3</td>
<td>0.254 ± 0.008</td>
<td>594.6 ± 9.2</td>
<td>46.9% ± 0.2%</td>
</tr>
<tr>
<td>Puna-4</td>
<td>0.103 ± 0.001</td>
<td>256.7 ± 1.6</td>
<td>pending</td>
</tr>
<tr>
<td>CRB-1</td>
<td>0.126 ± 0.001</td>
<td>289.9 ± 3.5</td>
<td>pending</td>
</tr>
<tr>
<td>SS-01</td>
<td>0.829 ± 0.003</td>
<td>1710.8 ± 2.6</td>
<td>pending</td>
</tr>
<tr>
<td>LS-01-002</td>
<td>1.583 ± 0.009</td>
<td>1790.6 ± 6.6</td>
<td>pending</td>
</tr>
</tbody>
</table>

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**Table 2.** Preliminary thermal results taken from the C-Therm ambient sensor of the samples listed in Table 1. Samples SS-01 and LS-01-002 are described for mechanical strength in [10].