MEASUREMENT OF THERMAL PROPERTIES OF THE ORDINARY CHONDRITES RELEVANT TO PLANET-FORMING PROCESSES. K. A. McCain1,2, F. J. Ciesla1,3, P. R. Heck2,3, S. S. Rout2,3, M. Pellin1,3,4 C. Malliakas4 and J.F. Mitchell1. Department of the Geophysical Sciences, 1The University of Chicago, Chicago, IL, USA. 2 Robert A. Pritzker Center for Meteoritics and Polar Studies, Field Museum of Natural History, Chicago, IL, USA. 3Chicago Center for Cosmochemistry, The University of Chicago, Chicago, IL, USA. 4Materials Science Division, Argonne National Laboratory, Argonne, IL, USA. (kamccain@uchicago.edu)

Introduction: As chondritic meteorites avoided differentiation, they are considered to provide the best record of the dust that was present in the solar nebula at the time of planetesimal formation. However, all meteorite classes show evidence of varying degrees of aqueous and/or thermal metamorphosis that have altered the initial assemblages and changed the properties of the dust once it was incorporated into the meteorite parent body. A detailed understanding of this planetary processing is thus required to reconstruct the Solar System’s earliest history.

The presence of differentiated and metamorphosed meteorites provides evidence of large-scale thermal alteration which has been attributed to the decay of $^{26}\text{Al}$ [1]. The build up of the heat within a meteorite parent body, and thus the extent to which primitive components were altered, would have been controlled by the thermal properties of the materials it contained. Specifically, the heat capacity ($C_p$, kg·m$^2$·s$^{-2}$·K$^{-1}$), density ($\rho$, g/cm$^3$) and thermal diffusivity ($D$, mm$^2$·s$^{-1}$) would control the temperatures reached and how energy propagated through the body. The values of these parameters are known for pure substances, but as meteorites are mixtures of minerals and components of a range of sizes, their properties are expected to be much more complex.

Previous studies [2-4] have measured values for these parameters for different meteorite types, including iron meteorites, achondrites, and a variety of ordinary and carbonaceous chondrites. These studies focused on measuring the properties at low temperatures (5-300 K) relevant to temperatures that the materials would experience in the present-day Solar System. In the early Solar System, however, these materials would have reached much higher temperatures as a result of radiogenic heating. To better quantify how a meteorite parent body would have evolved after its formation, the thermal properties of these materials must be determined at temperatures relevant to thermal metamorphism. We are carrying out a systematic study to determine the thermal properties of a suite of ordinary chondrites at the elevated temperatures they would have seen in the early Solar System. Specifically, we are focusing on samples of petrologic type 3-6, meaning that they reached temperatures between 500-1100 K on their parent body [5,6]. Here we report preliminary results for the thermal properties of two ordinary chondrites.

Samples and Methods: For our overall study, we selected twenty-two ordinary chondrite samples representing petrologic types from 3.3 to 6 from the collection of the Field Museum of Natural History. The meteorites are falls—with the exception of Grady (H3.7) and Ragland (LL3.4)—in order to minimize the effects of surface weathering, which fills pore space with relatively conductive Fe-rich material [7]. Low-shock samples were also preferred, as shock effects such as fracturing have been shown to lower the conductivity of a sample [2,3]. Sample descriptions of the two meteorites Chelyabinsk (LL5; FMNH ME 6050.234) and Mount Browne (H6; FMNH ME 1329.5) have preliminary data and are summarized in Table 1.

A slice of ~10 mm x 10 mm x 3 mm of each sample was prepared and imaged by two methods (Fig. 1): (1) Reflected light microscopy and (2) electron microscopy using the Field Museum’s Zeiss Evo 60 scanning electron microscope (SEM). After imaging, the samples were cut into parallelepipeds, polished, and carbon coated. The thermal properties of the samples were measured using the NETZSCH LFA 457 MicroFlash instrument at Argonne National Laboratory (temperatures between 148-1373 K). The sample temperature was gradually increased to 1022 K then decreased to 308 K, allowing measurements to be performed along the entire cycle. Two heating cycles were performed to check the reproducibility of the measurements.

Results: Table 1 presents the key properties of two of the samples used in our study, Mount Browne and Chelyabinsk, along with our measurement for the ther-

Figure 1. Reflected light (Left) and backscattered electron (Right) images of the Chelyabinsk meteorite specimen ME 6050.234. Scale bar is 2 mm. The grey bar in the right hand image is a scanning error.
Table 1. Physical properties of Chelyabinsk and Mount Browne meteorites in this study. Conductivity is an average of measurements at 800 K, near the observed minimum. Chelyabinsk density and porosity from [8], Mount Browne density and porosity from [9]. Shock and weathering from Metbull (retrieved 11/3).

<table>
<thead>
<tr>
<th>Meteorite</th>
<th>Kind</th>
<th>Bulk dens. (g/cm³)</th>
<th>Grain dens. (g/cm³)</th>
<th>Porosity</th>
<th>Shock</th>
<th>Weathering</th>
<th>κ at 800 K (W/m²·K⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chelyabinsk</td>
<td>LL5</td>
<td>3.32</td>
<td>3.51 ± 0.07</td>
<td>6.0% ± 3.2%</td>
<td>S4</td>
<td>W0</td>
<td>0.906</td>
</tr>
<tr>
<td>Mount Browne</td>
<td>H6</td>
<td>3.46</td>
<td>3.66</td>
<td>7.2% ± 0.6%</td>
<td>S3</td>
<td>W0</td>
<td>0.682</td>
</tr>
</tbody>
</table>

Figure 2. Thermal diffusivity (D) for the Chelyabinsk and Mount Browne meteorites between 300-1050 K.

Overall, our results are consistent with the measurements of meteorites of the same class and petrologic type done at lower temperatures [3,4]. The trend of decreases in thermal conductivity with increasing temperature is consistent with elementary models of an anharmonic lattice, which predict that thermal conductivity will fall as 1/Tn where 1<n<2 as the phonons which transport thermal energy begin to interfere with one another [10].

Work by [3,4] suggests that porosity and shock-induced microcracks are also important controls on the heat transport abilities of meteorites, with cracks tending to decrease conductivity. Here, Chelyabinsk is more conductive, which is consistent with its lower porosity but inconsistent with its higher shock state in relation to Mount Browne. High metal content is expected to increase conductivity, but this is difficult to test with only two samples of which we have preliminary data.

We will continue to measure our selection and incorporate heat capacity measurements into our estimates of thermal conductivity. Accurate values of C_p will be required before finalizing measurements of conductivity. Continued experience with calibration of the Microflash instrument is expected to decrease variability between heating cycles.

Measurements of the other 20 samples are expected to improve our understanding of the factors controlling thermal properties at high temperatures.

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