METEORITE PHYSICAL PROPERTIES RELATED TO ASTEROID ATMOSPHERIC ENTRY. D. R. Ostrowski[1,2] and K. L. Bryson[1,2], [1]NASA Ames Research Center, Moffett Field, CA, USA., [2]Bay Area Environmental Research Institute, Ames Research Center, Moffett Field, CA, USA, E-mail: daniel.r.ostrowski@nasa.gov.

Introduction: Meteorites provide vast amounts of information on the make up and history of the solar system. Physical properties provide information to understand the behavior of meteors during atmospheric entry. These measurements help determine methods to deflect potentially hazardous objects [1] and are essential to determine the characteristics of parent bodies[2].

The Asteroid Threat Assessment Project (ATAP) has been set up to investigate the full risk and outcomes that near Earth asteroids pose to the planet. One of the tasks of this program is to study the physical properties of meteorites that pertain to how a meteor behaves during atmospheric entry.

Experimental: The physical properties studied to support this project include density, porosity, acoustic velocity, and thermal emissivity. Bulk density is determined from 3D laser scanning, while grain density is determined from gas pycnometery. Porosity is calculated from these densities. Acoustic velocities are measured using an Olympus 45-MG meter, allowing for the calculation of Young's and Shear moduli. Emissivity is measured from 20°C up to atmospheric entry temperatures. NEO properties along with physical properties of meteorites measured in this study and collected from other authors are available at https://neoproperties.arc.nasa.gov.

Results: The suite of physical properties has been measured for each meteorite examined during this study on ordinary chondrite fall and Antarctic ordinary chondrites.

Densities and Porosities. Bulk densities of the ordinary chondrites studied range from 3.2027 ±0.0001 to 3.53±0.07 g/cm^3, which is within published class values (Fig 1.) [3]. The porosity of Chelyabinsk impact melt, 8.81±0.01%, is within published class values, while the regular piece of Chelyabinsk has a high porosity of 12.50±0.02%. Tenham has a very low porosity at 4.9±0.1%, compared to L and most ordinary chondrites. Tamdakht's slightly above average grain density gives the meteorite a porosity of 8.66±0.06%. All Antarctic meteorites have 1.5-2 times larger porosities caused by weathering.

Acoustic Velocities. Acoustic velocities of ordinary chondrite falls and published class averages [5] are listed in Table 1. The low porosity of Tenham causes high velocities, yielding high moduli, 1357.23±26.83 MPa Young's and 613.30 ±20.62 MPa shear modulus (Fig 2). Reduced porosity in the Chelyabinsk impact melt compared to a normal Chelyabinsk fragment,

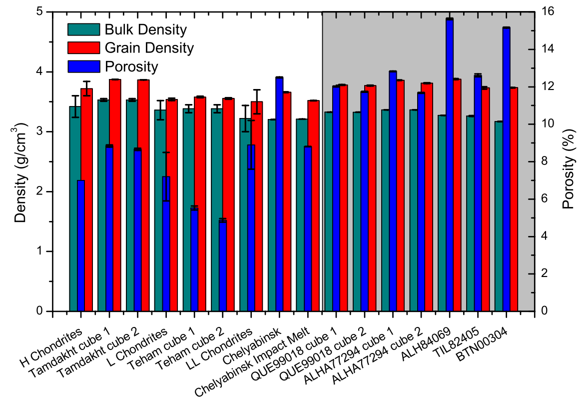

Figure 1. *Bulk density, grain density, and porosity comparison of laboratory measurements with literature class averages [4]. Gray region denotes Antarctic meteorites.*

Meteorite	Longitudinal (m/s)	Shear (m/s)
H Chondrite	4874.90	2935.00
Tamdakht 1	3683.51±9.23	2777.74±1.39
Tamdakht 2	3791.20±8.54	2769.62±5.85
L Chondrite	3536.71	2103.52
Tenham 1	6341.87±14.64	4191.51±7.05
Tenham 2	6318.50±17.08	4148.33±4.54
LL Chondrite	5110.00	2450.00
Chelyabinsk	3754.63±14.41	2794.00±2.54
Chelyabinsk impact melt	6265.67±20.35	3157.73±8.69

Table 1. *Acoustic velocities of ordinary chondrites and previously published averages [5].*

results in increased acoustic velocities and higher moduli. Tamdakht appears to be a weaker H chondrite with slower acoustic velocities and lower moduli. The shear moduli for all meteorites appear to be less affected by increasing porosity than the Young's moduli. Poisson's ratio for Antarctic meteorites is negative and thus they act as auxetic materials. This can happen when saturated rocks, like Antarctic meteorites, are dried [6]. The drying expose micro cracks that allow the meteorites to become auxetics.

Thermal Emissivity. The average emissivity of ordinary chondrite falls and Antarctic's at 20°C is 0.988±0.008, in agreement with most ordinary chondites [7]. As temperature increases to 100°C the emissivity decreases then rebounds a little and stabilizes for

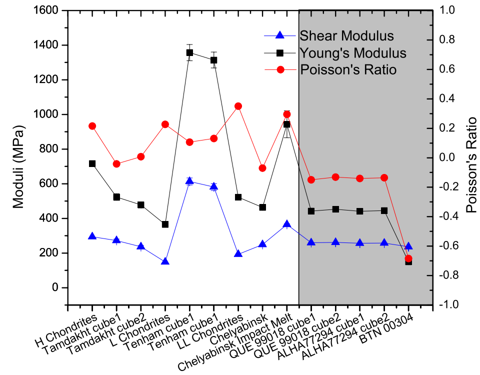

Figure 2. *Poisson's ratios, Young's moduli, and Shear moduli of ordinary chondrites and Antarctic meteorites (gray region).*

the next 100° (Fig. 3). Heated meteorites range in emissivity, 0.85-0.95, with no notable differences between falls and Antarctic meteorites. The next major change in emissivity will likely occur at the first mineral phase change.

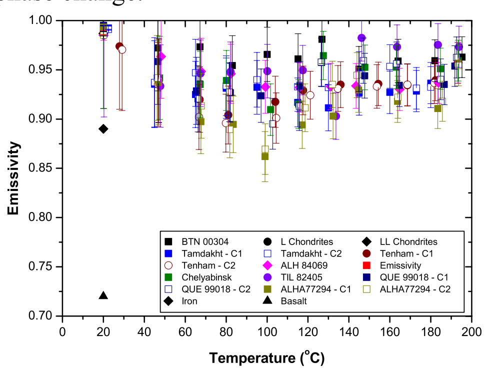

Figure 3. *Emissivity of meteorites, iron, basalt, and average emissivities of H chondrites (0.988±0.004), L chondrites (0.987±0.003), and LL chondrites (0.987±0.002) [4].*

Conclusion: Of the meteorite falls studied, Tamdakht is the closet to being an average ordinary chondrite. Both Chelyabinsk and Tenham are non-average ordinary chondrites, but their densities and porosity fall with in the normal range for their respective class [3]. In the case of Tenham, its porosity is on the low end of the range and causes the meteorite to have nearly double the class average in both longitudinal and shear velocities. This calculates to high Young's and shear modulus, meaning that Tenham is very rigid and thus probably strong. On the other hand Chelyabinsk is the reverse, meaning between mineralogy and porosity the meteorite is weak compared to average LL chondrite falls. When comparing Chelyabinsk to its impact melt, the impact melt resembles more of an average LL chondrite physical property wise.

Slight changes to the physical properties of asteroids can cause large changes to how the body interacts with the atmosphere, with porosity being one of the more important property. These same changes will affect impact midigation of potentially hazardous bodies [2]. The study of meteorites is what gives the best insight into all these physical properites to fully understand asteroids. The measured range of values provides the best inputs for modeling asteroids, their threat level, and how to best midigate that threat.

Acknowledgments: We acknowledge the support of NASA's NEO program, Jim Arnold for leading the Asteroid Threat Assessment Project at NASA Ames Research Center and Derek Sears for support and discussion.

References: [1] Sears D.W.G. et al. (2016) *PSS, 124,* 105–117. [2] Bruck Syal M. et al. (2016) *Icarus*, 269, 50-61. [3] Britt D.T. and Consolmagno G.J. (2003) *M&PS, 38,* 1161-1180. [4] Consolmagno G.J. et al. (2008) *Chemie der Erde*, 68, 1-29. [5] Yomogida K. and Matsui T. (1983) *JGR, 88,* 9513-9533. [6] Nur A. and Simmons G. (1969) *Earth and Planetary Science Letters*, 7, 183-193. [7] Baldridge A. M. et al. (2009) *Remote Sensing of Environment, 113,* 711-715.