METEORITE FRACTURES AND SCALING FOR ATMOSPHERIC ENTRY. K. L. Bryson[1,2] and D. R. Ostrowski[1,2], [1] NASA Ames Research Center, Moffett Field, CA, 94035, kathryn.bryson@nasa.gov, [2] Bay Area Environmental Research Institute, 625 2nd St. Ste 209 Petaluma, CA 94952.

Introduction: We are attempting to understand the behavior of asteroids entering the atmosphere and quantify the impact hazard. Arguably the major difficulty faced to model the atmospheric behavior of objects entering the atmosphere is that we know very little about the internal structure of these objects and their methods of fragmentation during fall. Among the uncertainties required for this task are the composition and physical properties of the incoming objects [1] and their fracture mechanics [2,3]. Strength of meteorites plays an important role in determining the outcome of impact events in which a meteorite is the impactor [3]. Our ultimate objective is to determine a scaling factor for fracture parameters in meteorites.

Experimental: Meteorites in the Natural History Museums of Vienna and London were examined using different strategies at each. In Vienna we looked at a few samples from all classes while in London we looked at all of their H and L chondrites. The fracture patterns in selected individuals were imaged. The density and length of the observed fractures were measured (Fig. 1). Thin sections of selected samples were also imaged and density and length of fractures were measured (Fig. 2).

Results: In this study of over a thousand meteorite fragments (mostly hand-sized, some 40 or 50 cm across), we identified six kinds of fracturing behavior. (1) Chondrites usually showed random fractures with no particular sensitivity to meteorite texture. Approximately 80% of these indicated no point of origin (Fig. 3a), while 20% show an origin (Fig. 3b). (2) Approximately 10% of the chondrites, have a distinct and

Figure 1. *Fractures (red tracings) in this slab of Bluff (a) are insensitive to meteorite texture and have no point of origin*

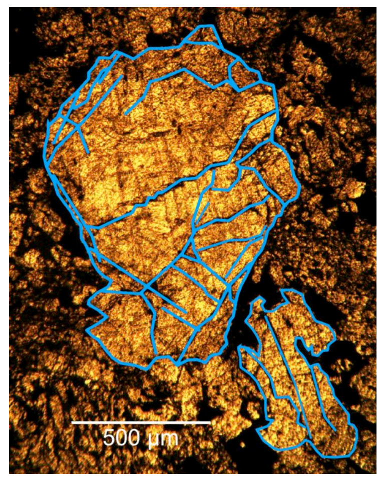

Figure 2. *Fractures (blue tracings) in thin section of Bluff (a). Fracture density and length are used to determine the Weibull coefficient.*

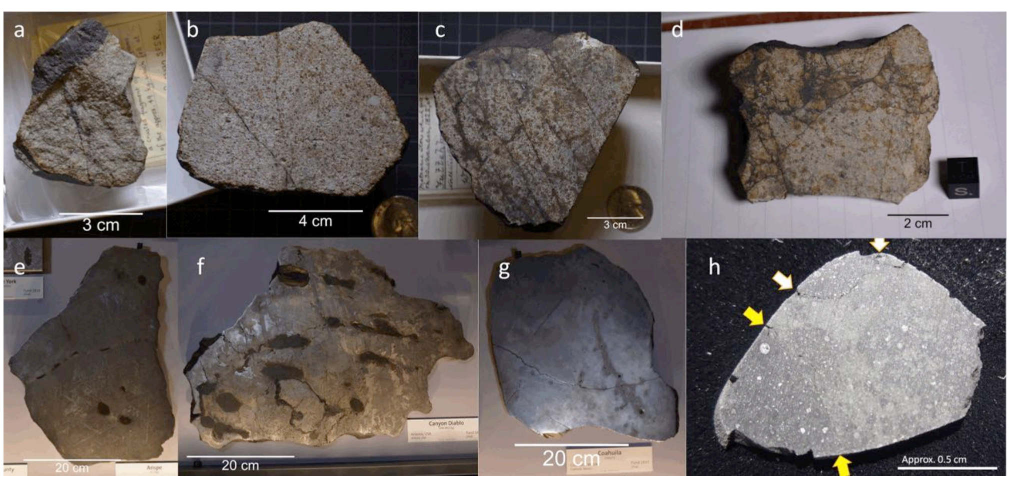

Figure 3. *Fracture Patterns: a. Pervomaisky, b. Chandpur, c. Futtehpur d. Pacula, e. Arispe, f. Canyon Diablo, g. Coahuila, h. Sutter's Mill*

strong network of fractures making an orthogonal (T-intersections) (Fig. 3c) or triple intersection (Y-interesctions) (Fig. 3d) structure. The Chelyabinsk meteorite has the triple intersection structure of fractures, which explains the very large number of centimeter-sized fragments that showered the Earth. (3) Fine irons with large crystal boundaries fragmented along the crystal boundaries (Fig. 3e). (4) Coarse irons fractured along kamacite grain boundaries (Fig. 3f), while other (5) fine irons fragmented randomly (Fig. 3g), c.f. chondrites. Finally, (6) CM chondrites showed that water-rich meteorites fracture around clasts (Fig. 3h).

Discussion: We assume that fracturing follows the Weibull distribution [5], where fractures are assumed to be randomly distributed through the target and the likelihood of encountering a fracture increases with distance. This results in a relationship:

$$\sigma_l = \sigma_s(n_s/n_l)^{\alpha} \quad (1)$$

where σ_s and σ_l refers to stress in the small and large object, n_s and n_l refer to the number of cracks per unit volume of the small and large object, and α is the shape parameter called the Weibull coefficient. The value for α is unclear [6] and a large range in α has been determined from light curve data [3].

The images collected of the six fracture behaviors provide a two-dimensional view of the fractures. A relationship exists between the distributions of measured trace length and actual fracture size [7]:

$$N_L = k_L L^{1/(2\alpha)+1} \quad (2)$$

where N_L is the number per unit area of 2D fracture traces greater than length, L, and k_L is a constant.

Based on the fracture lengths and densities measured of both the slab and thin section of Bluff (a), we are able to plot Figure 4. Figure 4 does show that the fracture distribution is not a power law over the entire range of sizes displayed, this is due to the limitations in counts at the smaller end and limitations of the sample size at the larger end. A power law can still be fit to the data, and 0.166 was determined for the value of α based off these samples.

Conclusions: Based on the meteorites examined thus far in our study, six different fracture patterns have been observed. The majority of these meteorites displayed no particular sensitivity to meteorite texture. An initial value of α of 0.166 has been determined for a chondrite with a fracture pattern that shows no sensitivity to meteorite texture and have no point of origin. This study will continue to examine additional meteorites with similar fracture patterns along with the other5 patterns to see if there is a correlation between fracture pattern and α. This may be able to explain the variations in α determined from fireball data [1,3]. Values

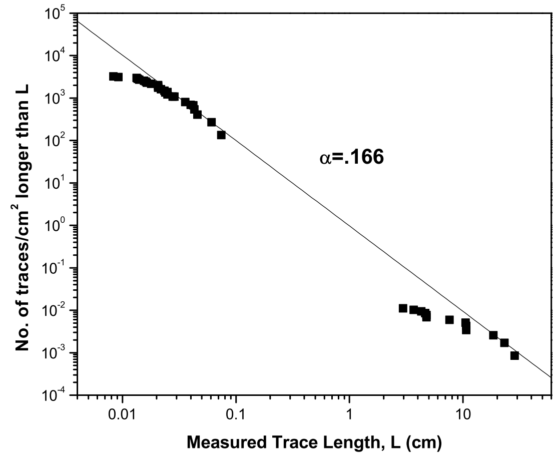

Figure 4. *Distribution of flaw trace length for Bluff (a) determined from figures Figures 1 and 2. The line is based on equation 2 with a slope providing a value of 0.166 for α.*

of α will be used in the models created by the Asteroid Threat Assessement Project to attempt to determine the behavior of asteroids entering the atmosphere and quantify their impact hazard.

References: [1] Sears D.W.G. et al. (2016) *Proceedings of the AIAA SciTech,* AIAA-2016-0997 [2] Baldwin B. and Sheaffer Y. (1971) *JGR.* 76, 4653-4668. [3] Popova O. et al. (2011) *Meteorit. Planet. Sci.* 46, 1525–1550. [4] [5] Weibull W. (1939) *Proceedings of the Royal Swedish Institute for Engineering Research*. No. 153. [6] Asphaug E. et al. (2002) *Asteroids III.* 463-484. [7] Piggot A.R. (1997) *JGR,* 102, 18,121-18,125.

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