SHOCK DARKENING OF H CHONDRITES APPEARS TO CORRELATE WITH THEIR COSMIC RAY EXPOSURE AGE A. R. Hildebrand[1] , M. I. Ibrahim[2], and S. F. Jones[3], [1]Department of Geoscience, University of Calgary, Calgary, AB T2N 1N4 (ahildebr@ucalgary.ca), [2]Department of Earth Science, University of Western Ontario, London, ON N6A 5B7, and [3]Department of Geography, University of Calgary, Calgary, AB T2N 1N4.

Introduction: The meteoroids (derived from asteroids) that enter Earth's atmosphere have been 1) ejected from a larger "parent" asteroidal body (where they experienced a relatively long residence time) and 2) orbited the Sun for a highly variable (and typically much shorter) time exposed in the solar system before they intersected the Earth. A primary constraint on this history derives from study of the cosmic ray exposure (CRE) ages of meteorites fallen from these bodies [e.g. 1]. During solar orbit the meteoroids are subject to bombardment by other similar bodies as well as galactic cosmic rays; collision with another object with sufficient energy can result in their destruction. The collisional history experienced as meteoroids includes numerous subdisruptive collisions, however. The frequency of collisions is evidenced by orders of magnitude variation in CRE ages observed for different meteoroid lithologies [1] with shorter age ranges corresponding to weaker meteoroid strengths. The range of variation in meteoroids' strengths has been most completely recorded in the observed fireball population [e.g., 2] as not all classes of objects are preserved as meteorites. The rate of collisions of the different meteoroid classes has been previously discussed [3], indicating that ordinary chondrite lithologies have on average survived ~15 collisions with weaker lithologies before their destruction. This collisional history potentially allows for shock-induced changes in the ordinary chondrites.

Shock Darkened Chondrites: Amongst the ordinary chondrites a significant fraction have been darkened apparently by shock; ~15% of ordinary chondrite falls have been darkened which has led to the deduction that the darkening is the result of a relatively common and widespread process [4]. The darkening process is attributed to shock induced remobilization of metal and sulfides as dispersed small grains and narrow veinlets [5]. The occurence of shock darkening has been attributed to large impacts on meteorite parent bodies having shocked volumes of material adjacent to impact sites [e.g., 5].

CRE and Darkness of H Chondrites: Fig. 1 plots CRE ages of 40 H chondrite falls vs. their observed darknesses. Individual meteorites' darkness was classified by comparing slab surfaces with the gray scale of the Rock-Color Chart prepared by the The Rock Color Chart Committee and distributed by the Geological Society of America (based on the Munsell system).

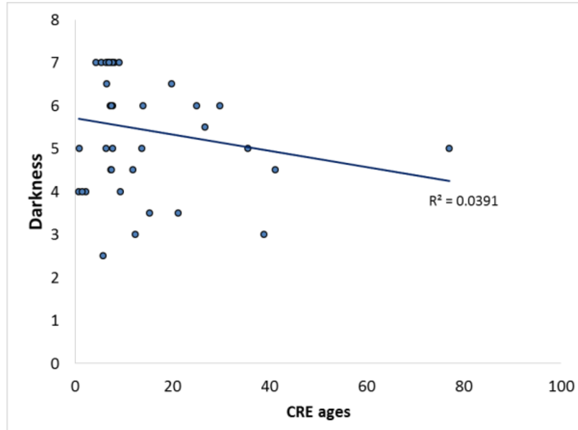

Figure 1: Observed darkness of 40 H chondrites from falls vs. their CRE ages from literature values; on the y axis darkness increases downward (value of one is black following the Rock Color Chart use for comparison.

Although the data are highly scattered, a possible correlation of increasing darkness with increasing CRE age is observed. The R^2 value of 0.0391 represents an ~90% chance of statistical significance for a population of 40 (or slightly less than 2σ).

Complicating Effects. Rather than all of the shock darkening occurring during the meteoroid's relatively brief exposure, some of the H chondrites may have been darkened on their parent bodies before ejection [5] as noted above; the level of darkening due to parent body impacts would be uncorrelated with exposure durations (reducing the correlation in a plot such as in Fig. 1). This contribution must exist at some level and it remains to be determined what the potential relative contributions of the two shock locales are.

A second complication is that the stochastic nature of impact ejection producing meteoroids results in pulses of meteoroid injection. For the H chondrites the most common exposure age of ~8 M.y. [e.g., 6] results in Fig. 1 including several unshocked/undarkened meteorites with a few associated variably darkened examples of this CRE age. Given a pulse of released meteoroids, the inferred subsequent collisional history for some can result only in formation of a vertical line on a plot like Fig. 1 which results in lower statistical significance than if 40 different meteoroids had been released at 40 different times.

Darkening During Exposure Scenario: Fig. 2 schematically illustrates the scenario of meteoroids being shock darkened during their exposure (after being excavated from their parent body). In the case of H

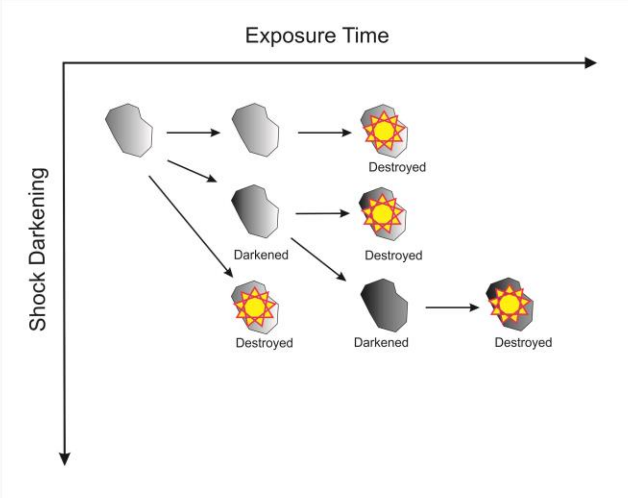

Figure 2: Schematic illustration of collision history during exposure leading to shock darkening and/or disruption of meteoroids. Note that the longer a meteoroid survives collisions the likelier it is to have been darkened from those collisions.

chondrites, the mean exposure age is approximately 17 M.y. during which time ~15 collisions with weaker objects are expected [3] (as noted above); CRE ages are highly variable reflecting the stochastic nature of collisions in the exposure environment of solar orbit. Note that for the 40 H chondrites plotted the maximum exposure age is 77 M.y., but most are <40 M.y. After ejection from parent bodies meteoroids may be destroyed if they experience a sufficiently strong collision, but in this scenario some meteoroids experience collisions sufficient to shock them enough to result in darkening from mobilizing metal and sulfide phases. This may be a repeated process although eventually the collisional environment will reduce the meteoroids to dust, if they do not impact another large body such as a planet or the Sun. Note that this scenario probably requires the existence of shock levels sufficient to induce darkening, but below levels that would reset the CRE exposure "clocks" (or that would mechanically disrupt the meteoroids). In theory, the meteoroids could be darkened by shocks and have their CRE "clocks" reset in the same collision thus obscuring their true exposure age, but the preservation of the ~8 M.y. CRE exposure peak in both undarkened/unshocked and darkened/shocked meteorites indicates that, at least in that group, if shock is responsible for the darkening, it has not reset their CRE "clocks".

Conclusions: A possible correlation between CRE age and darkening levels of forty H chondrites suggests that the observed darkening resulted from collision shocks during the meteoroids' exposure in solar orbits rather than on the meteoroids' parent bodies.

Acknowledgements: M. Hons also contributed some darkness observations. We gratefully acknowledge access to meteorite collections at the Center for Meteorite Studies, Arizona State University, and the Natural History Museum, Kensington, London, and support from R. Hines and M. Grady, respectively.

References: [1] Eugster O. et al. (2006) *in Meteorites and the Early Solar System II*, eds. D.S. Lauretta and H.Y. McSween, U of Az. Press, pp. 829-851. [2] Ceplecha Z. and McCrosky R.E. (1976) *JGR, 81*, 6257-6275. [3] Ibrahim M.I. and Hildebrand A.R. (2012) *ACM* Abs. #6376 [4] Britt D.T. and Pieters C.M. (1991) *Meteoritics & Planet. Sci., 26,* 279-285 [5] Britt D.T. and Pieters C.M. (1994) *GCA, 58,* 3905–3919. [6] Graf T. and Marti K. (1995) *JGR 100,* 21247-21263.