METAMORPHISM AND IMPACTS ON THE PARENT ASTEROID OF H CHONDRITES. Edward R. D. Scott[1], Douglas Mandell[2], Jijin Yang[2], Joseph I. Goldstein[2], Tatiana Krot[1], and G. Jeffrey Taylor[1], [1]Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, Honolulu, Hawaii 96822, USA, [2]Dept of Mechanical and Industrial Engineering, University of Massachusetts, Amherst, MA 01003, USA. E-mail: escott@hawaii.edu

Introduction: The thermal and impact histories of ordinary chondrites provide important clues to the formation and evolution of asteroids and their impact histories. Trieloff et al. [1] inferred from their Ar-Ar and Pb-Pb ages and Pu fission track data for 9 H4-6 chondrites that the H chondrite parent body accreted quickly, was heated by ^{26}Al (in agreement with other radiometric studies [2]), and was then undisturbed by impacts so it cooled with an onion-shell structure. The least metamorphosed H4 chondrites cooled to 500 K on the exterior in ~5 Myr and the most metamorphosed H6 chondrites in the central region cooled to 500 K in 100 Myr.

Cooling rates at ~750-900 K determined for ordinary chondrites by comparing observed and calculated Ni zoning profiles across taenite grains do not show any correlation with petrologic type in the H, L, or LL chondrites [3], though there is a weak inverse correlation for H chondrites if two H3 chondrites are neglected. Trieloff et al. [1] inferred that the metallographic cooling rates of H chondrites recorded cooling after the onion-shell structure was disturbed by late-stage impact heating. Evidence for post-metamorphic disruption comes from H chondrite fragmental breccias that contain clasts with diverse petrologic types and cooling rates [3, 4]. However, metallographic cooling rates for unshocked or mildly shocked meteorites are fairly well correlated with Ar-Ar ages suggesting that the metallographic cooling rates for these meteorites were not reset [5]. Either the sample suite of Trieloff et al. was too small and unrepresentative, as other Ar-Ar ages suggest [6], or metallographic cooling rates of ordinary chondrites are flawed.

Settling the question of an undisturbed onion-shell or a disrupted onion-shell body for the H chondrites is important because undisturbed cooling is difficult to reconcile with the presence of an Earth mass of planetary embryos and planetesimals in the asteroid belt [7].

As part of a larger study of H chondrite metamorphism in silicate and metal phases, we have determined the sizes of high-Ni particles in cloudy taenite in H chondrites. These particles formed by spinodal decomposition of taenite and coarsened by diffusion-controlled growth. Their size therefore reflects the cooling rate at 600-700 K and is inversely correlated with the metallographic cooling rates in 5 groups of irons and stony-iron meteorites [8-10]. Cloudy taenite studies also provide a robust check on possible effects of impact heating on taenite composition as cloudy taenite is modified by nanometer-scale Fe-Ni diffusion whereas micrometer-scale diffusion is required to change the central composition of taenite grains [11].

Cloudy Taenite Measurements: Polished and etched sections of 12 selected H3-6 chondrites were prepared for study in the scanning electron microscope (SEM). All were shock stage S1 or S2 [12] except for Ashmore and Kesen, both S3 chondrites that showed normal cloudy taenite with no evidence for shock heating. Sizes of high-Ni particles in cloudy taenite at the boundary with the tetrataenite rim were measured following the procedures of Yang et al. [13].

Results: Two H4 chondrites, Beaver Creek and Forest Vale, show no cloudy taenite or shock heating in the SEM indicating that they cooled at >5000 K/Myr, the fastest cooling rate of irons having cloudy taenite that could still be observed using the SEM [8]. The other ten H3-6 chondrites contained cloudy taenite with particle sizes between 70 and 125 nm. Mean particle sizes show an excellent correlation between cloudy taenite high-Ni particle size and petrologic type (Fig. 1).

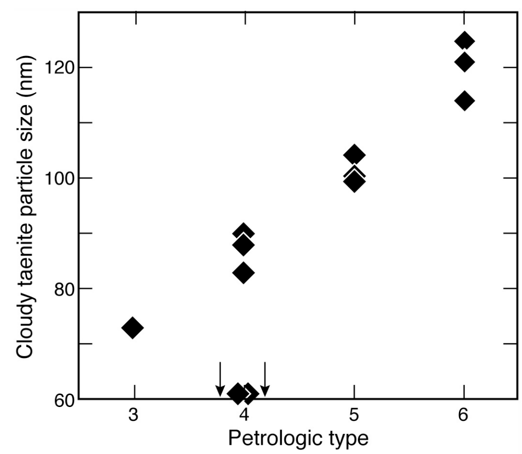

Fig. 1. Cloudy taenite particle sizes in 12 H3-6 chondrites as a function of petrologic type.

Discussion: Our cloudy taenite data for 10 H3-6 chondrites are consistent with the metallographic cooling rates determined from central Ni concentrations in taenite grains [3, 14, 15] (Fig. 2). Except for Bath, these H chondrite data lie close to the trend line defined by iron meteorite groups IIIAB, IVA, IVB, mesosiderites and pallasites using Widmanstätten taenite plates [8-10], although the chondrite metallographic cooling rates may be biased towards higher values by a factor ≤1.5. The two H4 chondrites without cloudy taenite have metallographic cooling rates of 5000 and >1000 K/Myr

[3, 14] consistent with rates inferred above from the absence of cloudy taenite. Bath appears to have cooled much slower at 600-700 K than at ~750-900 K.

Published metallographic cooling rates for unbrecciated shock stage S1 and S2 H3-6 chondrites (Fig. 3) show the same general features as the cooling rates that can be inferred from our cloudy taenite studies. Both studies show a systematic trend of decreasing cooling rate with increasing petrologic type, broadly consistent with the onion-shell model and the data of Trieloff et al. [1]. However, it is clear that cooling rates of the H4 chondrites are bimodally distributed: Beaver Creek, Forest Vale and Ste. Marguerite cooled rapidly through 750-900 K at >1000 K/Myr, whereas Conquista, Bath, Kesen, Menow, and Sena cooled at 20-80 K/Myr. Since the slower cooling rates are comparable to that of the H3 Dhajala (Figs 1, 3), we suggest that Beaver Creek and the other fast cooled H4 chondrites did not cool in situ but may have cooled rapidly on the surface of the H chondrite body after they were excavated from depth by impact (Fig. 4).

Conclusions: Our cloudy taenite data show that: a) metallographic cooling rates provide reliable constraints on H chondrite thermal histories, 2) Cooling rates at 600-900 K are largely correlated with petrologic type: H6 < H5 <H4, as in an onion shell body; 3) the rapidly cooled H4 chondrites including Ste Marguerite and Forest Vale did not cool in situ during metamorphism but were probably excavated by an impact a few Myr after the body accreted. This impact may have formed the Portales Valley breccia and shocked other seemingly unshocked S1 and S2 chondrites [16].

References: [1] Trieloff M. et al. (2003) *Nature* **422,** 502-506. [2] Kleine T. et al., (2008) *Earth Planet. Sci. Lett.* **270***,* 106-118. [3] Taylor G. J. et al. (1987) *Icarus* **69**, 1-13. [4] Williams C. V. et al. (2000) *Chemie der Erde* **59**, 287-305. [5] Haack H. et al. (1996) *Geochim. Cosmochim. Acta* **60**, 2609-2619. [6] Schwarz W. H. et al. (2006) *Meteor. Planet. Sci.* **41**, A161. [7] Chambers J. E. and Wetherill G.W. (2001) *Meteorit. Planet. Sci.* **36**, 381–399. [8] Yang J. et al. (2008) *Geochim. Cosmochim. Acta* **72**, 3043-3061. [9] Goldstein J. I. et al. (2009) *Chemie der Erde* **69**, 293-325. [10] Yang J. et al. (2009) *Geochim. Cosmochim. Acta* submitted. [11] Goldstein J. I. (2009) *Meteorit. Planet. Sci.* **44**, 343-358. [12] Stöffler D. et al. (1991) *Geochim. Cosmochim. Acta* **55***, 3*845-3867. [13] Yang C.-W. et al. (1997) *Meteorit. Planet. Sci*. **32**, 423-429. [14] Willis J. and Goldstein J. I. (1981) Proc. 12th LPSC, 1135; (1983) Proc. 14th LPSC, B287. [15] Lipschutz M. E. et al. (1989) In *Asteroids II* (eds Binzel R. P. et al.) 740-777. [16] Rubin A. E. (2004) *Geochim. Cosmochim. Acta* **68**, 673-689.

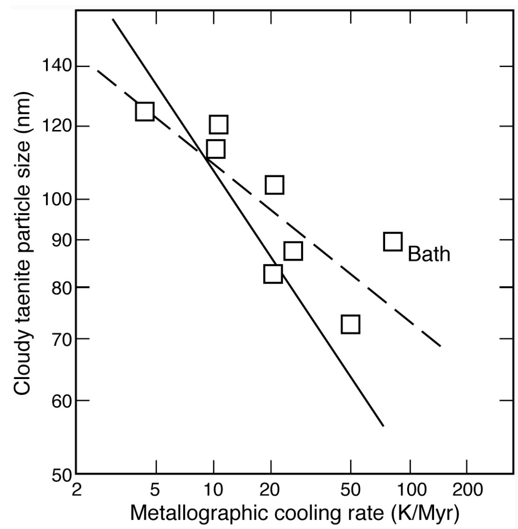

Fig. 2. Cloudy taenite particle size vs. metallographic cooling rate [3, 14] for 8 H3-6 chondrites: dashed line, H chondrites; solid line, iron and stony iron meteorites [8, 10].

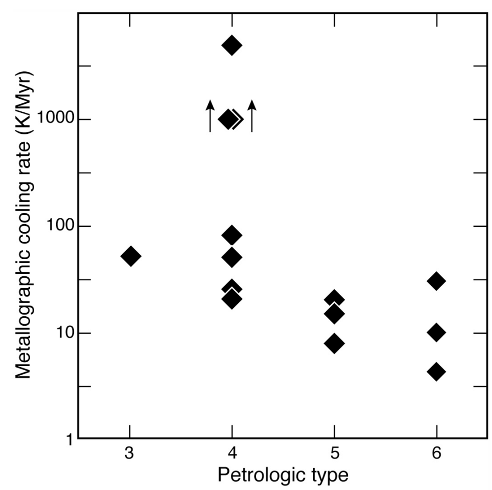

Fig. 3. Metallographic cooling rates vs. petrologic type for 14 shock stage S1-2 H3-6 chondrites [3, 13, 14].

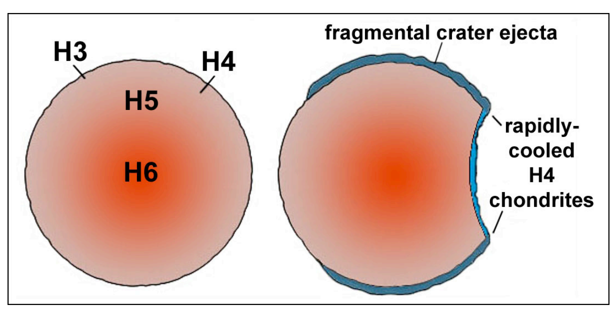

Fig. 4. Hypothetical impact modification of H chondrite onion-shell body.