POSTSHOCK ANNEALING IN H4 CHONDRITES: IMPLICATIONS FOR THE IMPACT HISTORY OF THE PARENT BODY. S. P. Goudy[1], M. Telus[1], and B. Chapman[2], [1]University of California Santa Cruz (Earth and Planetary Sciences, Santa Cruz, CA 95064, sgoudy@ucsc.edu, mtelus@ucsc.edu), [2]Arizona State University (ASU School of Earth and Space Exploration, Tempe, AZ 85287, blchapma@asu.edu).

Introduction: The early history of the H chondrite parent body has been the subject of much debate in recent decades, with some authors (e.g. [1]) proposing a development as an undisturbed onion shell body, others (e.g. [2]) arguing for a history of collisional disruption and re-accretion as a rubble pile, and more (e.g. [3]) contending that the body could have merely experienced large excavating, but not necessarily disruptive, impacts. Cases for all of these scenarios have largely been founded on the basis of diffusive geothermometers and radiogenic dating. Here we use electron backscatter signatures from H4 chondrites to infer the early impact history of the H chondrite parent body, with the goal of testing these historical models with a novel approach.

Samples: We analyzed thin sections of H4 chondrites Beaver Creek, Forest Vale, Quenggouk, Sena, and Ste. Marguerite, which represent a spread of previously determined cooling rates, ranging from 10^4 K/Ma to 10 K/Ma near 500°C [1,4,5]. The fast-cooled samples, Beaver Creek, Forest Vale, and Ste. Marguerite, have previously been interpreted to have cooled rapidly due to impact excavation, whereas the slow-cooled samples Quenggouk and Sena were interpreted to have cooled undisturbed [1,4,5]. Given these histories, it would be expected that the fast-cooled samples should show evidence of synmetamorphic shock without annealing, and if the slow-cooled samples have been shocked, they should show signatures of unannealed post-metamorphic shock or annealed synmetamorphic shock.

Methods: The samples were examined using the electron backscatter diffraction (EBSD) methods of Ruzicka and Hugo [6] to determine inferred annealing and codeformational temperature signatures from olivine grains. Grain orientation spread (GOS) is a measure of grain deformation. The skew (mean GOS/median GOS) of GOS measurements in a population of olivine grains is an indicator of annealing, for it increases during annealing as free dislocations are removed from grains or congregate into subgrain boundaries [6]. $f_{<010>} + f_{<001>}$ serves as a codeformational temperature indicator, as it is the fraction of olivine crystal rotation axes associated with high temperature (>800°C) a-slip dislocations (**b**=[100]) [6].

Step sizes used were 2 µm or 4 µm, with a beam current of 10 nA, and an accelerating voltage of 20 kV. Data were collected on a Thermoscientific Apreo scanning electron microscope, and the EBSD data were processed using Channel 5 software and R.

Results: Inferred annealing parameters and deformational temperature parameters for the samples are shown in Figure 1, along with reference data ranges from previous studies [6,7]. Specific data are in Table 1. All samples display broadly similar results, with elevated GOS skews and large proportions of high temperature a-slip dislocations, and are roughly consistent with reference ranges for synmetamorphic shock with postshock annealing. Spread among the samples is much greater for $f_{<010>} + f_{<001>}$ than for GOS skew, with Ste. Marguerite having a notably higher $f_{<010>} + f_{<001>}$ than all other samples, and Sena being noticeably lower.

Discussion: All samples studied have EBSD signatures consistent with reference samples that were sub-

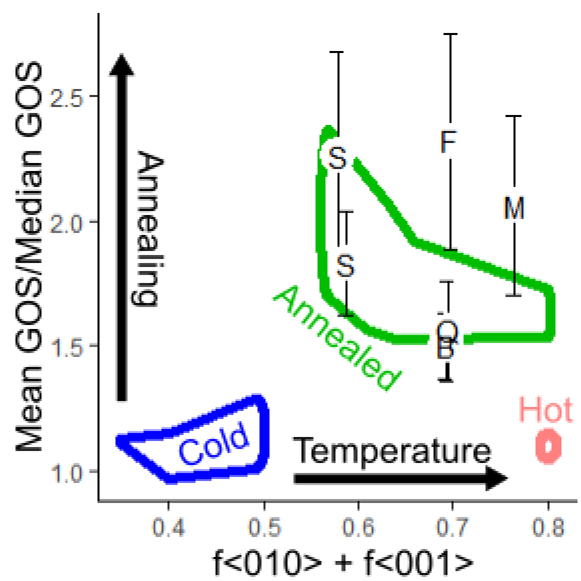

Figure 1. Inferred Annealing and Deformational Temperature Plot. Green perimeter is reference data for samples shocked while hot and subsequently annealed. Blue perimeter is reference data for samples shocked while cold and not annealed [6,7]. Red perimeter is reference data for a sample that was shocked while hot and not annealed [7]. B is Beaver Creek, F is Forest Vale, M is Ste. Marguerite, Q is Quenggouk, and S is Sena. Mean GOS/Median GOS is the inferred annealing parameter, and $f_{<010>} + f_{<001>}$ is the inferred deformational temperature parameter [6].

Table 1. Annealing and Temperature Parameters[a].

Sample (Step Size in μm)	**GOS Skew**	$f_{<010>} + f_{<001>}$
Beaver Creek (4)	1.50 ± 0.13	0.692 ± 0.003
Forest Vale (2)	2.32 ± 0.43	0.698 ± 0.003
Quenggouk (2)	1.56 ± 0.20	0.695 ± 0.002
Sena (4)[b]	1.83 ± 0.21	0.588 ± 0.009
Sena (2)[b]	2.26 ± 0.42	0.579 ± 0.005
Ste. Marguerite (2)	2.06 ± 0.36	0.765 ± 0.002

[a]Ranges are 95% propagated standard errors. [b]Two maps of the same Sena sample were collected at different step sizes.

ject to impact shock while hot due to thermal metamorphism, and which were able to anneal their shock deformation after impact through extended cooling, whether by burial after excavation or a lack of excavation. This is intriguing because these samples have varying thermal histories inferred from thermochronometers and radiogenic dating work.

Beaver Creek, Forest Vale, and Ste. Marguerite have rapid cooling rates on the order 10^4 K/Ma around 500°C, whereas Quenggouk and Sena have slow cooling rates on the order of 10 K/Ma at the same temperature [1,4,5]. The fast-cooled samples have been interpreted to have been excavated while the H parent body was young and metamorphically hot, whether by large impacts or planetesimal disruption, to explain their rapid cooling. Such an early excavation is supported by evidence of live ^{26}Al being present in them during their rapid cooling [8].

Naïvely, it should be expected that only the slow-cooled samples should have evidence of postshock annealing and that the fast-cooled samples should not, if only a single early impact had been experienced by each sample. The slow-cooled ones, not being excavated, would remain at high temperature for an extended period. This would facilitate annealing. The fast-cooled samples would have cooled too quickly to allow for annealing.

For a fast-cooled sample to bear evidence of postshock annealing and rapid cooling after excavation requires a history of at least two early impact events. The annealed shock signature of these meteorites could not have resulted from their excavating impact(s). Based on the dislocation diffusion equation of Goetze and Kohlstedt [9] and grain sizes on a 10-100 μm scale, annealing these samples at ≈800-1000°C would require 10-100 Ma, which is incompatible with such rapid cooling. The simplest plausible scenario to explain both observations requires two impacts, wherein the first is recorded by EBSD and the second by conventional techniques. The first shocked these samples, and either did not excavate them or allowed them to cool under a debris blanket, allowing annealing to occur in either case, perhaps aided by shock-induced heating [10]. After annealing, a second impact would have excavated these samples, allowing them to cool quickly on the surface. These secondary impact(s) would have been smaller impact(s), such as to be consistent with the low S1-S2 shock grades of these samples and to not overprint the deformational signal of the preceding impacts [4,10].

The double-impact history of the fast-cooled samples, and the history of synmetamorphic shock and postshock annealing found in the slow-cooled samples as well as H6 meteorites Kernouvé and Portales Valley [6] implies a history of multiple major impacts occurring to the H parent body co-occurrent with its thermal metamorphism. This is consistent with the models of an early H parent body with significant impact excavation or impact disruption.

Conclusions: All of our H4 samples, whether they have previously inferred histories of undisturbed slow cooling or excavation-related fast cooling, have evidence for shock metamorphism during thermal metamorphism with subsequent annealing at elevated temperatures, as determined from EBSD analyses. These shock event(s) that had their microscale deformations annealed occurred prior to the impact(s) that excavated the fast-cooled samples Beaver Creek, Forest Vale, and Ste. Marguerite, all of which must have been excavated while ^{26}Al was still live in these rocks. This indicates that the H chondrite parent body was subject to two or more major impacts in its early history, supporting models of an impact-battered onion shell body or collisional disruption.

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