UNSCRAMBLING THE HISTORY OF ENSTATITE CHONDRITES K.N. Hill[1], E. S. Bullock[2], C.M. Corrigan[2], and T.J. McCoy[2]. [1] Lock Haven University, 401 N. Fairview Street, Lock Haven, Pennsylvania 17745. [2]National Museum of Natural History, Smithsonian Institution, Washington, D.C, 20560 USA. E-mail: BullockE@si.edu.

Introduction: Enstatite chondrites contain a suite of unusual sulfide minerals; a product of their formation under highly reducing conditions in the innermost region of the solar nebula [e.g. 1-3]. These highly reducing conditions resulted in the formation of a suite of unusual metal and sulfide grains. The enstatite chondrite parent body/ies experienced varying degrees of thermal metamorphism and impact melting [4], which modified the original assemblages. Previously, we have presented results from an EH3 chondrite that contains a characteristic mineralogical indicator of impact melting and rapid cooling: keilite in the EH3 chondrite KLE 98300 [4]. Subsequently, we also expanded the study to include coexisting sulfides in other EH3 chondrites that give a clearer overview of the processes that have affected the enstatite chondrite parent body/bodies [5].

Here, we further expand this study to include newly-obtained data from additional enstatite chondrites, including examples of EH and EL chondrites from Type 3-5.

Analytical techniques: Thin sections were initially studied in reflected light using a petrographic microscope. They were then studied using an FEI Nova NanoSEM 600 at the Smithsonian Institution, using EDS detectors and the Thermo Scientific Noran System Six software. Sections were imaged in back-scatter electron mode, and semi-quantitative chemical analyses obtained. Finally, regions of interest underwent full-element X-ray mapping, in order to identify zoning within sulfide and metal grains.

Results and Discussion: All of the additional sections came from the Antarctic Meteorite Collection at the National Museum of Natural History. We can use the presence or absence of various sulfides in these meteorites to discriminate formation via nebular condensation, subsequent parent body metamorphism, impacts or post-impact cooling on the parent body.

Impact melting produces the most immediately recognizable texture in both the EH3 and EL3 chondrites: euhedral enstatite laths, surrounded by metal and sulfide (Figures 1, 2). In order to determine the cooling rate following impact, we need to determine the chemistry of the sulfides present.

The presence of keilite, ([Fe>0.5,Mg<0.5]S) in both EH3 and EL3 chondrites [4-6] constrains the equilibrium temperature [4], and points to impact melting followed by rapid cooling [7]. Keilite forms by reaction between troilite (FeS) and niningerite/alabandite ((Mg,Mn)S), and requires rapid cooling in order to prevent decomposition back to those original components. Keilite was identified in only one EH3 chondrite, KLE 98300, and in the EH4 chondrite LAP 031220.

In contrast, the presence of daubréelite ($FeCr_2S_4$) exsolution lamellae within troilite suggests slow cooling following impact melting, in order to allow the lamellae to form (figure 3). The majority of the enstatite chondrites included in this study contained troilite with daubréelite lamellae, indicating that slow cooling is more prevalent than rapid cooling.

Therefore, we would not expect to find keilite and daubréelite-bearing troilite within the same sample. Indeed, the two keilite-bearing EH chondrites both lack daubréelite, instead containing troilite with up to 4.5 wt.% Cr, consistent with rapid cooling and lack of exsolution. Conversely, in enstatite chondrites that host daubreelite-bearing troilite, we find alabandite or niningerite, but no keilite.

The sulfide djerfisherite is another mineral that may also provide clues as to the impact history of enstatite chondrites. In some cases, djerfisherite is suggested to be a primary nebular condensate [8], but other occurrences are thought to form by reaction between troilite and K-bearing silicates such as roedderite [9], possibly as a result of impact melting. We observe djerfisherite and daubréelite occurring in consort with other indicators of impact melting, including enstatite embaying metal-sulfide assemblages, in the St. Mark's EH5 chondrite. Future analyses of the composition and morphology of djerfisherite, combined with a closer examination of its mineral associations, will help to clarify the role of impact melting in the formation of part of the djerfisherite population.

Not all enstatite chondrites show petrographic evidence for impact melting. Some, such as EET 87746, contain large, complex sulfide assemblages, but these are distinctive in that they are not associated with enstatite laths (figure 4). In EET 87746, we find niningerite occurring in association with kamacite, schreibersite, and daubréelite-bearing troilite.

Many enstatite chondrites show evidence of impact melting, as suggested by a wide range of petrologic and mineralogical features. The suite of exotic sulfides – when studied as an assemblage – can provide unique insights into the physical-thermal history experienced by the enstatite chondrites [7]. The study of non-impact melted enstatite chondrites can provide us with another avenue for exploring the history of the enstatite chondrite parent body, and gives us a chance to study sulfide grains that may have condensed directly from the nebula gas.

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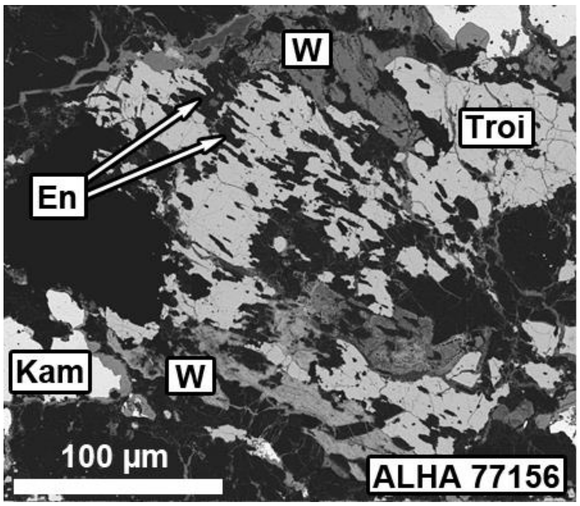

Figure 1. ALHA 77156, an example of an EH3 chondrite that has undergone impact melting, resulting in enstatite laths surrounded by metal. In this back-scatter electron image, the darkest grey phase (En) is enstatite, dark grey (W) is weathering product, light grey (Troi) is troilite, and the brightest phase (Kam) is kamacite.

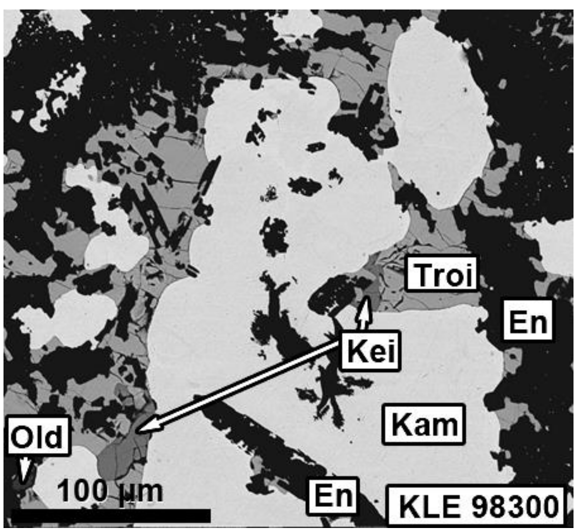

Figure 2. KLE 98300, an EH3 chondrite that again shows textural evidence of impact melting, followed by rapid cooling that did not allow troilite to exsolve daubréelite. Abbreviations as in figure 1, plus Old = oldhamite, Kei = keilite.

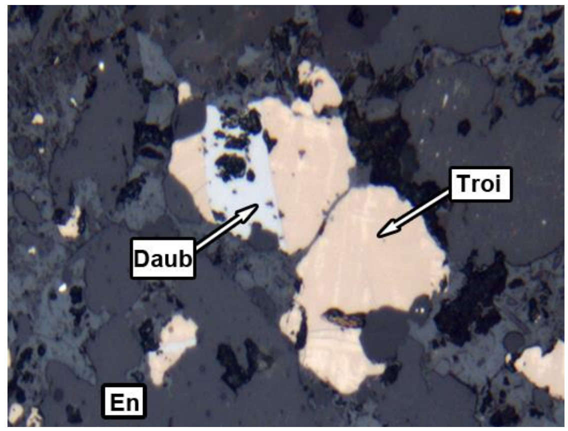

Figure 3. Reflected light image of troilite with daubréelite exsolution lamellae, indicative of slow cooling following impact melting on the enstatite chondrite parent body. Troi = troilite, Daub = daubréelite. Field of view is approx. 1mm.

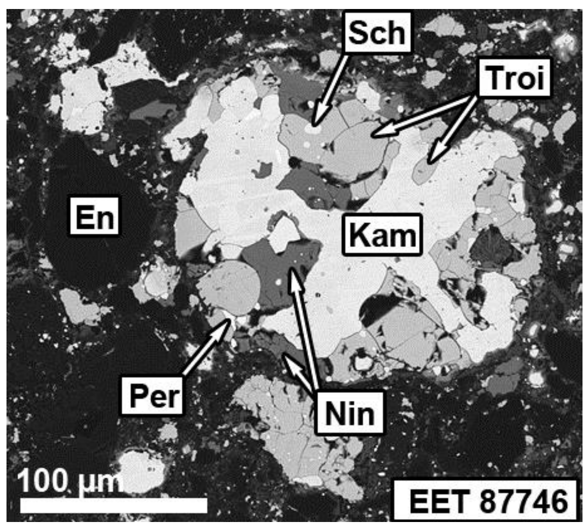

Figure 4. Sulfide assemblage in EET 87746, an EH3 chondrite that does not show petrographic evidence for having undergone impact melting. Abbreviations as previously, plus Per = perryite, Nin = niningerite, Sch = schreibersite.