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Metal size distributions in EH and EL chondrites

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[1] EL chondrites exhibit larger average metal grain sizes than EH chondrites, a difference attributed by *Easton* [1983] to metamorphic coarsening, as most EL chondrites are equilibrated, and most EH chondrites are unequilibrated. In this paper, we present metal grain size data for three unequilbrated EL3 chondrites (PCA 91020; ALH 85119; MAC 88180) , and three EH3 chondrites (ALH 84170; PCA 91085; PCA 91238). We find that EL3 chondrites have larger average metal grain sizes than EH3 chondrites, and that grain sizes of the unequilibrated enstatite chondrites are similar to those of equilibrated chondrites of the same class. We thus interpret the metal size distributions of enstatite chondrites as primarily reflecting their pre-metamorphic distributions. Shock processing appears to have had only minor influence on metal grain size distributions in these meteorites. *INDEX TERMS:* 6205 Planetology: Solar System Objects: Asteroids and meteoroids; 6215 Planetology: Solar System Objects: Extraterrestrial materials; 6240 Planetology: Solar System Objects: Meteorites and tektites. **Citation:** Schneider, D. M., P. H. Benoit, A. Kracher, and D. W. G. Sears, Metal size distributions in EH and EL chondrites, *Geophys. Res. Lett.*, *30*(8), 1420, doi:10.1029/2002GL016672, 2003.

1. Introduction

[2] Most chondrites contain three major phases, chondrules, sulfide grains, and metal grains [e.g., *Urey and Craig*, 1953]. They also have varying amounts of matrix, a mixture of fragments of chondrules and fine-grained phases with a separate origin and evolution prior to inclusion in the meteorite. Chondrules have been the subject of extensive studies, including attempts to delineate their sizes and, in some cases, their degree of sphericity [e.g., *Hughes*, 1978; *King and King*, 1979; *Rubin*, 1989; *Rubin and Keil*, 1984; *Rubin and Grossman*, 1987; *Eisenhour*, 1996]. The goal of these studies has been to place constraints on the chondrule formation environment or to investigate possible sorting mechanisms for chondrules prior to their emplacement and lithification. Metal and sulfide grains have not been studied as extensively as chondrules, reflecting their relatively small size in chondrites, and their limited textural variety [e.g., *Dodd*, 1976; *Kuebler et al.*, 1999]. Most studies of chondrite metal have focused on compositional profiles, the shape of which reflect metamorphic cooling rates or impact processing [e.g., *Wood*, 1967, 1979; *Holland-Duffield et al.*, 1991; *Bennett and McSween*, 1996]. In addition, metal grains are subject to annealing and alteration of grain sizes at low metamorphic temperatures, relative to chondrules [*Wood*, 1967; *Reuter et al.*, 1989].

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[3] Despite the limitations of studies of metal and sulfide grains, their size populations are an important parameter in the evaluation of possible formation/sorting mechanisms [e.g., *Kuebler et al.*, 1999]. Some models postulate that metal and sulfide grains formed in the same or similar environment as chondrules, and thus should have experienced the same sorting processes [e.g., *Huang et al.*, 1996]. Metal and sulfide size data for three ordinary chondrites, compared to chondrule size data, support the concept of aerodynamic sorting rather than sorting within the nebula [*Kuebler et al.*, 1999].

[4] In this paper, we present data on the metal size population in the enstatite chondrites. The enstatite chondrites cover a full range of petrologic types, and thus a range of thermal metmorphism. Previous work [*Easton*, 1983] focused on metal grain sizes in EH 3, 4, and 5 and EL6 meteorites, which were the only samples available at the time. These data indicated that metal grains in EL6 chondrites tended to be larger than metal grains in EH chondrites, and *Easton* [1983] interpreted these data to reflect metal coarsening as a function of metamorphism (e.g., that EL chondrites probably had similar metal grains of similar size to EH chondrites prior to metamorphism and their metal grains grew due to diffusion of iron). In this study we present data on metal and sulfide grains in the least metamorphosed EL (EL3) chondrites and compare them to the least metamorphosed EH3 chondrites, as an assessment of metal coarsening during metamorphism in this group.

2. Methods

[5] We studied six meteorites, namely three EL3 chondrites [Allan Hills (ALH) 85119, MacAlpine Hills (MAC) 88180, and Pecora Escarpment (PCA) 91020] and three EH3 chondrites [Allan Hills (ALH) 84170, Pecora Escarpment (PCA) 91085, and Pecora Escarpment (PCA) 91238]. We have previously presented chondrule diameter data for these meteorites [*Schneider et al.*, 2002]. Metal grains were examined using a reflected light microscope, each grain being identified as metal or sulfide; grains containing both were not used. Metal grains clearly associated with chondrules and chondrule rims were not used; most grains were rounded and tended to be elongated, but with no preferred orientation within a section. The longest axis and its perpendicular of each grain was measured using an calibrated ocular, and the data averaged to obtain an average diameter.

[6] We do not attempt to correct grain sizes to account for the effects of sectioning [e.g., *Eisenhour*, 1996]. Our purpose in this study is a comparison of relative grain sizes, and thus such corrections are not essential and could distort

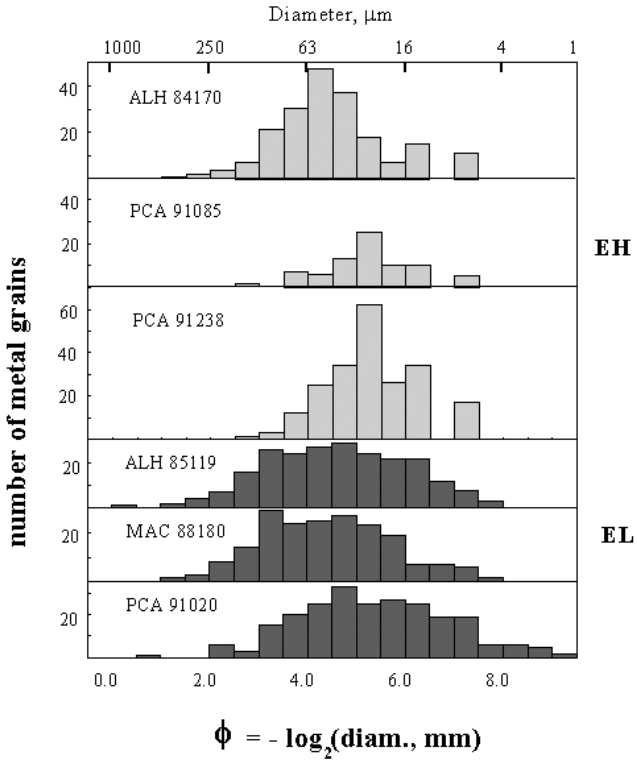

Figure 1. Size distribution of metal grains in type 3 EH and EL chondrites. The average grain size tends to be larger in the EL chondrites as compared to the EH chondrites.

the dataset, depending on the assumptions made in the correction. In addition, it is not necessary to correct for optical depth for size estimates on opaque metal grains.

3. Results

[7] The issue of pairing, or the fragmentation of meteorites during terrestrial history or atmospheric passage, is a concern whenever an attempt is made to use meteorite finds for comparison of data distributions. The identification of paired fragments of finds involves delineation of petrographic similarities as well as similarities in other properties, such as cosmic ray exposure ages or natural thermoluminescence levels [*Scott*, 1989; *Benoit et al.*, 2000]. Additional considerations are the rarity of the type of meteorite and proximity; two enstatite chondrites found in close proximity are more likely to be paired than two ordinary chondrites found far apart. For most of the specimens in the current study, pairing is not an issue because they different in major class (EH/EL) or they were found at widely separated sites in Antarctica. PCA 91085 PCA 91238, however, are both EH3, a relatively rare class, and were found at the same locale, and we cannot rule out their pairing based on presently available data.

[8] Histograms of the average diameter of all grains in our sections is given in Figure 1. In this plot, diameters are shown plotted in φ units, a common practice in sedimentalogy grain size studies, in which $\varphi = -\log_2$ (diameter, in millimeters). With the exception of ALH 84170, the metal grains in EH chondrites tend to be slightly smaller than metal grains in EL chondrites, the average grain diameter being 0.04 mm for EL chondrites, and 0.08 mm for EL chondrites (Table 1).

[9] We prepared a cumulative frequency plot for metal grains from each meteorite, showing the cumulative weight percent of grains as a function of φ. These plots are used in sedimentology as a statistical verification that a dataset exhibits a normal distribution as a function of φ [*Geer and Yancey*, 1938; *Rubin and Grossman*, 1987]. Statistically normal populations appear on these plots as straight lines. Deviations for linearity are typically interpreted as reflecting gain or loss of specific grain size ranges or reflect some process that produces a distribution not based on $\log_2$. These plots are not shown here, but the distributions for all the meteorites are approximately linear on these plots, except at the very smallest grain sizes. The deviation from linearity observed can be explained by the small number of grains (statistically) and decreased precision in the measurement of the smallest grains using the optical microscope.

[10] In Figure 2 we compare our data with the data for metal from other EH and EL chondrites collected by *Easton* [1983]; his data were presented as number of grains binned by their surface area in thin-section, requiring us to numerically convert our data. We estimated surface assuming circular grains with the average diameter of each grain. Our work shows that the differences noted by *Easton* [1983], with EL6 chondrites exhibiting a greater range of metal sizes, extending to larger grain sizes, than EH3-5 chondrites, is also observed when comparison is made between EL3 and EH3 chondrites.

4. Discussion

[11] Figures 1 and 2 illustrate the primary observations of our study. The tendency for EL metal grains to be larger than EH metal grains noted by *Easton* [1983] continues to hold even when metal grains for EL3 chondrites are considered. The main conclusion is thus that difference in metal grains sizes between EH and EL chondrites is not a result of metamorphic coarsening, but must instead reflect the original grain size distributions, unlike the case for ordinary chondrites [*Rubin et al.*, 2001].

[12] Our study does exhibit a few differences from previous work, showing that the metal grain populations of the enstatite chondrites are somewhat more diverse than previously thought. ALH 84170 (EH3) has a metal grain size distribution dominated by small grains, typical of EH chondrites, but differs from the other EH chondrites in having a significant number of larger grains (Figure 1). Evidence for metamorphic coarsening in the EL chondrites

Table 1.

	Metal Grains		
Sample	#	average diameter, mm	average diameter, ϕ
ALH 84170	200	0.06 ± 0.05	4.5 ± 1.1
PCA 91085	77	0.03 ± 0.02	5.2 ± 0.9
PCA 91238	214	0.03 ± 0.02	5.3 ± 0.9
EH3 average		**0.04 ± 0.04**	**4.9 ± 1.1**
ALH 85119	227	0.09 ± 0.11	4.2 ± 1.5
MAC 88180	196	0.09 ± 0.09	4.0 ± 1.4
PCA 91020	237	0.05 ± 0.07	5.1 ± 1.6
EL3 average		**0.08 ± 0.09**	**4.5 ± 1.5**

is confined to a few unequilibrated meteorites (PCA 91020 and ALH 85119), which exhibit a significant number of small grains compared with EL6 chondrites (Figure 2), but even these meteorites exhibit typical metal grains with sizes similar to those in EL6 chondrites.

[13] Shock is another mechanism for modyfing the shapes and sizes of metal grains after accretion [e.g., *Stöffler et al.*, 1991]. Depending on the local stress regime, shock could result in dispersion of iron and nickel to fine grains along grain boundaries and fractures in silicate grains [e.g., *Rubin*, 1992] or could result in accumulation of iron and nickel to form larger grains or even veins. In general, unequilibrated EH and EL meteorites tend to be moderately to strongly shocked (S4–S5), equilibrated EH meteorites tend to also be moderately shocked (S3–S4), while EL6 meteorites tend to be weakly shocked (S2) [*Rubin et al.*, 1997]. In our data, we do not observe any significant difference in metal grain size between the moderately shocked EH3 and the weakly shocked EL6 chondrites (Figure 2). Within the unequilibrated enstatite chondrites, it is not clear whether differences in grain size distributions can be attributed to shock processing. ALH 84170 and PCA 91238 differ in average metal grains size (Figure 1), but are both moderately shocked (S4) [*Rubin et al.*, 1997]. In contrast, in the EL chondrites the meteorite with the smallest average grain size (PCA 91020) is also the most strongly shocked (S5), compared with the moderately shocked ALH 85119 (S4); possibly the grain size distribution in PCA 91020 reflects local stress mobilization of iron and nickel.

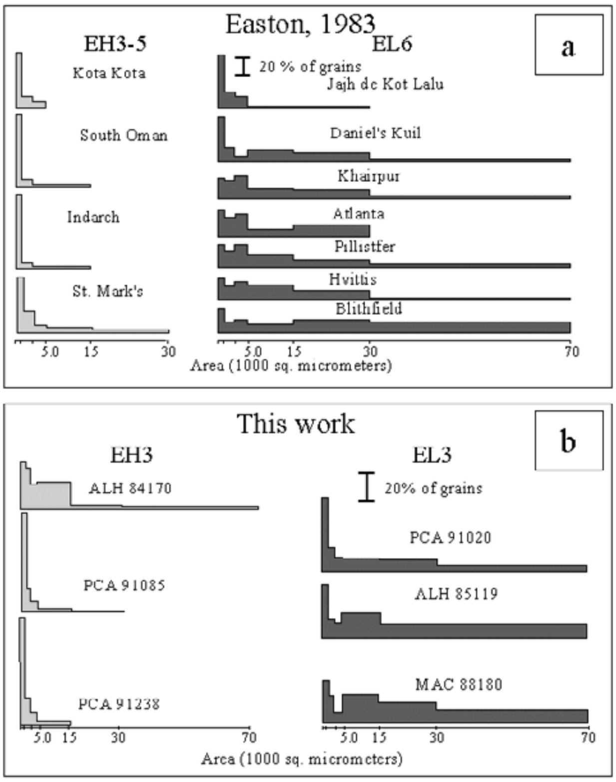

Figure 2. Histograms of metal sizes (by surface area) in enstatite chondrites. (a) EH metal compared to EL metal [from *Easton*, 1983]. (b) EH vs. EL metal in unmetamorphosed chondrites. The difference in metal grain sizes is still apparent in these chondrites, indicating that metal grain size is a primary effect.

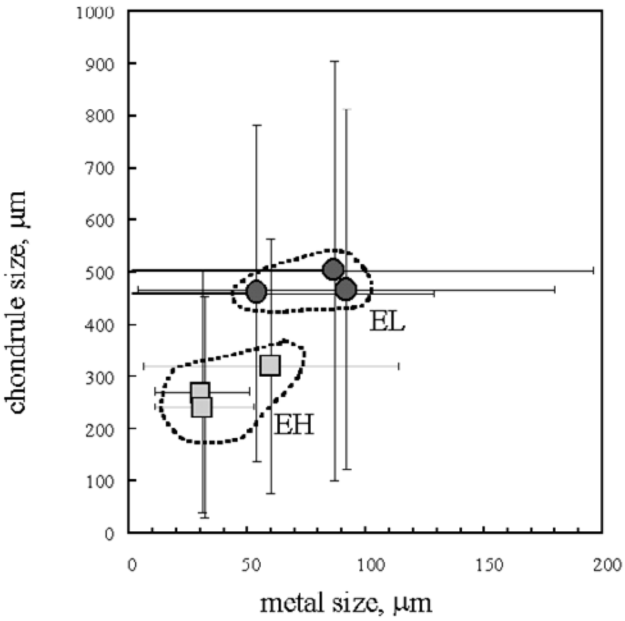

Figure 3. Comparison of metal and chondrule size distributions for unequlibrated EH and EL chondrites. There is a general trend of larger chondrules and metal grains in the EL chondrites compared to the EH chondrites. Shown are arithmetic mean and 1-sigma error bars. Chondrule data from *Schneider et al.* [2002].

[14] Additional evidence that the metal size distributions of EH and EL chondrites are a primary rather than secondary property is that metal size appears to be related to chondrule size (Figure 3); the unmodified axes emphasize the overlap in size distributions (Figure 1). Unlike metal, there is little or no evidence that chondrule sizes were altered by metamorphism; that metal size is related to chondrule size seems to indicate that either the size of chondrules and metal grains reflects a common limitation of their formation [e.g., *Clayton*, 1980], or that both were subjected to a common sorting process, either in the early solar nebula or on the surface of an early parent body [e.g., *Cameron*, 1995; *Akridge and Sears*, 1999].

5. Conclusions

[15] Examination of metal grain sizes in unequilibrated EL chondrites shows that there is a primary size difference between metal in EH and EL chondrites, in addition to any possible effect of metamorphic coarsening or shock processing in the EL chondrites. Thus, any model of silicate/metal fractionation in the enstatite chondrites must explain why EL chondrites have larger chondrules [e.g., *Rubin and Grossman*, 1987; *Schneider et al.*, 2002] and larger metal grains than EH chondrites.

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