CHONDRULE SIZE DISTRIBUTIONS: WHAT DOES IT MEAN?

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One primary characteristic of chondrite groups is their distinctive size-frequency chondrule distributions [1,2, 3]. The restricted ranges of chondrule size has been interpreted as indicative of a sorting mechanism, such as some form of aerodynamic drag [3, 4]. We re-examine this concept in light of the current database.

The database and its limitations. Chondrule sizes are typically determined by disaggregation or thin-section measurements. Sedimentalogy laboratory measurements are based almost entirely on disaggregation [5]. Samples of Bjurbole and Chainpur [6] and Qingzhen [1] have been disaggregated, and chondrule sizes estimated from photographs. Application is limited by the need to destroy significant quantities of material and the resistance of many meteorites to physical disaggregation. It is possible that disaggregation of meteorites results in undercounting of very small chondrules [1] and it is likely that some relatively friable chondrule types are underrepresented [7], and typically statistics are <100 chondrules per meteorite [6]. Another limitation to disaggregation studies of meteorites is that it is difficult to classify significant numbers of chondrules after separation [7].

Measurement of chondrule sizes in thin-section overcomes some of the limitations of disaggregation studies, being less subject to undercounting of friable or small chondrules [1,7], and easily applicable to a wide array of meteorites. Thin-section size measurements are not as a substitute for disaggregation techniques due to significant problems in estimating true grain sizes from random sections and measurement biases [5, 8]. Without extensive correction procedures, the data can only be compared to each other, the apparent means and standard deviations being inaccurate. Thin-section data size distributions are often based on very small numbers of chondrules, typically <100 [1,3], and are available for only ~50 meteorites (Fig. 1).

Major chemical groups tend to exhibit fairly uniform mean chondrule sizes, with ordinary chondrites having the largest and CM/CO having the lowest average size [Fig. 1; see also ref. 1]. With the exception of CV chondrites, major chondrite classes have similar ranges of standard deviation. Data for Apollo 14 crystalline spherules (CLS) [9] are shown for comparison.

Chondrule Size Distributions - Data Boundaries.

Chondrule Size Limits: Size distributions are the primary guide to the upper and lower limits to chondrule size in a given meteorite class, an estimate of boundaries being obtained from a fitted mathematical function. Chondrule size data from thin-section estimates tend to fit best to a Weibull distribution, in which there is a non-zero minimum chondrule size, typically about 10-20% of the mean size (40-150 μm) [8]; this may be an artifact of thin-section measurement [8], but disaggregation data also tends to support a minimum chondrule size [6, 10]. However, it is possible that both disaggregation and thin-section analysis undercount very small "microchondrules" (5-40 μm in diameter), which are found in the matrix or in rare clasts in at least a few chondrites, and "megachondrules" (>1 cm in diameter), which occur as fragments [11].

Multiple Chondrule Populations in Chondrites: It is often assumed that chondrules in a given meteorite are a uniform size-distribution population. However, there are significant differences in chondrule sizes and degree of sorting with textural and chemical class within individual meteorites. Rubin [12] noted significant differences in diameters of textural types in CO chondrites, with PO>PP and POP, PP>POP, and BO>porphyrtic chondrules. Textural groups tend to exibit the same degree of heterogeneity as meteorites in general. Chemical group A chondrules tend to be smaller than group B chondrules in highly unequilibrated ordinary chondrites [7]. In the CM chondrite Murchison, group B chondrules tend to be smaller than group A chondrules [13]. Chemical groups tend to exhibit less heterogeneity than chondrules as a whole.

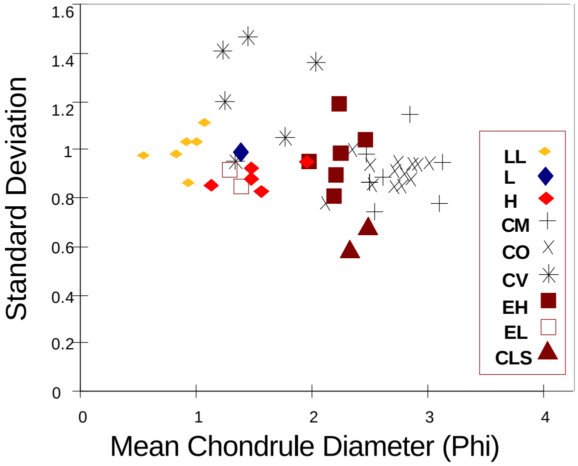

Fig. 1. Chondrule diameter and heterogeneity in major chondrite groups. Data from thin-section measurements, not corrected for sectioning effects. Data from [1,9]. Diameter is given in Phi units = - $\log_2$(diameter in mm)

Interpretations.

Sorting? While there are pronounced differences in chondrule sizes between major chondrite groups (Fig. 1), technically chondrules cannot be described as “sorted”. Sorting is reflected in decreasing heterogeneity, or standard deviation [e.g., 14]. Mean sizes can decrease or increase, depending on the sorting mechanism. Significant variation in heterogeneity is not observed among major chondrite groups (Fig. 1), and the only possible “sorting” trend would suggest that CV chondrites were subjected to less sorting than other chondrite groups, and thus their chondrules might be considered more “primitive”. Oxygen isotope data have been used to support the argument that chondrules in different chondrite groups are not from a single population [15].

The present database is insufficient to address the issue of subtle sorting within chondrite groups. However a sorting trend might be present in the ordinary chondrites (Fig. 1). L chondrites exhibit slightly greater heterogeneity in chondrule size than H chondrites. The present database may thus support limited “sorting” based on chondrule type/class, rather than on major chondrite grouping.

Post-formation Sorting vs. Preferred Formation Size. A restricted grain size distribution can be produced by transport sorting or grain formation processes. The former dominates discussion in traditional sedimentology, and is also often inferred for meteoritic chondrules. However, since there is no significant evidence for sorting across major groups , it is not necessary to argue that their size distributions are caused by size-sorting, either in a nebula or planetary setting, although it is possible that such sorting may account for some chondrule class size variation. An additional argument against nebular sorting is the presence of “chondrule-like” objects with fairly homogeneous size distributions (Fig. 1) in lunar samples [9]. Current knowledge on condensation and other nebular models do not allow prediction of chondrule size distributions, but it is possible to estimate melt droplet sizes from impact processing [16]. Using a typical asteroid-belt collisional velocity of 5 km/s [17] and various assumptions on target/projectile characteristics [16], we find that droplets of about chondrule size are produced by impactors <10 km in diameter . This process involves an active vaporization stream, small droplets being coagulated and larger droplets being disaggregated. Such an environment would be conducive to slower cooling rates than in free space, a feature common in chondrules [18]. The lack of newly formed chondrules in the meteorite collection might reflect the rarity of impacts involving relatively large asteroids in the modern asteroid belt.

Conclusions: (1) The chondrule size distribution database is unevenly developed and subject to possible biases due to sampling and measurement technique, (2) There is little evidence that chondrules are technically “sorted”, as there is little difference in size heterogeneity among major chondrite groups, (3) It is possible that there is some size-sorting within major chondrite groups (e.g., L - H chondrites), (4) Since there is little evidence for widespread transport sorting of chondrules, it can be argued that size distributions represent formational distributions, major chondrite group chondrules representing individual large scale events.

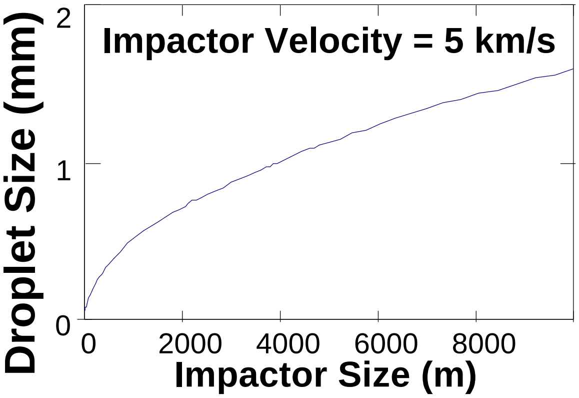

Fig. 2. Molten droplet size produced by impact, assuming volatization of impactor and part of target, and a relative velocity of 5 km/s. Calculations from Melosh and Vikery [16].

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