IMPLICATIONS OF TEXTURAL DISTRIBUTIONS FOR CHONDRULE FORMATION: A SURVEY OF CR CHONDRULES.
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Introduction. The chondrule formation mechanism remains elusive. A useful approach to help constrain the process is to compare and contrast key differences in chondrules among the different classes of pristine chondrites. These differences in style may require differences in intensity and number of the flash-melting events amd possible also in the composition of nebular solids.

Although chondrule characteristics vary widely within each chondrite group, one can define the style of each group based on the common “typical” chondrules. Among the properties that show easily recognized differences are (a) the chondrule diameter, (b) the amount of metal associated with chondrules and its siting, and (c) the distribution of FeO/(FeO+MgO) ratios Additional, less obvious, features are (d) evidence of secondary melting events (such as igneous rims and independent compound chondrules), (e) deviations from sphericity and (f) distribution of O-isotopic compositions.

The well preserved CR chondrules show several interesting textural features. The most comprehensive descriptions [1] show that high-FeO chondrules are rare, less than 1% of the total set, and that high-FeO chondrules are smaller, on average, than low-FeO chondrules. Typical olivine compositions are about Fa1.5. A crude histogram [2] shows that about 63% of the CR olivine to be in the range Fa0-2.

CR chondrule textures: We have observations on chondrules in the pristine and relatively unweathered Antarctic CR LAP02342,12. Its chondrules are remarkably intact. Based on our studies we make the following generalizations. As noted previously [1], most (≥95%) have low FeO contents corresponding to olivine fayalite contents ≤4 mol%. Among the large (>500 μm) chondrules, about half have roughly circular outlines, with either little metal in the interiors or with one or a few large (typically 50 to 200 μm) round grains; chondrule J5l is an example (Fig. 1). In contrast, many of the remaining low-FeO chondrules (a) are non-spherical (aspect ratios ≥1.2), (b) have lobate outer margins; and (c) are speckled with abundant squiggly (non-round) small (typically 20 to 50 μm) metal grains. Chondrule G2a (Fi.g 2) is an example.

Rubin and Wasson [3] described the lobate outer margins found in many CO3.0 low-FeO chondrules but did not discuss the metal characteristics of the round or lobate Y81020 chondrules; We find that they show the same metal styles found in CR chondrules; round chondrules are relatively metal free, the lobate chondrules are commonly speckled with small squiggly metal grains.

About half the round chondrules in LAP have thick igneous rims speckled with metal and have lobate outer margins; chondrule K3m (Fig. 3) is an example. The phase compositions and the sizes and shapes of metal grains appear to be essentially the same in these rims as in the lobate chondrules: we infer that they are the same materials. Thus the igneous rims can be thought of as outer, enveloping, chondrules in independent compound chondrule sets [4].

Our studies of low-FeO CR chondrules show that the FeO contents of the round and lobate chondrules are similar; olivine compositions range from 0.2 to ca. 4 mol%. The range is similar to that observed by Rubin and Wasson in the smaller chondrules in CO Y81020. Because the FeO contents are the same, the textural differences are not attributable to differences in the mafic mineral composition.

The compositional evidence suggests that the same precursor materials were flash melted to produce the two kinds of low-FeO chondrules. If we assume that this is correct, the differences must be associated with the nature of the melting process. Rubin and Wasson [3] discussed that the lobate shapes imply low degrees of melting and thus that the bulk chondrule viscosities were too high to permit surface forces to cause the assemblages to relax into spherical shapes. If the precursor mixes are essentially the same, then temperature is the variable most likely to be responsible (differences in the duration of the heat pulse might play a minor role). Clearly the speckled lobate materials had lower degrees of melting, perhaps <50%, whereas the typical round chondrules must have had high degrees of melting, >80%. From simulations (e.g., [5]) we infer a relatively large temperature difference of ~300 K.

As noted by many authors going back at least to Wood [6], CR chondrules frequently are surrounded by coarse metal as shown in Fig. 1. Grossman and Wasson [7] suggested that such metal was expelled from the interior by centrifugal action, thus leading to an equatorial distribution. This model predicts that, in section, most chondrules would show a uni- or bipolar distribution of metal, in contrast to the commonly observed ring-like distribution. It is therefore clear that this metal is present as a shell, not as a ring or belt. We suggest two mechanisms to account for these shells. They could form (a) as a metallic igneous rim; or (b) during the period when the chondrule was molten, surface forces may lead to the gradual transfer of metal from the interior onto the surface. We will tentatively choose the first model, which implies that silicates and metal were not uniformly mixed in the precursor solids, but tended to occur as metal-rich and silicate-rich clumps.

As noted by Weisberg et al. [1], it is not uncommon to find inner and outer metal shells separated by silicates, chondrule F3o (Fig. 4) is an example. The silicates between the metal shells presumably have the same origin as the silicate-rich lobate igneous rims, but the degree of melting was much higher. This chondrule is also surrounded by a lobate igneous rim. Depending on the correct scenario to account for the metal shells, the inner portion of this chondrule has participated in at least 3 and possibly 5 global melting events. One round chondrule (H2q) in our set is texturally and compositionally unique. It has abundant small, round, Si-bearing metal grains in its interior; their Si contents average 25 mg/g, similar to values in EH chondrites.

In summary, as we have inferred previously for the LL and CO chondrules, the CR chondrules experienced multiple flash-melting events. In past studies we have argued that high-FeO chondrules formed late in nebular history, and that chondrule formation at low nebular temperatures tends to convert metallic Fe to FeO. If this simple interpretation is correct, it would appear that the chondrule-forming process stopped at higher nebular temperatures at the CR and CO locations. An alternative is that the mean degree of oxidation of nebular solids was lower where the carbonaceous chondrites formed; our discovery of the chondrule with Si-bearing metal suggests that this could be the correct scenario.

References:[1] Weisberg M. K. et al. (1993) GCA 5**7**, 1567. [2] Weisberg M. K et al. (1995) Proc. NIPR Symp. Ant. Met. 8, 11. [3] Rubin A. and Wasson J. (2005) GCA 69, 211. [4] Wasson J. et al.. (1995) GCA 59, 1847. [5] Wasson J. (1996) Chondrules Protoplan. Disk, p. 45. [6] Wood J. (1963) Icarus 2, 152. [7] Grossman J.N. and Wasson J. (1985) GCA 49, 925.

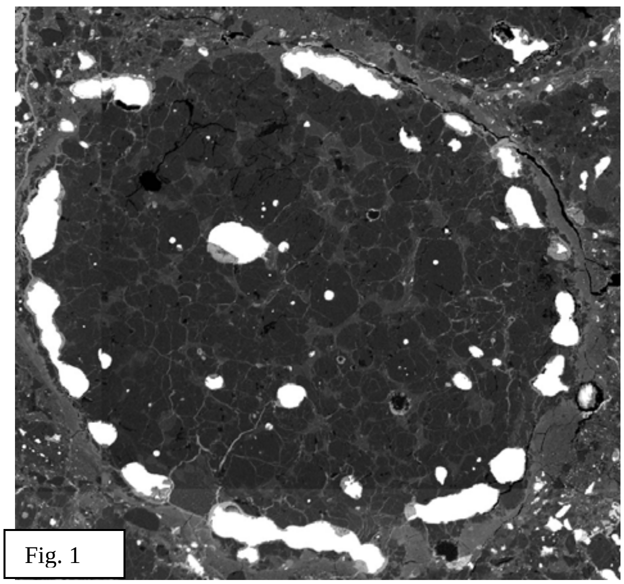

Fig. 1

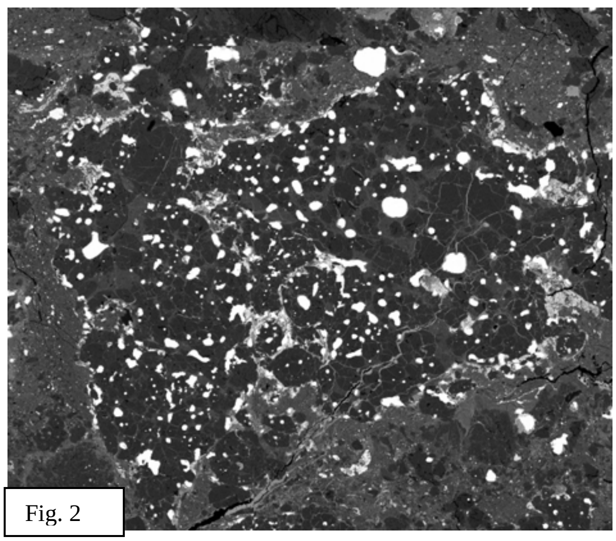

Fig. 2

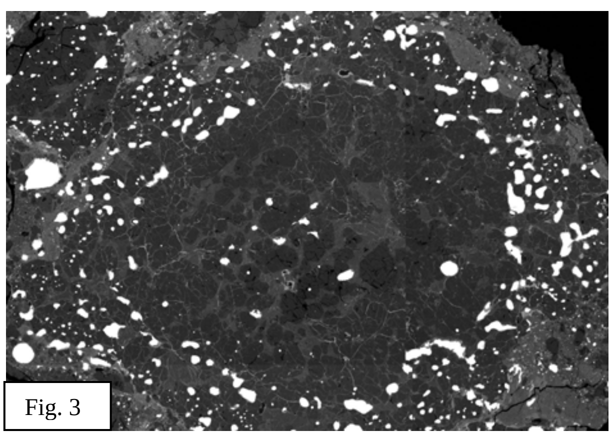

Fig. 3

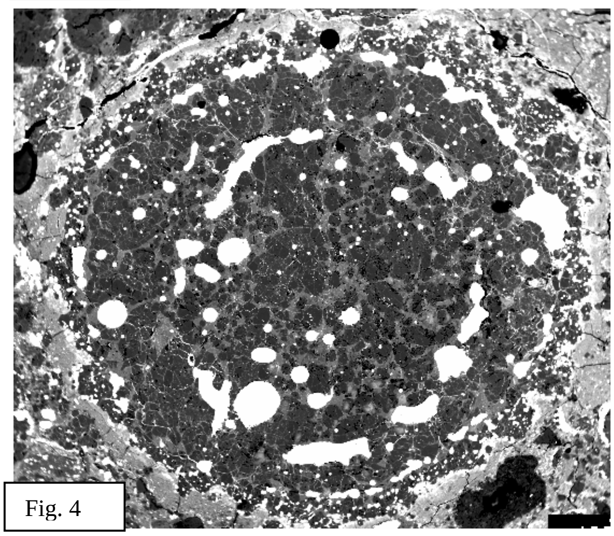

Fig. 4