GENETIC RELATIONSHIPS BETWEEN CHONDRULES, RIMS AND MATRIX. G. R. Huss[1], C. M. O'D. Alexander[2], H. Palme[3], P. A. Bland[4] and J. T. Wasson[5], [1]Department of Geological Sciences, Arizona State University, Box 871404, Tempe, AZ 85287-1404, USA [gary.huss@asu.edu], [2]Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road NW, Washington, D.C. 20015, USA, [3]Universität Köln, Institut für Mineralogie und Geochemie, 50674 Köln, Germany, [4]Department of Earth Science and Engineering, Imperial College London, South Kensington Campus, London SW7 2AZ, UK, [5]Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095-1567, USA.

Introduction: The most primitive chondrites are composed of chondrules and chondrule fragments, various types of inclusions, discrete mineral grains, metal, sulfides, and fine-grained materials that occur as interchondrule matrix and as chondrule/inclusion rims. Understanding how these components are related is essential for understanding how chondrites and their constituents formed and were processed in the solar nebula. For example, were the first generations of chondrules formed by melting of matrix or matrix precursors? Did chondrule formation result in appreciable transfer of chondrule material into the matrix? Here, we consider three types of data: 1) compositional data for bulk chondrites and matrix, 2) mineralogical and textural information, and 3) the abundances and characteristics of presolar materials that reside in the matrix and rims. We use these data to evaluate the roles of evaporation and condensation, chondrule formation, mixing of different nebular components, and secondary processing both in the nebula and on the parent bodies. Our goal is to identify the things that are reasonably well established and to point out the areas that need additional work.

Compositional Data: The bulk compositions of chondrites exhibit systematic elemental fractionations compared to CI chondrites, the meteorites that most closely represents the bulk composition of the solar system. The most important are: 1) volatility-controlled depletions of volatile and moderately volatile elements, 2) variations in refractory element abundances, perhaps sited in CAIs, 3) variations in Mg/Si ratios, and 4) metal-silicate fractionation [1].

There are data to suggest that fractionations of the first three types occurred in large part prior to chondrule formation [e.g., 2, 3]. Incomplete nebular condensation has long been considered a primary mechanism for these fractionations [e.g., 1, 4, 5], but differential sublimation of the dust inherited from the sun's parent molecular cloud, which in many ways is indistinguishable from incomplete condensation, may have played a substantial role [e.g., 6]. Chondrule formation superimposed additional fractionations. Volatile elements were lost during chondrule melting, although the time scale for chondrule melting was most likely too short to permit complete loss [7, 8]. Volatile elements lost from chondrules may have recondensed onto chondrule surfaces [e.g., 3] or in the matrix [8]. There is a complimentary relationship in the compositions of matrix and chondrules in CR and CV chondrites, which suggests that the two components originated in the same material reservoir [8-10]. Metal may be largely a by-product of chondrule formation, either due to reduction of FeO during melting and ejection of the immiscible metal melt from the chondrule, or through evaporation of iron and recondensation as metal [e.g., 3, 8]. This implies that at least some metal-silicate fractionation could have post-dated most chondrule formation.

Mineralogy and Petrology of Matrix and Rims: Matrices and fine-grained rims on chondrules and CAIs differ significantly in mineralogy among the meteorite classes, in large part due to parent-body processing. Aqueous alteration and/or thermal metamorphism has destroyed or significantly modified the primary mineralogies of rims and matrix in most chondrites, but in a few, such as Bishunpur (LL3.1) and ALH77307 (CO3.0), there is an abundance of amorphous and nanocrystalline material [11, 12]. Amorphous material is very susceptible to alteration and recrystallization, so its preservation suggests that some of the primary material has survived in these meteorites. The amorphous material could be chondrule glass fragments, nebular/chondrule condensates or interstellar material accreted directly into the meteorites.

Rims are generally thought to have accreted onto chondrules in the nebula, although their low porosity (~10%) remains problematic. In some instances, it seems that the rims accreted while the host chondrules were still hot [13]. If so, then at least some fine-grained dust was present during or shortly after chondrule formation, and it may have acted as an important site for recondensation of material that evaporated from chondrules. However, the majority of rim and matrix material cannot have experienced the high temperatures of chondrule formation, because it is in them that presolar materials (circumstellar grains and interstellar organics) are found [e.g., 14].

Abundances and Characteristics of Presolar Grains: The known types of presolar materials exhibit a broad range of chemical and thermal resistance. Thus, their relative abundances provide a means of probing the conditions that they and any accompanying material experienced, both on the meteorite parent bodies and prior to accretion [6, 14]. There are clear correlations between the volatile abundances of primitive chondrites and the complex of presolar grains that are present in their matrices [6]. The CI chondrites and CM matrices have the highest abundances of most presolar components and these components show the widest range of thermal stability. The most primitive members of the other classes show varying depletions of labile components in the order CI+CM<OC<CO<CR <CV. These depletions can best be understood in terms of thermal processing of the mixture of components represented by CI chondrites and CM matrices [6].

Insoluble organic material (IOM) constitutes the bulk of the organic material in chondrites. The matrices of all chondrite classes seem to have started out with roughly the same CI-like IOM abundances [15]. However, unlike for the presolar grains, the most primitive IOM is preserved in the CR chondrites [16]. The IOM in aqueously altered meteorites (type 1-2) appears to have undergone low temperature oxidation, perhaps associated with the melting of irradiated ices. The IOM in other meteorites of petrologic type ≥3 have experienced varying degrees of thermal maturation.

Discussion: In order to successfully evaluate questions like those posed in the introduction, it is important to consider the extent to which parent-body processing has altered the original record. In CM chondrites, aqueous alteration has altered both matrix and chondrules, significantly changing the mineralogy and moving elements between them [e.g., 17]. The oxidized CV chondrites also show considerable evidence of elemental mobilization [e.g., 18]. Even the most primitive UOCs show evidence of exchange of alkalis between matrix and chondrules [19]. The nature and extent of these processes must be understood before we can get a clear picture of the original state of the various types of chondrites. CR chondrites, CO3.0 chondrites, and the most primitive UOCs may be the best samples to work with.

Returning to our original questions: Were the first generations of chondrules formed by melting of matrix or matrix precursors? Compositional studies indicate that much of the chemical fractionation that produced the various classes of chondrites from bulk solar-system material occurred prior to chondrule formation [e.g., 2, 3]. Data for presolar grains in the least metamorphose members of each class combined with bulk compositional data for the host meteorites indicate that the precursors of matrix and chondrules experienced the same nebula processing [6]. And the complementarity of the compositions of matrix and chondrules, particularly in CR chondrites, indicates that they formed from a common reservoir [8-10]. These observations suggest that the answer may be yes, but there are problems. The melting temperature of chondrules is ~600 K above the evaporation temperatures of chondritic silicates, and matrix heated to these temperatures will have experienced extensive evaporation [20]. Also, the bulk compositions of rims and matrix in most chondrite classes do not appear to be consistent with a simple exchange model and the IOM, particularly in CR chondrites, seems to have escaped significant nebular heating [13, 16].

Did chondrule formation result in appreciable transfer of chondrule material into the matrix? This question is difficult to answer because redistribution of elements by parent body processes can mimic this transfer. However, metal and silicates in CR and OC chondrites make a relatively convincing case that material evaporated from chondrules during melting partially recondensed on fine-grained matrix precursors and on the surfaces of chondrules [3, 8-10, 13]. A major challenge for the future will be to understand the details of the processes and material transfers that generated the observed effects.

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