ON THE ORIGIN AND EVOLUTION OF MINERALS IN CHONDRITE MATRIX MATERIAL;

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Abstract:

We have developed the outline of a model to account for the mineralogical diversity of matrix, rims and chondrules in all chondrite groups. We infer that FeO-poor, fine-grained, amorphous silicates and metallic Fe,Ni, which condensed in the nebula above 800 K were major precursor materials for FeO-poor chondrules (type I). At lower ambient nebular temperatures, amorphous silicate materials became enriched in FeO providing precursor materials for FeO-rich chondrules (type II). The higher proportion of FeO-rich chondrules in O chondrites relative to C chondrites can be attributed to the formation of more chondrules at lower ambient temperatures in the O chondrite source region. Recycling of some chondrules accounts for FeO-rich relict grains in FeO-poor chondrules. Amorphous material may have been hydrated below 400 K in the nebula [1]. Chondrite matrix materials mostly formed by nebular and asteroidal processing of amorphous nebular materials that accreted to chondrules [2]. Some matrix grains were reheated, probably during chondrule formation to make larger, well ordered phases which were relatively unaffected by subsequent nebular and asteroidal processing.

Introduction.

Most matrix in chondrites is believed to be material that condensed in the solar nebula and was subsequently modified by nebular and asteroidal processing, but there is little agreement on the nature of the condensed phases, the nebula conditions during condensation and the processes that may have modified them in the nebula and in asteroids. To help elucidate the origin and evolution of matrix material we use constraints from studies of chondrules, their coarse and fine-grained rims and matrices in a wide variety of type 2 and 3 chondrites that have been altered and metamorphosed under diverse asteroidal conditions. We assume that chondrules formed in the nebula from both fine-grained, matrix-like and coarser-grained materials and that these materials subsequently accreted to form diverse kinds of rims. Chondrules and their rims were recycled through the flash heating process. Accretion and chondrule formation may have operated simultaneously over a period of several Myr after CAI formation while ambient nebular temperatures decreased.

Chondrules and rims.

Most chondrules in carbonaceous chondrites are FeO-poor (type I) whereas in ordinary chondrites, FeO-rich chondrules (type II) are more common. Fine-grained agglomerates that appear to represent lower degrees of melting than chondrules are also typically FeO-rich in ordinary chondrites [3] and FeO-poor in carbonaceous chondrites [e.g., 4]. Igneous rims on chondrules which formed by accretion of fine-grained material and subsequent partial or complete melting, have FeO concentrations that are similar to those of the enclosed chondrule [5]. This suggests that the two types chondrules were made from FeO-rich and FeO-poor precursor materials [6].

Matrix mineralogy.

A few exceptional type 3 chondrites have relatively homogeneous matrices. The Allende matrix, which is largely composed of large plates (1-10 um in size) of olivine (Fa 50), probably formed on an asteroid during dehydration of phyllosilicates [7]. The Kakangari matrix (Fs 1-4), which was quenched from high temperatures probably formed in the nebula by sintering during chondrule formation [8]. But most type 2 and 3 chondrites matrices, like IDPs [e.g., 9], are characterized by more complex mixtures of olivines with diverse compositions (Fa1-90) and grain sizes (10-1000 nm), phyllosilicates, and amorphous materials that may be hydrated (e.g., CM chondrites [10], ALHA77307 [2], and Semarkona [11, 12]). The origins of components in such mixtures in type 3 chondrites are generally less certain: olivines may have formed from phyllosilicates or amorphous material or altered to phyllosilicates; amorphous material may have formed during alteration or dehydration in the nebula or in asteroids.

Model.

Despite arguments for condensation under non-solar conditions such as highly oxidizing environments [13] or from vapors generated during chondrule formation [14], we interpret the similarities with IDPs to favor simpler models such as condensation from a slowly cooling nebula. Under such conditions, amorphous silicates are more plausible than highly ordered silicate minerals [e.g., 1, 2, 15]. We infer that FeO-poor amorphous material, which condensed above 800 K, was the precursor material for type I chondrules. Mn-rich forsterites and enstatites, which are present in CM, CO and LL matrices and chondritic IDPs [12], may have formed by heating of such material [2], conceivably during chondrule formation.

Amorphous silicate condensates reacted with nebular gases and metal below 800 K forming FeO-rich materials that became precursors for type II chondrules. We suggest that few chondrules were formed in the C chondrite source region after ambient temperatures fell below 800 K, whereas in the O chondrite region, chondrule formation continued to lower temperatures. Chondrules and matrix in E chondrites and Kakangari probably formed by reduction during chondrule formation from low-temperature C-rich [16] and FeO-rich amorphous condensates [8]. Amorphous FeO-rich silicate material may have been hydrated in the nebula [1] and may be partly preserved in the least altered chondrites. Chondrules and coarse (100-1000 nm), well-ordered matrix grains preserve a partial record of the nebula evolution of amorphous condensates. Chondrules and coarse grains were also best able to survive subsequent asteroidal alteration and metamorphism.

Matrices of type 2 and 3 chondrites and chondritic IDPs typically contain a wide variety of submicron silicates because of a) wide variations in grain size and crystallinity of the nebular products, b) chemical heterogeneities in amorphous materials on submicron scales [e.g., 2], and c) the complexity of asteroidal and nebula processing.

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