

OC CHONDRULE, RIM AND MATRIX COMPOSITIONS: A MODEL. C.

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The peak temperatures chondrules experienced, based on their liquidus temperatures, range from 1500 to 2000 K [1]. At these temperatures and nebular pressures most elements are volatile, but generally the alkali metals and S have been the only major elements considered as such. However, correlated variations in Mg and Al abundances, if they are not due to precursor compositions, require the loss of up to 50% of the SiO₂ from some chondrules [2]. The more volatile FeO would have been lost to an even greater extent.

If chondrules did lose material, particularly FeO and SiO₂, a likely place for it to recondense is on the chondrule rims and matrix. FeO and SiO₂ exhibit correlated behavior, relative to more refractory elements like Al and Ti, in rims and matrix [3]: most rims being enriched in FeO and SiO₂, and the matrix being generally enriched in refractory Al (Fig. 1). Both rims and matrix are also enriched in the alkalis and S, amongst other 'traditional' volatiles. In the UOCs and CO3s, the rims and matrix appear to have been composed of amorphous material and mineral fragments (mostly chondrule minerals) prior to metamorphism. The concentration of chondrule glass in the matrix could explain the general Al-enrichment of matrix in many UOCs [4], but in other meteorites, such as the CO3 ALHA77307 [5], chondrule fragments are only a minor constituent, prompting the suggestion that the amorphous materials are condensates [5]. Neither explanation for the Al-enrichments seems consistent with observed depletions of most refractory lithophiles relative to Al [3, 5], although these depletions may be secondary [3].

Here, the initial results of a model to test the likely effect of volatile loss and recondensation during chondrule formation on chondrule, rim and matrix compositions are presented. In this model it is assumed that chondrules/dust, with uniform L-chondrite compositions and radii of 0.1–1500μm, form a single power law distribution. During a chondrule-forming event, it is assumed that the gas and dust are heated instantaneously to some peak temperature and then cool linearly to 1400K, at which point the calculation is stopped. It is assumed the dust remains completely molten during the calculation. The p(H₂), gas/dust ratio, fraction of dust <100μm, peak temperatures and cooling rates are all adjustable parameters. At the end of the calculation, all material in the vapor is assumed to recondense as a uniform coating on the grains that remain.

The evaporation rates of components in chondritic melts have only been measured for MgO, SiO₂ and FeO [6, 7]. Here the rates of [6] were used but they were only measured up to the point of almost complete FeO loss (~50% wt. loss). Beyond this, corrections to the rates are required to account for the changes in activities as evaporation proceeds. This was done using the model of [8] for MgO-SiO₂-Al₂O₃-CaO melts and produces good fits to 1800°C evaporation experiments [6, 7] up to 95% weight loss. For those elements without measured rates, the rates were estimated from calculated equilibrium vapor pressures. However, these estimates can be significantly in error [9] and where possible correction factors were estimated by comparison between the model and the few evaporation experiments in the literature [7, 10, 11].

In addition to vacuum evaporation reactions, reactions involving H₂ must also have occurred in the nebula and may dominate at p(H₂)>5x10⁻⁶ atm [12]. Many oxide vacuum evaporation reactions involve dissociation to O₂, but in the presence of sufficient H₂ formation of H₂O is the energetically favored reaction. H₂ reactions are included, again using calculated rates, with the constraint that the flux of H₂O leaving the surface could not exceed that of H₂ hitting it.

Fig. 1 compares the expected and observed major element compositional trends in UOC rims and matrix as a function of peak T (p(H₂)=10⁻⁵ atm, dT/dt=1000°C/hr and 20wt% of grains<100μm). The lines connect the compositions of grains with different initial sizes. For all three peak temperatures the vapor compositions are too depleted in refractory Al to be plotted. On condensation, the vapor coats all grains with a uniform layer on the order of 1μm thick. Thus, the condensates will dominate the compositions of the finest grains present and they plot in the upper right, but with increasing size the influence of the refractory cores that survived evaporation becomes more important. The most Al-rich compositions are generally in the 5-10μm size range, depending on the assumed conditions, after which grain compositions trend towards the initial bulk

composition (not shown for clarity). Thus if the rims formed predominantly from the finest dust and the matrix from somewhat coarser material the differences in their compositions would be explained. Thick chondrule rims would have to form by accretion of the fine dust rather than by direct condensation. The vapor, and therefore the finest grained material, is also depleted in most refractory elements relative to Al. However over the range of conditions explored, when the finest material is combined up to the grain size (a few microns) necessary to produce the observed major element rim compositions these depletions are no longer significant.

One reason for this discrepancy may be that the model does not, at present, allow for the survival of or formation of olivine and pyroxene, which will reduce the absolute and relative evaporation rates of MgO, SiO₂ and FeO. This, in turn, will reduce their enrichments in the vapor. As a result, less of the coarser, more refractory grains will have to be added to the fine grained material to produce the observed rim compositions, perhaps preserving the refractory element depletions relative to Al. The predicted trends are sensitive to all of the assumed conditions. Nevertheless, for reasonable assumptions the results are broadly consistent with the observed compositions. Hence, these preliminary results suggest that evaporation and recondensation during chondrule formation could explain rim and matrix compositions, just as it may also partially explain chondrule compositions [2]. Indeed the sensitivity of the results to the assumed conditions may ultimately enable limits to be set on the conditions during chondrule formation.

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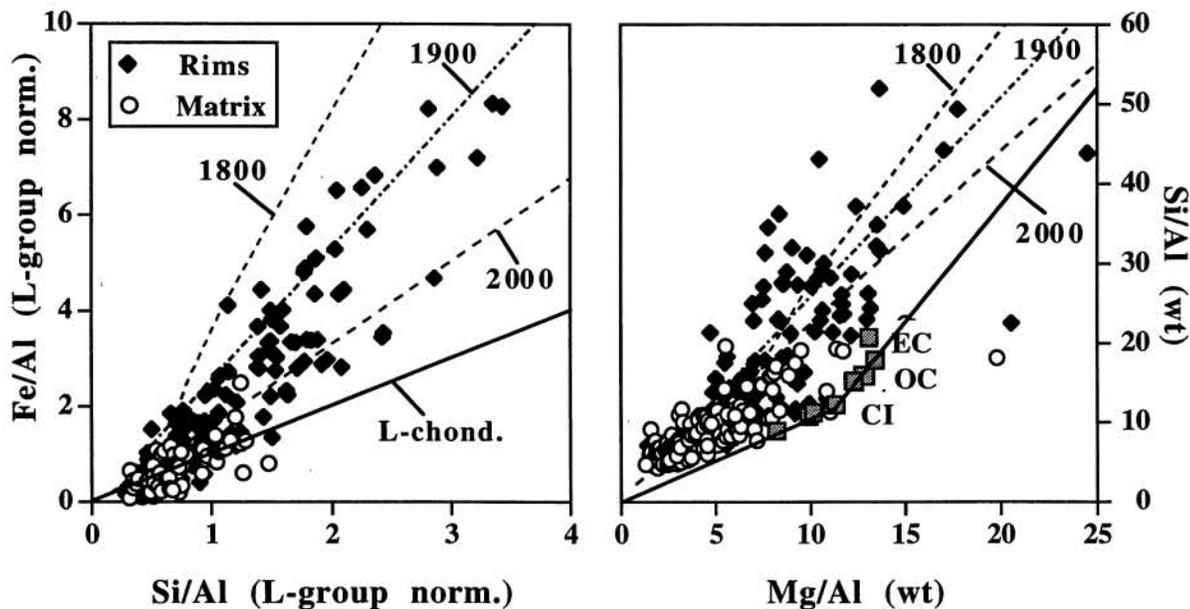


Fig. 1. Comparison of UOC rim and matrix compositions, determined by EMPA and ion probe, with model predictions for peak temperatures of 1800 K, 1900 K and 2000 K. The other assumed conditions are $p(\text{H}_2)=10^{-5}$ atm, cooling rate=1000°C/hr and 20wt% of grains <100µm in size.