OXIDIZING CONDITIONS IN THE SOLAR NEBULA AND THE ORIGIN OF
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The vast majority of chondrules have Cr/Si ratios that are the same as those in
bulk chondrites to within ±50% (Grossman and Wasson, 1983). The Cr/Mg or Cr/Si
ratios in chromite chondrules (Ramdohr, 1974) and Cr-rich inclusions are 180 - 750
times higher than ratios in the bulk chondrites (Krot et al., 1992). Nebular mechanical
processes such as size sorting or selective adherence seem unable to account for
such Cr enrichments.

Calculations by Palme and Fegley (1990) indicated that chromite (FeCr2O4)
would condense from a highly oxidized nebula at a temperature much higher than the
condensation temperature of forsterite (Mg2SiO4), suggesting that chromite
enrichment offered evidence for oxidizing nebula conditions. Our examination of
nebular equilibrium processes failed to confirm such a dramatic dependence on fO2.
We do agree that 50%-condensation temperatures of Cr from nebulae with pH2/pH2O
in the "canonical" range 1500-2000 are several tens of degrees below those of Mg as
Mg2SiO4, consistent with the observation that bulk-chondrite CI-normalized Cr/Mg
ratios are typically ~0.95. Condensation in a nebula with pH2 = 10^{-3} atm is primarily
as Cr in Fe-Ni; at lower pH2 pressures Cr condenses as MgCr2O4 (not as FeCr2O4 as
earlier studies had indicated) dissolved in spinel (or possibly in Mg2SiO4). A
decrease of the pH2/pH2O by a factor of 1000 to make a much more oxidizing nebula
reduces the difference between Cr
and Mg condensation temperatures but Mg remains slightly more refractory. We
conclude that nebular equilibrium processes cannot be responsible for the enhanced
Cr/Mg or Cr/Si ratios in Cr-rich objects.

Our proposed mechanism for the formation of such objects calls for incomplete
evaporation of presolar lumps to enrich both Cr and Al in residues. We suggest that
spinel remained as solid phases when the bulk of the silicates were incorporated into
the evaporating melt. Silicates in the melt evaporated efficiently whereas vaporization
of Al and Cr were inhibited by the slow kinetics of diffusion from the solid through a
liquid boundary layer. These spinel-rich residues had Cr/Al ratios near or below the
solar value of 0.16. Subsequent melting and crystallization of these residues
fractionated Cr from Al. Fragmentation of these materials produced some fragments
that had extreme enrichments in Cr or Al. Some of the resulting materials constituted
major components in the precursors of Cr-rich and Al-rich chondrules. This model is
similar to that proposed by Bischoff and Keil (1984) to account for the Al-rich
chondrules, and we propose that Cr-rich chondrules are end members in a set of
refractory chondrules that includes the more common Al-rich chondrules.

This model implies that the Cr in Cr-rich objects has never been mixed with
"common" nebular Cr. If there were significant variations in Cr isotopic ratios in
presolar matter, these should best be preserved in Cr-rich objects.