SULFIDES IN R CHONDRITES: EVIDENCE FOR SULFIDIZING CONDITIONS IN THE EARLY SOLAR SYSTEM

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Introduction: R chondrites are a highly oxidized class of meteorites that may have formed between the ordinary chondrites and the carbonaceous chondrites in the early solar nebula [1]. The material was likely oxidized before accretion, and then thermally metamorphosed with increasing depth in the parent body [2]. It is known that the silicates in the R chondrites record one of the most highly oxidizing regions of the early Solar System. Study of the sulfides from these meteorites can provide analogous information about the sulfidation state of this environment. Kallemeyn reported sulfides with pyrrhotite, troilite, and pentlandite, and rarely with chalcopyrite, pyrite, metallic Cu, and ilmenite [1]. He reported very rare to non-existent metallic Fe-Ni.

Analytical Techniques: We analyzed thin sections of LAP 04890, PRE 95411, and PCA 91002. We stitched together complete mosaics of each section using images obtained with an optical microscope, and then acquired elemental maps with a Cameca SX50 electron microprobe. We identified three assemblages in each thin section for further study, and then investigated these areas using a Hitachi S-4800 field emission scanning electron microscope and the electron microprobe.

Results: The abundances of Si, Al, Mn, and Ti are all below detection limit in the sulfide assemblages. Pyrrhotites are abundant in these meteorites and have three distinct compositions: $(Fe,Ni)_{0.87}S$, $(Fe,Ni)_{0.90}S$, and $(Fe,Ni)_{0.97}S$. Iron and Ni are the only cations present above detection limits in these phases. The Ni content increases with increasing cation-to-S ratio, averaging 1.3 at.% in the S-rich phase, 0.26 at.% in the intermediate pyrrhotite, and 0.13 at.% in the S-poor phase. Pentlandite occurs throughout the assemblages with an average composition of $(Fe_{0.50}Ni_{0.48}Co_{0.02})_9S_8$. Grains of chromian spinel are common in the LAP 04890 assemblages that contain inclusions of phosphates, perhaps chlorapatite. Assemblages in PRE 95411 contain metallic iron-nickel ($Fe_{32.5}Ni_{66.0}Co_{1.5}$) and chalcopyrite ($CuFeS_2$). There is one grain that could be ilmenite in an assemblage of PCA 91002, though further analysis is needed for confirmation.

We use the composition of these sulfides to estimate the sulfur fugacity (f_{S2}) under which they formed and compare them to the ordinary chondrites. The presence of chalcopyrite along with reports of metallic Cu [1], allow us to determine an equilibrium f_{S2}. In addition, the presence of Ni in the pyrrhotite provides a second way to determine this value. We considered the following reactions: $Cu + Fe + S_2(g) = CuFeS_2$ and $2\ Ni + S_2(g) = 2\ NiS$. We assume uniform activity for Cu. We use the composition of Fe-Ni metal and pyrrhotite to constrain the activity of Fe, Ni, and NiS. We find that the measured compositions are consistent with equilibration at relatively low temperature (300 – 400 K) and high f_{S2} ($\log f_{S2}$ = IT + 1.6 to IT + 2.8), where IT refers to the f_{S2} of the iron troilite buffer. Since ordinary chondrites are buffered at IT it is clear that the R chondrites formed in a much more S-rich environment.

References: [1] Kallemeyn G. W., Rubin A. E., and Wasson J. T. 1996. *Geochimica et Cosmochimica Acta* 60:2243–2256. [2] Bischoff A. 2000. *Meteoritics & Planetary Science* 35:699–706.