AN EXPERIMENTAL STUDY OF METALLIC DIFFUSION AND PHASE EQUILIBRIA IN FREMDLINGE

J.D. Blum, G.J. Wasserburg, J.T. Armstrong, I.E. Hutcheon, J.R. Beckett, and E.M. Stolper, *Geology 170-25, Caltech, Pasadena, CA 91125*

Fremdlinge are opaque assemblages within CAIs that are mainly composed of NiFe metal, V-magnetite and μm-sized RuOs nuggets. The prevailing scenario for their origin includes condensation, aggregation and equilibration at low T ($\lesssim$ 600°C); they are then thought to be introduced into CAIs at high T, followed by rapid cooling, thereby preserving the textures and assemblages from the pre-CAI, low T histories (Armstrong *et al.*, 1985; Armstrong *et al.*, 1987). A constraint on cooling rates of Fremdlinge comes from sharp contacts observed between RuOs nuggets and NiFe metals that enclose them. To determine the length of time that these contacts could have been held at high T, thin-film diffusion experiments were conducted with an electroplated Ru film on Ni. Samples were annealed at 1400, 1200, 1000 and 800°C for 0.3-137 hours. Measured Ru profiles in Ni were consistent with the following Arrhenius expression: $D(cm^2/sec) = 0.0050\exp(-2.3\times10^{12}/RT)$ (T in K, R in Cgs units). Based on these data, we calculate that cooling rates of $\gtrsim 10^5$°C/hr are necessary to preserve sharp contacts between RuOs and NiFe metals if they experienced the T of CAI melting (~ 1400°C) (Stolper and Paque, 1986). We consider this rate unreasonable in light of cooling rates inferred from experimental studies of the silicate portions of CAIs (10^{-1} to 10^{2}°C/hr) (Stolper and Paque, 1986).

An alternative hypothesis for Fremdlinge origin is that when the silicate portions of CAIs melted, siderophile elements including Ni, Fe, V, Ru and Os partitioned into a molten metallic phase; as CAIs cooled and experienced more oxidizing conditions, these once molten metal droplets exsolved into immiscible metallic phases and oxidized partially to V-magnetite. To explore this hypothesis, phase equilibria were investigated in the system Ni-Fe-Ru-O. Homogeneous NiFeRu alloys were sealed in evacuated silica tubes with a Ni-NiO buffer. The diffusion of oxygen into the alloy produced magnetite intergrown with the alloy. By analyzing the compositions of the coexisting Ru-rich and NiFe-rich metals, the positions of the two phase boundaries on the Ni-Fe-Ru phase diagram were determined at 800 and 1000°C; phase boundaries at 400 and 600°C were inferred based on previously determined binary phase diagrams. By comparing Fremdlinge metal compositions with the Ni-Fe-Ru phase diagram, we conclude that the Fremdling assemblages are consistent with equilibration at 400 to 600°C. The variability in RuOs nugget compositions found in Fremdlinge requires a change in bulk metal composition during exsolution; this could be achieved by oxidation of NiFe metal to magnetite during exsolution. This is the process that occurred in our experiments, and the textures and mineral chemistries of the run products are very similar to Fremdlinge. If this explanation is correct, our diffusion data can be used to constrain cooling rates in the range over which exsolution occurred to 10^{-3}, or to 10^{-8}°C/hr, depending upon whether exsolution began at 600 or 400°C.

Based on our experiments, we suggest that Fremdlinge may not contain much information on the high T cooling histories of CAIs or record an independent history prior to CAI genesis; they are not "strangers" in the sense implied by the name "Fremdlinge." Instead, they provide equally important constraints on the lower T histories of CAIs and on the changing oxygen fugacity they experienced on cooling in the nebular and/or planetary environment.