ELEMENTAL ABUNDANCE CONSTRAINTS ON CONDENSATION OF ALLENDE MATRIX OLIVINE. L. Grossman[1] and A. V. Fedkin., Dept. of the Geophysical Sciences, The University of Chicago, 5734 South Ellis Ave., Chicago, IL 60637. [1]Also Enrico Fermi Institute, Univ. of Chicago.

The matrix of Allende and other CV3 chondrites is composed largely of single crystals of olivine which are ~10 x 1μ in size [1], have X_{Fa}~0.5 [2], and which have been interpreted as direct condensates from the solar nebula [3]. A solar gas is very reducing, however. Equilibrium thermodynamic calculations show that a metallic NiFe alloy condenses from a solar gas at 1450-1250K at reasonable nebular pressures, causing the co-condensing olivine to be pure forsterite. Significant amounts of oxidized iron become stable only below 600K in the form of fayalite, whose mole fraction in olivine gradually increases with decreasing temperature [4]. Thus, in order for the Fe^{2+} to condense at equilibrium, it must diffuse into the interiors of previously condensed forsterite grains at relatively low temperatures. Fe-Mg interdiffusion rates in olivine are so low that a 1μ grain could only equilibrate within 10^4 yr at T>830K. At these temperatures, however, the equilibrium X_{Fa}<0.005 [5].

Nebular regions enriched in vaporized interstellar dust are more oxidizing than a gas of solar composition. A system enriched in dust of C1 chondrite composition by a factor of 75, for example, relative to solar composition has an atomic O/H ~42x greater than a solar gas. Such a composition was shown in [5] to be sufficiently oxidizing that X_{Fa} reaches 0.26 at temperatures where 1μ grains equilibrate on reasonable nebular time-scales. Because the curve of X_{Fa} *vs* temperature levels off at this point, even smaller olivine grains which can equilibrate at lower temperature will have $X_{Fa} \leq 0.28$. Thus, although the X_{Fa} typical of olivine in ordinary chondrites can be produced in such a region, the much higher X_{Fa} of Allende matrix olivine cannot. Although increasing the degree of dust enrichment will increase the oxygen fugacity, there are two reasons for believing that this is not the solution to the problem of making the Allende matrix olivines by condensation. First, in dynamical models of the solar nebula, dust enrichment occurs by coagulation and settling to the midplane, but difficulty is encountered in enriching dust by factors of >100 by this mechanism [6]. Second, in the above calculation for 75x dust enrichment, since virtually no metallic iron remains in the temperature interval where X_{Fa} reaches its maximum and levels off, oxygen fugacity is obviously not the limiting factor. Instead, the S abundance limits the maximum achievable X_{Fa}. For example, while 43.6% of the iron is in fayalite at 600K, another 55.5% is in pyrrhotite ($Fe_{0.98}S$), which accounts for 98.9% of the S.

Equilibrium condensation calculations were done at a total pressure of 10^{-3} bars and a C1 dust enrichment of 75x relative to solar composition, using the computer code of [4] with updated thermodynamic data and new photospheric abundances of C and O [7]. To see if the oxygen fugacity in such a system is sufficient to yield the fayalite content of Allende matrix olivine, the sulfur abundance was set to zero. As in the normal-S case, X_{Fa} rises continuously with falling temperature, reaching 0.28 at 850K, where it levels off. The rise is due to reaction of progressively more of the metallic Fe with gaseous oxygen and orthopyroxene to form olivine with falling temperature. The reason why X_{Fa} levels off at 850K is that this is where orthopyroxene is exhausted. In contrast to the normal-S case, however, as the temperature continues to fall below 850K in the zero-S case, X_{Fa} rises sharply at 760K and levels off again in stepwise fashion. The sharp increase is due to onset of the reaction of residual metallic Fe with gaseous oxygen and albite to form nepheline and fayalite. In this reaction, the additional SiO_2 for fayalite formation comes from conversion of albite to nepheline. This causes X_{Fa} to rise steeply and level off at 0.39 at 704K, where albite is exhausted. Below this temperature, no more fayalite forms and X_{Fa} is constant. This is due neither to lack of available Fe nor to low oxygen fugacity, as 28% of the Fe is still present as metal, which is converted into pure Fe oxides below 550K. The reason why X_{Fa} remains constant is that there is no more SiO_2 available. In this temperature range, 85% of all the Si is already present as olivine, with the remainder being used to stabilize all of the Na and Ca, and most of the Al, in grossular, nepheline and diopside.

It is thus seen that modest enrichments in C1 dust are sufficient to oxidize all Fe in this system but that, even when chemical equilibrium would otherwise allow this to occur, the high solar S/Fe ratio causes pyrrhotite condensation to exclude a large fraction of the Fe from combining with oxygen. Furthermore, even if the S abundance is set to zero, thus allowing all Fe to oxidize, there is insufficient Si in the system for the equilibrium X_{Fa} to reach 0.5, the value in Allende matrix olivine. This suggests that the way to form the Allende matrix olivine by condensation is to isolate early, high-temperature forsterite from chemical communication with the gas at low temperature, thereby removing more Mg than Si from the system. Perhaps this occurred when forsterite crystals grew to the mm sizes seen in Allende.

Another calculation was done at 10^{-3} bars and a 75x enrichment in dust of C1 composition except for S, which was depleted by 75% relative to Si, as in the Allende meteorite. To test the forsterite isolation hypothesis, 50% of the olivine that had condensed by 1700K, equivalent to 33% of the total Mg, was removed in one step. In this run, troilite condensed at 960K and X_{Fa} rose steadily with falling temperature, levelling off at 0.37 at 858K, where orthopyroxene was exhausted. When nepheline began to form at 776K, X_{Fa} began to rise and levelled off at 0.50 at 719K, where albite was exhausted. Here, 13% of the Fe is metallic, and the alloy contains 30 mole% Ni. Although X_{Fa} of Allende matrix olivine can be made in this way, the amount of metal is higher and its Ni content lower than in Allende. Furthermore, the assumption that the dust used to enrich the system in oxygen had the composition of C1 chondrites except for S is completely arbitrary.

A similar calculation was done in a system of solar composition except for an enrichment in water ice by such an amount that the atomic O/H was 42x that of a solar gas, the same as made by enrichment in C1 dust by 75x. In this run, 50% of all olivine condensed by 1470K was removed in one step. X_{Fa} rose with falling temperature, levelling off first at 0.37 at 984K, where orthopyroxene was exhausted, and then at 0.50 at 788K, where albite was exhausted. Pyrrhotite condensed at 728K. Because pyrrhotite consumes 27% of the total S at 700K, accretion of condensates at this temperature produces a parent body with the observed S content of Allende, but it would contain too much residual metal (13% of the Fe) and the latter would contain too low a Ni content (30 mole%) compared to Allende. Although this system is sufficiently oxidizing to yield the X_{Fa} of Allende matrix olivine at a high enough temperature for equilibration, the assumption of selective enrichment of a solar nebular region in only one volatile component, water ice, seems without physical basis.

References:

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