CHEMICAL CHARACTERISTICS OF HIGH-TEMPERATURE CONDENSATES, R. Ganapathy and L. Grossman*, Dept. of Geophysical Sciences, University of Chicago, Chicago, Ill. 60637. *Also Enrico Fermi Institute.

The coarse-grained, Ca-rich inclusions in the Allende Meteorite are thought to be high-temperature condensates (HTC) from the solar nebula(1,2,3). Some of them contain a mineral assemblage, melilite+spinel+perovskite, identical to that predicted from thermodynamic models to have condensed from the cooling vapor of the solar nebula at temperatures greater than 1450^{o}K, using a total pressure of 10^{-3} atm. (3). Several groups (4,5,6) consider them or their analogs to be important chemical components in models of lunar and planetary accretion. Grossman and Ganapathy (7,8) measured concentrations of 21 elements in a suite of ten of these inclusions by INAA. New RNAA data for an additional 9 elements, U, Ba, Sr, Zr, Re, Pd, Zn, Se and Ag, in the same inclusions are discussed here.

Figure 1 shows that Re contents of the inclusions are highly variable and strongly correlated with their Ir contents along a straight line whose slope equals the cosmic Re/Ir ratio. This implies that Re and Ir condensed totally into a common alloy whose grains were incorporated in varying amounts by the major phases of the different inclusions as they condensed from the solar nebula. Several other pairs of refractory trace elements also exhibit this behavior: Re-Os, Ir-Ru, Hf-Sc, Sc-Ta, Sc-REE (8). The Zr-Hf correlation shown in figure 2 suggests that this refractory element pair also condensed totally into a common phase. The mean Zr/Hf ratio is 31.3, identical to the average of 4 chondrites determined by Ganapathy et al. (9). This ratio is within analytical error of their Cl chondrite ratio, 28.2, but far from Ehmann and Chyi's Cl measurement of 52(10). In contrast, some refractory elements such as Ir and Sc are not correlated with one another and their concentration ratios vary widely from inclusion to inclusion (8). This suggests that they condensed in separate phases which were sampled in different proportions by different inclusions. If the inclusions formed by incomplete vaporization of presolar solid matter (11), then, in any particular inclusion, all refractory elements would be expected to be equally enriched, which is certainly not the case.

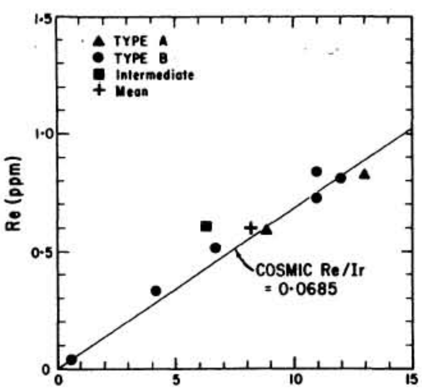

Figure 1

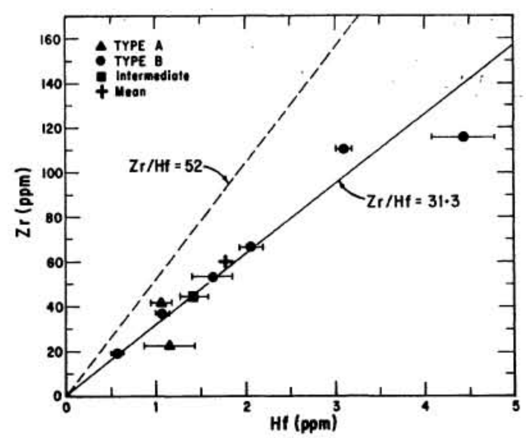

Figure 2

Regardless of their correlation behavior, all refractory elements studied, both lithophile and siderophile, are enriched in the inclusions relative to Cl chondrites. This is because the trace elements all condensed above or within the range of condensation temperatures of the major phases of the inclusions and they probably became associated with one another because of their interdependence for condensation nuclei. A remarkable feature of the inclusions is the uniformity of the enrichment factors for all refractory elements, regardless of chemical properties or geochemical behavior. Excluding sample 5 which is probably a melted fine-grained inclusion (13), the mean concentration of every refractory element in the remaining 9 inclusions divided by its abundance in Cl chondrites is nearly the same, 17.67±1.83, as seen in figure 3. This supports the contention that all the trace refractories were virtually totally condensed in this temperature range and were efficiently scavenged from the vapor by the major phases of the inclusions which represent about 100/17.67 = 5.7% of the total condensable matter of the solar system (8,14). A random group of inclusions is apparently a representative sample of the HTC but the widely-varying concentrations and abundance ratios of refractory elements in individual inclusions suggest that any particular inclusion did not necessarily sample all the available condensate phases in the mean proportions in which they were present in the nebula. The Ru enrichment in figure 3 is essentially the same as that for all other refractories, indicating complete condensation of Ru. According to Blander and Fuchs (12), this is a fundamental criterion of equilibrium condensation and indicates that supersaturation effects were negligible.

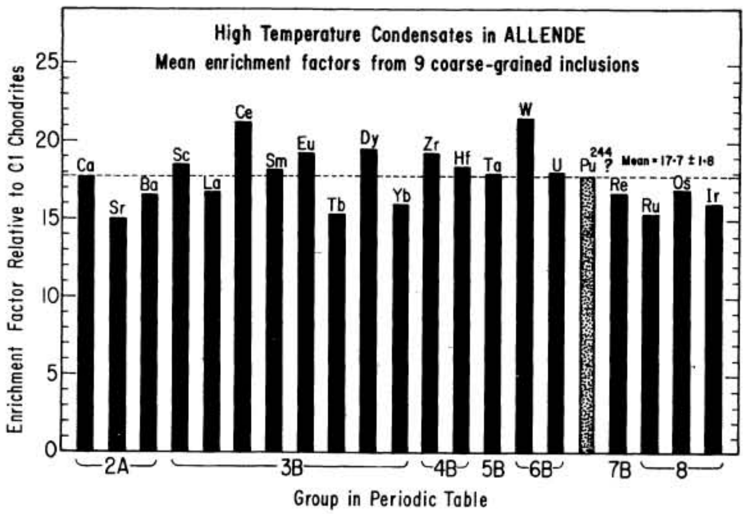

Figure 3

Both Pu and U can be shown to be refractory elements in the solar nebula. The fact that the Allende inclusions are enriched in all refractory elements in virtually unfractionated proportion to one another suggests that a relatively unambiguous estimate of the initial Pu/U ratio of the solar nebula can be obtained from them, free of the fractionation effects which may hamper the

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interpretation of this ratio in arbitrarily chosen meteoritic standards (15).

Assuming that HTC was the sole carrier of refractory elements, some workers (4,5) calculated the proportion of HTC in the moon from its bulk U content. For this calculation, Ganapathy and Anders (4) used 197 ppb as the HTC U content, assuming that U was totally concentrated into it and that HTC represents 4.6% of the total condensable matter. The latter would have been the case had diopside not yet condensed into it (14). The meteoritic analogs of HTC, however, contain abundant clinopyroxene (2,3,16). Wänke et al. (5) used 120 ppb as the HTC U content based on the analysis of a single inclusion. As seen here, however, the concentration of a refractory element in any particular inclusion is, in general, not representative of all such inclusions and this is certainly true for the U value in (5). As seen in figure 3, U has a normal enrichment factor of 18.0 in our suite of 9 inclusions. If, in spite of their major oxygen isotopic differences from the moon (17), the Allende inclusions continue to be used as a major chemical building-block for the moon, we suggest the use of 163 ppb as their U content, based on the mean concentration in this group of 9 inclusions.

Volatility, not geochemical affinity, was the controlling factor in establishing the composition of the inclusions, as seen in figure 4. Siderophile, chalcophile and lithophile volatiles are severely depleted in the Allende inclusions, in contrast to the refractories. This is particularly well demonstrated by the platinum metals. Ru, Os and Ir show normal enrichments in figure 3 but Pd is strongly depleted in figure 4. The former 3 can be shown to be refractory, condensing from the solar nebula above 1450°K, while Pd is volatile, condensing below 1100°K.

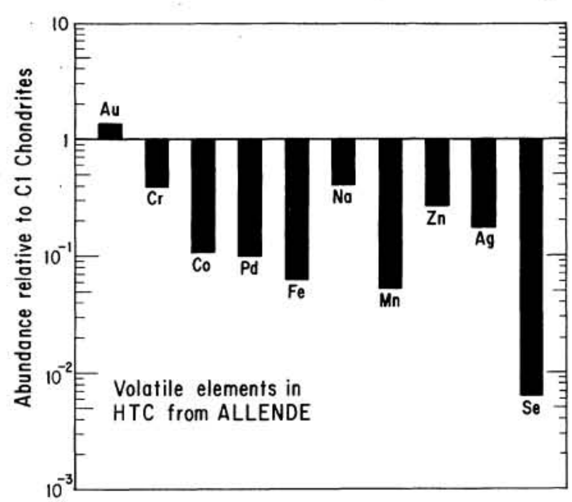

Figure 4

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