BULK CHEMICAL COMPOSITION OF A FREMDLING FROM AN ALLENDE TYPE B INCLUSION; L.Grossman[1,2], A.M.Davis[3], V.Ekambaram[1], J.T.Armstrong[4], I.D. Hutcheon[4], and G.J.Wasserburg[4]. [1]Dept. of the Geophysical Sciences, [2]Enrico Fermi Institute, [3]James Franck Institute, University of Chicago, Chicago, IL 60637. [4]Div. of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125.

Detailed petrographic and mineral-chemical study of Willy, a very large Fremdling, revealed a core composed predominantly of V-magnetite and Ni-Fe metal enclosing the magnetite, a mantle of V-magnetite and a rim of V-fassaite and V-spinel (1). Refractory platinum metal nuggets are found in the core. Willy formed prior to incorporation into its host Allende Type B inclusion and was not substantially recrystallized afterwards (1). A multi-stage formation process is indicated in which conditions changed from oxidizing to reducing to oxidizing to reducing again. A similar study of Zelda, a mm-sized Fremdling from the Allende Type B inclusion Egg-6, revealed major amounts of pentlandite and pyrrhotite surrounding embayed Ni-Fe metal grains, V-magnetite and refractory platinum metal nuggets (2). Zelda formed by sulfidization of a Willy-like magnetite-metal precursor (2).

A second large (200 μm diam.) Fremdling, Zorba, was discovered on a rough surface of the same inclusion in which Zelda was found. An exploratory SEM survey of Zorba revealed a porous outer surface rich in iron sulfide. Zorba was easily removed from its silicate matrix: it simply rolled out when touched by a stainless steel dental tool. The entire sample (18 μg) was subjected to INAA.

The concentrations of Fe(39.1%), Ni(29.1%) and V_2O_3(1.29%) were used to calculate the mineralogical composition, assuming that Zorba belongs to the sulfide-rich class of Fremdlinge and has the same V_2O_3 content in magnetite, 26.5%; Ni-Fe alloy, pyrrhotite and pentlandite of the same compositions; and the same pyrrhotite/pentlandite ratio, ∿1, as Zelda. On this basis, Zorba would contain 41% Ni-Fe alloy, 45% pyrrhotite + pentlandite and 4.9% magnetite. The total sulfur content contributed by these two sulfides is 16%. The magnetite and total sulfide contents are each 15% less than in the case of Zelda but the metal content is 35% higher (2). The low W concentration of Zorba, <210 ppm, suggests that scheelite, so prominent in Willy (1), is virtually absent from Zorba. On the other hand, Zorba contains 4.5 ± .5% Mo, equivalent to a molybdenite content of 7.5 ± .8% which is close to that of Zelda, 6% (2). This would contribute an additional 3% S to the Fremdling, giving a total sulfur content of ∿19%. Low levels of Al_2O_3(.6%), MgO(<3.3%), TiO_2(<.17%) and Na_2O (.06%) indicate the relative absence from this sample of silicate and oxide phases common in CAI. The CaO content (2.0%) could be due to the presence of 4% whitlockite of the composition seen in Zelda (2).

Concentrations of many siderophiles are extraordinarily high in Zorba: 1.35% Ir, 1.34% Os, 4580 ppm Ru, 597 ppm Re, .6% Cr, .79% Co and 451 ppm Au. It is clear that refractory siderophiles are strongly fractionated from one another in Zorba, enrichment factors relative to Cl chondrites being 49,700 for Mo, 29,000 for Ir, 26,700 for Os, 16,200 for Re, 6420 for Ru and < 2200 for W. Armstrong _et al_. (1) presented compelling textural and chemical evidence that Fremdlinge formed prior to their incorporation into Allende coarse-grained inclusions, suggesting that they may be the component proposed by Grossman and Ganapathy (3) that carried the bulk of the refractory siderophiles into group I inclusions. If true, the refractory siderophile abundances of Zorba cannot be identical to those of most Fremdlinge, since Re/Os and Ir/Ru ratios in individual bulk inclusions seldom deviate from Cl chondritic values by more than 15% (3). In Zorba, the Re/Os ratio is 40% less and the Ir/Ru ratio a factor of 4.5

greater than in Cl chondrites. The fact that individual inclusions contain Cl chondritic proportions of these refractory siderophiles implies that the average composition of the Fremdlinge sampled by each inclusion also contained these elements in Cl chondritic proportion. This, in turn, implies that Fremdlinge, despite their multi-stage history, formed from a Cl chondritic reservoir of refractory siderophiles. If, like Zorba, most individual Fremdlinge contain refractory siderophile abundances which are strongly fractionated from one another, individual inclusions must have sampled very large numbers of Fremdlinge in order for the inclusions to end up with Cl chondritic proportions of these elements.

Zorba contains only 5.5 ± 1.4 ppm Sc and < 3.5 ppm La. The enrichment factors for these elements relative to Cl chondrites, .97 and <15, resp., are much lower than for refractory siderophiles. If Zorba-like Fremdlinge account for the total Ir inventory of the average group I inclusion, they can only account for $3x10^{-5}$ of the total Sc and $<5x10^{-4}$ of the total La in the average group I inclusion. If Fremdlinge were indeed the carriers of refractory siderophiles, other components must have brought Sc and light REE into the inclusions, as was suggested in (3) on the basis of inclusion bulk compositions.

Palme and Wlotzka (4) investigated the condensation of siderophiles from a solar gas into a common alloy. For a given equilibration temperature, enrichment factors should be equal for the most refractory elements which have fully condensed in such an alloy and should steadily decline with increasing volatility of the remaining elements. No such regular pattern emerges for Zorba. W, Re and Os condense at similar, extremely high temperatures but enrichment factors for Re and W are lower than that for Os by 40% and a factor of >12, resp. Mo and Ir have nearly coincident condensation curves and are considerably less refractory than Os; yet, the enrichment factor for Mo is nearly double that of Os, while that of Ir is essentially the same as that for Os. Ru is only slightly more volatile than Ir but has an enrichment factor 4 times lower than that for Ir. Au is much more volatile than Ru but its enrichment factor, 3040, is almost half that of Ru. It is conceivable, however, that condensation of refractory siderophiles resulted in formation of several alloys of different composition, each of which changed its composition as the gas temperature fell. Some of these phases may have separated from one another prior to aggregation into Fremdlinge and different grains of those that were incorporated may have stopped equilibrating with the gas at different temperatures. It is also possible that refractory siderophile condensation was interrupted by major changes in physicochemical conditions that are indicated by the multi-stage history of other Fremdlinge. Although the presence of refractory siderophile nuggets within V-magnetite in Willy and the low W/Os ratio of Zorba suggest condensation of these elements from a gas more oxidizing than one of solar composition, Zorba's enrichment of Mo over Os argues against this (5). Abundances of such volatile chalcophiles as S and Se, 860 ± 240 ppm, in Zorba indicate that the alloys may have been exposed to temperatures much lower than the condensation temperatures of the refractory siderophiles, possibly in a separate event when the more volatile siderophiles like Cr and Au could have been added. In Fremdlinge, low-temperature phases coexist with isotopically normal (6) phases that formed in a reservoir containing Cl chondritic proportions of refractory siderophiles. The existence of Fremdlinge prior to formation of coarse-grained inclusions poses important questions about solar nebular thermal history.

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