

CHEMICAL COMPOSITIONS OF LEOVILLE AND VIGARANO INCLUSIONS; P.J. Sylvester¹, L. Grossman^{1,2} and G.J. MacPherson³, ¹Dept. of the Geophysical Sciences, ²Enrico Fermi Institute, Univ. of Chicago, Chicago, IL 60637, ³Dept. of Mineral Sciences, Smithsonian Institution, Washington, DC 20560

Compositions of Allende inclusions have been used to construct a general scenario of nebular condensation based on the assumption that they are representative of the available inventory of inclusions. Mao *et al.* [1] cast doubt on this assumption when they analyzed five refractory inclusions from Leoville and Vigarano, members of the reduced subgroup of C3V meteorites [2], and found that three of them had refractory element anomalies which are rare in inclusions from Allende, a member of the oxidized subgroup. We have examined this matter further by analyzing the bulk compositions of one additional Leoville and ten additional Vigarano inclusions by INAA.

The Leoville inclusion and most of the Vigarano inclusions have Group I REE patterns which suggest that they were isolated from the nebular gas at sufficiently low temperatures to have fully condensed each REE. Leoville 3537-2 is a Type B1 CAI with a slight enrichment in the middle REE (La = $15.8 \times C1$, Tb = $19.0 \times C1$, Yb = $16.5 \times C1$) and Sc ($23.2 \times C1$). Vigarano Vlc is a forsterite-bearing CAI that has a similar pattern, except for a small positive Eu anomaly (Eu/Sm = $1.35 \pm .07 \times C1$). Vig 1623-8 and Vig 1623-11 are CAIs that also have positive Eu anomalies, but are HREE-enriched (La = $17.0 \times C1$, Yb = $20.5 \times C1$ in Vig 1623-8 and La = $13.7 \times C1$, Yb = $18.8 \times C1$ in Vig 1623-11). Inclusions enriched in the middle REE, HREE and Sc may have been preferentially sampled for fassaite, which partitions these elements relative to LREE during crystallization from melt.

Vig 1623-5 is a fassaite-, olivine-rich FUN inclusion [3]. It is LREE-depleted (La = $8.6 \times C1$, Sm = $13.7 \times C1$, Lu = $14.4 \times C1$) with a large depletion in Eu ($<1.5 \times C1$) and a large enrichment in Sc ($61.5 \times C1$). This may be a Group I inclusion but our sample is clearly dominated by the chemical characteristics of pyroxene crystallized from a melt. It is possible that we sampled this phase preferentially, as only a few grains of this inclusion were available for analysis. Unlike the FUN inclusion HAL [4], which condensed under oxidizing conditions, there is no negative Ce anomaly in Vig 1623-5, although V, which is more volatile than Ce in an oxidizing gas, is depleted relative to La (V/La = $.25 \pm .01 \times C1$).

Vig 1623-10 is a relatively MgO-rich (43.8 %), CaO-poor (4.4 %), Al₂O₃-poor (5.69 %) inclusion with low and rather constant enrichment factors for REE ($3.2-4.9 \times C1$), Sc ($4.1 \times C1$) and refractory siderophiles (Ir = $4.8 \times C1$), suggesting that it is a mixture of Group I CAI-like material with large amounts of a MgO-rich, refractory element-poor phase such as olivine. Vig 1623-13 is a barred olivine chondrule (MgO = 34.0 %, FeO = 3.71 %, CaO = 9.9 %, Al₂O₃ = 15.2 %, Na₂O = .49 %) with low Sc ($10.4 \times C1$) and REE (Tb = $7.1 \times C1$, Yb = $7.4 \times C1$) enrichment factors, a slight depletion in LREE (La = $5.4 \times C1$) relative to HREE and low enrichments in refractory siderophiles ($<5 \times C1$). The chondrule was probably melted from a mixture of Group I CAIs and lower temperature condensates.

Several Vigarano inclusions do not have Group I REE patterns. Vig 477-5 is a fluffy Type A CAI in which LREE (Sm = $21.8 \times C1$) are slightly less enriched than HREE (Tb = $25.8 \times C1$, Lu = $25.1 \times C1$). The REE pattern is unusual in having a small negative Ce anomaly (Ce/La = $.82 \pm .01 \times C1$) and a large negative Yb anomaly (Yb/Lu = $0.57 \pm .02 \times C1$) unaccompanied by a large negative Eu anomaly (Eu/Sm = $1.10 \pm .02 \times C1$). Group III REE patterns are characterized by large negative Eu and Yb anomalies. They formed by removal of condensates from the nebular gas at temperatures too high for Eu and Yb, the two most volatile REE, to have completely condensed. If removal had occurred at a slightly higher temperature, Ce, the next most volatile REE, would also have a small negative anomaly. But for the absence of a negative Eu anomaly, Vig 477-5 appears to have formed in this way. Perhaps it accreted from high temperature condensates which were depleted in Ce, Eu and Yb and lower temperature melilite, which has a much greater crystal-chemical preference for Eu than Yb.

Vig 1623-14 and 1623-16 are pink, fine-grained, spinel-rich inclusions that have Group II REE patterns. Vig 1623-14 is similar to most Allende Group II inclusions in that Tm and the LREE are comparably enriched ($\sim 40 \times C1$), the other HREE are progressively depleted with increasing Z (Tb = $23.7 \times C1$, Dy = $16.1 \times C1$), and Eu ($4.5 \times C1$) and Yb ($6.7 \times C1$) exhibit negative anomalies. Refractory siderophiles ($<5 \times C1$) and Sc ($5.5 \times C1$) have low enrichment factors. Group II inclusions are explained by condensation from a solar gas after removal of an early condensate containing the most refractory lithophiles (Sc and the HREE, except Tm and Yb) and siderophiles. The most volatile REE, Eu and Yb, are depleted in Group II inclusions because they did not fully condense at the temperature at which the inclusions were isolated from the gas.

Vig 1623-16 has a modified Group II REE pattern, with LREE (La = $5.8 \times C1$, Sm = $8.3 \times C1$) depleted relative to Tm ($23.6 \times C1$) and enriched relative to Tb ($1.90 \times C1$) and Dy ($<1.7 \times C1$), and with La fractionated from Ce (La/Ce = $.59 \pm .01 \times C1$). Scandium ($1.05 \times C1$) and refractory siderophiles ($<1 \times C1$) are depleted relative to LREE, but Eu ($6.95 \times C1$), Yb ($8.0 \times C1$) and V ($6.9 \times C1$) are not. Such a pattern has been reported for only one CAI in Allende, A-2 [5], two in the unique chondrite ALH85085 [6] and one in Leoville,

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3537-1 [1]. A few hibonite and perovskite grains from Murchison [7] also exhibit these patterns. Formation of such modified Group II patterns is caused by removal from the nebular gas of the early, ultrarefractory condensate at relatively low temperatures, so that the most refractory of the LREE are removed along with the refractory HREE. Thus, La, which is more refractory than Ce, was preferentially depleted in the gas from which the inclusions subsequently condensed. In contrast to all but one of the other samples exhibiting modified Group II patterns, Vig 1623-16 equilibrated with the gas at a sufficiently high temperature that Eu and Yb did not fully condense. Thus, condensation proceeded to temperatures more typical of normal Group II inclusions.

Vig 477-B is a Type B1 CAI with a unique REE pattern. Enrichment factors are highest for Tm ($99 \times C1$), somewhat less for the most refractory of the HREE ($Tb = 52 \times C1$, $Dy = 63 \times C1$, $Lu = 53 \times C1$) and even lower for the LREE ($La = 24.5 \times C1$, $Sm = 25.3 \times C1$). Negative anomalies are shown by Ce ($Ce/La = .86 \pm .02 \times C1$), Eu ($Eu/Sm = .62 \pm .05 \times C1$) and Yb ($Yb/Lu = .55 \pm .01 \times C1$). Scandium and the refractory siderophiles are enriched to $55 \times C1$ and $\sim 13 \times C1$, respectively. The REE pattern of Vig 477-B resembles that of an ultrarefractory condensate except for the relative enrichment of Tm, which is about as volatile as Tb, and the relative depletion of Lu, which is the most refractory REE. If the sample contains an ultrarefractory condensate, these differences need to be explained. Perhaps it is a mixture of ultrarefractory condensates and lower temperature, Group II condensates, which are enriched in Tm and depleted in Lu relative to the other refractory HREE.

The Leoville and Vigarano coarse-grained inclusions tend to have lower Na (<585 ppm) and Au (<46 ppb) than their counterparts in Allende (271-8329 ppm Na, 6-765 ppb Au) [8, 9], confirming previous suggestions [1, 10] that CAIs in the reduced subgroup of C3V meteorites are generally poorer in volatiles than those in the oxidized subgroup. Two samples, however, Vig 1623-10 (1670 ppm Na) and Vig 1623-5 (177 ppb Au) are anomalously enriched in these elements compared to other coarse-grained inclusions in the reduced subgroup. The two Vigarano fine-grained inclusions, 1623-14 and 1623-16, have Na (7.14 %, 3.17 %) and Au (<6 ppb, <30 ppb) contents that are indistinguishable from those in Allende fine-grained inclusions (1.08-5.14 % Na, 3-42 ppb Au) [8, 11]. This suggests that while Leoville and Vigarano coarse-grained inclusions may have separated from the nebular gas during secondary alteration at a higher temperature or after a shorter time than their counterparts in Allende, this may not have been so for Vigarano fine-grained inclusions. One Leoville fine-grained inclusion, however, is lower in volatiles than both types of inclusions in Allende and Vigarano [1].

Three out of eleven refractory inclusions in Leoville and Vigarano studied herein and three out of five studied by Mao *et al.* [1] show refractory element characteristics that are rare or absent in those from Allende. Two of the six anomalous samples have modified Group II patterns, one has a large negative Yb anomaly without an Eu anomaly, and another has a unique REE pattern that is similar, but not identical, to an ultrarefractory condensate. These findings seem to confirm the notion that the inclusions sampled by Allende are not representative of all early nebular condensates, or even of all those found in C3V chondrites.

REFERENCES: [1] Mao, X.-Y. *et al.* (1990) *GCA* (submitted). [2] McSween, H.Y. Jr. (1977) *GCA* 41, 1777-1790. [3] Clayton, R.N. *et al.* (1987) *LPSC XVIII*, 185-186. [4] Davis, A.M. *et al.* (1982) *GCA* 46, 1627-1651. [5] Conard, R. (1976) M.S. Thesis, Oregon State Univ. [6] MacPherson, G.J. *et al.* (1989) *Meteoritics* (in press). [7] Ireland, T.R. *et al.* (1988) *GCA* 52, 2841-2854. [8] Grossman, L. and Ganapathy, R. (1975) *Proc. Lunar Sci. Conf. 6th*, 1729-1736. [9] Grossman, L. and Ganapathy, R. (1976) *GCA* 40, 331-344. [10] Bischoff, A. *et al.* (1987) *LPSC XVIII*, 81-82. [11] Grossman, L. and Ganapathy, R. (1976) *GCA* 40, 967-977.