DARK INCLUSIONS IN ALLENDE, VIGARANO, AND LEOVILLE: IMPLICATIONS FOR OXIDATION PRIOR TO FINAL ACCRETION OF CV3 PARENT BODIES

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Dark lithic inclusions (DI) are known to occur in three CV3 meteorites: Allende, Leoville, and Vigarano. The three occurrences have received different amounts of study ranging from Allende DI, which have been the subjects of several studies [1-7], to Vigarano DI, for which only one oxygen isotopic composition has been reported [8]. Because they were incorporated as clasts, DI carry important information about the types of material that were present when CV3 parent bodies formed, and about the processes which predated the accretion of the Allende, Leoville, and Vigarano meteorites. In order to address these issues, we report herein petrologic observations and bulk oxygen isotopic analyses for 9 DI: 6 from Allende, 1 from Leoville, and 2 from Vigarano. The data will be supplemented by the results of major, minor and trace element analyses currently in progress. In addition, we report oxygen isotopic compositions for 3 Leoville DI (1b, 2a, 730118-3) and 1 Vigarano DI (USNM 447). For these 4 samples, there are no petrographic descriptions available.

The DI studied are all angular, black clasts ranging in longest dimension from 0.6 to 2 cm. Texturally, the Allende DI form a sequence in which mineral fragments, chondrules and olivine aggregates contained within them are progressively replaced. Non-replaced examples resemble CV3 carbonaceous chondrites; they contain Type I chondrules, olivine fragments, olivine aggregates and fine-grained spinel-rich inclusions in a fine-grained dark matrix. Compared with the Allende host, DI differ texturally in that chondrules are slightly smaller in size (<0.5mm) than normal Allende chondrules. With increasing degree of replacement, mineral fragments and chondrules decrease in abundance in favor of porous aggregates of platelike Fe-rich olivine ($Fo_{61\pm3}$) (noted in [6,7]). The most extensively replaced DI clasts also have silicate rims separating them from host Allende. Diopside occurs as the innermost rim material ($En_{16-40}Fs_{14-35}Wo_{45-52}$, 0.6-3.1% Al_2O_3) and finely intergrown hedenbergite and andradite occur as the outermost rim material. Nepheline and andradite fill interstices between platelike Fe-rich olivines in the interior of the DI. Nepheline also occurs within the silicate rims, apparently filling voids. Two Allende DI, one of which is described in [3], are composed of very fine grained CV3 matrix-like material and lack chondrules, refractory inclusions, and their replaced equivalents, the porous aggregates of Fe-rich olivine. Texturally, it is not clear how these DI are related to the replacement sequence.

Oxygen isotope data for Allende DI, including data from [5] and [9], form a linear array of slope approximately one on the three-isotope diagram at the upper end of the Allende mixing line (Table 1, Fig. 1). The array appears to have a slightly shallower slope than the Allende mixing line, but the limited range of the DI data precludes a firm conclusion that the array differs in slope from the mixing line. The new data clearly indicate that the oxygen isotopic composition of the DI correlates with the degree of replacement. Non-replaced examples fall nearest the bulk Allende value on the lower end of the DI array; completely replaced examples fall near the upper end of the array. The correlation indicates that replacement and oxygen exchange were coupled.

The silicate rims on the most extensively replaced DI in Allende constrain the conditions under which the DI were processed. Andradite, which occurs in the outermost rimming material, is stable with respect to magnetite and wollastonite only at low temperatures (T) and high fO_2, and has no stability above ~1250K at 10^{-3} bar (calculations using data from [10,11]). The Fe-rich composition of the platelike olivines provides further evidence that the DI processing took place at low T and/or high fO_2. However, the values of fO_2 required by the olivines, assuming that they formed by reaction of enstatite and metal [12], are several orders of magnitude lower than those required to stabilize andradite at reasonable ranges of T and fO_2. The sequence: Fe-poor olivine, followed by Fe-rich olivine, followed by andradite, requires large increases in fO_2, large decreases in T, or a combination of both factors over the course of DI processing.

Leoville and Vigarano DI are similar to Allende DI in their Fe-rich mineralogy and oxygen isotopic compositions (Table 1 and [8, 13, 14]). On the three isotope diagram, the DI data for each of the two meteorites extend from near the bulk meteorite values to more ^{16}O-depleted compositions, much like the Allende DI array (Fig. 1). The data from Leoville and Vigarano extend to heavier values than the Allende DI, and the data arrays for them clearly have slopes shallower than the CAI mixing lines for their respective hosts. Also, the DI arrays extend beyond the mass fractionation line which joins Murchison (CM2) matrix and Murchison calcite. The data, therefore, do not reflect aqueous alteration of the type that affected Murchison, as suggested in [13].

We conclude that DI were formed by the following sequence of events: (1) Accretion of the DI constituents-chondrules, CAI and matrix-onto a parent body, (2) Impacts on the DI parent body, and ejection of angular fragments, (3) Replacement of DI constituents by Fe-rich olivine by reaction with a low T and/or oxidizing nebular gas, (4) Formation of rims on the DI in the presence of a still lower T and/or more oxidizing nebular gas, and (5) Incorporation of the rimmed DI as clasts in CV3 parent body(ies). The displacement of Allende, Leoville and Vigarano DI to the right of their respective CAI mixing lines on the three-isotope plot is compatible with DI processing (events (3) and (4)) at low T. The displacement is what one would expect of silicates exchanging with the nebular gas below ~550K when H_2O was the dominant oxygen carrier [15].

Further, the progressive increase in fO_2 with mineral paragenesis that is evident in Allende DI may have significance for the oxidized and reduced groups among the CV3 meteorites [16]. If the processing that affected Allende DI operated during the formation of other CV3 meteorites, as appears to be the case for Leoville and Vigarano, then it provides a mechanism for producing the observed range of oxidation states. Such a model would require that oxidized CV3's be depleted in ^{16}O relative to reduced CV3's. The existing bulk CV3 data are provocative in that they appear to show such a relationship, but a more definitive test of the model awaits more precise characterization of the bulk isotopic compositions of CV3 meteorites. The small number of reduced examples among the known CV3's is particularly troublesome in defining the range of compositions for that group; new CV3 recoveries in Antarctica may resolve this sampling problem.

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Table 1. Oxygen Isotopic Compositions of Dark Inclusions.

	$\delta^{18}O$ (SMOW)	$\delta^{17}O$ (SMOW)		$\delta^{18}O$ (SMOW)	$\delta^{17}O$ (SMOW)
Allende			Leoville		
4294	3.43	-1.01	4337	9.53	3.13
4297	4.05	-0.47	1b	9.98	3.90
4301	5.76	0.99	2a	12.09	5.76
4314	3.41	-1.02	730118-3	11.25	4.16
4320	3.96	-0.48	Vigarano		
4322	5.93	1.13	2226DI1	4.29	-0.82
			2226DI2	4.33	-0.71
			USNM 477	1.58	7.4

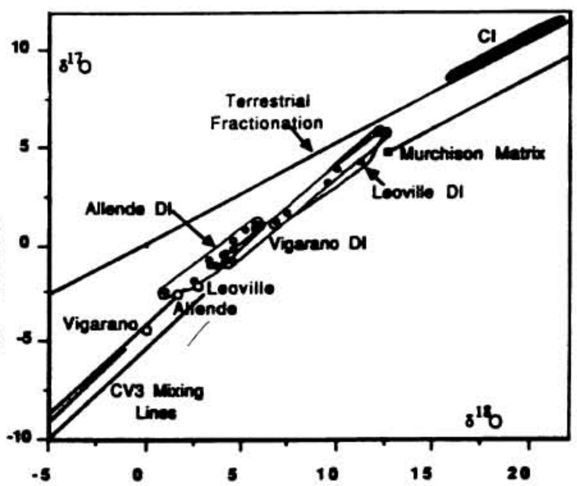

Fig. 1. Oxygen isotopic compositions of Allende, Leoville and Vigarano DI (filled circles) and bulk meteorite samples (open circles) with CAI mixing lines for the 3 meteorites.