A PETROLOGIC AND OXYGEN ISOTOPIC STUDY OF SIX ALLENDE DARK INCLUSIONS: EVALUATION OF NEBULAR VS. ASTEROIDAL MODELS FOR THEIR ORIGIN. M. K. Weisberg[1], M. Prinz[1], J. S. Boesenberg[1], G. Kozhushko[1], R. N. Clayton[2], T. K. Mayeda[2] and M. E. Ebihara[3]. (1) Dept. Earth Planet. Sci., Amer. Mus. Nat. Hist., NY, NY 10024, (2) Enrico Fermi Institute, Univ. Chicago, Chicago, IL 60609, (3) Dept. Chem., Tokyo Metro. Univ., Hachioji, Tokyo, Japan.

Summary: Dark lithic inclusions (DIs) are important components in chondrites because they are records of complex events that clearly predate incorporation into their host chondrites. In CV and CR chondrites most DIs show a bulk chemical and oxygen isotopic association with their host chondrites. Allende DIs have recently sparked considerable debate as to whether their unusual characteristics represent primary aggregates of materials overprinted by metasomatic exchange in the nebula [1,2] or are secondary materials which were affected by aqueous alteration and subsequent dehydration by heating after accretion [3,4]. To address the broad question as to their origin and relationship to their host chondrite we carried out a petrologic and oxygen isotopic study of six newly found DIs from the Allende CV3 chondrite. We conclude that some of the characteristics of Allende DIs are difficult to explain by a process of heating/dehydration of pre-existing phyllosilicates, but are also difficult to explain entirely by a process of condensation. The issues are complex and require experimental study to help resolve some of the questions.

Results: **Texturally**, the DIs are lithic clasts that contain chondrite components, including chondrules or porous chondrule-like aggregates, mineral fragments, and refractory inclusions, all embedded in a fine-grained porous aggregational matrix. The six DIs range from having <1-50 vol.% chondrule-like aggregates (+ refractory inclusions and fragments), with the upper value in the range for CV3 chondrites. The ones with few chondrules are mainly matrix-like material with no chondrule ghost textures or any evidence that they ever had a greater chondrule abundance. The average chondrule diameter in each inclusion we studied is smaller (≤400µm) than that in the Allende host (~760µm). Chondrule-like aggregates in one inclusion show a lineation, consisting of elongated oval-shaped aggregates with a preferred orientation. The other 5 inclusions have spherical to semi-spherical chondrules/aggregates. The chondrule-like objects are generally aggregates of tabular to platy crystals (up to ~30µm in length) of Fe-rich olivine (a highly unusual morphology for olivine) mixed with high-Ca pyroxene which is mostly Fe-poor diopside; however, in some cases hedenbergite is also present, as well as minor amounts of a feldspathic component, generally nepheline. Some chondrules contain forsterites which are zoned with Fe-rich edges that are similar in composition to the platy olivine. The core/rim boundaries of these olivines are nearly always in sharp contact, resulting in steep zoning profiles. Some core/rim boundaries are marked by submicrometer-sized chromite and pentlandite inclusions. One DI (4884-2) is very similar to a previously studied inclusion called Allende AF [1,2]. Its aggregates superficially resemble normal chondrule textures, but with stacked platelets of olivine which formed equant crystal outlines. These unusual olivine morphologies in AF led Kurat et al. [1] to hypothesize that they are proto-chondrules, whereas Tomeoka et al. [3] concluded that they are pseudomorphs after chondrules. One unusual aspect of 4884-2 is chondrule-like aggregates consisting of forsterite in close contact with fayalitic olivine, and diopside in sharp contact with hedenbergite, attesting to the highly unequilibrated nature of the DIs. The matrix of the six DIs is mainly a haphazard mixture of platy (up to ~10µm in length) and irregular-shaped olivine and diopside that is generally finer-grained than, but compositionally similar to, the platy olivine in the aggregates. **Modally** (major and minor mineralogy), the six inclusions differ markedly from host Allende (or any CV3) in having 77-87 vol.% olivine, 8-12 Ca-pyroxene (mainly diopside), 1-4 feldspathic component (mainly nepheline), up to 1 spinel, 2-6 sulfide (mainly pentlandite), and up to 0.3 awaruite. Low-Ca pyroxene is absent. **Mineral compositions** indicate a highly oxidized assemblage for all six DIs. The platy olivine ranges in composition from Fa_{32-45} with up to 2.2wt.% Al_2O_3, 0.2 TiO_2, 1.3 Cr_2O_3, and 0.3 CaO. Most olivine contains submicrometer-sized Al-rich spinel inclusions and, although these were avoided during microprobe analysis, it is possible that some or all of the Al found in the olivine is due to overlap with these inclusions during analysis. The diopside ranges from $Fs_{0.6-4.5}$, Wo_{34-49}, with <0.1-1.5 TiO_2, 0.8-10.5 Al_2O_3, <0.1-1.4 Cr_2O_3, and <0.1-1.5 MnO. A TEM study of other DIs from Allende shows that the diopside is also filled with submicrometer-scale inclusions of ilmenite, chromite and pentlandite [5]. Thus, some of the minor elements detected in the diopside may also be due to phase overlap during microprobe analysis; however, some diopsides are homogeneous suggesting that this is not the case. **Oxygen isotopic compositions** of the six DIs plot near previously analyzed Allende DIs [6-9] and are close to or on the Allende mixing line suggesting that they probably share a common history with other components in Allende (Fig. 1). DIs from the Vigarano CV3 chondrite are slightly displaced from the Allende DI line, as are four Leoville inclusions (Fig. 1). Two Allende DIs that have <1% chondrules, and are essentially all matrix, plot at the ^{16}O-rich end of the trend close to Allende host matrix suggesting they are closely related materials.

Discussion: The heating/dehydration model for formation of Allende DIs [3,4] has uncertainties, as does the nebular model. In dehydrated chondrites, such as Y793321, a phase intermediate between phyllosilicate and olivine occurs [10], but no evidence of such a phase is found in Allende DIs. The oxygen isotopic signatures of the Allende DIs do not appear to reflect any major degree of hydration, unless a major reinterpretation of the oxygen data is undertaken. The high modal abundance of olivine and absence of low-Ca pyroxene in the Allende DIs presents a problem, since heating/dehydration experiments on the Murchison CM chondrite result in formation of low-Ca pyroxene or some Si-rich phase in addition to the olivine, as required by mass balance. The lack of textural and compositional equilibrium is not necessarily expected from thermal metamorphism and requires a rapid disequilibrium process; although this is possible on a parent body it could also be the result of a nebular process. One major petrologic argument against a condensation model for the DIs is that both the fayalitic olivine and diopside grains contain numerous inclusions of pentlandite, oxides, and spinels which, in some cases, are rimmed by poorly graphitized carbon [5]; this presents a difficult obstacle for a condensation model since it requires formation of hydrocarbons, at very low temperatures, prior to growth of the olivine and diopside. In conclusion, we see problems with both nebular and parent body models for formation of Allende DIs. Nevertheless, we see less problems with a nebular model for formation of the DIs which includes condensation of some olivine in an oxidizing nebula along with metasomatic exchange reactions to result in the formation of the phases such as nepheline and hedenbergite.

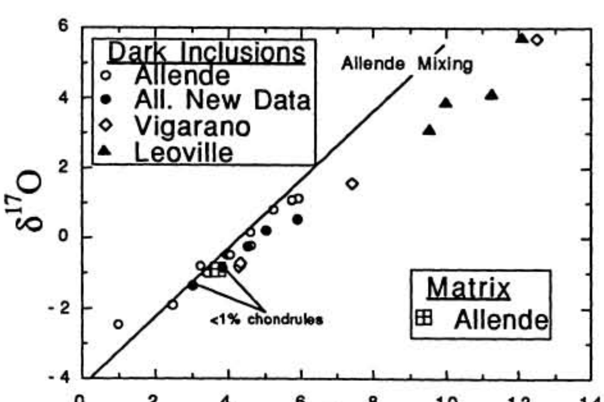

Figure 1

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