**CLARITY AND CONFUSION: THE HISTORY OF ALLENDE CHONDRULES AS EVINCED BY OXYGEN ISOTOPES.** R. D. Ash[1] and E. D. Young[1], [1]Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR, UK (Richard.Ash@earth.ac.ox.uk).

**Introduction:** The Allende (CV3) meteorite has played a pivotal role in our understanding of the early history of the solar system; a result of it's abundance and the coarse grainsize of its constituent parts, *i.e.* chondrules, CAIs *etc.* However recent work has suggested that it is not a pristine sample of the solar nebula but has undergone secondary, parent body metasomatism. We have continued our study of oxygen isotopes in well characterised chondrules from Allende [1] to determine the degree and provenance of these secondary processes.

Conventional analyses of mineralogical components in Allende CAIs show that they are in isotopic disequilibrium, but similar studies have not been possible for chondrules due to their small size. However conventional bulk analyses show that chondrules are arrayed along and slightly above the CCAM line on a three isotope plot [2]. However correlations with size, mineralogy, texture and chemistry have proven difficult.

Initial results from high precision bulk data and high resolution mineral specific data were reported last year [1] and suggested a well defined Allende Mass Fractionation (AMF) line with a $\Delta^{17}O$ of *ca.* –2.8‰. A subset of chondrules lie on this line, most of which are relatively pristine; with alteration limited to iron enrichment at the edges of the chondrule. The oxygen isotopic systematics of these chondrules are those expected from the crystallisation of chondrules from a melt. The altered chondrule edges have isotopic ratios similar to that of the chondrule mesostasis. Other Allende components also lie on this line, including ion probe measurements of magnetite [3] and a matrix separate [4] as well as a significant proportion of bulk chondrules [2].

The chondrule with oxygen ratios not on the AMF line are inconsistent with such a simple crystalisation but shows evidence for non-equilibrium oxygen isotope systematics arranged along the CCAM line, with relatively unaltered regions showing the most $^{16}O$ enriched ratios and the Fe-Na-Cl enriched, altered areas exhibiting oxygen ratios close to the heavy end of the AFM.

**Samples and Techniques:** Chondrules were separated from a crushed sample of Allende, split in half. One half was used for Mg isotope analysis (see Galy *et al*. this volume), the other for textural, petrographic and mineralogical characterisation (JEOL SEM) and oxygen isotope ratio analysis. Oxygen isotope analysis was carried out using the UV laser fluorination system at the University of Oxford [5]. Sample requirement are such that a pit *ca.* 50μm square yields sufficient oxygen for an analysis with a precision in $\delta^{17}O$ and $\delta^{18}O$ of ±0.3-0.4‰. Thus large single minerals or groups of finer grained minerals may be analysed within the chondrules.

**Results:** Chondrule masses (including rims where present) textures and mineralogy are outlined below. Oxygen data have not been obtained on all chondrules but are included for completeness (see GALY *et al*. this volume)

*Allende A2*: (11.08mg) Radial pyroxene. Largely enstatite with interstitial diopside and sodium-rich feldspathic material. The edges show some iron enrichment accompanied by a rise in Na and Cl in the mesostasis.

*Allende A3*: (17.68mg) Porphyritic olivine with thick, pyroxene-rich rim. A single large olivine grain surrounded by smaller grains of similar composition (Fa10). Also some scattered magnetite .

*Allende A4*: (2.22mg) Aluminium-rich chondrule with small (*ca.* 20μm) spinel scattered throughout acicular Al-rich pyroxene, and throughout the feldspathic groundmass. The chondrule shows evidence for heterogeneous alteration, with the edges and some central patches enriched in Fe-Cl-Na. The spinels and pyroxene are zoned with Fe-rich edges. Interestingly this is the chondrule which shows a $^{26}Mg$ excess [GALY *et al*,., this volume].

*Allende A5*: (2.75mg) Porphyritic olivine-pyroxene. Olivine with iron-rich edges poikilitically enclosed by pyroxene with Ca-rich feldspathic mesostasis. Some areas are altered with Na & K-rich mesostasis.

Allende A6: (13.53mg) Porphyritic olivine. Forsteritic olivine with blebs of troilite and taenite, the latter largely oxidised. The chondrule edges are also enriched in iron with the formation of iron-rich pyroxene in some areas.

*Allende A7*: (12.36mg) Barred olivine with thick, coarse rim. Wide homogeneous olivine bars (Fo5) in feldspathic mesostasis, the latter is locally with up to 4% Cl in areas which correlate with enrichments in Fe and Na. The rims are largely olivine and pyroxene with interstitial Ca-rich feldspathic material.

*Allende A8*: (30.07mg) Porphyritic olivine with thick rim. The core mesostasis is highly altered.

*Oxygen*: The oxygen isotopic abundances conform broadly to observations made previously, and are shown below in Figure 1.

One group of chondrules are arrayed on the AMF line ($\Delta^{17}O$ *ca.* -2.85‰) with their primary minerals lying toward isotopically lighter ratios. Their corresponding mesostases, which has invariably undergone alteration and new mineral growth, is isotopically

heavier than the co-existing primary minerals, with ratios approaching those measured for Allende matrix [4].

A second group of chondrules lie on or close to the CCAM line and show isotopic systematics which indicate a primary mineralogy which is $^{16}$O-rich, but with $^{16}$O-poor alteration, again with an oxygen isotopic abundance strongly trending toward that of the matrix. This results in unequilibrated oxygen isotope systematics within single chondrules such that $^{18}$O/$^{16}$O and $^{17}$O/$^{16}$O vary along the CCAM within individual chondrules on a micron scale.

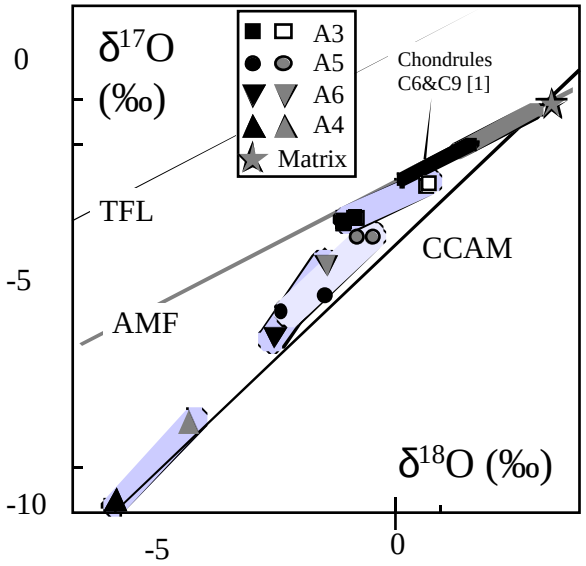


Figure 1. Oxygen isotopes in Allende chondrules. Black points are unaltered material, grey points are analyses of altered regions. White squares are rim and black squares core data from Allende A3. Matrix is from [4]. Data from chondrules C6 and C9 are from [1]. N.B. The isotopically light triangular data are measurements of the Al-rich chondrule A4. The precision of the data is a little worse than the size of the symbols (*ca.* ±0.3-0.4‰)

**Discussion**: The mineralogical studies have shown that all of these Allende chondrules have undergone metasomatic alteration which has resulted in the iron enrichment of some phases, the co-enrichment of alkalies, iron and halogens and the growth of new minerals such as sodalite and nepheline. The new oxygen isotope data confirm that this metasomatism is accompanied by the modification of oxygen isotopic abundances in the chondrules, either by exchange, diffusion or the growth of new minerals. The isotopic modification is the result of interaction with a reservoir of oxygen which has a composition common to all the chondrules. The data for the chondrules may be explained if this common oxygen reservoir is isotopically indistinguishable from Allende matrix (as defined in [4]). Furthermore the two refractory chondrules, Al-rich chondrule A3 and the forsteritic chondrule C8 (from [1]), show oxygen isotope systematics identical to Allende CAIs, with multiple analyses arrayed along the CCAM line. In the case of the chondrules the position along the CCAM line can be correlated with the degree of alteration in the form of Fe-Cl-Na enrichment, mesostasis leaching and secondary growth of minerals such as sodalite and nepheline. Primary minerals with low iron abundances and little textural evidence for metasomatism have the most $^{16}$O-rich isotopic abundances, conversely where there is evidence for alteration the isotopic abundances approach that of the matrix.

The chondrules whose primary minerals already lie on the AMF line clearly cannot be disturbed from this line by alteration, merely moved along it toward the Allende matrix point. This is what is seen in the altered, recrystalised mesostasis, in the iron enriched, altered areas (C6, C9 [Ref.1]) and in chondrule rims which show that these too tend to be isotopically more matrix-like than their corresponding cores. In chondrule Allende A6 there may be a complication from the presence of a significant quantity of magnetite (from the oxidation of metallic iron) which has been shown, by ion probe analysis [3], to lie toward lighter compositions, but still on the AFM line. Thus the admixture of some of this magnetite would result in isotopic ratios slightly lighter than other chondrules devoid of magnetite.

The correlation between metasomatic reactions and oxygen isotope modification suggests that they have a common cause, but the provenance of this alteration, whether nebular or parent body, has provoked much debate. Nebula alteration has the advantage of explaining the similarity in primary isotopic characteristics of both chondrules and matrix – they simply formed form the same materials, and alteration during accounts for the fayalite formation and volatile enrichments. Recent mineralogical evidence suggests that Allende matrix was formed by low temperature parent body recrystalisation [6] which would suggest a pervasive alteration mediated by fluid flow on the parent body [7].

**Conclusion:** All Allende chondrules and probably CAIs, whatever their initial oxygen isotopic signature, have undergone metasomatism accompanied by oxygen isotope exchange with a single reservoir with isotopic characteristics indistinguishable from present matrix.

**References:**

[1] Ash *et al*. (1999) *LPS XXX*. [2] Clayton *et al.* (1983) *In:* Chondrules and Their Origins. *Ed.* E.A. King Jr. Lunar Planet. Inst., Houston. 37. [3] Choi *et al.* (1997) *EPSL 146* 337. [4] Clayton & Mayeda (1999) *Geochim. Cosmochim. Acta 63*, 2089. [5] Young *et al*. *Geochim. Cosmochim. Acta 62*, 3161. [6] Brearley (1999) *Science 276*, 1103. [7] Young *et al*. (1999) *Science 286*, 1331.