

OXYGEN ISOTOPE SYSTEMATICS IN ALLENDE CHONDRULES. R. D. Ash¹, E. D. Young², C.M.O'D. Alexander¹, D. Rumble III¹, and G.J. MacPherson³. ¹Carnegie Institution of Washington, 5251, Broad Branch Road NW, Washington DC 20015 (e-mail ash@gl.ciw.edu), ²Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR, UK. ³Department of Mineral Sciences, MRC NHB-119, National Museum of Natural History, Smithsonian Institution, Washington DC 20560.

Introduction: We have measured oxygen isotopes in petrographically characterised chondrules from Allende (CV3) using high precision UV laser fluorination techniques. Until recent instrumental developments these studies have been impossible. Conventional techniques require large sample sizes and ion probe methods do not have the requisite high precision to enable small isotopic effects to be resolved.

Techniques: We used the Carnegie Institution UV laser fluorination system, coupled with conventional mass spectrometry for high precision, low spatial resolution (500-800 μ m spot size), pseudo-bulk chondrule analyses [1]. The precision using this technique is typically $\pm 0.1\%$ for both $\delta^{17}\text{O}$ and $\delta^{18}\text{O}$, with a reproducibility for $\Delta^{17}\text{O}$ of *ca.* 0.04‰. In addition we have used the Oxford University high spatial resolution (*ca.* 80 μ m spot size) laser fluorination GCIRMS technique [2] for the *in situ* analysis of individual mineral phases within separated chondrules. The precision is somewhat lower for $\delta^{17}\text{O}$ and $\delta^{18}\text{O}$ and for $\Delta^{17}\text{O}$ is *ca.* $\pm 0.2\%$.

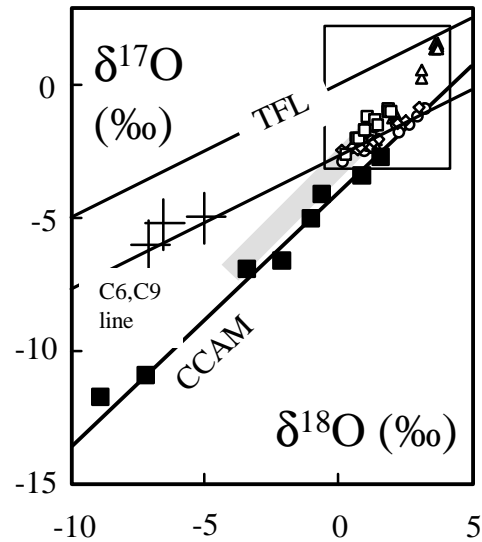
Results: The bulk chondrules fall within the range observed previously [3], although none of the three barred chondrules lie in the exclusive ¹⁶O-poor, barred olivine field [3]. Four chondrules have thus far been analysed in detail using the GCIRMS system and these data are shown and discussed below.

The oxygen isotopes in individual minerals show two distinct trends. Two of the chondrules (C6 and C9) exhibit apparent internal mass fractionation between olivine/pyroxene and mesostasis, whereas the other two (C8 and C13) each show an array of compositions defining slope 1 lines. These modes of behaviour are not related to texture as each group contains a barred chondrule and a porphyritic chondrule.

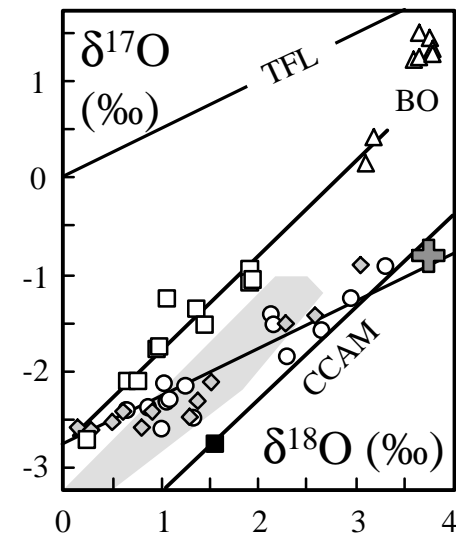
Chondrule C6 is a coarse barred olivine (29.23mg) chondrule with devitrified mesostasis consisting of albitic feldspar and enstatite. The chondrule edges and patches of the mesostasis are Cl-rich. The mineral oxygen isotopic composition lie on an apparent mass fractionation line with a mean $\Delta^{17}\text{O}$ of -2.75‰. The range in $\delta^{18}\text{O}$ for the olivine is between +0.6 and +1.4‰ and for the mesostasis from +2.1 to +3.3‰.

Chondrule C8 (13.88mg) has 10-40 μ m porphyritic olivine (Fo>99) grains in a poorly defined radially textured mixture of pyroxene and feldspar. Some regions of the chondrule have undergone alteration characterised by leaching and Fe, Cl and Na enrichment. In these altered areas the olivine has same size distribution, crystal habit and abundance, as in the pristine areas but is iron rich, highly zoned and shows reaction rims with the surrounding material. The

oxygen isotopic compositions of C8 minerals lie on



Filled boxes = Allende C8. Allende CCAM from [4]. Crosses = magnetite from [5]. Shaded area porphyritic chondrules [3].



Open boxes C13, circles C6, diamonds C9. With best fit lines. Triangles = barred olivine chondrules, thick cross = Allende matrix [3].

the CCAM line, with $\delta^{18}\text{O}$ values ranging from -8.9‰ to +0.85‰. The ¹⁶O rich regions are characterised by forsteritic olivine whilst altered regions are ¹⁶O poor.

Chondrule C9 [36.93mg] has porphyritic pyroxene with normally zoned 20-90 μ m Fe-rich olivine chadacrysts. Pyroxene grains are typically 0.5-1mm. It has a devitrified mesostasis which is Fe, Na and Cl rich. The oxygen systematics are remarkably similar to C6,

Oxygen isotopes in Allende chondrules: R.D. Ash et al.

with an identical $\Delta^{17}\text{O}$ of -2.75‰ and a $\delta^{18}\text{O}$ range in pyroxene from +0.2 to +1.5‰ and for mesostasis from +1.6 to +3.1‰. Heavily altered, iron-rich areas at the chondrule edge are also isotopically heavy, with $\delta^{18}\text{O}$ values between +2.3 and +2.6‰.

Chondrule C13 (4.88mg) is a fine barred olivine chondrule with oxygen isotopic compositions defining a short, slope 1 line. The line trends from $\delta^{18}\text{O}$ +0.24, $\delta^{17}\text{O}$ -2.68‰ toward the field of Allende barred chondrules [3], reaching a heaviest composition of +1.92, -1.06‰. The fine grained nature of this chondrule (bars typically 10-15 μm) wide, and variable alteration prevent the analysis of individual phases.

Discussion: The figures show the oxygen isotopic compositions of the individual minerals of Allende chondrules. None of the data for individual minerals lie to the right of the CCAM line as is observed for the hydrously altered materials in the CM and CI meteorites [6].

Chondrule C8. The ^{16}O enrichment in this chondrule is associated with the regions containing unaltered forsterite olivine grains. The most extreme enrichments are associated with a region containing ~60% forsterite, surrounded by Fe- and volatile-poor mesostasis. This contrasts with the most ^{16}O -poor C8 data which are from regions adjacent the chondrule edge and to a leached hole where olivines are Fe-rich, as is the mesostasis which is also fractured, porous and enriched in Na and Cl.

This chondrule is not the pristine result of simple equilibrium crystallisation from a melt. The euhedral shape, lack of resorption features and no indication of reaction with the surrounding iron-poor material suggests that the forsterite crystallised during chondrule formation. Thus the ^{16}O compositions of the forsterite are primitive and the ^{16}O poor material is the result of post-crystallisation alteration. This alteration resulted in oxidation, oxygen isotope exchange, leaching and the introduction of Fe, halogens and alkalis.

The near slope 1 array, for C8 minerals, is indistinguishable from the Allende CCAM, defined by minerals separated from CAIs [4], but clearly differs from the bulk chondrule line and the "primitive" CAI slope 1 line [2]. The C8 array is due to either the sampling of varying amounts of the altered and pristine material or to different degrees of alteration.

Chondrules 6 and 9. The oxygen isotope fractionation line defined by these two chondrules is coincident with the compositions of apparently asteroidal features of Allende, *i.e.* the magnetite composition [5], the composition of matrix material [3] and altered CAI melilite [2]. Hence it is tempting to interpret the observed oxygen isotope distribution within these two chondrules as resulting from isotope exchange and re-equilibration during parent body alteration. If this assemblage has equilibrated then the isotopic distribution in the magnetite-olivine-feldspar system [7]

is consistent with an alteration temperature between 400° and 500°C.

Chondrule C13. The fine-grained nature of this chondrule prevented the analysis of single mineralogical phases, so each analysis consists of varying proportions of altered and unaltered olivine and mesostasis. That it trends along a line connecting the barred olivine field [3] with that of the mafic material in chondrule C6 and C9 suggests that the array may be due to sampling of varying degrees of altered and unaltered olivine.

We are seeking further barred chondrules in an attempt to clarify the relationship between these chondrules and the other Allende materials.

A similar situation is observed in the UOCs (*e.g.* Tieschitz [8]) where some chondrules clearly demonstrate internal oxygen isotopic equilibration, apparently related to the composition of the chondrite matrix. Other Tieschitz chondrules lie on a slope 1 line thereby indicating both inter- and intra-chondrule disequilibrium.

Conclusions: Allende shows both inter- and intra-chondrule isotopic disequilibrium. Some chondrules show internal equilibration (C6, C9), and are possibly also in equilibrium with other Allende components. Other chondrules are clearly not in isotopic equilibrium (C8, C13), retaining some pristine, unaltered material. The alteration was extremely localised in extent and heterogeneous in degree.

The fluid responsible for the alteration was oxidising and introduced iron, halogens and alkalis. Oxygen isotopes suggest that this fluid was also responsible for the formation of magnetite, the alteration of CAIs and the oxygen isotopic composition of Allende matrix. The CCAM results from a mechanical mixture between isotopically pristine ^{16}O -rich materials, in this case Fe-rich olivine, and altered material with an oxygen isotope composition close to that of the isotopically equilibrated meteorite matrix.

Whether this alteration took place in the parent body or nebula remains equivocal.

References: [1] Rumble *et al.* (1997) *GCA* **61**, 4229. [2] Young & Russell (1998) *Science* **282** 452. [3] Clayton *et al.* (1983) *In: Chondrules and Their Origins. Ed. E.A. King Jr. Lunar Planet. Inst., Houston.* 37. [4] Clayton *et al.*, (1977) *EPSL* **34**, 209. [5] Choi *et al.* (1997) *EPSL* **146** 337. [6] Clayton & Mayeda (1984) *Earth Planet. Sci. Lett.* **67**, 151. [7] Clayton & Kieffer (1991) *In: Stable Isotope Geochemistry. Eds. Taylor et al. Geochemical Society.* [8] Ash *et al.* (1998) *LPSC*, **XXIX**.