

OXYGEN ISOTOPE HETEROGENEITY IN THE MESOSTASIS OF A SEMARKONA GROUP A1 CHONDRULE Sears D. W. G.^{*}, Lyon I. C.[†], Saxton J. M.[†], Symes S.[‡], and Turner G.[†] ^{*}Cosmochemistry Group, Department of Chemistry and Biochemistry, University of Arkansas, Fayetteville, Arkansas 72701, USA, [‡]SN4 NASA Johnson Space Center, Houston Texas 77058, USA. [†]Department of Earth Sciences, University of Manchester, Manchester M13 9PL, UK.

We have measured the oxygen isotope distribution in a large group A1 chondrule from the Semarkona LL3.0 chondrite in order to explore the formation of chondrules [1] and the causes of oxygen isotope variations between chondrites [2]. Group A1 chondrules are mafic but refractory, having forsteritic olivine grains in an anorthositic mesostasis [3]. About 35% (by number) of the chondrules in the essentially unmetamorphosed Semarkona chondrite are members of group A1 (sometimes referred to as "droplet" chondrules, "type IA" chondrules, "microporphyrritic metal-rich" chondrules, or simply "low FeO" chondrules). The chondrule in this study is unusual for its size (about 800 μm), for its large amount of mesostasis and, most importantly, compositional zoning in the mesostasis [4]. Outer regions of the mesostasis of this chondrule are enriched in Na and other volatiles and depleted in refractories. Matsunami *et al.* suggested that volatiles lost from the chondrule during formation had recondensed into the chondrule during cooling. Grossman suggest that alkaline fluids had interacted with the chondrules [5], although there is no petrographic evidence for this.

We analyzed the same chondrule as Matsunami *et al.*, but as it appeared on the opposing cut face. The apparent diameter of the chondrule in our section was only 400 μm , although it showed all the properties of the opposing half. Oxygen isotope analyses were made with the Manchester Isolab 54 ion microprobe [6]. Analysis craters were about 10 μm in diameter. A synthetic glass with the same composition as group A1 chondrule mesostasis were manufactured at JSC, by fusing mixed oxides in a resistance wire furnace; this glass was used as an ion microprobe standard.

Twenty-four points were analyzed throughout the chondrule mesostasis (Figs. 1 and 2). The data show a very large spread, from ($\delta^{17}\text{O}$, $\delta^{18}\text{O}$) of $\sim(+10\text{‰}, +12\text{‰})$ to $\sim(-4\text{‰}, -2\text{‰})$ with a slope 0.92 ± 0.13 , indistinguishable from that displayed by the equilibrated ordinary chondrites and inconsistent with mass dependent fractionation. Chondrules from ordinary chondrites plot in a tight field in the middle of the mesostasis data. Most significantly, data from central region of the chondrule are depleted in ^{16}O relative to data from the outer regions of the chondrule (figure 2). The central region of the chondrule, which we estimate is $\sim 350 \mu\text{m}$ from the true center of the chondrule, has $\delta^{17}\text{O}$ and $\delta^{18}\text{O}$ values $+5$ to $+10\text{‰}$ while the outer 360-

420 μm region of mesostasis has values of -2 to $+4 \text{‰}$. Preliminary measurement of two olivine phenocrysts show them to have even lighter oxygen than the outer mesostasis region, with ($\delta^{17}\text{O}$, $\delta^{18}\text{O}$) values of $(-4, -7)$ for one and $(-5, -3)$ for the other; they are thus lighter than Semarkona group A1 olivines measured previously.

The considerable isotopic heterogeneity of this chondrule cannot be ascribed to precursor heterogeneity because group A1 chondrules were totally melted during formation. The isotopically heavy mesostasis, compared with the phenocrysts, implies exchange with an ^{16}O -poor reservoir; consistent with the observations of two previous research groups who studied density separates from a range of UOCs (but not Semarkona) [8,9]. In contrast, the gradient in O-isotope composition throughout the present chondrule suggests exchange with an ^{16}O -rich reservoir, consistent with data for Dhajala size-sorted chondrules [2].

The present data suggest interaction with *two* external reservoirs; one at high temperature (presumably just after solidification) and one at lower temperatures (when only the outermost region could exchange). Bridges *et al.* [8] observed that, whilst always heavier than the olivine and pyroxene, the feldspar and glass became lighter as the petrographic grade increased from 3.2 to 3.9, suggesting that metamorphism acted to equilibrate initially ^{16}O -poor mesostasis with the remainder of the meteorite. Assuming that the glass partitions oxygen in a similar way to anorthite, and that the matrix is mainly fine grained olivine and pyroxene, then published fractionation factors [10,11] suggest it should be slightly ($1-2 \text{‰}$) heavier than the matrix at equilibrium. Grossman *et al.* [12] measured the oxygen isotopic composition of several Semarkona matrix samples; they all had $\delta^{18}\text{O} \sim +6 \text{‰}$. Since the chondrule mesostasis rim shows lower $\delta^{18}\text{O}$ values, exchange with the fine grained matrix appears to be an unlikely explanation for the second oxygen exchange event. (We discount O exchange with the chondrule olivine owing to its low diffusion coefficient [13]). Before discounting metamorphism entirely we note that one UOC matrix sample (ALH77299, H3.7) was found to have a lower $\delta^{18}\text{O}$ value [$\delta^{18}\text{O} = -1.7\text{‰}$, 14]; it is also possible that the matrix is inhomogeneous on a small scale. Nevertheless, the simplest interpretation of the available data

suggests that stage two was not parent body metamorphism.

It is therefore possible that both oxygen exchange events predate accretion. This might imply transport between two discrete oxygen reservoirs during chondrule cooling, or that the chondrule was subsequently heated in the presence of a second, different, reservoir (perhaps on the periphery of another chondrule forming event). Alternatively, the chondrule forming event itself may have been the source of mass-independent fractionation. We suggest that the chondrule and ambient gas (perhaps partly derived from volatilized chondrule solids) may have had similar initial isotopic compositions but during chondrule formation the mesostasis became ^{16}O -depleted and the gas ^{16}O -enriched by a mass-independent fractionation process [15]. Gas phase thermal dissociation of Si oxides and condensation are both known to show mass independent fractionation; both these processes may have operated during chondrule formation. After cooling, the outermost part of the mesostasis may have undergone exchange with the now ^{16}O -enriched external reservoir, either directly (gas-solid exchange), or with a condensate (possibly ^{16}O -enriched [15]) which may have rimmed the newly formed chondrule. Having the chondrule forming event as the source of mass independent isotopic fractionation has the advantage of not requiring multiple events and reservoirs and is similar to the proposed mechanism Na

zoning in this chondrule, in that both ^{16}O and Na are lost from the chondrule at high temperatures, but re-enter the chondrule on cooling.

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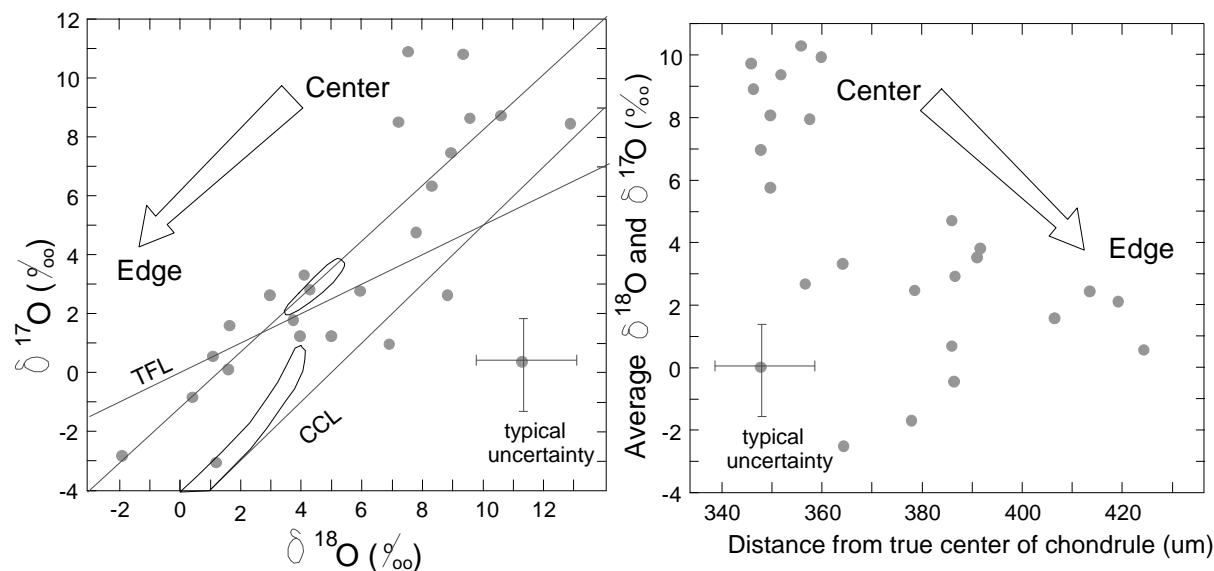


Figure 1 $\delta^{17}\text{O}$ against $\delta^{18}\text{O}$ for compositionally zoned mesostasis in a large Semarkona group A1 chondrule. Typical 1σ uncertainty shown. TFL, terrestrial fractionation line; CCL, carbonaceous chondrite line; unlabelled line, regression line through the present data which is identical equilibrated ordinary chondrite line. Fields for chondrules from ordinary chondrites (smaller field) and chondrules from carbonaceous chondrites [2] are shown.

Fig. 2 (Right) $\delta^{17}\text{O}$ and $\delta^{18}\text{O}$ (averaged to minimize experimental error) against calculated distance from the center of the original chondrule.