

**OXYGEN ISOTOPES IN ISOLATED CHONDRULES FROM THE TIESCHITZ ORDINARY CHONDRITE: INITIAL COMPOSITIONS AND DIFFERENTIAL PARENT BODY ALTERATION.** R. D. Ash<sup>1,2</sup>, D. Rumble III<sup>1</sup>, C.M.O'D Alexander<sup>2</sup> and G.J. MacPherson<sup>3</sup> <sup>1</sup>Geophysical Laboratory, Carnegie Institution of Washington, 5251 Broad Branch Road NW, Washington DC 20015-1305; e-mail ash@gl.ciw.edu. <sup>2</sup>Department of Terrestrial Magnetism, Carnegie Institution of Washington, 5241 Broad Branch Road NW, Washington DC 20015<sup>3</sup>. Department of Mineral Sciences, MRC NHB-119, National Museum of Natural History, Smithsonian Institution, Washington DC 20560.

**INTRODUCTION:** We have used a high precision UV laser fluorination technique [1, 2] to investigate the oxygen isotopic compositions of size sorted, petrographically characterised chondrules from Tieschitz, an H/L 3.6 ordinary chondrite. Chondrules in this meteorite show evidence for varying degrees of aqueous alteration [3]; some chondrules show the effects of heavy aqueous alteration whereas others appear petrographically quite pristine. However Tieschitz has not experienced metamorphic temperatures high enough to significantly re-equilibrate its oxygen isotopic compositions.

Our aim is to deconvolve the original oxygen isotopic signature from the later hydrous alteration overprint.

#### SAMPLES AND TECHNIQUES:

Chondrules were hand picked from a freeze-thaw disaggregated sample of Tieschitz, then were visually inspected and adhering matrix material was removed using tweezers and scrapers. A sub-sample of these chondrules was then cleaned by a compressed-air powered abrasion device to more completely remove loosely adhering and softer material. Thus it was hoped that the abrasion cleaned samples would have less alteration associated with them.

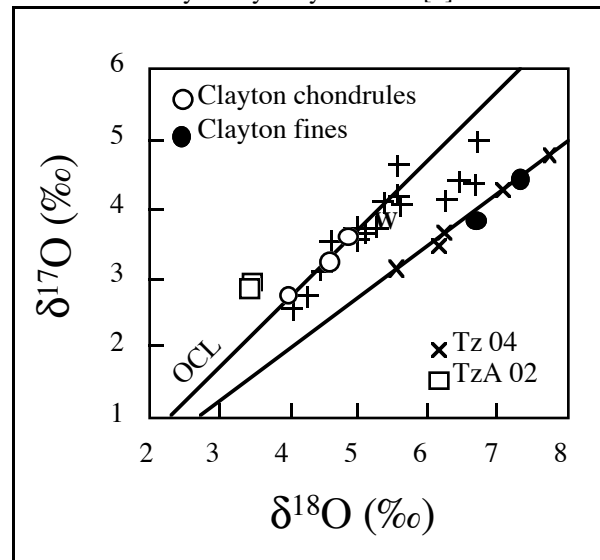
It is probable that there is some sample bias in this selection method. Because of their more friable nature, it is probable that a disproportionately small number of altered chondrules survived the initial sample disaggregation. However, as will be shown, some of these altered samples were in the final aliquot of analysed samples.

Chondrules were weighed, and their diameters measured, hence their densities could be estimated. Samples ranged in mass from 0.41mg up to 76mg.

Samples were loaded into a vacuum chamber for analysis of their oxygen isotopes by UV laser fluorination. The  $1\sigma$  accuracy of this technique is better than 0.15‰ for  $\delta^{17}\text{O}$  and  $\delta^{18}\text{O}$  and ca.0.06‰ for  $\Delta^{17}\text{O}$ . Laser beam diameter was varied depending upon the chondrule size; usually a broad 600-800 $\mu\text{m}$  beam was used but, for smaller samples, this was stopped down to 200-400 $\mu\text{m}$ . Following isotopic analysis, the chondrule remnants were removed for SEM petrographic examination and microprobe mineralogical analysis.

**RESULTS:** The oxygen isotope results for 18 chondrules are shown in Figure 1. Of these, 12 lie on a well defined slope 1 line. Of the remaining six, one

lies to the left of this line and the other five to the right. A best fit line drawn through these points also passes through the data for the three Tieschitz chondrules analysed by Clayton *et al.* [4] which will be



**Figure 1.** Oxygen isotopic composition of Tieschitz chondrules. Errors are smaller than the points. Tz04 is five repeat analyses, TzA02 is two repeat analyses. Other samples are represented by a single point. W is Whole rock Tieschitz analysis from [4].

included in the discussions below. No correlation between chondrule size (or mass) and oxygen isotopic composition is observed unlike chondrule size separates from Dhajala [4] and Chainpur [5], nor do initial petrographic examinations show any correlation with chondrule texture.

There are no systematic differences between the abrasion cleaned chondrules and those which were cleaned solely by scraping. However one chondrule, which was cleaned solely by scraping, lies off the slope 1 line, has a density significantly lower than that of the majority of the chondrules and has a variable oxygen isotopic composition (see Figure 1 for 5 repeat analyses). This chondrule was also somewhat friable and broke upon loading into the chamber.

**DISCUSSION:** *Chondrules on the slope 1 line:* The majority of chondrules from Tieschitz lie on a line with a slope close to 1. This line (henceforth the Ordinary Chondrule Line - OCL) lies extremely close,

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and parallel, to the Equilibrated Chondrite Line (ECL) as determined by Clayton *et al.* [4], in fact they may be the same line.

We interpret this line as strong support for the common origin of all ordinary chondrite chondrules arising from a two component mixing between  $^{16}\text{O}$ -rich and  $^{16}\text{O}$ -poor end members. Comparing these Tieschitz data with those for other ordinary chondrite chondrules [4,6] there is a preponderance of chondrules from other, non-hydrously altered meteorites to lie on the same slope 1 line. Chondrules from the hydrously altered UOCs form a miasma of data points with more  $^{18}\text{O}$ -rich compositions, presumably from interaction with  $^{18}\text{O}$ -rich waters [4].

One implication is that, during the chondrule forming event there was no recorded mass dependent fractionation of oxygen isotopes as this would move oxygen isotopes away from the slope 1 mixing line.

*Chondrules lying off the slope 1 line:* The scattering of chondrules from the OCL toward more  $^{18}\text{O}$ -rich compositions can be attributed to hydrous alteration and/or the adhesion of matrix material. Multiple analyses of one large, friable chondrule (Tz04) with an anomalously low density, lie off the OCL but do not define a mass fractionation line. These analyses are consistent with a mixing line passing through the composition of fine grained (<8 $\mu\text{m}$ ) material separated from Tieschitz (see Figure 1) [4]. This may be due to the presence of fine-grained matrix material, either on or in the chondrule, or the chondrule and the fine grained matrix experienced a similar hydrous alteration episode. Each of the other  $^{18}\text{O}$ -rich chondrules lying off the OCL are smaller and have more uniform isotopic compositions - possibly reflecting their more pervasive and uniform alteration.

The chondrule lying off the slope 1 line, toward  $^{18}\text{O}$ -depleted composition, has not yet been examined petrographically. Hence whether there is any correlation between isotopic composition and other characteristics remain to be determined. Visual inspection showed no features to distinguish it from any other chondrule. Tieschitz metamorphic temperatures were probably not high enough for the reduction of silicates to produce  $\text{CO}_2$  which has been suggested as a mechanism for the fractionation of the oxygen isotopic compositions of the more metamorphosed, low carbon content whole rock ordinary chondrites which appear lie toward  $^{18}\text{O}$  depleted values [4].

*Chondrule size and  $\delta^{18}\text{O}$ :* The lack of correlation between chondrule size and oxygen isotopic composition in this study may be attributable to the relatively limited range in chondrule sizes analysed. The correlations observed in Dhajala are clearest in bulk analyses of large numbers of chondrules with sizes below 500 $\mu\text{m}$  [4]. A consequence of analyzing chondrule aggregates is that other potential influencing factors (such as texture, degree of heating *etc.*) would

be averaged out. Larger numbers of individual Tieschitz chondrules will need to be analyzed in order to have data for a comparable statistically significant population.

*Speculations:* Intriguingly, an extension of the best fit line of the unaltered chondrules extends through the ordinary chondrite aluminium-rich chondrule field, as defined by Russell *et al.* [7] and ordinary chondrite blue luminescing olivines of Saxton *et al.* [8]. Whilst care must be taken in interpreting these low precision ion probe data, they are consistent with a continuum of oxygen isotopic compositions down to  $\delta^{17}\text{O}$  vs.  $\delta^{18}\text{O}$  of ca -15, -15‰.

The blue luminescing olivines have been commonly interpreted as representing a "primitive", possibly nebula condensate [9]. Furthermore, some of the aluminium-rich chondrules show evidence of live  $^{26}\text{Al}$  when they were formed, which has been interpreted as a sign of their primitive, early nature. Until now there has been no clear link between these primitive, early materials and "normal" chondrules. If these samples do in fact lie on the OCL then this may be indicative of a genetic relationship and that the Al-rich chondrules and blue luminescing olivines represent precursor materials of the "normal" chondrules. Subsequent chemical evolution of these solids produced the majority of chondrules observed in the ordinary chondrites. This evolution towards a "mean" Solar System composition may be temporal, spatial or related to the degree of reprocessing undergone by the individual materials. This reprocessing may have been the chondrule forming event, if so it would imply that the process was, on the whole, remarkably efficient as evinced by the paucity of Al-rich chondrules.

**CONCLUSIONS:** Thus it appears that the vast majority of chondrules found in ordinary chondrites initially lay on a slope 1 mixing line and that subsequent aqueous alteration by  $^{18}\text{O}$ -rich fluids led to alteration and secondary mineral growth causing the general drift of chondrule compositions to more  $^{18}\text{O}$ -rich compositions in unequilibrated ordinary chondrites.

The presence of  $^{16}\text{O}$ -rich, aluminium-rich material at one end of the mixing line and oxidised, iron-rich material at the other could imply an evolutionary trend of equilibration with more oxidising, lower condensation temperature component with radial movement in the nebula, increasing time and/or degree of processing

**REFERENCES:** [1] Rumble *et al.* (1997) *Met. Planet. Sci.* **32** A111. [2] Rumble *et al.* (1997) *G.C.A.* **61**, 4229. [3] Hutchison *et al.* (submitted to *Met. Planet. Sci.*). [4] Clayton *et al.* (1991) *G.C.A.* **55**, 2317. [5] Bridges *et al.* (1997) *L.P.S.C.* **XXVIII**, 155. [6] Ash *et al.* (1997) *Met. Planet. Sci.* **32**, A8. [7] Russell *et al.* (1997) *L.P.S.C.* **XXVIII**, 1209. [8] Saxton *et al.* (1996) *Meteoritics* **30**, 571. [9] Steele (1986) *G.C.A.* **50**, 1379. [10] Russell *et al.* (1997) *Meteoritics Planet. Sci.* **32** A111.