

PRIMARY OXYGEN ISOTOPE DISTRIBUTION IN CHONDRULES AND REFRACTORY INCLUSIONS FROM CV CARBONACEOUS CHONDRITES. R. H. Jones¹, N. G. Rudraswami^{1,2} and K. Ziegler³, ¹Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, ²National Institute of Oceanography, Dona Paula, Goa 403004, India. ³Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131. rjones@unm.edu.

Introduction: Oxygen isotopic compositions of refractory components in carbonaceous chondrites are distributed along the carbonaceous chondrite anhydrous mineral (CCAM) line, which is defined on the basis of high-precision measurements of CAIs from the Allende CV chondrite [1,2] (see Fig. 1). The slope of the CCAM line, 0.94, has been the source of some discussion, because knowing the slope precisely is important to interpreting the process(es) that controlled the initial isotopic distribution in the early solar system. For example, a slope of exactly 1 is predicted by a self-shielding model for oxygen isotope evolution [e.g. 3]. A primitive line of slope 1.00 for unaltered components from a type B1 CAI in Allende is referred to as the Young and Russell (Y&R) line [4] (see Fig. 1). [4] and [5] have suggested that the CCAM line is the result of secondary alteration processes that displaced primary isotopic compositions from the slope-1 line via mass-dependent fractionation processes.

Measurements of bulk chondrule oxygen isotopic compositions from Allende and Mokoia show more dispersion around the CCAM line than do CAIs, especially for ¹⁶O-poor compositions [6-8]. SIMS oxygen isotope analyses on individual mineral grains from Allende and Mokoia chondrules show a systematic difference from bulk chondrule measurements and lie on a line with a slope close to 1 [8,9]. This difference has been attributed to the effect of alteration, which could have displaced bulk chondrule compositions towards the CCAM line [9,10], similar to the process that has been proposed for CAIs.

Allende and Mokoia are both oxidized CV chondrites (CV-ox), in which metal in chondrules has been altered to magnetite, and mesostasis is commonly altered. Both chondrites have also undergone significant metamorphism, with petrologic subtypes estimated as >3.6 (Allende) and 3.6 (Mokoia) [11]. Hence, there is uncertainty about the extent of deviation of bulk chondrule isotopic compositions from primary values for these samples. Currently, the primary oxygen isotope distribution in chondrules from CV chondrites is not known precisely enough to be able to interpret isotopic relationships between chondrules and CAIs.

We are attempting to resolve some of the ambiguities in the oxygen isotope arrays for primitive components (CAIs and chondrules) in CV chondrites, by performing high-precision oxygen isotope analyses of a large number of objects separated from four

chondrites: oxidized CVs Allende and Mokoia, and reduced CVs (CV-red) Vigarano and Leoville. Since Vigarano and Leoville have not undergone aqueous alteration (oxidation), and they are both relatively low petrologic subtypes, both 3.1-3.4 [11], bulk chondrules in these chondrites should have oxygen isotopic compositions that are very close to primary values.

Samples and Analytical Methods: For Mokoia, we analyzed 23 individual chondrules with masses 1 to 6 mg that were prepared previously by disaggregation [12]. For Allende, Vigarano and Leoville, samples of masses ~1, 1.5 and 0.5 g were disaggregated using a freeze-thaw method, and particles of masses around 1-5 mg were separated. Allende material was from PRL, India; Vigarano from MCSNF, Ferrara, Italy; and Leoville from UNM, USA. Material described as "chondrules" was clearly identified as chondrule material after mounting in Crystalbond, polishing, and examination using SEM. These chondrules were subsequently dissolved out of the Crystalbond using acetone, and washed before oxygen isotope analysis. Material described as "CAIs" was not examined in this manner because its fluffy nature made it difficult to mount, so petrologic descriptions are not available. Visual inspection showed that much of this material was white in color and most likely to be CAIs.

Oxygen isotope analyses were performed on 1-2 mg fragments of material using the laser-fluorination method of [13]. Molecular O₂ was extracted in a BrF₅-atmosphere, cryogenically and gas-chromatographically purified, and the isotope ratios measured on a gas source mass spectrometer (Delta PlusXL). Analytical precision for Δ¹⁷O is 0.02 ‰. Isotope values presented here are all linearized.

Results: Oxygen isotope results of individual components from oxidized CVs, Allende and Mokoia, and reduced CVs, Vigarano and Leoville, are shown in Figs. 1a and 1b, respectively. In Fig. 1a, additional data for Mokoia chondrules with masses 2 to 21 mg are from [8]. For the CV-ox chondrites, δ¹⁸O values range from -15 to +5 ‰. Linear regression lines are very similar for all Mokoia chondrules, all Allende samples, and all CV-ox samples combined. The regression line for all CV-ox data has a slope of 0.94 and R² = 0.970. For the CV-red chondrites, δ¹⁸O values range from -32 to +5 ‰. Linear regression lines are very similar for all Vigarano data, all Leoville data, and all CV-red samples combined. The regression line for all CV-red data

has a slope of 0.95 and $R^2 = 0.997$. Regression lines for CV-ox and CV-red data are compared in Fig. 1c.

Discussion: Our new high-precision oxygen isotope data give highly correlated regressions through all data for CAIs and chondrules, for both CV-ox (Fig. 1a) and CV-red (Fig. 1b) chondrites. Chondrules in CV-ox chondrites show more dispersion about the regression line compared with CV-red chondrites, especially for ^{16}O poor compositions, but the slopes of the regression lines are remarkably similar. The offset between the CV-ox and CV-red regressions (Fig. 1c) is statistically significant, with standard errors on the slopes and intercepts of <0.01 and <0.07 respectively.

Our data confirm the slope and intercept of the CCAM line [1,2], which we find to be 0.94 (CV-ox) or 0.95 (CV-red). The CV-red regression is essentially indistinguishable from the CCAM line. Since these observations include reduced CVs, where the effects of secondary processes are minimal, we conclude that the primary distribution of oxygen isotopes in CV chondrite components is that of the CCAM line. The Y&R line with slope of 1.00, which is based on limited data for a single inclusion in a CV-ox chondrite [4], has little general significance for bulk chondrules and CAIs from either oxidized or reduced CV chondrites. It is highly unlikely that alteration of components on the Y&R line would result in the excellent correlations along the CCAM line that we observe.

SIMS analyses of mineral grains from Mokoia and Allende chondrules lie along an array with slope close to 1 [8,9], and this array is very similar to the “Primitive Chondrule Minerals” (PCM) line of [10], based on Acfer 094, that has slope 0.987 (Fig. 1c). The reasons for differences between SIMS and bulk data are not clear, but arguments that bulk composition data have been displaced from a slope-1 line by alteration are weakened by the observation that bulk analyses of CV-red components are similar to CV-ox data.

Bulk oxygen isotopic compositions of CAIs and chondrules from all the CV chondrites studied lie along essentially the same line. This strongly suggests that the process(es) that resulted in the oxygen isotopic distribution along the CCAM line affected both CAIs and chondrules, and that these CV chondrite components shared a closely related isotopic reservoir.

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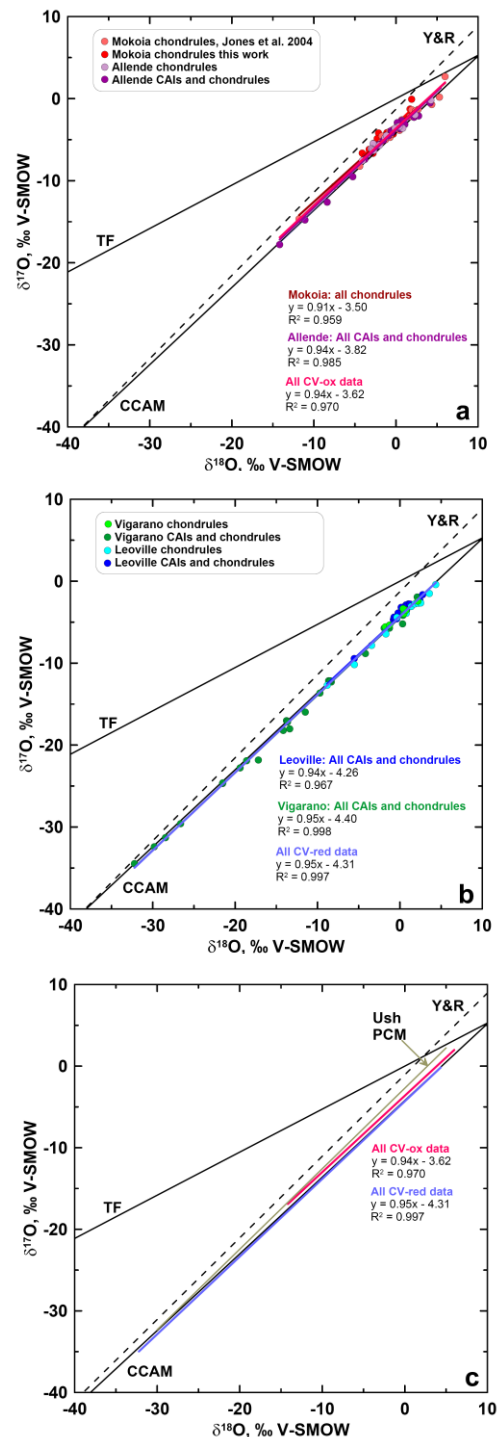


Fig. 1: Bulk oxygen isotopic compositions of chondrules and CAIs from: (a) CV-ox chondrites Allende and Mokoia, (b) CV-red chondrites Vigarano and Leoville. (c) Comparison of regressions for all CVox and all CVred analyses. CCAM line from [1,2], Y&R line from [4], Ush-PCM line from [10].