FORMATION OF OXYGEN ISOTOPE RESERVOIRS BY MIXING CHONDritic COMPONENTS

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Introduction:  Chondrites, the most primitive rocks in the solar system are assemblages of high temperature components CAIs and chondrules embedded in a volatile-rich, fine-grained matrix. Different chondrite groups have long been known to have distinct populations of petrological components [1] as well as specific oxygen isotopic signatures [2-4]. Varying bulk oxygen isotopic composition might result from spatial or temporal heterogeneities in the nebular dust and gas, generating reservoirs from which the different chondrites and their components formed. Here we show that chondrite oxygen isotopic compositions throughout the chondrite groups are linearly related to modal abundances of petrological components in the most primitive objects. This is consistent with the mixing model of [5] and indicates that major chemical and isotopic variations between chondritic reservoirs were established after chondrule formation, not because of early heterogeneity in the nebula. It also explains the differences between H, L and LL chondrites as well as the unique position of OCs and linear relationships between the chondrite groups in 3-isotope space.

Method: In a companion abstract [5], we show that systematic relationships exist between the relative proportions of the various petrographic components in each chondrite group. These relationships are interpreted in terms of mixing in variable proportions of 2 to 3 out of eight primary chondritic reservoirs with fixed abundances of the components. In the present work, we study oxygen isotope systematics as a function of petrographic component abundances based on the data of [6] and references therein. For convenience, we define \( \Delta^{17}O \) as \( \delta^{18}O - \delta^{17}O \) in a similar fashion to \( \Delta^{18}O \), to describe mass fractionation effects exclusively, independently of the nebular group. \( \Delta^{18}O \) corresponds to the excess of \( \delta^{18}O \) along a mass fractionation line with respect to the slope 1 line going through the origin in the 3-isotope space (\( \delta^{16}O=0, \delta^{18}O=0 \)). The calculated (\( \Delta^{18}O, \Delta^{17}O \)) are equivalent to the measured (\( \delta^{18}O, \delta^{17}O \)) for characterizing a sample. Their interest lies in decoupling (nebular) group effects from mass fractionation effects as \( \Delta^{18}O \) only depends on the former and \( \Delta^{17}O \) on the latter.

Results: Figures 1 and 2 show that linear correlations exist between \( \Delta^{18}O \) and the abundance of CAIs in carbonaceous chondrites and of type II chondrules in ordinary chondrites and between \( \Delta^{17}O \) and the abundance of matrix in all the groups.

Figure 1: Correlation between \( \Delta^{17}O \) and volume of type IIs in OC and correlation of \( \Delta^{18}O \) with volume of CAIs in CCs. Because of the scatter of the data, in particular for CM and CO, the slope and origin constant of the linear correlation were estimated using only CI and CV chondrites, which yields a better regression (\( R^2=0.92 \) vs \( R^2=0.83 \)). The two lines intercept the origin at ~0.17, close to the CI point.

Figure 2: Correlation of \( \Delta^{18}O \) with volume of matrix across the chondrite groups.

Based on these correlations, we construct a model for bulk rock chondritic \( \Delta^{18}O \) by making a regression on Type IIs and CAI in OC, CI and CV chondrites:

\[
\Delta^{17}O (\text{‰}) = -0.398 \text{ vol\% CAI} + 0.0157 \text{ vol\% Type II} + 0.2 (1)
\]

\[
\Delta^{18}O (\text{‰}) = 0.0712 \text{ vol\% matrix} + 1.0 (2)
\]

Such equations can be solved by substituting values of 0% and 100% to identify virtual isotopic components associated with CAI, etc. The virtual isotopic components carried by Type I chondrules and matrix both have \( \Delta^{17}O=0.2 \text{ ‰} \) and consequently do not appear...
in equation (1). In (2) the regression line has been set to intercept the X-axis at 1.0‰ (instead of 1.3‰) so that 0‰ matrix corresponds to the Young and Russell (Y-R) [29] line (i.e. to not aqueously altered CAI material). Moreover, the isotopic components carried by chondrules and CAI lie close to the Y-R line and consequently do not affect Δ18O.

Fig. 3 and 4, where calculated Δ17O and Δ18O are plotted as functions of the measured values [2-4], show that equations (1) and (2) adequately reproduce the observations and therefore that the oxygen isotopic signatures of OC, CC and EC chondrites can be successfully estimated from the proportions of their petrological components.

Discussion: Oxygen isotopic signatures are considered to characterize each of the chondritic reservoirs [2-4]. Our results indicate that the various petrological components within a chondrite did not form in a pre-existing reservoir with a fixed chemical and isotopic composition, but that the chondrite groups originated by mixing petrological components which carried isotopically and chemically distinct components.

By setting petrological component abundances at 0% or 100% in our equations, we can define the model compositions of 4 isotopic components carried by CAI, Type I and type II chondrules as well as matrix. Although trends are preserved [8], the present isotopic compositions of chondrules, CAIs and matrix do not coincide with those of the isotopic components they carry (defined by equations (1) and (2)), and they vary from one group of chondrites to the next. This implies, as suggested by Clayton et al. [4], that the individual chondrules and CAI we now find in chondrites are the result of protracted mixing involving several generations of chondrule (and possibly also CAI) recycling. The existence of mixing trends in the oxygen isotopic systematic of chondrites is consistent with the results of [5] indicating that all the chondrite groups are made from the mixing of a limited number of primary chondritic reservoirs, each of which contain only a few of the chondritic components in fixed abundances.

The systematic aspect of the relationship between the oxygen isotopic composition of all chondrites and their petrographic component abundances allows us to apply our mixing model to differentiated objects, including planets, falling on the same oxygen isotopic trends even though their initial petrographic constituents remain unknown. The Mixes of [5] could be used to generating planet compositions and the link between the Earth and chondrites (especially EHs) should be revisited. However, Mars, falling above the TFL, can be made only from Mix 8 present in OC (the only one to contain type II chondrules) and Mix 2 (matrix only). Accordingly, a better solution than using Mixes 5 and 6 of [5] (that make up CR, CH and EH chondrites) is to build the Earth from the same Mixes as Mars. This yields a metal abundance better representative of the mass of the Earth’s core.

References: