

O-ISOTOPE ANOMALIES: INTERPRETATION IN TERMS OF PRESOLAR SOLID AND GAS COMPONENTS AND NEBULA FRACTIONATION PROCESSES. John T. Wasson and David N. Shirley, University of California, Los Angeles, CA 90024, USA.

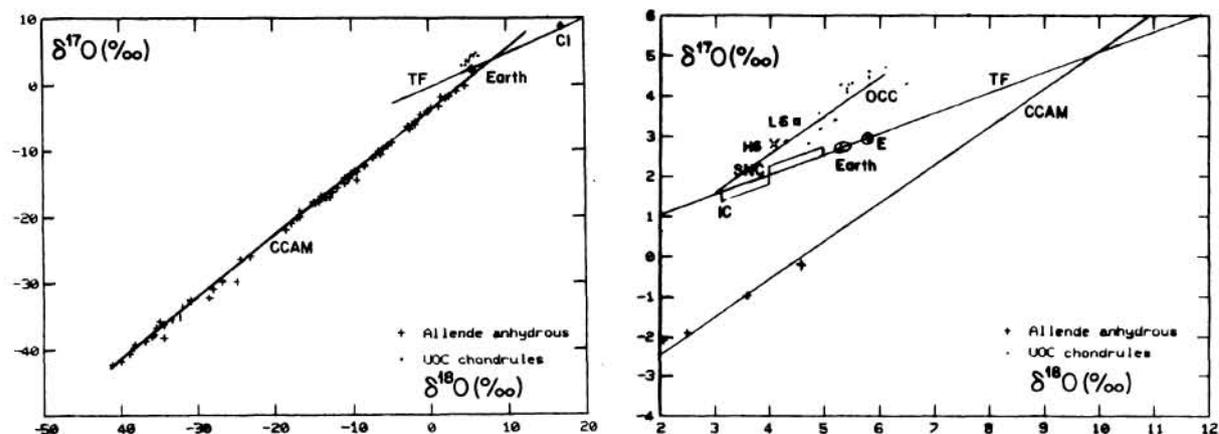
The O-isotope compositions of chondrites and chondrite components range from -42 to +9 ‰ $\delta^{17}\text{O}$, and from -40 to +17 ‰ $\delta^{18}\text{O}$ (1, 2). In $\delta^{17}\text{O}$ - $\delta^{18}\text{O}$ diagrams such as Figs. 1 and 2 two arrays have slopes distinctly higher than the 0.5 produced by fractionation: The CCAM (carbonaceous chondrite anhydrous mineral) and the OCC (ordinary chondrite chondrule) arrays. We examine models to generate these fields and arrays by solar-nebula mixing and fractionation processes. In contrast to previous studies, we consider effects related to the formation of chondrites at different places and times, and to a possible radial gradient in nebular composition.

The $\text{FeO}_x/(\text{FeO}_x+\text{MgO})$ ratio in chondritic meteorites ranging from ~ 0.001 in enstatite chondrites to ~ 0.5 in the CI and CM chondrites is a measure of oxidation; it is generally held that oxidation increased with decreasing mean temperature of nebular equilibration, and thus with increasing distance from the Sun. In our preferred models we assume that the mean O-isotope composition of the nebula lay near the TF line, and was the same at all times and places for the combined gas and solids, since the Earth formed in the hot inner nebula (its mean O-isotope compositions are near 5.3 ‰ $\delta^{18}\text{O}$) and enstatite chondrites (6 ‰ $\delta^{18}\text{O}$ on TF line) probably formed ≈ 1 AU from the Sun.

If the nebular O-isotope composition was constant, we suggest it was in the range $\delta^{17}\text{O}, \delta^{18}\text{O} = 3-4, 6-8$ ‰ (henceforth number pairs are in order $\delta^{17}\text{O}, \delta^{18}\text{O}$). For discussion we will use 3, 6. Given O, Mg and Si solar abundance of $1.9 \cdot 10^7, 1.06 \cdot 10^6,$ and $1.00 \cdot 10^6$, one finds that 83 ‰ of O is in gas, 17 ‰ in solids.

The CCAM and OCC mixing arrays intersect the TF line at different $\delta^{18}\text{O}$ values, seemingly in conflict with the idea of a uniform nebular composition. The CCAM array is generally attributed to the mixing of residual presolar solids with nebular gas lying on the TF time at about +9 ‰ $\delta^{18}\text{O}$. However, this interpretation fails to allow for fractionation between gas and reacting/condensing solids; at temperatures $\approx 700\text{K}$ the solids have lower $\delta^{18}\text{O}$ values than the gas, at low temperatures higher values (3). Thus the 3 ‰ difference is explained by formation of the ^{16}O -poor materials having $\delta^{17}\text{O}, \delta^{18}\text{O}$ above 5, 6 ‰, and equilibration with a nebular gas at temperatures $\leq 700\text{K}$. The inferred temperature is consistent with other evidence indicating that OC formed nearer the Sun than CC.

The following two mixing models can account for the compositional location of the CCAM and OCC arrays: (1) Presolar solids and gas had mean compositions that were grossly out of equilibrium; the mean solids composition was near -42,



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-40 ‰, the mean gas near +12, +15 ‰. (2) The gas composition lay near the TF line; solids ranged from -42, -40 ‰ to roughly +9, +10 ‰ (these compositions and those in model 1 are to be understood to represent the minimum range allowed by the observations with a mean near 3, 6 ‰).

Model 1 accounts for the CCAM array by formation of solids at -42, -40 ‰ by partial evaporation of presolar solids followed by mixing with a reactate/condensate near the TF line; much of the low temperature condensate was not incorporated into planetesimals, but lost from the solar system with the uncondensed nebular gas. The OCC array is formed by evaporation of about half the presolar solids followed by condensation of the chondrule precursor components; the unevaporated presolar solids were also lost with the gas. The inner solar system materials formed from solids produced almost entirely by condensation from a homogenized nebula. The serious difficulty with model 1 is finding a priori grounds that the presolar gas and solids should be so far out of equilibrium, but astrophysical mechanisms exist that can yield this result. A second objection is that more extensive evaporation is required at the CC region than at the OC region.

In order to form the CCAM array by model 2 we propose that the bulk of the refractory lithophiles were in a minor ^{16}O -rich fraction of the presolar solids. Evaporation of the presolar solids left a ^{16}O -rich residue near -42, -40, and condensation/reaction with the gas yielded the ^{16}O -poor component in the mixing array; as in the previous model, most recondensed materials were lost. The OCC array is explained by incomplete evaporation that yielded a grossly different size distribution. Refractory-rich, ^{16}O -rich materials were finer-grained and a considerable fraction was lost with the gas. Perhaps large refractory liquid droplets that survived at the CC location were destroyed by a higher turbulence at the OC location nearer the Sun. The ^{16}O -poor O survived as large silicates that did not evaporate, or possibly as O strongly bound to Si in SiO which recondensed before exchange with nebular H_2O or CO. The chief problem is finding an a priori reason for expecting the refractories and ^{16}O -rich materials to be in the same presolar component, although certain astrophysical mechanisms can produce this distribution.

It has been suggested that a supernova sibling of the Sun produced the ^{26}Al responsible for ^{26}Mg excesses and was the compressionary trigger forming the solar system. Since ^{16}O -rich O should be produced in the same supernova shell as the ^{26}Al , we examine a third model in which supernova remnants only contaminated the outer part of the nebula where the CM, CO and CV chondrites formed. In this case the isotopic variation in inner solar-system materials could be understood if the presolar solids were only slightly ^{16}O -poor (near +5, +6) relative to the gas near the TF line. This model offers a less quantitative explanation of the parallel nature of the CCAM and OCC arrays, but a more serious objection is that it does not allow the CI chondrites to form in the CC region, since the addition of supernova debris would bring the mean O-isotope composition below the TF line.

All these models are complex, but the O-isotope fields scatter too widely to allow a truly simple model. We find the second model or one intermediate between the first and the second to be the least contrived, and suggest that they offer a useful basis for future discussions.

REFS. (1) R. N. Clayton et al., *Science* 1982, 485, 1973. (2) J. L. Gooding et al., *LPS* 13, 271, 1982 (3) N. Onuma et al., *GCA* 36, 169, 1972.