OXYGEN ISOTOPIC COMPOSITION OF REFRACTORY INCLUSIONS FROM THE MILLER RANGE (MIL) 090019 CARBONACEOUS CHONDRITE

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Introduction: Primitive meteorites contain Calcium-Aluminum-rich Inclusions (CAIs) that preserve the records of the earliest times in the Solar System. CAIs record O isotopic variations with time and/or location from solar (^{16}O-rich) to planetary (^{16}O-poor) compositions [e.g., 1, 2]. However, CAIs were also affected by parent body processing to varying degrees. The goal of this work was to identify the processes that resulted in the fine-scale spatial variations in oxygen isotopic compositions within the most ancient Solar System solids. We report oxygen isotopic composition of CAIs from MIL 090019 CO3.1 carbonaceous chondrite. MIL 090019 contains a high abundance of CAIs showing mineralogical as well as textural variations [3].

Methods: We analyzed 10 CAIs with different mineralogical assemblages, classified as corundum-bearing, grossite-bearing, hibonite-bearing, melilite-bearing, anorthite-bearing inclusions and amoeboid olivine aggregates (AOA's). The mineralogical and petrological characterization of CAIs was performed using the JOEL Hyperprobe 8530 electron microprobe at NASA JSC. Oxygen isotopic imaging of the CAIs was done using the Cameca NanoSIMS 50L ion microprobe at NASA JSC. We followed the analytical protocol described in [4]. O-isotopic maps of the CAI were acquired by rastering a ~3 pA primary Cs^+ beam at 16 keV over an area of 20 × 20 μm^2 over a period of ~7 hours. Negative secondary ions of $^{16}O^-$, $^{17}O^-$, $^{18}O^-$, $^{28}Si^-$, $^{24}Mg^{16}O^-$, $^{27}Al^{16}O^-$, and $^{40}Ca^{16}O^-$ were simultaneously acquired using electron multiplier detectors at a mass resolving power sufficient to resolve the $^{16}OH^-$ interference from the $^{17}O^-$ peak, where the contribution of $^{16}OH^-$ was <0.1 %. An electron flood gun was used to mitigate sample charging during the analyses. We used San Carlos olivine and Madagascar hibonite as isotopic standards to correct for the instrumental mass fractionation. The O-isotopic ratios were corrected for the quasi simultaneous arrival (QSA) effect and the detector dead time. All reported errors are 1 sigma.

Results: The MIL 090019 carbonaceous chondrite hosts refractory inclusions varying in their mineralogies and textures [2, 3]. We found the oxygen isotopic compositions of mineral phases in MIL 090019 CAIs show large variations with $\Delta^{17}O$ values varying from -27 to 0‰. A corundum-bearing inclusion records isotopic variations with corundum, melilite, perovskite, and anorthite showing $\Delta^{17}O$ values of -20 ± 2.5, -10.2 ± 6.5, -10.7 ± 1.3, and -1.2 ± 3.2‰ respectively. A grossite-hibonite-bearing inclusion also records O-isotopic heterogeneity, where grossite, hibonite, Mg-rich spinel, and melilite show -3.7 ± 2.7, -22.9 ± 2.5, -21.4 ± 2.6, and -17.3 ± 2.8‰ respectively, whereas perovskite grains record a heterogenous isotopic composition ranging from -22.6 to -13.9‰. A hibonite-bearing inclusion shows average $\Delta^{17}O$ values of -17.6 ± 5.3 ‰ and -15.1 ± 4.8 ‰ for hibonite and spinel respectively. The two perovskite grains also show relatively ^{16}O-poor composition ($\Delta^{17}O$ = -11.8 ± 6.4 ‰ and -8.6 ± 5.2 ‰). Anorthite has ~0.1 wt% Na_2O and ~0.52 wt% FeO and a $\Delta^{17}O$ value of -7.2 ± 5.0 ‰, whereas diopside records a $\Delta^{17}O$ value of -3.5 ± 5.0 ‰. A hibonite-spinel-rich inclusion contains spinel and hibonite that are ^{16}O-rich ($\Delta^{17}O$ values -21.3 ± 2.8‰ and -19.4 ± 3.0‰, respectively). Melilite shows heterogenous oxygen isotopic composition, with an inner ^{16}O-rich region and an outer ^{16}O-poor region separated by a sharp boundary, with a bulk $\Delta^{17}O$ = -16.2 ± 2.1‰, whereas two perovskite grains are relatively ^{16}O-poor ($\Delta^{17}O$ = -13.2 ± 3.7‰ and -7.1 ± 3.4‰). A spinel-rich inclusion contains perovskite grains with $\Delta^{17}O$ ranging from -27.0 to -22.8 ‰ and spinel with average $\Delta^{17}O$ value of -21.4 ± 2.8 ‰. In a melilite and spinel-rich CAI, perovskite, spinel, diopside, melilite, and Al-Ti-rich pyroxene record $\Delta^{17}O$ values of -26.9 ± 4.6‰, -22.4 ± 4.3‰, -23.4 ± 4.9, -19.3 ± 3.4, and -19.0 ± 4.3 ‰ respectively. Olivine and spinel components of 2 AOA's record a ^{16}O-rich composition with $\Delta^{17}O$ ~-23‰.

Discussion: The coexistence of ^{16}O-rich and ^{16}O-poor minerals within CAIs has been attributed to differing degrees of O isotopic exchange, reflecting a wide range of O diffusion rates [5]. However, the O isotopic heterogeneity observed in these CAIs cannot be explained by oxygen diffusion in nebular or parent body settings alone. The isotopic imaging of CAIs from the MIL 090019 meteorite shows variations in the O isotopic composition recorded in their mineral components, suggesting that these CAIs record the oxygen isotopic heterogeneity in the nebular gas from which they condensed. The coexistence of ^{16}O-rich and ^{16}O-poor mineral components in the CAI-forming region suggests that the gas in this region was not well-mixed and consisted of distinct ^{16}O-rich and ^{16}O-poor gaseous reservoirs.

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