Evidence for a long duration of the ^{16}O-rich reservoir in the Solar Nebula.

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Introduction: The difference of typical oxygen isotopic compositions between refractory inclusions (Δ^{17}O~−24‰) and chondrules (Δ^{17}O=−6 to 1‰)[e.g., 1,2] indicates temporal and spatial variation of oxygen isotope ratios of the Solar Nebula. To correctly understand characteristics of O isotope reservoir in the Solar Nebula, eliminating effects of parent body alteration, which disturb intrinsic isotope signatures, is critically important. Here, we measured oxygen isotope ratios and the ^{26}Al-^{26}Mg isotope systematics of fine-grained refractory inclusions from the least metamorphosed carbonaceous chondrites, Acfer 094 (C-ung. 3.0) and Y-81020 (CO3.0).

Samples and Analytical Procedures: Five spinel-melilite-rich CAIs (Y81020-E-8, G5, G16, G49, and G104), four AOAs (G17, G28, G44, and G58), and one pyroxene-anorthite-rich CAI (G92) were selected. Petrographic observation and major element oxides concentrations of the samples were obtained by SEM and EPMA. Analyses of oxygen three-isotopes and ^{26}Al-^{26}Mg isotope systematics were measured with the WiscSIMS CAMECA IMS-1280 ion microrprobe at the University of Wisconsin-Madison. Four separate sessions (O and Al-Mg isotope analyes with different primary beam sizes) were conducted to obtain isotopic signatures of multiple phases. Analytical conditions are similar to those described in previous works [3-5].

Results and Discussion: Oxygen isotope ratios of interior minerals and rims of all measured samples are highly ^{16}O-rich and are distributed near the CCAM line. Averaged Δ^{17}O of the samples have values of −22.0‰ to −24.3‰ with uncertainties of ±0.3‰ to ±0.9‰ (95% confidence). High Al/Mg phases have resolvable exvess ^{26}Mg (δ^{26}Mg*), allowing for inferring (^{26}Al/^{27}Al)$_0$ values for all CAIs and one AOA (G17). Inferred (^{26}Al/^{27}Al)$_0$ of melilite-rich CAIs are $(4.08\pm0.75)\times10^{-5}$ to $(5.05\pm0.18)\times10^{-5}$, which are within the (^{26}Al/^{27}Al)$_0$ range of CAIs from CV chondrites but are slightly lower than the canonical value (5.25×10^{-5})[6-8]. The (^{26}Al/^{27}Al)$_0$ of AOA G17 [$(5.32\pm0.81)\times10^{-5}$] is also within the range of CAIs. In pyroxene-anorthite-rich CAI G92, two distinct isochrons are produced. Melilite and high-Ca pyroxene data are distributed along a ^{27}Al/^{24}Mg vs. δ^{26}Mg* line corresponding to an inferred (^{26}Al/^{27}Al)$_0$ of $(5.2\pm2.0)\times10^{-5}$. In contrast, anorthite data exihibit high ^{27}Al/^{24}Mg ratios (>700) but significantly smaller δ^{26}Mg* (<50‰) than that of the canonical value. Assuming anorthite formed by decomposition of melilite [e.g., 9,10], the inferred (^{26}Al/^{27}Al)$_0$ is $(5.2\pm0.5)\times10^{-6}$, which is close to the typical chondrule values [5].

The consistent ^{16}O-rich signatures of the studied refractory inclusions indicate that condensation of refractory phases from the nebular gas, aggregation, and diopsidic rim formation occurred in a ^{16}O-rich environment. This result is in agreement with previous studies of CAIs from primitive chondrites [11,12]. Regarding pyroxene-anorthite-rich CAI G92, anorthite with small δ^{26}Mg*, as well as other phases, are ^{16}O-rich. A later Mg isotopic disturbance of anorthite in the Acfer 094 parent body is unlikely because (1) Acfer 094 is one of the least metamorphosed carbonaceous chondrites and (2) other anorthite grains from the same thin section, including those from CAI G16 and from chondrules, do not exhibit evidence for isotopic disturbance [5]. As such, we interpret that the low (^{26}Al/^{27}Al)$_0$ of G92 anorthite recorded the timing of decomposition of melilite by a later thermal process in the solar nebula at ~2.3 Ma after CAIs. Since decomposition of melilite to anorthite was likely caused by interaction with ambient nebular gas [9,10], the ^{16}O-rich signature of anorthite indicates the ambient gas was also ^{16}O-rich. The lack of ferromagnesian phases (olivine and low-Ca pyroxene) or Fe-Ni metal suggests that G92 anorthite formation occurred in an environment devoid of ferromagnesian-rich dust. We hypothesize that G92 originally formed as a spinel-melilite-rich CAI with the canonical (^{26}Al/^{27}Al)$_0$, and was reheatd ~2.3 Ma after CAIs, at a vertically distant location from the chondrule-forming mid-plane of the protoplanetary disk. This heating event transformed most of melilite into anorhtite by involving interactions with ^{16}O-rich ambient gas.

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