EVIDENCE FOR OXYGEN-ISOTOPE EXCHANGE IN CHONDRULES AND REFRACTORY INCLUSIONS DURING FLUID-ROCK INTERACTION ON THE CV CHONDRITE PARENT BODY

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Introduction: Refractory inclusions [amoeboid olivine aggregates (AOAs) and Ca,Al-rich inclusions (CAIs)] formed in a high-temperature nebular region having approximately solar chemical and oxygen isotopic ($\Delta^{17}O$ ~ –25‰) compositions, most likely near the protoSun [1]. In unmetamorphosed carbonaceous chondrites, most CAIs and their Wark-Lovering (WL) rims are uniformly ^{16}O-rich, suggesting formation in the same nebular region [e.g., 2,3]. In contrast, most CAIs and WL rims in CV chondrites are isotopically heterogeneous, with anorthite, melilite, and, occasionally, Al,Ti-diopside being ^{16}O-depleted relative to hibonite, spinel, and forsterite [4,5]. This O-isotope heterogeneity has been interpreted as evidence for transport of CAIs between the solar-like (^{16}O-rich) and planetary-like (^{16}O-poor) nebular reservoirs multiple times [5]. However, since CV chondrites experienced fluid-assisted thermal metamorphism on their parent asteroid [6], a postcrystallization O-isotope exchange during fluid-rock interaction cannot be excluded [2,3,7]. In order to understand the nature of ^{16}O-depletion of primary anorthite and melilite in CV CAIs and their WL rims, we studied O-isotope compositions of primary (olivine, high-Ca pyroxene, plagioclase and melilite) and secondary (fayalite and magnetite) minerals in CAIs, AOAs, chondrules, and matrix of one of the least thermally metamorphosed CV chondrite Kaba (CV3.1) with the UH Cameca ims-1280 SIMS. Terrestrial minerals (San Carlos olivine, Miyaka-jima anorthite, augite, fayalite and magnetite) were used as standards.

Results: On a three-isotope oxygen diagram, compositions of fayalite ($\delta^{18}O$ ~ 8÷9‰) and magnetite ($\delta^{18}O$ ~ 2÷5‰) in Kaba plot along mass-dependent fractionation line with $\Delta^{17}O$ value of ~ –1.5±1.2‰. Chondrule olivines and plagioclases are in O-isotope disequilibrium: olivine phenocrysts plot slightly to the left from a carbonaceous chondrite anhydrous mineral (CCAM) line and show a range of $\Delta^{17}O$ values, from –8 to –4±1.4‰; plagioclases deviate significantly to the right from the CCAM line ($\delta^{18}O$ ~ 13÷16‰) and plot along mass-dependent fractionation line defined by fayalite and magnetite ($\Delta^{17}O$ ~ –0.5±1.2‰). Forsterite and Al-diopside in CAIs and AOAs from Kaba have ^{16}O-rich compositions ($\Delta^{17}O$ ~ –23±1.7‰), whereas melilite and anorthite show a range of $\Delta^{17}O$ values from –14 to –2±2‰ and from –14 to 0±2‰. Anorthite analyses plot to the right from CCAM line and significantly overlap with compositions of chondrule plagioclases.

Discussion: Mineralogical observations and thermodynamic analysis suggest that fayalite and magnetite in Kaba resulted from fluid-assisted metasomatic alteration at ~100–300°C experienced by the CV parent body [8,9]. Since magnetite and fayalite formed by oxidation of Fe,Ni-metal and by precipitation from a fluid [6,8], their $\Delta^{17}O$ values most likely reflect O-isotope composition of this fluid. Chondrule phenocrysts and mesostases in unmetamorphosed chondrites are in O-isotope equilibrium [e.g., 10], whereas plagioclase and olivine in Kaba chondrules are out of equilibrium, indicating postcrystallization oxygen-isotope exchange. The O-isotope compositions of plagioclase in Kaba chondrules plot along mass-dependent fractionation line defined by magnetite and fayalite, suggesting the exchange was due to interaction with the metasomatic fluid. The similar process must have affected anorthite in Kaba CAIs and AOAs. The presence of water leads to significantly enhanced oxygen diffusion rates in many silicates, whereas the diffusion rates of cations are largely insensitive to the presence of water [11]. In plagioclase, oxygen diffusion rate under wet (hydrothermal) conditions [12] is considerably faster than that under dry conditions [13]. Under the inferred conditions of metasomatic alteration experienced by Kaba, anorthite crystal of ~10 µm in size (typical grain sizes of plagioclase in chondrules and WL rims) would exchange its O-isotope composition with a fluid within ~1000 years, which is not unreasonable for the duration of metasomatic alteration on the CV parent asteroid. We conclude that (1) O-isotope heterogeneity in CV CAI WL rims is not a nebular signature; it is due to O-isotope exchange with a fluid on the CV parent asteroid; (2) CCAM line defined by CV CAIs and chondrules, both affected by O-isotope exchange with metasomatic fluid and containing metasomatically formed secondary minerals, is a mixing line between nebular and asteroidal O-isotope reservoirs.

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