OXYGEN-ISOTOPE COMPOSITIONS OF FAYALITE AND MAGNETITE IN CV CARBONACEOUS CHONDRITES ASUKA-881317 AND MET 00430: IMPLICATIONS FOR SOURCES OF WATER ICE ON THE CV AND ORDINARY CHONDRITE PARENT ASTEROIDS. K. Jogo, A. N. Krot, and K. Nagashima, Hawai'i Institute of Geophysics and Planetology, School of Ocean, Earth Science and Technology, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA. E-mail address: kaori@higp.hawaii.edu.

Introduction: Although olivine is one of the major minerals in meteorites, its iron-rich end-member, fayalite (Fe_2SiO_4), was found only in several carbonaceous (CVs [e.g., 1], and MAC 88107 (ungrouped) [2]) and unequilibrated ordinary chondrites [e.g., 3]. In CV chondrites, fayalites occur in chondrules and matrices as grains or veins coexisting with magnetites and sulfides [e.g., 1]. Although both nebular and asteroidal models for the origins of fayalite and coexisting magnetite have been proposed [e.g., 4,5], the mineralogy, thermodynamic calculations, Mn-Cr and oxygen-isotope measurements suggest that these minerals formed during aqueous alteration in an asteroidal setting, rather than in the solar nebula [4, 6−9]. Recent thermodynamic analysis of fayalite stability field [10] indicates that fayalite could have formed in a very limited temperature range (from ~30°C to ~350°C), pressures, and water/rock ratios (0.06–0.2). Here we describe mineralogy, petrography, and O-isotope compositions of fayalite and magnetite in CV carbonaceous chondrites Asuka-881317 (A-881317) and MET 00430, and discuss the implications of these results for understanding the sources of water on the CV and OC parent asteroids.

Analytical techniques: Oxygen isotopic measurments were performed with the UH Cameca ims-1280 ion microprobe. Fayalite grains, 20−50 μm in size, were measured with a focused primary Cs^+ beam rastered over ~7 μm in multicollection mode: $^{16}O^-$, $^{17}O^-$ and $^{18}O^-$ were measured simultaneously using multicollection Faraday cup (FC), monocollection electron multiplier (EM), and multicollection FC, respectively. Oxygen-isotope compositions of magnetite grains, <5 μm in size, were measured using a primary Cs^+ beam forcused to ~1 μm in diameter and multicollection mode: $^{16}O^-$, $^{17}O^-$, and $^{18}O^-$ were measured simultaneously using FC–EM–EM, respectively.

Mineralogy and petrography: In both A-881317 and MET 00430, fayalite occurs as isolated grains, aggregates of grains, and veins coexisting with magnetite and Fe,Ni-sulfides (Fig. 1). The fayalite-bearing assemblages occur inside and at margins of chondrules and in matrices. Magnetite grains coexisting with fayalite are compositionally pure Fe_3O_4.

In A-881317, the fayalite grains have a range of fayalite content from 79 to 98 mol%. Most fayalite grains are compositionally uniform; only a few grains show Fe-Mg zoning with fayalite content decreasing from the center to the periphery of a grain. Petrographic observations indicate that A-881317 is a breccia containing numerous clasts. Since chemical compositions of fayalite grains are sensitive to temperature, total pressure, and water/rock ratio [8, 9], we suggest that fayalites in each clast may have formed under different physico-chemical conditions.

In MET 00430, most fayalite grains are compositionally uniform; there are, however, compositional differences among the grains ($Fa_{72–94}$). Petrographic observations provide no evidence that MET 00430 is a breccia; no clasts or chondritic fragments were found. We infer that observed variations in fayalite contents among the grains may reflect variable on a local scale physico-chemical conditions during fayalite crystallization [e.g., 1].

Oxygen-isotope compositions of fayalites and magnetites: Oxygen-isotope compositions of the coexisting fayalite and magnetite grains in A-881317 and MET 00430 are shown in Fig. 2. The data plot along mass-dependent fractionation line with $\Delta^{17}O$ value of ~ –1‰. Our obtained data overlap with O-isotope data of fayalites and magnetites in Kaba and Mokoia [6, 7].

In A881317, the $\delta^{18}O$ values of fayalite grains from three clasts, #4-2, #4-3, and #6-2, are nearly identical (~14–15‰). In contrast, $\delta^{18}O$ values of magnetite grains coexisting with fayalite in the same clasts are ~0‰, ~6‰, and ~6‰, respectively. These results may indicate that fayalite and magnetite formed either in O-isotope disequilibrium or under different physico-chemical conditions. In the latter case, based on the O-isotope thermometer [11, 12], the observed $\delta^{18}O$ differences between fayalite and magnetite of ~14‰ and ~9‰ in the clasts #4-2 and #6-2 indicate that these assemblages formed at ~140°C and ~40°C, respectively.

In MET 00430, the $\delta^{18}O$ values of fayalite and coexisting magnetite are ~11–12‰ and ~2–4‰, respectively. Based on the O-isotope thermometer [11, 12], the observed difference in $\delta^{18}O$ values between fayalite and magnetite corresponds to their formation temperature of ~110–140°C.

Implications for sources of water ice on the CV and ordinary chondrite parent asteroids: The similar $\Delta^{17}O$ values of fayalites and coexisting magnetites in both CV meteorites measured suggest that these minerals precipitated from a fluid with the same $\Delta^{17}O$ value of ~ –1‰.

Secondary fayalite and magnetite grains are also present in unequilibrated ordinary chondrites (UOCs) [3, 13] and were interpreted as a product of fluid-assisted thermal metamorphism [3]. On a three-isotope oxygen diagram, these minerals plot along a single mass-fractionation line with a $\Delta^{17}O$ value of ~5‰ (Fig. 2), indicating that they precipitated from a fluid with $\Delta^{17}O$ of ~5‰ [3].

The $\Delta^{17}O$ values of a fluid, from which fayalite and magnetite grains precipitated or equilibrated with, resulted from O-isotope exchange between anhydrous silicates and primordia water, that probably accreted as water ice together with anhydrous silicates into chondrite parent bodies and was subsequently melted by decay of ^{26}Al. The $\Delta^{17}O$ differences of the fluids in CV and UOC chondrites may indicate that $\Delta^{17}O$ values of aqueous solutions were different due to the different O-isotope compositions of anhydrous silicates and water/rock ratio in CV and UOC parent asteroids, even though oxygen-isotope compositions of water ices that accreted into these parent asteroids were similar. Alternatively, oxygen-isotope compositions of water ices that accreted into CV and UOC parent asteroids were different.

Fayalite and magnetite in CVs and UOCs appear to have formed under similar p-T conditions, as can be inferred from differences in $\delta^{18}O$ between fayalites and magnetites (Fig. 1), and similar water/rock ratios [9]. As a result, the observed differences in $\Delta^{17}O$ values of fayalite and magnetite in CVs and UOCs may imply differences in O-isotope compositions of ices that accreted into their parent asteroids.

Oxygen-isotope composition of water ice in the protoplanetarty disk is not well-understood, but could be variable in time and/or in space [e.g., 6, 14−16]. Choi et al. [6] hypothesized that $\Delta^{17}O$ value of the nebular gas increase with time. Based on this model and the observed differences in $\Delta^{17}O$ values of CVs and UOCs, CVs may have accreted earlier than OCs.

According to the CO self-shielding models [e.g., 14−16] and dynamical modeling of radial transport of dust in the protoplanetary disk [17], O-isotope compositions of water ice in the outer solar system is heavier than in the inner solar system, and the proportion of the inner and outer solar system ices in the Main Asteroid Belt could vary in time [17]. According to these models, water ices that accreted into OC parent bodies had higher proportion of the outer solar system ice than those that accreted into CV asteroid. More work is needed to test this hypothesis.

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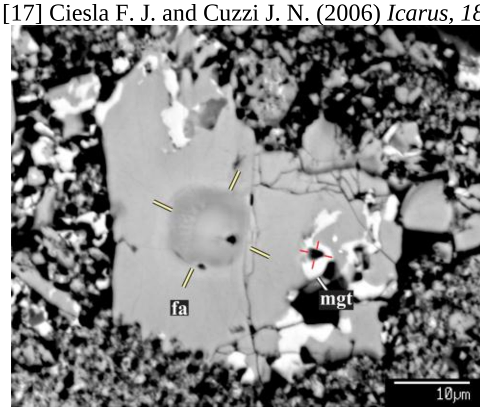

Fig. 1. Backscattered electron image of a fayalite (fa) – magnetite (mgt) grain in A-881317. Measurement spots by ion microprobe are indicated.

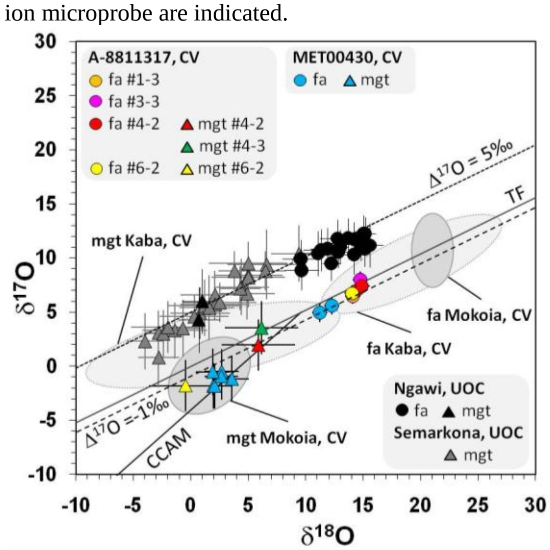

Fig. 2. O-isotope compositions of fayalite (fa) and magnetite (mgt) in CV chondrites A-881317 and MET 00430 and unequilibrated ordinary chondrites (UOC) Semarkona and Ngawi. Errors are 2σ. Data of fayalites and magnetites in UOC and CV Kaba and Mokoia are from [3, 6, 7, 12].