SECONDARY FAYALITES AND METAMORPHIC OLIVINE-RICH AGGREGATES IN THE YAMATO-86009 CV3 CARBONACEOUS CHONDRITE: EVIDENCE FOR COMPLEX FORMATION OF CV3 ASTEROIDS

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Introduction: Vigarano meteorite, classified to reduced subgroup of CV3 chondrite ($CV3_{Red}$), contains some Bali-like oxidized subgroup ($CV3_{OxB}$) clasts including fayalite [1-3]. These clasts are considered to have formed in asteroids prior to formation of Vigarano breccia. Petrographic characteristics of $CV3_{OxB}$ clasts in $CV3_{Red}$ Vigarano are similar to those of $CV3_{OxB}$ meteorites [4-6]. In addition, Mn-Cr formation age of fayalite in $CV3_{OxB}$ clasts in $CV3_{Red}$ Vigarano is identical within errors to that of fayalite in $CV3_{OxB}$ Mokoia and Kaba [5, 6]. Therefore, $CV3_{OxB}$ clasts in $CV3_{Red}$ Vigarano and $CV3_{OxB}$ Mokoia and Kaba might have been derived from a single $CV3_{OxB}$ asteroid. This implies that fragments of a single $CV3_{OxB}$ asteroid were incorporated into adjacent CV3 asteroids. In this case, the fragments might have also re-accreted into different locations of the same $CV3_{OxB}$ asteroid. Thus, some $CV3_{OxB}$ breccia should contain the fragments as clasts.

To check this scenario, we studied Yamato-86009 meteorite, classified to oxidized subgroup of CV3 chondrite. Detailed petrographic characterization was performed by electron microscopes and isotope analysis was carried out on fayalite and adjacent minerals by a secondary ion mass spectrometer (SIMS imf 6f). Oxygen-isotope ratios of a fayalite crystal used for SIMS standard were determined by using an oxygen isotope mass spectrometer equipped with a CO_2 Laser-BrF_5 fluorination system that was newly installed in Korea Polar Research Institute.

Results and Discussion: Yamato-86009 contains some clasts; a clast is composed of a chondrule and a surrounding fine-grained material. Clasts are embedded in host matrix or have direct contact with adjacent clasts, which can be recognized by the boundary lines in SEM images. Some clasts are difficult to distinguish from the host. However, these observations indicate that Yamato-86009 is a breccia.

Among eleven chondrules investigated, four chondrules contain fayalite ($Fa_{>80}$). These fayalite-bearing chondrules are surrounding by fine-grained materials, suggesting that the chondrule and the fine-grained material constitute the $CV3_{OxB}$ clast. Were the $CV3_{OxB}$ clasts the re-accreted fragments of a single $CV3_{OxB}$ asteroid? In addition, several large olivine aggregates (up to 300 μm in size) showing metamorphic textures are found. They are probably embedded in the host matrix, because boundaries of clasts containing these aggregates were not recognized. Similar aggregates are found in some carbonaceous chondrites [7]. Did the aggregates also originated from the $CV3_{OxB}$ asteroid? We studied one fayalite-bearing $CV3_{OxB}$ clast and one olivine-rich aggregate in detail as described below.

Fayalite-bearing $CV3_{OxB}$ clast: We found sixteen occurrences of fayalite in a single POP chondrule in this clast. The fayalite with sizes 10 to 50 μm occurs in chondrule interiors or peripheries, as discrete grains or constituents of large laths (Fig. 1ab). It commonly coexists with troilite and/or magnetite. The adjacent olivine phenocryst ($Fa_{\sim1}$) in the chondrule also shows evidence for alteration (Fig. 1b). These observations suggest that a genetic relationship between fayalite and magnetite, troilite or olivine phenocryst.

Oxygen-isotopic compositions of fayalite, magnetite and olivine phenocryst were studied. On a three oxygen isotope plot, fayalite and magnetite distribute along a single mass fractionation line, suggesting that these phases formed from the same oxygen isotopic reservoir. The $\delta^{18}O$ values of fayalite are ~10 ‰ higher than those of magnetite. The large fractionation in $\delta^{18}O$ provides evidence for low-temperature formation (<300 °C) of fayalite and magnetite in an aqueous environment, assuming that fayalite and magnetite were in equilibrium. Whereas olivine phenocrysts data do not fall on the same fractionation line, but on the CCAM line, suggesting that olivine phenocrysts were not in isotopic equilibrium with fayalite and magnetite. These results imply that fayalite replaced magnetite, or fayalite and magnetite precipitated from aqueous solution simultaneously.

Both nebular and asteroidal origins for $CV3_{OxB}$ fayalite have been proposed [8, 9]. According to the nebular model, fayalite was produced by high-temperature (>800 °C) reactions associated with SiO gas [9]. It is not consistent with our oxygen-isotope evidence indicating low-temperature formation of fayalite in an aqueous environment. Thus, the fayalite in the

$CV3_{OxB}$ clast in Yamato-86009 was probably an asteroidal origin. Then, where did the fayalite form; in situ in the present structure or in a different location of Yamato-86009, or in a different asteroid (e.g., a $CV3_{OxB}$ asteroid)?

Based on the oxygen-isotope evidence, fayalite in $CV3_{OxB}$ materials in CV3 chondrites could form at a single $CV3_{OxB}$ asteroid. The details are as follows. The oxygen-isotopic compositions of fayalite and magnetite in the $CV3_{OxB}$ clast in Yamato-86009 are different from those in $CV3_{OxB}$ Mokoia and Kaba [4, 5]. This isotopic difference indicates that the final oxygen-isotopic compositions of water, in which fayalite and magnetite formed, were different between these meteorites. The isotope ratio of final water is determined by conditions of water/rock ratio and temperature at the location where aqueous alteration occurred [10]. Because these conditions were expected to vary in a single asteroid [11], the $CV3_{OxB}$ clast and $CV3_{OxB}$ Mokoia and Kaba could originate from different locations of a single asteroid where the initial oxygen-isotope composition of water was homogeneous. However, we cannot rule out the possibility that they had different parent asteroids. The fayalite formation ages in each meteorite will constrain their formation processes.

Olivine-rich aggregate: An olivine-rich aggregate is coarse-grained (10-50 μm in size), granular, polymineralic rocks, consisting of olivine, Al-diopside, plagioclase and large sulfide (Fig. 2). Olivine, pyroxene and plagioclase typically form aggregates with 120° triple junctions. This texture requires prolonged annealing of pre-existing material at high temperature, which are not expected to occur in the solar nebula during chondrule formation, but could have taken place on the parent bodies of differentiated or metamorphosed meteorites [7].

Olivine (Fa_{35}) and pyroxene (Fs_1Wo_{50}) are almost compositionally uniform, suggesting that the aggregate experienced metamorphism enough to equilibrate olivine and pyroxene. Plagioclase (An_{40}) does not occur interstitially, unlike that in most chondrules, but forms separate crystals.

Oxygen-isotopic compositions of olivines in the aggregate were studied. On a three oxygen isotope plot, data of the olivines fall along a CCAM line, suggesting that olivines in the aggregate did not originated from a highly differentiated parent body where mass-dependent fractionation of oxygen-isotope occurred. Metamorphosed R chondrites have similar equilibrated composition of oilivine (Fa_{37-40}) [12]. However, oxygen-isotopic compositions of olivines in the aggregate and R chondrites are significantly different [13], implying that the parent body material of this aggregate is not made of R chondrites.

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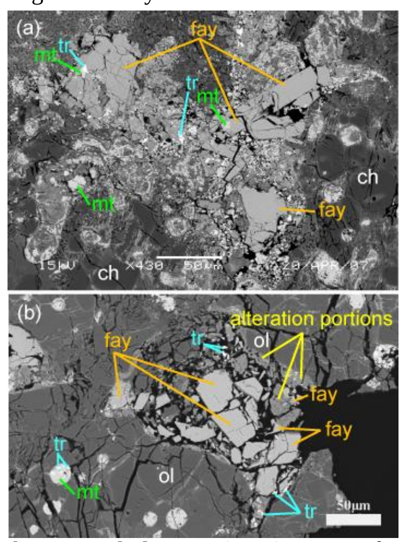

Fig 1. Back-scattered electron (BSE) image of two occurrences of fayalite (fay) in a POP chondrule (a) Fayalite grains coexist with magnetite (mt) and troilite (tr) at the chondrule (ch) periphery. (b) Fayalite grains coexist with troilite and associate with the alteration portions of olivine (ol) phenocrysts inside the chondrule.

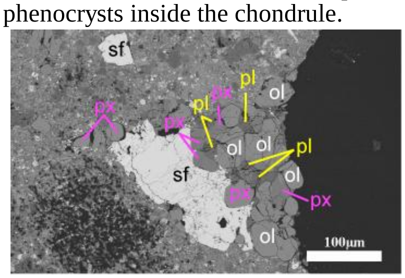

Fig 2. BSE image of an olivine-rich aggregate in the matrix The aggregate consists of olivine, pyroxene (px), plagioclase (pl) and large sulfide (sf), typically with 120° triple junctions.