Evidence for Incipient Alteration in Amoeboid Olivine Aggregates from the Ungrouped Carbonaceous Chondrite NWA 1152.

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Introduction:

Amoeboid olivine aggregates (AOAs) are irregularly shaped, fine-grained objects that constitute a few volume-percent of meteorites in most carbonaceous chondrite groups. The significance of AOAs is that they have escaped from extensive melting and preserve evidence for condensation from solar nebula gas [1]. In addition, because of their fine-grained texture, AOAs can be used as sensitive indicators of aqueous/thermal alteration [1, 2].

NWA 1152 is a primitive ungrouped carbonaceous chondrite which has an affinity to both CR chondrites and CV chondrites; the petrology of NWA 1152 is similar to CRs, but its oxygen isotope composition falls in the CV field [3] and it is enriched in refractory lithophile elements at concentrations comparable to CVs [4]. Although the variation within the individual carbonaceous chondrite group is widely studied, the relationships among and between carbonaceous chondrites remains unclear. In this study, we have examined the mineralogy of AOAs in NWA 1152 and the possible relationships between primitive carbonaceous chondrites.

Results and Discussion:

Occurrence and textures

Two thin sections of NWA 1152 (1152A and 1152B) were examined by optical microscope, SEM and EPMA. NWA 1152 has well-defined chondrules ranging between ~200μm to 1.5mm in size. Type I porphyritic olivine chondrules are dominantly observed. Iron-oxide with association with FeNi-metal is commonly observed probably due to terrestrial weathering and/or parent body alteration.

AOAs are not abundant: only three AOAs are identified in two thin sections. This is consistent with the low abundance of refractory inclusions identified by [3]. The AOAs are irregularly shaped, 150μm to 1mm across in thin section, and consist of aggregates of fine-grained olivine, Al-diopside, spinel, and blebs of FeNi metal (Figs. 1,2). No phyllosilicates were observed. These AOAs are texturally similar to those in reduced CV chondrites [1] and CR chondrites [5].

Mineral compositions

Most of the olivine grains in NWA 1152 AOAs are near pure forsterite (Fo_{96-99}, Fig. 3). It has been suggested that enrichment of olivine in fayalite component is correlated with petrologic subtype of a host meteorite [1,2]. The low Fa-contents of most olivine in NWA 1152 AOAs suggest that primary compositions are preserved. However, FeO-rich olivines ($Fa_{>20}$) do occur in isolated pocket-like areas along cracks or edges of AOAs (Fig. 4). This local occurrence of FeO-rich olivine is similar to that observed in Bali-type oxidized CV3 chondrites [1], and is consistent with crystallization in a relatively oxidizing environment during alteration.

In the NWA 1152 AOAs, MnO does not show a correlation with FeO (Fig. 5); thus, the FeO and MnO concentrations in olivine may result from distinct processes. The occurrence of FeO-rich olivine in local pockets favors an origin by secondary alteration. Several olivine analyses show enrichments in MnO, with MnO/FeO approaching 1.0 (Fig. 4). These compositions are similar to low-Fe Mn-enriched (LIME) olivine, which has been reported in AOAs from CR chondrites [5], the unclassified C-chondrite Acfer 094 and CO 3.0 Y-81020 [6]. LIME olivine has also been described in interplanetary dust particles (IDPs), isolated Mn-rich forsterite grains in matrices in primitive meteorites [9], and the Wild 2 cometary particles [10]. Thermodynamic models show that LIME-like olivine in AOAs can form by gas-solid reactions as temperature declines to near 1100 K [6,7]. The model of Ebel et al [7] indicates that Mn-rich, Fe-poor olivine forms under relatively low oxygen fugacities (solar composition, no dust enrichment). LIME olivines are not characteristic of CV AOAs (Fig. 5).

Behavior of Cr

Some tiny grains of a Fe-Cr rich phase are observed with FeO-bearing olivine in the pocket-like areas of NWA 1152 AOAs. Qualitative EDS indicates that the Fe-Cr-rich phase is probably chromite and we refer to this phase as chromite herein. A condensation origin of the chromite contradicts the low $f(O_2)$ environment inferred from LIME olivines, and the textural occurrence favors a metamorphic origin. The association of chromite and Fa-rich olivine in NWA 1152 AOAs represents a shift to higher oxygen fugacities during metamorphism, probably due to the local presence of aqueous fluid. Metamorphic conditions in NWA 1152 may have shared similarities with moderately metamorphosed type 3 ordinary chondrites (sub-type > 3.2), which have a fine-grained Cr-rich phase (likely chromite) mantling olivine phenocrysts in type II chondrules [11].

AOA-like particle in Wild 2 cometary dust

AOA-like particles are found in Wild 2 cometary dust [e.g., 12]. These include particle T112, which is composed of olivine and associated fine-grained chromite [13]. T112 olivine is similar in chemical and oxygen isotopic composition to olivine in primitive AOAs, but prior to this study, chromite had not been found in AOAs in chondrites. However, our work shows that chromite does occur as a secondary mineral in AOAs from NWA 1152. This strengthens the link between particle T112 and chondritic AOAs, and supports our earlier interpretation that chromite in T112 formed by secondary alteration [13].

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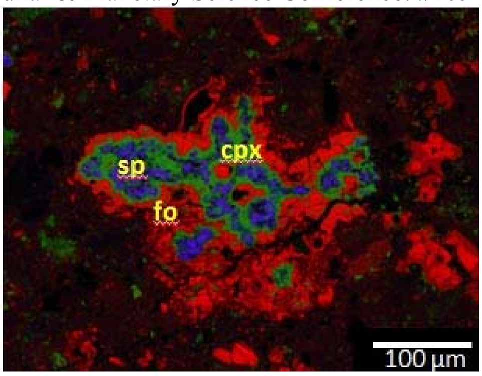

Fig.1. Combined X-ray elemental map of AOA #B05 in NWA 1152 (R;Mg, G;Ca, B; Al). AOAs in NWA 1152 are texturally similar to those in primitive C chondrites. Fo-forsterite, cpx-Al-diopside, sp-spinel.

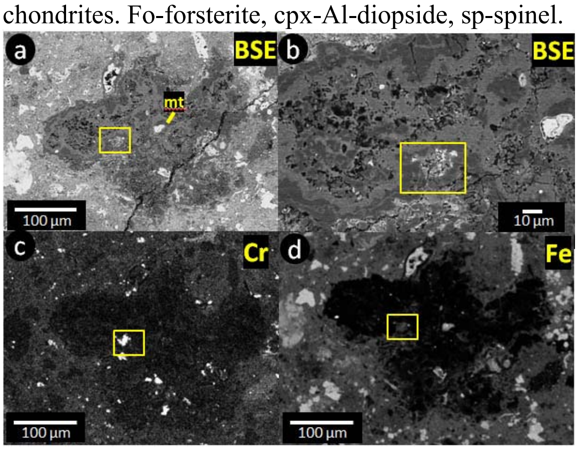

Fig. 2. BSE maps (a,b) and X-ray elemental maps of Cr (c) and Fe (d) of AOA #B05. The outlined area is shown in Fig. 4. Local Cr–enrichment is observed in pocket-like area.

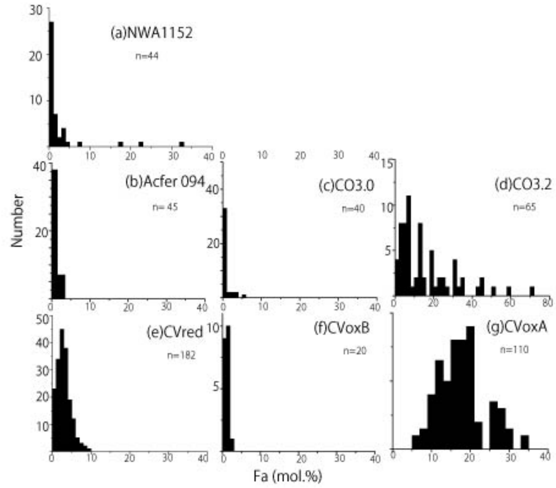

Fig.3. Compositions of olivine in AOAs in NWA 1152 (a), (b) Acfer 094 [8], (c) Y-81020 (CO3.0), (d) Y-82050 and Rainbow (CO3.2) [9], (e) Efremovka, Leoville, Vigarano (CVred) [10], (f) Kaba (CVoxB) [8], and (g) Allende (CVoxA).

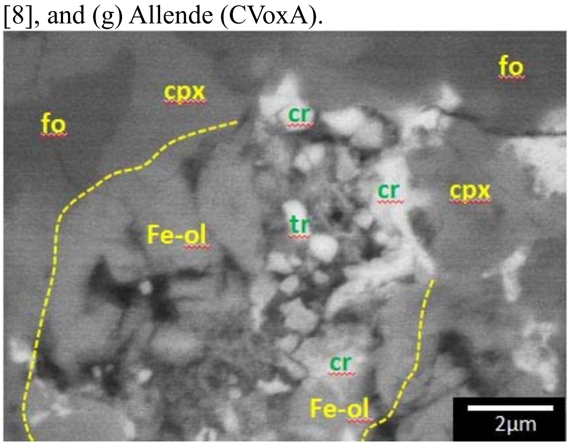

Fig.4. BSE image of pocket-like area in AOA #B05. Fine-grained Fe-Cr-rich phases (probably chromite) are associated with FeO-rich olivine.

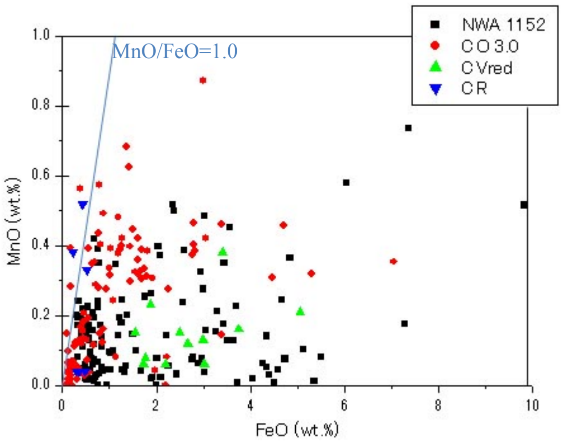

Fig.5. Plot of FeO versus MnO for olivine in AOAs in NWA 1152 together with the AOA olivine from primitive carbonaceous chondrites Y-81020 (CO3.0), reduced CV chondrites [8], and CR chondrites [7].