MINERALOGICAL AND PETROFABRIC STUDY OF PAIRED BRACHINITES ELEPHANT MORAINE 99402 AND 99407.
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Introduction: Asteroidal differentiation is considered to be one of the most fundamental processes to have occurred during the early evolution of the Solar System [e.g., 1]. Differentiated achondrites (e.g., eucrites) are believed to be the products from chondritic materials through differentiation, while some unusual meteorites called primitive achondrites have been found, showing both chondritic and achondritic features. As a result, primitive achondrites are generally thought to be the materials intermediate between chondrites and achondrites [e.g., 2]. This suggests that studying primitive achondrites leads to a better understanding of the asteroidal differentiation in variable degrees.

Brachinite is an important primitive achondrite group to know the initial planetary differentiation because it has a very old ^{53}Mn-^{53}Cr age of 4564.8 ± 0.5 Ma (Brachina: the type specimen of brachinite) and is suggested to have formed at the early stage of differentiation [3]. A lot of researchers have indicated that brachinites are partial melt residues [e.g., 4,5], while there are some suggestions that brachinites are olivine cumulates and are not primitive achondrites [e.g., 6]. In fact, there has been no consensus on the origin of brachinite. Additionally, there are numerous ungrouped achondrites with generally similar petrologic, compositional and isotopic characteristics to brachinites ("brachinite-like") [e.g., 4]. In this way, the formation process of brachinites is still unclear. In this abstract we discussed the formation process of two paired brachinites EET 99402 and 99407 with the viewpoint of mineralogy and petrofabrics.

Samples and Analytical Methods: We studied two polished thin sections (EET 99402,47 and EET 99407,10) and one polished thick section (EET 99407,16) supplied from the Meteorite Working Group. Back-scattered electron (BSE) images were taken with JEOL JSM-7100F scanning electron microscope (SEM) with energy dispersive spectrometers (EDS) equipped with an electron backscatter diffraction (EBSD) detector at NIPR. For the measurement of the crystallographic preferred orientation (CPO) of olivine grains, we employed SEM-EBSD and obtained crystal orientation stereographic nets using HKL's CHANNEL 5 software. X-Ray elemental distribution maps were acquired by JEOL JXA-8530F electron microprobe (EPMA) at the University of Tokyo. Quantitative wavelength dispersive analyses were also performed on the same EPMA.

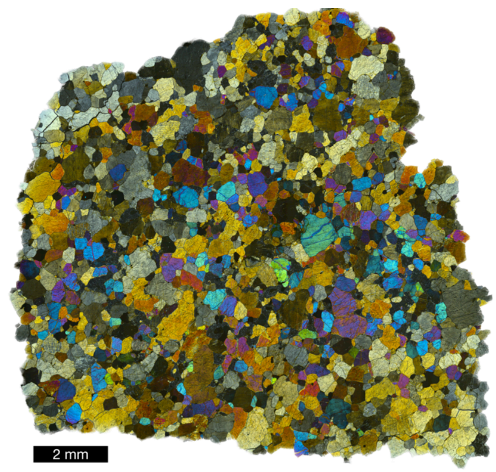

Fig. 1: The optical photomicrograph under crossed nicols of EET 99407,10. It is mostly composed of granular olivine grains which show wavy extinction.

Results: Optical microscopic observation shows that both EET 99402 and 99407 are coarse-grained rocks with a granular texture (Fig. 1). They are mostly composed of olivine (grain size: ~0.5-1.5 mm) showing wavy extinction. Other constituent minerals are clinopyroxene, plagioclase, chromite, Fe sulfide and Fe-Ni metal. Clinopyroxene and plagioclase grains are anhedral and their sizes are ~0.5-2.0 mm. Chromite has a subhedral rounded shape and is ~0.5-1.0 mm in size. Fe sulfide and Fe-Ni metal ubiquitously exist as very fine-grained inclusions (<10 µm) in other coarse-grained minerals (Fig. 2).

Mineral compositions of EET 99402 and 99407 are identical. X-ray elemental maps show that olivine, clinopyroxene and plagioclase have homogeneous compositions similar to other brachinites [e.g., 7]. Olivine compositions are $Fo_{\sim 63-64}$. Clinopyroxene ($En_{\sim 44}Wo_{\sim 46}$) and plagioclase ($An_{\sim 41}Or_{\sim 0.2}$) also have typical compositions as brachinites.

We measured one point per one olivine grain (total 243 grains) of the polished thick section (EET 99407,16) to analyze CPO of olivine crystals. EET 99407 has clear CPO patterns of olivine that are preferentially aligned along [010] (*b* axis) (Fig. 3). This result is consistent with the previous study using the universal stage [6].

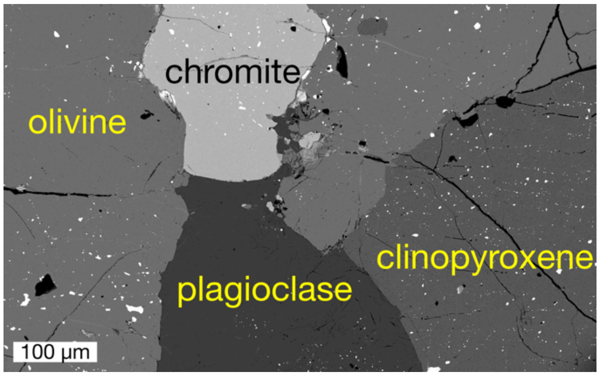

Fig. 2: BSE image of EET 99407,10. There are olivine, clinopyroxene, plagioclase and chromite. Tiny white inclusions are Fe-sulfide and metal.

Discussion: The observations and the analyses of EET 99402 and 99407 in this study show that the modal abundances, textures and the mineral compositions of these two meteorites are indistinguishable. The existence of tiny sulfide and metal inclusions in the whole thin section is also common. These facts clearly support that EET 99402 and 99407 are paired meteorites [8].

Olivine grains in EET 99402 and 99407 show undulatory extinction. This suggests that these are moderately shocked meteorites unusual for brachinites [7]. The occurrence of tiny sulfide and metal grains (Fig. 2) is also uncommon in brachinites [7]. Fe-sulfide and metal are generally present as fine-grained assemblages with orthopyroxene at the grain boundaries of coarse-grained minerals in typical brachinites [e.g., 9]. The texture of sulfide and metal in EET 99402 and 99407 indicates that a shock event may have caused melting of low temperature components and recrystallization of tiny Fe-sulfide and metal grains from the melt of the Fe-Ni-S system on the parent body.

The olivine CPO pattern of *b* axis concentration was detected in EET 99407,16 (Fig. 3). We found a similar olivine CPO pattern in Reid 013 (brachinite) and MIL 090206/090340/090405 (brachinite-like meteorites) [10]. So far, the measurements of olivine CPO in brachinites other than these brachinite-like meteorites have not been performed. We plan to measure olivine CPO in other brachinites to verify that olivine in brachinites commonly shows the CPO pattern of *b* axis concentration.

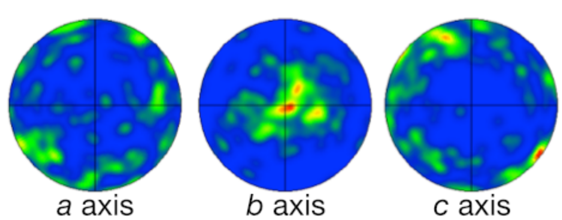

Fig. 3: Stereographic nets of olivine crystals (space group: P_{bnm}) in EET 99407,16. Total measured points were 243 points. These show that *b* axes concentrate on one direction (perpendicular to the surface of the polished thick section).

Olivine *b* axis concentration is generally found in terrestrial cumulate rocks [e.g., 11]. The same pattern is also formed by simple shear experiments (P=300 MPa, T=1250 ^{o}C) [12]. The facts suggest that brachinites formed by olivine accumulation or they were exposed to simple shear after partial melting on their parent body. On the other hand, olivine CPO patterns with *c* axis concentration have been found in brachinite-like meteorites (Divnoe and NWA 6112) [13]. This *c* axis concentration pattern was also found in other primitive achondrites (lodranite: Yamato 791493, ureilite: Dingo Pup Donga) [14,15] and thought to have been formed in melt flows by olivine accumulation. If brachinites and brachinite-like meteorites discussed above came from the same parent body or experienced a similar formation history, their parent body(s) was/were melted and they formed by olivine accumulation. Two different olivine CPO patterns reflect the presence or absence of melt flow on the parent body(s).

Conclusions: The existence of olivine CPO patterns of *b* or *c* axis concentration indicates that the parent body(s) of brachinites experienced melting strongly enough to cause olivine accumulation. However, brachinites have the oxygen isotope variation greater than any other groups of differentiated achondrites and the high abundances of REEs and highly siderophile elements [7,16]. This is in conflict with olivine accumulation process. More study is needed to clarify the formation process of brachinites.`

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