Mineralogical study of silica minerals in Camel Donga eucrite

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1. Introduction
Eucrite is one group of the HED clan meteorites that are considered to be from the asteroid 4 Vesta (e.g., McSween et al., 2011). Eucrite is mainly composed of pyroxene and plagioclase, whose mineralogy is used to classify their degrees of thermal metamorphism (e.g., Takeda & Graham, 1991). Silica is present as an accessory mineral, and its abundance sometimes reaches up to 10 vol% (Mayne et al., 2009). However, most of previous studies did not focus on silica and their mineral species have not been identified. Silica minerals are known to have >23 polymorphs (e.g., Kihara et al. 2001). Especially, tridymite has many polymorphs and bears complex transformation processes (e.g., from hexagonal into monoclinic or pseudo orthorhombic via orthorhombic below 400 deg. C.) (Graetsch & Flörke, 1991). Therefore, we have focused on silica minerals in eucrites and tried to understand their formation conditions and thermal histories at low temperature. In our previous studies, we have studied 3 cumulate and 6 non-cumulate eucrites (e.g., Ono et al., 2017) and revealed that the assemblages of silica minerals relate to degrees of thermal metamorphism (Ono et al., 2018). For example, type 2 has orthorhombic tridymite, quartz, and cristobalite, and type 4 has only quartz (Ono et al., 2017). In this study, we observed Camel Donga, a non-cumulate eucrite, classified into type 5 in the thermal metamorphic degree, and analyzed silica minerals to confirm the relationship between silica phases and thermal metamorphism.
2. Sample and Methods
We observed a thick section of Camel Donga (ca. 22 mm x 11 mm). We located silica minerals using FE-SEM and then identified them by EBSD patterns and Raman spectra. Quantitative chemical analyses were performed using FE-EPMA.
3. Results and Discussions
Five lithic clasts (2-4 mm in size) have large pyroxene grains and lathy plagioclase. There are smaller lithic clasts and fragments of plagioclase and silica grains are also present. EBSD patterns and Raman spectra show that quartz is commonly present in all clasts, but most of them are composed of multiple silica species. The assemblages of silica minerals are roughly classified into 3 groups by clasts, (1) clasts containing only quartz, (2) clasts containing aggregates of quartz and monoclinic tridymite, and (3) clasts containing aggregates of quartz and orthorhombic tridymite. Additionally, we found monoclinic tridymite grains as mineral fragments. Quartz in the (1) clasts forms fragments and are included in pyroxene. Quartz in the (2) and (3) clasts includes tiny opaque minerals and vesicles (<5 μm) and monoclinic tridymite in these clasts does not contain them. Aggregates of silica minerals in the (2) clasts have characteristic tiny cracks, but aggregates in the (3) clasts do not have them. We consider that such cracks are formed by the transformation from cristobalite to tridymite. However, orthorhombic tridymite in the (3) clasts is not formed by such phase transformation because it is known that tridymite transforms to monoclinic via orthorhombic below 400 $^{\circ}$C. Thus, the presence of different assemblages of silica minerals in different clasts suggests that they experienced different thermal histories before incorporation by brecciation. Although Camel Donga is monomict breccia and classified into type 5 of thermal metamorphism (Roszjar et al., 2017), we classified (1) is type 4, (2) is type 5 or 6, and (3) is type 2 by mineralogy of silica minerals.
4. Conclusions
We studied Camel Donga, monomict brecciated eucrite. We found the presence of clasts with different thermal metamorphic degrees that are classified into types 2, 4 and 5 or 6 although this meteorite is considered to be type 5 by earlier studies. We plan to analyze chemical composition of pyroxene in each

clast to see the relationship with silica mineralogy.

Keywords: Eucrite, Silica minerals, Tridymite, Quartz, Thermal metamorphism

