Metamorphic history of Vestan crust: Petrologic evidence from monomict basaltic eucrites

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Introduction

The asteroid 4 Vesta is one of the survived proto-planets formed in the early Solar System. Vesta is the second largest asteroid (~520 km in diameter). The outermost crust of Vesta consists of basaltic eucrites. Detail observations by DAWN revealed the numerous impact craters on the surface of Vesta. The fact implies that Vestan crust has affected by multiple impact events after the crust formation. The petrologic study of basaltic eucrites provides the information about the formation history of the Vestan crust. We observed the textures associated with impact and thermal metamorphism in seven monomict and unbrecciated eucrites. All the samples have the evidence for shock metamorphism, and some experienced multiple shock and thermal metamorphism. In this study, we report the petrologic and mineralogical features of these eucrites and discuss the secondary processing to better understand the formation history of the Vestan crust.

Samples and Methods

We studied five brecciated eucrites (Juvinas, Millibillillie, Cachari, A-881747, and Y 792510) and two unbrecciated eucrites (Y-790266 and Y 983366). We examined polished thick and thin sections (PTSs) of these eucrites using an electron microprobe analyzer (EPMA; JEOL JXA-8200), a field emission scanning electron microscope (FE-SEM; JEOL JSM-7100F) equipped with an energy dispersive detector (EDS; Oxford AZtec Energy) and, a cathodoluminescence system (CL; Oxford Mono CL2) at NIPR. We also used a luminoscope (ELM-3) at OUS and a Raman spectroscope (JASCO NRS-1000) at NIPR to distinguish silica minerals.

Results and discussions

Brecciated eucrites:

Juvinas, Millibillillie, Cachari, A-881747 and, Y 792510 show textural variations. Our observation distinguished the textures to a crystalline clast and a clastic matrix. The most of crystalline clasts of these eucrites show a subophitic texture of pyroxene and plagioclase with minor minerals. The clastic matrix is composed of lithic clast and mineral fragments.

Juvinas consists of a coarse-grained crystalline portion (CG), a fine-grained crystalline portion (FG), and a clastic matrix. The CG portion shows a subophitic texture of large (up to 1mm) pyroxene and plagioclase. The FG portion shows a poikilitic texture mainly composed of acicular plagioclase (~200 μm long), anhedral pyroxene and large lathy tridymite (~2-3 mm long). The clastic matrix is composed of the fragments of the crystalline clasts described above (CG and FG) and mineral fragments. The clastic matrix of Juvinas has a high porosity (~20 vol.%). The grains boundaries of mineral fragments join smoothly and welded. The facts indicate that Juvinas located to near the surface of Vestan crust, and did not suffer compaction. Juvinas only suffered from subsequent mild thermal metamorphism after brecciation. The clastic matrix of Juvinas formed by shock metamorphism at the last stage of formation history for Juvinas.

Millibillillie consists of a coarse-grained crystalline portion (CG), a fine-grained crystalline portion (FG), recrystallized clastic matrix, and very fine-grained igneous matrix. We observed shock veins which transect the crystalline clast to the recrystallized clastic matrix of Millibillillie. The CG portion shows a subophitic texture of large (~1 mm) pyroxene and plagioclase. The FG portion shows a subophitic texture of pyroxene and thin plagioclase (50 μm thick, ~400 μm long). The very fine-grained igneous matrix seems to a quench texture. The clastic matrix consists of mineral fragments (<100-600 μm) which meet at a 120° triple junctions at the grain boundaries. The lithology of the clastic matrix of Millibillillie is texturally similar for type A granulitic eucrites. A shock-veins cutting the recrystallized clastic matrix of Millibillillie indicates that Millibillillie suffered from shock metamorphism after thermal metamorphism.

Cachari consists of a coarse-grained crystalline portion and a recrystallized clastic matrix. The crystalline portion shows subophitic texture of coarse-grain (~0.5-1 mm) pyroxene and plagioclase. Most of the plagioclase in the crystalline portion shows rounded corners. The clastic matrix consists of mineral fragments (<800 μm) and fine-grained rounded minerals (<100 μm). The clastic matrix in Cachari resembles that of Millibillillie. We observed a large (100 μm thick, ~3 mm long) shock-vein in the recrystallized clastic matrix of Cachari. A network-like shape of thin shock-veins branched from the large shock-vein spread into crystalline portions. The occurrence of the shock-veins indicates that Cachari suffered from shock metamorphism after brecciation and recrystallization.

A-881747 consists of subophitic clast set in a fine-grained clastic matrix. The subophitic portion is composed of large (0.5-1 mm) pyroxene and plagioclase and relatively small (<300 μm) silica and opaque minerals. Fine-grained clastic matrix is composed of ~50 μm polygonal silicate minerals and ~10 μm opaque minerals. This lithology of the fine-grained portion is very similar for type B granulitic eucrite (e.g., Agoult). The crystalline clast and clastic matrix of A-881747 are cutting by several shock-veins. We observed maskelynite in the clastic matrix of A-881747 which adjacent to the shock veins. Therefore, the maskelynite in clastic matrix obvious relates to the formation of the shock-vein after brecciation.

Y-792510 consists of subophitic crystalline clasts and clastic matrix. The crystalline clast consists of large (>500 μm) pyroxene and lathy plagioclase. The recrystallized clastic matrix around the crystalline clasts consists of mineral fragments (<500 μm). The 120° triple junctions at the grain boundaries are not remarkable than Millibillillie, A-881747, and Cachari. The occurrence implies that the incomplete recrystallization by thermal metamorphism after brecciation.

Millibillillie, Cachari, A-881747 and, Y-792510 have recrystallized clastic matrixes. The presence of the recrystallized clastic matrixes is the evidence for subsequent thermal metamorphism after brecciation. We observe shock-veins which cross the crystalline clast to the recrystallized clastic matrix in these eucrites. These facts indicate Millibillillie, Cachari, Y-792510, and A-881747 suffered from at least two shock and thermal metamorphism. Juvinas and Millibillillie experienced multiple metamorphic histories. On the base of the previous studies, Juvinas experienced two stages of shock metamorphism and three stages of thermal metamorphisms [1], Millibillillie experienced three stages of shock metamorphism and thermal metamorphism [2]. These studies suggest that the metamorphic history of the brecciated eucrite is more complex than previously suggested.

Unbrecciated eucrites:

Y-790266 and Y 983366 are unbrecciated eucrites that show a subophitic texture of pyroxene and plagioclase with minor minerals. The pyroxene in the two samples has a remnant Ca-zoning. This is a typical petrologic feature for basaltic eucrites subdivides into type 4 pyroxene [3]. This pyroxene suffered from incomplete equilibration after crystallization. We observed shock veins in Y-790266 and Y 983366. Part of the plagioclase in Y-790266 converts to maskelynite which locates along the shock-veins. On the other hand, we could not find maskelynite in Y 983366. Based on the observation in this study, Y-790266 and Y 983366 seem to only suffered from a one shock event and mild thermal metamorphism.

The shock and thermal history of Y-790266 and Y 983366 imply that these eucrites keep the information for primitive lithology of Vestan crust. The subophitic texture implies relatively quick solidification from magma. Several of crystalline portion of brecciated eucrites also have the subophitic lithology.

Summary and implication

We observed metamorphic textures in both brecciated and unbrecciated eucrites. The petrologic features of brecciated eucrites (Millibillillie, Cachari, Y-792510, and A-881747) indicate that the samples suffer from shock and thermal metamorphism, and compaction after brecciation. Moreover, the textural variation in Juvinas and Milbillillie implies the multiple shock and thermal metamorphism at the local area in the crust. The metamorphic history of unbrecciated eucrites studied here is not more complex than the metamorphic history of the brecciated eucrites. However, the presence of shock textures in unbrecciated eucrites indicates shock event is a common process for basaltic eucrites. These results from monomict eucrites are consistent with geologic history of the surface of Vestan crust inferred DAWN's observations.

References

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