Discovery of coesite and stishovite in HED meteorite

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Introduction

Howardite-Eucrite-Diogenite (HED) meteorite is the biggest clan in achondrite group. It is expected that HED meteorite originates from one of the largest asteroids in the solar system, 4 Vesta. Recent Dawn mission also supports the prediction [1][2]. Dawn also clearly revealed the existence of many craters on 4 Vesta, which will be a record of heavy meteorite bombardment. The existence of a high-pressure polymorph in a shocked meteorite is a clear evidence for a dynamic event on its parent-body (e.g., [3][4]). A high-pressure polymorph can be used for estimating the magnitude of a dynamic event (e.g., [5][6]). Some previous studies propose that 4 Vesta also might suffer from late heavy bombardment (LHB) as well as the moon [7]. However, a high-pressure polymorph has not been found in HED meteorite so far.

It is likely that eucrite contains a high-pressure polymorph because the surface of 4 Vesta, where there are many craters, consists mainly of eucrite. We got one of eucrites, Bereba to clarify a dynamic event occurred on 4 Vesta using a high-pressure polymorph. Bereba has several dark-colored shock-melt veins, implying that it was heavily shocked. Here, we report a first evidence for existence of a high-pressure polymorph of silica, coesite and stishovite in HED meteorite.

Experimental methods

We prepared the petrologic thin section of Bereba. The petrological and mineralogical textures of Bereba were studied with the thin section by a low-vacuum SEM without any coating. Detailed mineralogical texture observations were conducted with a field-emission SEM. Chemical compositions of the constituent minerals were determined with an EMPA. A laser micro-Raman spectroscopy was used to identify a high-pressure polymorph. Several silica grains including high-pressure polymorphs were observed with a TEM. Samples for TEM observations were prepared by a FIB system. We excavated some silica grains using a FIB system and investigated them with a synchrotron X-ray diffraction (sXRD) at BL-10 of SPring-8.

Results and discussion

Major constituent minerals of present Bereba are low-Ca pyroxene ($Fs_{59-63}En_{34-37}Wo_{2-3}$), augite ($Fs_{25-32}En_{29-31}Wo_{38-44}$), feldspar ($An_{86-92}Ab_{7-14}Or_{0-1}$), silica, metallic Fe and iron sulfide. Most low-Ca pyroxene has exsolution lamellae of augite. There are many melt-pockets and shock-melt veins. Feldspar transforms into maskelynite partly or completely. Silica grain is up to ~300 μm in dimension, and includes several inclusions such as pyroxene and metallic iron. We especially focused our interest on the silica grains in this study.

Raman spectroscopy analyses show that the silica grains in the host-rock of Bereba are cristobalite, tridymite and quartz. Most quartz grains entrained in the shock-melt veins are partly replaced with coesite. BSE images show that silica grains entrained in or adjacent to the shock-melt veins have a network-like or lamellae-like texture. Raman spectroscopy, sXRD analyses and TEM images indicate that such silica grains include coesite, stishovite and silica glass along with quartz.

The existence of stishovite indicates that pressure condition recoded in Bereba should be ~8 GPa at least based on a phase diagram obtained from static high-pressure synthetic experiments [8]. Two giant impact basins on 4 Vesta are depicted by Dawn mission. Crater chronology obtained by Dawn mission reveals that the giant impact basins were formed around 1.0 Ga ago [9]. Its fragments became Vesta family in asteroid belt, and a part of them fell into the Earth as HED meteorite. U-Pb age of apatite in Bereba, which is very sensitive to temperature, is ~4.2 Ga [10]. We could regard the U-Pb age as a shock age because the existence of coesite and stishovite proves high-pressure and temperature condition. However, the shock age contradicts the crater chronology of 4 Vesta. More detailed and careful studies based on high-pressure mineralogy, which was overlooked for a long time, are essential for clarifying the origin of HED meteorite and evolution of 4 Vesta.

References:

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