Discovery of stishovite in Apollo 15299 sample

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ABSTRACT

High-pressure polymorphs recovered in terrestrial craters are evidence of meteoroid impact events on the Earth’s surface. Despite countless impact craters on the Moon, high-pressure polymorphs have not been reported to date in returned Apollo samples. On the other hand, recent studies report that the high-pressure polymorphs of silica, coesite, and stishovite occur in shocked lunar meteorites. We investigated regolith breccia 15299, which was returned by the Apollo 15 mission, using the combined techniques of focused ion beam (FIB), synchrotron X-ray diffraction (XRD), and transmission electron microscopy (TEM). The regolith breccia 15299 studied here consists of a mafic impact melt breccia with millimeter-sized, coarse-grained, low-Ti basalt clasts. The mafic melt breccia consists of fragments of minerals (olivine, pyroxene, plagioclase, silica, and ilmenite) and glass. Several quartz, tridymite, and cristobalite grains of 10–100 µm across occur in the mafic impact melt breccia. Vascular melt veins of less than ~200 µm wide cut across the mafic melt breccia matrix and mineral fragments. Some silica grains are entrained in the melt veins. One of the silica grains entrained in the melt veins consist of stishovite [a = 4.190(1), c = 2.674(1) Å, V = 46.95 Å3], space group P42/mnm along with tridymite and silica glass. This is the first report of high-pressure polymorphs returned from lunar samples. TEM images show that the stishovite is needle-like in habit, and up to ~400 nm in size. Considering the lithologies and shock features of 15299, it is inferred that the stishovite possibly formed by the Imbrium impact or subsequent local impact event(s) in the Procellarum KREEP Terrane (PKT) of the nearside of the Moon.

Keywords: Apollo, stishovite, Imbrium impact, Procellarum terrane

INTRODUCTION

Numerous craters and a thick layer of soil (called regolith, hereafter) on the Moon indicate that the Moon has been heavily bombarded by meteoroids. It is expected that lunar surface materials are exposed to transient high-pressure and high-temperature conditions upon meteoroid impacts, and constituent minerals should transform into high-pressure polymorphs. Breciated rocks (breccias) are products of meteoroid impacts in which rocks of the Moon are shattered by impact. Local pressure and/or temperature spikes occur during impact, thus allowing for the formation of high-pressure polymorphs in breccias. The shattered rock fragments are consolidated, being buried in mixed impact debris, megaregolith layers. Thus, breccias are among ideal reservoirs of impact-induced high-pressure polymorphs. However, no high-pressure polymorph has been reported to date in Apollo samples. We investigated the regolith breccia 15299, which was collected by the Apollo 15 mission, with a focused ion beam (FIB) system, synchrotron X-ray diffraction (XRD), and a transmission electron microscope (TEM). High-pressure polymorphs of silica have recently been found in shocked lunar meteorites (Ohtani et al. 2011; Miyahara et al. 2013), which were excavated and launched from the Moon by meteoroid impacts. Accordingly, we focused on silica minerals in the regolith breccia 15299. Here, we report the discovery of a high-pressure polymorph of silica, stishovite, in Apollo sample 15299.

MATERIALS AND EXPERIMENTAL METHODS

We observed the detailed fine textures of Apollo 15299,200 polished thin section using a field-emission gun scanning electron microscope (FEG-SEM), JEOL JSM-71010 and 7100 F with an accelerating voltage of 15 kV. A laser micro-Raman spectroscopy, JASCO NRS-5100 was used for the identification of minerals in the sample. A microscope was used to focus the excitation laser beam (532 nm lines of a green laser). The laser beam was focused through microscope objectives (~100) to ~1 µm on the sample. The laser power was kept at 6.7 or 7.3 mW.

A part of the sample was excavated with a FIB system, FEI Quanta 200 3D for synchrotron X-ray diffraction (XRD) analysis. We placed the extracted block piece (~15 × 7 × 5 µm) on a cuvette of single diamond plate attached to a dedicated optical microscope. The extracted block piece on the diamond was scanned at the SPring-8 BL10XU beamline. A monochromatic incident X-ray beam with a wavelength of 0.4136(7) Å was collimated to less than 10 µm. XRD spectra were collected on an imaging plate (IP) using an exposure time of 10 or 15 min. The XRD spectrum of cerium dioxide (CeO2) was used to determine the wavelength and the distance between the sample and the IP.

A slice for TEM observation was prepared from the excavated block piece on