COESITE AND OTHER SILICA POLYMORPHS IN THE NAKHLA MARTIAN METEORITE.

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Introduction: In our recent studies of shergottites we focused on "brown" olivine and pointed out the importance of high post-shock temperature (>1200~1170 K) associated with high pressure (around 55 GPa) shock metamorphism, inducing back-transformation of high-pressure polymorph(s) of olivine [1,2]. Nakhlites are less shocked (14-20 GPa) compared to other Martian meteorites [3] and such a level of shock pressure usually yields formation of high-pressure polymorphs (and no back-transformation) [4]. However, there are no reports of high-pressure phases in nakhlites. In this study we studied silica minerals in Nakhla to search high-pressure polymorphs in order to better understand shock metamorphism of Martian meteorites.

Sample and Analytical Methods: A polished thin section of Nakhla was first observed by optical microscopy. Then, it was analyzed with electron microprobe (JEOL JXA-8530F at University of Tokyo) to locate silica minerals and to obtain their quantitative compositions after careful back-scattered electron (BSE) image observations. We analyzed silica minerals by micro-Raman spectrometers (JASCO NRS-1000 at NIPR and micro-Raman spectrometer system at University of Tokyo) and subsequently by SEM-EBSD (JEOL JSM-7000F at University of Tokyo) to identify their mineral species.

Results: Silica minerals are exclusively present in the mesostasis that is interstitial to cumulus augite and olivine. The mesostasis is mainly composed of plagioclase laths (~0.5 mm long) with Si-(K-)rich glass, silica minerals, titanomagnetite, Fe-rich pyroxene and some other minor phases, which is consistent with previous studies [e.g., 5,6]. Silica minerals are present as blocky grains up to 100 μm in size, but they also occur as fine-grained (~a few μm) mixture with Si-(K-)rich glass. In this study we only analyzed blocky silica grains. The Raman analysis showed high fluorescence probably due to shock, but we could detect cristobalite and tridymite (orthorhombic). There is no clear difference in occurrence between these two silica phases. The EBSD analysis of the same crystals gave only faint Kikuchi bands in many cases probably due to sample damage by Raman analysis and we could identify only cristobalite. We also found coesite, whose presence was inferred from a sharp Raman peak at around 516-520 cm^{-1} along with a weaker peak at around 270 cm^{-1}. The coesite Raman spectra were mostly mixed with those of cristobalite and tridymite, indicating that they coexist on submicrometer scale. BSE observations of these silica grains did not show a distinct texture for coesite compared to cristobalite and tridymite. The Kikuchi bands of coesite were not properly obtained by EBSD. A few Raman analyses showed signs of a weak peak at around 750 cm^{-1}, which is the main Raman peak of stishovite, but there is no other evidence for its presence, and thus the presence of stishovite has not been confirmed. Quartz is reported from Nakhla [7], but we have not come across clear Raman spectra of quartz in our sample.

Discussion and Conclusion: This is the first report of coesite from Nakhla. Furthermore, this is the first discovery of any high-pressure polymorphs formed by shock in nakhlites. Since suggestive peak shock pressure of nakhlites is 14-20 GPa [3] and there are several pieces of evidence for shock metamorphism (e.g., mechanical twinning of pyroxene), there is no wonder for the discovery of coesite from nakhlites. Coesite was probably shock transformed from cristobalite or/and tridymite. The presence of coesite and stishovite has been known in a shocked eucrite Béréba, but they formed associated with shock melts [4]. In our Nakhla sample, we did not find any shock melting textures in the mesostasis, and therefore, coesite in Nakhla would be a solid-state transformation product. Cristobalite and orthorhombic tridymite are present in some eucrites and they are considered to have been formed by relatively rapid cooling at low temperatures (<400 ^{o}C) after crystallization from magma compared to samples with quartz and monoclinic tridymite [8]. Therefore, the presence of cristobalite and orthorhombic tridymite in Nakhla is consistent with the formation at a shallow region (several meters from the surface) of the nakhlite igneous body [e.g., 9]. It is further required to analyze detailed spatial distributions of these silica polymorphs not only in Nakhla, but in other nakhlites by an FIB-TEM study.

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