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Traces of water in lunar meteorite

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Based on the Apollo mission, the lunar rocks from the Moon's surface to interior were considered to be anhydrous because of absence of hydrous minerals, lack of aqueous alteration effect evidence, and very low water contents below 1 ppb [1]. However, recent remote sensing observations, e.g. Chandrayaan-1, revealed that there exists molecular water and hydroxyl groups on the lunar surface by the refraction spectroscopy [2]. Furthermore, hydroxyl water was detected in volcanic glasses in lunar basalt at 46 ppm [3] and plagioclase in anorthosite at 5 to 6.4 ppm [4]. Previous study also founds hydroxyl-rich apatite (0.7 to 1.7 wt.%) in lunar meteorite NWA2977 [5]. These investigations had demonstrated that the water (or hydroxyl) contents on lunar surface are more abundant than expected previously, but there is still little evidence of water in the lunar interior. In this study, gabbroic and basaltic breccia lunar meteorites that have clasts interpreted as products of crystallization of late-stage magmatic residual liquids were studied using an electron microscope and spectroscopic analyses for the evaluation of their mineralogy and water contents.

Electron microscopic observation revealed that the lunar meteorites consist of gabbroic and basaltic clasts in their breccia matrix. The basaltic clasts contain quartz grains up to a several tens of micrometers in length. The quartz was crystallized above 40 MPa under a dry condition, which is corresponding to the depth below 10 km from the lunar surface [6]. It suggests that the lunar meteorites in the present study were originally formed in the lunar interior. As a result of synchrotron XRD analysis and Raman spectroscopy, the silica grains mainly consisting of moganite (monoclinic silica polymorphs) were observed in the breccia matrix, where the moganite content reaches $>$90 wt.% based on Raman spectroscopic methods [7-8]. These moganite grains were also present in shock veins, and they were surrounded by high-pressure polymorphs of silica, coesite and stishovite, implying that the moganite grains originally formed in the Moon, irrespective of terrestrial weathering nor back-transformation during an impact event. Terrestrial microcrystalline silica with $>$20 wt.% moganite content are known to be precipitated from alkaline fluid as evaporite [9]. Microcrystalline calcite also coexists with moganite in the lunar meteorites, and they possess traces of foaming in shock veins and close to fusion crusts with the melt glasses, implying their formations in the Moon. These facts suggest that a significant amount of water was present in the original magma in the lunar interior, where fluids probably assisted chemical/physical evolution of lunar inner materials. For quantitative estimation of water content in the magma, we will perform infrared spectroscopy for the constituent minerals such as olivine, pyroxene and feldspar in gabbroic and basaltic clasts of the lunar meteorites.

References: [1] Taylor S.R. et al. (2006) Geochim. Cosmochim. Acta. 70, 5904-5918, [2] Pieters C.M. et al. (2009) Science. 326, 568-572, [3] Saal A.E. et al. (2008) Nature. 454, 192-195, [4] Hui H. et al. (2013) Nature Geosci. 6, 177-180, [5] McCubbin F.M. et al. (2010) Proc. Natl. Acad. Sci. USA, 107, 11223-11228, [6] Charles R.W. et al. (1971) Proc. Second Lunar Sci. Conf. 1, 645-664, [7] Gotze J. et al. (1998) Contrib. Mineral. Petrol. 133, 96-105, [8] Schmidt P. et al. (2013) Eur. J. Mineral. 25, 797-805, [9] Heaney and Post (1992) Science. 255, 441-443