Origin of water and water reservoirs on the Moon as considered from the perspective of material sciences

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Water-bearing deposits have been discovered on the Moon by the spacecraft missions and the spectral data identified the water species as hydroxyl groups, mineral-bound H_2O and ice. The water supply sources to the surface were suggested to be derived from solar wind and cometary/asteroidal water. However, both of them are insufficient to explain abundant hydroxyl groups, the origin of mineral-bound H_2O and heterogeneous distribution of water on the Moon. Recent studies proposed the wet lunar mantle based on results of various microanalyses of lunar meteorites, and found the mantle-originated olivine-bearing sites and the plutonic Olivine Hill on the South Pole Aitken (SPA) and Procellarum basin by the spacecraft missions. Therefore, the possibility that mantle-originated water significantly act as a new candidate of the water supply source to the surface must be considered from the perspective of meteorite and Apollo samples. Here we identified the water species in lunar meteorites with various lithologies using microanalyses to determine the origin of water on the Moon. The bulk water contents of the lunar soil and the outcrop rocks (anorthosite crust, mare basalt, Olivine Hill, the brecciated layers and olivine-bearing site) were also estimated to clarify the lunar water reservoir.
Gabbroic lunar meteorites include the constituent minerals of olivine, clinopyroxene and plagioclase and the basaltic lunar meteorites typically have clinopyroxene phenocrysts within a fine-grained feldspar-pyroxene-rich groundmass. In the brecciated lunar meteorites, fine to coarse grains of the lithic minerals fill the interstices between the basaltic and gabbroic lithologies as breccia matrix.
In-situ transmission FTIR heating absorption measurements of these lunar meteorites showed pronounced water bands for all gabbroic minerals, but weak water bands for the basaltic clinopyroxene phenocrysts. As a result of the *in-situ* FTIR stepwise heating measurements, the water bands can be assigned to hydroxyl groups and mineral-bound H_2O. According to Lambert-Beer's law, the absorbance of the bands can be converted into the water contents of 663, 627 and 674 ppm in the gabbroic olivine, clinopyroxene and plagioclase, respectively, but only 169 ppm in the basaltic clinopyroxene phenocrysts. Amygdaloidal silica exists in a breccia matrix as nanocrystalline aggregates with ~9.0 nm in grain size under electron microscopy. The silica aggregates originated from the lunar hydrous fluid that was captured in the interstices between the mineral grains during the shock-brecciation.
With corrections of shock-induced water loss and solar wind supply, water amount and mode compositions of the constituent minerals obtained here provide a constraint on the bulk water contents: 757 ppm for Olivine Hill, 25 ppm for mare basalt, 668 ppm for the brecciated layers (780

ppm in the permanent shadow), 808 ppm for olivine-bearing site, 70 ppm for the lunar soil and 23 ppm for anorthosite crust. The olivine-bearing site, Olivine-Hill and the surrounding brecciated layers play a role in the wettest lunar water reservoirs on the Moon rather than the lunar soil. The origin of water on the Moon can be determined as follows: (1) hydroxyl groups supplied mainly from the mantle-originated water and slightly from solar wind, (2) mineral-bound H_2O only from the mantle-originated water and (3) ice from cometary/asteroidal water and mantle-originated hydrous fluid from the shock-brecciation. Since the cometary/asteroidal water were commonly supplied into both the lunar soil and outcrop rocks according to the temperature distribution on the Moon, the outcrops at high latitude tend to contain more abundant bulk water than those at low latitude. The olivine-bearing site and Olivine Hill on the SPA and then Procellarum basin are the most important candidate sites of future lunar landing and sample return missions.

Keywords: Moon, Origin of water, Water reservoir, Lunar meteorite, Olivine-bearling site, Olivine Hill

