

Water in olivine, clinopyroxene and plagioclase of lunar meteorites of the NWA 773 clan by IR micro-spectroscopy

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Introduction: Spectral signatures of hydroxyl, mineral-bound molecular and ice water have been remotely detected on the Moon by spacecraft [1]. Such water species may be considered to be limited to the surface regolith [2] and permanently shadowed regions [3] on the Procellarum KREEP Terrene and South Pole Aitken by the remote sensing observations. Moreover, secondary ion mass spectrometry and Fourier-transform infrared (FTIR) spectroscopy of Apollo samples and lunar meteorites discovered hydrogen species in volcanic glass [4], olivine-hosted melt inclusion [5], apatite [6] and plagioclase [7]. In this study, we characterized water species in olivine, clinopyroxene and plagioclase of gabbroic lunar meteorites of Northwest Africa (NWA) 2977 and 6950 and gabbroic/basaltic brecciated lunar meteorite of NWA 2727 using *in-situ* FTIR micro-spectroscopy.

Samples and Methods: NWA 2977 and 6950 include coarse olivine, clinopyroxene and plagioclase grains (0.2–1 mm). NWA 2727 is mainly composed of gabbroic clasts similar to NWA 2977 and 6950, and basaltic clasts with clinopyroxene phenocrysts and pyroxene and plagioclase-rich groundmass. In NWA 2727, fine to coarse lithic fragments and mineral grains fill interstices between the basaltic and gabbroic lithologies as breccia matrix. *In-situ* FTIR micro-spectroscopy of all the lunar meteorites were conducted at 120 °C for 60 minutes to eliminate terrestrial adsorbed water.

Results and Discussion: The *in-situ* FTIR spectra of the gabbroic lithologies in all meteorites are characterized by strong OH bands at ~3750, ~3600 and ~3500 cm⁻¹ for clinopyroxene, ~3550, ~3500 and ~3250 cm⁻¹ for olivine and ~3550 cm⁻¹ for plagioclase. The *in-situ* FTIR spectra of these minerals entrained on the shock veins and fusion crusts include similar water bands but with obviously lower absorbances. This behaviour appears to be the result of the dehydration of intrinsic water due to post-shock annealing in an impact event for the shock vein, and due to aerodynamic heating during the atmospheric entry for fusion crust. Therefore, the abundant water in the gabbroic minerals appears to be derived from the Moon, not from the Earth. The *in-situ* FTIR heating measurements of the gabbroic clinopyroxene and olivine at 200–550 °C demonstrated that the absorbances show almost no change up to 300 °C but drastically decrease in temperature from 300 to 550 °C. This result can be attributed to the dehydration of tightly bound molecular water [8]. The other OH bands remained after heating to 550 °C, and exhibit anisotropies of the absorbance during rotation of the polarizer. Therefore, the remaining bands can be assigned to structurally oriented OH species.

Following the Beer-Lambert law, the abundances after 550 °C of the constituent mineral in NWA 2977 and 6950 suggest a possibility of the structural H₂O contents of at least 198–210 ppm (wt.) for clinopyroxene, 238–268 ppm for olivine and 85–99 ppm. Each water content appears to be higher than the bulk water contents estimated by previous studies: 70–83 ppm [2] for the lunar soil and 3 ppm for anorthosite crust [5], but is no more than prediction from *in-situ* FTIR micro-spectroscopy, not determination by secondary ion mass spectrometry (SIMS). Therefore, we plan to conduct SIMS of the gabbroic minerals to determine their water contents more accurately and examine D/H ratios.

References: [1] Colaprete et al. 2010. *Science* 330: 463–468. [2] Liu et al. 2012. *Nature Geoscience* 5: 779–782. [3] Gladstone et al. 2010. *Science* 330: 472–476. [4] Saal et al. 2008. *Nature* 454: 192–195. [5] Hauri et al. 2011. *Science* 333: 213–215. [6] McCubbin et al. 2010. *Proceedings of the National Academy of Sciences* 107: 11223–11228. [7] Hui et al. 2013. *Nature Geoscience* 6: 177–180. [8] Yamagishi et al. 2010. *Physics and Chemistry of Minerals*. 24: 66–74.