

WATER ON THE MOON: INSIGHTS FROM PYROXENES IN THE LUNAR BASALTIC METEORITE ELEPHANT MORAINÉ 96008.

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Introduction: The H isotope compositions (expressed here as δD) of planetary bodies can indicate the origin of their volatile components and allow investigations into trace magmatic processes ([1] and references therein). Since the discovery of H₂O in lunar volcanic glasses [2], studies of water in lunar samples have primarily focused on melt inclusions in nominally anhydrous minerals (NAMs) and late-formed minerals, such as apatite [e.g., 3,4]. NAMs are the first to crystallize in a melt and are more likely to preserve the original signatures of magmatic water than the later formed minerals [e.g., 5–8]. We are studying NAMs in a variety of lunar basalts to provide further insights into lunar petrogenesis and the origin of the Moon's water. Here we report H isotope compositions and H₂O concentrations of nominally anhydrous pyroxene in the lunar basalt Elephant Moraine (EET) 96008.

Sample and Analytical Methods: EET 96008 is a low-Ti to very low-Ti (VLT) lunar basalt with pyroxenes up to 1.2 mm in diameter that range in major element compositions from Wo₁₁Fs₃₁ to Wo₄₀Fs₁₈ [9]. This sample was selected as it has a relatively low cosmic ray exposure age of ~10 Ma, thus requiring minimal correction for cosmogenic deuterium [10,11]. EET 96008 also has a low terrestrial weathering grade of A [9], potentially limiting the effects of terrestrial weathering. An interior, fusion-crust free chip of EET 96008 was co-mounted with terrestrial standards in indium metal in a one inch aluminum disc using anhydrous sample preparation techniques [4,6,7]. Element mapping and high-resolution secondary and backscattered electron imaging were performed on a JEOL JXA-8530F electron probe microanalyzer (EPMA) at ASU. SIMS analyses to determine the H₂O– δD systematics of pyroxenes were conducted on the Cameca IMS-6f at ASU following analytical protocols like those of [7]. The H₂O concentrations were estimated using a H⁻¹⁸O⁻ vs. H₂O (ppm) calibration curve on the terrestrial standards (PMR 53 pyroxene [12,13] and P-1326 basaltic glass [14]). A background water concentration of 3 ppm and ~ $\delta D = -100\%$ were determined by analyzing NAM San Carlos olivine throughout the analytical session. The background water concentration and H isotope ratio were corrected by the methods of [15] and [16], respectively. Instrumental mass fractionation was corrected for and monitored throughout the run on the pyroxene standard PMR 53 [12,13].

Results: We analyzed six pyroxenes in EET 96008 that ranged in diameter from ~200 to ~425 μm , have H isotope compositions of $\delta D = -82 \pm 35 \%$ to $+259 \pm 108 \%$ and H₂O concentrations of 11 ± 2 ppm to 403 ± 81 ppm ($n = 9$). Although the isotopically heaviest δD is correlated with the lowest H₂O concentration, there is no evident relationship between H₂O concentration and H isotope ratio. Significant intragrain variations were observed as one pyroxene grain ranged from $\delta D = -82 \pm 35 \%$ to $+259 \pm 108 \%$ and H₂O content that ranged from 11 ± 2 ppm to 188 ± 38 ppm ($n=3$).

Discussion: Prior measurements of hydrogen isotope compositions in EET 96008 were performed on apatites that exhibited 150 to 3750 ppm water and δD of up to ~900 ‰ [17]. Since NAMs formed earlier than apatite, they are expected to contain less H₂O [e.g., 5]; the EET 96008 pyroxenes analyzed here contain ~11 ppm to ~400 ppm water. While some of these H₂O concentrations are higher than expected for NAMs, the H isotope compositions are in the range of those inferred for indigenous lunar water (δD from –200 to +200 ‰ [3]). It is unlikely that terrestrial water was introduced during the sample preparation stage as the samples were prepared anhydrously and stored in a nitrogen cabinet. Nonetheless, it is possible that some of the higher water concentrations observed in pyroxenes for EET 96008 are due to minor terrestrial alteration during the meteorite's residence in Antarctica, even though it has a low weathering grade. It is also possible that the primary magmatic H₂O– δD systematics may have been affected by secondary alteration processes on the Moon (e.g., [3]). To investigate these possibilities, we will compare with future analyses of NAMs in other lunar meteorites and Apollo samples, which are assumed to have remained pristine since their collection on the Moon.

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Acknowledgements: This work was funded by NASA Solar System Workings grant 80NSSC21K0181 (PI: M.W., CoI: J.D.).