WATER ON THE MOON: INSIGHTS FROM NOMINALLY ANHYDROUS PYROXENE IN THE LUNAR BASALTIC METEORITE ELEPHANT MORAINE 96008.

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Introduction: The hydrogen isotope ratios (expressed here as δD) of planetary bodies can indicate where their volatile components originated and allow us to investigate the source(s) and timing of delivery of their volatiles, as well as trace magmatic processes ([1] and references therein). Since the discovery of water in lunar samples [2], studies of water in extraterrestrial igneous samples have primarily focused on melt inclusions in nominally anhydrous minerals (NAMs) and late-formed minerals, such as apatite [e.g., 3,4]. Since NAMs crystallize first in a melt, they are more likely to preserve the original characteristics of magmatic water than later formed minerals [e.g., 5–8]. We are studying NAMs in lunar samples to provide further insights into the origin of the Moon's water. Here we report H isotope compositions and water contents of nominally anhydrous pyroxene in the lunar basalt Elephant Moraine (EET) 96008 via secondary ion mass spectrometry (SIMS).

Sample and Analytical Methods: EET 96008 is a lunar basalt that contains pyroxenes up to 1.2 mm in diameter, which exhibit a range of major element compositions from $Wo_{11}Fs_{31}$ to $Wo_{40}Fs_{18}$ [9]. This sample was chosen as it has a relatively low cosmic ray exposure age of ~10 Ma (thereby requiring minimal correction for cosmogenic deuterium) and a low terrestrial weathering grade of A [9–11]. An interior, fusion-crust free chip of EET 96008 was co-mounted with terrestrial standards in indium metal in a one inch aluminum disc. Anhydrous sample preparation techniques were used [4,6,7]. Element mapping and high-resolution secondary and backscattered electron imaging were undertaken on a JEOL JXA-8530F EPMA at ASU. SIMS measurements to determine H isotope compositions and water contents of pyroxenes were performed on the Cameca IMS-6f at ASU using analytical protocols similar to those of [7]. The H_2O concentrations were estimated using a $H^-/^{18}O^-$ vs. H_2O (ppm) calibration curve on terrestrial standards (PMR 53 pyroxene [12,13] and P-1326 basaltic glass [14]). A background H_2O concentration of 3 ppm and H isotope ratio of ~ $\delta D = -100‰$ were determined by analyzing NAM San Carlos olivine throughout the analytical session. The background water content and H isotope composition were corrected by the methods of [15] and [16], respectively. Instrumental mass fractionation, which was corrected, was monitored throughout the analytical session on the pyroxene standard PMR 53 [12,13].

Results: Six pyroxenes in EET 96008, ~200 to ~425 μm in diameter, have broadly chondritic H isotopic compositions of $\delta D = -82 \pm 35$ ‰ to $+259 \pm 108$ ‰ and H_2O contents of 11 ± 2 ppm to 403 ± 81 ppm (n = 9). While the isotopically heaviest H is associated with the lowest water concentration, there is no apparent relationship between water concentration and H isotope ratio. There was significant intragrain variation; for example, one pyroxene grain had δD that ranged from -82 ± 35 ‰ to $+259 \pm 108$ ‰ and H_2O contents that varied from 11 ± 2 ppm to 188 ± 38 ppm (n=3).

Discussion: Previous measurements of apatites in EET 96008 yielded 150 to 3750 ppm H_2O and δD of up to ~900 ‰ [17]. Since NAMs formed earlier than apatite, they are expected to contain less water [e.g., 5]; melt inclusions hosted in pyroxene and olivine in Apollo samples contain only up to ~200 ppm H_2O [3]. The EET 96008 pyroxenes analyzed here contain ~11 ppm to ~400 ppm H_2O. While some of these water concentrations are higher than anticipated, the H isotope ratios are in the range of those inferred for indigenous lunar water [3]. Since samples were prepared anhydrously and stored in a nitrogen cabinet, it is unlikely that terrestrial water was introduced during sample preparation. However, we cannot eliminate a contribution from terrestrial water adsorbed during the meteorite's residence in Antarctica, even though it has a low weathering grade. Alternatively, the primary magmatic signatures may have been altered by secondary processes on the Moon (e.g., [3]). To address this, we will compare with future analyses of NAMs in Apollo samples, which are assumed to have remained unaltered since their collection on the Moon.

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