D/H RATIOS AND WATER CONTENTS IN EUCRITE MINERALS: IMPLICATIONS FOR THE SOURCE AND ABUNDANCE OF WATER ON VESTA.

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Introduction: Recent investigations of the hydrogen isotope compositions and water abundances in apatites of eucrite meteorites have implications for the origin of water and the timing of its accretion on planetary bodies in the inner Solar System [1-3]. Specifically, since eucrites formed early in Solar System history (close to ~4.56 Ga; e.g., [4]) and the D/H ratios in their apatites are similar to values in the carbonaceous chondrites and Earth [1-3], it seems likely that water was added early to bodies in the inner Solar System from a carbonaceous chondrite-like source. A nominally anhydrous early-formed major mineral such as pyroxene in the eucrites may be more reliable than a later-fomed trace mineral such as apatite for constraining the hydrogen isotope composition and water content of the eucrite source reservoir on Vesta. In fact, recent work has shown that the water content of apatite in basaltic rocks may not be a simple indicator of the abundance of water in the parent magma [5]. Therefore, in this study we have investigated the H_2O contents and D/H ratios of not only apatites and merrillites, but also pyroxenes in four eucrites.

Samples and Methods: The H_2O concentrations and hydrogen isotopic compositions were measured in individual phases in polished sections of the Juvinas, Pasamonte, Stannern and Tirhert eucrites. Measurements of the H_2O concentrations and D/H ratios in pyroxenes were performed with the Cameca IMS 6f at ASU. A Cs^+ primary beam of 13 nA was rastered over an area of 30×30 µm². A field aperture was set to accept secondary ions from a smaller (15 µm diameter) area, which reduced the background associated with edge effects. Each measurement consisted of 60 cycles of measuring H^- and D^- ions, with counting times per cycle of 1s and 10s, respectively. At the end of each measurement, $^{16}O^-$ was measured. The H_2O concentrations and D/H ratios of phosphates (apatites and merrillites) in Juvinas and Tirhert were analyzed with the Cameca NanoSIMS 50L at ASU. A Cs^+ primary beam of 150 pA was rastered over 10×10 µm² and 5×5 µm² surface areas for merrillites and apatites, respectively; electronic gating was used to accept secondary ions from just the inner 25% of these rastered areas. Each measurement consisted of 50-100 cycles of measuring H^-, D^- and $^{18}O^-$ secondary ions with a counting time per cycle of 1s for each of these ions. The H_2O contents in the analyzed minerals were determined using a H^-/O^- vs. H_2O calibration performed for the Cameca IMS 6f and NanoSIMS 50L based on analyses of a variety of standards (including rhyolitic glasses) with a range of H_2O abundances (180-4000 ppm H_2O). The H_2O concentrations and δD values reported here have been corrected for the background. Moreover, the δD values have additionally been corrected for the maximum possible spallation contributions (4 to 56 ‰, which were negligible compared to the typical analytical uncertainties).

Results and Discussion: The H_2O concentrations in pyroxenes range from 39±10 to 81±20 ppm in Juvinas, 25±1 to 123±7 ppm in Pasamonte, 173±10 to 193±11 ppm in Stannern, and 29±7 to 76±18 ppm in Tirhert. The following are the ranges of δD values (where $\delta D = [(D/H_{sample})/(D/H_{standard})-1] \times 1000$) in pyroxenes of these four eucrites: -326±80 to +60±114 ‰ for Juvinas, -343±53 to -162±54‰ for Pasamonte, -322±11 to -45±62 ‰ for Stannern, and -397±71 to -69±101 ‰ for Tirhert. The weighted average of δD values in eucrite pyroxenes analyzed in this study is -241±64 ‰ (2σ, n=18). The H_2O concentrations in apatites range from 319±22 to 2601±201 ppm in Juvinas and from 1396±55 to 2248±115 ppm in Tirhert. The δD values in these apatites range from -299±74 to +232±127 ‰ for Juvinas and -292±66 to -58±89 ‰ for Tirhert. The weighted average δD values in eucrite phosphates is -173±72‰ (2σ, n=21), which is identical within the errors to the weighted average δD in the pyroxenes.

The weighted average δD value of the pyroxenes analyzed here (-241±64‰) is lower than those of the Earth's depleted upper mantle (-60±5 ‰; [6]) and most carbonaceous chondrite bulk samples [7]), but is similar to the value recently estimated for the Earth's deep mantle reservoir (<-218 ‰; [8]). This may suggest that at least some portion of water in Vesta may be derived from a nebular source [9]. Finally, based on the measured compositions of the cores of eucrite pyroxenes (i.e., having the lowest H_2O concentrations) and using appropriate clinopyroxene-melt partition coefficients [10-12], we estimate a maximum H_2O content in eucrite parent melts to be ≤0.2 wt. %.

References: [1] Sarafian A. et al. 2013. *Meteoritics & Planetary Science* 48:2135-2154. [2] Sarafian A. et al. 2014. *Science* 346:623-626. [3] Barrett T. et al. 2016. *Meteoritics & Planetary Science* doi: 10.1111/maps.12649. [4] Hopkins M.D. et al. 2015. *Icarus* 245:367-378. [5] Boyce J. et al. 2014. *Science* 344:400-402. [6] Clog M. et al. 2013. *Earth and Planetary Science Letters* 381:156-165. [7] Alexander C.M.O'D. et al. 2012. *Science* 337:721-723. [8] Hallis L. J. et al. 2015. Science 350:795-797. [9] Sharp Z.D. et al. 2016. Abstract #3021. 47th Lunar and Planetary Science Conference. [10] Hauri E. et al. 2006. *Earth and Planetary Science Letters* 248:715-734. [11] Wade J.A. et al. 2008. Geological Society of America. 36:799-802. [12] O'Leary J.A. et al. 2010. *Earth and Planetary Science Letters* 297:111-120.