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The Origin of water and other volatiles in the inner solar system as shown by Howardite-Eucrite-Diogenite (HED) meteorites.

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Introduction: Volatile elements play a fundamental role in planetary formation and evolution through their influence on melting, silicate melt viscosity, magma crystallization and eruption processes. The Howardite-Eucrite-Diogenite (HED) suite of meteorites represents the largest suite of crustal rocks available from a differentiated basaltic asteroid and account for between 2-3% of all meteorites collected globally [1]. This group of meteorites are also some of the oldest igneous rocks in the solar system, remaining relatively unaltered since their formation ~8 to 20 Ma after the formation of the solar system, and offer insight into the planetary accretion process(es). Therefore, by investigating the abundance and source(s) of volatiles they contain we can begin to constrain the timing when water (H_2O) existed in the inner solar system. Knowing precisely when water accreted in the inner solar system also has implications for how and when life emerged on Earth and possibly beyond.

The source of volatiles in planetary bodies can be investigated in a number of different ways. For water, the ratio between the two isotopes hydrogen (deuterium, D or ^{2}H and hydrogen, ^{1}H) has been widely used, since measured D/H ratios in different objects, formed in different regions of the solar system, vary widely (~25-fold variation in D/H ratios) [2]. Isotopic measurements of other volatile elements such as C and N can also provide additional constraints on volatile source regions. Recent advances in analytical instrumentation and techniques have enabled high-precision *in situ* measurements in volatile-bearing minerals such as apatite [e.g. 3-5].

Apatite $[Ca_5(PO_4)_3(OH,F,Cl)]$ is a widely distributed mineral, albeit in trace amounts, in planetary materials which acts as a recorder of volatile abundances in magmas and magmatic source regions [6] and is the most common volatile-bearing phase in lunar rocks [7,8] and eucrites [6]. New apatite data has shown that eucrites have similar D/H ratios to those measured in terrestrial rocks and in CI chondrites, implying that water could have accreted early in the inner solar system [5] as opposed to dry accretion and subsequent late delivery of water [9,10].

The putative parent body of the HED meteorites is the asteroid 4 Vesta [11, 12], which is believed to have experienced a similar differentiation history as the Moon, making it an excellent analogue [13]. We are currently undertaking a detailed study of HED meteorites using *in-situ* Secondary Ion Mass Spectrometry (SIMS) on apatites and Step Combustion Mass Spectrometry on whole-rock samples to better constrain the volatile inventory and evolutionary history of 4 Vesta.

Methods & Results: We used the Cameca NanoSIMS 50L at the Open University to measure H_2O abundances and D/H ratios in apatite grains from four basaltic eucrites (DaG 844, DaG 945, Millbillillie, Stannern) using the protocol described in [3]. In total, 21 measurements were made on 15 different apatite grains. Apatite H_2O abundances range from ~50 to ~3450 ppm, and are associated with a weighted average δD values of -9 ± 55 ‰ (2σ).

Discussion: Our results are within error of and extend the range of data reported by [5] and are consistent with a common source of water for Vesta, the Earth, the Moon, Mars and carbonaceous chondrites [9, 14, 15]. No systematic variation is seen between H_2O abundance or δD and different geochemical trends and metamorphic grades. DaG 945 contains less water and is believed to have undergone granulitic metamorphism and at least some partial melting [16], which could explain the low water contents measured in apatite in this sample.

Other volatile elements. We are currently in the process of obtaining samples for C, N and noble gas isotope data for a small selection of eucrites to complement our SIMS studies.

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