THE HYDROGEN ISOTOPIC COMPOSITION OF APATITES IN LUNAR IMPACT-MELT BRECCIAS.

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Introduction: Recent re-analyses of lunar samples for their volatile inventories have largely focused on the products of basaltic volcanism, i.e. picritic glasses and apatite in mare basalts [1-9], and apatite in intrusive rocks from the lunar highlands [10-13]. In contrast, relatively little work has been carried out on lunar impact breccias. Previous studies of apatite in four impact breccias (12013, 14305, 79215, and 72395) [3,14] for their H_2O-δD systematics revealed that apatite is consistently dry (~ 0 ppm H_2O) with variable δD (covering a total range from -96 to 1000 ‰). Of these four samples, 72395 is an Impact Melt Breccia (IMB) in which Greenwood et al. [14] analysed an apatite grain reporting it as dry with an associated δD of ~ 350 ‰. It is important to further investigate volatiles in IMBs as they can provide critical insights into the volatility of hydrogen in response to shock, an understanding of which is crucial when attempting to fingerprint the sources for lunar volatiles, particularly in lunar highlands samples. In this study we have measured the OH content (which is reported as H_2O equivalent) and H-isotopic composition of five apatite grains in two Apollo lunar IMBs 15405 and 65785.

Samples: 15405 is a clast-bearing IMB. The clasts in the breccia are predominately KREEP basalts and granites. The rock also contains a large proportion of mineral fragments (e.g. plagioclase). The impact melt (IM) itself is very fine-grained and composed of intergrown plagioclase, pyroxene and ilmenite grains (Fig. 1a) with a groundmass composition similar to that of KREEP basalts [15]. Although our polished section of this sample contained different clasts, all of the analysed apatites were located within the IM itself. Apatite crystals are typically > 20 μm in length, isolated but usually intergrown with merrillite. Their scalloped and partially resorbed crystal shapes suggest that they are relict grains of pre-existing target material.

65785 is also classified as an IMB although the IM itself is somewhat coarser-grained than that in 15405 (Fig. 1). The IM is composed predominately of plagioclase (~ 200 μm in length) intergrown with olivine, minor pyroxene, and other accessory phases such as spinel and apatite (Fig. 1b). Only two apatite grains were large enough to be analysed in this sample, the largest of which being ~ 50 μm in length.

Method: Polished sections of samples 15405 and 65785 were mapped for their elemental abundances using an FEI Quanta 3D Dual beam Scanning Electron Microscope at The Open University, using a 0.6 nA and 20.05 kV electron beam. The OH content and H-isotopic measurements of apatites were performed using the Cameca NanoSIMS 50L ion probe at The Open University following protocols described in [1,9].

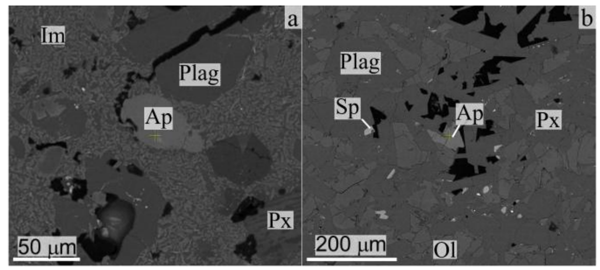

Figure 1: Back scatter electron images of selected areas within the studied samples a) 15405 and b) 65785. Ap = apatite, Im = impact melt (matrix), Ol = olivine, Plag = plagioclase, Px = pyroxene, Sp = spinel.

Results: We analysed a total of five apatite grains from the two samples. In sample 15405 apatite H_2O contents range from 60 to 120 ppm with corresponding δD values ranging from ~ -480 ‰ to ~ 330 ‰. The H_2O content of apatites in 65785 ranges between ~ 20 and 30 ppm with δD values between 620 and 710 ‰.

Discussion: Before using the measured H-isotopic composition of apatites to identify potential sources for H in IMBs it is important to apply appropriate corrections for spallogenic production of both H and D [e.g., 8]. In this study the measured values were corrected using previously published cosmic-ray exposure (CRE) ages (11 ± 1.1 Ma for 15405 [16], 271 Ma for 65785 [17]). For samples that have relatively young CRE ages (e.g., 15405) spallation corrections are insignificant (Fig. 2). In contrast, the elevated δD values (620 to 710 ‰) measured originally in sample 65785 are dramatically lowered following the CRE-age correction, with corrected values ranging from ~ 50 to 100 ‰ (Fig. 2), due to the relatively long CRE age of this sample. The resultant δD strongly influences the interpretation and understanding of data in the context of source region characteristics and/or magmatic processes involved in giving rise to the H-isotopic composition of apatites. Therefore, previously reported δD values, of apatite in impact breccias (including IMBs), that were not corrected for spallogenic effects should be used with caution. For sample 79215 (a holocrystalline feldspathic impact rock), the published CRE ages range from 170 ± 10 to 339 ± 24.2 Ma [18,19]. Using an average CRE age of 245 ± 24.2 Ma [18,19], we corrected the data of [14] for 79215 for comparative purposes as shown in Figure 2.

To a first order, the spread in δD values for IMBs is larger than that observed for mare basalts and lunar highlands samples (Fig. 2). The range in δD spans from non-terrestrial (i.e. elevated values up to ~ 400 ‰) to terrestrial like or CI chondrite-like values and extend towards even lower δD values (~ -500 ‰), albeit with large uncertainties that overlap with the terrestrial range. One of the characteristics of apatite in these breccias is that they are very dry (< ~ 100 ppm H_2O, and < 30 ppm H_2O, excluding 15405). It is attractive to relate this feature to dehydration during breccia formation, especially given the temperatures (up to ~ 2000 ºC) invoked for impact-melt formation [e.g., 22 and references therein].

In sample 15405, apatites occur as mineral fragments surrounded by IM. Therefore, given the diversity of clasts within this IMB, it is impossible to identify specific lithologies from which these apatites might have originated. Interestingly, the occurrence of isolated relict apatite grains in IM has the potential to record the modification in their original D/H signatures through interaction with IM at elevated temperatures. In 15405 two analyses of one particular apatite grain span the entire range of IMB-apatite δD, ranging from 320 to -490 ‰ at constant H_2O content (Fig. 2). The elevated δD value (320 ‰) could be related to degassing/diffusive processes [e.g., 9], whereas the lowest δD values(~ -500 ‰) could suggest some incorporation of solar wind H [20,21]. However it is difficult to definitively attribute any process(es) or source(s) to the 15405 apatite δD compositions given the large associated uncertainties on δD values (Fig. 2). Therefore, the most conservative interpretation of δD values measured in apatites in 15405 is that they are similar to H-isotopic compositions reported for other lunar samples, both shocked and unshocked (Fig. 2).

In contrast the texture of IMB 65785 (Fig. 1b) suggests that the apatite in this sample crystallised from the IM. If true then it could be speculated that the consistent δD of apatites in 65785 represents the δD signature of the homogenized melted target lithology [22] which incidentally has a composition (δD ~ 50-100 ‰) similar to that of some carbonaceous chondrites and other highlands lithologies (Fig. 2). Clearly further work must be conducted on apatite in these samples and other IMBs in order to fully assess the behaviour of H in response to impact-related thermal metamorphism.

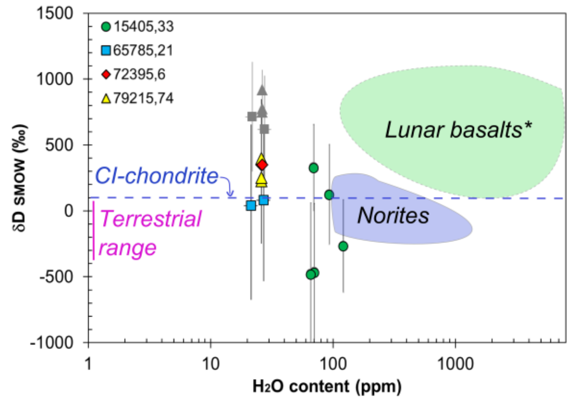

Figure 2: Plot showing both the measured (grey symbols) and spallation corrected H_2O contents and δD values of apatites in samples 15405, 65785 [this study] and 79215 [14]. Data for 72395 are also from [14] but are not spallation corrected. Uncertainties are the combined 2σ analytical error and uncertainties associated with CRE ages and spallogenic production of H and D. Plotted for comparison are the available literature data for H_2O-δD values of lunar basalts (* = Apollo mare basalts and lunar basaltic meteorites [1,3,9]), Mg-suite norites [10,13], terrestrial range in δD [23 and references therein] and CI chondrites (bulk) δD [24].

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