ASSESSING THE VOLATILE INVENTORY OF APATITES IN LUNAR IMPACT MELT BRECCIAS.

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Introduction: The recent discoveries of hydrogen (H) bearing species on the lunar surface and in samples derived from the lunar interior have necessitated a paradigm shift in our understanding of the water inventory of the Moon. The Moon was considered to be 'bone-dry' following the Apollo missions. However, since then estimates of interior lunar water have varied from 'dry' (few ppm) to 'wet' (several 100s ppm) [1-4].

Most recent sample-based studies have attempted to characterise the source(s) of lunar water, which is present in melt inclusions, glass beads, and the mineral apatite [1-12]. A number of sources have been suggested ranging from cometary [10], to chondritic [13], to the Proto-Earth [4,9].

Since the Moon is a heavily impacted planetary body, it is important to investigate if impact processes coud affect the volatile budget of lunar samples such as pyroclastic glasses or apatite in rocks. A recent study has investigated the volatile inventory of apatite in ancient (> 4.0 Ga old) lunar highlands samples [9] that had been exposed to extensive impact processing. This study concluded that shock didn't seem to affect/disturb the volatile inventory nor the H-isotopic composition of apatite in the highlands samples studied [9].

In order to gain further insight into potential effect of impacts on volatile inventory of lunar apatites, we examined two impact melt breccias (IMB) 15405 and 65785 for their volatile abundances and hydrogen isotopic composition.

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. The impact melt (IM) itself is very fine-grained and composed of intergrown plagioclase, pyroxene and ilmenite crystal laths with a groundmass composition similar to that of KREEP basalts [14]. Although our polished section of this sample contained different clasts, all of the analysed apatites were located within the IM itself. Their scalloped and partially resorbed crystal edges 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. The IM is composed predominately of plagioclase intergrown with olivine, minor pyroxene, and other accessory phases such as spinel and apatite. The IM protolith is suspected to be QMG/felsite like with a KREEP component [15].

Methods: Polished sections of samples 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. Two protocols were used for performing NanoSIMS ion probe analyses at The Open University 1) D/H-OH measurements and 2) volatile abundance measurements following the protocols described in [8,9,11,12].

Results: We report the measured OH contents as water equivalent to make them comparable to previous studies. We analysed a total of five apatite grains from the two samples. In sample 15405 apatite H_2O contents range from 40 to 120 ppm with corresponding δD of between ~ 300 and ~ -500 ‰ (Fig. 1). The H_2O content of apatites in 65785 ranges between ~ 20 and 30 ppm with δD values of 620 and 710 ‰ (Fig. 1).

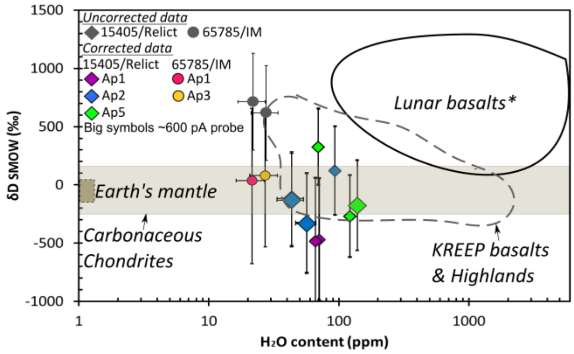

Figure 1: Plot showing both the measured (grey symbols) and spallation corrected H_2O contents and δD values of apatites in samples 15405 and 65785. Uncertainties are the combined 2σ analytical error and uncertainties associated with the CRE ages. Plotted for comparison are the available literature data for H_2O-δD values of lunar basalts (* = Apollo mare basalts & lunar basaltic meteorites [8,10,11]), KREEP basalts [12] and lunar highlands samples (norites and granite, [9]), range in Earth's mantle δD [19 and references therein] and range in δD for CI, CM, CV, and CO chondrites [20].

Discussion: Before using the measured H-isotopic composition of apatites to identify potential sources for H in IMB apatites it is important to apply appropriate corrections for spallogenic production of both H and D [e.g., 4]. This correction is negligible for 15405 as this sample has a relatively short (11 Ma, [16] cosmic ray exposure (CRE) age. However, 65875 has a relatively long CRE age (271 Ma, [17]) and hence the correction is large yielding corrected δD values between 37 and 81 ‰.

One of the characteristics of apatite in these breccias is that they are relatively dry (< 150 ppm H_2O). 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., 18].

To a first order, the spread in δD values for IMBs is similar to that observed for lunar highlands and KREEP basaltic samples (Fig. 1). The range in δD spans from non-terrestrial (i.e. elevated values up to ~ 400 ‰) to terrestrial-like or carbonaceous chondrite-like values and extend towards even lower δD values (~ -500 ‰), albeit with large uncertainties.

It is perhaps not surprising that apatites in 15405 yield almost identical signatures to those of KREEP basalts and lunar highlands samples (e.g. granite 14303) given that the clasts in this breccia are KREEP basalts and granites, and that the IM itself has a bulk composition characteristic of KREEP suggesting a KREEP-like protolith [14]. Despite the range in δD for apatite in this sample, the H_2O content remains uniform within and between grains. NanoSIMS abundance measurements performed on apatites 2 and 5 in sample 15405 also revealed that these apatites are dry. Interestingly the F contents are similar between grains (3 wt.% versus 3.5 wt.%) whilst the Cl contents differ in the two grains by almost two orders of magnitude (1 wt.% versus 0.05 wt.%). This may suggest that these grains have retained their primary volatile heterogeneities. However, in order to fully assess the potential for dehydration of the apatite and likely reaction of the apatite with the impact melt (textural modification) it is important to also investigate the volatile inventory of the IM surrounding apatite grains. However, these measurements are extremely challenging and require further development of existing analytical protocol. Nevertheless, such measurements will also help evaluate any potential involvement of solar wind derived H in the IM.

In contrast to 15405 the texture of IMB 65785 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 [18] which incidentally has a composition (δD ~ 40 to 80 ‰) similar to that of some carbonaceous chondrites and other highlands lithologies (Fig. 1).

Clearly further work is required on apatites in these samples and other IMBs in order to fully assess the behaviour of H in response to impact-related thermal metamorphism.

Acknowledgements: CAPTEM are thanked for allocation of Apollo samples. STFC is thanked for a PhD studentship to JJB, a research grant to MA (grant No. ST/I001298/1), and NanoSIMS access was through UKCAN by the STFC-funded grant ST/1001964/1.

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