

THE HYDROXYL CONTENT AND HYDROGEN ISOTOPE COMPOSITION OF LUNAR APATITES.

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Introduction: Initial studies of Apollo rock samples concluded that the Moon was an anhydrous planetary body [1]. Recently there has been a change of opinion with several research groups detecting variable amounts of H₂O in lunar mare glass beads [2], melt inclusions [3] and hydroxyl in lunar apatites [4-9]. The maximum amount of water detected thus far has been from mare basalt 12039 [10]. These authors also measured the D/H ratio of lunar apatites, with δD values ranging from -215 ‰ to +1010 ‰ in the case of mare basalts and from +240 ‰ to +340 ‰ in the case of highlands anorthosite clast 14305. The water content of these samples varied from ~0 to 0.6 wt.%. Here we report δD values and hydroxyl contents of apatite grains from Apollo mare basalt 12064 and lunar mare basalt meteorite Miller Range MIL 05035.

Samples: The two lunar samples analysed in this study have similar mineralogies. 12064 is a coarse-grained ilmenite basalt, being of low-Ti, low-Al and low-K variety [11] whereas MIL 05035 is a coarse-grained lunar mare gabbroic meteorite also of low-Ti, low-Al and low-K type [12].

Analytical Methods: Apatite grains were identified from high resolution back scatter imagery and EDS elemental X-ray mapping using the FEI Quanta 200 3D scanning electron microscope at the Open University. Ion microprobe analyses of apatites in 12064 were carried out using the Cameca NanoSIMS 50L at the Open University. Apatite grains were analysed using a large Cs⁺ primary beam of ~900 pA current, rastering over an area of 10x10 μm . Analyses lasted 20 minutes, and were preceded by a 2 minute pre-sputter. Charge compensation was provided by the electron gun. Negative secondary ions ¹H⁻, ²D⁻ and ¹⁸O⁻ were collected from a central 5 μm area at a mass resolving power of ~5000. Ion microprobe analysis of apatites in MIL 05035 was carried out using the Cameca NanoSIMS 50 at the University of Tokyo. Apatite grains were analysed using an O₂⁻ primary beam of ~300 pA current. Positive ions ¹H⁺, ²H⁺, ⁴⁰Ca²⁺, ²⁴Mg⁺ and ³¹P⁺ were collected at a mass resolving power of ~6000.

The same standard block was used on both instruments consisting of homogeneous Morocco and Imaichi apatite grains mounted in a 1 inch round block.

Analytical spots on apatite grains were carefully chosen such that they were fracture and inclusion free.

Results: We analysed three apatite grains in 12064 (Fig. 1). The δD_{SMOW} values range from +822 to +998 ‰, with the hydroxyl content ranging from ~2800 to 4744 ppm. The results for 12064 produced well constrained δD although, there is slight inter- and intra-grain variation in both δD and hydroxyl contents. Five apatite grains were analysed in MIL 05035 with δD values ranging from -137 to +830 ‰. Hydroxyl content ranges from ~470 to 2690 ppm. The analytical setup for MIL 05035 yielded relatively low count rates for ²H (an order of magnitude less than those obtained for 12064). The low count rates for this sample introduced large errors into the analysis (Fig. 2).

Discussion: The results for ilmenite mare basalt 12064 overlap with the upper limits of δD measured so far in lunar apatites [10] and plots well outside the range for terrestrial water (+100 ‰ to -500 ‰) [13, 14]. This suggests that the hydrogen isotopic composition measured in these apatites has not been compromised by terrestrial contamination. When compared to the previous study, 12064 data overlaps with the highest δD measured for 12039 – an Apollo 12 pigeonite basalt, and show a smaller range in H₂O (wt.%). Cometary material has a high δD and therefore, it could be interpreted that at least some lunar hydrogen is of cometary origin [10, 13, 14].

However, it is also likely that these mare basalts have experienced degassing of volatiles during magma ascent/eruption onto the lunar surface, suggesting that the values reported here may represent the minimum hydroxyl content of these lunar apatites [15]. It is also possible that during apatite crystallization (apatite is commonly considered to start crystallizing after 95-98 % crystallization of basaltic magma), there was a diffusive loss of volatiles in apatite. This process may have contributed to heterogeneities in the volatile content and the hydrogen isotope composition of lunar apatite.

Interestingly, the overlap in high δD values for ilmenite basalt 12064 and pigeonite basalt 12039 indicate that these magmas sampled a similarly D-enriched mantle. It has been recognized that the basalts from the Apollo 12 landing site may represent a layered se-

quence with older olivine basalt overlain by pigeonite basalt which are in turn overlain by the younger ilmenite basalt [11, 16]. The results of Greenwood et al. [10] for 12039 show relatively large intra-sample variations in both δD and H_2O (wt.%). However, such a large variation is not observed in 12064 (data from this study). Perhaps this basaltic sequence could be used to investigate the processes that may have operated during the crystallisation of parental magmas to these basalts.

MIL 05035 has δD values much closer, even overlapping, with terrestrial δD values. It is unclear if any of the observed isotopic variation relates to the low, and variable hydroxyl content in this rock.

To better constrain the hydroxyl content and hydrogen isotopic composition of lunar basalts and the lunar interior we are in the process of analyzing apatite crystals from a range of additional lunar samples.

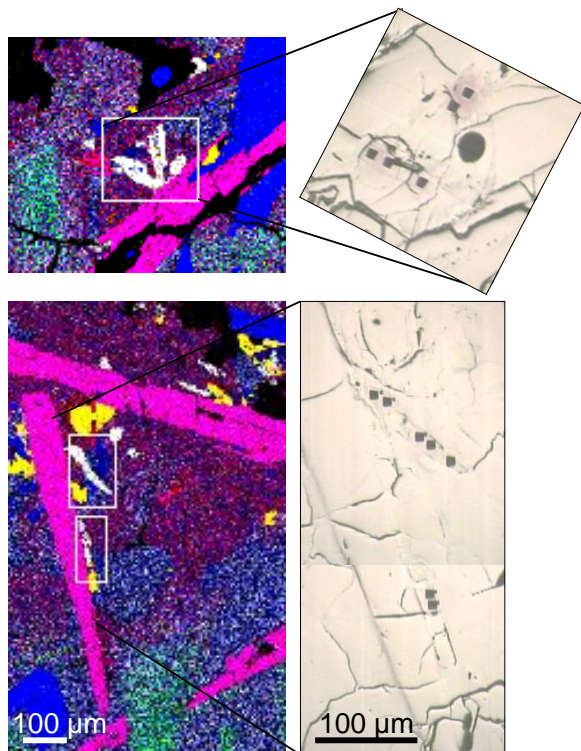


Figure 1. The false colour X-ray maps (left) depicting apatites 1, 2 & 3 (from top to bottom) which were analysed in sample 12064. The apatite grains are shown in white and their locations within the sample highlighted by the boxes. The optical images on the right are of the same apatite grains and show raster areas (black squares) post ion-probe analysis.

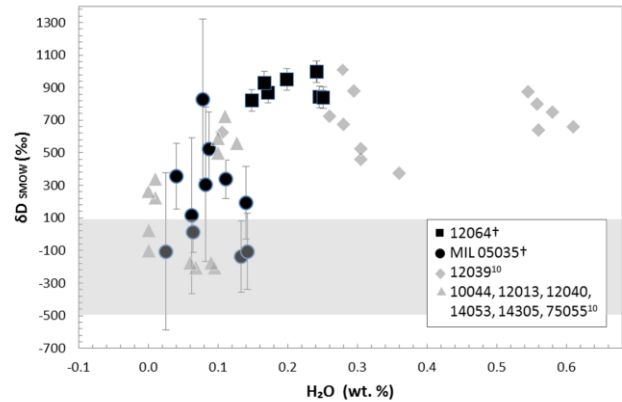


Figure 2. Plot showing the variation of H_2O (wt. %) with δD_{SMOW} (‰) in apatites from 12064 and MIL 05035 (\dagger from this study). Results from Greenwood et al. [10] have been plotted for comparison. The grey box indicates the range for terrestrial δD values. Errors are at 2σ .

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