

## Apollo 15 low-Ti and KREEP basalts: Two distinct “water” reservoirs?

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### Abstract

Apatites in low-Ti mare basalts from the Apollo 15 landing site display a large range of OH content from about 100 ppm up to ~ 2000 ppm. The D/H ratios measured in these apatites yielded  $\delta D$  values of ~ 550-1050 ‰. On the other hand, apatites in the KREEP basalt 15386 have less than 250 ppm OH and yielded  $\delta D$  values in the range ~ 20-500 ‰. These data suggests that the source of KREEP basalts was much drier than the mare basalt mantle sources, implying a late addition of H-bearing species into the mare source regions.

### 1. Introduction

The last few years have seen the longstanding paradigm of a dry lunar interior challenged by in-situ measurements of variable amounts of “water” in volcanic glass beads [1-2] and in mineral apatite in various rock types [3-10]. Overall, mare basalts and volcanic glasses, derived from the lunar mantle, appear to be enriched in H-bearing species compared to KREEP lithologies and rocks from the lunar crust [1-10], suggesting a heterogeneous distribution of water in the lunar interior. The hydrogen isotopic composition of this water has also been reported [3,5-6,10], which is of prime importance to constrain the origin of the lunar water. Here we present the first ion microprobe measurement of OH and D/H ratios in apatite in rocks from the Apollo 15 landing site and discuss the implications of these new results.

### 2. Samples and methods

We investigated three Apollo 15 basaltic samples. Sample 15058 is a pigeonite mare basalt containing trace of olivine, and which is believed to have experienced a slow cooling [11]. Sample 15555 is an olivine-normative mare basalt containing 10-20 % of olivine, pyroxene and plagioclase. Its bulk chemical composition is thought to represent a primitive volcanic liquid [11]. Sample 15386 is a pristine

KREEP basalt containing mostly pyroxene and plagioclase [11].

OH contents and D/H measurements in apatites were carried out using the OU Cameca NanoSIMS 50L. A large  $Cs^+$  primary beam of ~ 270 pA current was rastered over a  $10 \times 10 \mu m$  area, and secondary ions  $^1H$ ,  $^2D$ ,  $^{12}C$  and  $^{18}O$  were collected from a central  $5 \times 5 \mu m$  area. D/H ratios were normalised against the Morocco apatite (OH = 2640 ppm,  $\delta D = -85$  ‰). A second reference apatite, Imaichi (OH = 189 ppm), was used to build calibration lines relating  $^1H/^{18}O$  ratios measured in apatites to their OH content.

### 3. Results

Figure 1 displays results from this study, together with some literature data. Apatites in basalt 15555 have 700-2050 ppm OH with  $\delta D$  values of 550-830 ‰. In pigeonite basalt 15058, apatites have less OH, with 130-450 ppm OH, and have a large range of  $\delta D$  values between 600 and 1050 ‰. Finally, apatites in KREEP basalt 15386 are the most OH-depleted, with 100-250 ppm OH, and  $\delta D$  values ranging from about 20 up to 510 ‰.

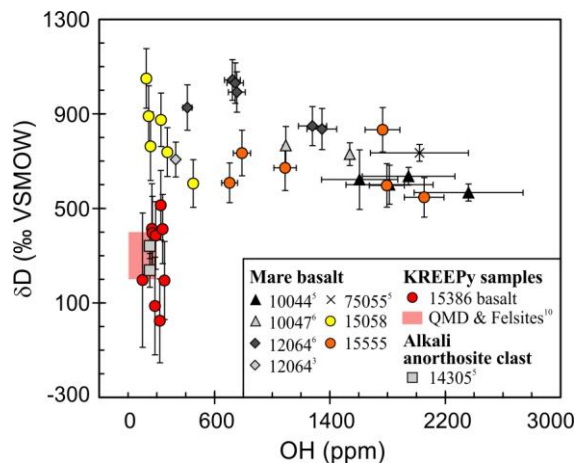


Figure 1:  $\delta D$  vs. OH content of lunar apatites. Data are from this study and from [3,5-6,10]. Error bars are  $2\sigma$ .

## 4. Discussion and conclusion

In mare basalts, trends of increasing  $\delta D$  with decreasing OH could be related to  $H_2$  degassing. Indeed, it drives  $\delta D$  values of residual OH upward as shown on Figure 2. Consistently, the dominant H-bearing species in lunar magmas is likely to be  $H_2$  at the very low oxygen fugacity that prevails in the lunar interior [12]. Starting from a source with a  $\delta D$  of 100 ‰ requires at least 98 % of H to be degassed to achieve  $\delta D$  values above 600 ‰. Further degassing ultimately drives  $\delta D$  towards very high values at low OH contents. In the studied samples, the Figure 2 suggests that 15555 is less degassed than 15058, which could be related to its more primitive nature.

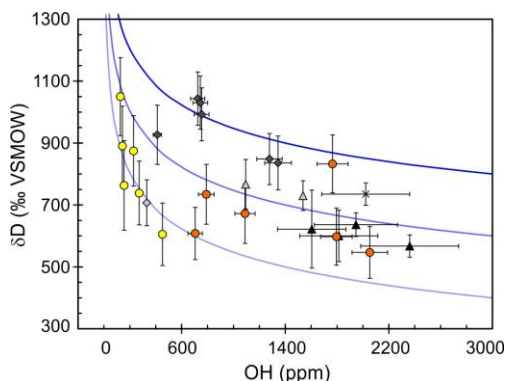


Figure 2: Effect of  $H_2$  degassing illustrated in a  $\delta D$  vs. OH diagram. Data are the same than in Fig. 1. Trends illustrate degassing at 1000°C starting with different initial  $\delta D$ .

The KREEP basalt studied here has a low OH content, which is consistent with previous reports [9-10]. KREEP basalt 15386 is related to some extent to the urKREEP component, which is thought to represent the very late stage crystallisation products of the lunar magma ocean (LMO). This suggests a H-bearing species poor LMO, as these are incompatible and would have been concentrated in this urKREEP component. The few analyses carried out on lunar crustal rocks also suggest the lunar crust to have low H-bearing species content. Apatite in both KREEP basalt, QMD and felsites of [10], and crustal rocks have  $\delta D$  values in the range 100-500 ‰, lower than mare basalts, but still elevated compared to most of the terrestrial rocks. Such values might also be related to  $H_2$  degassing from a drier source compared to the source regions of mare basalts, either during the molten LMO stage or during solidification of individual urKREEP-related and crustal products.

The main implication of the data presented here are that mare basalt source regions require an extra-addition of H and/or H-bearing species compared to KREEP and crustal components. This is consistent with other geochemical characteristics of mare basalts such as their highly siderophile and highly volatile element contents [13-14].

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