

Tracking secular changes in the “water” content of lunar interior using basaltic lunar meteorites

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Abstract

Lunar meteorites provide a wider sampling of the lunar surface compared to the samples collected during the Apollo and Luna Missions. Apatite is the main hydroxyl-bearing (proxy for water) mineral in lunar samples, especially in basaltic rocks. Apatite is also amenable to *in-situ* U-Pb age dating studies. The ages of lunar basaltic meteorites also span over a larger range compared to basaltic samples from Apollo and Luna collections. Thus, by determining the age, the H-content, and the H isotopic composition of apatites from lunar basaltic meteorites, it is possible to investigate any secular variation in the water contents of the lunar interior.

1. Introduction

Recently, we have witnessed a paradigm shift in our understanding of the history of water on the Moon. Currently, there is less disagreement over the presence of water in the lunar interior as documented by sample analysis [1-10]. However, uncertainties exist regarding the abundance, distribution, and the source(s) of water in the lunar interior. In addition, it is also not known if the water content of the lunar interior has changed through time [11]. The giant-impact origin of the Moon is thought to have involved a lunar magma ocean (LMO) phase. Much of any water present during the accretion of the Moon would presumably have been lost to space because of high-temperatures but some primordial water may have been sequestered in minerals and rocks formed by LMO solidification [12]. There is also a possibility that some additional water was accreted to the Moon after the LMO solidification through impacts of chondritic materials [13-14]. Mare basalts (and volcanic glasses) derived by partial melting of the lunar mantle have erupted episodically onto the lunar surface. Any evidence for the presence of water in the lunar mantle is likely to be preserved

in mare basalts as water behaves incompatibly during mantle partial-melting and is thus partitioned preferably into the melt. The Apollo and Luna missions collected a range of lunar samples including those of primary LMO products (e.g., anorthosites, Mg-suite rocks etc.) and a variety of mare basalts with crystallization ages predominantly ranging from ~ 3.9 to ~ 3.1 Ga [15]. However, Apollo samples were collected from geographically restricted areas from the equatorial nearside of the Moon. In contrast, lunar meteorites potentially may have originated from areas of the Moon, far away from the Apollo sites and thus provide a wider sampling of the lunar surface. There are a number of lunar basaltic meteorites ranging in age from 4.35 Ga to ~ 2.8 Ga [15]. By combining age-dating of apatites, from lunar basaltic meteorites, with measurements of their H-content and H isotopic composition, we can investigate any secular changes in the water content of the lunar interior.

2. Samples and methods

We have selected three lunar basaltic meteorites (Kalahari 009 – 4.35 Ga [16]; MIL 05035 – ~ 3.9 Ga [17]; NEA 003 – ~ 3.1 Ga [18]), covering nearly the entire age-range of lunar basalts that have been age-dated using various radiometric techniques. Kalahari 009 and MIL 05035 samples belong to the very-low-Ti lunar basaltic samples whereas NEA 003 belongs to the low-Ti group. We are in the process of measuring the OH contents and D/H measurements in apatites using a Cameca NanoSIMS 50L located at the Open University. So far, we have analysed apatites from MIL 05035. The analytical conditions involved a large Cs^+ primary beam of ~ 270 pA current, which was rastered over a $10 \times 10 \mu\text{m}$ area. Mass resolving power was set at ≈ 4000 and secondary ions ^1H , ^2D , ^{12}C , and ^{18}O were collected from the central $5 \times 5 \mu\text{m}$ area. Analysis times were typically 25 minutes, including a 3 minute pre-sputter.

D/H ratios were normalised against a standard, Morocco apatite ($\text{OH} = 2640 \text{ ppm}$, $\delta\text{D} = -89 \text{ ‰}$). A second reference apatite, Imaichi ($\text{OH} = 189 \text{ ppm}$), was used to build calibration lines relating ${}^1\text{H}/{}^{18}\text{O}$ ratios measured in apatites to their OH contents.

3. Results

For MIL 05035, the OH contents and H isotope composition obtained from 4 analyses, carried out on 3 separate grains, range between 2000-4600 ppm and 320-540 ‰, respectively.

4. Discussion and conclusion

The δD values measured in MIL 05035 apatites show a rough inverse correlation with their OH content. Such a trend could reflect contamination by low δD terrestrial water. This is confirmed by secondary ion images of the analysed area that show H- and C-enriched cracks and hotspots. A mixing model between 2000 ppm Antarctic water with a δD of -200 ‰ and 2000 ppm of indigenous lunar hydroxyl with a δD of ~800 ‰ fits well with the amount of terrestrially contributed water in the apatites estimated through ion imaging. Such a δD estimate of ~800 ‰ for the lunar hydroxyl is consistent with measurements made on Apollo mare basalts [4,9-10].

These initial data suggest that the H isotopic composition of apatites in lunar meteorites are not widely compromised by terrestrial contamination and that it is possible to quantitatively estimate the amount of terrestrially-contributed water in order to obtain the indigenous signatures of lunar water.

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