National Aeronautics and Space Administration

Assessment of pre-eruptive concentrations of volatiles and post-eruptive loss in lunar basalts

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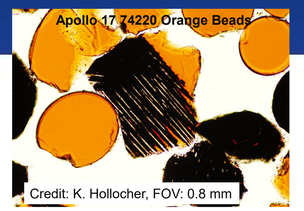
Program: FY21 SURP **Strategic Focus Area: Lunar science**

Objectives

- The objective of this research partnership proposal is to answer some of the most important questions about lunar volatiles, how volatiles are lost from the Moon and what are the mantle abundances of volatiles, by systematically assessing pre-eruptive and post-eruptive volatile element concentrations in lunar basalts.
- The partnership between the analytical capability at JPL/Caltech and experimental and theoretical expertise at UM will lead to long-lasting collaboration at the forefront of lunar science.



Background

This research partnership aims to constrain volatiles in lunar mantle. For this goal, understanding post-eruptive loss of volatiles in lunar basalts is critical in assessing pre-eruptive volatile element concentrations and hence mantle abundances (e.g., [1-6]), but also provides essential data for evaluating isotope fractionation related to degassing in the Moon. However, abundant data are only available for H_2O, F, S, and Cl. For many other volatile elements, data are either limited or nonexistent. This research partnership proposal seeks to expand such knowledge to other volatile elements.

The partnership between the analytical capability at JPL/Caltech and experimental and theoretical expertise at UM will enhance the visibility of lunar science at JPL. The initiative will lead to long-lasting collaboration at the forefront of lunar science. In the long run, this collaborative effort will lead to lunar mission concepts such as *in situ* missions of volcanic processes or sample returns of new terranes (beads from other dark mantling deposits) or mantle rocks from the wall of large impact craters. Analytical methods developed in this partnership by pushing the limit of SIMS can be applied to other returned planetary samples, be Mars or asteroids.

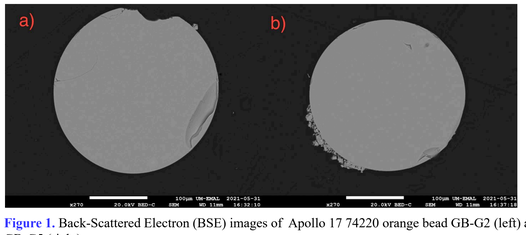


Figure 1. Back-Scattered Electron (BSE) images of Apollo 17 74220 orange bead GB-G2 (left) and GB-G5 (right).

Results, Implications and Significance

This is the first discovery that, in addition to outgassing, there is also ingassing of Na into the glass beads during their flight in a fire-fountain eruption [A]. The occurrence of both outgassing and ingassing of Na in orange glass beads might sound unintuitive initially. A diffusion model was developed, which successfully reproduces the observed Na profiles and both the outgassing and ingassing processes. The model assumes simple monotonic cooling, and a surface condition that depends on temperature with free fitting parameters. The key to understand the occurrence of both outgassing and ingassing during the flight and cooling of a glass bead is that the equilibrium Na vapor pressure has a positive dependence on temperature [7]. At the eruption temperature, the equilibrium Na pressure for a given glass bead is higher than the ambient Na partial pressure. Hence, Na diffuses out of the bead, leading to outgassing. At sufficiently low temperatures, the equilibrium Na pressure becomes lower than the ambient Na partial pressure. Hence, Na diffuses back into the bead, leading to ingassing. Therefore, the occurrence of both outgassing and ingassing is a natural consequence of cooling of a flying glass bead in an atmosphere containing some Na. Our modeling results are shown as the blue curves in Fig. 2 and can provide constraints on the cooling history of individual beads.

The excellent agreement of EMPA and SIMS data proves the true existence of the "U"-shaped Na profiles of 74220 orange glass beads. It is consistent with the discovery of high Na signals in the ~20-nm thick surface layer of 74220 orange glass beads from depth profiles [8]. The occurrence of higher Na contents near the edge indicates that the whole process is more complicated than degassing alone, and there should be ingassing that also play an important part in the process. This is the first time that such ingassing is investigated, well modeled, and proved that it can also affect compositions of the volcanic products.

In addition, by fitting the data in modeling, the cooling history of SINGLE glass beads can be constrained. For example, the cooling time scale of single glass beads is estimated to vary from 220 to 390 s, which is consistent with literature [9]. Different cooling histories of individual glass beads are expected because they reflect various flight trajectories of glass beads through the eruption plume.

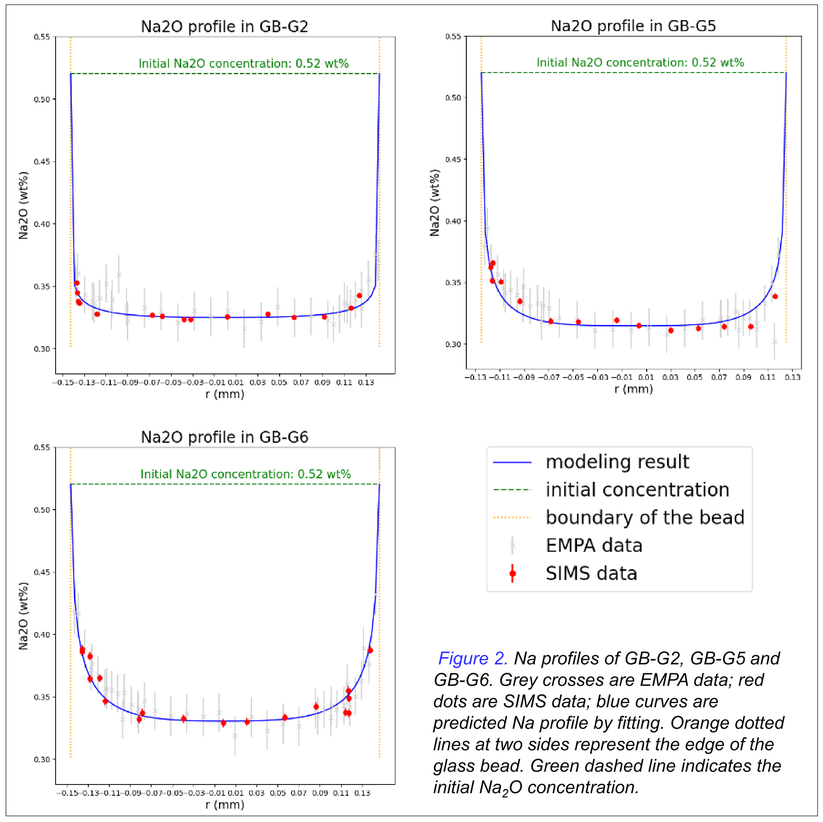


Figure 2. Na profiles of GB-G2, GB-G5 and GB-G6. Grey crosses are EMPA data; red dots are SIMS data; blue curves are predicted Na profile by fitting. Orange dotted lines at two sides represent the edge of the glass bead. Green dashed line indicates the initial Na_2O concentration.

Publication: [A] Xue Su, Youxue Zhang, and Yang Liu, "Outgassing and Ingassing of Na in Lunar 74220 Orange Glass Beads," submitted to AGU Fall Meeting 2021, New Orleans, LA.

Approach

In Year 1, we focused on the behavior of Na, in order to confirm and understand the preliminary data of a U-shaped Na_2O profile in glass beads.

Spherical orange glass beads of 200-300 μm in diameter were handpicked from pristine 74220 sample. These glass beads were embedded in epoxy discs and polished on sandpapers and alumina powder to expose the center section of the beads. Textures of the orange glass beads were examined under a Scanning Electron Microscope. Homogenous glass beads with no obvious crystallization were selected for compositional analyses (Fig. 1). Ten orange glass beads in total have been analyzed using EMPA for major element profiles.

For the profile of Na_2O, special efforts have been made to achieve smaller uncertainties. The data show that the orange glass beads contain lower Na_2O than olivine-hosted melt inclusions in 74220, indicating Na_2O degassing. On the other hand, U-shaped profiles, in which the Na concentration increases towards the edge of the bead, were observed in most of 74220 orange glass beads studied. It was a surprising result at first because Na is a volatile element, and hence we expected its concentration would be lower at the edge due to degassing.

Because of the lower precision of the EMPA method, we analyzed selected orange glass beads using a CAMECA IMS 7-f GEO SIMS at Caltech. After overcoming some analytical complexities, high-precision data were obtained. Na profiles obtained from EMPA and SIMS of three orange glass beads are compared in Fig. 2, which displays excellent agreement but much improved data from SIMS than from EMPA, confirming the U-shaped Na profiles and the diffusion of Na into the glass beads.

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Clearance Number:
RPC/JPL Task Number: SP21015