

## LUNAR VOLCANIC GLASSES: TRACE ELEMENT ABUNDANCES IN INDIVIDUAL SPHERES USING SYNCHROTRON X-RAY FLUORESCENCE

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**Introduction:** Mare volcanic glasses appear to be primary magmas from the lunar mantle [e.g., 1,2]. For this reason, major- and trace-element analyses of these glasses furnish constraints on the geochemistry of the Moon's interior [3-8] at depths of perhaps 400-500 km [e.g., 9-11]. The 26 varieties of high-Mg magmas [1,8] were produced by partial melting of differentiated source-regions [e.g., 3,5,8]. These regions of the lunar mantle consist of multiple components [e.g., 6,8] formed during the global differentiation of the Moon at 4.6-4.4 Ga.

Many questions remain to be answered about the mare volcanic glasses, but one of the most interesting ones deals with the source(s) of volatile elements (e.g., Cu, Zn, Ga, Pb) associated with these magmatic eruptions [e.g., 12-15]. Based upon Pb-isotopic analyses [14,16,17], the source-reservoir for these volatiles appears to have escaped the global differentiation event on the Moon. Although details remain complex [e.g., 17], these volatiles may have implications for not only the Moon's earliest thermal history but also its origin [e.g., 18,19].

Analysis of mare volcanic glasses by synchrotron x-ray fluorescence provides data on the trace abundances of lithophile and volatile elements that bear on these scientific issues.

**Analytical Techniques:** The synchrotron x-ray microprobe (XRM) on beamline X26 at the National Synchrotron Light Source (NSLS, Brookhaven National Laboratory, NY) was used for trace element analyses on individual glass spheres. Spheres > 100  $\mu\text{m}$  in diameter were doubly polished to produce free-standing, circular slabs between 200 and 400  $\mu\text{m}$  thick. The purposes of preparing the samples in this way were (1) to allow analyses on the glass interiors and (2) to provide well-defined geometry for self-absorption corrections. This thickness range was chosen to optimize fluorescence/background ratios for transition elements in these glasses. The slabs were subsequently placed on 8  $\mu\text{m}$  thick Kapton plastic film for analysis. We found that electrostatic attraction between the glass and plastic was sufficient to keep the samples in place.

The XRM was used in its conventional configuration (see e.g., [20]) consisting of a Ta slit assembly to collimate the white synchrotron radiation and a Si(Li) x-ray detector. In this case, a relatively large beam of 30  $\mu\text{m}$  was used and a 170  $\mu\text{m}$  Al filter was placed on the detector to suppress the intense K fluorescence from Fe. The use of this filter maximizes sensitivity for trace elements but precludes the detection of fluorescence lines below that of Mn K $\alpha$  (i.e., analyses are restricted to > 6 keV).

Acquisition times were 10 minutes but one specimen was analyzed for 10 mins., 1/2 hour and 8 hours to demonstrate that volatilization of the detected elements by the beam was negligible. X-ray spectra were processed using the SPCALC fitting routine and the intensities of small peaks were verified using the interactive fitting program STRIP. Elemental concentrations were calculated using our standardless version of NRLXRF [21] and major element compositions determined for each sphere by electron microprobe analysis at Albany. Fe was used as the internal element standard. Slab thicknesses were determined with an optical microscope. The minimum detection limit was about 1 ppm for all elements reported here.

**Results:** A total of 13 spheres was analyzed - 10 Apollo 15 green, 1 Apollo 17 orange and 2 Apollo 15 yellow. Of the 10 green glass specimens, 7 fell in the composition group D and 3 in group A,B as previously defined by Delano [22]. The detected trace elements included Ni, Cu, Zn, Ga, Rb, Sr, Y, Zr and Nb. Table 1 summarizes the results for these different groups. The data are in agreement with analyses of individual glass spherules by instrumental neutron activation [Ni, Rb, Sr; e.g., 4-6] and ion microprobe [Zn, Sr, Zr; e.g., 3,7,8] with the exception of Cu. Our result for the Apollo 17 orange glass gives < 1 ppm Cu, whereas ion microprobe analyses yielded abundances of about 450 ppm [7]. To the best of our knowledge, our results for Ga, Y and Nb are the first reported for the interiors of individual spheres.

Figure 1 is a ternary diagram involving non-volatile, geochemically incompatible elements (Ti, Zr) and a volatile, incompatible element (Zn). Due to the large differences in abundances among these elements, coefficients have been applied (e.g., 500 \* Zn) to give comparable weighting to each

element. This practice merely prevents all of the data from plotting as a single blob in the Ti corner of the figure. Our data show that the abundance of Zn in the high-Mg magmas represented by the mare volcanic glasses (i.e., not surface-correlated Zn) is strongly enriched compared to the magmas represented by the crystalline mare basalts. This figure supports the view [23] that the volcanic glasses were derived from generically different mantle source-regions than the mare basalts.

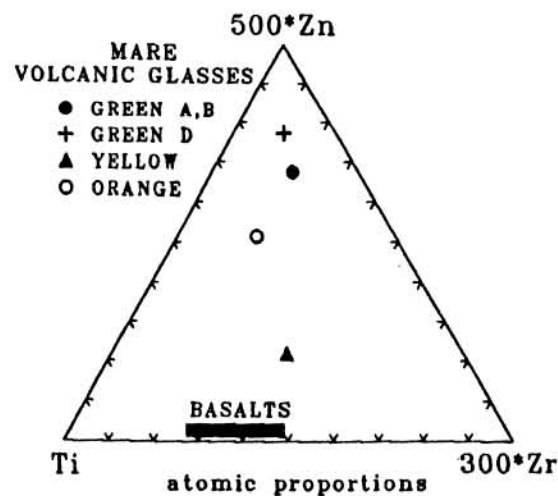
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**Table 1:** Mean Element Concentrations (by weight) for Lunar Glass Groups.

Glass Group	Spheres Analyzed	Ni (ppm)	Cu (ppm)	Zn (ppm)	Ga (ppm)	Rb (ppm)	Sr (ppm)	Y (ppm)	Zr (ppm)	Nb (ppm)
Green Glass A,B	3	150 (12)	4 (2)	30 (21)	3 (1)	6 (3)	27 (2)	6 (1)	19 (5)	1 (1)
Green Glass D	7	130 (20)	2 (1)	46 (22)	4 (2)	3 (1)	24 (5)	5 (2)	16 (5)	1 (2)
Yellow	2	84 95	4 5	45 19	7 5	1 5	150 154	37 37	135 130	4 3
Orange	1	59	< 1	250	13	4	265	46	205	9

Values in parentheses are 1 standard deviation of the abundances for each glass group.



**Figure 1:** Ti-Zr-Zn ternary diagram of the mean volcanic glass compositions and the field of mare basalt compositions. The volcanic glasses are enriched in the volatile element Zn relative to the crystalline mare basalts.