

PROTON INDUCED X-RAY EMISSION (PIXE) MICRO-ANALYSIS OF APOLLO 15 GREEN GLASS. PRELIMINARY EXPERIMENTS.

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The Apollo 15 green glass spherules represent quenched, picritic, low Ti magma(s) explosively erupted at the lunar surface. The green glasses are among the most primitive magmatic compositions discovered in the lunar sample collection. As such, the green glass compositions have been extrapolated and inverted to constrain geochemical models for the chemistry, mineralogy, redox state, compositional heterogeneity and origin of the lunar mantle, to estimate the bulk composition of the moon and to construct models for the origins of the earth-moon system (1, 2, 3, 4, 5, 6). Although this volcanic glass is of importance to understanding the nature and evolution of the earth-moon system, the petrogenesis of the green glass is not well understood.

Early studies suggested that the A15 green glass was essentially homogeneous (7, 8). Follow on studies recognized that the green glass was compositionally heterogeneous (9, 10) and consisted of compositionally distinct groups (11, 12, 13, 14, 15). Petrogenetic relations among the various groups, however, have not been established, nor has it been determined whether they were erupted simultaneously or sequentially. Over the last 20 years, the models for the origins of this "simple volcanic glass" have become increasingly complex. Numerous studies have suggested that an assemblage consisting of olivine and orthopyroxene with minor amounts of aluminous clinopyroxene controlled compositions during partial melting or fractional crystallization processes. Delano (11) and Ma et al. (13) noted that these types of processes failed to account for (a) positive correlation between SiO₂ and Mg and (b) inverse correlation of Ni and Co with Mg'. Grove (6) proposed that the fractionation of an Fe-rich metallic phase or FeS-rich immiscible melt in the source region or during ascent was responsible for the compositional relations among Ni, Co, Fe, Mg', and SiO₂. Secondary ion mass spectrometry (SIMS) analysis of individual glasses (14) showed positive correlations between highly compatible Co and incompatible elements, such as Zr, Ba, and the REE. This observation is inconsistent with a simple iron metal or sulfide fractionation mechanism. Galbreath et al. (14) suggested that these compositional variations reflected source heterogeneity and source mixing processes. The debate continues. The purpose of this initial PIXE study is to analyze individual green glass beads for additional siderophile, chalcophile, and incompatible lithophile elements that are difficult to analyze by other micro-analytical techniques (EMP, SIMS). These elements may shed additional light on the petrogenetic history of these important volcanic products.

Analyses of absolute concentrations of trace elements Ni, Cu, Zn, Sr, Y, Zr, Nb, and Pb were made on selected A15 glasses using the proton microprobe at Los Alamos National Laboratory. The individual glass beads had been previously analyzed by electron microprobe and SIMS. Elements noted with a (*) had been previously analyzed with SIMS. The Los Alamos proton probe consists of a 3MV S-series National Electrostatic tandem accelerator which provides ion beams for experiments. The PIXE microprobe uses a super-conducting solenoid as its final lens to obtain nanoampere currents in a micron diameter spot without severely sacrificing beam current. A Si (Li) detector, is used for the detection of x-rays produced by proton beam interaction with the geological sample. X-ray peaks for lower-z elements and the REE are attenuated by an Al filter (~ 80 mg/cm²) to minimize the deadtimes associated with the production of Fe x-rays. X-ray spectrum for an A-15 green A is illustrated in Figure 1. To deconvolute spectra, a fitting routine using only one variable parameter per element is used. This procedure requires that the relative peak intensities, corrected for the sample matrix, be calculated independently for each element. This method is "standardless" because the elemental concentrations are obtained by reference to a single element, in the same spectrum, that can be analyzed independently. Additional analytical protocols and methodology of data reduction are described by Rogers et al. (16, 17) and Duffy et al. (18). Comparison of element abundances in chondritic meteorites (19) and mineral separates from mantle nodules (20) determined by PIXE and other methods suggests that the accuracy of the PIXE technique is better than +/- 10%-15% one-sigma for most of these elements at greater than the 5 ppm level for the twenty minute count time used in this study. In our experiment, previously analyzed lunar glasses provide an additional analytical evaluation of this technique.

Preliminary analyses of the green glass indicate Cu, Zn, and Pb concentrations are below our lower limits of detection using the analytical technique in this initial study. The Ni peak is adjacent to the large Fe peaks (Figure 1), but can be resolved in fitting routines. Sr, Y, Nb and Zr can be resolved from the x-ray

spectrum at the concentration levels in the glasses. Comparisons between PIXE and SIMS analyses for Zr are presented in Figure 2.

As with the SIMS study of the A15 green glasses [14], concentrations of incompatible elements, such as Y, Zr, Nb and Sr show a positive correlation with strongly compatible elements such as Ni and Co. This feature implies the compositional variation observed in the green glass reflects source heterogeneity and source-magma mixing processes.

REFERENCES. (1) Burns, R.G. and Dyar, M.D. (1983) PLPSC 14th, B221-B228. (2) Delano, J.W. (1986) PLPSC 16th, D201-D213. (3) Delano, J.W. (1986) In *Origin of the Moon*, 231-247. (4) Seifert, S. and Ringwood, A.E. (1986) In *Origin of the Moon*, 247-267. (5) Seifert, S. and Ringwood, A.E. (1988) *Earth, Moon and Planets* 40, 45-70. (6) Grove, T.L. (1981) PLPSC 12th, 935-948. (7) Reid et al. (1972) *Meteoritics* 7, 395-415. (8) Ridley et al. (1973) *Phys. Earth Planet. Inter.* 7, 133-136. (9) Stolper, E.M. (1974) A.B. Thesis, Harvard University, Cambridge, MA. (10) Delano, J.W. and Ringwood, A.E. (1979) *Proc. Lunar. Planet. Sci.* X, 286-288. (11) Delano, J.W. (1979) PLPSC 10th, 275-300. (12) Ryder, G. (1986) PLPSC XVII, 738-739. (13) Ma et al. (1981) PLPSC 12th, 915-933. (14) Galbreath et al. (1990) *G.C.A.* 54, 2565-2575. (15) Steele et al. (1989) *Abstr. Workshop on Lunar Volcanic Glasses*, 21-22. (16) Rogers et al. (1987) *Nuc. Instr. Meth. B* 22, 133-137. (17) Rogers et al. (1984) *Nuc. Instr. Meth. B* 3, 671-676. (18) Duffy et al. (1987) *Nuc. Instr. Meth. Phys. B* 22, 91-95. (19) Burnett et al. (1988) *Nuc. Instr. Meth. B* 35, 67-74. (20) Hickmott et al., in prep.

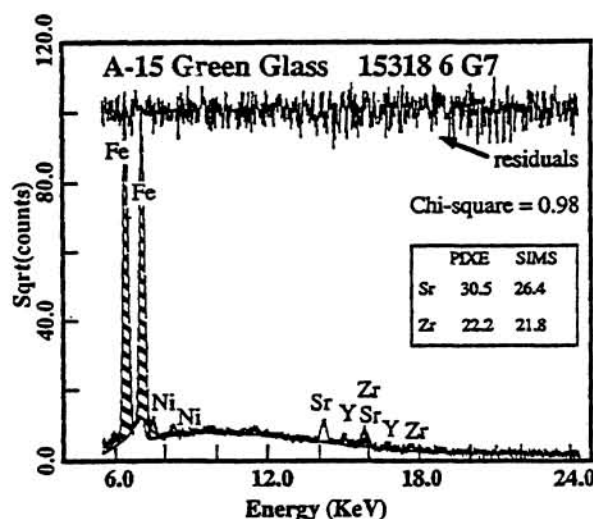


Figure 1

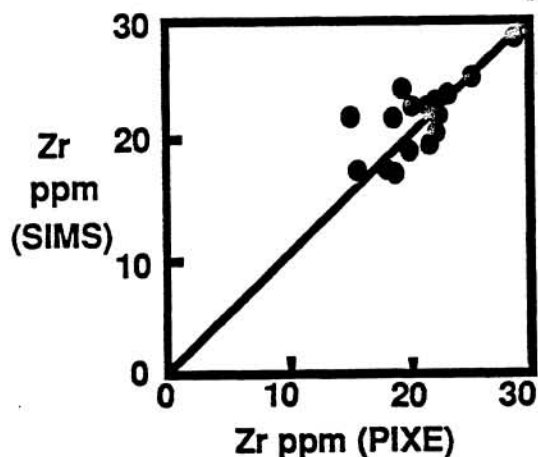


Figure 2