# DISTINGUISHING BETWEEN APOLLO 14 HIGH-ALUMINA BASALTS AND OLIVINE VITROPHYRES: TEXTURAL AND CHEMICAL ANALYSES OF OLIVINES.

A. L. Fagan[1], C. R. Neal[2], and A. Simonetti[3] [1,2,3] Dept. of Civil Eng. and Geo. Sci., University of Notre Dame, 156 Fitzpatrick Hall, Notre Dame, IN, 46556, abacasto@nd.edu; neal1@nd.edu; Antonio.Simonetti.3@nd.edu.

**Introduction:** The Apollo 14 (A-14) basalts, coined "High-Alumina" [1], are relatively enriched in $Al_2O_3$ (11.1-13.8 wt%, [2]) compared to other mare basalts. High-Alumina (HA) basalts tend to be predominantly composed of pyroxene (50%) and plagioclase (25-40%) with 0-10% olivine and 5-15% accessory phases such as ilmenite, cristobalite, chromite, whitlockite, glasses and metallic Ni-Fe [3]. The HA basalts are known predominantly from clasts in impact melt breccias (e.g., [2,4-6]).

Olivine vitrophyres (OVs) are also found as clasts in the A-14 breccias [e.g. 4-5]. Composed primarily of olivine phenocrysts in an opaque glass matrix with occasional pyroxenes and lath-like plagioclase crystals, the OVs are petrographically similar to quenched HA basalts. However, these vitrophyres can be distinguished from mare basalt clasts by high modal olivine, high MgO content, and low $CaO/Al_2O_3$ ratios [5]; additionally, olivines are more Fo-rich in the OVs (79.0-91.2) than in the HA basalts (64.2-75.1; [6]). However, while the OVs contain relatively high incompatible trace element abundances, they also exhibit elevated MgO contents [7], suggesting the mixing of evolved and primitive lithologies [4-5,8].

The Ni contents of olivines in HA basalts suggest these crystals to be early-formed in a pristine fractionating magma [3,9-11]. The low non-volatile/volatile elemental (e.g., Ba/Rb) ratios of the melts add further support to the contention that the HA basalts are pristine mare basalts [11]; alternatively, an impact origin has been proposed for the HA basalts [12-13] based on contrasting Sm -Nd and Rb-Sr isochron ages. Major and trace element compositions of olivine phenocrysts in the HA basalts have been compared with those in OVs (known impact melts, [6]); they (and others e.g. [15]) concluded on the basis of the distinct trace element compositions between the groups that the Apollo 14 HA basalts are not impact melts.

The objective of this work is to distinguish between the A-14 impact melt-generated OVs and pristine, HA mare basalts using olivine chemistry and petrographic evidence. We use textural and chemical analyses of vitrophyre and basalt samples from Apollo 14 breccia 14321 to provide information about the melts from which the olivine crystallized. In addition, we compare the analyses with two vitrophyric basalts from the nearby Apollo 12 (A-12) site (12008, 12015), as well as textural analysis of A-12 Olivine Basalt, 12004.

**Samples:** 4 OV clasts and 9 HA basalt clasts (Table 1) were analyzed from lunar breccia 14321 [e.g. 14]; each has been previously analyzed for major element mineral and whole rock chemistry, with the exception of ,1486, which was too small for whole rock analysis. The HA basalts represent samples from each of the three groups (A, B, C, [15]) that cover a wide range of incompatible element abundances and ratios. Additionally, two A-12 vitrophyre samples (12008, 12015) were analyzed; these samples are true basalts and not impact-generated in contrast to the Apollo 14 OVs [e.g. 16-17]. Finally, a textural analysis was conducted of an A-12 Olivine Basalt (12004).

**Table 1. Samples types and analyses performed.**

| Thin Section # | Sample Type | Olivine Analysis | CSD |
|---|---|---|---|
| 14321, 1305 | A14 OV | ✔ | ✔ |
| 14321,1246 | A14-"A" Basalt | ✔ | **N/A** |
| 14321,1376 | A14-"B" Basalt | ✔ | ✔ |
| 14321,1471 | A14 OV | ✔ | ✔ |
| 14321,1480 | A14-"A" Basalt | ✔ | ✔ |
| 14321,1482 | A14-"B" Basalt | ✔ | ✔ |
| 14321,1483 | A14-"B" Basalt | ✔ | **N/A** |
| 14321,1486 | A14 OV | ✔ | ✔ |
| 14321,1602 | A14 OV | ✔ | ✔ |
| 14321,1611 | A14-"A" Basalt | ✔ | **N/A** |
| 14321,1612 | A14-"B" Basalt | ✔ | **N/A** |
| 14321,9057 | A14-"C" Basalt | ✔ | ✔ |
| 14321,9080 | A14-"C" Basalt | ✔ | ✔ |
| 12004,137 | A12 Olivine Basalt | **N/A** | ✔ |
| 12008,65 | A12 OV | ✔ | ✔ |
| 12015,29 | A12 OV | ✔ | ✔ |

**Methods:** *Olivine Chemistry Analyses.* Major element analyses were performed using a JEOL JXA-8200 electron microprobe (EMP) at Washington University in St. Louis, on all samples except 12004,137. Samples were analyzed using a 25nA beam current, 5 μm spot size, and 30 second on-peak counting time. Mineral standards were used and data were reduced using *Probe for Windows* software. Three analysis points on each of the two group C basalts (,9057 and ,9080) were previously gathered using the JEOL JXA-860 Superprobe EMP at the University of Notre Dame using a similar setup. Olivine trace elements (Ca, Sc, Ti, V, Cr, Mn, Co, Ni, and Y) were quantified by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS), using a New Wave UP-213 laser ablation system coupled with a ThermoFinnigan Element2 ICP-MS at the University of Notre Dame. Mn abundances obtained by EMP were used as the internal standard while NIST SRM 610 glass was employed as the external standard; Ca abundances were used as the internal standard for the samples probed at Notre Dame due to a lack of MnO EMP data. LA-ICP-MS analyses were conducted using a repetition rate of 5 Hz, spot diameter of 25 μm and a corresponding fluence of ~17 J/cm$^2$. Elemental abundances were determined using *GLITTER* © software.

*Textural Analyses*. Crystal size distributions (CSDs) can be used as a guide for compositional analyses and to quantitatively investigate igneous processes. CSDs were determined for most samples. Samples for which we did not conduct CSDs had too few olivines (ie <10) to create an accurate model. The method used for CSD construction is the same as that reported in [18]. Crystal size distributions are plotted as the natural log of the population density against the corrected crystal size length [19].

**Results:** *Whole Rock Chemistry vs Mineral Analyses.* Whole rock REE abundances [2,5,8,20-22] can be used to distinguish between the OVs and the HA basalts. However, this identification process runs into trouble when the sample is simply too small to analyze (according to this method) as is found with regards to 14321,1486. The latter has been previously identified as a mare basalt [21], but it is more likely to be an impact melt-generated OV based on its olivine chemistry [23].

*Mineral Chemistry*. Olivines in the A-14 impact melt-generated OVs and basalts have some similar major and trace elements, but there are distinct differences as well. For example, the olivines in A-14 OVs have the highest Fo values (Fig. 1) in comparison to the A-14 and A-12. In addition to higher Mg abundances, basaltic olivines typically have higher V, Co (Fig. 1), Sc, Cr, and Mn and lower Ti and Y abundances than those in the impact-generated vitrophyres. Furthermore, the A-12 basalts have the highest abundances of Cr, Co (Fig. 1), and Ni among the olivines.

*Textural Analyses (CSDs)*. Previous work has suggested that plagioclase crystals in impact melts may exhibit systematically different plagioclase CSD shapes than in basalts [24]. Our textural analyses of the olivine-rich basalts and impact melts complement this earlier work on plagioclase. Basaltic olivine CSDs from 14321 and 12004 have lower slopes than their A-14 impact-melt OV counterparts (Fig. 2). Additionally, each basalt group displays a unique olivine CSD shape/slope as previously shown with regards to plagioclase [24]. These slope differences would seem to indicate that 14321 impact melts and basalts undergo distinctly different crystallizing conditions. Given their distinct mineral chemistry, this provides further evidence that the HA basalts are not impact melts as has been suggested by some [12-13]. Additionally, the similar slope of 12004 with the A-14 basaltic samples suggests there may be a general trend for olivine-rich basalts (without a vitrophyric texture).

**Conclusions**: Mineral chemistry and textural analyses show the A-14 OVs are distinct from pristine A-12 and A-14 basalts. We conclude that mineral chemistry and textural analysis can be used to distinguish impact-generated melts from pristine basalts. Such an approach requires less time and sample than the traditional determination of highly siderophile elements analyses for distinguishing between impact melt and basalt samples.

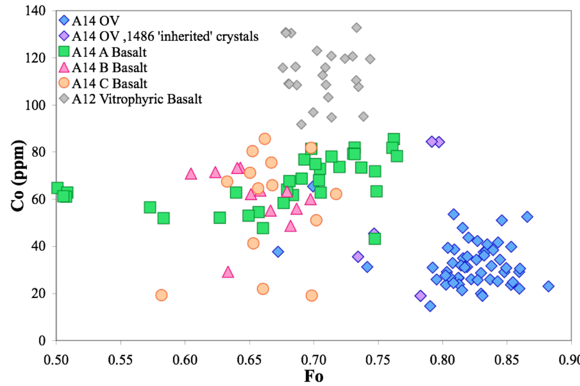


**Fig. 1: Co vs Fo for A-14 OV and HA basalts and A-12 vitrophyric basalts.**

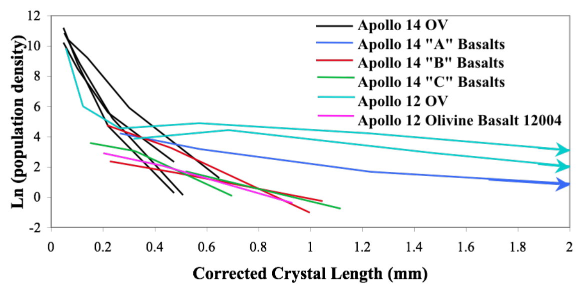


**Fig. 2: CSD analyses of samples in this study.**

**References:** [1] Ridley, WI (1975) *PLPSC 6th*, 131-145. [2] Dickinson, T et al. (1985) *PLPSC 15th, JGR, 90*, C365-374. [3] Hagerty, JJ et al. (2005) *GCA, 69*, 5831-5845. [4] Allen, FM et al. (1979) *PLPSC 10th*, 695-712. [5] Shervais, JW et al. (1988) *PLPSC 18th*, 45-57. [6] Neal et al. (2005) *LPSC 36th*, 1665. [7] Neal, CR & LA Taylor (1988) *LPSC 19th*, 839. [8] Neal, CR & LA Taylor (1989) *GCA, 53*, 529-541. [9] Hagerty, JJ et al. (2001) *LPSC 32*, 1235. [10] Hagerty, JJ et al. (2002) *Wkshop Moon Beyond*, 3041. [11] Hagerty, JJ et al. (2003) *LPSC 34th*, 1773. [12] Snyder et al. (2000) *Origin of Earth & Moon*, 361-395. [13] Snyder & Taylor (2001) *Met & Planet. Sci., 36, Supp*, A194. [14] Duncan et al. (1975) *GCA, 39*, 255-273. [15] Neal, CR & GY Kramer (2006) *Am. Min., 91*, 1521-1535. [16] Neal, CR et al. (1994) *Meteoritics, 29*, 334-348. [17] Neal, CR et al. (1994) *Meteoritics, 29*, 349-361. [18] Fagan, AL & CR Neal (2011) *this conference*. [19] Cashman, KV & BD Marsh (1988) *Contrib. Min. Pet., 99*, 292-305. [20] Shervais, JW et al. (1984) *LPSC XV*, 771. [21] Neal, CR et al. (1988) *LPSC 18th*, 139-153. [22] Neal, CR et al. (1989) *PLPSC 19th*, 147-161. [23] Fagan, AL et al. (2010) *LPSC 41st*, 1533. [24] Oshrin, J & CR Neal (2008), *LPSC 39th*, 1085.