GEOCHEMISTRY OF REEPy BASALTS: A NEW BASALT SUITE FROM APOLLO 14

Gregory A. SNYDER & Lawrence A. TAYLOR, Dept. of Geological Sciences, University of Tennessee, Knoxville, TN 37996-1410; Y.-G. LIU & Roman A. SCHMITT, Radiation Center and Dept. of Chemistry, Oregon State University, Corvallis, OR 97331.

The variety and ages of basalts from the Apollo 14 site have provided invaluable insight into the nature of ancient basaltic volcanism. In an effort to reap even more information from the rocks at Fra Mauro, fifteen new rocks were picked from Apollo 14 soils (2-10 mm clasts) for geochemical study. The mineralogy and petrology of these samples are given in companion abstracts in this volume [1,2].

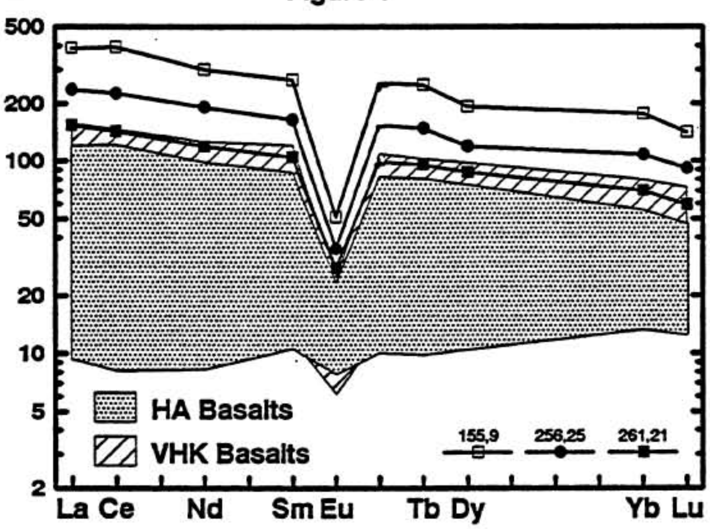
All of the rocks contain geochemical signatures which are consistent with mixing of high percentages of high-K KREEP [3]. **In fact, two of the rocks (155,9 and 160,193) exhibit major and trace element characteristics which are identical to high-K KREEP [3].** Previously, KREEP has only been identified as a **chemical signature**, ubiquitous in soils, and common in rocks from many landing sites. These two new rocks give primary evidence of both the **geochemistry** and **mineralogy** of this KREEP component at the Apollo 14 landing site. The other basalts from this study are compositionally distinct from either very-high K (VHK) basalts or high-Al (HA) basalts at Apollo 14.

BASALT STUDIES AT APOLLO 14: Two different basalt suites have been discribed from Apollo 14. The most abundant suite, the HA basalts, contain 11-14 wt.% Al_2O_3, <0.3 wt.% K_2O, and characteristically have K/La ratios of approximately 100 [4]. The range in compositions for these basalts was likely generated by a process of assimilation of KREEP coupled with fractional crystallization of a HA basaltic magma. The second suite, the VHK basalts, were first recognized by Shervais et al. [5] to be a unique subset of high-Al (HA) basalts. This suite is similar in composition to HA basalts with a few noteable differences. First, the K_2O abundances of VHK basalts are generally >0.3 wt.% with K_2O/Na_2O >1 and K/La >150. Second, VHK basalts contain interstitial K-Ba-feldspars and Si-rich glass which are not found in HA basalts. Third, VHK basalts often contain both fayalitic and forsteritic olivines, whereas HA basalts contain only forsteritic olivines. Both the unique mineralogy and range in chemical compositions for this suite can be explained by assimilation of lunar granite by a fractionating HA basalt magma.

EXTENDING THE ENVELOPE -- REEPy BASALTS FROM APOLLO 14: Major element chemistry of these new basalts include: TiO_2 = 1-2%, Al_2O_3 = 14-22%, FeO = 6-11%, MgO = 6-16%, CaO = 8-14%. These new basalts generally have lower TiO_2 and FeO and higher Al_2O_3 than HA basalts, but are within the range of published data for VHK basalts [5,6,7,8]. However, these new data would extend the VHK major element envelope to even higher abundances of both Al_2O_3 and MgO. The new suite of basalts also differ from HA basalts in having much higher K_2O (0.5-1.0 wt.% as compared to 0.03-0.29 wt.%). Although the K_2O values are similar to those found in VHK basalts, the K/La ratios are distinctly lower (<100) than those for VHK basalts (e.g. 150-500). Mineralogy and mineral chemistry of the major phases in these rocks are similar to the VHK basalts (see companion abstracts, [1,2]). One noteable difference is the absence of fayalitic olivine (both fayalitic and forsteritic olivine are found in many VHK basalts) and the *presence of whitlockite* (a REE- and P-rich mineral) in these new basalts. Ir abundances (4 ± 3 ppb) in these samples are consistent with a small amount (<2%) of meteoritic contamination (as per the criteria of Warren & Wasson [9]). However, this small proportion of meteoritic contamination would likely not affect major element compositions and lithophile trace element abundances. Furthermore, many of the basalts exhibit primary igneous (ophitic to subophitic) textures. The pristine textures indicate that remelting during impact did not occur. We contend that the small proportion of meteoritic component (as evidenced in the siderophile element abundances) could be due to vapor-phase "metasomatic" infiltration during an impact event.

The basalts reported herein have more evolved trace element chemistry than *most* previously studied HA basalts, but are similar in many aspects (except the REE) to VHK basalts from Apollo 14. Abundances of the trace elements include: La = 43-84 ppm, Lu = 2.0-3.4 ppm, Sc = 10.8-21.2 ppm, Ni = 95-580 ppm, Ba = 620-1120 ppm, and Hf = 15-28 ppm. The basalts exhibit LREE enrichment ($(La/Lu)_n$ = 2.1-3.1) and large negative Eu anomalies (Eu/Eu^* = 0.18-0.31). Representative REE analyses, normalized to the chondritic meteorites, are presented in Figure 1 along with fields from the literature for both VHK and HA basalts.

Figure 1



ACTUAL KREEP ROCK FOUND AT APOLLO 14: Relative to all other basalts at the A-14 site, two rocklets (155,9 and 160,193) have REE abundances that are elevated by

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Table 1: HKK vs. 14-KREEP

	High-K KREEP#	A-14 KREEP*
SiO2	47.9	46.08
TiO2	1.65	1.91
Al2O3	16.6	15.6
FeO	10.6	10.5
MgO	10.6	14.8
CaO	9.52	9.4
Na2O	0.86	0.94
K2O	0.83	0.64
Mg#	0.64	0.71
La	110	128
Ce	270	340
Nd	180	189
Sm	49.0	54
Eu	3.00	3.93
Tb	10.0	11.8
Yb	36.0	39
Lu	5.00	4.8
(La/Lu)n	2.27	2.74

[3].
* Basalt 14155,9.

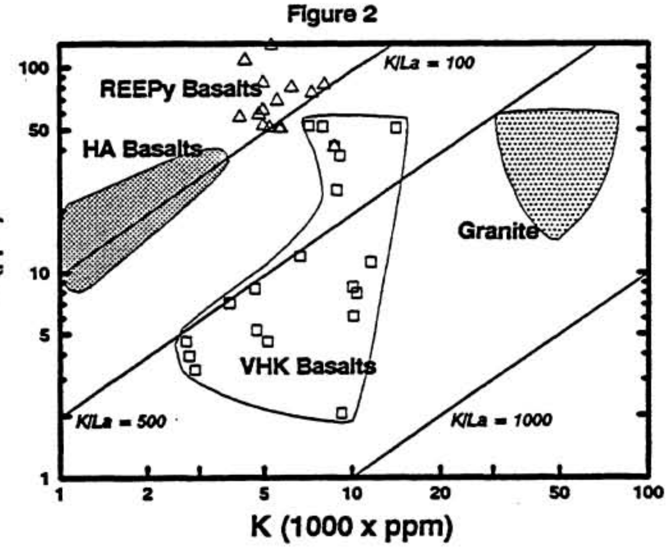
30%; other trace element abundances are also more evolved than previosly reported data for basalts. As indicated in Table 1, the whole-rock chemistry of these rocks is similar to the high-K KREEP of Warren & Wasson [3]. This high-K KREEP composition was derived from bulk soil analyses. **These two new samples could represent actual KREEP rocks from the Apollo 14 site.**

ATTEMPTED AFC MODELING OF REEPy BASALT DATA: Calculations were performed in an attempt to explain all VHK basalt data and our new basalt data as a continuum of a single process – i.e., coupled assimilation and fractional crystallization (AFC a la DePaolo [10]). Approximately 4-15% fractional crystallization coupled with assimilation (r = mass of assimilant/mass of cumulate = 0.5) of a granitic component similar to 73255c will generate the most primitive VHK basalts [8,9]. Substituting our newly found KREEP rocklets as representative of the assimilant, the bulk of the trace element data for the VHK basalts can be modeled as a process of simultaneous assimilation of KREEP (r = 0.35) coupled with fractional crystallization of this primitive VHK basalt. Utilizing the most primitive samples at the lowest degree of granite assimilation (2% for 304,108) and the the highest degree of assimilation (7.5% for 305,304), two AFC curves can be calculated which encompass all of the VHK data, but which pass by the new basalt data at higher K2O values (Figure 2). Changing the r value in the AFC modeling will not allow the explanation of our new basalts as a continuation of the VHK trend.

If it is assumed that these new basalts are derived from a primitive HA basalt parent, a similar modeling approach (AFC) can be undertaken. Modifying the r value as presented by Neal et al. to 0.29 and utilizing a KREEP assimilant will allow the modeling of most of our new data as a continuation of the HA basalt AFC trend. However, all of our samples have higher Mg#'s than even the most primitive HA basalt rendering this relationship untenable. Neither fractional crystallization, nor AFC, nor mixing of KREEP and/or lunar granite with either a VHK basalt or an HA basalt will generate our new data set. If the conventional is untenable, then the unconventional may be postulated.

REEP METASOMATISM OF VHK BASALTS: These new basalts are compositionally very similar to VHK basalts, but for their high REE contents and the ubiquity of whitlockite. We postulate that these samples were originally VHK basalts and have been metasomatized by a REE- and P-rich (REEP) fluid, the evidence of which is the abundance (up to 2-3 vol%) of whitlockite. This fluid could be a byproduct (REEP-frac) of silicate liquid immiscibility during the last stages of evolution of the Lunar Magma Ocean [11]. This metasomatic event would leave the major element and most of the trace element chemistry unaltered, but would elevate the REE.

Figure 2



CONCLUSIONS: A new group of basalts has been discovered in Apollo 14 soils. These samples are compositionally similar to VHK basalts, albeit with much higher REE abundances. These new basalts also contain up to 2-3 vol.% whitlockite. **Two rocks have trace element compositions which are representative of actual KREEP.** The new REEPy basalts can be explained by metasomatism of an original VHK basalt by a REE- and P-rich fluid which was possibly produced during silicate liquid immiscibility (REEP-frac).

REFERENCES: [1] Snyder & Taylor (1991), *LPSC XXII, this volume*; [2] Snyder & Taylor (1991), *LPSC XXII, this volume*; [3] Warren & Wasson (1979), *Rev. Geophys. Space Phys. 17*, 73-88; [4] Neal & Taylor (1990), Mare Basalt Workshop, in press; [5] Shervais et al. (1985), *PLPSC 15*, D3-D18; [6] Goodrich et al. (1986), *PLPSC 16*, D305-318; [7] Neal et al. (1988), *PLPSC 18*, 121-37; [8] Neal et al. (1989), *PLPSC 19*, 147-161; [9] Warren & Wasson (1977), *PLSC 8*, 2215-2235; [10] DePaolo (1981), *EPSL 53*, 189-202; [11] Neal & Taylor (1989), *GCA 53*, 529-541.