DIVERSITY IN HIGH-TITANIUM LUNAR MARE BASALTS. Y. Liu[1], M.J. Spicuzza[2], J.W. Valley[2], J.M.D. Day[3], A.J.V. Riches[1], K.I. Singer[1], and L. A. Taylor[1]; [1]Planetary Geosciences Institute, Department of Earth & Planetary Sciences, University of Tennessee, Knoxville TN 37996. (yangl@utk.edu). [2]Department of Geoscience, University of Wisconsin, 1215 W. Dayton St., Madison, WI 53706. [3]Department of Geology, University of Maryland, College Park, MD 20742

Introduction: Mare basalts, derived from partial melting of the lunar mantle, provide important information regarding magmatic processes in the Moon. Mare basalts from the Apollo and Luna collections are typically divided into three major-groups, based on their TiO_2 contents: very low-Ti (<1.5 wt%), low-Ti (1.5-6 wt% TiO_2), and high-Ti (>6 wt% TiO_2) [1]. Additional types were defined using Al_2O_3 and K_2O contents [1]. Here, we focus on high-Ti types with low-Al (<11 wt% Al_2O_3) from the Apollo 11 and 17 missions. An accompanying abstract by Singer et al. [2] addresses the mineralogy, petrography, and differences within these high-Ti basalt suites.

Diversity in High-Ti Basalts: High-Ti mare basalts display considerable diversity in petrography, mineralogy, bulk-rock trace-element, and O-isotope geochemistry [e.g., 1, 3-6]. Early petrographic studies of high-Ti basalts classified them according to their textures [e.g., 7-9]. Different groups were also defined based on major- and minor-element contents: Apollo 11 high-K and low-K groups, and Apollo 17 low-K and very high-Ti groups [7, 9]. The very high-Ti groups generally contain >12 wt% TiO_2. Almost all Apollo 11 samples contain <12 wt% TiO_2. Olivine-norm and quartz-norm high-Ti mare basalt classifications, similar to those for Apollo 15 low-Ti basalts, were also used to group samples that contain modal and normative silica phases (c.f. [3]). Subsequent studies have led to the development of the widely used classification based on trace elements in high-Ti mare basalts (Fig. 1, [1]). Except for Apollo 11 Type B1, B3, and Apollo 17 Type C [10,11], all subgroups of high-Ti mare basalt have been demonstrated to by generated from distinct mantle sources (e.g., [1, 3, 12-13]).

Near-surface Differentiation of High-Ti Basalts: Investigation of major- and trace-element compositions of Apollo 11 and 17 subgroups highlight the effect of near-surface fractional crystallization within each subgroup (e.g., [3, 12-15]). Specifically, models on major-element variations in Apollo 17 Type A samples suggested removal of olivine and armalcolite, or ilmenite (e.g., [3]). Complimentary cumulates derived from this process are missing.

Recent studies on oxygen isotope compositions of mare basalts have reported significant variations of $\delta^{18}O$ in high-Ti basalts, correlating with major elements (e.g., [4, 5]). Eight high-Ti subgroups were studied in [4, 5]. Values of $\delta^{18}O$ in these high-Ti basalts increase by ~0.3‰ from Mg# = 53 to Mg# = 34,

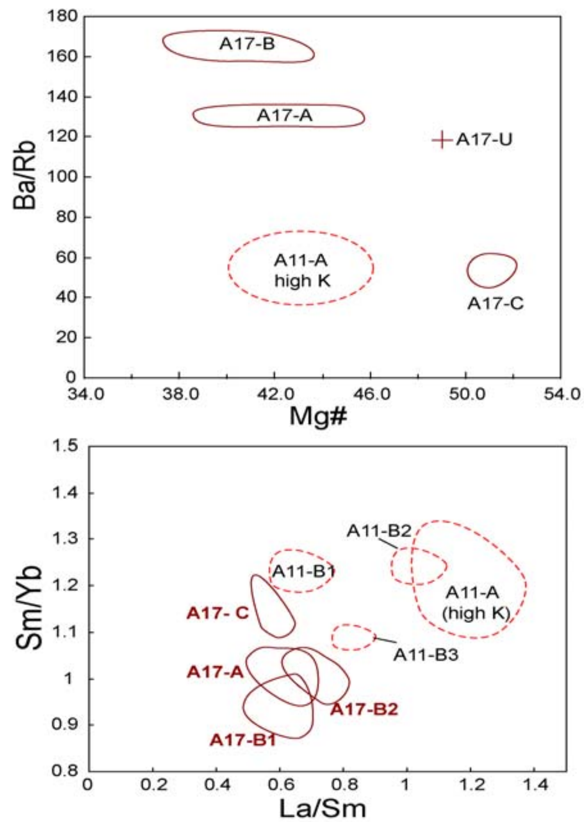

Figure 1. *Chemically distinct subgroups recognized in high-Ti mare basalts. A11 = Apollo 11 and A17 = Apollo 17. Ten sub-groups have been defined including Apollo 11 Types A, B1, B2, B3, and C; Apollo 17 Types A, B1, B2, C and U (e.g., [1]). For clarity, other Apollo 11 types were not shown in the top figure. Adapted from [3].*

and from ~13 wt% TiO_2 (corresponding to the very high-Ti samples defined in [9]) to ~9 wt% TiO_2 (Fig. 2a). Effects of magma mixing can be assessed by plotting $\delta^{18}O$ with ratios of similarly compatible trace elements (e.g., La/Sm in Fig. 2b), which are only mildly susceptible to crystal fractionation effects. The high-K high-Ti basalts (Apollo 11 Type A) lie between the fields of high-Ti and KREEP basalts, consistent with derivation from a distinct source with possible incorporation of a small amount of KREEP basalt. Very-low-Ti, low-Ti and high-Ti basalt compositions are inconsistent with assimilation of ilmenite (equilibrium $\delta^{18}O$ ≈ 4.6‰ [*c.f.*, 5] and assuming $La/Sm_n \approx 2$ on the basis of partitioning coefficients [16]), nor mixing of low-Ti and high-Ti magmas. Other high-Ti subgroups show a nearly vertical trend, suggesting fractional crystallization from a source with similar La/Sm values. For each subgroup (especially Apollo 17 Type A), the correlation of $\delta^{18}O$ and La/Sm is more consistent with fractional crystallization. The variation of $\delta^{18}O$ with major-elements in Apollo 17 Type A can be successfully modeled by mass-balance involving 9 wt% olivine + 9.5 wt% armalcolite + 14 wt% pyroxene and trace amounts of ilmenite + plagioclase [5]. This simple model demonstrates that high-Ti basalts with >12 wt% TiO_2 and high Mg# are more primitive than those with 9-12 wt% TiO_2. The modeled crystal assemblage is in agreement with similar models that account for major-element variations [3]. Interestingly, samples with 9-12 wt% TiO_2 are quartz-normative with a few vol% of primary silica phase (cristobalite or tridymite) and minerals are general more Fe-rich [3]. However, as mentioned above, none of Apollo samples contain such high abundances of armalcolite and olivine [14]. Possible explanations include accumulation of armalcolite and olivine at the bottom of the lava flow and reaction of these minerals with liquid. Geochemical constraints therefore imply unrepresentative sampling of lava flows at the A11 and A17 sites

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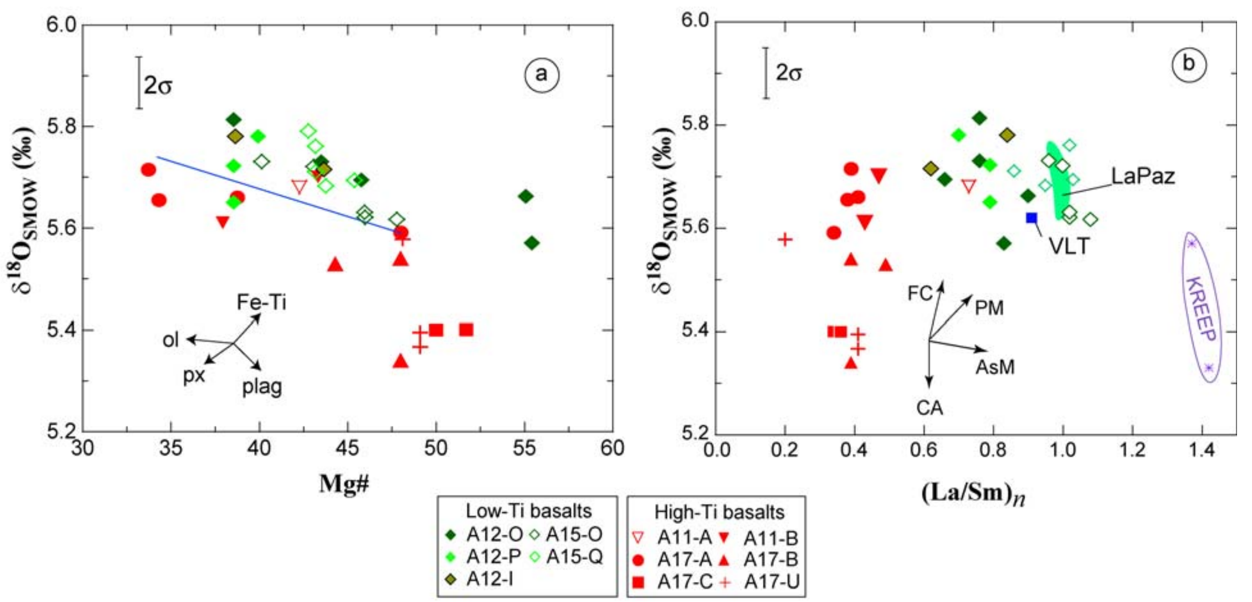

Figure 2. *$\delta^{18}O$ (WR) vs. Mg# and CI-chondrite normalized La/Sm of mare basalts. Different symbols represent different subgroups (see key). Vectored lines in (a) show, schematically, crystal fractionation effects on liquid compositions. The blue line in (a) shows a simple mass-balance calculation of removing olivine, armalcolite, and augite from the system [5]. Vectored lines in (b) show, schematically, the effect of fractional crystallization (FC), crystal accumulation (CA), partial melting (PM), and assimilation (AsM). The capped vertical bar marks the 2σ uncertainty (0.1‰) in $\delta^{18}O$. Data sources: $\delta^{18}O$ from [4-6] except for KREEP and VLT. For demonstration purpose, $\delta^{18}O$ of the very-low-Ti and KREEP basalts from Wiechert et al. [17] were plotted, although the obtained $\delta^{18}O$ values are generally lower than those in [4-6]. For consistency, trace-element contents of Apollo samples are from Neal [18]. Trace elements of LaPaz are from Day et al. [19]. Major-element contents of all samples and trace-element contents of samples not in [18] are average values from the 'lunar sample compendium' [20].*