DERIVATION OF APOLLO 14 HIGH-AL BASALTS FROM DISTINCT SOURCE REGIONS AT DISCRETE TIMES: NEW CONSTRAINTS. C. R. Neal[1], C.-Y. Shih[2], Y. Reese[3], L. E. Nyquist[4], and G. Y. Kramer[1], [1]Dept. Of Civil Eng. & Geological Sciences, University of Notre Dame, Notre Dame, IN 46556, USA (neal.1@nd.edu), [2]Mail Code JE-23, ESCG/Jacobs, Houston, TX 77058, [3]Mail Code JE-23, ESCG/Muniz Engineering, Houston, TX 77058, [4]Mail Code KR, NASA Johnson Space Center, Houston, TX 77058.

Introduction: Apollo 14 basalts occur predominantly as clasts in breccias, but represent the oldest volcanic products that were returned from the Moon [1]. These basalts are relatively enriched in Al_2O_3 (11-16 wt%) compared to other mare basalts (7-11 wt%) and were originally classified into 5 compositional groups [2,3]. Neal et al. [4] proposed that a continuum of compositions existed. These were related through assimilation (of KREEP) and fractional crystallization (AFC). Age data, however, show that at least three volcanic episodes are recorded in the sample collection [1,5,6]. Recent work has demonstrated that there are three, possibly four groups of basalts in the Apollo 14 sample collection that were erupted from different source regions at different times [7]. This conclusion was based upon incompatible trace element (ITE) ratios of elements that should not be fractionated from one another during partial melting (Fig. 1). These groups are defined as Group A (Groups 4 & 5 of [3]), Group B (Groups 1 & 2 of [3]), and Group C (Group 3 of [3]). Basalt 14072 is distinct from Groups A-C.

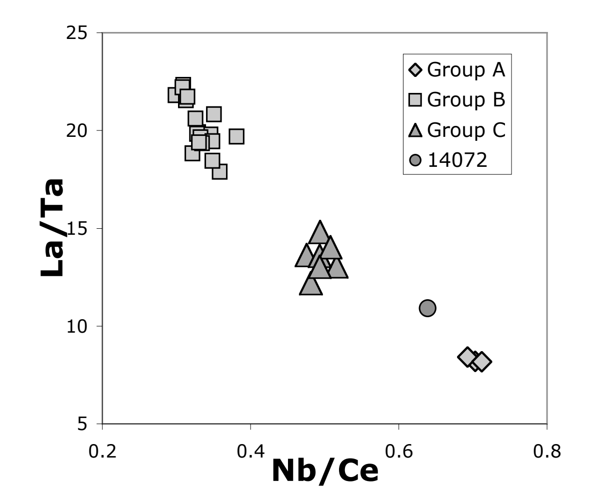

Figure 1: ITE ratio plot for the Apollo 14 high-Al basalts demonstrating derivation from distinct source regions [7].

We report here a Rb-Sr age for Group B high-Al basalt 14321,1353 and examine high-Al basalt petrogenesis using trace element and isotopic data.

Analytical Method: Chips of the basaltic clast 14321,1353 weighing ~90 mg were processed. The bulk rock sample (WR) was obtained by crushing the sample to <100 mesh (74um). Mineral samples were obtained by heavy liquid separation. Plagioclase (Plag) is mainly concentrated in the <2.85 g/cm^3 density fraction and pyroxenes are concentrated in the >3.32 g/cm^3 fraction. The pyroxene fraction was further separated into to: (1) 3.32-3.45 g/cm^3 Mg-rich pyroxene (Px1); and (2) >3.45 g/cm^3 Fe-rich pyroxene (Px2). The intermediate density fraction, 2.85-3.32 g/cm^3 (Plag+Px), contains plagioclase and pyroxene intermixed grains. All separates were washed with 1ml 1N HCl and sonicated for 10 min. to eliminate surface contamination. The acid washes (Leach) of these samples were combined and analyzed. A total of six samples [four acid-washed (Plag(r), Px1(r), Px2(r), Plag+Px(r)), one unwashed (WR), one leachate (Leach)] were analyzed for Rb and Sr following the methods of [8]. Rb and Sr isotopic measurements were made on a Finnigan-MAT 262 multi-collector mass spectrometer following the procedures of [9]. The average values of $^{87}Sr/^{86}Sr$ for NBS 987 during the course of the study were 0.710275±0.000033 ($2\sigma_p$, 23 analyses), normalized to $^{88}Sr/^{86}Sr$=8.37521. The $^{87}Sr/^{86}Sr$ results reported here were renormalized to the NBS 987 $^{87}Sr/^{86}Sr$ =0.710250.

Results: The isochron (blue line, Fig. 2) recalculated without the Leach datum (red open circle)

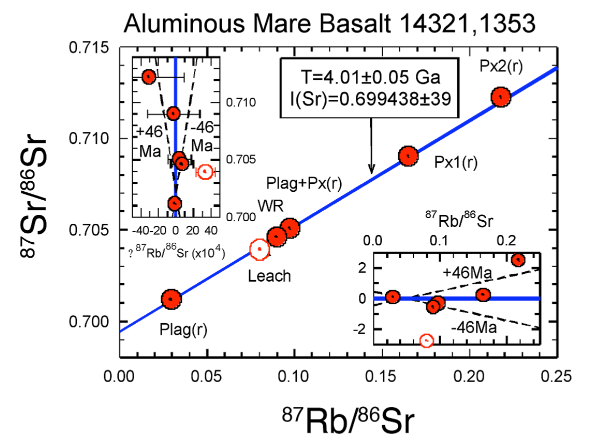

Figure 2: Rb-Sr isochron plot for 14321,1353.

yields an age of 4.01±0.05 Ga. The Leach datum is excluded because it deviates from the isochron (blue line) both in $^{87}Sr/^{86}Sr$ and $^{87}Rb/^{86}Sr$ ratios more than its experimental errors, as clearly shown in the insets. All the other five data plot on the isochron within their errors. This age probably represents the crystallization age of the clast, which is in excellent agreement with the ages of 4.09 Ga (±0.05) and 4.04 Ga (±0.06) for Groups 1 & 2 basalts (terminology of [3]) reported by Dasch et al. [1].

Discussion: The availability of samples to produce Rb-Sr isochrons for the Apollo 14 high-Al basalt suite is now practically nil. Therefore, we have mined the literature to obtain both whole-rock and Rb-Sr-isotopic data for these samples [9-14]. These data have been re-processed using $\lambda(^{87}Rb) = 0.01402$ Ga^{-1}. Unfortunately, not all of the samples have accompanying whole-rock data, but can be classified in terms of their Rb-Sr compositions (Table 1). It is evident that our new age support the idea that Group B basalts were erupted at ~4.06 Ga after those of Group A and before those of Group C (Table 1).

Table 1: Average A-14 High-Al Basalt Group Rb-Sr Data.

Sample	$^{87}Rb/^{86}Sr$	Age	2s	I(Sr)	2s	N	Refs.
Group A	0.0349	4.25	0.05	0.69910	5	3	[1,11]
Group B	0.0899	4.06	0.04	0.69938	10	7	[1,12-15]
Group C	0.0768	3.93	0.04	0.69943	5	2	[10]
14072-Type	0.0574	4.09	0.02	0.69928	11	2	[1,15]
Tridymite Ferrobasalt							
14321,1383	0.1535	4.02	0.04	0.69971	8	1	[1]

While in some cases the ages and I(Sr) compositions of different basalt groups are overlapping (e.g., Group B and 14072-Type), integration of trace element data demonstrate that while eruptions may have been contemporaneous, different source regions were tapped (Fig. 3). Consideration of the published isotope data has identified another sample that plots

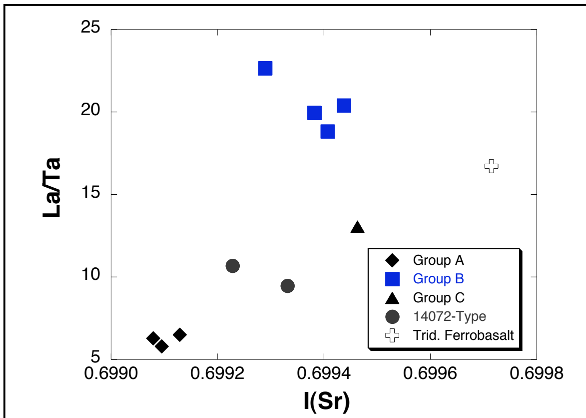

Figure 3: I(Sr) vs. La/Ta for the Apollo 14 high-Al basalts demonstrating derivation from distinct source regions at discrete times.

with 14072 (which was compositionally distinct from Groups A-C defined by [7]) adding weight to the suggestion of [7] that 14072 may be defining a fourth group of high-Al basalts returned by Apollo 14. Sample 14321,1394 (reported by [1]) has a similar age, I(Sr), and La/Ta ratio as 14072 (Fig. 3).

The Rb-Sr data demonstrate that the Apollo 14 basalt sources evolved with $^{87}Rb/^{86}Sr$ ratios varying between those of Bulk Moon (0.04) and approximately 0.1 (Fig. 4). Fig. 4 suggests some basalts may have been systematically derived from a common source (e.g., [1,3]), but the trace element data preclude this (Figs. 1 & 3). The variability of initial Sr isotope (and ITE) ratios for the Group B basalts is consistent with the open system petrogenesis proposed by [7]. While previous workers have suggested the Apollo 14 high-Al basalt Sr isotopes can be interpreted in terms of a source evolving with a defined $^{87}Rb/^{86}Sr$ ratio (between 0.05 & 0.06; e.g., [1]), inclusion of ITE ratios indicates that this is a fortuitous coincidence and that distinct source regions (up to 4) were tapped at discrete times between 3.9-4.3 Ga, making the Apollo 14 site extremely important as it not only returned the oldest volcanic samples from the Moon, but contains evidence of several source regions being active prior to the formation of the Imbrium basin.

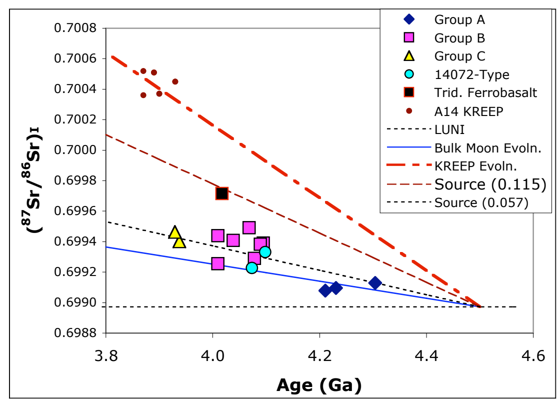

Figure 4: Age vs. I(Sr) for the Apollo 14 high-Al basalts (error parallelograms are not included in order to enhance clarity). Evolution lines represent single stage histories from source formation at 4.5 Ga, using $^{87}Rb/^{86}Sr$ values of 0.04 (Bulk Moon), 0.057, 0.115, and 0.17 (KREEP).

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