Rb-Sr AND Sm-Nd ISOTOPIC STUDIES OF LUNAR GREEN AND ORANGE GLASSES. C.-Y. Shih[1], L.E. Nyquist[2], and Y. Reese[3]. [1]Mail Code JE-23, ESCG/Jacobs Technology, P.O. Box 58477, Houston, TX 77258-8477, chi-yu.shih-1@nasa.gov; [2]Mail Code KR, NASA Johnson Space Center, Houston, TX 77058-3696, laurence.e.nyquist@nasa.gov; [3]ESCG/Muniz Engineering, Houston, TX 77058, young.reese-1@nasa.gov.

Introduction: Lunar volcanic glassy beads have been considered as quenched basaltic magmas derived directly from deep lunar mantle during fire-fountaining eruptions [1]. Since these sub-mm size glassy melt droplets were cooled in a hot gaseous medium during free flight [2], they have not been subject to mineral fractionations. Thus, they represent primary magmas and are the best samples for the investigation of the lunar mantle. Previously, we presented preliminary Rb-Sr and Sm-Nd isotopic results for green and orange glassy samples from green glass clod 15426,63 and orange soil 74220,44, respectively [3]. Using these isotopic data, initial $^{87}Sr/^{86}Sr$ and ε_{Nd} ratios for these pristine mare glass sources can be calculated from their respective crystallization ages previously determined by other age-dating techniques. These isotopic data were used to evaluate the mineralogy of the mantle sources. In this report, we analyzed additional glassy samples in order to further characterize isotopic signatures of their source regions. Also, we'll postulate a relationship between these two major mare basalt source mineralogies in the context of lunar magma ocean dynamics.

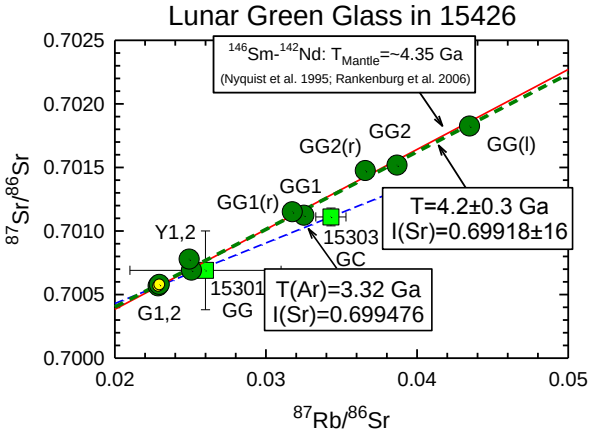

Figure 1. Rb-Sr isochron of green glass.

Samples and experiments: In the earlier study [3], we reported Rb-Sr and Sm-Nd isotopic results for green glassy beads (G1, G2, and G3) and yellowish vitrophyric beads (Y1 and Y2) handpicked from 15426 and orange beads from 74220. In this study, we analyzed five bulk green clod samples from 15426, GG1 (100-200 mesh), GG2 (<200 mesh) and their respective 2N HCl sonicated residues, (GG1(r) and GG2(r)), and a combined leachate sample, GG(l). Three bulk orange soil samples from 74220, OG, 2N HCl washed residue OG(r) and a leachate sample (OG(l)) were also analyzed. Significant portions (~25% - ~50%) of the bulk sample materials were dissolved in the washing process. We also analysed Sm isotopic compositions for both green and orange glassy samples in order to correct the thermal neutron effects on their $^{147}Sm/^{144}Nd$ and $^{143}Nd/^{144}Nd$ results. The effects are large for green glass samples but insignificant for the orange samples due to their respective large $\varepsilon^{149}Sm$ differences (-53.7ε vs -1.1ε).

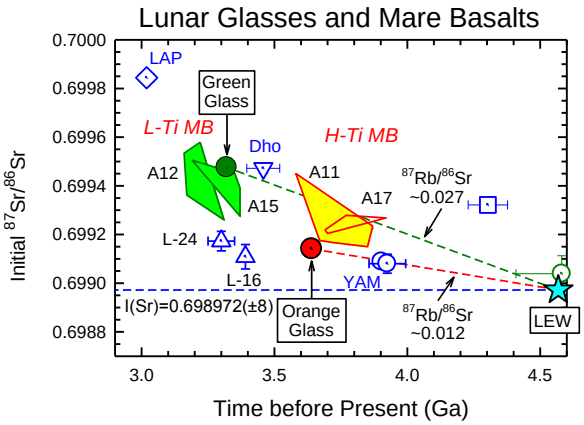

Figure 2. I(Sr) vs. T(age) of green and orange glasses.

Rb-Sr isotopic results: Rb-Sr results for bulk green glass samples are shown in Fig. 1. Also plotted are previously reported data of green glasses from two different breccias, 15301 and 15303 [4]. All nine samples are collinear yielding an imprecise old age of 4.2 ±0.3 Ga (green dotted line) for $\lambda(^{87}Rb)$ =0.01402 Ga^{-1}. and I(Sr)= 0.69918 ±0.00016. Delano [5] identified five chemically distinct groups of green glasses at the Apollo 15 site representing five different magmas derived from different source regions. Heterogeneities in green glass sources were also implied in [6]. Perhaps, the old ~4.2 Ga bulk green glass age represents the formation time of the various green glass sources by an early lunar differentiation as given by the ~4.35 Ga ^{146}Sm-^{142}Nd mantle isochron (red line, [7,8]). The T_{Ar-Ar}=3.32 Ga reference isochron (blue dotted line, [e.g. 9]) also includes green glass samples 15301 and 15303. $^{87}Rb/^{86}Sr$ and $^{87}Sr/^{86}Sr$ ratios of orange glass samples are not shown. However, The initial $^{87}Sr/^{86}Sr$ ratio for the orange glass is ~0.699146 at T_{Ar-Ar} =3.64 Ga [e.g. 10]. Using a single stage model, the mantle sources for green (G1) and orange glasses were calculated to have $^{87}Rb/^{86}Sr$ = ~0.027 and ~0.012, respectively (Fig 2). The extremely low initial $^{87}Sr/^{86}Sr$ ratio clearly suggests the orange glass came from a very fractionated, plagioclase-bearing source.

Sm-Nd isotopic results: Fig. 3 shows Sm-Nd results for green glass samples analyzed so far. Also plotted are green glass data from [11]. Again, five green glassy and vitrophyric samples yield an imprecise old age of 4.2±0.3 Ga for $\lambda(^{147}Sm)=0.00654\ Ga^{-1}$ (green dotted line), similar to that obtained from the Rb-Sr system and the ~4.35 Ga ^{146}Sm-^{142}Nd mantle isochron (red line, [7,8]). Except the leachate GG(l), the other four green glass data lie close to the reference T_{Ar-Ar}=3.32 Ga isochron (blue dotted line, [e.g. 9]). The orange glass data (not shown) lie above the T_{CHUR}=4.56 Ga isochron by as much as 4 ε-units. The initial ε_{Nd} ratio of orange glass is +7.3±0.3 for T_{Ar-Ar}=3.64 Ga [e.g. 10]. Based on a single stage model, the $^{147}Sm/^{144}Nd$ for the green glass source for G1 is nearly chondritic (~0.201) and that for the orange source is extremely fractionated (~0.258) (Fig. 4).

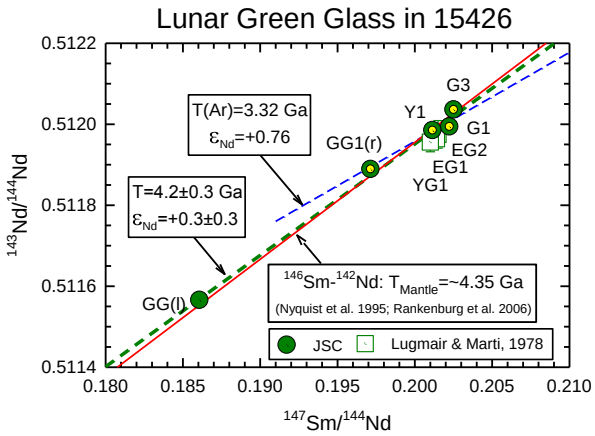

Figure 3. Sm-Nd isochron of green glass.

Isotopic constraints on source mineralogies: In Fig. 5, $^{87}Rb/^{86}Sr$ and $^{147}Sm/^{144}Nd$ ratios for sources of volcanic glasses and mare basalts are calculated for a single-stage model. The orange glass sources (OG, red circles) are low in Rb/Sr and high in Sm/Nd, whereas the green glass source (G1, green square) is high in Rb/Sr and low in Sm/Nd. High-Ti mare basalt and YAM (L-Ti basalts, [12,13]) sources tend to have higher Sm/Nd. The isotopic data clearly suggest that the source mineralogies for mare basalts are heterogeneous. The heterogeneous sources are probably due to mixing of late-stage Ti-bearing cumulates with the early cumulates (green glass source) at depth [14-17]. In order to evaluate this mixing process, we assume (1) the initial LMO has Rb abundance ~10x less than that proposed by [18], (2) Rb, Sr, Sm, and Nd abundance data for the late-stage clinopyroxene, plagioclase and ilmenite crystallized from LMO at 99.5 PCS of [19], (3) residual LMO liquid at 99.5 PCS for urKREEP, and (4) a green glass source of ~0.3xCI Nd and probably ~0.3xCI for Sr, as suggested by [14]. The dashed curves show the effects of addition of these late-stage minerals to the green glass source. The orange glass and high-Ti mare basalt sources (red curve) and YAM and Low-Ti (blue curve) of various Rb/Sr and Sm/Nd ratios are probably hybrid sources composed of the green glass source (early orthopyroxene+olivine cumulate) mixing with late-stage cumulate assemblages of various amounts of ilmenite, clinopyroxene, plagioclase and residual liquids, shown in solid curves, due to the LMO mantle cumulate overturn [15-17].

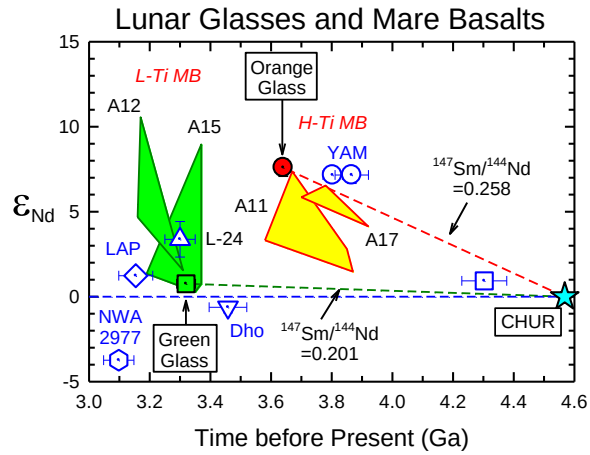

Figure 4. ε_{Nd} vs. T(age) of green and orange glasses.

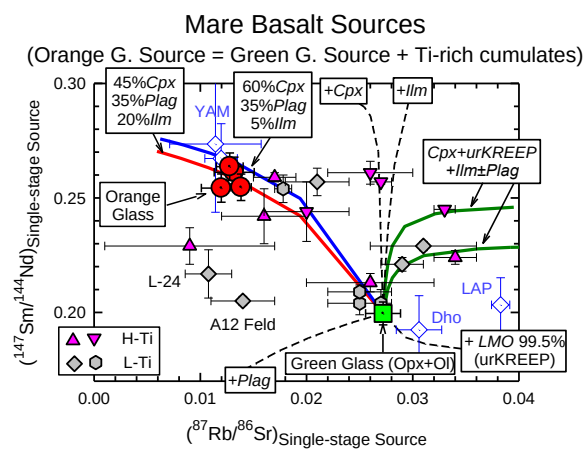

Figure 5. Calculated Rb/Sr and Sm/Nd for green and orange glasses, and mare basalt sources.

References : [1] Meyer C. Jr. et al. (1975) *PLSC 6*, 1673-1699. [2] Arndt J. et al. (1984) *PLSC 15, JGR*, 89,C225-C232. [3] Shih C.-Y. *et al*. (2001) *LPS **XXXII***, CD-ROM #1401. [4] Nyquist et al. (1973) *PLSC 2*, 1823-1846. [5] Delano J.W. (1979) *PLPSC 10*, 275-300. [6] Longh J. (2006) GCA 70, 5919-5934. [7] Nyquist L.E. et al. (1995) GCA 59, 2817- 2837. [8] Rankenburg K. et al (2006) Science 312, 1369-1372. [9] Spangler R.R. et al. (1984) *PLPSC 14;JGR 89*, B487-B497. [10] Husain L. and Schaeffer O.A. (1973) *Science 180*, 1358-1360. [11] Lugmair G.W. and Marti K. (1978) *EPSL 39*, 349-357. [12] Misawa K. et al. (1993) *GCA 57*, 4687-4702. [13] Nyquist L.E. *et al*. (2007) *LPS **XXXVIII***, CD-ROM #1702. [14] Hughes S.S. et al. (1988) *GCA 52*, 2379-2391. [15] Hess P.C. and Parmentier (1995) EPSL, 134, 501-514. [16] Elkins-Tanton L.T. et al. (2002) EPSL, 196, 239-249. [17] Elkins-Tanton L. T. et al. (2003) MPS 38, 515-527. [18] Snyder G.A. et al. (1992) *GCA 56*, 3809-3823. [19] Snyder G.A. and Taylor L.A. (1993) *NIPR 6*, 246-267.