^{238}U-^{206}Pb AGE AND URANIUM-LEAD ISOTOPE SYSTEMATICS OF MARE BASALT 10017.

A. M. Gaffney[1], L. E. Borg[1], and Y. Asmerom[2], [1]Institute of Meteoritics, University of New Mexico, Albuquerque, NM 87131, [2]Dept. of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131.

Introduction: Analysis and interpretation of lunar Pb isotopic compositions has been challenging, given the low Pb concentrations of lunar materials and the ease with which the Pb isotopic system can be disturbed. Because lunar ^{204}Pb concentrations are low, and thus difficult to measure, previous Pb investigations primarily relied on using combined ^{238}U-^{206}Pb and ^{235}U-^{207}Pb systematics to determine crystallization ages and initial Pb isotopic compositions of the samples, and to interpret magma source region history. With the current study, we have measured the Pb and U isotopic compositions of Apollo 11 sample 10017, and we interpret the Pb isotope systematics in the context of previously determined Rb-Sr ages. 10017 is an ilmenite-rich, high-Ti basalt, with a moderate KREEP component, and represents an enriched end-member of mare volcanism. For comparison, we also discuss 15085, which represents a more depleted mare end-member.

Analytical Techniques: An ~700 mg aliquot of 10017 was crushed in a sapphire mortar and pestle, and sieved to 325, 200 and 100 mesh sizes. We used the Frantz isodynamic magnetic separator and hand-picking to obtain mineral fractions from the 325-200 mesh size fraction. Visually-estimated purity levels of mineral fractions are: plagioclase, >99%; plagioclase-rej, >95%; pyroxene, >95%; pyroxene-rej, >75%.

Prior to dissolution, mineral and whole-rock fractions were leached in 0.5 M acetic acid and 1 N HCl, at 25˚C, for 10 minutes. The 1 N HCl leachates of the plagioclase, pyroxene and whole rock fractions were also analyzed for U and Pb isotopic composition. We spiked samples with a ^{236}U-^{233}U-^{205}Pb mixed spike, and passed them through standard anion exchange columns to separate U and Pb. Total procedural Pb blanks are 15-25 pg.

10017 U-Pb Isochrons: The most precise age we determined is a ^{238}U-^{206}Pb isochron on plagioclase (R), plagioclase-rej, pyroxene-rej, pyroxene (L) and whole rock (R) fractions (Fig. 1). Fractions excluded from this isochron either have low Pb concentrations or poor analytical results. These five fractions yield an age of 3.640 ± 0.094 Ga with initial $^{206}Pb/^{204}Pb$ of 32.3 ± 7.9. These same fractions give an initial $^{207}Pb/^{204}Pb$ of 33 ± 13 and a ^{235}U-^{207}Pb isochron age of 3.821 ± 0.130 Ga (Fig. 2), which, although older, is within uncertainty of the ^{238}U-^{206}Pb age. Both of these ages are concordant with the Rb-Sr age determined by Nyquist et al. [1], 3.669 ± 0.07 Ga (recalculated for λ_{87Rb}=0.01402), but only the ^{238}U-^{206}Pb age is in agreement with the Rb-Sr age of 3.56 ± 0.05 Ga from Papanastassiou et al. [2] (recalculated for λ_{87Rb}=0.01402). We take our ^{238}U-^{206}Pb age to represent the time of crystallization. The relatively large uncertainties in the initial Pb isotopic compositions reflect the presence of small amounts of ilmenite, resulting in elevated μ values ($^{238}U/^{204}Pb$), for the plagioclase fraction. A perfectly pure plagioclase fraction would much more precisely represent the initial Pb isotopic composition of the magma source because it should have a low μ value. The μ value of the 10017 source, determined from the initial $^{206}Pb/^{204}Pb$, is 85 ± 29 (using primordial Pb isotopic compositions from [9]). This is consistent with previous estimates of lunar μ values (60-300, [3]) which are significantly higher than estimates for either bulk silicate Earth or Mars.

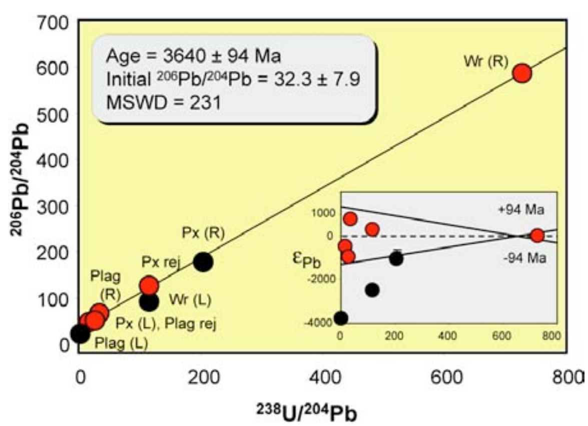

Figure 1. ^{238}U-^{206}Pb isochron from preliminary data for whole rock, mineral fraction and leachates of 10017. (R) denotes leaching residue, (L) denotes leachate, rej indicates rejects from handpicking of magnetic separates. Age was calculated using Isoplot/Ex rev. 2.49 [8]. Black symbols were excluded from age calculation.

U-Pb concordia: 10017 yields an imprecise discordia. The best discordia solution includes only the pyroxene (R), pyroxene-rej, whole rock (R) and whole rock (L) fractions. Radiogenic Pb is calculated by subtracting common Pb with μ = 85 at 3.640 Ga. The upper intercept of the discordia is 3.971 ± 0.420 Ga, and the lower intercept is 2.318 ± 1.700 Ga; thus combined ^{238}U-^{206}Pb and ^{235}U-^{207}Pb systematics do not yield precise age information for this sample.

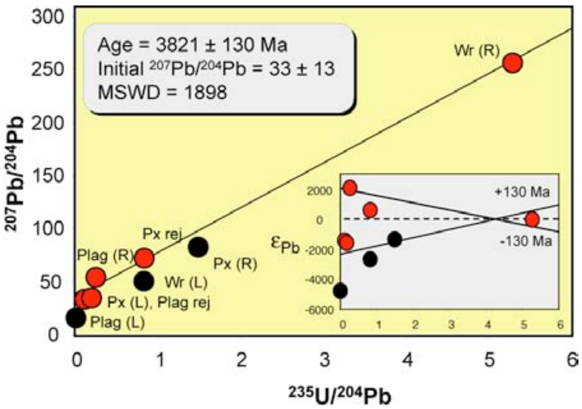

Figure 2. ^{235}U-^{207}Pb isochron from preliminary data for whole rock, mineral fraction and leachates of 10017. (R) denotes leaching residue, (L) denotes leachate, rej indicates rejects from handpicking of magnetic separates. Age was calculated using Isoplot/Ex rev. 2.49 [8]. Black symbols were excluded from age calculation.

Mare basalt source characteristics: To discuss our 10017 results in the context of mare basalts, we compare our data to Apollo 15 sample 15085, which represents a depleted compositional end-member of the mare basalts. 15085 also has U-Pb isotopic data that yields a ^{238}U-^{206}Pb age that is concordant with the Rb-Sr age [5]. This sample has lower concentrations of rare earth elements (REE) and other incompatible elements relative to 10017, which, given the relatively more evolved major element characteristics of 15085, indicates that the 15085 source is depleted in incompatible elements relative to 10017.

The ^{238}U-^{206}Pb isochron age for 15085, recalculated from Unruh and Tatsumoto [5], is 3.531 ± 0.180 Ga, which is in agreement with the Rb-Sr age of 3.37 ± 0.040 Ga (recalculated for $\lambda_{87Rb} = 0.01402$) [4]. The 15085 source μ (54 ± 3, recalculated from data in [5]) is high relative to bulk silicate Earth, but still lower than the 10017 source μ (85 ± 29). The higher μ value of the 10017 source and higher incompatible element concentrations of 10017 relative to 15085 are both consistent with a more enriched mantle source for 10017, compared to 15085.

The high Ti content, incompatible element enrichment and high-μ source of 10017 are consistent with this magma originating from ilmenite-rich, late-stage cumulates of the lunar magma ocean. These late-stage cumulates of a crystallizing magma ocean should be enriched in incompatible trace elements relative to earlier-forming cumulates. The high-U/Pb nature of ilmenite is reflected in the very high μ value (730) we observe for the ilmenite-rich whole rock fraction of 10017, as well as is observed for the oxide mineral fraction of 15085 [5] and the oxide mineral fraction of the martian meteorite Zagami [6]. Thus, although variable but high μ values of the Moon may reflect accretionary Pb loss, they could also partially reflect magmatic processes in the Moon.

The ^{235}U-^{207}Pb isochron age of 15085 is 3.808 ± 0.170 Ga, which, although in agreement with the ^{238}U-^{206}Pb age (3.531 ± 0.180 Ga), is older than the Rb-Sr age (3.37 ± 0.040 Ga). Likewise, the ^{235}U-^{207}Pb age of 10017 is older than the ^{238}U-^{206}Pb age, and the ^{235}U-^{207}Pb age is not in agreement with one of the Rb-Sr ages. Furthermore, 10017 yields a very imprecise discordia. Thus, there is consistent observation that the ^{235}U-^{207}Pb system has been disturbed in these lunar samples. The disturbance of this system is also apparent in many martian samples [6]. This disturbance might result from contamination of the basalt at the time of eruption by high ^{207}Pb/^{206}Pb lunar soil [7], post-eruption thermal metamorphism, or preferential loss of one Pb isotope relative to another through diffusion from lattice sites damaged by high-energy intermediate daughters in the U decay chain.

The ^{238}U-^{206}Pb system appears to give a precise age for 10017 that is concordant with Rb-Sr ages. This is achieved through precise measurement of ^{204}Pb. With current analytical capabilities (ion counting, stable gain stability enabling simultaneous Daly-Faraday measurements, very low (~20 pg) Pb blanks), it is now possible to make much more precise ^{204}Pb measurements, and thus obtain good ages using the ^{238}U-^{206}Pb system. With precise Pb isotopic measurements, it becomes possible to address lunar petrogenetic processes for which Pb isotopes are the best suited (e.g., U/Pb ratios of magma sources, effects of thermal metamorphism, contamination of magmas by lunar soils, and the presence of ilmenite in magma source regions).

References: [1] Nyquist, L., et al. (1987) *LPSC **XVIII***, 732-733. [2] Papanastassiou, D. A., et al. (1970) *EPSL*, **8**, 1-19. [3] Tera, F. and Wasserburg, G. J. (1974) *Proc. 5th Lunar Conf.*, 1571-1599. [4] Papanastassiou, D. A. and Wasserburg, G. J. (1973) *EPSL*, **17**, 324-337. [5] Unruh, D. M. and Tatsumoto, M. (1977) *Proc. Lunar Sci. Conf.*, **8**, 1673-1696. [6] Borg, L. E., et al. (2005) *LPSC **XXXVI.*** [7] Tera, F. and Wasserburg, G. J. (1972) *EPSL*, **13**, 457-466. [8] Ludwig, K. L. (2001) *Berkeley Geochron. Ctr.* **Spec. Pub. 1a.** [9] Tatsumoto, M., et al. (1973) *Science*, **180**, 1279-1283.