

**AGE OF LUNAR METEORITE LAP02205 AND IMPLICATIONS FOR IMPACT-SAMPLING OF PLANETARY SURFACES.** L. E. Nyquist<sup>1</sup>, C.-Y. Shih<sup>2</sup>, Y. Reese<sup>3</sup>, and D. D. Bogard<sup>1</sup>, <sup>1</sup>Mail Code KR, NASA Johnson Space Center, Houston, TX 77058, laurence.e.nyquist1@nasa.gov, <sup>2</sup>Mail Code C23, Lockheed-Martin Space Operations, Houston, TX 77058, <sup>3</sup>Hernandez Engineering Inc., Houston, TX 77058.

**Introduction:** We have measured the age of lunar meteorite LAP02205 by the Rb-Sr and Ar-Ar methods. Sm-Nd analyses are in progress. The Rb-Sr and Ar-Ar ages indicate a crystallization age of ~3 Ga. Comparing the ages of LAP02205 and other lunar mare basaltic meteorites to mare surface ages based on the density of impact craters shows no significant bias in impact-sampling of lunar mare surfaces. Comparing the isotopic and geochemical data for LAP02205 to those for other lunar mare basalts suggests that it is a younger variant of the type of volcanism that produced the Apollo 12 basalts.

Representative impact-sampling of the lunar surface contrasts to apparently unrepresentative impact-sampling of the Martian surface by Martian meteorites. We consider possibilities to explain this paradox.

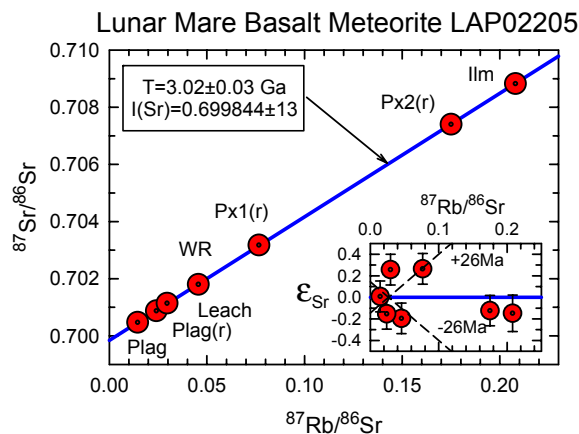


Figure 1. Rb-Sr isochron for LAP02205. Pyroxene separates were leached in 2 N HCl and the residues analysed (Px1(r), Px2(r)). The leachates were combined (Leach). Plag(r) was leached in 1 N HCl. Plag, Ilm, and WR (bulk) were not leached.

**Rb-Sr Age and Initial  $^{87}\text{Sr}/^{86}\text{Sr}$ :** The Rb-Sr data are shown in Fig. 1. Mineral separates obtained by density separations were hand-picked for purity prior to analysis. For pyroxene the densities were chosen to correspond to Ca-rich- (augite) and Fe-rich- (pigeonite) pyroxenes, respectively. Data for all the samples define an internal isochron age of  $3.02\pm 0.03$  Ga ( $2\sigma$ ). Because (a) this age relies heavily on Ilm and Px2(r), (b) Sm-Nd analyses now in progress indicate the possibility of an older age, and (c) the Ar-Ar age spectrum (below) shows some disturbance, the final error on the crystallization age of LAP02205 may be larger than given by the Rb-Sr isochron.

The initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ( $I(\text{Sr})$ ) is  $0.699844\pm 13$  and is insensitive to the age uncertainty. Fig. 2 shows the ( $T$ ,  $I(\text{Sr})$ ) parameters for LAP02205 compared to ilmenite basalt 12056 and averages for Apollo 12 olivine-, pigeonite-, ilmenite-, and feldspathic basalts [1]. It has been suggested that LAP02205 resembles Apollo 12 ilmenite basalts [2,3], but this suggestion is not supported by the Sr isotopic data. Rather, ( $T$ ,  $I(\text{Sr})$ ) parameters for LAP02205 most closely resemble those for Apollo 12 olivine basalts. The Sr-isotopic data suggest that LAP02205 represents younger volcanism from a lunar mantle source region resembling that of the A12 olivine basalts, but having a slightly higher time-averaged  $^{87}\text{Rb}/^{86}\text{Sr}$   $\sim 0.038$  compared to  $^{87}\text{Rb}/^{86}\text{Sr}$   $\sim 0.031$  in the A12 basalt source region.

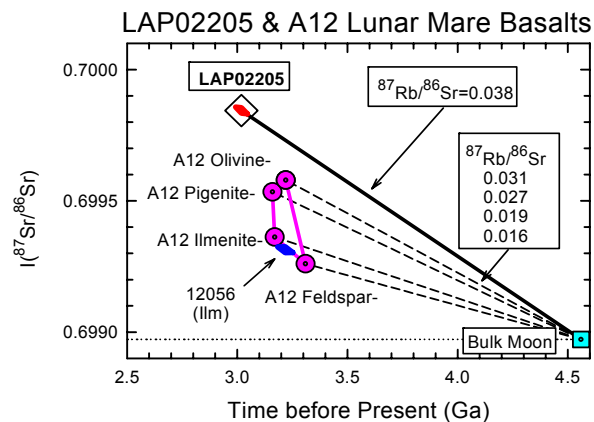


Figure 2. Initial  $^{87}\text{Sr}/^{86}\text{Sr}$  ( $I(\text{Sr})$ ) vs. age for LAP02205 and ilmenite basalt 12056 (error ellipses) compared to those for Apollo 12 basalts. Also shown are  $^{87}\text{Rb}/^{86}\text{Sr}$  values for evolution of  $^{87}\text{Sr}/^{86}\text{Sr}$  in mantle sources.

**Ar-Ar Age:** Fig. 3 gives the  $^{39}\text{Ar}$ - $^{40}\text{Ar}$  age spectrum for LAP02205. The alkali-rich mesostasis released ~45% of the  $^{39}\text{Ar}$  ( $\text{K}/\text{Ca}$   $\sim 0.2$ - $0.3$ ) around  $500^\circ\text{C}$ . For the mesostasis, Jolliff et al. [4] reported  $[\text{K}] = 3.5\%$  and  $\text{K}/\text{Ca} = 0.26$ , whereas Mikouchi et al. [2] reported  $[\text{K}] = 5.8\%$ . Twelve extractions of this mesostasis phase define a flat Ar-Ar age plateau with an average value of  $2.955 \pm 0.010$  Ga ( $1\sigma$ ). Six extractions above  $1000^\circ\text{C}$  released the last ~15% of the  $^{39}\text{Ar}$ , probably from plagioclase, and suggest a similar age plateau of  $2.936 \pm 0.017$  Ga. Plagioclase comprises ~30% of LAP02205 and contains 12.3% Ca and ~0.07% K, with  $\text{K}/\text{Ca} \sim 0.005$  [4], similar to  $\text{K}/\text{Ca}$  ratios of 0.001-0.006 we observed in the high temperature release.

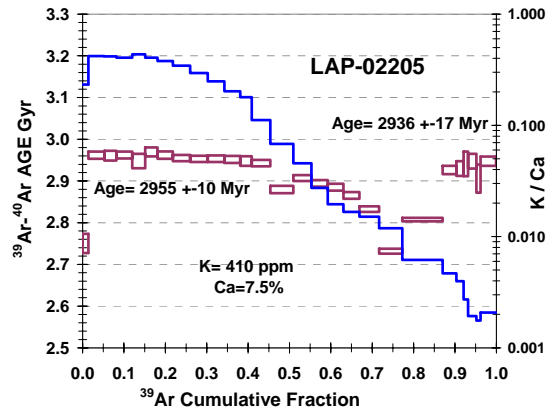


Figure 3. Ar-Ar age spectrum for LAP02205. Variation in the K/Ca ratio by  $\sim 200\times$  indicates the existence of K in two or more phases. [K] and [Ca] were 410 ppm and 7.5%, respectively, in this 29.5 mg sample.

Younger Ar-Ar ages are observed over  $\sim 45\text{--}86\%$  of the  $^{39}\text{Ar}$  release for K/Ca ratios intermediate between those of mesostasis and plagioclase. Possibly this argon was released from the  $\sim 20\text{-}\mu\text{m}$ -sized blebs of alkali-rich glass in fayalite [2]. Then the higher temperature release of argon compared to that from mesostasis might be the result of slower Ar diffusion in fayalite, and the younger ages might be the result of  $^{40}\text{Ar}$  loss during terrestrial weathering. An alternative explanation is that the younger Ar ages result from gain of recoiled  $^{39}\text{Ar}$  produced in the reactor. The Ar-Ar age for LAP02205 is probably  $2.95 \pm 0.02$  Ga ( $1\sigma$ ). Taking [Ca]=7.5% measured in our sample, and adopting a lunar surface  $^{36}\text{Ar}$  production rate of  $0.93 \times 10^{-8}$  cm<sup>3</sup> STP/g-Ca/Ma, we estimate an integrated cosmic ray exposure age for LAP02205 of  $\sim 4$  Ma.

**Comparison to Apollo 12 Basalts:** Although the Ar-Ar age and the Rb-Sr internal isochron age agree closely, a preliminary Sm-Nd internal isochron suggests a somewhat older age of  $3.15 \pm 0.02$  Ga. An age of  $\sim 3.15$  Ga for LAP02205 would place its (T, I(Sr)) parameters into close agreement with those of the Apollo 12 olivine basalts; i.e., I(Sr) $\sim 0.6997$ . However, REE abundances in LAP02205 are about twice as high as in the Apollo 12 basalts, and LREE are more enriched relative to HREE resembling a KREEP pattern, features shared by lunar meteorite NWA 032 [5]. Jolliff et al. [4] concluded that LAP02205 closely resembled NWA 032 and possibly was launch-paired with it. Subsamples of NWA032 exhibited complex Ar-Ar age spectra, but total Ar ages averaging  $2.779 \pm 0.014$  Ga [6] are similar to the Ar-Ar age of LAP02205. The age and geochemical data for LAP02205 and NWA 032 suggest a source terrain near the Apollo 12 site, possibly in the maria Insu-

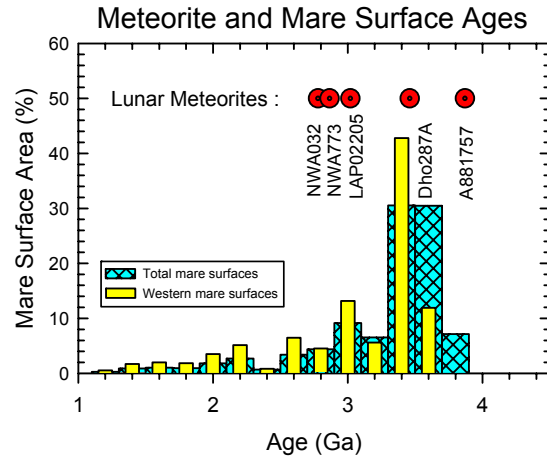


Figure 4. Lunar basaltic meteorite ages ([6,10,11,12], this investigation) compared to lunar mare surface ages [7,8]. Ages range  $\sim 2.8\text{--}3.8$  Ga, approximately the same as for Apollo and Luna samples, except aluminous mare basalt clasts in the Apollo 14 breccias [9].

larum, Cognitum, or Nubium, further west in south-central Oceanus Procellarum, or in west-central Mare Imbrium (*cf.* Fig. 10 of [8]).

**Comparison to Lunar Mare Surface Ages.** Hiesinger et al. [7,8] reported ages of mare surfaces as determined by crater densities and also the surface area represented by each basalt unit. Fig. 4 is derived from their data and shows total areas of mare units of a given age as a percentage of the total and western mare surfaces. The meteorite ages reliably reflect the mare surface ages, with the exception of the youngest surface units making up only a small percentage of the mare surface area. Cratering of the lunar surface over the last  $\sim 4$  Ga has not resulted in a meteorite age distribution skewed towards young ages because of brecciation and weakening of target rocks. One might expect the same for Martian meteorites. The young ages of most Martian meteorites ( $\leq 1.3$  Ga) imply either (a) much of the Martian surface is younger than thought, or (b) chemical weathering of Martian “volcanic” surfaces has weakened the older surface rocks so that they do not withstand the rigors of impact excavation followed by deceleration in the Martian atmosphere.

**References:** [1] Nyquist L. E. et al. (1979) *PLSC10*, 77-114. [2] Mikouchi T. et al. (2004) *LPS XXXV*, #1548. [3] Righter K. et al. (2004) *LPS XXXV*, #1667. [4] Jolliff B. et al. (2004) *LPS XXXV*, #1438. [5] Anand M. et al. (2004) *LPS XXXV*, #1438. [6] Fernandez V. A. et al. (2003) *Met. Planet. Sci.* 38, 555-564. [7] Hiesinger H. et al. (2000) *JGR*, 105, 29,239-29,275. [8] Hiesinger H. et al. (2003) *JGR 108 (E7)* 5065, 1-1 to 1-27. [9] Nyquist L. E. et al. (2001) *The Century of Space Science*, Kluwer, pp. 1325-1376. [10] Misawa K. et al. (1988) *GCA* 57, 4687-4702. [11] Shih C.-Y. et al. (2002) *LPS XXXIII*, #1344. [12] Borg L.E. et al. (2004) *Nature* 432, 209-211.