# $^{40}$AR-$^{39}$AR AGES FROM LASER STEP-HEAT EXPERIMENTS ON LUNAR METEORITE IMPACT MELT CLASTS.

B. A. Cohen, T. D. Swindle, and D. A. Kring, Department of Planetary Sciences, 1629 E. University Blvd., The University of Arizona, Tucson AZ 85721 (bcohen@lpl.arizona.edu).

**Introduction:** There are currently two competing hypotheses for the early bombardment history of the Moon: a smooth power-law distribution of impactor sizes and frequencies tailing off at about 3.0 Ga, and a "terminal lunar cataclysm" where a spike of impactors hit the Earth-Moon system at about 3.9 Ga [1, 2, 3, 4]. The former view has shaped our view of solar system evolution; but if true, the terminal lunar cataclysm would dramatically change our view of the early histories of the Moon, Earth, and inner solar system.

Apollo and Luna samples have been examined by multiple isotopic methods [1, 5, 6, 7] and no impact melts from these samples have ages older than about 3.85Ga. However, these samples were probably affected by the basin-forming impacts. Lunar meteorites might represent a more random sampling of the lunar surface and dating of lunar meteoritic impact melts may be a good test of the lunar cataclysm hypothesis [8].

This work provides $^{40}$Ar-$^{39}$Ar age data for lunar impact melt samples primarily from two unpaired lunar highland breccia meteorites, DaG262 [9] and DaG400 [10]. Thus far, we have examined ten samples of DaG262 impact melt, six samples from DaG400, and one each from MAC88105 and QUE93069, Antarctic highland breccia meteorites. The sections were examined with an electron microprobe [11] to try to find impact melts clasts that are different from those in the Apollo collection. In fact, the major-element chemistry of our samples is quite distinct from that of Apollo impact melts (Fig. 1). The impact ages recorded in these meteorites are therefore potentially unaffected by the impacts that formed the nearside basins.

**Preparation:** 100-µm thick sections were made from each meteorite. A microcoring device (diamond-bit drill attached to a rotating microscope stage) was used to extract individual impact melt clasts from the thick section. The weights of the resulting samples are listed in Table 1.

Samples were irradiated at the University of Michigan for 500 hours, producing a J-factor of $7.33\times10^{-2}$. $K_2SO_4$ and $CaF_2$ salts were irradiated simultaneously to correct for reactor-induced interferences, and MMhb-1 hornblende was used to derive the neutron fluence.

Laser step-heat experiments were carried out in the University of Arizona noble gas lab, which includes a continuous Ar-ion laser heating system, an extraction line with an SAES getter (run cold for most of these experiments), and a VG5400 mass spectrometer. Heating steps were determined solely by varying the laser amperage, beginning at 10A and increasing in steps no smaller than 0.5A each. The heating schedule was modified for each sample. While we can see that most samples begin to glow at 10A and melt at about 15A, the absolute temperature for each step is unknown. However, this information is not critical to our interpretations.

In addition to blank and interference corrections, argon produced by cosmic ray spallation was subtracted from each sample by deconvolving the relative contributions of $^{36}$Ar from spallation ($^{38}$Ar/$^{36}$Ar=1.5) and from atmospheric and/or lunar argon ($^{38}$Ar/$^{36}$Ar=0.19). This correction was minor in all samples. The contribution at mass 36 from HCl has not yet been determined, but is expected to be minor as well.

**Results:** Data, corrected for interfering reactions, system blanks, and spallation, is summarized in Table 1. Due to the small size and low K content (150 to 900 ppm), very few heating steps could be performed on each sample. In about half the cases, this means that plateaus are not immediately apparent. The argon release profiles for samples exhibiting good plateaus are shown in Figure 2.

Several of the samples exhibit anomalously high ages in the first steps and $^{40}$Ar/$^{36}$Ar ratios similar to air. We examined the fused samples after the experiments, and found that traces of epoxy (used to make the thick sections) had remained on some samples. We attribute the anomalous first steps to outgassing of air from this residual epoxy. However, subtracting air in these first steps (usually ~25% of $^{39}$Ar released) did not bring them in line with the other steps within any sample.

Subtracting out an air component from the entire sample was an overcorrection in all but two cases. Clasts 262H and 262R had all steps come to the same age when corrected for air. The small amount of Ar left over after this correction raises the error in these ages significantly, but these two samples are not the same age as each other. This suggests that they were formed by two different impact events.

400BB and 400DD exhibited plateaus over multiple steps. The ages of these two clasts agree with each other within error and probably represent a single impact event. On the other hand, three other clasts from DaG400 (400-01, 400Q, and 400T) also show good plateaus, but different ages. Within DaG400, we may be seeing up to five impact events recorded.

The clast from MAC88105 appears to be older than any from DaG262 or DaG400. The clast from QUE93069 has a qualitatively similar release profile to the sample from MAC88105 but with an apparent age >7Ga.

**Conclusions:** There are multiple impact events being recorded in these meteorites, possibly as many as eight, even though the chemistry of the impact melt clasts is similar. This implies that the source terrain is remarkably homogeneous, and extremely feldspathic. The impact ages are young; all are ≤3.9 Ga within error. So far, this evidence is consistent with a lunar cataclysm hypothesis, though it is not definitive.

We have about 20 more irradiated samples of impact melt from DaG400, as well as a dozen each from MAC88105 and QUE93069. We plan to continue our step heat experiments with these samples.

**Acknowledgements:** We thank A. Bischoff and J. Zipfel for providing us with DaG262 and DaG400, respectively.

**References:** [1] Tera, F. et al. (1974) *EPSL 22*, 1-21. [2] Baldwin, R.B. (1974) *Icarus 23*, 157-166. [3] Hartmann, W.K. (1975) Icarus 24, 181-187. [4] Ryder, G. (1990) *Eos 71*, 313. [5] Dalrymple, G.B. and Ryder, G. (1991) *GRL 18*, 1163-1166. [6] Dalrymple, G.B. and Ryder, G. (1993) *JGR 98*, 13,085-13,095. [7] Deutsch, A. and Stoffler, D. (1987) *GCA 51*, 1951-1964. [8] Taylor, G.J. (1991) *GCA 55*, 3031-3036. [9] Bischoff, A. et al. (1998) *MAPS 33*, 1243-1257. [10] Zipfel, J. et al. (1998) *MAPS 33*, A171. [11] Cohen, B.A. et al. (1999) *MAPS 34*, A26-27. [12] Heiken, G.H. et al. (1991) *The Lunar Sourcebook*, Cambridge University Press.

**Table 1: Samples and best fit ages**

| Sample | Weight (µg) | %$^{39}$Ar in plateau | Plateau age (Ga)[1] |
|---|---|---|---|
| 262 A | 9 | — | — |
| 262 D | 24 | — | — |
| 262 G | 16 | — | — |
| 262 F | 23 | — | — |
| 262 H | 3 | 100[2] | 4.04 ± 0.73 |
| 262 I | 15 | 70[3] | 3.23 ± 0.17 |
| 262 O | 19 | — | — |
| 262 P | 5 | — | — |
| 262 Q2 | 25 | 51 | 3.48 ± 0.34 |
| 262 R | 27 | 100[2] | 2.37 ± 0.21 |
| 400-01 | 80 | 64 | 3.40 ± 0.07 |
| 400 BB | 50 | 82 | 2.90 ± 0.08 |
| 400 DD | 48 | 69 | 2.74 ± 0.13 |
| 400 Q | 61 | 65 | 3.54 ± 0.03 |
| 400 T | 31 | 64 | 3.27 ± 0.21 |
| 400 V | 3 | — | — |
| MAC-01 | 100 | 47 | 3.87 ± 0.09 |
| QUE-01 | 63 | — | — |

[1] Data is not corrected for air or Cl, except as noted

[2] Corrected for air

[3] "Plateau" consists of one step only

**Figure 1:** Composition of samples compared with Apollo impact melt clasts

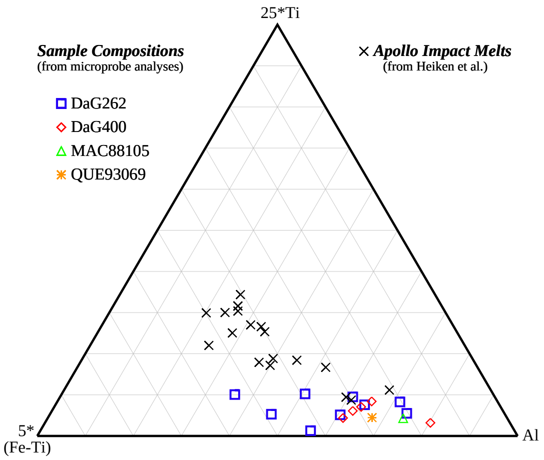

**Figure 2:** Argon release profiles of samples with good plateau ages