Ar-Ar Impact Heating Ages of Eucrites and Timing of the LHB. **Donald Bogard and Daniel Garrison[1]**, ARES, NASA Johnson Space Center, Houston TX 77058 ([1]also ESCD-Barrios, JE23, 2224 Bay Area Blvd. Houston, TX 77058; *donald.d.bogard@nasa.gov*)

Eucrites and howardites, more than most meteorite types, show extensive impact resetting of their ^{39}Ar-^{40}Ar (K-Ar) ages ~3.4-4.1 Ga ago, and many specimens show some disturbance of other radiometric chronometers as well (1,2). (1) argued that this age resetting occurred on Vesta and was produced by the same general population of objects that produced many of the lunar impact basins. The exact nature of the lunar late heavy bombardment (LHB or "cataclysm") remains controversial (3, 4), but the timing is similar to reset ages of eucrites. Neither the beginning nor ending time of the lunar LHB is well constrained. Comparison of Ar-Ar ages of brecciated eucrites with data for the lunar LHB can help resolve both the origin of these impactors and the time period over which they were delivered to the inner solar system (5).

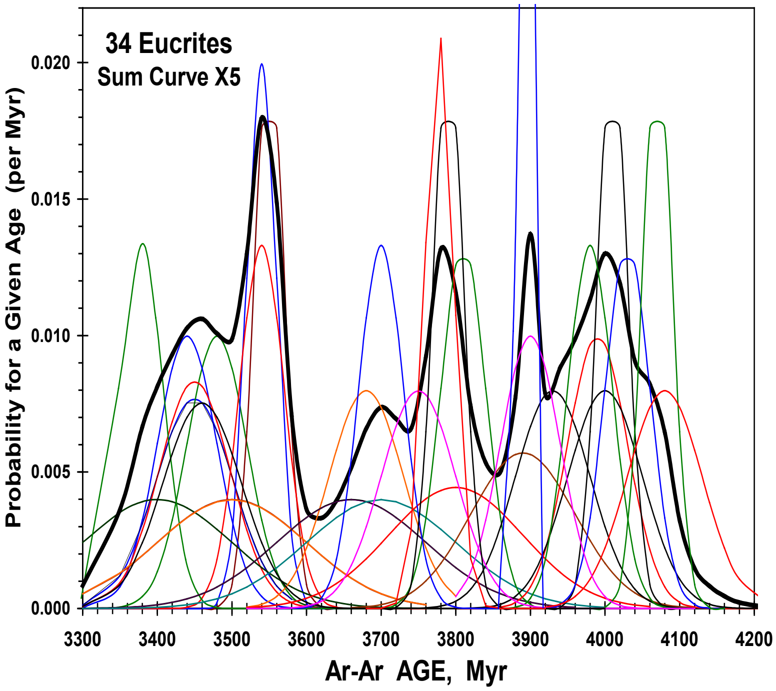
In this abstract we report some new Ar-Ar age data for eucrites, obtained since our 1995 and 2003 papers. An Ar-Ar impact heating age was obtained by averaging that portion of each age spectrum that exhibited approximately constant (plateau) ages. These impact ages are given in Table 1, along with that portion of the age spectrum used to obtain the age. Most of these eucrites show low temperature loss of ^{40}Ar, possibly due to terrestrial weathering. Some eucrites show an increase in age beyond the plateau portion of the age spectrum, which we interpret as incomplete ^{40}Ar degassing from more retentive lattice sites during impact heating.

Ar-Ar data for Y-82202 WR illustrate how multiple Ar loss episodes can be inferred. The age (rectangles, Fig. 1) increases, while the K/Ca ratio (stepped line) decreases. These and differential release of ^{39}Ar (from K) and ^{37}Ar (from Ca) indicate that Ar degassed at different temperatures from different mineral phases. The ^{36}Ar/^{37}Ar ratios indicate that only the first extraction released significant atmospheric Ar. Significant differences in Ar diffusion between low- and high-temperature phases is verified by Arrhenius diffusion plots (Fig. 2) of ^{39}Ar (circles) and ^{37}Ar (triangles). We interpret the thermal history of Y-82202 as follows. A mild heating event (possibly associated with space exposure) more recently than 1.4 Ga ago produced significant Ar loss in the low-T phase, but little Ar loss in the high-T phase.. A strong heating event 3.95 Ga ago significantly degassed Ar from the high-T phase, whose K-Ar age at that time exceeded 4.3 Ga. The time of this heating event is determined by a weighted isochron of extractions releasing 59-92% of ^{39}Ar.

Ar-Ar impact heating ages determined for 34 eucrites (most at JSC) are shown in Fig. 3 as a Gaussian probability curve for each meteorite (thin, colored lines) and the summed probability of all samples (heavy, black line, times 5). The uncertainty in the age determines the width and height of an individual curve. Significant overlap in individual curves occurs for heating times of ~3.45 Ga (6 samples), ~3.55 Ga (4 samples), ~3.78 Ga (5 samples), ~3.90 Ga (4 samples), and 3.98-4.07 Ga (7 samples). Each of these age clusters may represent a large impact event on the parent asteroid, Vesta. No Ar-Ar analysis of a eucrite made at JSC has given a plateau age in the range ~4.1-4.47 Ga, nor younger than ~3.3 Ga. Many lunar highland rocks give impact reset ages in the range 3.8-4.1 Ga: few give ages older than 4.1 Ga; and a small number give ages of ~3.7-3.8 Ga. However, one-third of these eucrite ages are younger than 3.7 Ga. Many lunar highland ages are dominated by the large Imbrium and Serenitatis basins, thought to have formed 3.85-3.89 Ga ago, but only a few eucrite ages (~4) fall in this range. The significant number of reset eucrite ages over 3.4-3.7 Ga may imply that intermediate size impacts persisted on Vesta after much larger lunar impacts had ceased. Evidence in lunar mare ages and crater densities suggest that sub-basin size lunar impacts may also have persisted until ~3.5 Ga ago. As we suggested previously (1, 6), we interpret these Ar-Ar ages of eucrites to represent impact resetting by the same population of objects that reset ages of lunar highland rocks during the LHB. Recent models for the origin of these impactors are consistent with these objects affecting the whole inner solar system (5). However, the relatively long time of this early bombardment, several times 10^8 years, as revealed in eucrites and in lunar rocks, may present a problem for recent models proposed for the origin of bombarding objects (7).

For several cumulate eucrites, (8) reported whole rock Sm-Nd and Lu-Hf isochron ages of 4.464 ±0.075 and 4.447 ±0.022 Ga, respectively, and suggested that cumulate eucrites formed ~100 Ma after basaltic eucrites. The Sm-Nd ages were mainly determined by the four cumulates, Serra de Magé, Moore County, Talampaya, and especially Nagaria. These ages, however, are similar to Ar-Ar impact reset ages of ~4.48 Ga for several *unbrecciated* basaltic and cumulate eucrites, including Serra de Magé and Moore County (6). BTN 00300 is a new member of this group.(Table 1). Nagaria also experienced strong Ar-Ar age impact resetting ~3.46 Ga ago. Although impact resetting of Sm-Nd and Lu-Hf ages are expected to be more difficult than K-Ar ages, artificial heating of a lunar basalt showed that the Sm-Nd isochron age can be rotated toward younger ages (9). Thus, we suggest that the conclusion of a younger Sm-Nd and Lu-Hf formation age of cumulate eucrites, based on meteorites whose Ar-Ar ages indicate significant shock heating, should be viewed with caution.

Fig.1, upper right; Fig. 2, lower right; Fig. 3, below.



References. (1) Bogard, *Meteoritics* 30, 244, 1995; (2) Kunz et al., *Planet. Space Sci*. 43, 527, 1995; (3) Hartmann et al., In *Origin of Earth and Moon*, 493, 2000; (4) Ryder, *J. Geophys. Res*. 107, 1, 2002; (5) Gomes et al., *Nature* 435, 466, 2005; (6) Bogard & Garrison, *MaPS* 38, 669, 2003; (7) Bottke et al., 10.1016/j.*Icarus*.2007.02.010; (8) Blichert-Toft et al., *Earth Planet Sci. Lett*. 204, 167, 2002; (9) Nyquist et al., *Proc 22 LPSC*, 985, 1991.

Eucrite	Age, Ga	^{39}Ar Range
EET92023	3.760 ±0.029	37-99%
PCA 82501	3.778 ±0.016	12-59%
Y-82202 WR	3.950 ±0.026	59-92%
Y-82202 Melt	3.925 ±0.006	74-100%
PCA 82501	3.778 ±0.016	12-59%
Padvarninka	3.893 ±0.007	75-99%
MET 01081	3.715 ±0.054	61-100%
Nagaria	3.468 ±0.053	64-99%
BTN 00300	4.479 ±0.013	57-95%