$^{39}\text{Ar}-^{40}\text{Ar}$ AGES OF ACAPULCOITES AND LODRANITES: EVIDENCE FOR EARLY PARENT BODY HEATING; D.D. Bogard, D.H. Garrison (NASA Johnson Space Center, Houston, TX 77058), T.J. McCoy, and K. Keil (Planetary Geosciences, Dept. of Geology and Geophysics, SOEST, University of Hawaii at Manoa, Honolulu, HI 96822).

Abstract. New age dating of acapulcoites (Acapulco, Monument Draw) and lodranites (Gibson) allow us to reconstruct the history of their parent body in a chronological framework. These meteorites originated on a common parent body ~4.55 Ga ago. Non-collisional heating caused partial melting, with lodranites having been heated slightly higher than acapulcoites. This parent body cooled to the Ar closure temperature at ~4.51 Ga for acapulcoites and ~4.48 Ga for lodranites. The difference in ages is consistent with the higher temperature and longer cooling time for lodranites. Cooling probably occurred at a few to tens of °C/Ma, with slower cooling rates at lower temperatures.

Previous Work. Acapulcoites and lodranites are samples of a single parent body [1] which experienced low degrees of partial melting [2,3]. These rocks have roughly chondritic compositions but achondritic textures. Acapulcoites were heated to just above the Fe,Ni-FeS eutectic (~980°C) [2], whereas lodranites were heated slightly more (~1000-1050°C) and experienced silicate partial melting [3]. These temperatures are broadly consistent with oxygen isotopic [1] and two-pyroxene [2] geothermometry. A diverse range of cooling rates has been reported, depending on the method used. For Acapulco alone, cooling rates of ~100°C/Ma from 900-1000°C, 20,000-700,000°C/Ma from 500-750°C [4], and ~1.7°C/Ma at ~300-100°C [5] have been estimated. These cooling rates imply very different times, from ~1 Ma to ~400 Ma, to cool to low temperatures, and possibly a complex thermal history.

Isotope chronology can provide a powerful tool to help unravel the formation and thermal history of these meteorites. Unfortunately, previous efforts have yielded uncertain results. A 4.60 ± 0.03 Ga Sm-Nd isochron age for Acapulco is significantly older than the widely accepted 4.55 Ga age of the solar system, suggesting that Acapulco may be the oldest precisely dated object [6]. U-Pb studies of Acapulco only suggested an early re-equilibration [7]. $^{39}\text{Ar}-^{40}\text{Ar}$ profiles for the acapulcoites Y-74063 and ALH 78230 [8] suggest "plateau" ages of 4.556 ± 0.053 and 4.531 ± 0.021, respectively, but individual temperature extractions have much wider age ranges and the ages are derived from a limited number of temperature extractions. No age dating of lodranites has been reported.

Results. Figures 1 a-c give our $^{39}\text{Ar}-^{40}\text{Ar}$ ages and K/Ca ratios as a function of cumulative release of $^{39}\text{Ar}$ for stepwise temperature extractions of Acapulco, Monument Draw, and Gibson. Six extractions of Acapulco, releasing 22-97% of the $^{39}\text{Ar}$, define a "plateau" age of 4.50 ± 0.01 Ga (error is one σ of deviations from the mean). Thirteen extractions of Monument Draw, releasing 0.2-99% of the $^{39}\text{Ar}$, define an age of 4.52 ± 0.02 Ga; nine extractions releasing 85% of the $^{39}\text{Ar}$ define an age of 4.514 ± 0.011 Ga. Seven extractions of Gibson, releasing 8-99% of the $^{39}\text{Ar}$, define a "plateau" age of 4.48 ± 0.02 Ga. In addition, all extractions of Monument Draw define a highly linear ($r^2 = 0.99995$) isochron of $^{40}\text{Ar}/^{36}\text{Ar}$ vs. $^{39}\text{Ar}/^{36}\text{Ar}$, which passes through 0 and whose slope corresponds to an age of 4.523 ± 0.005 Ga, identical to the "plateau" age. (Errors quoted for these ages include all analytical uncertainties but do not include an additional -1% uncertainty in the age of the hornblende monitor.) Ages of Monument Draw and Gibson (irradiated together) differ at the limits of their analytical uncertainties, suggesting that Gibson is 20-40 Ma younger.

The K/Ca ratios and rate of Ar release indicate that the presence in each meteorite of two K-bearing phases, high K/Ca plagioclase and low K/Ca pyroxene. Using temperature release data for Ar from each phase we calculated the diffusivity parameter D/a$^2$. Assuming a cooling rate of 10°C/Ma and using diffusivity data from an Arrhenius plot for Monument Draw, we calculate closure temperatures [9] of ~275°C for plagioclase and ~470°C for pyroxene. Given the much higher heating temperatures, complete Ar degassing from these meteorites would be expected, even at moderately fast cooling rates. Because the two phases have different closure temperatures but no observable age difference (i.e., <30 Ma, Fig. 1), the parent body must have cooled from ~470°C to 275°C at ~7°C/Ma. To cool from the peak temperature of ~980°C of Monument Draw to the 275°C closure temperature in ~30 Ma (i.e., 4.55 Ga minus 4.52 Ga), suggests an average cooling rate of the parent body of ~25°C/Ma. Clearly, neither very fast [4] nor very slow [5] cooling rates predominated during cooling of these meteorites. Cooling probably occurred at tens of °C/Ma above 500°C, decreasing gradually to a few °C/Ma below 300°C.
and Monument Draw released $^{36}$Ar at the highest extraction temperatures in concentrations comparable to type 5-6 ordinary chondrites.

**Discussion.** The $^{39}$Ar-$^{40}$Ar data presented here are entirely consistent with the petrologic [2,3] and oxygen isotopic [1] information about acapulcoites and lodranites. We can now reconstruct the history of the acapulcoite-lodranite parent body in a chronological framework.

**Accretion.** The parent body was of chondritic composition and accreted 4.55-4.56 Ga ago. Unless substantiated by additional data, the 4.60 ± 0.03 Sm-Nd age for Acapulco is assumed not to represent parent body accretion. The assertion of a common parent body for these meteorites is entirely consistent with similarities in oxygen isotopic compositions [1], mineralogy and mineral composition [2,3], and cosmic-ray exposure ages indicative of excavation in a single impact event (R. Wieler, pers. comm., 1992).

**Heating by Non-collisional Sources.** After accretion, the parent body was heated to the point of partial melting (Fe,Ni-FeS cotectic for acapulcoites; cotectic and silicates for lodranites). The heat source for this melting was non-collisional (e.g., $^{26}$Al, electromagnetic induction). No evidence for shock exists in the silicates, which is consistent with well-defined $^{39}$Ar-$^{40}$Ar release patterns. High two-pyroxene geothermometer temperatures (-950-1100°C) suggest that partial melting did not result from local excursions in shock pressures. The evidence for "early re-equilibration" seen in the U-Pb system [8] probably reflects this early heating. The higher temperature estimated for Gibson possibly caused total loss of $^{36}$Ar and lower K concentrations (Fig. 1).

**Cooling.** The parent body cooled below the Ar closure temperature -4.51 Ga ago for acapulcoites and -4.48 Ga ago for the Gibson lodranite. Cooling decreased gradually from tens of °C/Ma at higher temperatures to a few °C/Ma at low temperatures. Neither very fast or very slow cooling predominated. Lodranites were heated -100°C higher than acapulcoites, requiring longer cooling times and, thus, explaining the younger age. There is no evidence that these meteorites experienced any significant thermal event after closure of the Ar chronometer. These $^{39}$Ar-$^{40}$Ar ages of 4.48-4.52 Ga are identical to the upper range of $^{39}$Ar-$^{40}$Ar ages shown by unshocked ordinary chondrites [10]. The acapulcoites and lodranites apparently formed in a manner and time scale analogous to metamorphism on parent bodies of ordinary chondrites.


Figure 1. Plot of $^{39}$Ar-$^{40}$Ar ages ("boxes" contain all analytical uncertainties) and K/Ca ratios (dotted lines) vs. cumulative release of $^{39}$Ar for acapulcoites and lodranites. Determined K concentrations are also shown.