^{39}AR-^{40}AR AGES OF ACAPULCOITES AND EARLY PARENT BODY METAMORPHISM. Donald D. Bogard (code SN4) and Daniel H. Garrison (Lockheed Martin ES), NASA Johnson Space Center, Houston, TX 77058.

Acapulcoite Chronology: We determined precise ^{39}Ar-^{40}Ar ages for five acapulcoites, ALHA81261, ALHA81187, EET84302, Monument Draw, and Acapulco (Fig. 1). These ages are 4.511 ±0.007, 4.507 ±0.024, 4.512 ±0.017, 4.517 ±0.006, and 4.510 ±0.011 Ga, respectively. Each meteorite shows a constant age over a large fraction of its ^{39}Ar release, with only modest Ar loss at lower temperatures. All five meteorites are consistent with a common ^{39}Ar-^{40}Ar age of 4.51 ±0.01 Ga. When the age uncertainty (<0.5%) of the NL-25 hornblende age monitor is considered, the absolute K-Ar age of these five acapulcoites is 4.51 ±0.02 Ga.

The formation time of the acapulcoite parent body is undoubtedly older than these Ar-Ar ages. Other chronologies include a ^{147}Sm-^{144}Nd age of 4.60 ±0.03 Ga for Acapulco (1), and a Pb-Pb age of 4.557 ±0.002 Ga for Acapulco phosphate (2). This Sm-Nd age is older than the apparent formation times of ~4.56 Ga for the parent bodies of several other classes of meteorites (e.g., ordinary chondrites, angrites, and eucrites), and it is not clear that Acapulco actually formed this early. The ^{129}I-^{129}Xe formation interval between Acapulco phosphate and the Bjurböle chondrite standard is only 8 Ma (3) and supports a formation time for Acapulco of ~4.56 Ga.

Why are the K-Ar ages of acapulcoites ~50 Ma younger than the likely formation time of ~4.56 Ga for several meteorite parent bodies, including that for acapulcoites? The ^{39}Ar-^{40}Ar ages of other meteorite classes also appear younger than ages determined by other isotopic techniques. Ordinary chondrites that do not indicate gas loss due to shock show a wide span in Ar-Ar ages of ~4.38-4.52 Ga (4, 5). Pb-Pb ages of H chondrite phosphates vary over ~4.50-4.56 Ga and indicate an inverse correlation with metamorphic grade (6). Ar-Ar ages of silicate inclusions of six IAB iron meteorites are ~4.45-4.52 Ga, compared to the likely formation times of 4.55-4.56 Ga (7). Furthermore, the Ar-Ar ages of nearly all eucrites are <4.5 Ga, most in the range 3.4-4.2Ga, and have undoubtedly been reset by major impact heating (8). We now examine several possible reasons for the younger ^{39}Ar-^{40}Ar ages of chondrites and acapulcoites.

Decay constants: Any inaccuracies in the decay constants used in isotopic chronology can create a bias between any two techniques. The uncertainty in the U decay constant is small, <±0.1% (9), and Pb-Pb model ages often can be measured to high precision. The ~±0.8% uncertainty in the ^{147}Sm decay constant (10) produces a proportional uncertainty in Sm-Nd age, and the precision of Sm-Nd age measurements of meteorites often are no better than ~±30 Ma. To force agreement of ^{87}Rb-^{87}Sr ages of chondrites with their U-Pb age (4.555 Ga), the ^{87}Rb decay constant would have to differ by 1.2% (11) from the value of $1.42 \times 10^{-11} yr^{-1}$ that is commonly used (12). The uncertainty in the ^{40}K half-life is ±0.18%, but the largest error for K-Ar dating arises from the uncertainty in the minor decay path leading to ^{40}Ar (13). This uncertainty produces an age uncertainty of ±13 Ma in a 4.5 Ga old sample. The 0.34% uncertainty in the ^{40}K/^{39}K mixing ratio (14) produces a K-Ar age uncertainty of ±6 Ma. Thus, the compounded uncertainty in K-Ar ages due to errors in the ^{40}K relative abundance and decay parameters is unlikely to exceed ±15 Ma.

Age standards: Ages calculated in ^{39}Ar-^{40}Ar dating are always relative to a standard of known age that is neutron irradiated with the unknown sample. Thus, the determined ages can only be as accurate as the age of the standard. Ar-Ar ages of meteorites have been determined in several laboratories using different age standards. Each of these age standards had its age independently determined to an accuracy of ~0.5-2%. Furthermore, those age standards used in determining the meteorite ages quoted above were all irradiated together for cross calibration purposes (15, 16). The normalized ages of at least six of these standards agree to better than ±0.5%. Because it is most unlikely that any errors in the absolute ages of these standard samples all have the same magnitude in the same direction, this is a strong argument that their individual absolute ages are known to better than ±0.5%. Thus, it seems doubtful that systemic errors in the absolute ages of standard samples used in ^{39}Ar-^{40}Ar dating of meteorites could be greater than ~±15 Ma, and may well be less.

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The maximum bias in the absolute accuracy of ^{39}Ar-^{40}Ar ages of most meteorites, assuming correlated uncertainties in both the ^{40}K decay parameters and the absolute ages of various age monitors used, is thus estimated at ~±20 Ma. (Of course, analytical uncertainties of individually determined ages must also be considered in any comparison.) Such possible biases seem insufficient to explain the ~50 Ma difference between the ^{39}Ar-^{40}Ar ages of acapulcoites and formation of the acapulcoite parent body. Any biases in the Ar-Ar dating method certainly cannot explain the even larger differences between Ar-Ar ages of ordinary chondrites (~4.38-4.52 Ga) and likely formation times of their parent bodies of 4.55-4.56 Ga.

Early Parent Body Metamorphism: The observations that Ar-Ar ages of unshocked chondrites are ~4.38-4.52 Ga, Pb-Pb ages of H chondrites are ~4.50-4.56 Ga, and metal cooling rates of chondrites are commonly ~10-30 °C/Ma, all suggest an extended period of metamorphism of the chondrite parent bodies. The observed spread in ages would reflect different times of isotopic closure due to different cooling rates. The higher closure temperature for Pb in phosphate (6) compared to Ar in silicate could account for the Pb ages being older than the Ar ages. This scenario is approximately consistent with thermal models of the L chondrite parent body and with observations that metamorphic temperatures determined from pyroxene correlate with L chondrite petrologic grade (17).

We conclude that acapulcoites experienced an early thermal history similar to that of chondrites. Acapulcoites were heated as hot (~980°C) as the highest metamorphic grade chondrites and overall probably cooled as slowly (18). Thus, it is reasonable to conclude that the Ar-Ar ages of acapulcoites represent cessation of Ar diffusive loss during cooling from an extended period of metamorphism of the parent body. The fact that Ar-Ar ages of acapulcoites are younger than the Pb-Pb and Sm-Nd ages of Acapulco would then be explained by the greater ease of resetting of the K-Ar system at modest metamorphic temperatures. Earlier Ar closure of acapulcoites compared to many chondrites may indicate that the acapulcoite parent body was smaller and overall cooled faster, or that acapulcoites derived from exterior portions of that body.

One could ask why five acapulcoites give the same Ar-Ar age, whereas unshocked chondrites show a relatively wide spread in Ar-Ar ages. An explanation may come from the cosmic ray exposure ages of acapulcoites and lodranites, believed to have originated on the same parent body. At least 4 acapulcoites may have the same exposure age of ~6 Ma (18), and at least 7 lodranites may have a common exposure age of 5 ±1 Ma (19). The cosmogenic ^{21}Ne/^{22}Ne ratio for most acapulcoites and lodranites also indicate exposure as very small bodies in space. If all acapulcoites were ejected from their parent by a single impact, then they may represent sampling of a limited region of that body which experienced a similar metamorphic history.

References: (1) Prinzhoffer et al. GCA 56, 797, 1992; Göpel et al., Meteoritics 27, 226, 1992; (3) Nichols et al., GCA 58, 2553, 1994; 4) Turner et al., LPSC 9th, 989, 1978; 5) Pellas and Fiéni, LPS XIX, 915, 1988; (6) Göpel et al., EPSL 121, 153, 1994; (7) Herpfer et al.,GCA 58, 1353, 1994; (8) Bogard, Meteoritics 30, 244, 1995; (9) Jaffey et al., Phys. Rev 4C, 1889, 1971; (10) Lugmair and Marti, EPSL 39, 349, 1978; (11) Minster et al., Nature 300, 414, 1982; (12) Steiger and Jäger, EPSL 36, 359, 1977; (13) Beckinsale and Gale, EPSL 6, 289, 1969; (14) Garner et al., J.Res. Natl. Bur. Standards 79A, 713, 1975; (15) Alexander and Davis, GCA 38, 911, 1974; (16) Roddick, GCA 47, 887, 1983; (17) Bennett and McSween, LPS XXVI, 101, 1995; (18) McCoy et al., GCA, submitted, 1995; (19) Weigel et al., Meteoritics 29, 548, 1994.