AR-AR AND I-XE AGES OF CADDO COUNTY AND THERMAL HISTORY OF IAB IRON METEORITES.

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Background. Inclusions in IAB iron meteorites include non-chondritic silicate and those with more primitive chondritic silicate composition (1,2). Coarse-grained gabbroic material rich in plagioclase and diopside occurs in the Caddo County IAB iron meteorite (3) and represents a new type of chemically differentiated, extra-terrestrial, andesitic silicate. Other parts of Caddo contain mostly andesitic material (4). Caddo thus exhibits petrologic characteristics of parent body metamorphism of a chondrite-like parent and inhomogeneous segregation of melts. Proposed IAB formation models include parent body partial melting and fractional crystallization or incomplete differentiation due to internal heat sources, and impact-induced melting and mixing. Benedix et al. (1) prefer a hybrid model whereby the IAB parent body largely melted, then underwent collisional breakup, partial mixing of phases, and reassembly. Most reported ^{129}I-^{129}Xe ages of IABs are >4.56 Gyr and a few are ≥4.567 Gyr (5). These oldest ages exceed the 4.567 Gyr Pb-Pb age of Ca, Al-rich inclusions in primitive meteorites, which are thought to be the earliest condensates in the solar system (6). In contrast, ^{39}Ar-^{40}Ar ages of silicate from several IABs and the Sm-Nd age of one IAB meteorite appear significantly younger at ~4.53-4.43 Gyr (7). However, some uncertainty exists in the Ar-Ar and I-Xe age standards used in these early IAB age studies (5, 7). Herpfer et al. (8) used Ni concentration profiles in metal to determine cooling rates of ~25-70 ^{o}C/Myr for seven IAB meteorites, suggesting that an extended cooling history of the IAB parent body might result in different expected ages for different chronometer systems. Here we report precise Ar-Ar and I-Xe ages for Caddo County and examine these and literature ages against possible models for the IAB parent body thermal history.

Ar-Ar Age. We measured ^{39}Ar-^{40}Ar ages for three new samples obtained from different portions of the Caddo County IAB iron. Although temperature release data indicate that K in each sample resided in more than one diffusion domain, for each sample the Ar-Ar ages are relatively flat throughout most of the age spectrum and give well-defined plateaus. For sample #5 from the andesitic portion of Caddo, 15 extractions releasing 94% of the total ^{39}Ar define a plateau age of 4.507 ±0.013 Gyr (1σ, including ± in J). These same extractions define a very precise ^{40}Ar/^{36}Ar versus ^{39}Ar/^{36}Ar isochron (R^2=0.99999; corrected for cosmogenic ^{36}Ar) whose slope gives an age of 4.504 ±0.012 Gyr. The isochron ^{40}Ar/^{36}Ar intercept of 10 ±34 indicates that trapped ^{40}Ar is not present. For Caddo sample #027, 25 extractions (700-1350^{o}C) releasing 96.5% of the total ^{39}Ar define a plateau age of 4.506 ±0.010 Gyr, and the age for 16 extractions releasing 56-99% of the ^{39}Ar is 4.507 ±0.010 Gyr (Fig. 1). These same 25 extractions define a very precise isochron (R^2=0.999999; corrected for cosmogenic ^{36}Ar) whose slope gives an age of 4.510 ±0.008 Gyr and whose ^{40}Ar/^{36}Ar intercept is -33 ±15. For Caddo sample #EH, 20 extractions releasing 21-100% of the ^{39}Ar define a plateau age of 4.489 ±0.023 Gyr. The slightly younger age for EH compared to ages for #5 and #027 (although the same within uncertainties) may be the result of organic contamination during analysis, which may have contributed slightly to the mass 39 signal and artificially lowered the age.

I-Xe Age. Stepwise temperature analyses of Xe isotopes in irradiated sample #2 from the gabbroic portion of Caddo (3) gave ^{129}Xe/^{132}Xe and ^{128}Xe/^{132}Xe ratios as large as 53 and 134, respectively. Eight extractions (950-1330^{o}C) released 94% of the radiogenic ^{128}Xe* and define a highly linear trend with R^2=0.9999. Small corrections were applied to these data for cosmogenic Xe. The 500-850^{o}C extractions plot below this isochron, indicating that they have lost part of their ^{129}Xe* by diffusion at some point during the meteorite's history. The isochron slope is 0.3874 ±0.0047 (2σ) and the intercept on the ^{129}Xe/^{132}Xe axis is 1.17 ±0.06. The isochron fit was obtained using the formulism of Williamson (9), which weighs each isotopic ratio by its individual uncertainty. To obtain an absolute I-Xe age for Caddo, we irradiated with Caddo two samples of the Shallowater aubrite, which has a reported absolute I-Xe age of 4562.3 ±0.4 Myr (10). Five extractions of each of these samples (10 total), releasing 73% and 84% of their ^{128}Xe*, define a highly linear isochron (R^2=0.9998) having a Williamson-defined slope of 0.4718 ±0.0092 and a ^{129}Xe/^{132}Xe intercept of 0.94 ±0.05. From these various data we calculate an absolute I-Xe age for Caddo Co. of 4557.9 ±0.1 Myr.

Closure Temperatures. We used the stepwise release data for ^{39}Ar and ^{128}Xe*to calculate diffusion parameters for Ar and Xe in Caddo. We then used these diffusion data and the range of IAB cooling rates deduced from Ni profiles in metal (8) to estimate chronometer closure temperatures (CT) of 575-700^{o}C for K-Ar and ~1100^{o}C for I-Xe in Caddo. The CT for I-Xe in Caddo is similar to that estimated by (8) for IABs, whereas estimated CTs for two other IABs are only ~800^{o}C (4).

IAB Ages and Thermal Models. In an attempt to reconcile the diverse chronology data for IABs, we considered the complex IAB history described by (1), including the possibility of parent body breakup and reassembly at a time considerably after initial formation. Fig. 2 is a plot of age versus temperature (deg-Kelvin) and presents radiometric ages (see 4 for summary) and possible thermal cooling models for the IAB parent. We assume metamorphism to 1200^{o}C at either 4.53 Gyr or 4.56 Gyr (red diamonds). From each initial temperature, the pair of curved lines define two cooling rates of 10^{o}C/Myr and 100^{o}C/Myr, which bracket the measured Ni cooling rates of 25-70^{o}C/Myr measured for seven IABs by (8). These cooling curves are insensitive to reasonable uncertainties in starting temperature and final temperature, here assumed to be -100^{o}C. The large, green squares estimate closure temperatures for Ni diffusion of 350-500^{o}C and define approximate times of Ni closure for a given Ni cooling rate. Determined Ar-Ar ages (blue circles) of several IABs and winonaites (metal-poor meteorites likely derived from the IAB parent) are plotted within the open blue rectangle representing the estimated range in Ar-Ar closure temperatures. Measured Sm-Nd and Rb-Sr isochron ages for Caddo Co. (11,12; plotted as blue squares with 2-sigma uncertainties) have very uncertain closure temperatures (4), but probably higher than K-Ar closure. The I-Xe age for Caddo, which is the youngest among reported precise I-Xe ages of IABs (4,5), is plotted as an orange diamond at assumed closure temperatures of 1100^{o}C and 800^{o}C.

Fig. 2 depicts differences among radiometric ages of IABs that are difficult to explain, even by thermal models based on a complex parent body history. Metamorphism 4.56 Gyr ago followed by cooling at the Ni-determined rates is approximately consistent with the I-Xe age (especially for the higher closure temperature), whereas the Ar-Ar, Sm-Nd, and Rb-Sr ages are too young to be consistent with this thermal model. Metamorphism during IAB breakup and reassembly 4.53 Gyr ago is consistent with the Ar-Ar, Sm-Nd and Rb-Sr ages, but not with I-Xe ages of any IAB. We suggest that the explanation for these data lies in some combination of the following possibilities. a) I-Xe ages have very high closure temperatures and were not reset during metamorphism ~4.53 Gyr ago; b) a bias exists in the ^{40}K decay constants which makes all Ar-Ar ages ~30 Myr too young (e.g.,13); c) reported Sm-Nd and Rb-Sr ages for Caddo actually are larger by amounts equal to or exceeding their reported 2-sigma uncertainties; and d) about 30 Myr after the initial heating that produced differentiation of Caddo silicate and mixing of silicate and metal, a mild metamorphism of the IAB parent body reset the Ar-Ar ages.

References. (1) Benedix et al., *Meteor. Planet. Sci. 35*, p.1127, 2000; (2) Mittlefehldt et al., *Reviews in Mineralogy, Vol. 36, Planetary Materials*, 1998; (3) Takeda et al., *Geochim. Cosmochim. Acta 64*, p.1311, 2000; (4) Bogard et al., *Meteor. Planet. Sci. 40*, in press, 2005; (5) Niemeyer, *Geochim. Cosmochim. Acta 43*, p.843, 1979; (6) Amelin et al., *Science 297*, p.1678, 2002; (7) Niemeyer, *Geochim. Cosmochim. Acta 43*, p.1829, 1979; (8) Herpfer et al., *Geochim. Cosmochim. Acta 58*, 1353, 1994; (9) Williamson, *Can. J. Phys. 46*, 1845, 1968; (10) Gilmour et al., Workshop on *Chondrites and Protoplanetary Disk*, Hawaii, 2004; (11) Stewart et al., *Earth Planet. Sci. Lett. 143*, p.1, 1996; (12) Liu et al., *Lunar Planet. Sci. XXXIII*, #1389, 2002; (13) Trieloff et al., *Nature 422*, p.502, 2003.