Dating of impact events on the earth and moon commonly utilize $^{39}\text{Ar} - ^{40}\text{Ar}$ determinations of shock-melted material, which is thought to have the highest probability of having been degassed of $^{40}\text{Ar}$. Some terrestrial craters have remnants of massive melt sheets exposed, and large lunar formations such as Fra Mauro are believed to have experienced significant resetting of several isotope chronometers when ejected by large basin impacts such as Imbrium. On the other hand, meteorite samples involved in impacts on meteorite parent bodies frequently have either no available melt material or only small melt veins. The 105 kg, Chico melt chondrite is unique in that it is composed of 50-75% impact melt, which we interpret to have been impact-injected into host chondrite material located beneath a large crater on the L6 chondrite parent body. We undertook $^{39}\text{Ar} - ^{40}\text{Ar}$ determinations of a variety of melt and chondrite samples of apparently different shock temperatures and thermal histories to further understand resetting of the K-Ar system in such impact melts.

Sample Description: Most of the interior portion of Chico is melt, exposed when Chico was cut in half (1,2). One side of Chico (designated South, as one of six faces of a cube) is chondritic, and the opposite side (designated North) is melt invading highly fractured chondrite. We analyzed melt and chondrite samples from both the S and N ends of Chico and two interior samples (IS) located -1 cm apart and on either side of a distinct melt-chondrite boundary. We also analyzed a melt sample (IN) from the middle of the melt vein and a chondrite sample from the Bottom. The two exterior N samples were weathered, but the other, sub-surface samples were not. Chondritic samples showed unrumsted metal flecks. Macroscopically, the interior melt shows little texture, except for several vesicles and large blebs of metal that apparently coalesced during melting.

Examination of thin sections of our melt samples revealed no undigested clasts (K. Keil, pers. comm.).

$^{39}\text{Ar} - ^{40}\text{Ar}$ Ages and K/Ca Ratios: The profiles of $^{39}\text{Ar} - ^{40}\text{Ar}$ age versus fractional release of K-produced $^{39}\text{Ar}$ are shown in Fig. 1 for two typical samples, IS (melt) and S (chondrite). For all four chondrite samples, changes in the K/Ca ratio (dashed line, Fig. 1) during sample degassing usually occurred sharply between phases and indicate a high K/Ca phase of 0.3-0.4 at lower extraction temperatures and a low K/Ca phase of 0.02-0.04 at higher extraction temperatures. Four melt samples analyzed show similar K/Ca results, except that they have overall -2-times higher K concentrations and the K/Ca in the low-temperature extractions have higher values of >1. Apparently impact melting increased [K] in the melt over L6 chondrite material. The significant difference in temperature required to degas these two phases (Fig. 2), as well as differences in the diffusivity parameter D/a$^2$ we calculated for $^{39}\text{Ar}$ from the temperature data, imply that these two phases could have experienced different degrees of loss of radiogenic $^{40}\text{Ar}$. This was obviously true for all chondritic samples and appears to be true for most melt samples (e.g., Fig. 1). To separately evaluate the degree of resetting of the $^{39}\text{Ar} - ^{40}\text{Ar}$ system in the high-K/Ca and low-K/Ca phases, we divided the $^{39}\text{Ar} - ^{40}\text{Ar}$ release spectrum for each sample into these two phases, using as criteria the abrupt change in K/Ca and the distinct peaks in the release curve of $^{39}\text{Ar}$ versus temperature. For each phase we determined the lowest $^{39}\text{Ar} - ^{40}\text{Ar}$ age measured and the average age. These ages, along with the determined [K] and [Ca] are given in Table 1. We also give an estimated low-temperature, "plateau" age, which is a common technique for deriving an event "age" from such spectra. We also report data for Point of Rocks, an L6 find believed to be paired with Chico (2), for which a Rb-Sr isochron age of 0.46 Ga has been reported (3).

The "plateau ages" (column 3), which vary in "quality" among samples, do not suggest a common value. Most suggest an event age of 0.5-0.6 Ga, but both IS melt and chondrite samples suggest reasonably well defined "plateau ages" of 0.66 and 0.77 Ga, respectively. The average age of the low-temperature phase of the four chondrite samples (0.61 Ga) is identical to that for the melt samples (0.63 Ga). All of these "ages" are considerably higher than the inferred event age of 0.46 Ga. Only the chondritic B and S samples and the N exterior melt sample (which is more weathered and may have recently lost $^{40}\text{Ar}$) show $^{39}\text{Ar} - ^{40}\text{Ar}$ ages of individual temperature extractions (column 4) as low as the Point of Rocks Rb-Sr age. The average age of the high-temperature phase of the chondrite samples (1.25 Ga) is greater than that for the melt samples (0.80 Ga). Higher $^{39}\text{Ar} - ^{40}\text{Ar}$ ages for the high-temperature phase compared to the low-temperature phase might be expected, given the greater resistance to Ar diffusion from the high-temperature phase. Similar ages for the low-temperature phase of chondrite and melt samples, which are also significantly greater than the event age, is unexpected given the high temperature required to produce the melt and the possibility that it may have been superheated during injection into chondrite material. If the impact event occurred 0.46 Ga ago and affected L6
material not previously degassed, the apparent 0.62 Ga K-Ar ages of the low temperature phases indicate that -1% of the radiogenic 40Ar present at that time was not degassed. This 1% retained 40Ar would comprise -25% of the 40Ar present in this phase today. In the absence of a precise Rb-Sr isochron for Chico, it is also possible that the event age is somewhat older, say within the 0.50-0.55 Ga range suggested by several “plateau ages”, but even this age requires that some melt samples (e.g., IS) retained 40Ar.

Cooling Rate vs. Ar degassing: In spite of the significant size of this Chico melt vein (-30-40 cm wide), the cooling rate may have been sufficiently fast to prevent complete loss of radiogenic Ar. We estimate that a 30 cm slab with a thermal diffusivity of k=0.004 should lower its temperature by 10% in a time of the order of 3x10^-4 yr (e.g., 4). For a melt at >1200°C this represents a cooling rate of 1.5x10^-2°C/sec. Using this cooling rate and Ar diffusivity parameters measured on the low-temperature phases of our Chico samples (e.g., 30 Kcal/mole and D/a^2 of 10^-6 at 840°C), we calculate a closure temperature (4) against Ar diffusion of -1,000°C. If the melt initially cooled faster than this due to the presence of entrained cold clasts, it is conceivable that closure against diffusive loss of Ar could have occurred before Ar loss was complete. The chondrite phases are unlikely to have been heated to 1000°C, however, yet they lost comparable amounts of 40Ar. Most of the Ar loss from chondrite material, and possibly melt as well, probably occurred during much slower cooling at lower temperatures after the melt and surrounding chondrite material had come to thermal equilibrium. For example, the closure temperature against Ar loss is calculated to drop to ~600°C if the cooling rate decreases to -5x10^-3°C/sec, which corresponds to a cooling body ~5 meters thick.

These results suggest that even sizeable amounts of impact melt such as that in Chico may cool too rapidly to totally degass radiogenic Ar. This may lead to 39Ar-40Ar ages that are older than the impact age. The mere existence of an impact melt sample may not be sufficient to produce a totally reset K-Ar age and thus date the event. Chico melt and chondrite samples show that non-melted material which was not heated as hot as the melt may be as completely reset. Of perhaps greater importance in impact age resetting is the cooling rate of the shocked or ejected material after thermal equilibrium has been obtained. Strongly shocked samples incorporated into large ejecta volumes may be preferred for K-Ar dating.