Introduction. Radiometric dating of martian nakhlites by several techniques have given similar ages of ~1.2-1.4 Ga [e.g. 1, 2]. Unlike the case with shergottites, where the presence of martian atmosphere and inherited radiogenic 36Ar produce apparent 39Ar-40Ar ages older than other radiometric ages, Ar-Ar ages of nakhlites are similar to ages derived by other techniques. However, even in some nakhlites the presence of trapped martian Ar produces some uncertainty in the Ar-Ar age. We present here an analysis of such Ar-Ar ages from the MIL03346 and Y000593 nakhlites.

Ar-Ar Age Spectra. 39Ar/40Ar ages and K/Ca ratios for whole rock (WR) samples and mineral separates of low magnetic susceptibility (plagioclase plus mesostasis: “Plag”) from the MIL03346 and Y000593 nakhlites are shown in Figs. 1 and 2, and are compared with other radiometric ages of these meteorites [3, 4, 5]. All four Ar-Ar spectra show decreasing age with increasing extraction temperature, with most ages being slightly older than the Sm-Nd ages. All age spectra indicate a very small amount of recent diffusion loss of 40Ar. Discounting the low-temperature 40Ar loss, the average (total) Ar-Ar ages in Myr for these four samples are MIL03346 WR =1369, Plag=1413 and Y000593 WR=1397, Plag=1408. The total MIL-WR age is the same as the MIL Sm-Nd age, but the other three Ar ages are a few Myr older than the Sm-Nd ages. All four age spectra also suggest small 39Ar recoil effects at >90% 39Ar release, where an almost constant K/Ca ratio precipitously decreases. Probably pyroxene, even a small amount in the plag mineral separates, acted as the “catcher” for this recoiled 39Ar, thus lowering the apparent age at high temperature. Sloped age spectra as shown in Figs. 1-2 can be produced, in principle, by either release of a trapped martian Ar component or by significant 39Ar recoil produced during neutron irradiation. We use isochron plots to further examine these possibilities.

Isochron Plots of 40Ar/36Ar vs. 39Ar/36Ar were made for all four samples. Ar-Ar ages and trapped 40Ar/36Ar intercept ratios derived from these isochrons are given in Table 1. All Ar-Ar isochron ages are slightly older than the Sm-Nd ages, although several overlap within combined uncertainties. These isochrons were based on the range of 39Ar releases given in Table 1, and those extractions indicating 40Ar diffusion loss or gain of recoiled 39Ar were not included. The 36Ar in these samples is terrestrial at low extraction temperatures, primarily cosmogenic at higher temperatures, and martian at various temperatures. It is usually desirable to correct 36Ar abundances for cosmogenic 36Ar and use only trapped 40Ar in such isochron plots. We make such 36Ar corrections using the 39Ar/36Ar ratios [6]. However, because of variations in the 39Ar/36Ar ratios with temperature and because cosmogenic 36Ar dominates at higher extraction temperatures, applied corrections for 36Ar are uncertain. Thus, isochron results resulting from both making 36Ar corrections and not making such corrections are given in the table. In general, ages and trapped 40Ar/36Ar ratios derived from the two methods are similar, although sometimes they differ by an amount greater than the combined uncertainties. The Sm-Nd isochron ages [3, 4] are also given in Table 1.

Isochron-derived trapped 40Ar/36Ar ratios (Table 1) vary greatly, from +2000 down to -8039. Although all isochrons are strongly linear (R2>0.99), the uncertainties for most intercepts are relatively large, especially for the Plag. separates where the Ar is highly radiogenic. The most precisely determined trapped 39Ar/36Ar is for Y000593 WR, and the ratio derived for 39Ar in such trapped ratios determined for some shergottites [7]. Both Y000593 Plag. and MIL03346 WR give negative 40Ar/36Ar ratios, although the uncertainty on the Y593 Plag. ratio, corrected for 36Ar, is much larger than the ratio itself. Often negative 40Ar/36Ar intercepts on an Ar-Ar isochron plot indicate significant 39Ar recoil redistribution. Such an interpretation for MIL03346 WR would be consistent with the strongly sloped age spectrum. However, MIL03346 Plag also shows a partially sloped age spectrum, and the 40Ar/36Ar intercept for MIL Plag. is clearly positive. The most reasonable interpretation of these MIL03346 data is that both WR and Plag samples contain excess (trapped) martian Ar, primarily released at lower extraction temperatures, and that for the WR sample, but probably not the Plag sample, significant 39Ar recoil effects have also affected the age spectrum. This interpretation seems consistent with the fine grain size for MIL03346, and the observation that at high 39Ar release the WR ages fall significantly below the Sm-Nd age. This interpretation is also consistent with the observation that all isochron-derived Ar-Ar ages for MIL03346 are slightly older than the Sm-Nd age, particularly for the WR sample, which has a larger ratio of trapped 40Ar to in-situ-decay 40Ar. For Y000593, we conclude that higher observed ages for both WR and Plag. samples are primarily caused by excess martian Ar and that recoil redistribution of 39Ar plays only a minor role.
Excess $^{40}$Ar. Table 1 also gives for these four samples the concentrations of excess $^{40}$Ar (less the first extraction releasing significant terrestrial Ar) relative to the Sm-Nd isochron ages. Compared to the WR samples, the plagioclases contain not only higher $^{40}$Ar concentrations, because of their higher K, but also excess $^{40}$Ar concentrations that are larger by about an order of magnitude. The plagioclase/mesostasis in MIL03346 has been reported to comprise between 16% and 35% (average value ~ 23%) of the whole rock [8, 9, 10, 11, 12]. Plagioclase comprises ~5-10.5% of Y000593 WR [13, 14, 15]. Thus, it appears that plagioclase/mesostasis contains nearly all of the excess $^{40}$Ar in these meteorites. The inference that late crystallizing phases contain the excess $^{40}$Ar and the release of this component primarily from lower temperature sites suggest that the excess $^{40}$Ar was present in the melt and became incorporated into the last crystallizing phases. The excess $^{40}$Ar apparently was not acquired from the martian atmosphere by shock implantation. This conclusion may have implications for other trapped noble gases in nakhlites. MIL03346 cooled faster than Y000593 [16] and has a finer texture, which implies diffusion distances in the solid phase controlled retention of this excess $^{40}$Ar.