INTERPRETING THE ^{40}AR/^{39}AR AGES OF ANCIENT ORDINARY CHONDRITES: A CAUTIONARY TALE WITH IMPLICATIONS FOR ^{40}AR/^{39}AR DATING OF ALL SHOCKED METEORITES. M. E. Karageozian, T. Sharp, C. McDonald. The School of Earth and Space Exploration, Arizona State University, 781 Terrace Mall, Tempe, AZ 85287 (mekarage@asu.edu).

Intro: The impact history of the solar system is essential for constraining solar system-body surficial processes. Impact history is recorded in shocked meteorites from the full to partial resetting of isotopic systems during shock events. However, anomalous ^{40}Ar/^{39}Ar ages have been documented twice in shocked chondritic meteorites [1,2], where shock melt produced ages older than our solar system. From our previous study of the L-chondrite Mbale, we interpret that this age anomaly results from preferential retention of *Ar within quenched shock melt and expulsion of K from the melt into neighboring maskelynite during shock. Here we use the UV laser ablation microprobe (UVLAMP) ^{40}Ar/^{39}Ar dating technique and detailed microprobe analyses to interpret the shock ages of some of our most ancient ordinary chondrite samples and document K and Ar behavior in shocked meteorites.

Methods: Opposing sections were made for each sample; a polished thick or thin section for microprobe analyses and 7x7mm, >150 µm-thick slabs for ^{40}Ar/^{39}Ar analyses. Thick sections were irradiated for 100 hrs in the OSU CLICIT reactor. Ar isotopes were extracted by UVLAMP with a Teledyne/Photon Machines Analyte Excite UV (193nm) laser and measured with an attached Nu Instruments Noblesse noble gas mass spectrometer. Ablation spots were selected across shock-melted and non-melted regions. We reduced and corrected the data using standard techniques [3-8], with all uncertainties reported to 2σ. The facing sections were characterized with a JEOL JXA-8530F electron microprobe at ASU's Eyring Material Center (EMC). EDS and WDS were used to map K, Al, Si, Fe, and Mg concentrations. Mineral polymorphs were identified with Micro-Raman Spectroscopy, utilizing a 532 nm laser with a spatial resolution of ~0.5 µm.

Samples & Petrography:
Mbale: Mbale is classified as an L5/6 S5/6 fall [9,10] with a 479 ± 7 Ma ^{40}Ar/^{39}Ar impact age [10]. Our Mbale section is comprised of ~30% melt vein with abundant host inclusions. The non-melted matrix is comprised of olivine, pyroxene, plagioclase, and Fe-metal sulfides. The melt vein lithology consists of majorite garnet and wadsleyite with entrained clasts of partially transformed silicates, as documented by [2,11]. Maskelynite occurs adjacent to the melt vein with partial amorphization of plagioclase >1mm from the vein.
Yamato 75100: Y-75100 is an H6 S6 chondrite with an impact age of ~4.3Ga [12]. The non-melted matrix is comprised of olivine, pyroxene, diaplectic plagioclase glass, and Fe-metal sulfides. The shock vein consists of transformed, entrained clasts in a quenched melt matrix of ringwoodite and majorite. The vein has two distinct melt textures, a ~5µm-thick, fine-grained rim and a 0.1-1.5mm thick coarse-grained interior melt vein. Similarly to Mbale, maskelynite is abundant along the melt vein boundary.
Queen Alexandra Range 97071: QUE 97071 is an LL5 S2 chondrite with an impact age of 4.5 Ga [13]. The sample contains several small (<100 µm) melt pockets comprised of pyroxene, maskelynite, and plagioclase, with no preserved high-pressure minerals. The host rock is comprised of olivine and pyroxene chondrules, with plagioclase and maskelynite, in a fine-grained, optically-opaque matrix.
Patuxent Range 91501: PAT 91501 is an L7 unshocked, fully crystallized impact melt [14] with an age of 4.463 Ga. The sample is comprised of pyroxene, olivine, and plagioclase with no preserved high-pressure minerals nor any indicators of shock [15]. However, the plagioclase has a skeletal-like interior texture with localized high and low K regions

Results: *Microprobe Analyses:* In both Mbale and Y-75100, we measure very low K contents within the melt veins (<0.2 wt%) and much higher concentrations in maskelynite (1.8 wt%) at the melt vein boundary. The maskelynite K concentrations are higher than those in diaplectic plagioclase glass and plagioclase farther from the melt vein. The shocked plagioclase in QUE 97071 varies texturally from melted to fully crystalline. We measure the highest average K (1.2 wt%) concentrations in the melted phases and slightly lower concentrations in the equilibrated melt and fully crystalline phases (~0.7wt%). The range in K contents across the sample is much higher in Mbale and Y-75100 than in QUE 97071. PAT 91501 only contains plagioclase with no maskelynite or diaplectic glass. In the plagioclase, K is heterogeneously distributed in localized regions of very high K content (2.1wt% avg).
^{40}Ar/^{39}Ar Dating: The Mbale UVLAMP ablation results produced dates ranging from 444 ± 10 Ma to 6845 ± 137 Ma (Fig. 1). The youngest dates analyzed

are from the host rock and match the canonical age of the L-chondrite parent body breakup at ~470 Ma. The oldest and most variable dates were measured within the melt vein. The ages in Y-75100 follow a similar trend with host-rock ages of 3950 to 4450 Ga and melt-vein ages from 4200 to 4500 Ga (Fig. 1). The ages calculated from QUE 97071 range from 4348 ± 37 Ma to 4625 ± 22 Ma and cannot be correlated with melted and non-melted regions due to the spatial resolution limitations of our UVLAMP spot selection. Lastly, PAT 91501 is fully recrystallized, and the measured ages are nearly uniform, from 4490 ±14 Ma to 4534 ± 12 Ma.

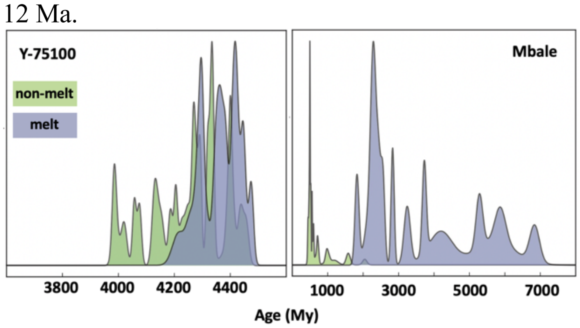

Figure 1. Probability density plot of the ages calculated from Y-75100 and Mbale, respectively. Melted regions are shaded blue, and non-melted regions are shade green.

Discussion: Mbale, like Peace River [1], has impossibly old $^{40}Ar/^{36}Ar$ ages from the quenched shock melt due to Ar retention and K loss [1,2]. Y-75100 and QUE 97071 have the same trend with older shock-melt ages, but the effect is less pronounced and does not produce impossible shock-melt ages. In all these samples, retention of Ar and loss of K from the shock melt results in anomalously old shock-melt ages. We posit that the relatively high solubility of Ar in silicate melts at high pressure [16], combined with the rapid quench of melt veins during shock, traps *Ar in the quench assemblages. The heterogeneous K distribution between melt veins and surrounding maskelynite demonstrates that the K is expelled from the shock vein. We conclude that the preserved shocked melt veins and pockets of ordinary chondrites like Mbale, Y-75100, and QUE 97071 create a K-incompatible, Ar-compatible lithology that, when dated using $^{40}Ar/^{39}Ar$ techniques, produces anomalously old ages. This effect is evident in L chondrites such as Mbale and Peace River [1], which record the ~ 470 Ma in the host rock and impossibly old ages for the quenched melt. This results from the significant accumulation of radiogenic Ar in the ~ 4100 Ma before the 470 Ma event. We posit that other meteorites with preserved shock melt will exhibit similar isotopic behavior in the K-Ar system. Ancient samples like Y-75100 and QUE 97071 still exhibit anomalous behavior, but to a lesser degree, because of the relatively little radiogenic Ar trapped in the quenched melt. We suggest that the old late-release ages in some $^{36}Ar/^{40}Ar$ step heating data come from Ar trapped in quenched shock melt [17]. Our results demonstrate that even in the oldest chondrite samples, the behavior of the K-Ar system during shock can result in a retrograde age disturbance. Therefore, if shock-melted regions and K-Ar artifacts are ignored in meteorites, incorrect impact ages and apparent multiple impact events are likely to be interpreted.

Conclusion: We find non-intuitive behavior of K and Ar in all three samples that preserve shock melt, i.e., Mbale, Y-75100, and QUE 97071, which results in $^{40}Ar/^{39}Ar$ age artifacts. This behavior is not present in PAT 91501. It is essential to account for shock-melted regions when interpreting shock ages to avoid misinterpreting multiple shock events and older average ages. We posit that any meteorites that preserve shock-melted regions that are quenched at high pressure are likely to have $^{40}Ar/^{39}Ar$ age artifacts that require careful interpretation to avoid inferring unlikely impact events or anomalously old ages.

Acknowledgments: We acknowledge support from Emerging Worlds Award 80NSSC18K0591. We acknowledge the use of facilities within the Eyring Materials Center at Arizona State University, supported partly by NNCI-ECCS-1542160. We also thank Dr. Axel Wittmann for his guidance and input in microprobe analyses and data processing.

References: [1] McConville et al. (1988) *GCA* 52, 2487-2499. [2] Karageozian & Sharp (2022) *In Prep*. [3] Wijbrans & McDougall (1987) *EPSL* 84, 226-242. [4] Stoenner et al., 1965 *Science* 184, 1325-1328. [5] Renne and Norman (2001) *Phys. Rev. C* 63. [6] Renne et al. (2011) *GCA* 75, 5097-5100. [7] Wieler, R. (2002) *Min. Soc. Am*. 47, 71-100. [8] Palma et al. (2002) *GCA* 66, 2929-2958. [9] Wlotzka et al. (1993) *Met. Soc. Bull.* 75. [10] Korochantseva et al. (2007) *Meteorit. Planet. Sci.* 42, 113–130. [11] Hu & Sharp (2017) *GCA* 215, 277–294. [12] Swindle T., and Kimura M. (2008). *Meteorit. Planet. Sci. Supplement* 43, A150–A150. [13] Dixon et al. (2004) *GCA* 68, 3779-3790. [14] Benedix et al. (2008) *GCA* 72, 2417-2428. [15] Stöffler et al. (2018) *MPS* 53, 5-49. [16] Jackson et al. (2021) *EPSL Letters* 553. [17] Sharp et al. (2022) *Meteorit. Planet. Sci.* 57.