ANOMALOUS ^{40}AR/^{39}AR SHOCK AGES IN MBALE: IMPLICATIONS FOR THE INTERPRETATIONS OF SHOCK AGES IN SHOCKED METEORITES.

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Intro: Mbale is classified as an L5/6 ordinary chondrite [1] with shock stage ranging from S5 to S6 [2] and an ^{40}Ar/^{39}Ar age of 479 ± 7 Ma [3]. Our section of Mbale has shock veins measuring up to several mm in apparent width. As in other shocked chondrites with S6 shock veins [4], shock effects in Mbale depend on proximity to shock veins [2]. This makes Mbale an ideal sample for laser-ablation ^{40}Ar/^{39}Ar dating of shock features in and around shock veins. Many shocked ordinary chondrites have been dated to constrain the impact history of our solar system [5]. Here we discuss Mbale's petrography, shock effects and ^{40}Ar/^{39}Ar dates in and around a shock vein. Our study demonstrates ^{40}Ar/^{39}Ar age anomalies that result from nonintuitive behavior of K and Ar in shock melt at high pressure. Our results have important implications for the interpretation of ^{40}Ar/^{39}Ar dating results from shocked meteorites with S6 shock veins.

Methods: A small block of Mbale was used to make facing polished sections; a 7x7mm, 150 µm-thick section and an opposing block. The thick section was irradiated for 100 hrs in the OSU CLICIT reactor. The slab was loaded into the UV laser chamber of an ultrahigh vacuum extraction line attached to a Nu Instruments Noblesse noble gas mass spectrometer in the Group 18 Laboratories at ASU. The sample chamber was pumped down to ultrahigh vacuum and baked overnight. Argon was extracted from the slab using a Teledyne/Photon Machines Analyte Excite UV (193nm) laser and after gas cleanup was analyzed in the mass spectrometer using a Secondary Electron Multiplier (SEM) in ion counting mode. Data was reduced using a combination of the Mass Spec software (Al Deino, BGC) and an in-house spreadsheet and are reported with uncertainties at 2-sigma levels. An interferometer was used to obtain ablation pit volumes to relate the ablated material with bulk K and Ar volumes of the sample. The polished facing section was used for petrographic and chemical analysis with a JEOL JXA-8530F electron microprobe at ASU's Eyring Material Center. We used backscattered electron (BSE) imaging and energy dispersive X-ray spectroscopy (EDS) to determine the mineralogy microstructures and for elemental mapping. We used wavelength dispersive X-ray spectroscopy (WDS) analyses for quantitative chemical analyses.

Results:

Petrography. The Mbale sections are comprised of ~30% melt vein. The host lithology is almost entirely comprised of olivine and pyroxene, with maskelynite and plagioclase accounting for ~10% of the bulk mineralogy. Similar to the findings of Hu and Sharp [2], the melt vein lithology is fine-grained and contains high-pressure garnet, high-pressure olivine polymorphs, sulfide/metal droplets, and entrained olivine and pyroxene clasts. Evidence of shock-related melting is most prominent around the vein due to the abundance of maskelynite in this region. With increasing distance from the vein, plagioclase becomes more abundant than maskelynite

^{40}Ar/^{39}Ar Dating. The dating was done on three tracks across a large melt vein (Fig. 1) sampling both quenched shock melt and host rock. The ablation results produced dates ranging from 444 ± 10 myr to 6145 ± 137 myr. The younger dates were sampled from the host rock while the oldest ones occurred within the melt vein. The dates determined within the melt vein were highly variable (Fig. 1)

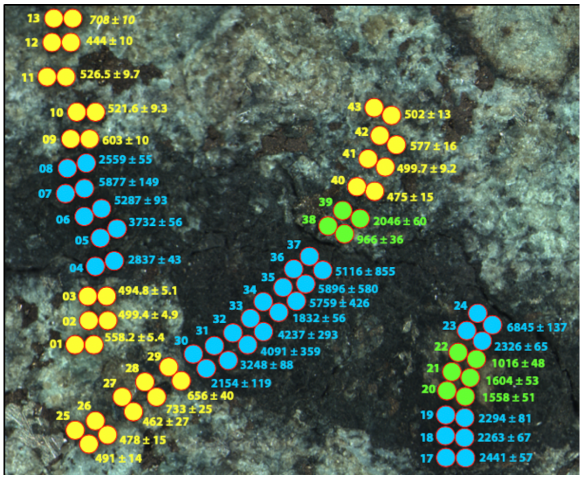

Figure 1. ^{40}Ar/^{39}Ar UV laser ablation dating results. Three tracks total (track 1, 2, and 3 from left to right).

Microprobe Analyses. Using the polished facing section, WDS and EDS maps and spot analyses were performed to measure the K content of the quenched shock melt and maskelynite or plagioclase outside of the melt vein. The analyses followed the mirrored path of the ^{40}Ar/^{39}Ar dating track 1 in the opposing section in order to correlate with the dating results. The WDS maps showed the melt vein to be nearly K-free and surrounded by K-rich maskelynite. The K content of the maskelynite decreases with distance from the melt vein. To quantify these results, WDS spot analyses were run both inside and outside the melt vein. A slight downward trend in K content is noted with increased distance from the melt vein. The average K content in maskelynite just outside the vein is around 1.5 wt% while the K within the melt vein averages around 0.02 wt% (Fig. 2).

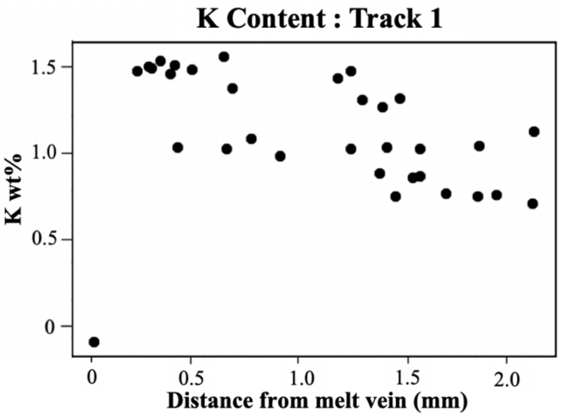

Figure 2. Plot of WDS spot analysis data of K content with distance from the melt vein. Track 1 corresponds to the isotope dating track 1in Figure 1.

Discussion: The ^{40}Ar/^{39}Ar age results within the melt vein yielded anomalously old ages; older than that of our solar system. The regions that yielded younger ages within the vein are the result of entrained olivine and pyroxene clasts. Using the microprobe analyses, we confirmed that there is a significant loss of K from inside the melt vein. The anomalous ^{40}Ar/^{39}Ar dates of the shock vein suggest that the shock vein lost more K than Ar. The bulk of the expelled K is found just outside the vein (Fig. 3), and the K content levels out to base levels farther from the vein source. However, the trends in K content are difficult to interpret because in this small sample, we do not know where the influence of the next shock vein starts. Using a microprobe beam for chemical analysis can also result in the sampling of subsurface minerals that intersect the X-ray excitation volume. This may account for data points that fall off trend in Figure 3.

The apparent preferential loss of K, vs. Ar from the shock melt suggests that K is less soluble in a high-pressure (20-25 GPa) silicate melt than Ar. Similar K-rich maskelynites have been reported adjacent to shock veins in other meteorites[6]. S6 shock veins, which crystallize at high pressure, have little capacity to retain K because the high-pressure minerals that crystallize, such as majoritic garnets, ringwoodite, wadsleyite, and magnesiowüstite lack crystallographic sites that can accommodate K+ cations. Plagioclase glass, either diaplectic glass or normal glass, accepts this excess K expelled from the vein. Farther from the melt vein, the plagioclase does not appear to have excess K. Our ^{40}Ar/^{39}Ar dates, combined with the K distribution analyses, imply that shock melt, that crystallizes at high pressure, preferentially loses K. This results in anomalously high shock ages within the vein. A similar result was reported for the Peace River L chondrite in 1988 by McConnville et al. [7]. Their 1060-nm laser results for a shock melt vein produced dates as old as 7 Ga. They also suggested K loss from the vein, but they did not document it.

Conclusion: Our laser ^{40}Ar/^{39}Ar dates, combined with K measurements demonstrate that K mobility during shock can result in anomalous ages in shocked meteorites. The shock effects and shock melt in Mbale are common in shocked meteorites. We expect to see this effect in any shocked meteorite that contains shock veins that quenched at high pressure.

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