MODELING THE DIFFUSIVE LOSS OF ARGON IN RESPONSE TO MELT VEIN FORMATION IN POLYGENETIC IMPACT MELT BRECCIAS.

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Introduction: Many of the surfaces of rocky bodies in the Solar System are heavily cratered due to prolonged impact bombardment. Dating impact events with high precision and accuracy is a fundamental problem associated with understanding the evolution of such planetary surfaces. The ^{40}Ar/^{39}Ar dating technique is commonly used to study terrestrial and extraterrestrial impact rocks (impactites) because the K-Ar isotopic system can be partially or fully reset by the high temperature conditions of impact. The fact that multiple unrelated impact events can occur within a small region (e.g., [1, 2]) poses a (perhaps underappreciated) challenge to geochronologists who study impactites. This is particularly true for samples from planetary bodies that lack the many agents of erosion associated with active plate tectonics and atmospheres.

The occurrence of multiple impact events within restricted geographic regions can produce impact rocks containing complex mixtures of now-solidified melt products and clasts of target rocks. In some cases, impact melt breccias (IMBs) may contain multiple generations of melt products from distinct impact events [3, 4]. Such samples can provide important insights into the extensive bombardment history of a region. For example, *in situ* phosphate and zircon U/Pb data [5] and ultraviolet laser ablation microprobe (UVLAMP) ^{40}Ar/^{39}Ar data [6] were interpreted as evidence that 73217 incorporated melt products from multiple impacts that occured over a period of more than a billion years. The UVLAMP ^{40}Ar/^{39}Ar dates alone indicate that three or more impacts affected sample 73217 over a period of more than 500 Ma.

Datasets like these raise a fundamental question: how does the formation of new melt products affect the mineral-isotopic chronometers of previous generations of impact melts in a polygenetic IMB? We model the thermal evolution of initially molten and clast-bearing impact melt veins and the resulting loss of Ar from K-bearing phases common in IMBs to assess the potential for preserving ^{40}Ar/^{39}Ar ages of individual melt generations. These numerical models provide insights into interpreting ^{40}Ar/^{39}Ar data from polygenetic IMBs, which can preserve extensive records of the impact histories of planetary surfaces.

Numerical Methods: We developed a 1D finite difference model as an approximate numerical solution to the heat conduction equation for potentially inhomogeneous and aniosotropic media with no internal heat production. We used a constant density of 3000 kg/m^3 to represent non-porous lunar impact melts [7], and temperature dependent equations for specific heat capacity, thermal diffusivity, and thermal conductivity [8]. We assumed that molten materials started with T_{pk} = 1500 ˚C, and T_{bg} = -33 ˚C for the temperature of clasts and country rocks [9]. We assumed that latent heat was realeased uniformly over the temperature range 990-1350 ˚C, estimated by rhyolite-MELTS v1.0.2 modeling [10, 11] using the compositions of Apollo 17 impact melt rocks 77115 and 77135 [12].

We implemented the finite difference model of Watson and Cherniak [13] for thermally activated diffusive loss from a sphere. We used experimentally determined diffusion parameters for Ar in Ca-rich plagioclase [14] and Apollo 16 glasses [15]. The integrated effects of radiogenic ingrowth and one or more thermal events were tracked for three scenarios: (1) Ar loss near entirely molten veins; (2) Ar loss near clast-bearing melt veins; and (3) Ar loss in a polygenetic IMB containing three generations of melt products.

Results: The peak temperatures reached in the country rock are shown versus distance from melt vein contacts in Fig. 1. Cooling times were on the order of seconds to tens of minutes. The addition of between 10–40% clasts to melt veins reduced the peak temperatures of the country rocks (e.g., by a few hundreds of K for a 10 mm-thick melt vein, not shown), and decreased cooling times.

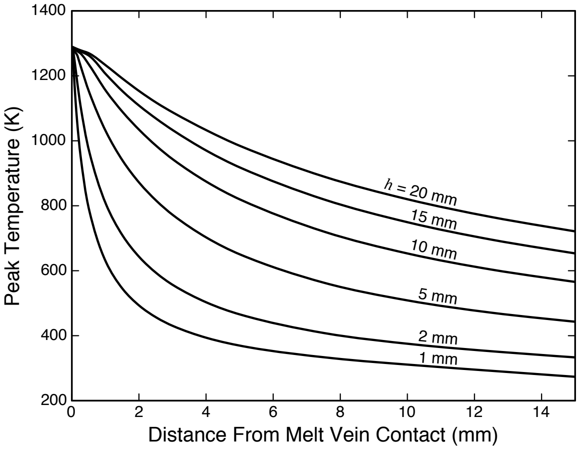

Figure 1. Peak temperature versus distance from melt vein contacts, for vein widths of 1–20 mm.

Example diffusive loss results for Apollo 17 sample 76535 anorthite are shown in Fig. 2. We assumed the melt veins formed near the end of the basin forming epoch on the Moon in a host rock with an ^{40}Ar/^{39}Ar

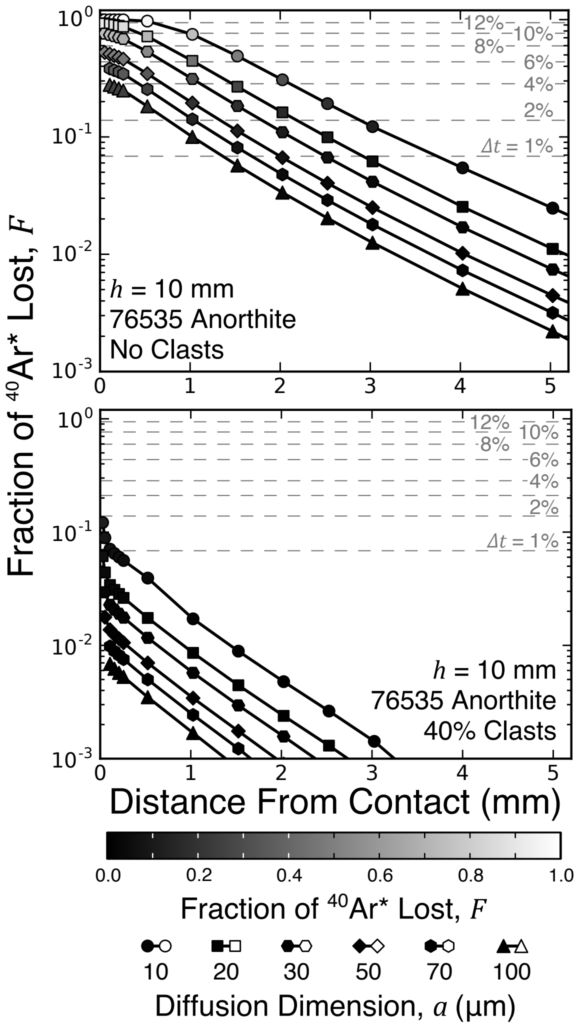

Figure 2. Diffusive loss results for 76535 anorthite diffusion domains near molten (top) and clast-bearing (bottom) 10 mm-thick melt veins. Horizontal dashed grey lines represent *F* loss values required to cause the labeled apparent age changes (Δt in %) assuming the melt veins formed at t_i = 3800 Ma in a t_0 = 4350 Ma host rock.

age of 4350 Ma to determine how much the apparent ages might shift near the contact. The addition of clasts reduces the amount of Ar loss, and can even make Ar loss undetectable by geochronologists assuming a typical analytical precision of 1% at 2σ (Fig. 2). Our models of glass diffusion domains typically lost less Ar than plagioclase close to melt veins, but would lose more Ar than plagioclase farther from the contact. In the polygenetic IMB case, some materials in areas close to vein contacts showed Ar loss while other regions did not.

Discussion: Argon loss will be the most pronounced near melt veins that were initially completely molten. However, many impact melts in meteorites and lunar samples contain clasts, which suppress heating and Ar loss in the country rocks. In either the molten or clast-bearing case, the relative timing of events (i.e., host formation, impact timing, and isotopic analysis) influences the ability of geochronologists to detect Ar loss through a change in the apparent age of sample materials. It is the most difficult to detect Ar loss from ancient materials that promptly experience one or more impact heating events, and less challenging to detect Ar loss if the impacts are more recent.

For a melt vein of a given width, this implies that the width of the near-contact zone where Ar loss is detectable varies with the relative timing of events. When the interval between host formation and impact is shorter, the zone of detectable Ar-loss will be thinner. When the interval is larger, the detectable Ar-loss zone will be wider. At most, the widths of detectable Ar-loss zones will be on the order of the vein width.

Our results indicate that IMBs containing multiple generations of melt products can reasonably retain quantitative evidence for the timing of individual impact events. This is especially true for IMBs containing thin (a few mm wide), clast-rich melt bodies. Careful selection of sample aliquots or *in situ* analysis locations can yield undisturbed results even for samples containing clast-poor melt bodies several mm or greater in width. For samples where melt veins are tightly grouped, the intervening selvages of older materials can be more heavily disturbed. This depends on the grain size distribution of older materials and the geometry of younger melt veins.

Overall, our modeling results are consistent with the interpretations of Mercer et al. [6] that multiple generations of impact melt products are preserved in 73217. Polygenetic IMBs currently in our sample collections, or that may be collected in the future, can be highly valuable for interrogating the impact history of other planetary surfaces.

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