COULD THE MARTIAN SHERGOTTITES BE FROM AN IMPACT MELT SHEET? S. J. Jaret[1], E. T. Rasbury[2], P. Reiners[3], M. S. Thompson[4], S. R. Hemming[5], D. S. Ebel[1,5], L. M. Thompson[6] and J. G. Spray[6], [1]Department of Earth and Planetary Sciences, American Museum of Natural History, [2]Department of Geosciences, Stony Brook University, [3]Department of Geosciences, University of Arizona, [4]Department of Earth, Atmospheric, and Planetary Sciences, Purdue University, [5]Department of Earth and Environmental Sciences, Columbia University, [6]Planetary and Space Science Centre, University of New Brunswick, Canada. sjaret@amnh.org

Introduction: Impact cratering is the dominant surface changing process on extraterrestrial planetary bodies. While impacts are most frequently associated with structural deformation from the planetary to the micro-scale, these events are also capable of generating large volumes of impact melt rocks through impact melting and crystallization. For example, the Manicouagan impact structure, Canada, hosts a differentiated melt sheet ranging from 1500 to 1800 m thick [1]. Only two other impact structures are currently known to have differentiated melt sheets present: Sudbury and Morokweng.

Recognizing impact melt sheets from lava flows, however, is a challenge because impact melt rocks exhibit petrographic and field characteristics of igneous rocks Specifically, 1) they are well-crystalline and can be both coarse grained and differentiated, 2) they lack shock deformation features since they crystallized after the passage of the shock wave, and 3) they frequently lack clasts common in other types of impact breccia deposits. Their recognition has been subject to significant debate (e.g. the origin of the Sudbury melt sheet), and often is only recognized in context of a known impact structure after confirmation of other shock-metamorphic lithologies (e.g. [2]).

For Mars, this presents additional challenges because the current set of martain samples – i.e. meteorites – do not have broader geologic context. The current suite of meteorites consists of 323 samples that include basalt and basaltic lherzolites (shergottites), clinopyroxenites (nakhlites), dunites (chassignites), and orthopyroxenite (ALH85001), and surficial breccias (NWA 7034 and associated polymict breccias).

A longstanding question about the origin and formational history centers on how to interpret isotopic and chronologic data from shergottites, which have old Pb-Pb isotope signatures, but surprisingly young argon ages [3-4]. These ages are surprising for two reasons, and are a known 'paradox' in the study of martian meteorites [3]. Based on crater count chronology overwhelmingly the martian surface is ancient. And, given cosmogenic exposure ages of shergottites which suggest at least four (maybe up to eight) unique ejection events [5], it is incredibly surprising that all these meteorites only sampled young terrain, and that none reflect the dominant surface age of Mars. This could be attributed to impacts preferentially ejecting material from young volcanic terranes. Secondly, generating large volumes of igneous rocks as recently as 200 million years ago is challenging for a small planet like Mars. It seems unlikely that there were enough anomalously hot areas within the martian mantle to have formed this many distinct young regions on Mars.

Currently argon ages for shergottites are frequently reported as "crystallization ages' but [6-7] argued that the ancient Pb represents the original age and the young argon values result from Ar loss during shock. However, the degree of shock resetting of argon in feldspars remains debated. Shock experiments show no evidence of argon resetting [8], whereas [9] showed partial resetting of argon in shocked feldspars from a terrestrial example. The debates over shergottite chronology and the argon/lead age discrepancy are reviewed by Jones et al. 2015 [4].

As a possible solution to the igneous rock paradox [10] suggested an impact melt origin for the Shergottites, but this hypothesis has not been seriously considered in detail. Here we present Pb isotope individual feldspars sampled from the melt sheet of the Manicouagan impact structure, and compare these results to martian shergottites.

Samples: Multiple single grains were separated from one hand sample of the medium grained quartz monzodiorite collected at Observation Lake [9]. This sample is clast-free, and contains subhedral to euhdedral (1-3 mm) plagioclase (albite to oligioclase) with co-occurring quartz, clinopyroxene, and occasional altered amphibole and orthopyroxene. In some cases, plagioclase exhibit K-feldspar overgrowths. One 6-cm hand sample was crushed and individual grains were hand-picked and analyzed with micro-Raman spectroscopy prior to argon irradiation and analysis [9]. Pb isotope ratios were measured on fused beads after argon analysis.

Methods: *Pb Isotope Chemistry*: Feldspar grains were leached before dissolution. Pb was separated using standard HBr anion exchange column chemistry [11-12].

Mass Spectrometry: Pb isotopic analyses were collected using dry plasma mode with a Nu Plasma II Multi Collector ICP-MS in the Facility for Isotope Research and Student Training (FIRST) at Stony Brook University. Samples were bracketed with NBS 981 which was used to make a fractionation correction.

Signal intensity and run precision was 1.2 % for 0.25 ppb and 0.5 % for 0.5 ppb.

Results: Individual feldspar grains from the melt sheet overlap with whole-rock Pb isotope analyses of the MIZ terrain [1] but also extend beyond that field towards a more radiogenic endmember (Fig. 1). These data fall along a paleoisochron consistent with ingrowth of Pb from 2.0 Ga to the time of impact at 215 Ma. While the Manicouagan Imbricate Zone (MIZ) terrane is considered to be 1.6 Ga, a model using this age for T1 does not reproduce the slope of the plagioclase Pb data. Nd model ages are 2.01 [1] and this mix of isotope compositions is likely seen in the Pb as well. The extreme spread of ratios suggests limited Pb isotope homogenization in this sample.

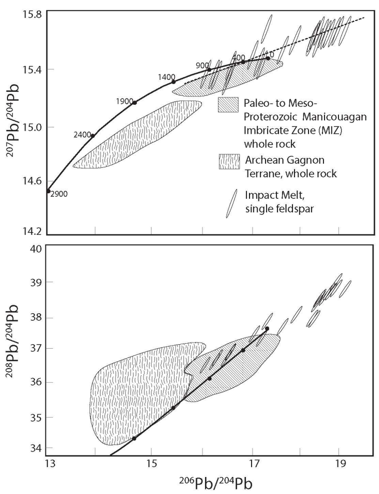

Figure 1: Pb isotope values of Manicouagan melt sheet feldspar crystals (error ellipses). Shown for context are single-stage U-Pb growth curves for μ=8 ($^{238}U/^{204}Pb$) and κ=4 ($^{232}Th/^{238}U$) and whole-rock values of the regional geologic units including the Paleoproterozoic to Mesoproterozoic Manicouagan Imbricate Zone (MIZ) and the Archean Gagnon Terrane [13]. The feldspar data lie along a line that can be explained by Pb evolution from 2.0 Ga to the time of impact at 214 Ma, with target source of MIZ. The feldspar data extend beyond the whole rock MIZ field consistent with a heterogeneous mix of minerals with variable μ within the target.

Modeling: To model the effect of partial resetting on isochron and Pb-Pb isotope arrays, we track the isotopic (e.g., $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, and $^{206}Pb/^{204}Pb$) and parent-daughter (e.g., $^{87}Rb/^{86}Sr$, $^{143}Nd/^{144}Nd$, and $^{238}U/^{204}Pb$) ratios of four aliquots (mineral separates or whole-rocks) formed with identical initial isotopic ratios at 1.6 Ga, aged as closed systems until 215 Ma, then isotopically requilibrated to some fractional extent towards an assumed bulk/average isotopic composition at 215 Ma, and then aged until the present.

Modeling Results: Modeled isotope Pb ratios generate a modeled paleoisochron that closely resembles measured values from Manicouagan. This simple analysis suggests that at least 1-10% of pre-impact Pb isotopic heterogeneity will persist over centimeter scales for large parts of the melt sheet. Interestingly, our model also predicts different degrees of resetting across multiple isotopic systems. While significant heterogeneity persists for Pb (and particularly for Pb in dry environments), Nd and Sr retain less heterogeneity. Argon follows Sr, but to a greater degree and is modeled to be nearly completely homogenized.

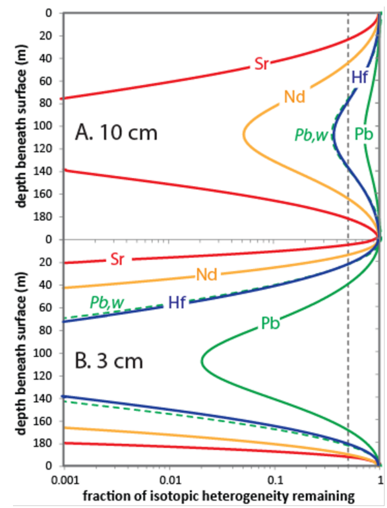

Figure 2: Fractional homogenization of isotopic heterogeneities over 10 cm (A) and 3 cm (B) length scales for a 200-m-thick melt sheet . Curves are not symmetric due to zero-temperature upper boundary constraint. Isotopic heterogeneities are predicted to be largest at any given depth or length scale for Pb and Hf, and least for Nd and Sr.

Implications for Mars: Our results show similarities to martian shergotties in that they both give young Ar ages with a range of ancient Pb. Similarly, recent, single-grain SIMS analyses of shergottites [14] shows heterogeneity in Pb isotopes analogous to what we observed in the Manicouagan melt sheet. Therefore, we propose re-evaluating the possibility of shergottites representing ejected pieces of a martin melt sheet.

References: [1] Spray, J. G. and Thompson, L. M. (2008) MAPS 43, 2049-2057 [2] French, B. M. 1968, in Shock Metamorphism of Natural Materials, 383–412. [3] Nyquist, L (2001). Chronology and Evolution of Mars 96, 105-164. [4] Jones, J. H. (2015). MAPS 50: 674-690. [5] Fritz, J. et al (2005). MAPS 40: 1393-1411. [6] Bouvier, A. et al. (008) EPSL 266, 105–124. [7] Bouvier, A. et al. (2009) EPSL 280, 285–295. [8] Stephan T. and Jessberger, E. K. (1992) GCA 56, 1591-1605. [9] Jaret et al. (2018). EPSL 501, 78–89. [10] Chen, J. H. and Wasserburg, J. G. (1986) GCA 50, 955–968. [11] Hemming and Rasbury Chemical Geology; [13] Gwiazda et al.; [13] O'Connell-Cooper, C. D. et al., (2012). EPSL 335-336, 48-48. [14] Bellucci, J. J. et al. (2015). JGR 120, 2224–2240.