DYNAMIC CRYSTALLIZATION OF SHOCK MELTS IN ALLAN HILLS 77005: IMPLICATIONS FOR MELT POCKET FORMATION IN MARTIAN METEORITES. E.L. Walton and C. D. K. Herd, Department of Earth and Atmospheric Sciences, 1-26 Earth Sciences Building, University of Alberta, Edmonton, AB, T6G 2E3, Canada (correspondence author's email: ewalton@ualberta.ca).

Introduction: Melt pockets are an important constituent of strongly shocked Martian meteorites, containing trapped noble gases, N_2 and CO_2, which closely match that of the Martian atmosphere [1]. Knowledge of the mechanism by which melt pockets form is crucial to understanding how the Martian atmospheric gases are implanted. Mechanism(s) for melt pocket formation can be roughly divided into two scenarios, the first involving injection of extraneous molten material into cracks and fractures in the host rock, and the second, in situ melting by void collapse by shock. The goal of this study is to constrain the heating and cooling regimes for the crystallization of a melt pocket in a strongly shocked Martian meteorite.

Although dynamic crystallization experiments alone do not present a unique model for the formation of melt pockets, they do set limits on existing, or yet to be proposed, models. An earlier crystallization study on melt pockets used homogeneous starting material of Los Angeles, DaG 476 and SaU 150 melt pocket composition [2]. In this study, we investigate the development of microporphyritic texture in starting material of Allan Hills (ALH) 77005 melt pocket composition, as a function of variable nucleation sites present at the onset of cooling. Crystal shapes have been quantified using the texture correlation technique of [3], enabling comparison between experimental run products and natural crystals by the measured fractal dimension (*df*).

Petrography of ALH 77005 melt pocket: Olivine crystallites occupy 75% of the melt pocket by volume. The remaining 25% is divided between chromite (3%), vugs/vesicles (4%) and entrained host rock clasts (8%), embedded in a glassy matrix (10%). The melt pocket has an irregular shape (~3 mm) characterized by a microporphyritic texture of olivine and chromite crystals embedded in silicate glass with minor acicular crystals of clinopyroxene. The olivine microphenocrysts exhibit two distinct shapes: equant euhedral and skeletal. Crystal shape changes as a function of distance from the melt pocket interior to margin (contact with the host rock) with central portions dominated by elongate skeletal crystals progressing to compact (equant) crystals near the margin.

Experimental Techniques: Twenty grams of Mg-rich, Al-, Ca-poor synthetic glasses, representative of the bulk composition of one microporphyritic olivine melt pocket (MPO-1) in ALH 77005, were produced from mixtures of high purity oxides and carbonates. The near liquidus melting relations were determined for MPO-1 with melt times varying from 1–2 hours. Olivine is the first phase on the liquidus at 1510 ^{o}C. In order to investigate the effect of heterogeneous nucleation on the resultant texture of the run product, the starting material was heated to superliquidus (1560 ^{o}C and 1520 ^{o}C), liquidus (1510 ^{o}C), and subliquidus (1500 ^{o}C and 1460 ^{o}C) temperatures, following the experimental technique of [4]. After an initial soak time of 30 min. the samples were cooled to 1380 ^{o}C at the QFM buffer using a Eurotherm controller, at a fixed rate (ΔT 10–1000 ^{o}C/hr). The run products were vacuum mounted in epoxy, polished to 0.25 μm, and carbon coated for characterization using a JEOL 6301F Field Emission SEM and a JEOL 8900 microprobe equipped with five wavelength dispersive spectrometers using an accelerating voltage of 1 kV and a beam current of 15 nA.

Fractal analysis was performed on BSE images of run products and natural melt pocket crystals converted to binary images, so that all pixels belonging to the crystal are black and all other pixels are white. A custom-designed Texture Correlation Calculation (TCC) program, written by Steven Cogswell at the University of New Brunswick, analyses the binary images by selecting a black pixel as the origin of a series of concentric shells, constructed with increasing radius, *r*, from the origin. The ratio of pixels that are black to the total amount of pixels in the shell, called the correlation function C(*r*), is computed for all *r* (2–100). This gives the probability that a pixel, separated from the origin by distance *r*, is part of the crystal. This function has been shown to scale in the same way as the density of pixels in a two-dimensional fractal object [5]. A quantitative value for *df* is obtained from a double logarithmic density-density plot of log C(*r*) versus log *r* for all pixels (slope = *df* – 2).

Experimental Results: A variety of microphenocryst shapes were observed including dendritic, skeletal and equant euhedral. The texture of runs cooled from melts heated above liquidus temperatures differ markedly from runs cooled from liquidus and subliquidus temperatures. Radial textures have been produced in the highest temperature runs (1560 ^{o}C; ΔT 500, 1000 ^{o}C/hr), comprised of radiating parallel chain olivine crystals in glass. When cooled at a slower rate (10 ^{o}C/hr), the same superliquidus run produced olivine dendrites with random orientations. Melts cooled from the liquidus temperature (1510 ^{o}C) yielded skeletal crystals ranging from equant to elongate forms with increasing cooling rates. Subliquidus melting conditions (1500 and 1460 ^{o}C) yielded dominantly microporphyritic textures with equant, euhedral olivine microphenocrysts when cooled at slow to moderate rates (10–500 ^{o}C/hr), with the exception of hopper crystals observed in the 1500 ^{o}C run cooled at 500 ^{o}C/hr. Fast cooling (1000 ^{o}C/hr) from subliquidus temperatures yield transitional run product textures characterized by dendrites nucleating from the corners of equant euhedra, embedded in a glassy groundmass.

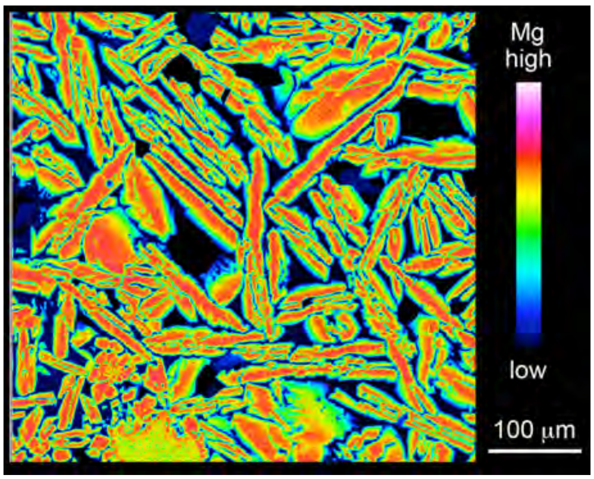

Fig. 1. Mg X-ray elemental map of elongate skeletal olivine crystals in ALH 77005 melt pocket center.

Texture Correlation Calculation Results: All analyzed dendritic and skeletal crystals fall along a straight line with negative slope, confirming their fractal nature [3, 5]. Olivine from the natural melt pocket shows higher fractal dimensions for crystals analyzed near the central portions (*df* = 1.85) compared to crystals located more proximal to the melt pocket margin (*df* = 1.78). For experimental crystals, radial olivine has a higher fractal dimension (*df* = 1.92) compared to elongate skeletal shapes (*df* = 1.79–1.85). Equant skeletal crystals have the lowest *df* (1.76–1.78), while equant euhedral grains have a more compact density distribution and are not fractal objects.

Discussion: Microphenocryst shapes in the natural melt pocket are equant euhedral, hopper and elongate skeletal, comparing well with representatives from the experimental run products. Radial olivine and transitional textures, produced experimentally in MPO-1, have not been observed in the natural pocket. Qualitative and quantitative analysis of experimental run products show best fits for central melt pocket temperatures of 1510–1520 ^{o}C, progressing to lower temperatures near the melt pocket margin. Cooling rates were fast (500–1000 ^{o}C/hr) corresponding to a short duration (~8–17 min) for the melt pocket forming event. This is consistent with the presence of trapped Martian atmosphere and high pressure polymorphs in natural melt pockets [1, 6], requiring rapid freezing of the melt for preservation. It should be noted that the melting temperatures are only minimum estimates, since temperatures in the natural melt pocket could have been much higher, but only for a short period of time (minutes to seconds).

Previous crystallization experiments on melt pockets in Martian basalts have shown that these melt pockets cool from post-shock temperatures within minutes at rates 780–1560 ^{o}C/hr [2]. This cooling environment yields randomly oriented dendritic olivine, apatite and clinopyroxene with minor chromite and Fe-oxides. The liquidus temperatures (1200, 1300 and 1455 ^{o}C, [2]) are lower than those determined for the more olivine-rich melt pocket observed in this study (1510 ^{o}C). The predominance of dendritic crystal shapes in the melt pockets of [2], reflects the likelihood that melt pockets with lower liquidus temperatures will be more completely melted, destroying most or all nuclei in the melt. Crystal growth occurs at high degrees of supercooling, yielding dendritic shapes [7].

Conclusions: Melt pockets are localized shock-generated hot spots in shocked Martian basalts and lherzolitic basalts, presumably formed during the impact event, which launched the rocks into eventual Earth-crossing trajectories. The results of this study constrain the heating and cooling regime for a microporphyritic melt pocket in ALH 77005. Within the melt pocket, strong thermal gradients existed at the onset of crystallization, giving rise to a heterogeneous distribution of nucleation sites resulting in gradational textures of olivine and chromite. Skeletal olivine (*df* = 1.85) in the melt pocket center crystallized from a melt containing few nuclei cooled at a fast rate (ΔT 500–1000 ^{o}C/hr). Nearer to the melt pocket margin elongate skeletal shapes progress to hopper (*df* = 1.78) and equant euhedral (non-fractal), reflecting an increase in nuclei in the melt at the initiation of crystallization and growth at low degrees of supercooling.

References: [1] Bogard D.D. and Johnson P. (1983) *Science* 221, 651-654. [2] Walton E.L. et al. (2006) *GCA* 70, 1059-1075. [3] Fowler A.D. (1995) *Fractals in the Earth Science*, Plenum Press, NY, pp. 237-249. [4] Lofgren G. and Russell W.J. (1986) *GCA* 50, 1715-1726. [5] Fowler A.D. and Stanley H.E. (1989) *Nature* 341, 134-138. [6] Beck P. et al. (2004) *EPSL* 219, 1-12. [7] Lofgren G. (1989) *GCA* 53, 461-470.