

PROPOSED EXPERIMENTS ON THE EFFECT OF RAPID DECOMPRESSION ON THE FRAGMENTATION OF BASALT WITH IMPLICATIONS FOR THE FORMATION OF MARTIAN RAMPART CRATERS. A. H. Rager¹, ¹University of Nevada Las Vegas (Department of Geoscience, M/S 4010, 4505 S. Maryland Parkway, Las Vegas, NV 89154-4010, ahrager@unlv.nevada.edu)

Introduction: Did Mars ever have water? To find out, NASA scientists sent the Opportunity Mars Exploration Rover (MER) to Meridiani Planum, a region with a high hematite concentration. Data and images of cross-bedded sediments containing hematite spherules returned by Opportunity have led MER Team scientists to propose these sediments were formed in a wet dune environment [1]. Were the sediments at Meridiani Planum really formed in the presence of surface water? Knauth et al. [2,3] have proposed the Meridiani Planum sediments were formed by a ground surge resulting from a meteorite impact(s) into a volatile-rich regolith and that this mechanism may explain another mystery of Martian geology – fluidized ejecta blankets surrounding Martian rampart craters.

Martian rampart craters are unique in the solar system [4,5,6]. They are characterized by fluidized ejecta that hugs topography and terminates in a distal rampart about 1 to 2 crater radii from the rim. Martian rampart craters have a global distribution with no apparent correlation to target age or composition [4]. There is currently a debate as to what mechanism is responsible for the emplacement of the fluidized ejecta and whether the process is controlled by the interaction of ejecta with the atmosphere, subsurface volatiles, or both [4]. Pyroclastic flow [7] and ground surge models [2,3] have been proposed by previous workers.

I propose a model for the emplacement of fluidized ejecta on Mars. In this model, the rapid decompression of carbon dioxide contained within the regolith causes an increased degree of fragmentation during the excavation stage of impact cratering. This results in an increased proportion of fine materials causing the ejecta to be emplaced in a fluidized fashion. The size of the largest blocks is decreased overall. Large blocks are emplaced ballistically, forming secondary craters within one-crater radii of the rim. However, these secondary craters are covered by a ground surge and/or finer materials collapsing behind an advancing ejecta curtain (explaining why rampart craters typically lack secondary craters within the ejecta blanket). I will test this model by conducting experiments in the volcanic fragmentation lab at the University of Munich.

Background: During the contact/compression stage of impact cratering, target materials can experience temperatures up to 10,000°C near the impact point and from 500° to 3000°C in the surrounding rock [5,6]. Rocks near the point of impact are shocked to over 100 GPa of pressure [6]. Pressures decrease away from the point of impact to about 10 - 30 GPa about one-crater radii from impact [6]. These high pressures are rapidly released within less than a second. At this point, the

excavation stage begins, during which rocks are fragmented and typically are ballistically emplaced as ejecta [6].

Methods: University of Munich has an experimental facility for the investigation of rock fragmentation by rapid decompression (Alidibirov and Dingwell 1996a). Using this facility, I will test the effect of rapid decompression of carbon dioxide on the fragmentation of basalt.

The experimental apparatus consists of a high-pressure, high-temperature section separated by a diaphragm from a low-pressure, low-temperature section [10]. The high-pressure section can reach pressures of 500 bars (50 MPa) and temperatures of 950°C [12]. The high-pressure, high-temperature section can be adapted for high-pressures and low-temperatures. When the diaphragm separating the two sections is broken, the pressure in the lower chamber rapidly drops. A release wave propagates through the sample at the speed of sound [12], generating dynamic tensile stresses in the sample. If the dynamic tensile strength of the sample is exceeded by the release wave, fracturing and fragmentation will occur. Compressed gas contained in the pore spaces of the sample will expand and accelerate the fragments.

Temperatures and pressures experienced by rocks during impact far exceed those of the experimental facility. However, this study is not intended to simulate the exact conditions during impacts. Rather, the purpose of this study is to investigate whether the rapid decompression of carbon dioxide increases the degree of basalt fragmentation.

Carbon dioxide and water are the most abundant volatiles in the Martian regolith. These volatiles vary in relative composition and phases present with latitude and depth [13]. Surface temperatures range from 150 – 230 K [16]. On the surface, carbon dioxide exists as a gas making up 95% of the Martian atmosphere. Carbon dioxide gas is contained in regolith pore space at or near surface conditions. With increased depth (increased pressure), carbon dioxide will occur in a solid or liquid phase, depending on latitude. Water will occur as ice near the surface and as liquid water at depth (increased pressure).

Most impacts will produce high shock pressures at depths of about 8 km [6]. At depths of 50m or more, carbon dioxide occurs as a solid or liquid. Water occurs as a solid and may occur as liquid at depths greater than 5000 m. Therefore, it is reasonable to assume that regolith containing solid, liquid, and gaseous carbon dioxide and solid and liquid water will be subjected to high shock pressures during impacts.

Previous studies suggest that, under peak impact temperature and pressure conditions, carbon dioxide may occur at a liquid or solid phases [17,18,19] and water may occur at solid, liquid, or supercritical fluid phases [20,21,22,23]. Regolith containing solid, liquid, and gaseous carbon dioxide and solid and liquid water will experience high shock pressures within a few seconds. This sudden increase in temperature and pressure will instantaneously drive carbon dioxide into solid or liquid phases and water into solid or liquid phases. During the transition from contact/compression to excavation, these extreme pressures will be instantaneously released, driving carbon dioxide and/or water to gaseous or liquid phases.

Only the effect of rapid decompression of carbon dioxide will be tested in this experiment. The fragmentation effect of rapid decompression of water and the interaction of various concentrations and phases of carbon dioxide and water may be the subject of future research. In this experiment, lower chamber conditions will simulate the solid and/or liquid phases of carbon dioxide and/or water under peak impact conditions. The upper chamber will be pressurized to average Martian atmospheric conditions (0.007 – 0.01 bars) using 90- 100% carbon dioxide. Breaking of the diaphragm will create a sudden release in pressure similar to what occurs during the transition from contact/compression to excavation. Temperature conditions in the excavated ejecta are not precisely known. Therefore, the upper chamber will have two temperature regimes to cover the solid and gaseous phases of water. This will facilitate comparison with the results of future experiments using water as a volatile.

Rock samples will be prepared according to the procedures outlined in [24]. The lower chamber will be cooled to average Martian surface temperatures (160 – 200 K). While in this temperature range, carbon dioxide gas (90 -100%) will be added to the lower chamber until average Martian atmospheric pressure (0.007 – 0.01 bars) are reached. For each experimental setup, the lower chamber will be cooled to starting temperatures. Additional carbon dioxide will be added to maintain average Martian atmospheric pressures. When both temperature and pressure conditions typical of Mars are reached, argon gas will be added until starting pressures are attained. Control tests will be setup the same way with the exception that no carbon dioxide will be added to the lower chamber. Three to ten replicates will be run for each set of conditions.

The temperature and pressure conditions between the contact/compression and excavation stages of impact cratering are not precisely known and may vary with distance from the impact point. The six P/T regimes were selected to test rapid decompression of carbon dioxide between the following phases (1) solid carbon dioxide (within solid water phase) to gaseous carbon dioxide (within liquid water phase);

(2) solid carbon dioxide (within solid water phase) to liquid carbon dioxide (within liquid water phase);
(3) liquid carbon dioxide (within solid water phase) to gaseous carbon dioxide (within liquid water phase);
(4) liquid carbon dioxide (within solid water phase) to liquid carbon dioxide (within liquid water phase);
(5) liquid carbon dioxide (within liquid water phase) to gaseous carbon dioxide (within liquid water phase);
(6) liquid carbon dioxide (within liquid water phase) to liquid carbon dioxide (within liquid water phase).

Although no water will be used in this study, the upper chamber and lower chamber conditions have been selected to fall within the solid, liquid, and gas phases for water. This will facilitate comparison to future experiments using water or a combination of carbon dioxide and water.

References: [1] Grotzinger, J. et al. (2006) *Geology*, 34:12, 1085-1088. [2] Knauth, L. P., et al. (2005), *Nature*, 438, 1123 – 1128. [3] Knauth, L. P., et al. (2006), *Lunar and Planetary Science XXXVII*, Houston, TX. [4] Barlow, N. G. (2005), Special Paper – Geological Society of America, 384, p. 433-442. [5] de Pater, I., Lissauer, J. J. (2001) *Planetary Sciences*, Cambridge University Press, New York, NY, 528 pp [6] Melosh, H. J. (1989) *Impact cratering; a geologic process: Oxford Monographs on Geology and Geophysics*, v. 11, p. 245. [7] Schultz, P. H., and Gault, D. E. (1979) *JGR*, 84, 7669 - 7687. [8] Visser, G. S. (1969) *Journ. of Sed. Petrol.*, 39:3, 1074-1106. [9] Wilson, C. J., N. (1981) *Studies on the origins and emplacement of pyroclastic flows*, Ph.D. theses, Imperial College, University of London. [10] Alidibirov, M. A., and Dingwell, D. B. (1996) *Bulletin of Volcanology*, 58:5, 411-416. [11] Spieler 2007, (pers. comm.). [12] Alidibirov, M., and Dingwell, D. B. (1996) *Nature*, 380:6570, 146-148. [13] Longhi, J. (2006) *JGR*, 111: E06011, 1-16. [14] Kieffer, H. H., et al. (1976), 194, 1341-1344. [15] Clifford, S. M., and Haberle, R. M. P. (1993) *JGR*, 98, 10-11,016. [16] Lodders, K., and Fegley, B., Jr. (1998) *The Planetary Scientist's Companion*: New York, New York, Oxford, 371 pp. [17] Giordano, V. M., and Datchi, F. (2007) *Europhysics Letters*, 77, 46002-p1-46002-p5. [18] Iota, V., et al. (1999) A new molecular solid phase of carbon dioxide at high pressure and temperature, UCRL-JC-135383, Lawrence Livermore National Laboratory, 3 pp [19] Santoro, M., et al. (2006) *Nature*, 441, 857-860. [20] Abascal, J. L. F., et al. (2005) *Journal of Chemical Physics*, 122:23, 1-9. [21] Mercury, L., Vieillard, P., and Tardy, Y. (2001) *Applied Geochemistry*, 16:2, 161-181. [22] Schwager, B., et al. (2004) *Journal of Physics Condensed Matter*, 16:14, S1177-S1179. [23] Song, M., et al. (2003) *Condensed Matter and Materials Physics*, 68:1, 141061-1410610. [24] Schue, B., 2005, *Understanding silicic volcanism: Constraints from elasticity and failure of vesicular magma* [Ph.D. thesis]: University of Munich, 139 p.