EFFECTS OF AN EARLY-TIME IMPACT GENERATED VAPOR BLAST IN THE MARTIAN ATMOSPHERE: FORMATION OF HIGH-LATITUDE PEDESTAL CRATERS.

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Introduction: Following impact, vapor expansion creates an intense airblast that interacts with the ambient atmosphere [1-3]. The resulting hemi-spherical shock wave leaves a signature on the surface that is dependent on initial atmospheric and surface conditions. Here we propose that the formation of pedestal craters (craters surrounded by an erosion-resistant pedestal) may be a direct consequence of extreme winds and elevated temperatures generated by such an impact-induced atmospheric blast.

Pedestal craters, first recognized in Mariner 9 data [4], are a unique feature on Mars and likely a signature of near-surface volatiles [e.g., 5-10]. They are found at high latitudes (small pedestals, Amazonian to Late Hesperian in age) and in thick equatorial mantling deposits (larger pedestals, early Hesperian to Noachian in age). Previously suggested mechanisms for pedestal crater formation (e.g., wind: ejecta curtain vortices [11] or vapor blast [5,11]; and ejecta dust: armoring [12]) do not provide a complete picture. The clear evidence for near-surface volatiles at high latitudes requires a re-evaluation of these alternative models. The results presented here suggest that a combined atmospheric blast/thermal model provides a plausible formation hypothesis.

Background: Impact-induced vaporization is a key component of early time cratering mechanics. Many previous studies, both experimental [13-15] and computational [e.g., 16], focused on the generation and expansion of vapor clouds in an attempt to better understand vaporization in hypervelocity impacts. Here we investigate the response from energy directly imparted from the early time vapor to the surrounding atmosphere on Mars. Such a response, and its possible expression on the surface, has been examined for impacts on Earth [e.g., 17].

The CTH shock physics analysis package [18] with adaptive mesh refinement [19] was used to construct a model of a point-source instantaneous release of a large amount of energy into a small volume of gas during a short time interval. Energies corresponding to 0.1% and 1.0% of the total impact energy (and momentum) required to create a 10 km diameter crater (6 km "apparent" pre-collapse crater) on Mars were coupled to a CO_2 atmosphere (specific heat ratio of 1.3) with an ambient density of 1.55e-5 g/cc and an ambient temperature of ~240 K at the surface (y=0).

The model results show a very good correlation to analytical calculations of the physics behind an airblast created by an intense explosion (see [20]).

Results: A fast blast wave (followed by recovery winds) and a large temperature pulse will engulf the surface surrounding a 10 km crater on Mars. Prior to ejecta emplacement, powerful winds (> 100 m/s) sweep over the region surrounding the impact, thereby stripping the surface of loose soil and dust (Figure 1). The surface is then immersed in an atmosphere with temperatures exceeding 273 K over times approaching 1 minute (even for the case of 0.1% coupling) (Figure 2).

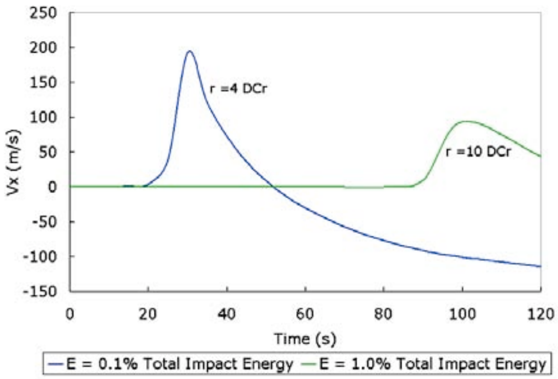

Figure 1: Horizontal velocity as a function of time for y=0 (surface) from computational models releasing 0.1% and 1.0% of the total energy required to create a 10 km diameter impact crater. DCr stands for apparent crater diameter. Results are displayed for positions of 4 apparent crater diameters (~25 km) for the case of 0.1% coupling and 10 apparent crater diameters (~60 km) for the 1.0% coupling case. These locations mark the distances from the crater center at which the front of the atmospheric shock blast equilibrates to ambient atmospheric pressure [11].

Residual temperatures behind the blast wave are much higher than ambient conditions, particularly close to the crater (1000 K at 2 apparent crater diameters). Even at greater distances (e.g., 4 apparent crater diameters), atmospheric temperatures radiating into the upper surface will produce a thermal wave that can extend down to ~15 cm in only 30 seconds for an ice-rich substrate (see Figure 3).

Implications: The combined effects of an intense atmospheric wind blast and thermal pulse should have particular significance for regions covered by an ice-rich mantle, e.g., high latitudes. Some possible residual signatures include; scoured zones (characterized by radial striations and muting of surface detail – see Figure 4a), armored surfaces created by thermally indurated soil (melting and migration of subsurface water), and pedestal craters.

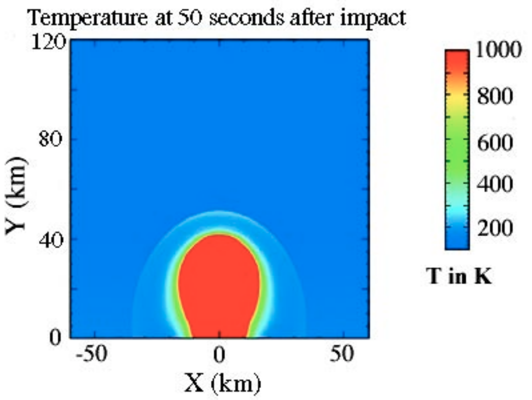

Figure 2: Temperature image from a computational model of a point source explosion releasing ~10^{23} ergs of energy into a Martian atmosphere. This energy correlates to a 0.1% coupling of the total energy involved in the creation of a 10 km diameter crater on Mars. Red denotes temperatures of 1000 K or greater. Blue indicates temperatures of 100 K or less.

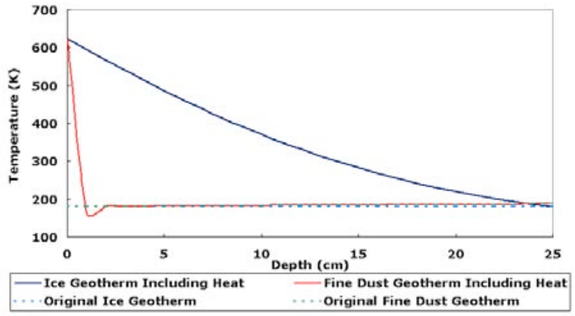

Figure 3: Temperature as a function of depth below the surface at 30 seconds after impact. The large temperature pulse and lingering atmospheric temperatures created from the direct coupling of impact energy (0.1% coupling plotted here) to the atmosphere results in a thermal wave that travels down into the upper surface layers. Comparisons between normal geotherms (for both ice and fine dust) and geotherms including this extra heat source are shown for the location of 4 apparent crater diameters (r = 25 km). Geotherm equations can be found in [21].

Pedestal Craters: Volatile-rich surface layers at high latitudes are highly susceptible to erosion over short times as a response to orbital forcing [6]. The calculated atmospheric winds and subsurface thermal wave discussed here would form a crater-centered erosion-resistant indurated surface layer around craters at high latitudes (Figure 4b).

Martian pedestals can extend up to ~10 crater diameters depending on crater size, age, and location [5-6]. Based on our study, energy coupling of at least 1.0% (into an atmospheric blast) would be necessary to create an erosion-resistant surface lag as a result of the combination of blast winds and thermal effects out to a distance of 10 crater diameters.

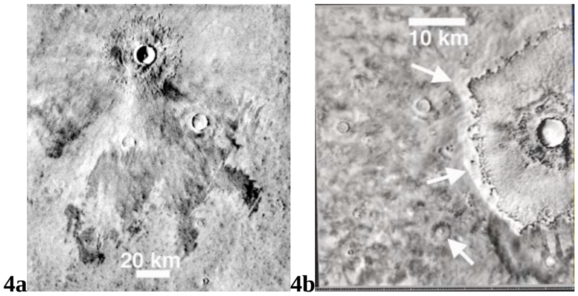

Figure 4: (4a): Image of a ~12 km diameter Martian pre-pedestal crater. Scouring of the surface extends to ~8 crater diameters. (4b): Image of a ~6 km diameter Martian pedestal crater. Pedestal extends out to ~4 crater diameters. The bottom arrow points out an example of a much smaller pedestal crater.

Present / Future Work: Recent laboratory experiments [15] have captured the interplay between the expanding vapor generated on impact and the developing ejecta curtain, permitting investigation of the mechanics of the early stages (~150 μs after impact) of the cratering process. Comparisons of this experimental data with computational data from applications of the present model at such early times will lead to a better understanding of the interactions between an impact-induced vapor blast and the surrounding atmosphere, perhaps narrowing down the possible values for the extent of energy transfer.

More detailed modeling, benchmarked by laboratory experiments, is needed to test the relative roles of the atmospheric wind blast and temperature pulse for different volatile-rich lithologies. This, in turn, will help assess locations of past volatiles across Mars.

References: [1] O'Keefe, J. D. and Ahrens, T. (1982) *Geological Implications of Impacts of Large Asteroids and Comets on the Earth, Special Paper 190*, 103-120. [2] Ahrens, T. and O'Keefe, J. D. (1987) *Int. J. Impact Eng.*, *5*, 13-32. [3] Roddy, D. J. et al. (1987) *Int. J. Impact Eng.*, *5*, 123-135. [4] McCauley, J. F. (1973) *JGR*, *78*, 4123-4137. [5] Schultz, P. H. (1988) *LPS XIX*, 1039-1040. [6] Schultz, P. H. and Lutz, A. B. (1988) *Icarus*, *73*, 91-141. [7] Thomson, B. J. and Schultz, P. H. (2004) *LPS XXXV*, Abstract #1885. [8] Schultz, P. H. (2003) *6th Mars Conf.*, Abstract # 3263. [9] Mouginis-Mark, P. J. (1987) *Icarus*, *45*, 268-286. [10] Barlow, N. G. (2005) *LPS XXXVI*, Abstract #1415. [11] Schultz, P. H. (1992) *JGR*, *97*, 16183-16248. [12] Arvidson, R. E. et al. (1976) *Icarus*, *27*, 503-516. [13] Sugita, S. *et al.* (1998) *JGR*, *103*, *E8*, 19,427-19,441. [14] Schultz, P. H. (1996) *JGR*, *101*, 21117-21136. [15] Wrobel, K. E. and Schultz, P. H. (2004) *LPS XXXV*, Abstract #1800. [16] Pierazzo E. and Melosh, H.J.(1999) *Earth Planet. Sci. Lett.*, *165*, *2*, 163-176. [17] Adushkin, V. V. and Nemchinov, I. V. (1994) *Hazards due to Comets and Asteroids*, 721-778. [18] McGlaun, J. M. et al. (1990) *Int. J. impact Eng.*, *10*, 351-360. [19] Crawford, D. A. et al. (2002) *New Models and Hydrocodes for Shock Wave Processes in Cond. Matter*, Edinburgh, U.K. [20] Wrobel, K. E. and Schultz, P. H. (2005) *LPS XXXVI*, Abstract #1221. [21] Arfstrom, J. D. (2004) *LPS XXXV*, Abstract #1105

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