# ATMOSPHERIC EFFECTS AND THE RECORD OF SMALL CRATERS ON MARS.

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**Introduction:** Impact crater populations, together with size-frequency isochrons derived for Mars [1], are currently used to estimate the absolute ages of Martian surfaces. These isochrons were originally developed for the Moon, and later transposed to Mars by attempting to estimate the cratering rate for Mars relative to that of the Moon. In the process, however, many idealizations are made in order to simplify the problem, one of which is to neglect the effects of Mars' current 6.1 mBar atmosphere. The presence of this atmosphere influences cratering efficiency by decelerating, ablating, and breaking up incident impactors. Each of these processes may affect cratering rates significantly but differently.

Mars' average surface pressure also varies, both spatially and temporally. Several workers [e.g. 2,3] have found that changes in Mars' obliquity may cause its surface pressure to vary between zero and ~35 mBar [4] on timescales of $10^5$-$10^6$ years, variations which might be detectable in the record of small craters that are resolvable with current MOC NA imagery and with upcoming capabilities of even higher spatial resolution. In addition, Martian topography results in surface pressures that currently span an order of magnitude from ~10 mBar in Hellas to less than 1 mBar on Olympus Mons (fig. 1); vast regions of Mars lie under surface pressures of ~4.5 mBar (southern highlands) and ~7.5 mBar (northern lowland plains). The purpose of this work is to investigate how the presence of the martian atmosphere, and its variations, affect small (< 250 m) impact cratering rates, and surface ages derived therefrom, and how its variations may be expressed in the cratering record.

**Methods:** We built a computer model which generates an impactor population with properties (impactor type, entry velocity and entry angle; types include 60% carbonaceous, 20% icy, 13% stony, and 7% iron) appropriate for Mars, and simulates their passage through a Martian atmosphere, using a Runga-Kutta 4th order method, and their impact on the surface. The model distinguishes catastrophic from non-catastrophic breakup by calculating a "scatter field" [5] whenever a breakup occurs. The scatter field is then required to be less than one third the diameter of the crater that would be formed by the same object in the absence of an atmosphere, in order for breakup to be *non*-catastrophic; otherwise breakup is catastrophic and no crater is produced. Thus more massive objects suffer catastrophic breakup less easily than smaller ones; indeed, for impactors of high enough mass, breakup makes essentially no difference and they crater the surface as if intact.

For each value of Martian surface pressure, the impacts of 2000 objects at each mass value $m=10^{n/2}$ kg (n=-2,-1,...,13,14) were simulated. This range of mass values was chosen to include all masses capable of producing 2-300 meter craters at cosmic velocities. The resultant crater populations were binned, multiplied by appropriate factors according to the mass-frequency law $N(m)=N_{ref}(m_{ref}/m)^{1.16}$ [6] (where $m_{ref}$ is a reference mass value and $N_{ref}$ is the number of objects of mass $m_{ref}$), and added together to form the final size-frequency distribution. With $m_{ref} =10^4$ kg and $N_{ref}$ = 2000, this is equivalent to a population of ~1.7 billion impactors. The resulting crater populations were plotted on cumulative size-frequency graphs, together with Mars isochrons for reference and comparison.

**Results and Conclusions:** Figure 2 demonstrates that the presence of Mars' current atmosphere has two effects. First, it reduces the crater population at all diameters studied by a factor of ~5, due primarily to the breakup of many icy and carbonaceous objects of all masses. This shift may cause underestimation of Martian surface ages derived from integrated cratering rates (e.g. isochrons) by a similar factor. Second, there is a slight 'turndown' in the slope of the data below about D=100 m, caused by increasing numbers of catastrophic breakups of lower mass objects, and by burnup and deceleration which significantly affect only these smaller masses.

Figure 3 shows that each successive 10 mBar increase in surface pressure results in an additional turndown-plus-displacement in the crater population, with the first few mBar of atmosphere clearly having the greatest influence on the cratering rate. Figure 4 displays the pressure range 0-10 mBar in more detail, and shows that the same sort of general behavior prevails at smaller scales. Notice that even a 2 mBar atmosphere produces a turndown at D~20 m. Our results indicate that impact cratering rates, R(D), fall off approximately as inverse power laws of the surface pressure.

While the turndown due to the current Mars atmosphere (fig. 2) is slight, and probably isn't observable in current cratering data, turndowns due to atmospheres of 30-40 mBar (fig. 3) are larger in magnitude, shallower in slope, extend to greater diameters, and show a pronounced downward curvature. Observations of such features in actual data may provide physical evidence of past, much denser atmospheres on Mars.

It is also possible, using figures 1 and 4, to estimate the effects of altitude on relative cratering rates from place to place. Taking as an example the case of the southern highlands vs. the northern plains, which differ in average surface pressure by about 3 mBar, figure 4 shows that, all else being equal, one may expect the cratering rate between D=4 m and D=80m to be larger in the south than in the north by a factor of ~2, due to its greater altitude alone. Thus a substantial difference in cratering rates exists between these two regions which, together, cover most of the planet.

Finally, it is interesting to note that the computer-generated size-frequency distributions, including the one for zero atmosphere, do not agree well with the Mars isochrons (figs. 2-4). We find that an exponent of 1.26 in the mass-frequency law brings our crater populations parallel to the isochrons. However, it remains an open question which needs adjusting: the mass-frequency-law or the slopes of the Mars isochrons.

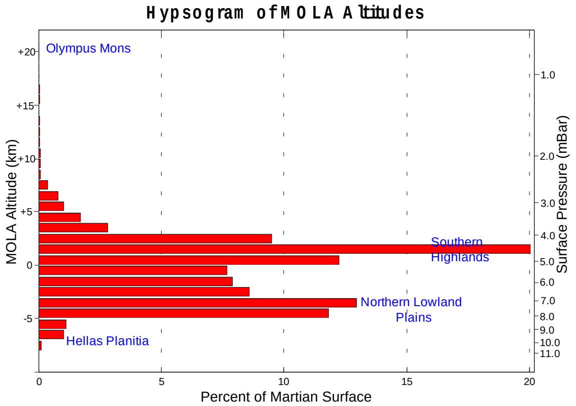

Fig.1:A hypsogram of Mars. The northern plains and southern highlands are prominent features.

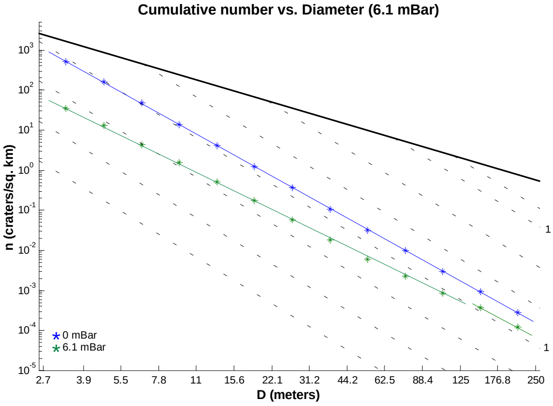

Fig.2: Cumulative size-frequency distribution for Mars current atmosphere, compared to that for zero atmosphere.

## References:

[1] http://www.psi.edu/projects/mgs/isochron.html [2] Bills, B. G. (1990) *JGR*, **95**, 14137-14153., [3] Ward, W. R. (1973) *Science*, **181**, 260-262. [4] James, P. B. et al. (1992) in Mars, U. of Arizona Press, p. 949. [5] Passey, Q. R. and Melosh, H. J. (1980) *Icarus*, **42**, 211-233. [6] Melosh (1989) Impact Cratering: A Geologic Process, Oxford U. Press, p. 189.

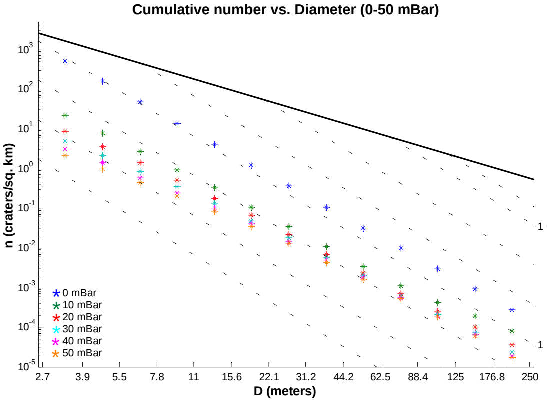

Fig.3: Cumulative size-frequency distribution for Martian atmospheres of 0, 10 20, 30, 40, and 50 mBar.

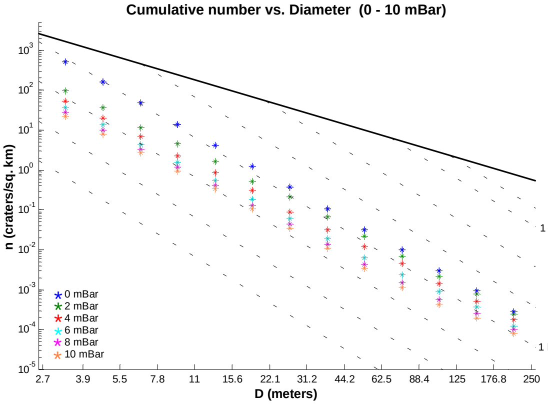

Fig.4: Cumulative size-frequency distribution for Martian atmospheres of 0, 2, 4, 6, 8 and 10 mBar.