

IMPACT CRATERS ON MARS: NATURAL 3D EXPLORATION PROBES OF GEOLOGICAL EVOLUTION.

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Introduction: The population of impact craters preserved on the surface of Mars offers fundamental constraints on the three-dimensional mechanical characteristics of the martian crust, its volatile abundance, and on the styles of erosion that have operated during essentially all epochs of martian geological history. On the basis of the present-day wealth of morphologic and geometric observations of impact landforms on Mars [1-3], an emerging understanding of the three-dimensional physical properties of the martian uppermost crust in space and time is at hand. In this summary, the current basis of understanding of the relatively non-degraded population of impact landforms on Mars is reviewed, and new Mars Global Surveyor (MGS)-based (MOLA) measurements of global geometric properties are summarized in the context of upcoming observations by Mars Reconnaissance Orbiter (MRO).

Depth/Diameter for global and polar pedestal craters

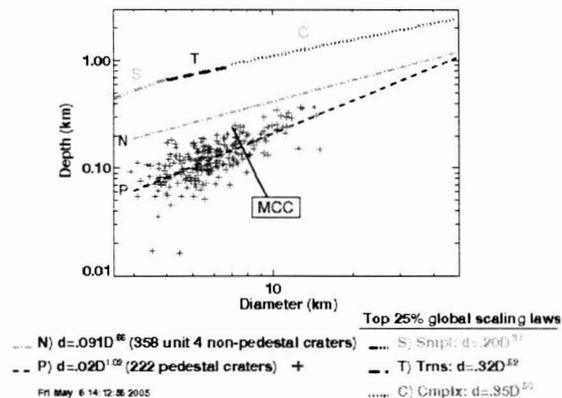


Figure 1. Global d vs D scaling for freshest craters versus population of pedestal craters in northern high latitudes.

MARTIAN CRATER SHAPES: Martian impact craters clearly reflect the interplay of geologic processes associated with erosion by wind, ice, water, volcanism, and tectonics, as reflected in the diversity of their morphologies and states of preservation [1-2]. 3D perspectives from MOLA (MGS) and via stereogrammetry from Mars Express (MEX) have provided a new tool whereby impact craters furnish quantitative boundary conditions in studies of crustal structure, volatile inventories, and sedimentology. And while at a gross scale, the shape or depth and diameter (d vs D) of craters on Mars resemble other planetary environments, at

regional scales there exists tremendous variability reflecting a wide range of characteristics associated with the upper most martian crust. Simplified binning of the global geologic units into 8 regionally-connected units allows for more appropriate examination. Near polar units in the northern hemisphere, and to a lesser extent those in the southern near-polar latitudes, display statistically unique scaling properties (i.e., *simple craters* less 7 km : $d = 0.22D^{0.71}$; *complex craters* 7-70km : $d = 0.68D^{0.17}$) in comparison with global scaling relationships for all presumably pristine (non-degraded) craters;

Simple: $d = 0.25D^{0.65}$ ($D < 7$ km)

Complex: $d = 0.33D^{0.53}$ ($7 < D < 70$ km)

Giant: $d = 3.5D^{0.017}$ ($D > 70$ km).

Pedestal-style craters within near-polar units are unique as well, apparently reflecting a history of burial and exhumation linked to specific times in the geologic and climatic history of Mars. Such craters display cavity floors that lie above the topographic level of the regional background upon which their preserved ejecta rests. As such, they appear as “pedestals” or “mesa-like” often with monotonically sloping ejecta deposits. We have exhaustively examined over 200 well-preserved pedestals (Fig 1.) in near-polar latitudes (dominantly northern), and across the complex crater diameter range ($5 < D < 40$ km), such landforms demonstrate a scaling relationship of the form: *Pedestals:* $d = 0.020D^{1.0}$

The non-degraded complex crater scaling law for the traditional impact features in the same simplified geologic unit as the pedestals is:

Near Polar (N): $d = 0.685D^{0.17}$

where the difference in exponent (0.17 vs 1.0) between these more shallow than typical (of global complex craters) and the pedestals is reflective of both target properties and erosional history. The essential linear relationship between pedestal depth and diameter D across a size range of 5 to 40 km is more akin to simple crater scaling relationships than for any other on Mars. This huge variability reflects the complexities associated with unraveling the full story behind even regional-scale impact crater populations. To first order, the high-latitude pedestal craters appear to reflect a history of post-formational burial and subsequent exhumation that differs strikingly from the freshest impact landforms in

the same region. While there remain several tenable “working hypotheses” that explain the formational physics of this population, one particularly attractive possibility may have implications for thick ground-ice within the target at particular times within the geologic record, making craters deepen faster with increasing kinetic energy (D), and allowing more rapid burial due to climate-related forcings, perhaps associated with precipitation or burial by rapidly advancing ground ice. These concepts clearly require further observations, using MRO, the 2008 *Phoenix* near-polar lander mission, and next-decade missions. However, the linkages between aspects of regional cratering history, cratering morphology, crater geometric properties, and the history of volatiles is but one of several scientifically-compelling concepts.

OTHER MORPHOLOGICAL ATTRIBUTES: The advent of global topography from MGS MOLA has augmented an impressive body of analysis of the geomorphic aspects of more than 40,000 martian impact craters, beyond just d and D . In the past five years, analyses by *Garvin and others* show appreciable evidence of major spatial sub-populations of impact features apparently correlated with target properties and specific erosional histories. The global scaling relationships of these various features is clearly a complicated, non-linear mixture of highlands crater statistics together with drastically different high latitude plains populations.

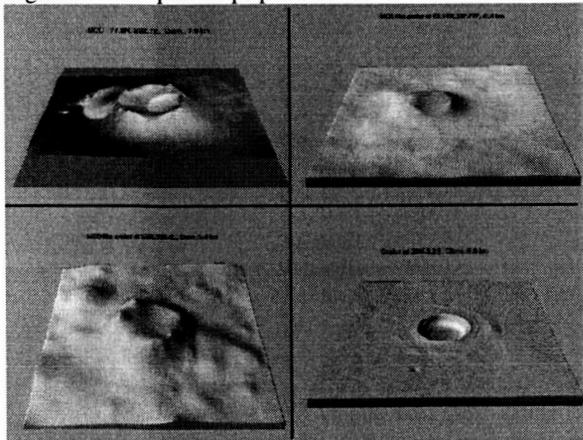


Figure 3: MCC pedestal crater (MOLA+THEMIS) with other high-latitude craterforms.

HIGH LATITUDES: Garvin and colleagues [2] first demonstrated the unique geometric characteristics of non-degraded impact craters in the northern high latitudes (55N to 90N), and interpreted several “pedestal” features as martian

lava shields on the basis of early MOLA topography and Viking era imaging. A population of pedestal craterforms has now been examined in detail using sub-km scale MOLA DEM’s and MOC and THEMIS imaging, with different conclusions (Figs 1-2). On the basis of geometric properties and their correlation with imaging textures, it is now apparent that the ~ 200 near-polar pedestals represent a unique class of differentially eroded impact craters. One feature in particular, which we originally described as a scoria cone [2], is more likely to be a relatively rare form of an exhumed complex crater with ejecta flank slopes that are a factor of 2-3 larger than are most typical, perhaps due to interactions with post-impact formation ice cover. These pedestal craters can be used together with the fresh population to estimate regional erosional volumes as a function of different time intervals.

CONCLUSION: We have explored the geometric properties of the non-degraded global population of well-measured (by MGS MOLA) impact landforms on Mars, ranging from ~2 km to more than 150km. It is evident that global statistical variations are regionally-controlled, given the global complex crater scaling law ($d = 0.33D^{0.53}$ for d, D in km) varies by geologic unit by large factors. Near-polar region fresh complex impact craters follow a scale law of the form: $d = 0.68D^{0.17}$, while pedestal craters follow the linear scaling relationship: $d = 0.020D^{1.0}$ ($N=222$). Clearly, burial and exhumation processes, perhaps related to climate-induced erosional process variations, have produced a population of landforms from which assessments of regional sediment removal volumes can be estimated. New data from the soon-to-be-launched MRO mission will extend these interpretations and facilitate more quantitative analysis of the impact crater population in the geomorphic history of the planet. Impact craters remain an invaluable, all-natural, probe of the vertical structure of the martian crust, awaiting further scrutiny.

Acknowledgements: This work was made possible via the support of the MGS Science team (MOLA and MOC), and in partnership with James Frawley (Herring Bay Geophysics). We gratefully acknowledge the encouragement of C. Schnetzler, R. A. F. Grieve, M. Malin, J. Boyce, Dave Roddy (*deceased*), and E. J. Weiler in this ongoing work.

References: [1] Barlow N. G. et al. (2000), *JGR* 105, 26733-26738. [2] Garvin J. et al. (2000) *Icarus* 144, 329-352. [3] Mouginis-Mark P. et al. (2005) *JGR*, in press, 26pp.