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Conference or Workshop Item

How to cite:

Wallis, D. and McBride, N. (2001). The detailed characterization of Martian impact craters from the 1/16 degree MOLA global topography grid. In: 32nd Lunar and Planetary Science Conference, 12-16 Mar 2001, Houston, Texas, USA.

THE DETAILED CHARACTERIZATION OF MARTIAN IMPACT CRATERS FROM THE 1/16 DEGREE MOLA GLOBAL TOPOGRAPHY GRID.

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The Mars Orbital Laser Altimeter (MOLA) [1][2] gridded global topography dataset provides an excellent opportunity to study the impact record of Mars. The resolution of the latest grid is $1/16$ degree, which translates to a horizontal resolution of less than 4 km, sufficient to provide gridded elevation maps of a vast number of Martian impact craters. We have extracted Digital Elevation Maps (DEM's) of impact craters (for example figure 1) from the global dataset for morphological comparison using new mathematical methods which can compare *complete* crater shapes (including asymmetries). By using the new technique, we aim to extend previously published global surveys (for example [3][4]) of the Martian crater record. The work is being undertaken under a new project at the Planetary and Space Science Research Institute at the Open University, U.K. In this paper we present an outline of the methods the project will use, and the areas of study we will undertake. The overall aim is to develop a more detailed understanding of the impact history of Mars. A *simple* impact history, consisting of the number of craters at each size, can be found easily from photographs by simply counting the craters. A more *complex* history would include more detail; ideally the class of object that hit the surface (for example comets versus asteroids).

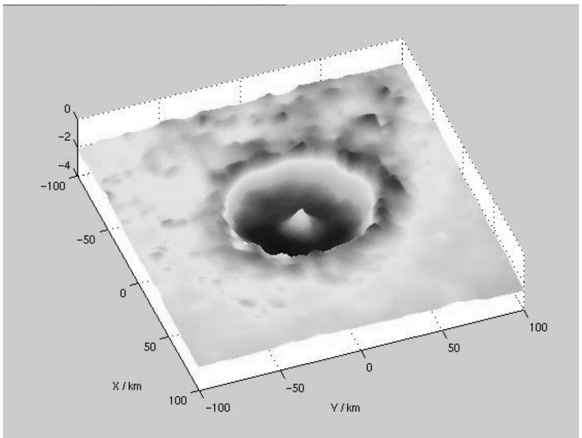

Figure 1: An example of a Digital Elevation Model (DEM) of a Martian impact crater, extracted from the 1/16th degree MOLA data grid.

Comparisons between crater shapes will be made using new mathematical methods developed specifically for impact crater analysis [5][6][7]. The DEM (consisting of many measurements arranged as a grid over the surface of the crater) is reduced to a set of parameters; the coefficients of a series orthogonal expansion,

$$z(r,\theta) = \sum_{i=1}^{N} a_i \phi_i(r,\theta) \qquad (1)$$

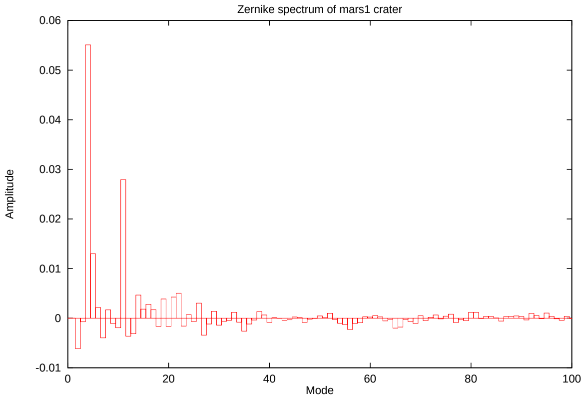

Figure 2: The expansion coefficients for a Martian impact crater. The two largest peaks (a_4 and a_{11} are for radially symmetric terms. This shows that the majority of the deformation of the surface has radially symmetry. Many of the other coefficients represent asymmetric features, which can be compared as easily as the symmetric components.

where $z(r,\theta)$ represents the shape of the crater (the DEM, see figure 1), $\phi_i(r,\theta)$ are a set of orthogonal functions defined in plane polar geometry, and a_i are the coefficients of expansion, chosen such that the sum converges on $z(r,\theta)$. The coefficients a_i are unique to the shape of each crater, and provide a convenient method of comparing crater shapes quantitatively, while considering all aspects of the crater shape (see figure 2). The expansion coefficients are analogous to the coefficients of a Fourier series expansion.

A particular advantage of the method is that asymmetries can be quantified as easily as symmetrical features. This will enable us to search for asymmetries due to oblique impact. Although most impact craters have a circular rim (except for very low angles of incidence), the circularity does not necessarily imply radial symmetry of the crater bowl. Laboratory studies have shown asymmetries in the crater bowl due to oblique impact, using the mathematical techniques applied here [5]. We expect similar asymmetries to be present in the Martian craters. By quantifying the asymmetries, we hope to deduce the impact angle for any crater, although at this stage is is unclear how large the uncertainties will be. Although this is an interesting result in itself, a knowledge of the impact angle could then be used to compensate for crater size variations due to oblique impact, and therefore make better estimates of impactor size (in other words, distinguish a large object at a shallow impact angle from a smaller object at near normal incidence). Although it is not possible to test this method experimentally at planetary-scales, there are two methods which we will use to provide some confirmation of our findings. First, asymme-

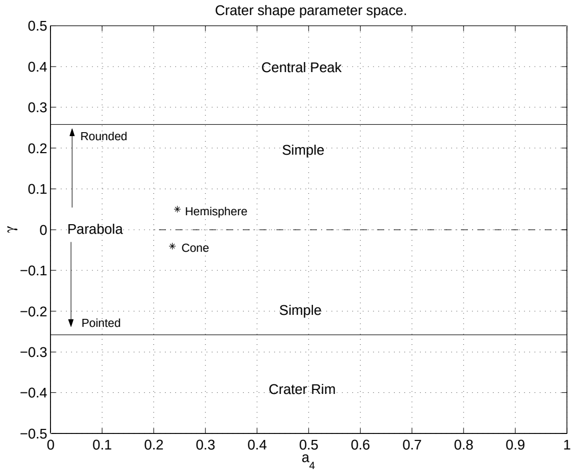

Figure 3: Feature space diagram for radially symmetric craters. Each point on the feature space represents a particular shape. The central region describes crater bowls (inside the crater rim) with *simple* morphology, and the top region describes crater bowls with a central peak. The lower region can be used to describe a complete crater shape, with a crater rim. Shallow craters are on the left of the map, becoming deeper to the right.

tries in craters showing asymmetric ejecta blankets, typical of oblique impact, will be measured and compared with craters whose ejecta blankets are symmetrical. This will quickly show if any asymmetries are present. MOC images will be used to study the ejecta patterns. Secondly, the expected distribution of impact angles for bodies hitting a planetary surface can be derived theoretically [8]. Therefore the distribution of impact angles found for the Martian craters should match the predicted distribution.

We will also look at symmetrical features of the Martian impact craters. Preliminary studies have shown that the mathematical method described above is able to identify morphological variations over the range of sizes between simple (bowl shaped) and more complex morphology (craters with a central uplift). This initial work has shown that the change in shape is gradual, and can be quantified using a ratio of two expansion coefficients, a_{11} and a_4, with the Zernike polynomials [9] chosen for the functions ϕ_i. The variation can be shown visually as a change in the γ axis ($\gamma = a_{11}/a_4$) when plotted on the radially symmetric feature space diagram (described by Wallis et al. in [7]). This feature space is shown in figure 3. Each point on the feature space represents a different shape. Crater *bowl* shapes appear in the top two portions of the feature space, and complete crater shapes (including the perimeter rim) are found in the lower part of the diagram. The central region describes simple bowl shapes, and the top region shows craters with a central peak. Shallow craters are on the left, becoming deeper to the right. Our initial studies show, as expected, that craters appear higher up and further to the left of the plot as the diameter increases. The feature space shown in figure 3 provides a very convenient method of distinguishing simple and complex craters, and quantifying the *degree* of modification. Again, MOC images will be used to estimate the degree of degradation.

Each crater from the MOLA grid will be considered during this programme of research, which in total will amount to several hundred craters at least. We believe that a detailed examination of crater morphology from MOLA DEM's can make a significant contribution to our understanding of the complex impact history of Mars.

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