INVERSION OF IMPACT CRATER MORPHOMETRIC DATA; R. R. Herrick, Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058; S. N. Lyons, Department of Geology and Geophysics, Texas A&M University, College Station, TX 77843

***INTRODUCTION.*** On all planets, the appearance of impact craters changes dramatically with increasing size; larger craters have central peaks, terraces, low depth-diameter ratios, etc.. However, these features have different onset diameters and different shapes on each planet, and these variations provide important clues about the formation process of complex craters. In the past, limited data necessitated a forward modeling approach to interplanetary comparisons. The recent addition of data from Venus and the icy satellites now makes the inverse approach a feasible method for determining the factors controlling interplanetary differences in crater morphometry.

Standard inversion techniques provide a structured framework for comparing models, incorporating data with errors, and determining ranges of acceptable parameters. As an example, here we consider inversions where all interplanetary differences in crater morphometry are directly controlled by the ratio of crustal strength ($c$) to crustal density ($\rho$) multiplied by surface gravity ($g$). This dependence can be approximated by an equation of the form

$$O_{ji} = A_i \left( \frac{c_j}{\rho_j g_j} \right)^{b_i}$$

where $O_{ji}$ is an observation of type $i$ for planet $j$, and $A_i$ and $b_i$ are constants. In log-log space

$$(\log O)_{ji} = (\log A)_i + b_i (\log c)_j - b_i (\log \rho g)_j .$$

Assuming $\rho$ and $g$ are known for each planet, then a set of nonlinear equations exists where the (log $A$)'s, (log $c$)'s, and $b$'s are unknowns that can be solved for (only relative strengths can be determined). In the examples presented here we have used the Marquardt-Levenberg method for nonlinear, iterative, least-squares inversion [1].

Table 1 shows the results for three sample inversions. We have examined five different types of measurements for four rocky bodies and three icy satellites. The measurement types, complex crater depth, diameter of the change in slope of the depth/diameter (d/D) curve, onset of central peaks, onset of peak rings, and onset of terracing, are heavily influenced by target properties and can be described by a single value for each planet. Crater depth was calculated for a 30 km diameter crater, and "onset" in this case refers to the crater diameter of the first occurrence in the most common terrain type (e.g., highlands for the moon, plains for Venus). The planets used were chosen to represent a wide range of target properties. For the first model (M1) the $b$ values were held constant at 1.0, making the problem an overconstrained linear problem with 29 equations and 12 unknowns. M1 is equivalent to assuming that all complex crater features are controlled by constant thresholds in hydrostatic pressure vs. crustal strength in a transient cavity of invariant shape. Allowing $b$ to vary (M2) adds 5 more unknowns and making the inversion nonlinear. If hydrostatic pressure truly controls crater depth, it may be more appropriate to use depths measured from the surrounding terrain rather than from the rim (M3); however, terrain-floor depths have much greater error bars than the other measurements used. The observations generally have error bars of ~20%, so an acceptable fit to the data is about ±10% in log-log space.

***DISCUSSION.*** To first order, reasonable solutions were obtained with the inversion, suggesting that the factor $c/(\rho g)$ is an important cause of interplanetary variations of crater morphometry. The results are fairly robust in showing an order of magnitude difference in strength between the rocky planets and the icy satellites. However, at least some of the measurements are influenced by factors other than $c/(\rho g)$. For example, no satisfactory value of $c$ could be found to make the Mars data match the

INVERSION OF CRATER MORPHOMETRY: Herrick, R. R. and S. N. Lyons

trends from other planets. Either the depths of Martian craters have been overestimated, or there is something unique about complex craters on Mars. M1 and M2 fit the terracing onset data about equally well with dramatically different *b* values, suggesting this data is controlled by at least one other factor besides $c/(\rho g)$. Using terrain-floor depths instead of rim-floor depths causes significant increases in the calculated strengths for the Venusian and Martian crusts. There does not appear to be a dramatic reduction in error when *b* is allowed to vary, but future work with more data and more sophisticated analysis techniques may reveal whether or not real departures from a simple linear dependence on $c/(\rho g)$ exist.

Table 1. Inversion Results

| | | | | % error of calculated values in log-log space | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Observation | | A | b | Venus | Merc. | Mars | Moon | Gany. | Rhea | Dione |
| Depth of | obs. | | | 1.1 [4] | 1.9 [2] | 1.7 [3] | 1.1 [3] | 1.0 [5] | 2.5 [6] | 2.5 [6] |
| 30 km | M1 | 1455 | 1 | 2 | 1 | -39 | 2 | -1 | 6 | 14 |
| crater | M2 | 402 | 0.79 | 2 | -1 | -43 | 3 | -1 | 5 | 13 |
| Terrain to | obs. | | | 0.8 [4] | 1.1 [2] | 1.3 [8] | 2.0 [7] | 0.7 [5] | -- | 2.0 [5] |
| floor depth | M3 | 1838 | 1.09 | -2 | 1 | -16 | 8 | -6 | -- | 10 |
| Diameter of | obs. | | | -- | 4.7 [2] | 3.1 [2] | 10.9 [2] | 4.8 [5] | 12.4 [5] | 17.5 [5] |
| d/D trans | M1 | 4564 | 1 | -- | 15 | 29 | -6 | -28 | -16 | -23 |
| | M2 | 2466 | 0.88 | -- | 17 | 26 | -2 | -31 | -13 | -21 |
| | M3 | 1270 | 0.83 | -- | -3 | 40 | -16 | -26 | 0 | -29 |
| Onset of | obs. | | | 9 | 12 [2] | 3 [3] | 15 [10] | 4 [5] | -- | 20 [6] |
| central | M1 | 5328 | 1 | -36 | -22 | 46 | -11 | -8 | -- | -22 |
| peak | M2 | 8722 | 1.04 | -39 | -18 | 45 | -2 | -15 | -- | -14 |
| | M3 | 1015 | 0.78 | -35 | -34 | 56 | -22 | -5 | -- | -29 |
| Onset of | obs. | | | 45 | 72 [9] | 45 [11] | 135 [9] | -- | -- | -- |
| peak ring | M1 | 5.56e4 | 1 | -1 | 0 | 4 | -3 | -- | -- | -- |
| | M2 | 3.6e4 | 0.91 | -3 | 1 | 3 | -1 | -- | -- | -- |
| | M3 | 1.4e4 | 1.15 | -2 | -6 | 9 | -3 | -- | -- | -- |
| Onset of | obs. | | | 9 | 18 [10] | 8 [3] | 16 [10] | 20 [5] | -- | -- |
| terraces | M1 | 11673 | 1 | 0 | -6 | 15 | 15 | -31 | -- | -- |
| | M2 | 95 | 0.29 | 8 | -11 | 17 | -1 | -22 | -- | -- |
| | M3 | 19 | 0.069 | 12 | -14 | 19 | -9 | -18 | -- | -- |
| g ($m/s^2$) | | | | 8.87 | 3.78 | 3.72 | 1.62 | 1.43 | 0.29 | 0.22 |
| Relative | M1 | | | 20.3 | 14.8 | 10.6 | 10.0 | 1.0 | 0.5 | 0.4 |
| strength | M2 | | | 15.6 | 12.9 | 8.3 | 10.0 | 0.7 | 0.5 | 0.4 |
| | M3 | | | 22.6 | 12.6 | 13.9 | 10.0 | 1.1 | 1.1 | 0.5 |

Notes:

M1 is linear inversion (b = 1); M1 and M2 use rim-floor depths, while M3 use terrain-floor depths.

Observations rows (obs.) are in km; remaining values are % error of calculated values relative to observations in log-log space.

A's, b's, and relative strengths are constants calculated in the inversion.

***REFERENCES.*** [1] Lines L.R. and Treitel S. (1984) *Geop. Prosp., 32,* 159. [2] Pike R.J. (1988) *Mercury,* 165. [3] Pike R.J. (1980) *Proc. LPSC 11,* 2159. [4] Sharpton V.L. et al. (1994) *EOS Fall Mtg. Supp., 75,* 413. [5] Schenk P.M. (1991) *JGR, 96,* 15635. [6] Schenk P.M. (1989) *JGR, 94,* 3813. [7] Pike R.J. (1977) *Imp. & Expl. Crat.* 489. [8] Pike R.J. and Davis P.A. (1984) *LPSC XV,* 645. [9] Pike R.J. and Spudis P.D. (1987) *Earth, Moon, & Planets, 39,* 129. [10] Smith E.I. and Hartnell J.A. (1978) *Moon & Planets, 19,* 479. [11] Wood C.A. (1980) *Proc. LPSC 11,* 2221.