GOLDILOCKS AND THE THREE COMPLEX CRATER SCALING LAWS. William B. McKinnon,[1] Paul M. Schenk[2], and Jeffrey M. Moore[3], [1]Dept. of Earth and Planetary Sciences and McDonnell Center for the Space Sciences, Washington University, Saint Louis, MO 63130, mckinnon@levee.wustl.edu; [2]Lunar and Planetary Institute, 3600 Bay Area Blvd, Houston, TX 77058, schenk@lpi.usra.edu, [3]NASA Ames Research Center, Moffett Field, CA 94035, jmoore@mail.arc.nasa.gov.

Introduction: Formed in the gravity regime, complex craters are larger than their simple crater equivalents, due to a combination of slumping and uplift. Just how much larger is a matter of great interest for, for example, age dating studies. We examine three empirical scaling laws for complex crater size [1-3], examining their strengths and weaknesses, as well as asking how well they accord with previously published and new data from lunar, terrestrial, and venusian craters.

Croft (1985): The most widely quoted complex crater scaling is due to the detailed study of S.K. Croft [1]. He gauged the upper and lower limits to the position of the transient crater rim provided, respectively, by the terrace sets and central peak complexes of lunar and terrestrial complex craters. Added to these were a range of crater enlargements based on theoretical and experimental evidence for the geometric similarity of ejecta blankets [4]. Finally, a geometric restoration model was used to get an independent estimate. Bracketed mainly by terrace sets for craters closer to the simple-to-complex transition and central peak complexes of very large lunar craters (a size range that could have included peak-ring basins), he determined that the transient diameter D_{tr} scaled as $D^{0.85 \pm 0.04}$, where D is the final diameter. Inverting, we get

$$D = D_{\mathrm{c}}^{-0.18 \pm 0.05} D_{\mathrm{tr}}^{1.18 \pm 0.06} , \quad (1)$$

where D_{c} is the diameter of the simple-to-complex transition. A little remarked on aspect of this scaling law is that it nearly restores the diameter (through not the volume) of complex craters to strength scaling (i.e., D is proportional to $a^{0.92}$, where a is the impactor radius).

McKinnon and Schenk (1985): We used a transient crater restoration model for the Moon, based on Pike's lunar crater morphometric data [5]. Crater rims were restored using a range of constant slope angles for the ejecta deposit, with the restoration criterion being that the transient apparent (ground-plane) crater had a depth/diameter of $1/2\sqrt{2}$ [6]. Remarkably, the derived depth/diameter ratios for the full transient crater were close to constant, which is self-consistent support for transient crater geometric similarity. In terms of fit to a power law, we found

$$D = k \, D_{\mathrm{tr}}^{1.13} , \quad (2)$$

where k is a constant. For the Moon, our k implied that simple craters near the simple-to-complex transition (~11 km from depth/diameter statistics) are ~15-20% wider than their original transient craters. This amount agrees with the amount of widening calculated for Brent and Meteor Craters due to breccia lens formation [6]. At the time it was less appreciated that all simple craters in rock are probably shallowed and widened by breccia lens formation. Breccia lens formation is something that has not been observed in laboratory impact studies to our knowledge (certainly not in dry sand), so direct application of sand crater scaling laws, even to simple craters, should be done with caution.

As for eq. (2), it can be put in the same functional form as eq. (1) if k is proportional to $D_{\mathrm{c}}^{-0.13}$, and we recommend $k = 1.17 D_{\mathrm{c}}^{-0.13}$. Using such, [2] were able to show that the continuous ejecta blankets on the Moon and Mercury measured by [7] could be close to geometrically similar if compared in terms of transient crater diameter.

Holsapple (1993): Holsapple presented, in his review of crater scaling, a new model for complex crater scaling, also based on volume conserving geometric restoration, but using improved functional forms for the ejecta blankets of craters derived from laboratory experiments in sand [e.g., 4]. Although details were not given, the overall functional form is familiar:

$$D = 1.02 D_{\mathrm{c}}^{-0.086} D_{\mathrm{tr}}^{1.086} . \quad (3)$$

A slightly different form was given in terms of transient excavation radius, which presumably refers to the ground plane.

Comparisons: All three scaling laws have similar forms but clearly different exponential dependences. They cannot all be correct. Each scaling law uses a different definition or value for D_{c} on the Moon, as well, which complicates comparisons. In terms of an "equivalent simple crater," however, eqs. (1-3) predict, e.g., 70.7, 74.1, and 79.7 km, respectively, for the 93-km-diameter Copernicus. We will discuss which of the formulations give too much or too little crater enlargement, and which if any might be considered "just right."

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