THE SIZE OF COMPLEX CRATERS; K.A. Holsapple, University of Washington FS-10 Seattle, WA 98195

Lunar craters larger than about *15 km* and terrestrial craters larger than about *3 km* in diameter presumably underwent gravity-driven, "late-stage" collapse that modified an initial transient bowl-shaped "simple" crater into the flat-floored complex craters observed. These same mechanisms were operative for the larger craters on other solar system bodies, at a threshold size inversely proportional to gravity. This paper presents a new look at the scaling relations for these complex craters.

There have been significant advances in the understanding of simple crater scaling relations over the past decade, those can be attributed to the combination of new experimental techniques, especially the centrifuge gravity methods Schmidt and Holsapple [1], to advances in the understanding of the theoretical basis for scaling Holsapple [2], and to the improvement in calculation techniques, e.g., O'Keefe and Ahrens [3]. It is now possible to predict with some degree of confidence and accuracy the crater that will result in a given geology from the impact of a relatively small body with given size, velocity and composition; or, from observations of a resulting crater, to ascertain combinations of conditions that would have created it. However, these advances apply only to the so-called simple craters characterized by the bowl shapes characteristic of small laboratory craters and not to the complex craters.

In addition to strength scaling for small craters, and gravity scaling for larger, there is a final complex crater regime for very large craters. The complete scaling relations are then as shown in figure 1. This complex crater regime has not been successfully calculated with codes, and require much larger combinations of gravity-scaled size than possible for experiments.

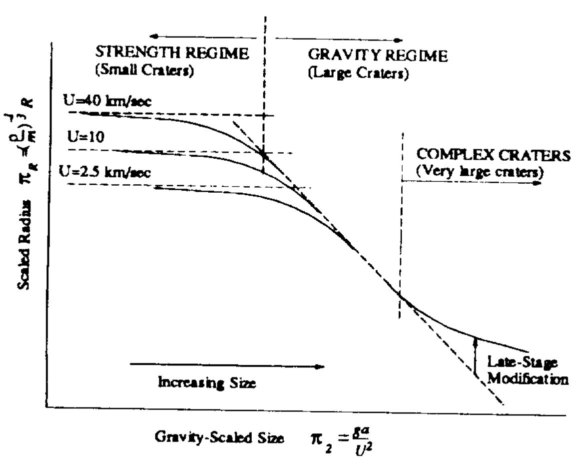

Figure 1. Scaling for crater radius, showing strength, gravity and complex crater regimes.

Previous researchers have studied the relations between a transient bowl-shaped crater and a final large complex crater, most notably Croft [4] and Melosh [5]. Both assumed that the gravitational-driven collapse of a transient bowl-shaped crater is a process that preserves volume. As a consequence, the relations for the volume scaling of simple craters should be extendible well into the regime of complex craters and basins, but the relations for crater depth and radius need significant modification.

If the slumping and rebound phenomena are effectively separate from the transient crater stages of the formation, then usual scaling relations for the gravity regime (e.g. Holsapple [2]) can be used for a maximum transient crater rim radius R_t. The subsequent crater modification stage does not depend at all on the impactor conditions but only on this transient crater size, on gravity g, on the mass density ρ of the material and on some material strength Y, so that the final rim radius is given by

$$R = f(R_t, \rho, g, Y) \qquad (1)$$

This has the dimensionless form

$$\frac{R}{R_t} = f\left(\frac{\rho g R_t}{Y}\right) \qquad (2)$$

and there is a single unknown function to be determined.

This relation will hold only when the crater radius is greater than some transitional crater radius R_*. At that transition $R_t = R_*$ and also $R = R_*$ so that the function must be unity when $R_t = R_*$. Thus (2) gives that

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$$R_* \propto \frac{Y}{\rho g} \tag{3}$$

and the transition radius must be proportional to some strength measure and inversely to the gravity. Using (3) gives a useful form of (2) eliminating the unknown crustal strength in terms of the observable transition radius as

$$\frac{R}{R_t} = f\left(\frac{R}{R_*}\right) \tag{4}$$

as given by Croft [4]. While it is tempting to introduce the usual power laws for this function, there is no known theoretical reason to do so. It is clear though that the function must be unity for craters below the transition size R_* and an increasing function above that threshold.

Here the function was determined from a comparison of the measured crater shapes for simple craters, and those observed for the complex craters on the Moon. The simple crater morphometry is based on laboratory craters by Schmidt et al [6] and Schmidt and Housen [7] rather than the simple analytical power law model used by Melosh [5]. The data of Pike [8] for lunar craters gives their volume as a function of the final radius *R*. Then the extent of the crater slumping can be determined, and a particular function determined.

The final results of this analysis are as shown in *Figure 2*. There are two curves shown, one the ratio of the final rim radius *R* to the transient rim radius R_r and one the ratio of the final rim radius to the transient excavation radius R_e. Previous studies have not distinguished between these, and there is a factor of *1.3* difference. Either curve is essentially a power law over most of the domain of interest. These results seem to be as consistent with the large variety of observed features given by Croft [4] as is his power-law estimate. The Shoemaker [9] estimate for Copernicus seems to be for the ratio of rim radii, so the present result is definitely below it. The Melosh [10] estimate for Copernicus is based on a model that has no difference in the two radii. The Grieve and Head [11] estimate for the *100 km* diameter terrestrial crater Manicouagan is applicable to the ratio using the transient excavation radius, and the present result agrees well.

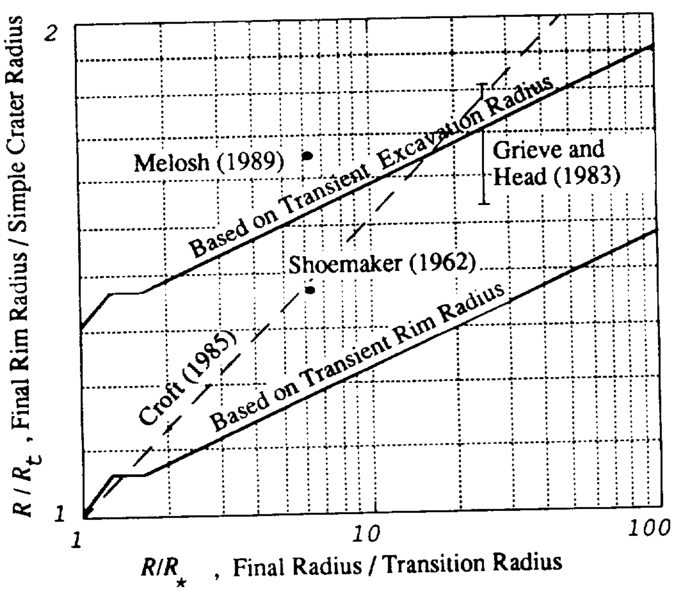

Figure 2. The radius enhancement due to late-stage modification.

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