MODELED AND OBSERVED IMPACT-MELT VOLUMES: POTENTIAL IMPLICATIONS FOR SCALING RELATIONSHIPS; M.J. Cintala[1] and R.A.F. Grieve.[2] [1]Code SN21, NASA JSC, Houston, TX 77058. [2]Geol. Surv. Canada, Ottawa, Ontario K1A 0Y3.

Considerable effort has been expended developing relationships that predict the dimensions of craters given the initial conditions of their formation.[1,2,3,4] These have ranged from extrapolating the results of explosive tests[1,4] to the current use of centrifuges and light-gas guns.[5] While much progress has been made, difficulties still remain. When observed and calculated model volumes of impact melt are scaled to cavity diameter with the most recent scaling relations, they present an apparent paradox.[6] Here, we attempt to reconcile this disagreement and, in doing so, propose a hybrid observational-empirical scaling relation for crater dimensions.

The Problem: Holsapple, Schmidt, and their coworkers have provided a number of detailed arguments leading to their scaling relationships,[3,5] which extend the results of laboratory experiments over orders of magnitude in scale. When these relationships are applied to craters of planetary scale, however, the predicted cavity dimensions do not necessarily agree with observations.[6] Much of the disagreement centers around the magnitudes of the shock stresses recorded at various locations in and around terrestrial craters, in the volumes of impact melt created by the events relative to the sizes of the craters in question, and in the amount of projectile contamination identified in various terrestrial impact melts. In short, given the observational data and previous, independent model calculations of impact melting,[7,8] the most recent scaling relationships yield craters that are too small.

The Approach: Since the derivations of the most recent scaling relationships[3,5] are logical and comprehensive, the general forms of the existing scaling functions are taken here as being sufficient to describe the terrestrial observations, at their current level of confidence. Although observational data are often of less than ideal quality because of erosion or crater burial (and hence extrapolation of few data points from drill-holes), they represent the best extant data set. Model volumes of impact melt have been calculated for the impact of chondritic projectiles into targets of granite[9] and, using the volume-scaling relationship of Schmidt[5] and a transient-cavity depth/diameter ratio of 0.33,[10] have been plotted as a function of the resulting transient-cavity diameter (Fig. 1). The trend of model volumes is paralleled by the observational data but with the calculations indicating unrealistically greater volumes of melt for a given cavity diameter. The observed melt volumes, taken from the literature, are estimates, particularly at structures where there has been erosion. The greatest uncertainty at eroded melt sheets is their original thicknesses, which have less effect on volume estimates than uncertainties in radius. It is also important to note that all of the observed volume estimates lie below the model relationship (Fig. 1), and are generally displaced from it by almost an order of magnitude. This is well in excess of the uncertainties associated with the observed data. The transient-cavity diameters of the observed craters were approximated by estimating the final crater diameter on the basis of field evidence and subsequently applying the "modification scaling" of Croft[11] in reverse. The similarity between the slopes of the calculations and field data, however, support the contention that the existing form of the scaling equations represent a sufficiently accurate, general description of the various relationships. Granted this supposition, it is assumed that the variation between the calculated and observed values of melt volumes for specific diameters is due simply to a constant coefficient in the scaling relationship that is too small. Derivation of a compatible coefficient is performed below.

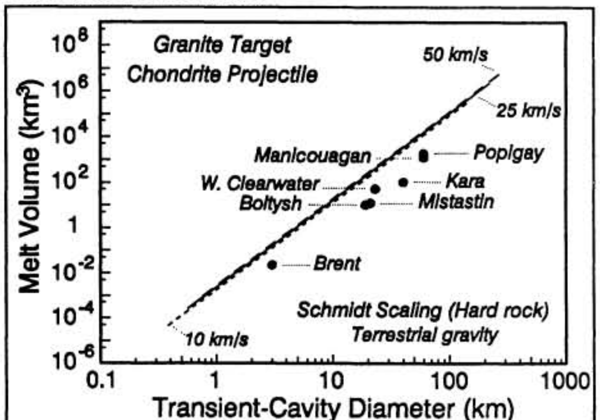

Figure 1. Volume of impact melt as a function of transient-cavity diameter. Note the very small differences between the three impact-velocity curves. See the text for details.

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The Results: Since there is, at present, no precise means of determining the impact velocity of the projectile that created any of the observed craters, it will be assumed that they were formed at the terrestrial root-mean-square impact velocity of 25 km/s.[12] In light of the similarity between the three velocity curves in Fig. 1 and the uncertainties in the field data, this assumption will have minimal negative consequences. A least-squares fit to the calculated distribution gives

$$V_{Mc} = 2.37\times10^{-3}\, D_{TC}^{3.83} \quad (1)$$

in which V_{Mc} is the calculated volume of impact melt and D_{TC} is the diameter of the transient cavity. A similar fit to the observational data yields

$$V_{Md} = 3.12\times10^{-4}\, D_{TC}^{3.64\pm0.60} \quad (2)$$

where V_{Md} is the observed volume of melt; the confidence limits on the exponent are at the 95% level. It is apparent that the permissible range in the exponent includes that in eq. (1); for the purposes here, the slopes of the two are taken to be identical, with the former value being used. Each of the two equations can then be rewritten, giving

$$D_{TC}^{calc} = 4.85\, V_{Mc}^{0.26} \quad (3)$$

for the calculated version and

$$D_{TC}^{data} = 8.23\, V_{Md}^{0.26} \quad (4)$$

for the data. While some impact melt is ejected from the growing cavity, the amount of which is a function of the initial conditions,[13,14] the minimum condition is imposed in this first approximation, namely, that $V_{Mc}=V_{Md}$. The ratio between the values of D_{TC} is then

$$D_{TC}^{calc}/D_{TC}^{data} = 1.70 \quad (5)$$

It is now a simple matter to multiply the coefficient in Schmidt's scaling relationship for cavity diameter by 1.7, and the coefficient in his volume relationship by $(1.7)^3$, or 4.91. One form of the resulting volume-scaling relationship can be written as

$$V_{TC} = 0.377 \left(\frac{\rho_P}{\rho_T}\right) g^{-0.65}\, v^{1.30}\, D_P^{2.35} \quad (6)$$

where V_{TC} is the volume of the transient cavity and all variables are in *cgs* units.

Concluding Remarks: The results given in eq. (5)and (6) are neither elegant nor intellectually satisfying. By virtue of its modification, this version of Schmidt's scaling relationship no longer holds for the small experimental craters on which it was founded. It might, however, serve as a better approximation to the situation existing with large, real craters. This modified version is offered simply as a first step in defining a more comprehensive working relationship. In the exercise above, for instance, varying degrees of melt ejection as cavity size changes were not considered. It is hoped that inclusion of such factors will eventually take place, improving the predictive accuracy of relationships such as eq. (6) above.

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