PROPORTIONAL VS. NON-PROPORTIONAL GROWTH OF BASIN-SIZED EXCAVATION CAVITIES: A RECONCILIATION, Steven K. Croft, Dept. of Earth & Space Sciences, UCLA, Los Angeles, CA 90024

On the basis of theoretical models and scaling considerations, the rim depth/rim diameter ratios ($\equiv d/D$) of impact excavation cavities prior to modification ought to be nearly independent of crater size (1,2). The relation $d/D \cong$ constant with increasing diameter is defined as proportional growth and implies the excavated crater volume, V_i, to be proportional to D^3. Assuming that the $d/D \cong 0.2$ found for small (10 km or less) lunar craters represents very nearly the d/D for the excavation cavity, then basins with cavities 500-1000 km across should have penetrated $\sim$100-300 km into the planetary crust. Field studies of complex terrestrial impact craters corroborate proportional growth (3), as does the existance of spinel cataclasites on the surface of the Moon which appear to have been excavated from depths of $\sim$60 km (4). In contrast, however, are the results of various crater restoration models (5,6,7) that attempt to estimate d/D by scraping material out of the presently observed shallow crater and restoring the material to assumed premodification positions on the crater wall. These models successfully restore lunar craters to $d/D \cong 0.2$ for diameters up to $\sim$50 km, but predict d/D to decrease sharply at larger diameters, culminating in maximum predicted depths of an Imbrium-sized basin of only 20-30 km. The purpose of this paper is to present a restoration model based on lunar crater volumes that reconciles these disparate d/D estimations.

The cavity and ejecta volumes of lunar craters (V_i & V_e, respectively) for D<13 km are found to be (8):

$$V_i = 0.040\ D^{3.00} \quad (1a) \text{ and } V_e = 0.026\ D^{3.00} \quad (1b),$$

whereas craters with D>19 km are found to obey the relations:

$$V_i = 0.238\ D^{2.31} \quad (2a) \text{ and } V_e = 0.084\ D^{2.65} \quad (2b)$$

(all units in km). The D^3 dependence of volume in equations 1a and 1b implies proportional growth for small craters. Larger lunar craters exhibit both non-proportional and unequal growth in V_i and V_e, leading to excess ejecta volume at large diameters. This latter effect has been interpreted as the increase in porosity (bulking) of ejected material over its initial porosity in the surface before the impact.

If it is assumed that the unmodified excavation cavity of large craters originally lay along the extrapolation of equation 1a (for which $d/D \simeq 0.2$), and that they reached their present locations near equation 2a by progressive collapse of the rim, then each crater will follow a "modification line" in the D vs V_i plane that can be explicitly specified if the ejecta thickness is known as a function of radius from the unmodified crater rim. Analysis of the ejecta blanket profiles of the craters used in determining the volume relation equations 1 and 2 shows that the average ejecta blanket thickness, t, can be satisfactorily represented by (9):

PROPORTIONAL VS. NON-PROPORTIONAL GROWTH

CROFT, S.K.

$$t = A(R/R_o)^B, \qquad (3)$$

where R is the radial distance beyond the initial rim R_o, and A and B are constants. B is found to average between -3 and -6 for craters up to ∿15 km in diameter, trending toward -3 at larger diameters for all craters.

Integration of equation 3 yields the total original ejecta volume:

$$V_{eo} = -(2\pi AR_o^2)/(B+2).$$

If the bulking of the ejecta is defined: $b \equiv V_{eo}/V_{io}$,

where V_{io} is the unmodified crater volume, then it can be shown that the ejecta and crater volumes of the modified crater of diameter $D(>D_o = 2R_o)$ are given by:

$$V_e = V_{eo}(D/D_o)^{B+2} \quad (4), \text{ and } V_i = V_{io}[1-b(D/D_o)^{B+2}] \quad (5)$$

The derivation of these equations is independent of the mechanism of modification (gravity, dynamic rebound, etc.) and requires only that material interior to D has descended below the original ground level. If a series of craters are allowed to move along modification lines like those illustrated in Fig. 1 until they reach the presently observed D vs V_i relation, then using equations 4 and 5, predicted loci of D vs V_e points may be found as functions of B and b. These loci are in turn compared with the observed ejecta volumes of large modified craters. The results for $-6<B<-3$ and b = 0.65, 1.0, and 1.5 are shown in Fig. 2. The observed V_e data match the b = 0.65 curves at diameters below ∿15 km and climb to the b = 1.5 curves in the interval $15<D<40$ km, remaining near the latter curves up to basin dimensions. This reflects the bulking pattern found for individual craters as a function of diameter (8). The higher exponent of equation 2b (valid for $19\leq D\leq 150$ km) appears to result from this change in effective bulking with diameter. The process can be reversed, restoring shallow craters larger than 50 km to $d/D\simeq 0.2$ for $b\simeq 1.4$.

The geometric dependence of the assumed excavation cavity diameter D_o on the final rim diameter, D_r, calculated by the modification model is very nearly a power law. For b = 1.4, the power law is found to be: $D_o = 1.43\ D_r^{0.86\pm 0.02}$, $D_r>15$ km.

This model demonstrates that large shallow basins can indeed be formed by collapse of the small, deep transient cavities predicted by the hypothesis of proportional growth, when bulking of ejecta is taken into account. It is consequently suggested that the failure of previous crater restoration models to reach $d/D\simeq 0.2$ for craters larger than ∿50 km is due to the neglect of bulking effects. This result does not prove the hypothesis of proportional growth, as some modification of cavity shape is expected at large diameters (2,10), but it does remove the motivation for postulating extreme non-proportional growth, and thus allows a reconciliation between the deep profiles of large craters predicted by theory and the shallow ones observed in nature.

PROPORTIONAL VS. NON-PROPORTIONAL GROWTH

CROFT, S.K.

References:
(1) Kreyenhagen K.N. & Schuster S.H. (1977) Impact & Explosion Cratering, 983-1002. (2) Chabai A.J. (1977) Impact & Explosion Cratering, 1191-1214. (3) Dence M.R. (1976) Imb. Consort. Vol. 1, LSI-Contrib. 267D, 147-155. (4) Bence A.E., Grove T.L. & Lindsley D.H. (1978) Lunar and Planetary Science IX, 67-69. (5) Settle M. & Head J.W. (1976) Imb. Consort. Vol. 1, LSI-Contrib. 267D, 139-146. (6) Malin M.C. & Dzurisin D. (1978) J. Geophys. Res. 83, 233-243. (7) Settle M. & Head J.W. (1978) Lunar and Planetary Science IX, 1053-1055. (8) Croft S.K. (1978) Proc. Lunar Planet. Sci. Conf. 9th (in press). (9) McGetchin T.R., Settle M. & Head J.W. (1973) Earth & Planet. Sci. Let. 20, 226-236. (10) O'Keefe J.D. & Ahrens T.J. (1978) Lunar & Planetary Science IX, 823-825.

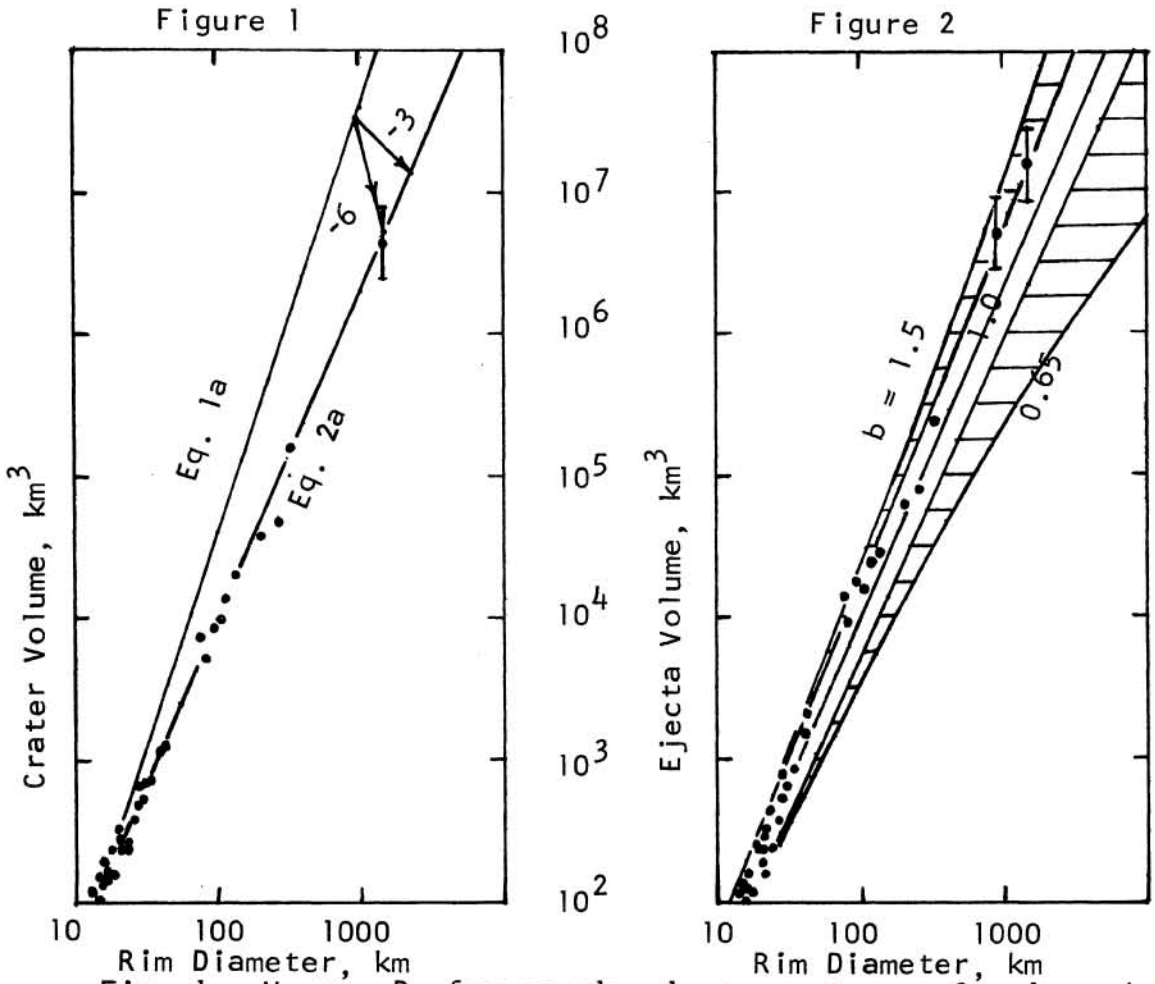

Fig. 1. V_i vs. D_r for complex lunar craters. Sample modification lines indicated.

Fig. 2. V_e vs. D_r for complex lunar craters. Predicted modified crater loci identified by 'b' value. Largest crater is new estimate of V_i & V_e for Imbrium basin. Next largest is V for Orientale from Moore et al(1974)Proc. Lunar Sci. Conf.5th.