VOLUMETRIC STUDIES OF LUNAR CRATERS: EVIDENCE FOR A MEGAREGOLITH,
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The variation of fresh crater morphology and morphometry with increasing diameter has been much discussed in the literature (1,2). The reason(s) for the variations, particularly for the breakpoint in slope in the log depth-log diameter (d-D) plot, has been the subject of debate, with suggestions including post-impact modification of a simple crater by gravity induced slumping and modification of the cratering event itself due to changes in the strength, size, and velocity of the projectile, affective depth of burst, strength or homogeneity of the target (layering), etc. (3).

In a study initially designed to determine the diameter-volume (D-V) relation of intermediate to large lunar craters, the depths, diameters, internal and external volumes of 47 lunar craters were determined from the NASA LTO charts. In general, the craters selected were fresh (Copernican and Eratosthenian in age), symmetric, on flat (generally mare) surfaces, with no obvious interior flooding and with sufficient topographic contours to yield a well defined interior structure and ejecta blanket. There were a few exceptions to each criterion chosen for comparison. The craters measured range from 1.5 to 200 km in diameter with the volumes and dimensions determined from 4-8 profiles for each crater, depending on crater symmetry and completeness of topographic coverage. The volumes are estimated to be correct within ±40% for small craters to ±20% for the large ones. Craters of similar size at different map scales gave very similar results establishing confidence in the lower end of the volume scale. The d-D plot of the craters measured is given in figure 1 with the Pike (4) relations superposed for comparison. The breakpoint at 10-15 km is evident. Figure 2 shows the plot of Schröters ratio (S.R.), exterior volume divided by interior volume, for the same craters to the same diameter scale as figure 1. It will be noted that for craters below 10 km in diameter, the value of S.R. <0.4-0.8, while for craters larger than 20 km, S.R. >1.5, with the transition occurring at the same diameters as the change in slope in the d-D plot, which is also the same range of diameters over which crater morphology changes from simple to complex. The increase in S.R. is due to an ~3 fold increase in the exterior (ejected) D-V relation over the extrapolation of the small (D<10 km) crater D-V relation, with no variation in the interior D-V relation. If it is assumed that the break in the d-D plot is due primarily to either dynamic or post-impact slumping and filling of large, simple transient cavities (i.e., simple crater shapes with the same relative dimensions as small craters), then decreases in both the interior and exterior D-V relations would be expected in the 10-20 km range. Since the opposite is observed to occur, the reason for the breakpoint apparently must be sought among those models postulating changes in the shape of the transient cavity.

Examination of the S.R. -D plot suggests that the variations are due to a megaregolith-type layering of the upper lunar crust similar to that proposed by Head (1), based on the following observations: a) compaction of materials accounts for 10-50% of the interior volume of an impact or explosion crater in sand or soil (5,6), producing a crater of greater interior volume than the volume of actual material ejected, with S.R. <0.6-0.9, b) rock that is broken
into sand increases its volume due to greater porosity by values commonly ranging from 30-50%, thus craters in rock will produce more ejecta volume than crater volume yielding S.R.'s in the range of 1.5-2.0. Craters in mixed rock and sand targets would have intermediate values of S.R. If this interpretation may be applied to figure 2, then craters smaller than 10 km in size interact only with the sandy upper layer yielding simple craters, while craters greater than 20 km are mostly in the rocky basement. The hypothesis is strengthened by the previously noted (1,2) similarity of progressive morphological changes with increasing relative diameter between lunar and laboratory craters in layered media (7). Layering also provides a natural explanation for the flattening of crater floors and the variable growth rates of the transient cavity as well as a surface for shock waves to rebound from to form central peaks.

The abrupt rise of S.R. over the relatively small interval of 10-20 km implies a fairly definite contact between the soil and bedrock, even though the discreet nature of random cratering on a given surface would imply an extremely irregular contact. It is therefore noteworthy that model bombardment histories of the lunar highlands (8) show that 65-90% of the total lunar surface is excavated to 3-5 km with only a few percent excavated more deeply and the remainder less deeply. This result implies a well defined average, but "fuzzy", contact at a depth of 3-5 km over large areas of the lunar surface, comparing well with the fairly sharp break at a depth 3-4 km in figure 1. In other words, the large number of intermediate impacts have created a roughly uniform pulverized layer which larger impacts penetrate at random intervals. One obvious problem to be considered in this interpretation is the similarity of mare and highland craters, since the mare regolith substrate is denser and presumably more competent than pulverized highland materials. A possible explanation is that the thickness of the mare flows are less than a kilometer or so except in a few places (9), thus craters larger than 4-5 km in diameter penetrate this layer. Also the thin and jointed nature of the marial flows would reduce coherence for any large impact. These explanations are not wholly satisfactory, however, without further experimentation and modelling. Further, the lack of large well defined concentric craters similar to those of the lunar regolith and the laboratory impacts mentioned above may be due to the boundary fuzziness and the fact that fracturing or weakening of the substrate extends far deeper than excavation in a cratering event. The extent to which the lower layer is fractured and weakened in a given location may explain why craters like King have a very large central peak complex, while nearby Langemak, a similar sized crater, has hardly any central peak at all.

Baldwin long ago (10) noted an increase of S.R. with diameter attributing the initial S.R. <1 to material thrown far from the crater, and the gradual increase to mechanism b) above. Unfortunately, the low accuracy of the data base led to very large uncertainties in S.R. and a somewhat different curve from that shown in figure 2. The actual error bars on the S.R. points are difficult to evaluate, but estimates for small craters yield values similar to the observed scatter (<±30-40%), while the error seems to be less (<±10-20%) than the observed scatter for craters larger than 20 km, implying some of the scatter to be real.
The hypothesis that layering is responsible for the d-D breakpoint on the Moon leads to the conclusion that the different breakpoints observed for the Earth, Mercury and Mars are due to differing crustal layering conditions resulting from different depositional processes (probably due to the presence or absence of liquid water), and possibly different surface materials. Consequently a better understanding of cratering in layered media could very easily yield information about crustal processes on other planets.

References