Volume of Material Ejected from Major Lunar Basins: Implications for the Depth of Excavation of Lunar Samples, James W. Head, Mark Settle, and Ross Stein, Brown University, Providence, Rhode Island 02912

Large lunar basins have had major effects on the shaping of the lunar surface and on the deposition and reworking of the outer portions of the lunar crust. Knowledge of the volume of material excavated and ejected from these major basins is of critical importance in determining such parameters as the maximum depth of excavation of material from the lunar interior and the amount of material available to participate in the production of exterior deposits. The purpose of this paper is to analyze critically methods of estimation of volumes, to present the most reasonable range of estimates, and to outline the implications of this range of estimates. Particular emphasis will be placed on the Orientale basin since it is the youngest crater of this size class.

Two basic approaches can be utilized in estimating the volume of material which is primary ejecta from major basins (Vp): determination of the volume of the crater of excavation from which the material was ejected (internal volume, Vf) and determination of the volume of the deposit of material surrounding the crater (external volume, Vx). Recent impact cratering experiments have demonstrated that a significant portion of apparent internal crater volume is produced by compression of target material, such that Vp is always less than Vf. At the same time, the energetic deposition of material excavated by a basin-forming impact will produce secondary excavation of local material forming deposits representing a mixture of primary basin ejecta (Vp) and local material2 such that the volume of the external deposit Vx is always greater than Vp.

Estimation of the volume of the hole (Vf) requires identification of the position of the rim of the original crater of excavation. For Orientale, estimates have varied but recent work suggests that the outer Rook Mountains (R = 310 km) represent the closest approximation. Estimates of the internal volume can then be attempted by: (1) assuming an original crater geometry such as a spherical cap and scaling up the dimensions of other large lunar craters to R = 310 km; (2) measuring the apparent volume of the area enclosed by the Outer Rook ring; and (3) measuring the apparent volume of the whole basin bounded by the Cordillera scarp, which implicitly assumes that there has been an approximate conservation of internal volume during the subsequent modification of the initial crater by slumping. The latter two methods based upon measurement of apparent volumes should be underestimates of Vf because of crater fill due to fallback of ejecta material, mare volcanism, and the rebound of the crater floor. Internal volume estimates have also been obtained by converting variations in gravity data to volumes.

Determination of the external volume of material beyond the crater rim has been estimated by modelling the thickness of material blanketing prebasin craters. This method results in overestimates of Vp and sometimes even Vx for several reasons: 1) the method relies on the geometry of prebasin craters for determining ejecta thickness and usually assumes...
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a geometry characteristic of fresh lunar craters; however, because of the intense bombardment characteristic of this period of lunar history, craters would tend to maintain a fresh geometry for a very short period of time; 2) since the process of deposition of ejecta material is very erosional, this will also add to degradation of underlying craters and result in ejecta thickness overestimates; in addition, this erosional aspect will cause considerable excavation and mixing of underlying material; 3) pre-existing craters tend to act as catch basins and preferentially trap ejecta, causing these estimates to be higher. Thicknesses derived from ejecta flow lobe heights are difficult to assess; their relation to large secondary craters indicates that they are probably unrelated to primary or total ejecta thicknesses. For Orientale, a variety of thickness determinations at different ranges have been converted into estimates for the volume of material ejected from Orientale. For the reasons cited above, these are believed to considerably overestimate the actual volume of material ejected. Finally, ejecta thickness decay from smaller craters has been scaled to larger basins in an attempt to estimate external volumes.

External volume estimates for Orientale (R = 310 km) made by a variety of methods are presented in Figure 1, and range from 0.9-7.0 x 10^6 km^3. Experimental evidence concerning the effects of compression within the crater of excavation and the effects of secondary craters outside the crater have demonstrated that estimates of internal and external volume must always be greater than the actual amount of material ejected by the impact. Therefore, the smaller end of the range of volume estimates for Orientale represents an upper bound on the amount of material ejected from the basin (V_p). Preferred estimates of the amount of material ejected from Orientale would thus lie in the range 1.0-2.0 x 10^6 km^3.

Another means of comparing this range of values and narrowing it further is to consider the implications of such volume estimates in terms of maximum depth of excavation (see Figure 1). By assuming a spherical cap geometry for the primary ejecta prior to excavation and a crater radius, a maximum depth of excavation can be inferred from volume estimates. This simple geometrical model provides a means of comparing the depth implications of a variety of volume estimates. Minor corrections for the effect of lunar curvature and changes in material density can be added. For Orientale, the geometrical model yields a depth of excavation of 6 to 14 km. Note that this depth is not equivalent to the original crater depth which is produced by excavation of material and compression. Applying this model to the larger Imbrium basin, around which Apollo sites are concentrated, yields an estimate of depth of excavation of 9 to 20 km. Such shallow depths of excavation lie in contrast to depths inferred from consideration of interior and exterior volumes alone and lie in the upper portion of the 60 km thick lunar crust as defined seismically. These considerations strongly suggest that even the largest of the major lunar basins has not played an important role in excavating material from the lunar mantle. Missions to the edges of major basins (e.g. Apollo 15, Apollo 17)
have not returned a recognized suite of deep-seated samples. The scarcity of such samples provides additional evidence for the shallow crustal depths of material excavated by basin-impacts on the lunar surface.