basin, for instance, is 3–4 km in Figure 8. On photogeological grounds, however, the basalt thickness has been estimated to be no greater than 1 km [*Head*, 1974]. A significant excess mass within the submare crust is a possible explanation for this discrepancy. The large uncertainty in the topography and gravity in the Orientale region may be at least an equal contributor, however.

GEOLOGICAL IMPLICATIONS

The structural models derived in this paper have a number of implications for the processes that accompanied the formation and evolution of large impact basins on the moon. We divide the discussion into basin formation processes, including transient cavity collapse and emplacement of ejecta deposits, and basin modification processes, including volcanism and lithospheric deformation on time scales longer than those normally associated with the basin formation event. We recognize that this division is somewhat arbitrary and that the present characteristics of each basin may be the product of a combination of both types of processes.

Early Cavity Geometry

The volume of material ejected from a basin during impact is an important quantity, for several reasons. Its relation to basin diameter provides a strong constraint on the cratering process for large impacts, particularly on the early cavity geometry. The ejecta volume also provides information on the sampling depths of large impacts and thus on the interpretation of returned lunar samples for crustal composition. *Head et al.* [1975] have defined the volume V_p of "primary ejecta" as the volume of material excavated from a crater and thrown beyond the crater rim. The quantity V_p is thus approximately equal to the volume of the early transient cavity minus the volume of material which falls back in to the collapsing cavity. This equality ignores the effects of density changes due to compression of target material, brecciation of fallback material, or other inelastic effects. The volume of primary ejecta residing outside a major basin, however, is a difficult quantity to determine from photogeologic observations of ejecta deposits, among other reasons because of the difficulty in separating primary ejecta from the locally derived, secondary ejecta surrounding the basin [*Head et al.*, 1975]. From a variety of observations, models, and scaling relations, *Head et al.* [1975] estimated that V_p for a basin the size of Orientale lies between 0.4×10^6 and 12×10^6 km^3. This wide range of possible ejecta volumes is equivalent to a large uncertainty in the thickness of ejecta deposits expected from an Orientale-sized impact. For instance, if the ejecta volume were spread evenly over the lunar surface, the thickness could be as little as 10 m or as large as 300 m.

More recently, *Spudis* [1982, 1983] and *Spudis et al.* [1984] have estimated the depth of excavation for lunar basins from remote geochemical observations and scaling relations under the assumption that the lunar crust is layered, with an anorthosite layer overlying a more noritic layer [*Ryder and Wood*, 1977]. *Spudis* [1982, 1983] and *Spudis et al.* [1984] concluded that the chemistry and mineralogy of the ejecta deposits of five nearside basins provide support for an excavation model in which the ratio of the depth of excavation to basin diameter is about 0.1 for basin-sized impacts. On the basis of such a model the excavation depth for the younger nearside basins ranged from 40 to 80 km [*Spudis*, 1983], and the volume V_p of primary ejecta excavated during the Orientale basin impact is estimated to be $5\text{–}8 \times 10^6$ km^3 [*Spudis et al.*, 1984]. These estimates have considerable uncertainty, however, associated with the reality of the assumed simple model of crustal layering and with the ability to separate primary from secondary ejecta.

The structural models for lunar nearside basins depicted in Figure 10 provide a straightforward and internally consistent framework with which to address cavity and ejecta volumes. Let V_b be the volume of the present basin, including the volumes of the topographic depression and of mare fill. We make the assumption that the crustal thickness of the preimpact basin region was similar to the present thickness at 2–3 basin radii from the basin center (excluding other nearby basins). Then the quantity $V_e = V_b + V_u$, where V_u is the volume of apparently uplifted mantle, provides a measure of preimpact crustal material now external to the basin rim.

The quantity V_e should be somewhat less than V_p. This is because inward transport of crustal material during basin modification as well as deposition of ejecta from younger basins or of nonmare volcanic material will act to reduce one or both of V_b and V_u. Therefore V_e can be regarded as the difference between the volume of crustal material ejected beyond the basin rim and the volume of crust returned to the basin region by these later processes. For the youngest nearside basins, which may have formed at a time when near-surface temperatures were comparatively low and the elastic lithosphere relatively thick (e.g., Orientale, Serenitatis, and Crisium), V_e may approach V_p.

Values for V_e derived from the smoothed cross sections of Figure 10 are given in Table 1. The values range from 2 to 9×10^6 km^3. It should be repeated that these values are insensitive to the assumption of premare isostasy, because to first order the Bouguer anomaly data yield the total anomalous mass (mantle uplift plus mare basalts), and it is the sum of the two components that contributes to V_e. By analogous reasoning, these values of V_e are also insensitive to the presence of high-density intrusions within the low-density crust underlying the basin. The uncertainties in gravity and topography and in the assumed densities and model simplifications result in an uncertainty in V_e of about 30% for Orientale and 20% for the other basins studied. The values of V_e in Table 1 fall within the range of estimates for V_p for basins the size of Orientale or Serenitatis [*Head et al.*, 1975; *Spudis et al.*, 1984]. The average value for V_e for the three youngest basins studied (Orientale, Serenitatis, and Crisium) is 8×10^6 km^3 and falls near the upper end of this range. An ejecta volume of 8×10^6 km^3, if spread evenly over the lunar surface, would constitute a layer 200 m thick. Considering the 30 or more impact basins preserved on the moon [e.g., *Wood and Head*, 1976], such an average thickness for ejected material from a single basin suggests that the accumulated thickness of basin ejecta deposits on the lunar surface may, on average, be several kilometers.

An interesting relationship between apparent mantle uplift and crustal thickness is suggested by the data from the six youngest basins in Table 1. The thickness t_c of the nonmare crust beneath the central region of each of these six basins is remarkably uniform, 20–30 km, despite differences in basin size, age, and preimpact crustal thickness. The Moho relief for five basins in crust 55–65 thick is nearly constant at about 30 km, despite a variation of 200 km in basin diameter. While the Moho relief beneath Orientale is greater than that of the other five basins by 30–40 km, the surrounding crust is also thicker by 20–30 km.

We suggest that this near uniformity of nonmare crustal thickness beneath the younger basins can be understood only