portant [*Wilhelms*, 1983]. Nubium and Tranquillitatis lie just within, and Fecunditatis just outside, the third ring of the Procellarum basin [*Whitaker*, 1981] and are thus within a radial range where significant thermal effects can be expected [*Bratt et al.*, 1981]. As noted earlier, the Procellarum basin may have contributed to the generally lower elevations and thinner crust on the central nearside than elsewhere on the moon. That the Procellarum basin did not itself experience complete viscous relaxation of surface and Moho topography may be ascribed to the insensitivity of the controlling time constant to spatial scale [*Solomon et al.*, 1982] and perhaps as well to the constraints on lateral flow imposed by spherical geometry when the basin diameter approaches the diameter of the moon.

Nonmare volcanism. An additional modification process that can act to reduce basin relief and that would be enhanced by higher temperatures is nonmare volcanism, i.e., deposition of nonmare basalts with a density similar to the typical density of the crust and therefore not resolvable from gravity anomalies. The volumetric significance of nonmare volcanism for lunar crustal evolution in general and for old lunar basins in particular is not well known. To the extent that the crust, as opposed to the upper mantle, is the source of magmas for this volcanic activity, this process involves lateral transport of crustal material to fill the basin depression and is not readily distinguishable from ductile flow (Figure 12). If temperatures exceed the solidus in crustal material adjacent to a newly formed basin, in fact, the effective viscosity might be sufficiently low so that bulk flow would dominate magma transport as a mechanism for reducing relief.

Mare volcanism. The source regions of mare basalt magmas are thought to lie at depths in excess of 100 km [e.g., *Wyllie et al.*, 1981]. At such depths the deposition of kinetic energy as heat, the release of hydrostatic pressure, and the uplift of mantle isotherms during basin formation [*Bratt et al.*, 1981] are likely to have had only a small effect on magma genesis and then only if the impact was very large [*Hubbard and Andre*, 1983] and the ambient temperature was already near the solidus. That the thickness of mare basalts appears to be less within the older basins (Nubium, Fecunditatis, Tranquillitatis) than nearby younger basins (Figure 8) suggests that mare volcanism probably has not contributed substantially to the age dependence of preserved basin structure.

Of the basin modification processes considered above, lateral flow of lunar crustal material, perhaps augmented by nonmare volcanism, is the most likely explanation of the general decrease of preserved mantle uplift with increasing basin age. Because both of these processes involve the radially inward movement of crustal material, the two are difficult to separate on the basis of gravity and topographic data alone. The poor degree of preservation of relief of the older basins on the central nearside may be a consequence of both the generally high temperatures in the early lunar crust and the extensive additional crustal and subcrustal heating associated with the formation of the ancient Procellarum basin.

SUMMARY AND CONCLUSIONS

We have presented models for the crustal and upper mantle structure beneath major impact basins on the nearside of the moon. The models are derived from an inversion of nearside gravity and topography, subject to the assumptions that premare topography was isostatically compensated by an Airy mechanism and that compensation of mare basalt units may be neglected. An additional constraint is the crustal thickness inferred beneath the Apollo 12 and 14 landing sites from seismic observations.

The basin structural models are characterized by thinned crust and an elevated Moho beneath the central basin regions, compared to surrounding areas, presumably the preserved effects of basin excavation and mantle uplift during collapse of the transient cavity. Orientale exhibits over 60 km of apparent mantle uplift, while the Moho relief beneath Serenitatis, Crisium, Humorum, Nectaris, and Smythii is about 30 km. The three oldest basins included in this study, Nubium, Fecunditatis, and Tranquillitatis, display only a modest ($\sim$10 km) amount of preserved Moho relief.

The general decrease in the amount of preserved mantle uplift with increasing basin age is attributed primarily to enhanced rates of lateral flow of crustal material early in lunar history when crustal temperatures were relatively high and the elastic lithosphere comparatively thin. Nonmare volcanic activity may also have contributed to the greater extent of modification of older basins. The relaxed topographic and Moho relief for older basins on the central nearside, in particular, may be at least partly a consequence of the extensive crustal and subcrustal heating associated with the formation of the large Procellarum basin.

If we make the assumption that the preimpact crustal thickness beneath the basin region was similar to the present thickness beneath surrounding regions, then the sum of the volume of uplifted mantle, the volume of mare basalt fill, and the volume of the topographic basin provides a lower bound to the volume of crustal material ejected beyond the basin rim during basin formation. This bound may be similar to the true ejected volume for the youngest basins formed when the elastic lithosphere may have been significant in thickness and when any modification subsequent to cavity collapse may have been relatively minor. On this basis, we estimate the volume of crustal material ejected from basins the size of Orientale to be of the order of 10^7 km^3.

The thickness of nonmare crustal material beneath the central regions of the six youngest basins considered in this study is remarkably uniform (20–30 km) despite large differences in basin size and in the preimpact thickness of the crust. These results suggest the hypothesis that basin excavation extended in depth at least to the lowermost crust for these impacts and that significant deepening of cavity excavation for the largest basins was most likely impeded by an abrupt increase in strength at the crust-mantle boundary. The preserved layer of nonmare crust beneath the basin centers, by this view, may be some combination of fallback and crustal material transported laterally during cavity collapse.

The structural models described in this paper provide important constraints on the thermal budget of the basin-forming process and on the subsequent thermal and tectonic evolution of the basin region [*Bratt et al.*, 1981]. While these models are of necessity simple, they provide a basis for testing the ideas presented here with data of higher spatial resolution in individual basin regions on the moon and the other terrestrial planets.

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