should have largely relaxed beneath the central basin region because of the elevated temperatures. A persistent source of stress that did not relax is that associated with basin topographic relief and its compensation by lateral variation in density (e.g., crustal thickness) at depth. If the pre-mare basin was in a state of nearly complete isostatic compensation, then the basin relief would give rise to a horizontal stress of order $\rho g h$, where ρ is the density, g is the gravitational acceleration, and h is the variation in topography [e.g., *Jeffreys*, 1970, pp. 249–268]. The Orientale basin inward of the Cordillera Mountains lies below the level of surrounding terrain (Figure 2), which would add a horizontal compressive stress at shallow depths in the basin interior. The band of extensive fissuring occurs in terrain 2 to 4 km below the local datum, suggesting that 100–200 bars of horizontal compressive stress should be expected from topography. This additional stress would have little effect on the development of fissures predicted by the stress models except to delay slightly the time at which σ_{rr} first satisfied the criterion for extensional failure.

The calculations of subsidence and the inferred constraints on E_B and s were obtained without consideration of the specific volume change that accompanies freezing. Several of the basin thermal models have initial temperatures well in excess of that necessary to induce melting (Figures 12 and 16). The temperatures immediately beneath the central basin region are probably unrealistically high in these models, a consequence of neglecting the heat of fusion and of the simplistic exponential relation for the distribution of impact heat. Geological arguments and scaling from melt volumes in terrestrial craters suggest that the Orientale melt sheet has an average thickness inward of the Outer Rook Mountains of about 1 km [*Head*, 1974]. The additional subsidence contributed by freezing of this melt sheet should not exceed a few hundred meters. In the basin thermal models, of course, it is the integrated heat rather than any given value of initial temperature that is important for the subsidence problem.

If we accept that E_B represents about 25% [*O'Keefe and Ahrens*, 1976] of the original kinetic energy E_K of the impacting projectile and we use the bounds on E_B suggested above, then E_K for the Orientale event was in the range 4×10^{32} erg to 3×10^{33} erg. These values for E_K may be useful for estimating scaling relations of the form $E_K \sim D^n$ for large impact craters; scaling Orientale from Teapot-Ess, for instance, would favor $n \simeq 3.4$–3.6, values similar to that derived by *Vaile* [1961] from small terrestrial craters. The estimate of impact kinetic energy derived here for Orientale may also provide constraints on models of planetary accretion calling for the impact of large planetesimals and for models of the early thermal histories of planets in which the fractional conversion of impact kinetic energy to heat and the spatial distribution of that heat are important parameters [e.g., *Kaula*, 1979].

CONCLUSIONS

We have explored the hypothesis that thermal stress has contributed significantly to the topography and tectonics of lunar multi-ringed basins. Thermal models have been calculated for a variety of assumptions about initial basin heating contributed by impact kinetic energy and uplift of isotherms during cavity collapse and basin formation. Thermal stresses and displacements have been calculated from the time-dependent thermal models using analytic expressions for the response of an elastic halfspace. Some stress models have included the effects of an elastic blocking temperature [*Turcotte*, 1974, 1983] to account approximately for high-temperature anelastic effects. These solutions have been compared with the topographic relief [*Head et al.*, 1981], the location of extensional fissures, and the timing of fissure formation [*Church et al.*, 1982] in the relatively well-preserved Orientale basin.

For all basin models considered, basin cooling and accumulation of thermal stress is most rapid within 100 m.y. after basin formation, in agreement with the inferred timing of fissuring within Orientale. The predicted state of stress in the region of fissuring (σ_{rr} extensional, $\sigma_{\theta\theta}$ compressional and smaller in magnitude) predicts well the form and orientation of fissures if these features are the product of extensional failure.

On the basis of the thermal stress models, the topographic relief of the central basin depression and the range of radial distances from basin center over which extensive fissuring occurred constrain the magnitude E_B and distribution of kinetic energy that was converted to buried heat beneath the newly formed Orientale basin. E_B must be comparable to or greater than 10^{32} erg because the contribution of impact heating to thermal stress must be at least comparable to that of isotherm uplift. E_B must be less than or equal to 7×10^{32} erg in order to be consistent with the topography of the central basin depression. The impact heat was concentrated within 100–200 km of the point of impact.

It is important to emphasize that there is an untested element of uncertainty in the ability of our models to represent the earliest portions of basin thermal history and the anelastic response of material at high temperature to cooling. The models presented here nonetheless suggest that cooling and thermal stress contributed significantly to the topography and tectonics of multi-ringed basins and that constraints on the quantity and distribution of impact heat emplaced during basin formation may be derived from geological observations of the youngest basins on the moon and on other planets and satellites.

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