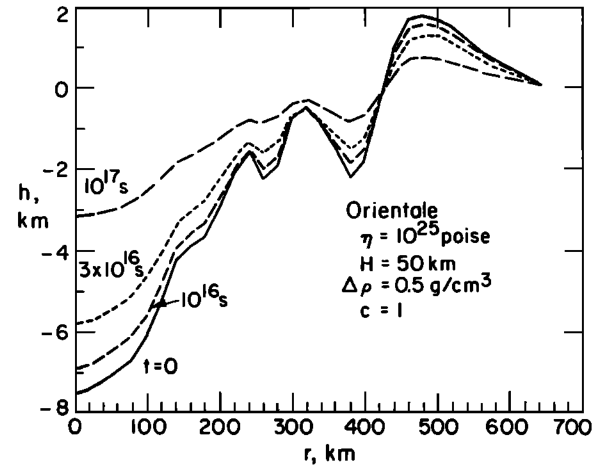

Fig. 8. Viscous relaxation of Orientale basin topography for a viscous layer over an inviscid half space and for complete Airy isostatic compensation of topography as an initial condition. The layer has viscosity $\eta = 10^{25}$ P, density $\rho = 2.9$ g/cm^3, and thickness $H = 50$ km; the half space has density $\rho + \Delta\rho = 3.4$ g/cm^3. Profiles are shown at $t = 0$, 10^{16} s (300 m.y.), 3×10^{16} s (1 b.y.), and 10^{17} s (3 b.y.); these times scale linearly with the assumed layer viscosity.

and F are of opposite sign in the presence of partial to complete isostatic compensation. In particular, the left-hand side of the third inequality is identically zero at all times for $c = 1$ and at $t \gg \tau_2$ for any c.

A major question for the application of this viscous relaxation model to ancient lunar basins is the value of c, i.e., the degree of isostatic compensation of lunar basins prior to mare basalt fill. There are, unfortunately, only limited gravity and topographic data available to answer this question. Further, the estimation of the initial degree of compensation is sensitive to the depths of all mass excesses and deficiencies beneath present basins, quantities poorly resolved by gravity field measurements at spacecraft altitudes. For the Orientale basin, *Sjogren and Smith* [1976] considered a number of simple models that matched existing gravity data with varying degrees of success. For a model in which mass anomalies are at the lunar surface, the central basin region of Orientale (within 150 km radial distance) contributes 3×10^{20} g excess mass, the region between 150 and 350 km radial distance contributes a mass deficiency of -17×10^{20} g, and the outer ring (350–620 km radial distance) contributes an excess mass of 7×10^{20} g [*Sjogren and Smith*, 1976, Table 1]; there is a net mass deficiency of -7×10^{20} g. This result may be compared to the mass deficiency calculated from the topography. If we assume that Figure 1*b* represents circularly symmetric topography of density 2.9 g/cm^3, then there is a total mass deficiency of -19×10^{20} g; the region $r = 0$ to 430 km contributes -38×10^{20} g, while the outer ring structure between $r = 430$ and 640 km contributes an excess 19×10^{20} g. Thus in the surface mass model for Orientale gravity, the mass deficiency is presently 38% of the topographic mass deficiency and would have been as high as 50% prior to mare basalt fill.

Sjogren and Smith [1976] obtained an improved fit to the gravity data for models including a large fraction of the excess mass at the base of the lunar crust; i.e., including a thinned crust beneath the basin to provide partial compensation of the topographic depression. For these models the net mass excluding mare fill is either negative (-8×10^{20} g for their model 5) or small (0.2×10^{20} g for their model 2). Even though the compensation of Orientale basin topography is not local, we may concude from these results that the net prefill mass deficiency for Orientale was considerably smaller than the mass deficiency of the present topography because of partial compensation by crustal thickness variations.

In all, the cases $c = 0.5$ and $c = 1$ appear to bracket the most likely Airy isostatic model for the Orientale basin and therefore for unmodified lunar basins in general. Gravity analyses for other lunar basins support this conclusion. The preferred model of *Bowin et al.* [1975] for the Serenitatis basin is in isostatic equilibrium prior to mare fill. *Phillips and Dvorak* [1981] give models for the Grimaldi basin in which the pre-mare topographic depression is 62 to 100% compensated. Thus the available gravity data over lunar basins indicate that early basin topography was at least partially compensated; this compensation must be included in the calculation of subsequent viscous relaxation of topographic relief.

APPLICATION TO ANCIENT LUNAR BASINS

We now apply the model of viscous relaxation to the topography of ancient (i.e., pre-Nectarian) lunar basins. Specifically, we assume that the topographic profiles of ancient basins shortly after their formation were similar to the present profile of Orientale, and we test the hypothesis that the ancient basin topography was subsequently modified by viscous relaxation during the time interval (between basin formation and perhaps 3.8 b.y. ago) when near-surface temperatures were high and the effective viscosity of the lunar lithosphere was low enough for creep to be important at geological time scales.

Tranquillitatis basin. We first consider the Tranquillitatis basin (Figure 10), one of the oldest identifiable basins on the lunar nearside [*Stuart-Alexander and Howard*, 1970; *Hartmann and Wood*, 1971; *Wilhelms*, 1981]. *Stuart-Alexander and Howard* [1970] have suggested that the irregular Mare Tranquillitatis fills two old basins, with the western basin the younger of the two. *Wilhelms and McCauley*

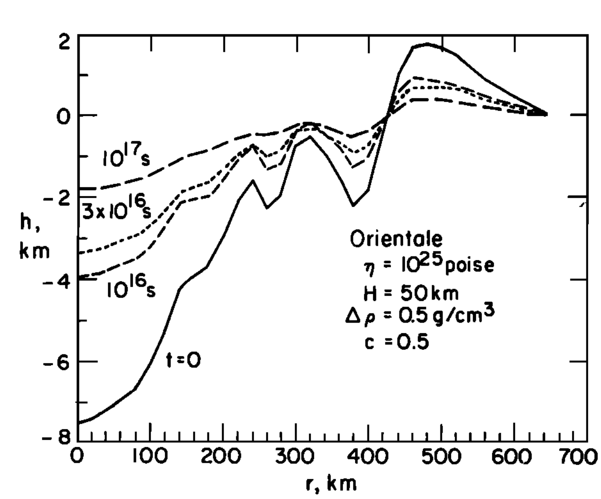

Fig. 9. Viscous relaxation of Orientale basin topography for a viscous layer over an inviscid half space and for 50% ($c = 0.5$) isostatic compensation of topography as an initial condition. Other physical parameters and profile times and their scaling with layer viscosity η are as in Figure 8.