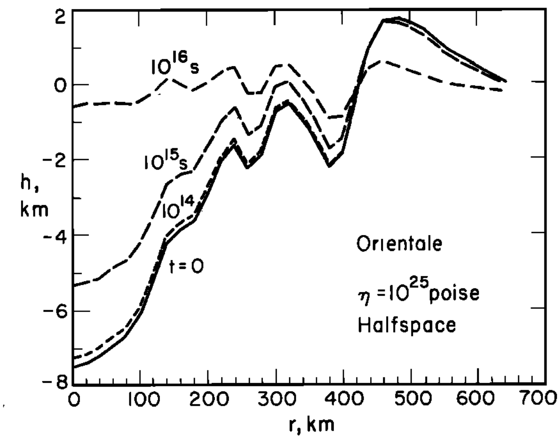

Fig. 2. Viscous relaxation of Orientale basin topography for a half-space model for lunar rheology. Profiles are shown at $t = 0$, 10^{14} s (3 m.y.), 10^{15} s (30 m.y.), and 10^{16} s (300 m.y.); these times scale linearly with the assumed viscosity, here taken as $\eta = 10^{25}$ P.

terized by temperatures low enough to resist viscous flow and to permit the long-term support of basin topography by finite strength.

VISCOUS RELAXATION

Half-Space Model

With the topographic profile of Orientale as an assumed initial state, we now examine the effect of viscous relaxation on the topography of basins formed earlier in lunar history when near-surface temperatures were high and solid state creep was a significant process at shallow depths and on relatively short geological time scales [e.g., *Solomon et al.*, 1981]. We consider a range of simple models for the response of the moon to initial basin topographic relief; in all of these models the response is determined analytically so that we may understand the effect of important parameters on the relaxation process.

The simplest model for lunar rheology is a half space of uniform Newtonian viscosity η, uniform density ρ, and uniform gravitational acceleration g. Consider topography that is initially two-dimensional and harmonic,

$$f(x) = F \cos kx \qquad (1)$$

where x is the horizontal coordinate and k is the horizontal wave number. Then at $t > 0$, the topography $h(x, t)$ is given by [e.g., *Cathles*, 1975]

$$h(x, t) = F\, e^{-t/\tau_0} \cos kx \qquad (2)$$

where

$$\tau_0(k) = 2\eta k/\rho g \qquad (3)$$

The relaxation is faster (i.e., τ_0 is less) for lower viscosity, for smaller k or greater wavelength ($2\pi/k$), and for greater gravitational acceleration.

The solution for circularly symmetric topography is analogous to (2). If the initial topographic profile is $f(r)$, where r is the radial coordinate, then at $t > 0$ the topography $h(r, t)$ is given by [*Cathles*, 1975]

$$h(r, t) = \int_0^\infty F(k)\, e^{-t/\tau(k)} J_0(kr)\, k\, dk \qquad (4)$$

where J_0 is the Bessel function of order zero, $\tau(k)$ is given by (3), and $F(k)$ is the Hankel transform of $f(r)$:

$$F(k) = \int_0^\infty f(r)\, J_0(kr)\, r\, dr \qquad (5)$$

Equations (3)–(5) have been used to evaluate the effect of viscous relaxation on lunar craters by *Daneš* [1965], *Scott* [1967], and *Hall et al.* [1981] and to estimate the lifetimes of crater and basin relief on Mercury by *Schaber et al.* [1977].

In practice, the initial topographic profile in Figure 1*b* is represented by a discrete series at a radial distance spacing of 20 km. The Hankel transform in (5) is evaluated by quadrature using the trapezoid rule and polynomial approximations to J_0 given by *Abramowitz and Stegun* [1964]. The integral in (4) is replaced by an equivalent sum over 200 wave numbers spaced evenly in k between wavelengths of 4000 and 40 km. The neglect of the spherical geometry of the lunar surface is likely to introduce some error in the relaxation times for the longest wavelengths (several hundred kilometers and greater) in the basin topographic spectrum.

The predicted viscous relaxation of Orientale basin topography with the half-space model for viscosity in the moon is shown in Figure 2. Profiles are given at a number of times t for the assumed values $\rho = 2.9$ g/cm^3, $g = 162$ cm/s^2, and $\eta = 10^{25}$ P. For the profiles shown, the indicated times would increase or decrease in direct proportion to changes in the assumed value for viscosity. Note that because long-wavelength features decay faster than short-wavelength features according to (3), the overall relief of the basin and the depth of the central depression decrease faster than the local relief of individual ring structures.

A uniform half space is not, for many reasons, an adequate model of the rheology of the moon. Laboratory experiments on the creep behavior of rocks and minerals appropriate to planetary crusts and mantles indicate that the effective viscosity of such materials is strongly dependent, in general, on temperature, strain rate (or deviatoric stress), and composition [e.g., *Tullis*, 1979]. Figure 3 displays, as examples, the effective viscosity of olivine [*Goetze*, 1978] and pyroxene [*Avé Lallemant*, 1978] at dry conditions as functions of temperature and stress difference. While a nonlinear relationship between stress difference and strain rate has been demonstrated for creep in rock-forming minerals at stress differences of hundreds of bars to kilobars and is characteristic of flow mechanisms controlled by the movement of dislocations [e.g., *Goetze*, 1978], Figure 3 indicates that the variations in the effective viscosity within planets is primarily a function of temperature and only secondarily a function of the stress difference. Thus to retain the simplicity and clarity of analytical models for planetary rheology, we maintain the assumption of a Newtonian viscosity (i.e., strain rate is linearly proportional to stress difference), but we permit viscosity to vary with depth in recognition of a strong dependence of rheology on temperature.

Layer Over Inviscid Half Space

The next simplest model that we consider for lunar rheology is that of a layer of uniform Newtonian viscosity η and thickness H overlying a half space of viscosity sufficiently low so that we may regard the material as inviscid ($\eta = 0$) at geological time scales. The conceptual motivation for such a model is that of a lithosphere in which viscous