CHARACTERISTICS AND EVOLUTION OF THE LUNAR LITHOSPHERE FROM THE DEFORMATION OF MASCON MARE BASINS. Sean C. Solomon, Dept. of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139 and James W. Head, Dept. of Geological Sciences, Brown University, Providence, RI 02912.

In an earlier study [1], the spatial and temporal relationships of linear rilles and mare ridges in the Serenitatis basin region of the Moon were explained by a combination of lithospheric flexure in response to basin loading by basalt fill and a time-dependent global stress due to the thermal evolution of the lunar interior. Both the basin-concentric rilles or graben and the mare ridges, interpreted as compressive features, are products of basin subsidence; the graben all formed prior to 3.6±0.2 b.y. ago [2], however, while ridge formation continued after emplacement of the youngest mare basalt unit ∿3.0 b.y. ago. Basing the distribution of fill in Serenitatis on the topography of the relatively unfilled Orientale basin, the radial distance of linear rilles from the Serenitatis center was shown to be consistent with an elastic lunar lithosphere 25 to 50 km thick 3.6-3.8 b.y. ago in that area. The locations of mare ridges, the depth of subsurface radar reflectors, and the present topographic relief indicated a thicker elastic lithosphere (∿100 km) at the time when mare volcanism ceased in Serenitatis. The cessation of rille formation and the prolonged period of ridge formation were attributed to a change in the global horizontal thermal stress from extension to compression as the Moon shifted from net expansion to overall cooling and contraction. Restricting the time of peak lunar volume to 3.6 b.y. or earlier, together with the constraint [3] that the accumulated thermal stress since the end of heavy bombardment did not reach levels capable of causing global-scale lithospheric failure, greatly limit the range of possible lunar thermal histories. The zone of horizontal extensional stresses peripheral to mare loads was also shown to favor the edge of mare basins as the preferred site for mare basalt magma eruption in the later stages of mare fill.

This work extends our study of the relationships among lunar mare filling, mare basin tectonics, and global thermal evolution to the other mascon maria: Imbrium, Crisium, Orientale, Humorum, Nectaris, Smythii and Grimaldi. The objectives of this work are to determine (1) the characteristics and geometry of tectonic features in mascon mare regions; (2) the distribution of major mare units and the flooding and subsidence history for each basin; (3) the temporal relations between tectonic features and geologic units; (4) the effective lithospheric thickness as a function of time in each mascon region; and (5) the relationship between local and global sources of stress in controlling lunar tectonic history.

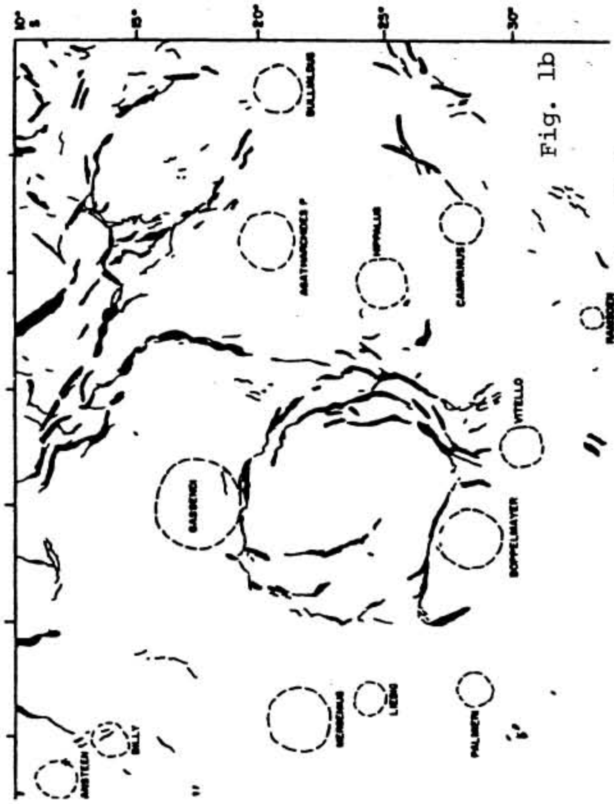
All mascon basins display tectonic features (rilles and ridges); however, Crisium, Smythii, and Nectaris have ridges, but no exposed concentric rilles. Mare ridges occur almost exclusively in mare basalt deposits. The main ridges and arches generally form a discontinuous concentric ring; occasional radial ridges are developed outside the ring and additional ridge components, often oriented north-south, are seen inside the ring. Where developed, rilles tend to be discontinuous, concentric to the basin, and to occur outside the ridge systems, usually in the adjacent highlands. In Humorum (Fig. 1) and Grimaldi, the rille systems become less arcuate and more rectilinear with increasing distance from the basin.

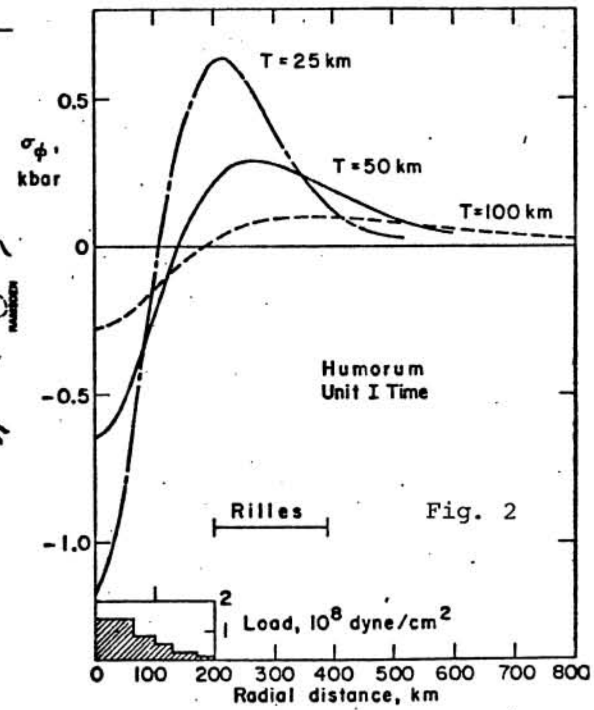
Sequences,volumes and timing of basalt emplacement were determined by stratigraphic reconstruction from remote sensing data [4-6], age determinations [7-8], and basin geometry [1]. Basin subsidence was determined from patterns of geologic units and present topography. Total volumes of basalt vary as a function of basin size, amount of subsidence, and stages of flooding (e.g., Orientale, little flooding; Imbrium, extensive flooding). The vast majority of filling for Crisium, Nectaris, Imbrium, Humorum and possibly Orientale occurred early (3.8-3.6 b.y.). Lesser amounts were added to Crisium, Imbrium and Humorum at 3.6-3.2 b.y. Minor amounts were subsequently added to Imbrium and Humorum. The earliest basalts have undergone subsidence, and subsidence continued for an undetermined length of time after the emplacement of the youngest basalts. Linear rille formation appears to be restricted to the period prior to about 3.6±0.2 b.y. [2], although subsidence continued well past that time. Mare ridges occur throughout mare regions, and must have continued to form until after emplacement of even the youngest mare basalt units.

Detailed models of the flexural response of the lunar lithosphere to the mare basalt loads at the times of emplacement of major mare units permit evaluation of the effective thickness T of the elastic lithosphere. The distribution of well-developed graben concentric to each mare basin center are matched by a spatially variable lithospheric thickness during rille formation 3.6 to 3.8 b.y. ago: $T \approx 25$ km for Grimaldi; $T \approx 25$ to 50 km for Serenitatis and Orientale; $T \approx 50$ km for Humorum (Fig. 2); $T \approx 50$ to 75 km for Imbrium; and $T \approx 75$ to 100 km for Nectaris, Smythii and Crisium. The good match of predicted stresses and rille positions about Mare Humorum (Figs. 1 and 2) in particular permits an important estimate of the extensional stress necessary to form graben: where $\sigma_\phi > 200$ bars graben have formed, whereas graben are absent in regions of lower extensional stress. The distribution of mare ridges and the topographic relief of present mare surfaces are matched by somewhat greater lithospheric thicknesses at the time of emplacement of the youngest mare units in most maria, and the required spatial variation in lithospheric thickness at $\sim$3.0 b.y. is less than at $\sim$3.6 b.y.

The growth of the lunar lithosphere beneath each mare basin is a natural consequence of the cooling of the outer portions of the Moon. The global synchronism for the cessation of linear rille formation can also be explained [1] as due to the superposition to the local stress of a global thermal stress that shifted from extensional to compressional as the Moon changed from net expansion to net contraction at or before 3.6±0.2 b.y. ago. The wide spatial variations in effective lithosphere thickness during the time of rille formation are not simply the product of the average lunar thermal evolution, nor are they explainable solely on the basis of variations in mare fill age or in the difference between basin excavation and mare fill ages. Rather these variations likely represent large scale inhomogeneities in the thermal structure of the lunar crust and uppermost mantle, inhomogeneities that appear to lessen in intensity with time as thermal variations are smoothed out by lateral conduction.

The primary conclusions of this study are as follows: (1) Although mare surfaces range in age from 3.8 to 3.0-2.5 b.y. ago, the major flooding of all circular basins occurred in the first 20 to 30 percent of the time of mare emplacement. (2) All mascon basins show evidence for superisostatic loading, subsidence and tectonics as a result of this flooding. (3) The fit of mascon stress models to the observed distribution of rilles in the mascon mare regions indicates significant spatial variations in lunar lithospheric thickness at 3.6-3.8 b.y. ago. (4) The global cessation of rille formation is attributed to the overriding of flexural extensional stress by thermal compressive stress associated with whole-Moon cooling. (5) The growth of the lunar lithosphere with time is evident in the evolving response of the Moon to continued loading of mascon basins by mare basalt fill. The present mascons are now supported by the finite strength of the lunar lithosphere.





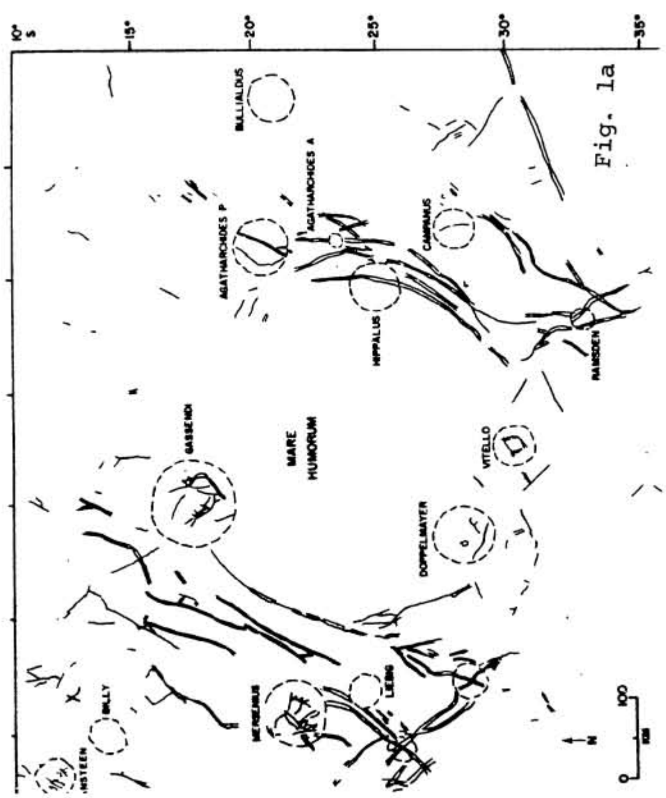


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Fig. 1. Humorum tectonics (a) rilles, (b) ridges. Fig. 2. Radial horizontal surface stress, Mare Humorum. T is the elastic lithosphere thickness.