VERTICAL MOVEMENT IN MARE BASINS: RELATION TO MARE EMPLACEMENT, BASIN TECTONICS, AND LUNAR THERMAL HISTORY. 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.

The thermal history, crustal tectonics, and surface volcanism on a planet are all interrelated [1,2]. For the Moon, the absence of global-scale tectonic features such as are prominent on Mercury or Mars implies a nearly constant volume for the period of lunar history following heavy bombardment. Thermal history models consistent with this requirement involve early heating to near-melting conditions to a depth of 200-300 km and an initially cold deep interior [1,2]. Smaller scale tectonic features, including linear rilles and mare ridges, are common but appear to be primarily the result of vertical tectonics closely associated with mare basins rather than a global tectonic stress system [3-6]. In this paper we argue that the sequence of tectonic styles near mare basins is related both to the history of mare loading and to the global stress field due to planetary heating and cooling. This hypothesized interrelationship permits refined constraints to be placed on the stress systems on both regional and global scales and leads to a number of other conclusions about lunar thermal and volcanic history.

Circular mare basins show evidence of downward movement and associated tectonic activity throughout the history of mare emplacement [3-6]. For Serenitatis in particular, there is a correlation between stage of lava filling and style of deformation [3,4]. Deformation was in part responsible for the patterns of emplacement of later lavas. Earliest basalt deposits of Serenitatis occur today in a belt around the southern rim, continuous with Mare Tranquillitatis, and including the Apollo 17 site. Subsequent to their emplacement they were downwarped toward the basin center and a series of basin-concentric graben were formed in these units and adjacent highlands along the edges of Serenitatis. A second stage of filling [3] is represented by basalts presently exposed as part of an annulus ring along the eastern and southwestern parts of the basin. These lavas flood graben developed in the earlier units. They have been subsequently downwarped toward the basin center, but contain only minor fractures and graben. The central downwarped part of Serenitatis was filled with a third stage of lavas which postdate virtually all graben formation. Mare ridges were developed extensively in this unit and appear to be compressional features [3-5,7-9] associated with downwarping. The main ridge system forms a roughly circular structure, probably controlled by inner basin substructure; several ridges radiate outward from the concentric system. The deformed surface indicates continued downwarping well past emplacement of the youngest lavas in Serenitatis. On the basis of this history, rille formation appears to have been limited to the period about 3.5-3.7 AE, while downwarping and mare ridge formation continued to a later period.

We hypothesize that both the rilles and ridges are products of a superposition of the regional stress due to loading of mare basins by basalt fill and the time-dependent global thermal stress associated with the Moon's thermal history. The formation of rilles at times prior to $\sim$3.6 AE is attributed to an extensional global thermal stress regime and the change to formation

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only of mare ridges at later times is attributed to a switch in the global thermal stress toward more compressive horizontal stresses [1,2].

The effect of mare basalt loading may be modeled using the solution for stress in spherical, liquid-filled, elastic shells due to a surface load with cylindrical symmetry [10]. The horizontal stress component σ_r radial with respect to the basin is shown in Fig. 1 for a model of the basalt load in Mare Serenitatis. The radial distribution of the load is taken after the excess mass as observed from gravity analysis [11] and from the expected geometry of pre-fill circular basins [12] and of identifiable mare basalt units. The load shown is a conservative estimate because partial compensation of the load due to crustal flexure and relaxation of the load since mare emplacement have been ignored. The stress σ_r at the surface is compressional beneath the load center and extensional outside the load. The variation of σ_r with radial distance from the basin center is strongly dependent on the elastic shell thickness T, a parameter not well known but related to the thermal structure of the lithosphere.

To the local stress field shown in Fig. 1 must be added the global stress due to differential heating and cooling of the lunar interior. Thermal models that produce acceptably small volume and stress changes since 4 AE predict a period of modest expansion and tangential extension followed by modest contraction and more compressive stress [1,2]. Shown in Fig. 1 is the accumulated tangential stress from 4.0 to 3.6 AE, about 280 bars extension, and from 3.6 to 2.6 AE, about 540 bars compression, for a thermal model with initial melting to 300 km and a central temperature of 300°C. Until 3.6 AE for such a model, the superposition of the regional extension with the local stress field shown will accentuate the tensional stress at the edge of the mare basin and lead to graben formation at the appropriate radial distance for T = 25 to 50 km. After 3.6 AE, the global thermal stress will be toward greater compression, reducing the extensional stress outside the fill margin and accentuating the horizontal compression beneath the load, thus accounting for formation of mare ridges continuing later than formation of concentric rilles. The radial horizontal stress is less compressive than the azimuthal stress near the outer portions of the mare basin, which will strongly favor radially-oriented mare ridges. At increasing times, the local stresses are reduced by failure and by an increase in the thickness T as the Moon cools.

The stress associated with mare loading may also control the eruption sites of mare basalt magma. With the reasonable assumption that magma ascent is more likely in the presence of horizontal extensional stress, a schematic path of magma ascent is shown in Fig. 2. The most likely eruption site in at least the later stages of mare fill is near the basin edges, in agreement with limited observations [e.g., 13].

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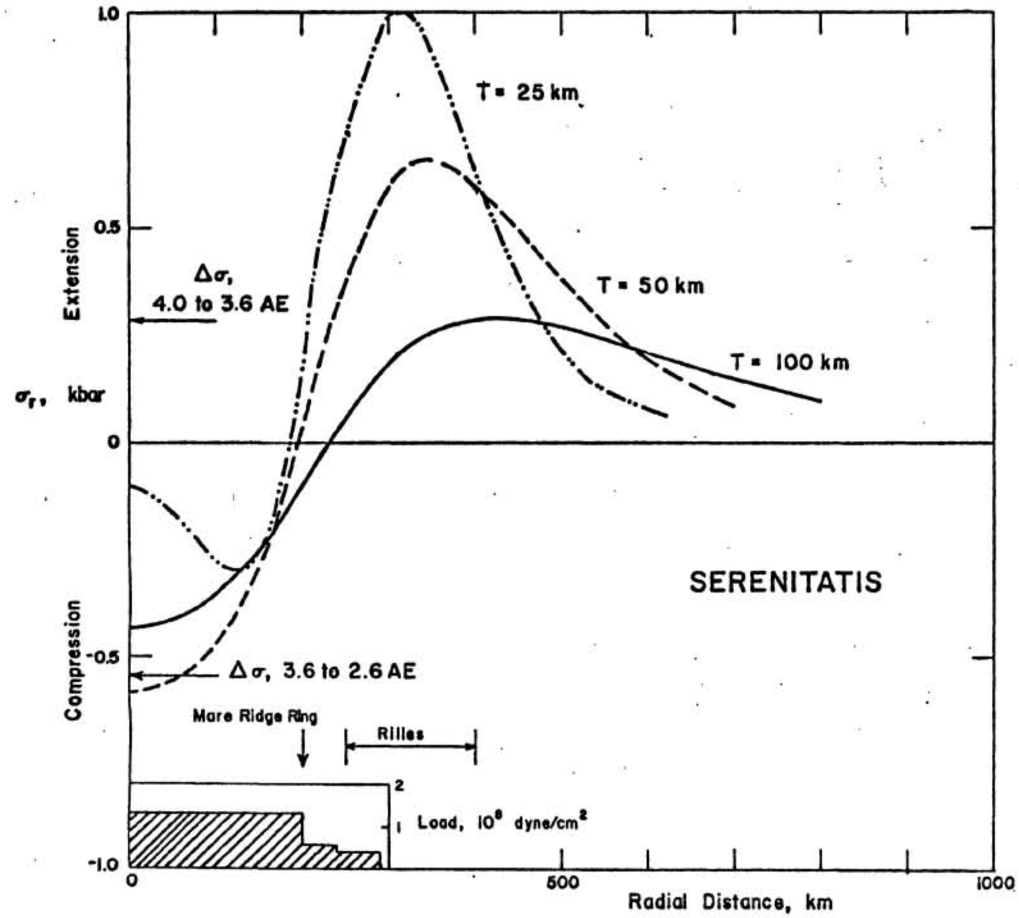

Figure 1: Radial horizontal stress at the lunar surface due to the Serenitatis load. See text for discussion.

Figure 2: Schematic bending stresses and predicted magma ascent path beneath a filled mare basin.