LITHOSPHERIC LOADING AND TECTONICS OF THE LUNAR IRREGULAR MARIA

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Introduction. Many of the tectonic features associated with the circular maria are the result of stresses generated by loading of the lunar lithosphere by mare basalt units [1]. In this paper we test the hypothesis that the irregular lunar maria share with the circular maria the processes leading to the formation of associated graben and mare ridge systems. We apply a formulation of the lithospheric flexure problem that accounts for the variable distribution of basalt loads for the irregular maria. On the basis of the tectonic structures and geologic history of each of the major irregular maria, as well as models for the distribution of mare basalt for each region, we compare the predicted stress fields with the distribution of tectonic features for a range of assumed values of the thickness of the elastic lithosphere. We then compare the best fitting values for lithospheric thickness beneath the irregular maria with those previously inferred for the circular maria [1].

Procedure. To model the stress field induced by lithospheric loading, we employ the theory [2] for flexure of a thin elastic shell overlying an inviscid fluid interior. The stresses due to an arbitrary surface load are approximated by summing the solutions for stress from a set of disk loads [2]. The load models are based on estimates of mare basalt thickness derived from a simultaneous inversion of nearside gravity and topographic data [3]; the contributions of mantle relief and mare basalt load are separated by assuming that basin topography was isostatically compensated prior to mare fill and that subsidence in response to mare loading may be neglected. These asssumptions lead to minimum values for the calculated mare basalt thicknesses [4]. Where appropriate, geological estimates of mare basalt thickness [5,6] are also employed for comparative models.

Fecunditatis. Mare Fecunditatis occupies an irregularly shaped depression 600 km by 900 km in dimension; the main northern part is generally held to be the site of a degraded impact basin [7]. Graben are found primarily adjacent to the northwestern mare margin, with some additional extensional features to the southeast; mare ridges occur throughout the northern section of the mare [8]. Lithospheric loading models provide a good fit to the distribution and orientation of extensional features surrounding Mare Fecunditatis, as long as the stress fields contributed by the nearby Nectaris and Crisium mascons are taken into account. The best fit of the area of maximum extensional stress difference to the observed locations of graben is for values of the thickness T of the elastic lithosphere between 40 and 75 km. The best-fitting value of T for the area of maximum compressive stress difference is somewhat greater, 50 to 100 km, consistent with lithospheric cooling between the times of graben formation [9] and of formation of mare ridges following emplacement of the youngest mare basalt lavas [10].

Tranquillitatis. Tranquillitatis is one of the oldest identified basins on the lunar nearside [7] and contains mare units that are among the oldest on the Moon [10]. Extensional features are concentrated to the western side, where basalt thicknesses are greatest [3,5]; mare ridges are located throughout, but are most concentrated in the Lamont region [8]. The best fit of the area of maximum extensional stress to the locations of observed graben is for T = 30 to 60 km. A lithospheric thickness of 60 to 150 km is implied by the distribution of mare ridges. Whether an episode of ridge formation postdating graben formation in fact occurred in Tranquillitatis is not clear from available age relationships [9,10].

Nubium. Located near the southern end of Oceanus Procellarum, Mare Nubium occupies an ancient basin [7]. A few isolated extensional features are present, as are several sets of mare ridges [8]. The best fit of the areas of maximum extensional stress to the observed graben positions is for T = 30 to 75 km. The corresponding best value at the time of formation of mare ridges postdating the youngest mare units [10] is 50 to 150 km.

Procellarum. Oceanus Procellarum, the largest lunar mare, has had a complex volcanic history [11]. A series of graben are located in the uplands to the west of the mare, and numerous ridges are located throughout the mare. The thickness of mare basalt exceeds 1 km along an axis trending NW from Mare Humorum. In constructing load models, we have divided Procellarum into separate western (including Grimaldi) and eastern segments; this division is an oversimplification to the loading history but has some correspondence in the surface mare units [11]. In western Procellarum, the best fit of extensional stresses at the time of graben formation is for T less than 25-35 km; the lithospheric thickness beneath eastern Procellarum at this time is indeterminate. The best match of predicted stress differences to the distribution of ridges is for T = 25-75 km beneath Procellarum and perhaps a slightly greater thickness (50-100 km) beneath the eastern portion.

Discussion and Conclusion. In general, most tectonic features in the vicinity of the irregular maria can be explained as the result of vocanic loading and flexure of the lunar lithosphere. The inferred values of the thickness of the elastic lithosphere at the time of formation of lunar graben 3.6-3.8 b.y. ago [9] and at the time of cessation of mare volcanism compare well with estimates of contemporaneous thicknesses beneath nearby circular maria (Figure 1). The thickness of the lunar lithosphere apparently varied smoothly in space and time, with the lowest values indicated for the west-central nearside. One possible source of the heterogeneous thermal gradients implied by the thinner lithosphere in this region is residual impact heat remaining from the formation of the large Procellarum basin [12].

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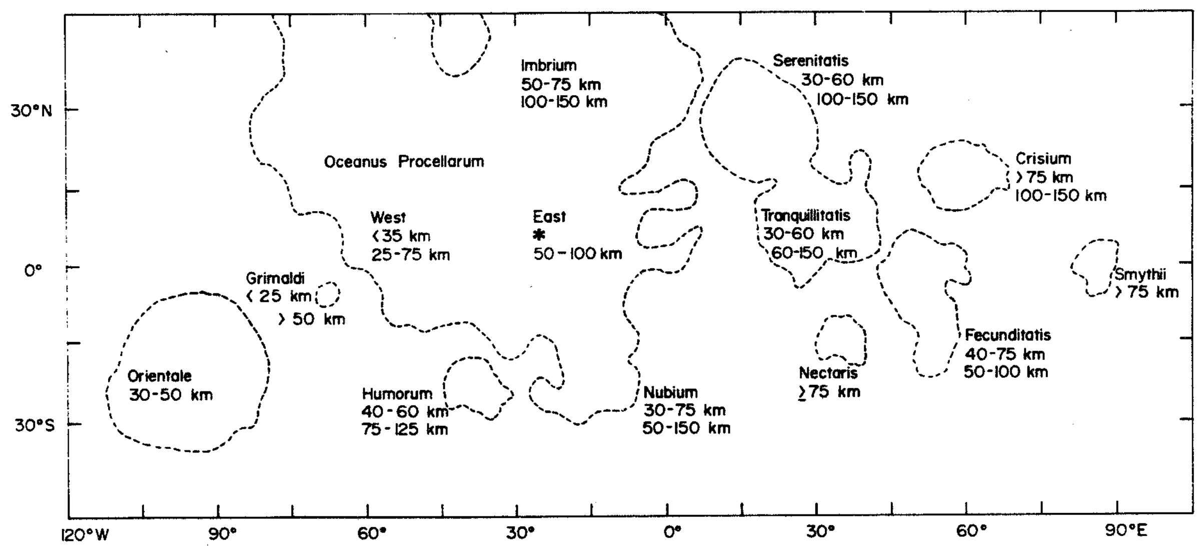

Figure 1. Summary of determination of the thickness T of the elastic lithosphere on the Moon from mare tectonic features. For each load, the upper figure gives T in km at the time of graben formation 3.6-3.8 b.y. ago [9]; the lower figure gives T at a later stage in mare flooding when mare ridge formation and subsidence were continuing but rille formation had ceased.