KINEMATICS OF BASIN SUBSIDENCE, GRABENS, AND LUNAR EXPANSION

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Although the moon is tectonically inactive relative to the earth, the presence of grabens and wrinkle ridges indicates that stresses sufficient to deform or fault surface rocks have existed for at least part of the \textasciitilde 3.9 by since the end of the early heavy bombardment. Because most of these grabens and wrinkle ridges are associated with large impact basins (1), they provide an interesting opportunity to constrain long-term modifications of the lunar crust in the vicinity of large basins (e.g., 2-5).

The time of formation of grabens and wrinkle ridges (6), and the apparently greater age of grabens than wrinkle ridges are consistent with models of lunar thermal evolution that predict an early phase of lunar expansion followed by long-continued contraction (7). As pointed out by Golombek (8), the geometry of the grabens permits a rough quantitative check on the magnitude of the expansion phase of these models, and his results indicated that predicted post-3.9 by radius increases of 1 km or more are inconsistent with surface-area increases calculated from graben geometry even if all the grabens are assumed to be due to global expansion. But because most lunar grabens are associated with impact basins, it is possible that most of them are not due to global expansion, but to basin subsidence instead.

Models of basin subsidence can be developed either by 1) assuming an idealized loading geometry, calculating the resulting stresses in the lunar lithosphere, and then, by assuming values for the relevant elastic constants, comparing the calculated results with observed deformation and faulting (grabens and wrinkle ridges); or by 2) assuming an idealized subsidence geometry, calculating the resulting length changes in the lunar lithosphere, and then comparing the results with observed deformation and faulting. The advantage of the second approach is that no assumptions about elastic properties are required. Even so, kinematic models of basin subsidence have not been pursued as diligently as dynamic models. Existing models (9,10) are incomplete or geologically not very realistic.

If the basin floor is assumed to approximate a circular arc, then subsidence could occur with or without change in the radius of curvature of this arc, and two end-member models may be investigated: 1) subsidence with increase in radius of curvature, and 2) subsidence with no increase in radius of curvature. Any combination of these end members is possible.

1. Increase in radius of curvature: All points on the basin floor are assumed to subside along lunar radii, hence the floor of the basin will be compressed both radially and tangentially as these points converge. The greatest compression occurs near the center of the basin; tangential (hoop) compression declines to 0 at the basin periphery, but radial compression declines to 0 inward of the basin periphery. The basin floor also is subject to radial compression due to " unbending" caused by the increase in radius of curvature. Finally, at the basin periphery, an anticlinal flexure is created by the subsidence. Although the bending extension that results from this flexure is critically dependent on its width, total lengthening is essentially independent of the flexure width selected unless an unrealistically narrow and sharp flexure is assumed. The logical value to assume is the width of the circumferential graben zone. Both the unbending compression of the basin interior and the extension due to the peripheral flexure depend on the thickness of the elastic lithosphere.

2. Constant radius of curvature: As with model 1, subsidence causes
radial and tangential compressions of the basin floor, but these are constant throughout the basin interior, and no unbending occurs. This model predicts both an anticlinal and a synclinal flexure at the periphery of the basin in order to maintain continuity of the lithosphere. In common with model 1, the anticlinal flexure is assumed to coincide with the zone of circumferential grabens; the synclinal flexure would be on the basinward side of the grabens.

Both models predict compression of the inner part of the basin, the first by arc shortening plus unbending, the second by arc shortening plus synclinal flexing (near the periphery only). Both also predict extension of an annulus around the basin due to anticlinal flexure. For a Humorun-sized basin (radius from basin center to inner edge of zone of grabens = 200 km, width of zone of grabens = 50 km), for an elastic lithosphere 50 km thick, and for 2 km of subsidence at the basin center some results are:

<table>
<thead>
<tr>
<th>Total radial shortening of floor of half basin in graben zone</th>
<th>Total radial lengthening</th>
<th>Maximum total hoop shortening of half circle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td>Model 2</td>
<td>Model 1</td>
</tr>
<tr>
<td>615 m</td>
<td>1765 m</td>
<td>505 m</td>
</tr>
<tr>
<td>280 m</td>
<td></td>
<td>-4075 m</td>
</tr>
</tbody>
</table>

For model 1, maximum total hoop shortening occurs about 6/10 of the distance from the basin center to the graben zone. For model 2, total hoop shortening increases outward until the zone of peripheral synclinal flexure is reached; beyond that, subsidence and thus hoop compression decrease rapidly. The value of maximum total hoop shortening given in the table is for a radial distance of about 150 km.

The lengthening in the zone of circumferential grabens for both models compares closely with the 470 m measured for Humorun by Golombek (8). In addition, the predicted shortening of the basin floor seems reasonable in light of shortening in the Serenitatis basin measured by Muehlberger (2) assuming that wrinkle ridges are structures resulting from compressive stresses. Consequently, it seems that basin subsidence is, in fact, capable of accounting for the length changes implied by those grabens and wrinkle ridges associated with basins.

The thermal model developed by Solomon and co-workers provides a satisfactory explanation for the timing of graben and wrinkle-ridge formation, but it predicts changes in the lunar radius that cannot be supported by the geological data. The limited extension implied by lunar grabens, and the probability that almost all of this limited extension can be explained by basin subsidence, constrains post-3.9 by lunar expansion to essentially trivial amounts. Our results do not similarly constrain later contraction, but they do indicate that most wrinkle ridges can be explained without this global contraction.