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IMPORTANCE OF EXPANSION AND CONTRACTION IN THE FORMATION OF TECTONIC FEATURES ON THE MOON

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The lack of globally distributed tectonic features on the lunar surface has been used to argue against significant changes in the radius of the Moon (1) since the formation of the presently observed surface, which dates to the end of heavy bombardment about 3.9 Ga. This observation has been used previously to limit the maximum stresses to ~100 MPa that could be supported by the lunar lithosphere without the formation of globally distributed tectonic features (2), which in turn limits the maximum radius change to ±1 km for a purely elastic lithosphere (3). In a previous abstract (4), limits on the elastic expansion or contraction of the Moon were reexamined with respect to realistic failure stresses necessary to produce actual lunar tectonic features. In addition, limits on the permanent (plastic) strain that could be accommodated by non-mascon grabens and wrinkle ridges were considered with more severe constraints placed on the total reasonable expansion and contraction of the Moon since 3.9 Ga. In this abstract, considerations of the distribution and mechanisms of formation of lunar tectonic features are used as an additional argument against their formation due to a planetary radius change or their accommodating much permanent plastic planetary expansion or contraction.

Grabens and wrinkle ridges are the generally accepted tectonic features on the Moon. The general approach assumed in this abstract is that the maximum elastic expansion or contraction of the Moon can be limited by application of generally accepted failure criterion (the frictional resistance to sliding on preexisting fractures [5]) to the particular structures of grabens and wrinkle ridges (4, 6, 7). Using this criterion, the maximum stresses possible before failure are about 10 MPa under extension and 30 MPa under compression, which restricts the elastic radius increase to about 100 m and the elastic radius decrease to about 300 m. Beyond this elastic limit, the surface of the Moon is everywhere on the verge of failure, so that any additional expansion or contraction will result in failure that would form structures visible on the surface. If, however, the surface of the planet is not uniformly covered by tectonic features the maximum global stress limit may be substantially lower than calculated in this manner, due to likely concentrations or inhomogeneities in the actual stresses.

Most grabens and wrinkle ridges observed on the Moon are found in and around mascon basins. Models of the flexure of the lithosphere due to mascon loading suggest that sufficient extensional stress and strain can be generated at the edges of basins to account for concentric grabens and sufficient compressional stress and strain can be generated in the interior of basins to account for wrinkle ridges (6-10). As a result, these structures should not be considered to form from global strain or stress fields. Nevertheless, there are a significant number of grabens and wrinkle ridges that are not related to mascon basin flexure and these could have formed from lunar expansion or contraction (even though these features are not globally distributed – all are on the lunar near side). In addition, only tectonic features that can be confidently assigned to extensional or compressional structural deformation are considered here (i.e., grabens and wrinkle ridges); no consideration is given to less well understood features of potential structural origin such as the lunar grid or highland scarps (11).

The total length of non-mascon related wrinkle ridges on the Moon is just short of 15,000 km and the total length of non-mascon related grabens on the Moon is just below 7400 km. Assuming these features are randomly distributed, the total radius change that can be accommodated in tectonic features is given by $\Delta R = (R^2 - \Delta A/4\pi)^{1/2} - R$ where R is the radius of the Moon and ΔA is the cumulative change in surface area, which is simply the total length of structures times their average horizontal extension or shortening (6, 7). As a result, non-mascon wrinkle ridges could have resulted from a 75 m contraction of the Moon and non-mascon grabens could have resulted from a 25 m expansion of the Moon. Nevertheless, lunar grabens and wrinkle ridges are not randomly distributed. Virtually all are found on the front side of the Moon, so that it could be argued that these results are overestimates.

If the existing non-mascon tectonic features on the Moon were indeed randomly distributed, then a simpler method could be used to determine the radius change accommodated permanently in non-mascon grabens and wrinkle ridges. For a randomly distributed set of tectonic features any great circle traverse around the planet would encounter the same cumulative shortening or extension, for a uniformly contracting or expanding planet. If all structures within each group of features (grabens and wrinkle ridges) had the same average shortening or extension, then all great circle traverses would encounter the same number of features. If this were the case, the total shortening or extension around any particular great circle traverse is equal to the total change in circumference of the planet, which is equal to 2π times the radius change. A simple test of the above was performed on the Moon. Two equatorial great circles were chosen to maximize the number of grabens and wrinkle ridges that were crossed. (There are, of course, great circle transects that could be constructed that would not cross any tectonic features.) About 30 wrinkle ridges were crossed on one transect and 10 grabens were crossed on the other. For average shortening and extension estimates (6, 7) these transects would predict of order 1 km contraction and 300 m expansion of the Moon, respectively. These radius changes are roughly an order of magnitude greater than the estimate based on the change in surface area calculated earlier. This seems to suggest that grabens and wrinkle ridges are quite non-randomly distributed (by an order of magnitude), which could be used to infer that the previous estimates of permanent radius change are also substantial overestimates.

If, in fact, grabens and wrinkle ridges are not distributed uniformly, then any shortening or extension by tectonic features that was related to a radius change would result in a non-uniformly shrinking or expanding planet. No doubt some non-uniformity of shortening or extension can be accommodated on the Moon, but large differences implied by the above calculations seem excessive. In addition, a non-random distribution of grabens and wrinkle ridges can also be used to argue for lower elastic limits on global expansion and contraction. If large portions of a planet do not have any tectonic features, then average global stress may be lower due to concentration of stresses in particular areas, such as the lunar near side. Some limits can be placed on the amount elastic stresses could be lowered due to stress concentrations. The maximum lowering of global stresses by regional stress concentration would be attained if, for example, the stresses on the near side of the Moon were doubled, leaving no stresses imposed on the far side. Then the average global stress due to global expansion or contraction could be lower by a factor of two. If true the required radius change would be similarly decreased by a factor of two. These considerations suggest that the elastic limits on radial expansion of 300 m and 100 m for contraction and expansion derived for uniform elastic stresses may be overestimates.

Taken together, these additional arguments would suggest that a maximum expansion of the Moon of 125 m and a maximum contraction of the Moon of 375 m that were derived earlier (4) for both elastic and plastic radius change are also overestimates and that actual lunar radius changes since the end of terminal bombardment 3.9 Ga are considerably less.

These limits on the change in lunar radius during the past 3.9 Ga have important implications for models of the origin of the Moon. Previous conservative thermal models assumed a warm exterior and cool interior to minimize the change in radius (3). New models for the origin of the Moon from a giant impact imply a substantially more energetic, and correspondingly warmer (and partially melted) early history, which may be even more difficult to reconcile with such restrictive constraints on radius change (e.g., 12).

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