ASYMMETRY OF THE MOON, John A. Wood, Smithsonian Astrophysical Observatory, Cambridge, Mass. 02138.

Examination of samples from the lunar terrae shows them to consist of feldspar-rich rock types of specific gravity (~2.9 g/cm^3), substantially less than that of the moon as a whole (3.35 g/cm^3). Seismic studies indicate that material of this type forms a crust about 40 km thick on the lunar nearside, overlying a rock mantle of higher seismic velocities (Toksöz et al., 1972). Variations in gravity on the lunar nearside (Wong et al., 1971) also dictate the existence of such a layer, and underline its small-scale variability in thickness. If the crust is x km thick beneath nearside terra regions, it should be x minus ~10 km thick beneath nonmascon maria and x minus ~25 km thick beneath mascon maria to reproduce the observed variations in lunar gravity (Wood, 1973).

Larger scale heterogeneities in crustal thickness are indicated by the noncoincidence of centers of mass and figure of the moon. Apollo 15 laser altimetry determined that the center of mass is offset from the center of figure 2.1 km in a direction 40° (lunar) east of earthward (Roberson and Kaula, 1972). This asymmetry is most straightforwardly interpreted in terms of a low-density lunar crust thicker by 15-20 km on the farside than on the nearside.

The most compelling evidence for large-scale crustal heterogeneity, however, comes from considerations of the moon's principal moments of inertia. Kopal (1972) has pointed out that differences between pairs of principal moments are more than an order of magnitude greater than could be accounted for by the form of a homogeneous moon, slightly flattened by monthly rotation and stretched by earth tides. He concludes that the moon has a nonequilibrium figure whose preservation precludes the body of the moon having had a high-temperature history. Another interpretation, however, is that the moment differences are due to variations in crustal thickness in an isostatically equilibrated moon.

A program was written that calculates moment differences to 1 part in 10^9 for moons with arbitrary crustal profiles. Nearside crust and mare basalt thicknesses were chosen to conform with seismically determined values (Toksöz et al., 1972), and various crustal thicknesses were tested elsewhere on the moon until the model reproduced the differences in moments of inertia observed for the moon (Fig. 1). The model is not unique, but latitude for variations is limited. If the moment differences are to be generated by a moon in a fair state of isostatic equilibrium, the crust must be substantially thicker on the farside than on the nearside, and remarkably thin at the poles.

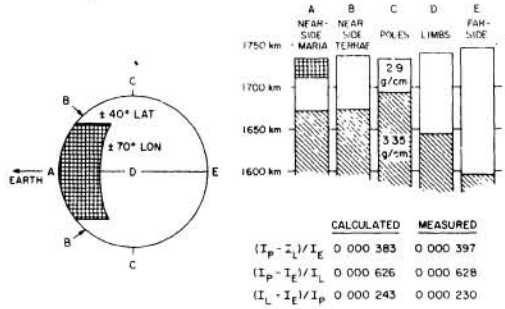

Fig. 1. Lunar crustal model that satisfies observed differences in moments of inertia. Doubly hatched material: mare basalt, density 3.35 g/cm^3. Thickness of low-density crust is assumed to vary smoothly between points specified.

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One possible explanation for these variations in crustal thickness is that selective bombardment of the moon, in which crustal material is systematically transferred as cratering debris from the most-beaten side of the moon to other (relatively protected) areas. Any bombardment of the moon by planetesimals in heliocentric orbit would have been to some degree biased by the gravitational influence of its massive companion, so that once it was spin-orbit coupled to the earth, the moon would have experienced more impacts in some places than in others. If planetesimals were still abundant in the solar system after the moon achieved approximately its present size and differentiated a crust, the integrated effect of many impacts may have caused the observed large-scale variations in crustal thickness.

Two effects bias the bombardment of the moon: gravitational focusing of planetesimals, by the earth, onto the lunar nearside, and the tendency of the "leading edge" (west limb) of the moon in its orbital motion to suffer more collisions than the trailing edge. The efficacy of each process is a function of the moon's orbital velocity (hence the earth-moon distance) and the approach velocity of planetesimals. A computer study of bombardment asymmetries was carried out in which many hypothetical planetesimals were fired into the earth-moon system, the equations of motion of each being integrated until it collided with earth or moon or passed through the earth-moon system. If lunar capture occurred, the position of impact was recorded (see Figs. 2 and 3); for some conditions, one face of the moon is bombarded 4 times as intensely as the opposite face.

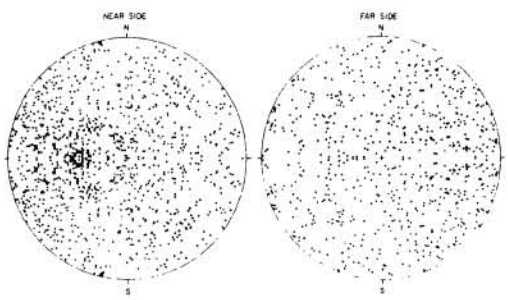

Fig. 2. Equal-area projections of nearside and farside of moon, showing distribution of impacts by planetesimals fired at 10 km/sec into solar system when earth-moon distance was 10 earth radii (ER).

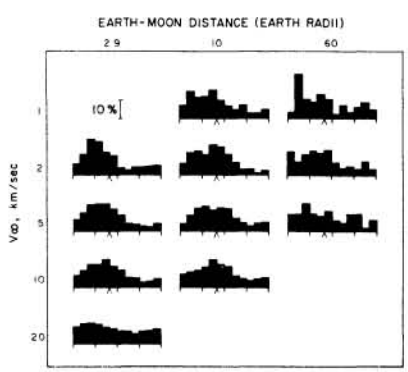

Fig. 3. Distributions of impacts on moon, by longitude, for five approach velocities of planetesimals and three earth-moon distances. (2.9 ER is just outside the Roche limit; 60 ER is the present earth-moon distance.) Vertical tick marks on histograms are, left to right, 180° longitude (farside); 90° W longitude; subearth point; 90° E longitude; 180° longitude.

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Whether this is the currently "thin-crusted" face of the moon is immaterial, as the moon would not maintain a static orientation after or even during bombardment. Changes in crustal profiles caused by bombardment redistributions (and later by eruption of mare basalts) would change the positions of principal axes of inertia, and these would reorient the moon such that the principal axis about which the moment moment of inertia was a maximum remained the rotation axis, and the principal axis about which the moment was a minimum pointed toward the earth. The orientation of the moon has probably evolved in a very complicated way.

The almost total restriction of basalt-filled maria to the lunar nearside probably follows simply from this asymmetry of crustal thicknesses. Lava would have to rise farther from the lunar center of gravity to flood the thick-crusted farside than it did on the nearside.

References

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