
Weiss and Coleman (1) found that the lunar craters in an otherwise spherically symmetrical shell, magnetized in a dipolar configuration, could produce remanent dipole moments close to the upper limit estimated by the Apollo subsatellites. Here we discuss an extension of the work with the cratered shell model which includes the evaluation of the higher order moments due to the cratering for both symmetric and asymmetric shell models.

As a first calculation, we evaluated the remanent lunar dipole moment, \( \mathbf{M}_g \), in a similar fashion as in reference (1), but included the effects of an offset inner core and/or an off-center magnetizing dipole, \( \mathbf{M}_o \). We found that the value of the outer shell dipole moment, \( \mathbf{M}_s \), was insensitive to displacement of the inner core but very sensitive to the position of the magnetizing field in relation to the center of figure of the outer sphere. For our calculation, we took the average thickness of the magnetized shell to be 100 km and a magnetizing dipole offset by 35 km towards the Earth. These values are consistent with the center of figure - center of gravity offset found by Kaula et al. (2), using the laser altimeter data from the Apollo missions.

Also, using a dipole moment per unit volume \( 3 \times 10^{-4} \text{ cm}^3/\text{cm}^3 \), our calculations give \( |\mathbf{M}_s| = 5.46 \times 10^{19} \text{ cm}^3 \) and oriented in the same direction as the magnetizing dipole \( \mathbf{M}_o \).

\( \mathbf{M}_g \) was then determined by subtracting from \( \mathbf{M}_s \) the dipole moment due to the removal of material from the shell by cratering. Our calculations of \( \mathbf{M}_g \) were done for the set of craters and the three mutually orthogonal orientations of...
the magnetizing field listed in reference (1). Thus for $\mathbf{M}_o = M_o \hat{x}$, $|\mathbf{M}_g| = 4.50 \times 10^{19} \text{ T cm}^3$; $\mathbf{M}_o = M_o \hat{y}$, $|\mathbf{M}_g| = 5.83 \times 10^{19} \text{ T cm}^3$; $\mathbf{M}_o = M_o \hat{z}$, $|\mathbf{M}_g| = 5.9 \times 10^{19} \text{ T cm}^3$. (\(\hat{x}\) is Earthward and \(\hat{z}\) is northward) All these values are larger, by a factor of about 5, than the upper estimate of the lunar permanent dipole moment of \(10^{19} \text{ T cm}^2\) given by Apollo subsatellite measurements (3). Also the angles between $\mathbf{M}_o$ and $\mathbf{M}_g$ are small for each orientation (7.7° for $\mathbf{M}_o = M_o \hat{x}$, 2.1° for $\mathbf{M}_o = M_o \hat{y}$, 5.7° for $\mathbf{M}_o = M_o \hat{z}$) and is due to the large value of $M_o$. Evaluation of the necessary integrals for an arbitrarily cratered surface allows a determination of the expected field components at any location outside the moon. Subsatellite ephemeris data can then be used to predict fields resulting from any orientation of the assumed magnetizing dipole permitting a direct comparison of observed and predicted fields. The required calculations for the ten-basin model described earlier are in progress.

For example, using the dimensions of our largest basin and a magnetization of order of ten gammas at the surface of our hypothetical shell (considered to be of lunar radius) would produce an observable field of order several gammas at 100 km directly above the basin. This compares to fields of order several tenths of gammas as measured by the Apollo subsatellites. Had our shell only contained basins located at greater distances from the magnetic poles, the observable field would be correspondingly smaller. Further, the net external field outside a heavily cratered shell must be the superposition of a large number of individual crater fields -- some adding, some subtracting from each component of the measured field at a given point. In light of the present uncertainties in the assumed magnetization magnitude, it therefore
Cratered-Shell Model . . .

H. Weiss, L. Hood, P.J. Coleman, Jr.

appears that order-of-magnitude discussions alone do not exclude the possibility that additional topographical effects could make a significant contribution to the observed external lunar fields.

The investigation of this simple cratered shell model is but the first step in the study of a long sequence of possible effects which must eventually be taken into account if the observed external field is to be even understood qualitatively. Should there be any correlations with topography for a particular orientation and/or magnitude of the assumed dipolar magnetization, then more elaborate models may be constructed. In particular, effects such as randomization of the magnetization in certain overturned areas (lunar gardening) and possible non-random re-orientation beneath lunar basins may be investigated. Finally, finite permeability and cooling time effects on both a global and local scale (due to compositional differences) should be considered. Hopefully, some reasonable constraints on the presence of an original magnetizing field and on some aspects of lunar history since it was removed will be the end product.

