LUNAR PALAEOMAGNETISM, POLAR DISPLACEMENTS AND PRIMEVAL LUNAR SATELLITES.
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It has long been argued that the lunar palaeomagnetic evidence is most simply explained by the hypothesis that the Moon had an early magnetic field (1) generated by a dynamo process in a small iron core (2). A decisive test has been lacking. The exponential decay of its palaeointensity with time (3) is, however, easily understood in terms of the dynamo process than by invoking locally produced transient fields. Cisowski (4) using a new method has found independent evidence for such a dependence of field intensity with age.

The modelling of the magnetic anomalies surveyed by the three component magnetometers of the Apollo 15 and 16 sub-satellites, first of the 35 far side anomalies (5), then of Reiner γ (6) and recently of many front side anomalies (7), have provided the opportunity for a decisive test. The initial modelling by dipoles placed them 50 km below the surface: it was shown that the equivalent surface magnetization must possess a uniformity in direction on the scale of a few hundred kilometers. Again this is most easily understood in terms of the dynamo theory.

Because the Coriolis force is much the largest term in the magnetohydrodynamic equation in planetary cores, it follows that the primeval lunar magnetic field was on average a dipole directed along the axis of rotation (8). Pole positions from the original 35 fell in clusters with mean poles nearly 180^{o} apart and along an axis nearly E-W in the present equator (9). Polar wandering, i.e. re-orientation of the Moon with respect to its axis of rotation, was suggested as an explanation (9). Poles calculated from the newer and more accurate determination of directions of crustal magnetization have been separated into 3 groups about 3 different axes (Table I). In each the N magnetic poles are grouped antipodally, the mean poles nearly 180^{o} apart (10).

The ages of the pole positions have been inferred from lunar geology, Pre-Nectarian (4.2 by), Lower Nectarian (4.0 by) and Upper Nectarian and Imbrian (3.9 - 3.85 by) (10). The corresponding palaeoequators fall near the multi-ring basins of the same ages as dated by Wilhelms (11): this supports the significance of the original separation into the 3 groups (12). A development of the Fisher distribution, the bi polar and girdle distribution finds an interesting application to the statistical analysis of the pole positions and the multi-ring basins respectively. The successive re-orientation of the Moon was explained by the creation of impact basins in low latitude provided that solid state creep below the thin lithosphere allows the re-orientation of the hydrostatic equatorial bulge (12). That impacts could have produced polar wandering on the Moon was suggested by Melosh (13) and his mascon model (14) suggests that the pole moved to its present position about 3 by ago. The low palaeolatitudes at which the multi-ring basins lie show that these impacts could not have been by comets or asteroids in heliocentric orbits and must have been satellites of the Moon. The alternative that the satellites were Earth satellites colliding with the Moon as it retreated by tidal friction is implausible. Support for this view is given by the directions of the incoming bodies determined from the asymmetries of the multi-ring basins. The impacting body for Orientale came from the NE (15) and other recently determined directions from other multi-ring basins by Wilhelms (11) lie parallel to the corresponding palaeoequators. Reid (16) argues that satellites of the Moon could have lifetimes of some 100 My before decaying by tidal friction.

Some evidence that the satellites were in retrograde orbit suggesting the influence of tidal friction has been obtained.

(1) Runcorn, S.K., Collinson, D.W., O'Reilly, W., Battey, M.H., Stephenson, A., Jones, J.M., Manson, A.J. and Readman, P.W. (1970) Proc.Apollo 11 Lunar Sci.Conf., p.2369-2387.
(2) Runcorn, S.K. (1967) Proc.Roy.Soc.London A296, 270-284.
(3) Stephenson, A., Runcorn, S.K. and Collinson, D.W. (1975) Proc.Lunar Sci. Conf. 6th, p.3049-3062.
(4) Cisowski, S.M. (1982) Proc. COSPAR meeting, Ottawa, Pergamon.
(5) Coleman, P.J. and Russell, C.T. (1977) Phil.Trans.Roy.Soc.London A285, 489-506.
(6) Hood, L.L., Russell, C.T. and Coleman, P.J. (1978) J.Geophys.Res.Lett., 5, 305-308.
(7) Stephenson, A. and Collinson, D.W. (1974) Earth Planet.Sci.Lett., 4, 361-369.
(8) Hood, L.L. (1980) Proc.Lunar Sci.Conf.11th, p.1879-1896.
(9) Runcorn, S.K. (1978) Nature, 275, 430-432.
(10) Runcorn, S.K. (1982) Phys.Earth & Planet.Ints., 29, 135-147.
(11) Wilhelms, D.E. (1983) USGS professional paper "Geologic history of the Moon", in press.
(12) Hood, L.L. (1981) Proc.Lunar Sci.Conf. 12th, p. 817-830.
(13) Melosh, H.J. (1975a) Earth Planet.Sci.Lett., 25, 322-326.
(14) Melosh, H.J. (1975b) Earth and Planet.Sci.Lett., 26, 353-360.
(15) Scott, D.H., McCauley, J.F. and West, M.N. (1977) Geologic Map of the West side of the Moon. U.S.Geological Survey, Map I-1034.
(16) Reid, M.J. (1973) Icarus, 20, 240-248.

Table I Mean Pole Positions

	Lat. (N)	Long. (E)	Radius of Circle of Confidence
IMBRIUM - UPPER NECTARIAN POLES			
Sites from Oceanus Procellarum, Cayley formation and South of Mare Crisium			
Based on discs (anomalies)	-48.4 (-60.2)	340.8 (339.2)	23.3° (31.6°)
Based on discs (anomalies)	37.8 (40.4)	177.3 (182.4)	7.7° (7.1°)
LOWER NECTARIAN POLES			
Sites mainly on eastern near side and western far side			
Based on discs (anomalies)	49.6 (54.9)	338.3 (335.8)	19.6° (29.4°)
Based on discs (anomalies)	-51.2 (-48.5)	165.9 (178.0)	56.2° (60.2°)
PRE-NECTARIAN POLES			
Sites from eastern far side of Moon			
Based on discs (anomalies)	-2.9 (-7.2)	275.1 (274.6)	53.2° (54.4°)
Based on discs (anomalies)	12.7 (22.6)	89.5 (92.0)	42.6° (59.8°)
Sources on far side earlier analysis			
(based on 35 anomalies)	0°	89°	30°
	0°	270°	21°