IS THE MOON A CAPTURED BODY? R. J. Malcuit, Department of Geology, R. R. Winters, M. E. Mickelson, Department of Physics and Astronomy, Denison University, Granville, Ohio 43023.

Two distinctive geological patterns (one lunar, one terrestrial) can be interpreted in terms of a capture origin for the earth-moon system. Computer simulation and photogeological studies suggest that an approximate great-circle pattern of large circular lunar maria can be interpreted as the signature of a close earth-moon encounter. In this case the older radiometric dates (about 3.9-4.0 b.y.) obtained from the mare rocks are considered to date the mare-producing encounter. The terrestrial evidence is geochemical-petrological and can be interpreted as a thermal event which occurred somewhere between 3.6 and 4.0 b.y. ago, the exact date depending on a number of assumptions (1, 2). If these two geological patterns are considered to be approximately co-temporaneous, a relatively simple scenario of lunar capture can be constructed.

The earth and primitive moon accreted from the solar nebula during the same epoch (about 4.6 b.y. ago) as the other terrestrial planets. The earth resulted from homogeneous accretion of nebular condensates (uncompressed density of about 4.4 g/cm$^3$) in the vicinity of the present earth's orbit. Accretion of the primitive moon with an uncompressed density of about 3.3 g/cm$^3$ would have occurred in an orbit somewhere between the present asteroid belt and the martian orbit, probably at about 1.7-2.0 A.U. (3 and personal communication).

Gravitation perturbations (see Figure 1) by Jupiter would then deviate the primitive moon into first a mars-crossing orbit and eventually into an earth-crossing orbit (4). Close gravitational encounters between earth and the deformable primitive moon result in dissipation of orbital energy within both planetary bodies. The amount of energy dissipated per close encounter depends on the mechanical parameters of the two bodies and on the closeness of the encounter. Using reasonable parameters for a deformable moon, it can be shown that about $10^{34}$ ergs can be stored in the deformed earth and moon per close encounter (within 3 earth radii of earth's center). Orbital energy dissipation per close encounter results in a decrease in the major axis of the moon's heliocentric orbit until the earth's and moon's orbits become nearly coincident.

Computer simulations of earth-moon encounters and photogeological studies of lunar surface features suggest that many of the circular maria, especially those located near a lunar great circle, could have resulted from a close earth-moon encounter (5). The geometric restriction is that the moon must come close enough to the earth for the differential gravitational forces to pull a large volume of lunar basalt from a lunar subcrustal molten zone. If the lunar magma undergoes viscous flow, then it would be expected...
to neck off from the source region and eventually form magmatic spheroids. These would then be trajectory above the lunar surface to an impact site. The impacting spheroids would form a series of lava lakes nearly along a lunar great circle. Deviation from a great circle could be caused by lunar spin during the encounter. Prominent features which lie nearly on a lunar great circle are: Maria Orientale, Imbrium, Serenitatis, Crisium, Smythii, and Tsiolkovsky. Maria Imbrium through Tsiolkovsky are interpreted as impact phase features; Mare Orientale and a portion of Oceanus Procellarum are interpreted as magma source regions for the mare-forming spheroids. Such a great-circle pattern of lunar surface features could result from any one of many non-capture encounters or from the capture encounter.

Lunar orbital evolution subsequent to the capture encounter can furnish a reasonable explanation for a major thermal episode recorded on earth (1,2) (Figure 1). Significant quantities of orbital energy (about $5 \times 10^{35}$ ergs) are dissipated as heat within the outer regions of both bodies via tidal friction processes. The bulk of this energy is dissipated over a short period of time while the perigee distance of the lunar orbit is small. The quantity of tidal friction heating per perigee passage decreases exponentially as perigee distance increases. Concomitant with this era of rapid energy transfer via strong tidal deformations, the lunar geocentric orbit, initially highly elliptical, becomes more nearly circular with a radius of a few tens of earth radii. Following this era of strong tidal interactions, the lunar orbit evolves very slowly to its present state via "weak" tidal friction processes.

REFERENCES:
(9) Saager and Koppel, 1976, Econ. Geol., v. 71, p. 44.
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Figure 1. Possible time scale for earth-moon interactions.
Sources of data for EARTH EVENTS: oldest rock dates (6, 7, 8); Pb-Pb age, Swaziland Sequence (9); best fit for beginning of 2nd stage (2).
Sources of data for LUNAR EVENTS: Indomitabile dates (10); "pre-mare" volcanism information (11); mare rock dates (12).
CAPTURE SEQUENCE symbols: J P H O = Jupiter-perturbed heliocentric orbit; E C H O = earth-crossing heliocentric orbit; C = capture.