TIDAL REGIME OF INTACT PLANETOID CAPTURE MODEL FOR THE EARTH-MOON SYSTEM: DOES IT RELATE TO THE ARCHEAN SEDIMENTARY ROCK RECORD?; Robert J. Malcuit, Dept. of Geology and Geog., Ronald R. Winters, Dept. of Physics and Astron., Denison Univ., Granville, Ohio 43023.

Regardless of one's favorite model for the origin of the earth-moon system (fission, coformation, tidal capture, giant-impact) the early history of lunar orbital evolution would produce significant thermal and earth and ocean tidal effects on the primitive earth. Three of the above lunar origin models (fission, coformation, giant-impact) feature a circular orbit which undergoes a progressive increase in orbital radius from the time of origin to the present time [1,2]. In contrast, a tidal capture model places the moon in an elliptical orbit undergoing progressive circularization from the time of capture (for model purposes about 3.9 billion years ago) for at least a few 10^8 years following the capture event. Once the orbit is circularized, the subsequent tidal history for a tidal capture scenario is similar to that for other models of lunar origin and features a progressive increase in orbital radius to the current state of the lunar orbit. This elliptical orbit phase, if it occurred, should have left a distinctive signature in the terrestrial and lunar rock records. Depositional events would be associated terrestrial shorelines characterized by abnormally high, but progressively decreasing, ocean tidal amplitudes and ranges associated with such an orbital evolution.

In previous work we have demonstrated that gravitational (tidal) capture of a lunar-mass planetoid by an earth-mass planet is physically possible [3,4]. A typical coplanar, three-body stable capture scenario is shown in Figure 1a. Figure 1b shows a semilog plot of Tidal Amplitude vs. Time for this 4-year stable capture sequence. To account for the angular momentum of the earth-moon system the earth rotation rate for such an tidal capture scenario is about 10 hours/day. Using a numerical two-body orbit evolution program and reasonable deformational and dissipative parameters for the interacting bodies, we find that the most realistic time scales for orbit circularization to 10% eccentricity are in the range of 1.0-1.6 billion years. Two such scenarios are shown in Figure 2. Figure 2a depicts a two-body orbit circularization sequence in which all energy is dissipated in the satellite by way of radial tidal action; thus the satellite orbit does not gain angular momentum during the orbit circularization. The scenario in Figure 2b is more realistic and features angular momentum transfer from the rotating planet to the satellite orbit via the tangential tidal mechanism. In this scenario the major axis of the lunar orbit decreases from about 183 R_e to 93 R_e as the rotation rate of the planet decreases from about 10 hours/day to 14.4 hours/day. Using a 3-body orbit program (4th order Runge-Kutta integrator) and a program for plotting the equilibrium tidal amplitudes and ranges directly from the numerical orbital data, we find that the maximum perigean earth tidal ranges at 2, 6, and 10 hundred million years after capture are about 20, 5, and 3 meters, respectively. Although solid rock tides tend not to yield much of a geological record, such action could contribute substantially to the thermal regime of a planet or satellite. The ocean tides, however, can be recorded in the sedimentary rock record. Several rock units in the age range 3.6-2.5 billion years before present are reported to have a major tidal component. Examples are the Warrawoona, Fortescue, and Hamersley Groups of Western Australia [5,6,7] and the Pangola and Witwatersrand Supergroups of South Africa [8,9]. Detailed study of the features of these tidal sequences may be helpful in deciphering the style of lunar orbital evolution during the Archean Eon.

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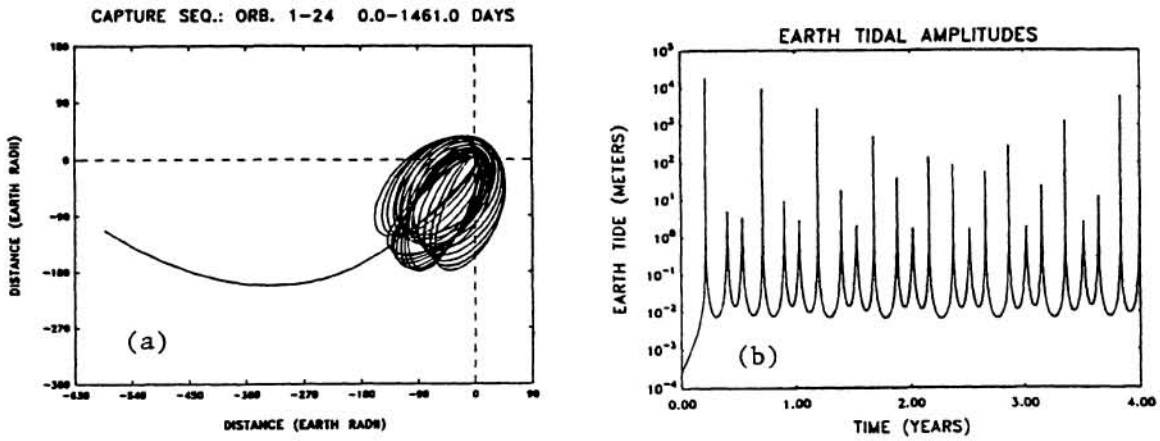

Figure 1. (a) Diagram showing the first 24 orbits (4 years) of a stable prograde capture scenario in a co-planar, non-rotating coordinate system. Some values for this run are r_p = 1.43 R_e, earth anomaly = 320°, planetoid anomaly = 190.392°, planetoid heliocentric eccentricity = 1.25%, h_m = 0.26, Q_m = 1 for the initial encounter and 10 for all subsequent encounters, h_e = 0.7, Q_e = 100. (b) Semilog plot of Earth Tidal Amplitude vs. Time for the four-year orbital sequence shown in Figure 1a. Note the irregular pattern of tidal spikes associated with the close encounters.

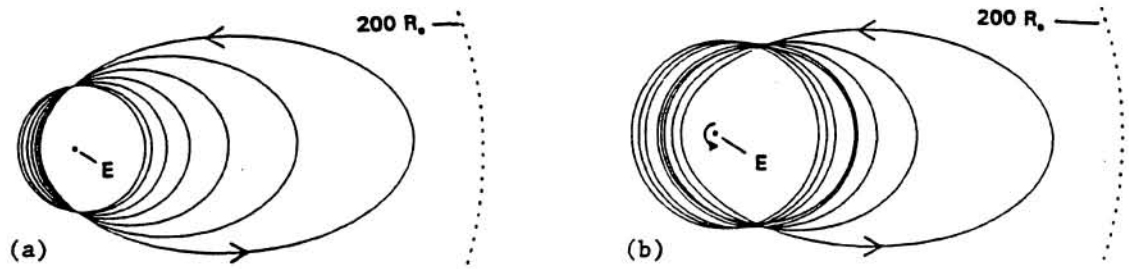

Figure 2. (a) Sequence of seven orbital stages in a two-body calculation of a post-capture orbit circularization seqeunce in which all energy is dissipated within the body of a lunar-like planetoid with h=0.5 and Q=1000. In this case the orbital angular momentum of the planetoid remains the same throughout the orbit circularization sequence. A 30 R_e prograde circular orbit is consistent with a 10 hour/day rotation rate for the pre-capture planet. The largest orbit on the diagram is the maximum size orbit that is stable relative to solar perturbations in a 3-body system for the specified quantity of angular momentum. Each of the orbital stages represent 200 million years of orbital evolution (circularization). The time scale for orbital circularization in this scenario is about 1.1 billion years. (b) Sequence of eight orbital stages in a two-body system calculation of a post-capture orbital circularization sequence in which energy is dissipated in both the lunar-like planetoid (radial tides) and the earth-like planet (radial and tangential tides). For this run h_m=0.5, Q_m=1000, h_e=0.7, Q_e=100. Note that the tangential tides operating on the planet transfer rotational angular momentum from the planet to the satellite's orbit. The timescale for circularization to 10% eccentricity is about 1.4 billion years. The resulting near circular orbit of the satellite has angular momentum equivalent to a circular orbit of about 46 R_e and the planet rotation rate is about 14.4 hours/day.