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Middle Devonian Day and Month

Aveni (*1*) argues that simple dynamical calculations conflict with conclusions drawn from the study of daily, monthly, and annual increments of coral growth. The number of months in the Middle Devonian year was obtained by Scrutton (*2*) from Middle Devonian rugose corals; he divided Wells's (*3*) count of daily-growth ridges in annual bands by his own count of their number in monthly bands. Aveni concludes that either the growth bands are not related to time, and the approximate agreement is fortuitous, or our understanding of the history of the Earth-Moon system is incomplete.

Aveni's conclusions are based on a false assumption—that is, a formula for the Earth-Moon distance (r) at time (t) since Earth's origin given by Jeffreys (*4*):

$$t \text{ (in } 10^9 \text{ years)} = 4.5\ (r/a)^{13/2} \qquad (1)$$

where a is the present Earth-Moon distance. Jeffreys assumed the simplest law of lunar friction: that the decelerating torque exerted by Moon on Earth is inversely proportional to the sixth power of the Earth-Moon distance (r). If L is the orbital angular momentum of Moon, this torque equals

$$dL/dt = k/r^6 \qquad (2)$$

The assumption that k has been constant may be unfounded. It is known that if tidal friction occurs in the oceans the dissipation of energy must be wholly in the shallow seas, the extents and positions of which have altered even within the last few thousand years. It could be argued that k may still have remained roughly constant because, if sea level had changed, the places where tidal friction was effective also would have changed, although the magnitude may have remained constant. If the dissipation of energy by tides occurs mainly in nonelastic processes in Earth's mantle, it may be more reasonable to suppose a constant k, although friction may occur between the faulted blocks of the crust rather than bodily throughout the mantle, because an elastic behavior of the mantle over periods as brief as 12 hours 50 minutes has not been found for strains as small as those in the bodily tides (10^{-7}). Tectonics, continental drift, and other crustal processes may then have altered the dissipation of energy over geological time.

By applying Kepler's second and third laws of motion to the Earth-Moon system and neglecting changes in the orbital eccentricity, Runcorn (*5*) obtains a formula, true for any time in the past, that gives the length of the sidereal month (T):

$$[G^2\ (M + m)^2\ m^3]T = 2\pi L^3 \qquad (3)$$

where G is the gravitational constant and M and m are the masses of Earth and Moon, respectively. Similarly one may also derive

$$[G\ (M + m)\ m^2]r = L^2 \qquad (4)$$

where r is the Earth-Moon distance.

The eq. 1 quoted by Aveni is simply obtained by integrating Eqs. 2 and 4, with the dubious assumption that k has been constant throughout Earth's life (4.5×10^9 years) and that the constant of integration equals zero—which is equivalent to accepting the entirely speculative hypothesis that r equalled zero at Earth's origin. Aveni's conclusions derive from these assumptions, which he did not state.

I believe that a more profitable way to examine the paleontological counts is to postulate only that, at least since the Devonian, Earth's orbital angular momentum about Sun has been constant. Runcorn (*5*) shows that the loss of angular momentum by Earth to Moon by tidal friction is given by

$$(L_o - L) = L_o\{1 - [13.4/(w/s)]^{\frac{1}{3}}\} \qquad (5)$$

where L_0 is the present orbital angular momentum of Moon, w is the number of sidereal days in the year (399), and s is the number of sidereal months (28.4) derived from Wells's and Scrutton's counts for the Middle Devonian. Runcorn shows from eq. 4 that the mean lunar tidal frictional torque over the last 370 million years is 3.9×10^{23} dyne cm, which is the same as the value given by Munk and MacDonald (*6*) from astronomical values of the longitudes of Sun, Moon, Venus, and Mercury for the last 300 years.

By use of Aveni's formula with Eqs. 1 and 4, a value of 1.5×10^{23} dyne cm for the present lunar tidal frictional torque is obtained, which would imply that the value obtained astronomically is anomalously large.

Aveni also seems to state in his last paragraph that, because of the change in r since the Devonian, the lunar tidal frictional torque determined from the paleontological data should be larger than that determined astronomically. This effect is not important, considering the degree of accuracy at present attainable. The paleontological data show that the present sidereal month is 1.048 times the Devonian sidereal month, if one takes the year to be a constant unit of time. Thus Kepler's third law shows that the Earth-Moon distance has increased by 3.2 percent since the Devonian. Now the average value of the torque since the Devonian will be greater by 9.6 percent than the present value if one assumes a constant k.

One should note that Scrutton's and Wells's results prove that the equilibrium tide during the Devonian was 9.6-percent higher than at present. The checking of this prediction by means of sedimentary structures and by study of paleotides seems a desirable next step.

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