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Comment

Comment on the paper "Fast tidal cycling and the origin of life" by Richard Lathe

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Abstract

We show that the fast tidal cycling postulated by Lathe [Lathe, R., 2004. Icarus 168, 18–22] is not a plausible mechanism to explain the origin of life on Earth about 3.9 Ga ago. The value of LOD at this remote epoch was probably comprised between 15 to 17 h, and the Earth–Moon distance was only about 20% smaller than nowadays, implying that the tidal frequencies and amplitudes were not so dramatically different from the present ones as stated in Lathe's paper.

Keywords: Tides, solid body; Prebiotic environments; Earth; Moon

We read with much interest Dr. Lathe's paper "Fast tidal cycling and the origin of life" which appeared recently in Icarus (Lathe, 2004). We are not in a position to comment on the biochemical aspects of the origin of life discussed by the author, but we wish to point out that his geodynamical assumptions concerning the length of the day (LOD) in the Earth's very remote past, namely 2–6 h, seem entirely unrealistic to us. Admittedly, there is a lot of conjecture based on very little data about what went on in the early Earth (Frank, 1990, p. 44); nevertheless, current knowledge favors the view that the Earth has never been spinning as fast about its axis as indicated in Lathe's paper. Thus, the scenario of life formation described there seems to us not a very plausible one.

Lathe extrapolates backward into the Archean Lambeck's (1977) linear regression on Phanerozoic LOD-data, which yields an *average* rate of change of LOD of approximately half an hour per hundred million years during the last 0.54×10^9 years. On this basis, he ends up with a rotation period of about 4.5 h at the time when life is supposed to have originated (3.9×10^9 years ago) which, indeed, would lead to tides with dominating periods slightly above 2 h. Unfortunately, from his list of references, we must conclude that the author seems to be unaware of the most essential papers related to LOD values in the Proterozoic; the latter have appeared in international journals since the late 1980s. A comprehensive review on the topic was given by Williams (2000). Moreover, Fig. 1 of Lathe's paper is misleading: indeed, Lambeck's (1980, Fig. 11.5, p. 360) data at −0.4 and −1.2 Ga (denoted c by Lathe) are *theoretically simulated* values based on the arbitrary assumption that the tidal phase lag had been $\epsilon = 6°$ throughout the geological past; they should not figure in a plot supposed to represent *empirical* data. Moreover, Lambeck (1980) provides in the very same Fig. 1.15 simulated data for the probably more meaningful parameter value $\epsilon = 3°$; Lathe omits to consider the latter. Also, the Big Cottonwood (Utah, USA) LOD datum at −0.9 Ga marked d in Fig. 1 of Lathe's paper, which is extracted from Sonett et al. (1996a, Table 2, p. 103), is generally considered not to be a very reliable datum (Sonett et al., 1996b; Sonett and Chan, 1998; Williams, 2000); on the other hand, Lathe does not take into account the Elatina (South Australia) datum (LOD = 21.9 ± 0.4 h) at −0.62 Ga, a well-determined refer-

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ence value. The latter is about an hour larger than the value expected from Lambeck's regression line, namely 20.9 h.

The oldest LOD value we know of for the moment has been determined for the cyclic banded iron formation of Weeli Wolli, Western Australia (Walker and Zahnle, 1986; Williams, 1989, 1990). With an age of about 2.45×10^9 years that places it close to the beginning of the Proterozoic eon, it is comprised almost surely between 17 and 19 h (Williams, 1989, 2000), *not* at 11.5 h as given by Lambeck's regression line. Actually, some arguments make us believe that the most probable value is closer to 19 rather than 17 h.

Varga et al. (1998) performed a linear regression analysis on the few published Proterozoic data, and obtained an *average* despinning rate roughly five times smaller than Lambeck's value for the Phanerozoic. Their linear regression equation for the Proterozoic reads

$$\mathrm{LOD} = 21.435 - 0.974\tau, \quad 0.64 \leqslant \tau \leqslant 2.50 \tag{1}$$

(LOD is expressed in hours, time τ is measured from the present in Ga [1 Ga = 10^9 years]). Although paleo-LOD values derived from paleontological or sedimentological samples may always be questioned to some extent, there is little doubt that tidal braking of the Earth's rotation had *on the average* been much less efficient in the Proterozoic than in the Phanerozoic. Extending tentatively Eq. (1) into the Archean, we estimate that LOD $\approx$ 17.6 h at $\tau = 3.9$ Ga. In any case, there is absolutely no evidence, neither empirical nor theoretical, that the solar day was much shorter than 15 h when life began (see also Eriksson and Simpson, 2000).

Apart from this direct empirical evidence relevant to the length of the day in the remote geological past, there are also theoretical arguments which provide evidence that, when life began 3.9 Ga ago, the Earth cannot possibly have rotated as fast as claimed by Lathe (2004).

Concomitantly with a lengthening of the day on geological time scales brought about mainly by the tidal torque associated with the semi-diurnal oceanic lunar tide M_2 (e.g., Varga and Denis, 1991), there is a transfer of the angular momentum associated with the Earth's spin to the angular momentum associated with the Moon's orbit in such a way that the total angular momentum of the Earth–Moon system is conserved. Consequently, the Moon must have been recessing from the Earth ever since the Earth–Moon system came into existence, and the mean Earth–Moon distance c must have been increasing ever since. Considering the Earth–Moon system as approximately isolated, and neglecting the Moon's mass m with respect to the Earth's mass M ($m \approx M/81.3$) and a fortiori the Moon's angular spin momentum with respect to the Earth's angular spin momentum $C\Omega$, where C and Ω are the Earth's polar moment of inertia and angular rotation speed, respectively, at any time τ. Denoting by n the Moon's angular orbital speed, the conservation of the total angular momentum of the Earth–Moon system is expressed at any instant τ by

$$C(\tau)\Omega(\tau) + mc^2(\tau)n(\tau) = C_0\Omega_0 + mc_0^2 n_0, \tag{2}$$

where the suffix '0' on the r.h.s. refers to the present values. We shall assume with the majority of the scientific community that core formation had been a runaway process occurring very soon after the Earth formed 4.6 Ga ago, and that it was completed long before $\tau = 3.9$. Then $C(\tau) = C \approx C_0$ after the core formation was completed. Taking account of Kepler's Third Law $n \approx (GM)^{1/2}c^{-3/2}$, we may write Eq. (2) in the following form

$$\begin{aligned}\Omega(\tau) &\approx \Omega_0 + \frac{(GM)^{1/2}m}{C_0}\left[c_0^{1/2} - c^{1/2}(\tau)\right] \\ &\approx \alpha\left[1 - \rho\gamma^{1/2}(\tau)\right],\end{aligned} \tag{3}$$

with $\alpha = 4.306 \times 10^{-4}\ \mathrm{rad\,s^{-1}}$, $\rho = 0.107$, and where the Earth–Moon distance γ is expressed in mean Earth radii R of 6.371×10^6 m, i.e.,

$$c(\tau) = R\gamma(\tau). \tag{4}$$

The values $\Omega_0 = 7.292115 \times 10^{-5}\ \mathrm{rad\,s^{-1}}$, $C_0 = 8.0363 \times 10^{37}\ \mathrm{kg\,m^2}$, $GM = 3.9860 \times 10^{14}\ \mathrm{m^3\,s^{-2}}$, $m = 7.348 \times 10^{22}$ kg, $c_0 = 3.8440 \times 10^8$ m are taken from Stacey (1992). Hence, neglecting the difference between sidereal and solar days, we find that Lambeck's regression line, yielding LOD = 4.5 h [that is, $\Omega(3.9) \approx 3.88 \times 10^{-4}\ \mathrm{rad\,s^{-1}}$] for $\tau = 3.9$ Ga, implies that the center of the Moon would have coincided, within 1 m, with the Earth's center since, by Eq. (3), $\gamma = 1.59 \times 10^{-7}$ [i.e., $c = 1.01$ m] for $\Omega = 3.88 \times 10^{-4}\ \mathrm{rad\,s^{-1}}$. Notice that Darwin's (1879) theory, later revived by Ringwood (1960) and Wise (1963), assuming that the Earth and Moon were originally a single body ($\gamma = 0$), leads to an initial spin rate $\Omega_{\mathrm{Darwin}} \approx 4.306 \times 10^{-4}\ \mathrm{rad\,s^{-1}} \approx 5.905\Omega_0$ and, thus, $\mathrm{LOD}_{\mathrm{Darwin}} = 4.053$ h.

There is compelling observational evidence, in particular from the geological record and from age determinations of lunar rocks, that the Earth and the Moon already existed as a double-planet system in the Archean, 3.9×10^9 years ago, and most probably also in the early Hadean, 4.5×10^9 years ago. This means that when life originated, the Moon's distance to the Earth must have been larger than the Roche radius R_{Roche}, defined in this context as the smallest Earth–Moon distance below which tidal forces would disrupt the Moon. According to Stacey (1992, p. 132), $R_{\mathrm{Roche}} = 2.97\ R \approx 18{,}922$ km. For the lunar orbit to lie, on the average, outside the zone of tidal disruption, the length of the Earth's day must have been larger than 4.97 h, according Eq. (3) evaluated for $\gamma = 2.97$. However, it should be realized that the lunar orbit must have moved away from the critical Roche zone in a very short time since tidal braking, at that epoch, must have been extremely efficient. Indeed, the tidal retarding torque $-N$ (see, e.g., Jeffreys, 1970, p. 299) is inversely proportional to the sixth power of the lunar distance implying that at the Roche limit, it would have been *at least* $(60.27/2.97)^6 \approx 7 \times 10^7$ larger than now. The present-day characteristic tidal despinning time τ_{tidal} is about 1.1×10^{11} years (Hubbard, 1984, pp. 103–105), but close to the Roche limit it must have been less than 10^4 years.

From fundamental laws of mechanics it is easy to establish (e.g., Walker and Zahnle, 1986) that, for any interval of time $[\tau_i, \tau_{i+1}]$ referenced by the subscript 'i,' we may write

$$\gamma(\tau) \approx \gamma_i\left[1 - \frac{13\langle\dot{\gamma}_i\rangle(\tau - \tau_i)}{2\gamma_i}\right]^{2/13}, \tag{5}$$

where γ_i is the mean radius (expressed in Earth radii) of the lunar orbit at time τ_i, and $\langle\dot{\gamma}_i\rangle$ is the average rate of lunar recession (expressed in Earth radii per 10^9 years) during the time interval $[\tau_i, \tau_{i+1}]$. Among four scenarios based on Eq. (5) considered by Williams (2000, Fig. 15, p. 56), only one leads to an acceptable time scale for the evolution of the Earth–Moon system. The latter uses past tidal dissipation rates implied by data obtained from the Elatina–Reynella and Weeli Wolli tidal rhythmites. It suggests that when life originated, 3.9 Ga ago, the Earth–Moon distance was about 320,500 km and the length of the day was about 16.8 h. As far as we accept the idea that at this very remote geological epoch there were oceans more or less similar to the present ones, with a salt content also more or less similar to the present one (Dr. Lathe should have discussed more at length this point so important for his scenario of life formation), the tidal regime should not have been dramatically different 3.9×10^9 years ago from what it is nowadays, and it seems difficult to imagine "tidal areas [that] could have extended several 100 km inland," with cycles of flooding and drying perhaps every 2–6 h (Lathe, 2004, p. 19).

Nevertheless, having spent an appreciable amount of time on studying *quantitatively* the fascinating topic of tidal phenomena, tidal friction and Earth rotation, and their geodynamical consequences (e.g., Denis, 1986; Denis and Varga, 1990; Denis, 1993; Varga et al., 1998; Denis et al., 2002), we like the idea that tides could also have contributed in producing life on Earth, though not as a result of such fast tidal cycling as invoked by Lathe (2004).

We would like to conclude our critical comments by thanking Dr. Lathe for having written a stimulating interdisciplinary paper, and the reviewers and editors of Icarus for letting it get published, despite its obvious shortcomings. Indeed, we believe that the origin of life can only be understood by interdisciplinary studies, and this fact is illustrated by Lathe's paper. Moreover, historically interested readers will understand that scientific certainty evolves with time and that, as nicely put by Dietz and Holden (1973), "hypotheses, like cats, have nine lives." We believe that there lies still a long way ahead before gaining any certainty about the manner in which life came into existence.

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