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Earth-Science Reviews 72 (2005) 119–123
EARTH-SCIENCE REVIEWS
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Discussion

Reply to the comment of G. Williams on "Tidal rhythmites and their implications" by R. Mazumder and M. Arima [Earth-Science Reviews, 69 (2005) 79–95]

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Received 18 April 2005; accepted 3 May 2005

Dr. George Williams (Williams, 2005) provided me an opportunity to clarify the misunderstandings and misconceptions prevailing among some so-called tidal rhythmite researchers. Ancient tidal rhythmites, like their modern counterparts, can preserve a record of astronomically induced tidal periods. Unlike modern tide and tidal deposits, analysis of ancient tidal rhythmites, however, is not straightforward. This is simply because spectral analysis of ancient tidal cycles is *not* an actual time series, but is in fact a thickness series. Many geologists use standard time-series techniques while analyzing ancient tidal rhythmites without concern to this basic fact! Complications are thus inherent with the analysis of ancient tidal rhythmite. In discrete-signal records the relationship between sediment thickness and time is more complex than for continuous signal records (Weedon, 2003, p. 28–32) Understandably, quality of rhythmite raw data and application of basic astronomical laws, if applicable at all, has nothing to do with these inherent complications. One of the major objectives of Mazumder and Arima (2005) was to review the methodologies of extracting lunar orbital periods from ancient tidal rhythmites and the mathematics behind the use of tidalites, their limitations and uncertainties; effort was made to highlight the shortcomings, methodological errors and oversimplifications associated with the application of tidal rhythmite to understand the history of Earth's rotation and the lunar orbit in the distant geological past that Williams could not follow. Herein I address and further clarify the misconceptions and misunderstandings raised in his commentary.

1. Analysis of bed/laminae thickness measurements

It has been clearly stated that the solar day is shorter than the lunar day while calculating the minimum number of solar days (33) and lunar days (32) during the Chaibasa sedimentation (Mazumder and Arima, 2005; see p. 87). It is unfortunate that this basic information derived from the tidal rhythmite data remained in oblivion to Williams. In no way the spectral periods of ~32 and ~2 are of dubious significance. It has been shown that the thick–thin

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doi:10.1016/j.earscirev.2005.05.002

laminae alternations (cf. De Boer et al., 1989) are characteristics of Chaibasa sandstone (Mazumder and Arima, 2005, p. 85; their Fig. 2). Cyclicities are revealed in plots of two successive foreset-thickness data sets measured from different stratigraphic levels (Mazumder and Arima, 2005, their Figs. 5A and 6A). Random meteorological events like storms may also impart thick–thin alternations in environments that lack semidiurnal tidal influence. A statistical test of the basic data, therefore, has been made following the methodology of De Boer et al. (1989), which reveals a significant semidiurnal signal (Mazumder and Arima, 2005, their Figs. 5A and 6A, B; see also Mazumder, 2004; Poppe L. de Boer, personal communication, 2003). The laminae count reveals 27–30 laminae (events) constituting the neap–spring cycle. It is difficult to recover the lunar orbital periods from direct laminae counting because periodically weak tidal currents (e.g. during neap tide) and random meteorological events (storms) may modulate or abbreviate tidal periods (De Boer et al., 1989; Williams, 2000). However, both the power spectra show consistent spectral periods at ~32 and ~2 (Mazumder and Arima, 2005, their Figs. 5B and 6B; number of laminae measured are 57 and 345, respectively). It must be noted that reliable lunar orbital periods have been successfully extracted through spectral analysis of shorter sequence of tidal rhythmites (cf. Yang and Nio, 1985; Archer, 1996). The spectral period of ~2 laminae strongly corroborate a dominantly semidiurnal tidal system during the Chaibasa sedimentation (De Boer et al., 1989; Mazumder, 2004; Mazumder and Arima, 2005, their Figs. 5B and 6B) and, therefore, neither artifact of sampling nor random alternation in thickness as incorrectly suspected by Williams. Williams (2000) counted 28–30 laminae couplets per cycle from the 2450 Ma Weeli Wolli Formation and suggested that these laminae couplets are either diurnal increments (following Cisne (1984)) grouped in monthly cycles or semidiurnal increments grouped in fortnightly cycles. By these interpretations there were ~28–30 lunar days per synodic month at 2450 Ma (Williams, 2000, p.54). Alternatively, these laminae couplets are fortnightly increments arranged in annual cycles implying thereby 28–30 laminae couplets or fortnightly increments per year (Williams, 2000, p. 54). It must be noted that both tidal and nontidal interpretations are available for the Weeli Wolli cyclicity (cf. Williams, 2000, 2004; Trendall and Blockley, 2004). Tidal periods derived from the Weeli Wolli Formation are based on two different tidal interpretations of cyclic banding (see Williams, 2000, his Table 1; see also Williams, 2004, his Table 5.9-1) and, therefore, are of dubious significance. As pointed out by Trendall and Blockley (2004), critical evidence for the origin of Weeli Wolli microbands will be provided by a precise determination of the depositional rate of BIF. Additionally, spectral analysis of the Weeli Wolli BIF microbands, yet unavailable, is urgently required. The data for the Chaibasa sandstone presented by Mazumder and Arima (2005) is thus the only available unambiguous Palaeoproterozoic tidal rhythmite data and undoubtedly throw significant light on tidal periods for the Palaeoproterozoic.

2. Application of Kepler's third law

Williams failed to understand the purpose of the data presented in Mazumder and Arima (2005, their Table 1). He rightly pointed out that the result $a/a_0>1$ is illogical and is in direct conflict with astronomical observations and the theory of lunar tidal friction. In applying Kepler's third law, the sidereal orbital period must be expressed in fixed units (e.g. seconds of atomic time). It was Kvale et al. (1999, p. 1166) who *incorrectly* used the length of the lunar sidereal month in terms of solar days per month to determine the Pennsylvanian (~305 Ma) Earth–Moon distance from the Brazil tidal rhythmite data using Eq. (1) of Mazumder and Arima (2005). As already pointed out by Mazumder and Arima (2005, p. 91), the number of solar days in a sidereal month is *not* an absolute unit of time and therefore cannot be used to compute absolute Earth–Moon distance in the geological past using Kepler's third law. Mazumder and Arima (2005) computed a/a_0 ratios from published Precambrian tidal rhythmite data (their Table 1) to demonstrate that misapplication of Kepler's third law following Kvale et al. (1999) may result $a/a_0>1$ which is geophysically impossible. It is unfortunate that Williams misunderstood this entire issue and made some irrelevant comments.

It must be noted that Deubner (1990) employed a somewhat different form of Kepler's third law. Let Y_1 be the year length (absolute time) and X_1 be the number of lunar sidereal months per year at time t_1. Then Y_1/X_1 is nothing but the absolute length of the lunar sidereal month. Similarly at time t_2, the absolute length of the lunar sidereal month will be Y_2/X_2. Let a_1 and a_2 be the mean Earth–Moon distances at t_1 and t_2 times, respectively. Then according to Kepler's third law,

$$(a_1/a_2)^3 = \{(Y_1/X_1)/(Y_2/X_2)\}^2 \quad (1)$$

If $Y_1 = Y_2$ (i.e. if the Newtonian gravitational constant G is really constant; interested reader may consult Gellies (1997)) then Eq. (1) may be expressed as follows:

$$(a_1/a_2)^3 = \{(Y_1/X_1)/(Y_1/X_2)\}^2 = (X_2/X_1)^2 \quad (2)$$

The "two ways" of "correctly" employing Kepler's third law as claimed by Williams are, therefore, virtually the same and both the forms (Eqs. (1) and (4) of Mazumder and Arima, 2005) employ, directly or indirectly, the *absolute* length of the lunar sidereal month. Mazumder and Arima (2005, p. 88 and 91) correctly stated that the absolute length of the lunar sidereal month cannot be determined *directly* from the tidal rhythmite record and that is well reflected in Williams' computational procedure. Williams (2000) computed the number of solar days per sidereal month (28.3) at 620 Ma *indirectly* with the help of number of solar days per synodic month (obtained *directly* from the rhythmite record through spectral analysis) and number of solar days per year (400 ± 7, calculated from the number of solar days per synodic month and the number of synodic months in a year both of which were obtained *directly* from rhythmite record through spectral analysis) employing the following equation of Runcorn (1979):

$$t = t_L/(1 + t_L/Y_D) \quad (3)$$

where t_L and Y_D are number of solar days per synodic month and year, respectively. Assuming that the length of the year at 620 Ma was similar to the present year length of 31.56×10^6 seconds, Williams (2000, p. 47) calculated the then day length (21.9 ± 0.4 h). From these data he computed the absolute length of the lunar sidereal month at 620 Ma (by multiplying the number of solar days in a sidereal month by the day length).

Unlike tropical, synodic and anomalistic months, the length of the lunar sidereal month (in terms of days) cannot be determined directly from rhythmite record since it is measured from a fixed point in the sky (cf. Runcorn, 1964; Kvale et al., 1999). Therefore one has to depend solely on the relationship between synodic, tropical and sidereal orbital periods. Note that the Eq. (3) that was employed by Williams to compute t is also based on the relationship between the synodic and sidereal periods! The Eq. (3), however, cannot be used to compute the sidereal period (t) if Y_D is unknown. But it is possible to calculate t using a ratio of 1.07 as the t_L to t conversion factor (cf. Mazumder, 2004). Thus, the discussion by Mazumder and Arima (2005, p.88) on the determination of solar days per lunar sidereal month is of course relevant.

Mazumder and Arima (2005, p. 91) pointed out that the determination of a/a_0 employing their Eq. (8) (relating the present and past periods of lunar nodal cycle) has inherent problems. Williams (2000, p.51) assumed that the inclination of the lunar orbit to the ecliptic (i) has undergone negligible evolutionary change during the 0–620 Ma time span. Understandably, the value of i in the distant geologic past, particularly during early Precambrian, is solely a matter of speculation and cannot be verified. Moreover, ancient sediments very rarely record the imprint of lunar nodal cycles because nearly two decades of uninterrupted sedimentation must be preserved (cf. Oost et al., 1993; Miller and Eriksson, 1997). Determination of past lunar nodal period is thus extremely difficult. The 60-year Elatina record of neap–spring cycle thickness reveals a long-term period of 19.5 ± 0.5 years by variations in the height of the semiannual peaks (Williams, 2000; his Fig. 9). But spectral analysis of the 60 year Elatina rhythmite data do not show any period near 19.5 years (cf. Williams, 1989)! Subsequently Williams (2000, p. 49) claimed that a period near 19.5 years is confirmed by spectral analysis of the Elatina data but he never presented the relevant power spectrum showing a 19.5 years periodicity. Williams' claim therefore remained hitherto unsubstantiated!

The equation relating the Earth's present (ω_0) and past (ω) rotation rates, the loss of the Earth's rotational angular momentum through tidal friction of the Moon and the Sun, and the change in lunar orbital angular momentum require ù to compute a/a_0 ratio (see Eq. (9) of Mazumder and Arima, 2005). Williams

(1989, 2000, 2004) put $\omega = 401 \pm 7$ in the equation and got $a/a_0 = 0.968$. Unlike the synodic months per year and the lunar (and the solar) days per synodic month, the values 400 ± 7 (solar days per year) and 401 ± 7 (sideral days per year) are *not* primary values determined directly from the rhythmite record (Williams, 2000, his Table 1; see the footnote). Williams (2000, p. 47) indirectly calculated the number of solar days per year (400 ± 7) at 620 Ma from the primary values (solar days per synodic months multiplied by the number of synodic months per year, see Williams (2000)).

Thus, the claim of Williams (2000, see section 3.2.) that internal self-consistency of Elatina–Reynella palaeotidal and palaeorotational data has been verified by employing three "independent" values determined "directly" from the rhythmite record is incorrect. Understandably, the determined a/a_0 values at 620 Ma are not independent at all and the methodology of evaluating internal self-consistency of palaeotidal and palaeorotational data as proposed by Williams is incorrect.

Williams' comment that Mazumder and Arima (2005) placed reliance on the views of Kahn and Pompea (1978) showed that he did not read the Mazumder and Arima (2005) critically. The work of Kahn and Pompea (1978) was referred by Mazumder and Arima (2005) because these authors calculated ancient Earth–Moon distances using palaeontological data. That palaeontologial data has certain inherent ambiguities (and hence not suitable for calculating ancient Earth–Moon distance) and there are some problematic aspects in the computational methodology of Kahn and Pompea (1978) was a subsequent realization. But in no way that underscores the effort of Kahn and Pompea (1978). Additionally I would like to mention following the introductory statements of Kahn and Pompea (1978) that the past dynamics of the Earth–Moon system cannot be derived solely from theoretical astronomical calculations since the tidal friction is critically dependent on the sea level and continental configurations both of which have changed *significantly* in the geologic past. Very few geologists are aware of this very basic fact and those aware of it never attempted to calculate the absolute ancient Earth–Moon distances, palaeotidal and palaeorotational parameters of the Earth–Moon system.

3. Length of the year, *G*, Earth's moment of inertia and Earth expansion

Both the third and fourth sections of Williams' commentary are basically related to the secular change, if there is any, of the Newtonian gravitational constant (G), and hence are virtually the same. As reviewed by Mazumder and Arima (2005, p.89–90), a secular decrease in G value has been postulated/speculated by a number of researchers from theoretical and observational viewpoint. Williams' effort to extrapolate the suggestion of the astronomers and astrophysicists based on present day's observation that negligible change occurred in the orbital parameters and G in the distant geological past, particularly in the Precambrian, is speculative as well since it cannot be deduced (verified) from the rock record. This is similar to the speculation of the astrophysicists that Earth–Moon collision occurred sometimes between 2000 and 1500 Ma resulting in total melting of Earth's mantle (cf. Lambeck, 1980; Walker and Zahnle, 1986), an event for which there is no corroborating geological evidence. Analysis of tidal rhythmite, on the contrary, reveals a fairly normal semidiurnal tidal system similar to the present day was in effect during the late Palaeoproterozoic (2100–1600 Ma; cf. Mazumder, 2004). It is unscientific to conclude that since early Precambrian secular change in G, if there is any, is insignificant simply because the present precise value of G is unknown as also its uncertainty limit (cf. Gellies, 1997). Neither laboratory experiments nor astronomical observations are capable enough to solve unequivocally whether secular change in G took place since early Precambrian. Therefore the calculated *absolute* Earth–Moon distances and Earth's palaeorotational parameters using the astronomical laws in the distant geologic past are highly speculative.

Williams' claim that Mazumder and Arima (2005) repeat his work on the probable overall constancy of the Earth's moment of inertia since 620 Ma is incorrect. The mathematical equations presented in section 4.3.of Mazumder and Arima (2005) were actually taken from the most fundamental paper by Runcorn (1964, 1979) and not from Williams' work. Of course Williams' work on the ~620 Ma Elatina–Reynella tidal rhythmite (cf. Williams, 2000) has been referred because that is the only available published account in which effort has been made to argue against the

Earth's expansion since Neoproterozoic. Additionally Mazumder and Arima, following Runcorn (1964, 1979), have demonstrated that slow Earth expansion might have occurred if *G* varies (Mazumder and Arima, 2005, p.90) that Williams bypassed in his reviews (Williams, 2000, 2004).

4. Concluding remarks

Analysis of ancient tidal rhythmites may help geologists to estimate the number of lunar days per synodic, tropical, sidereal, and anomalistic months accurately in the distant geologic past and therefore of course rewarding. Determination of *absolute* Earth–Moon distances and Earth's palaeorotational parameters and investigating the past Earth–Moon dynamics based on astronomical laws alone are, however, highly ambiguous. This is because the tidal friction is critically dependent on the sea level and continental configurations both of which have changed significantly in the geologic past. So geologists have to be very careful while analyzing ancient tidal rhythmite data.

Acknowledgement

My research on tidal rhythmite was supported by Japan Society for the Promotion of Science (JSPS) through a Post Doctoral Fellowship (ID. No. P02314). I gratefully acknowledge infra-structural facilities provided by the Geological Institute, Graduate School of Environment and Information Science, Yokohama National University, Japan.

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