Planetary evolution

Banded iron formations

from Kurt Lambeck

THE problem of the timescale of the dynamical evolution of the Earth–Moon system just does not go away, as attested by Walker and Zahnle on page 600 of this issue[1]. The mathematics of the evolution of a binary planet–satellite system, once it has formed, is reasonably well understood. Much less well understood are the physical mechanisms of dissipation of the energy of the tides raised by the two planets on each other, and this produces very considerable uncertainty in the timescale of any evolution[2]. In the absence of evidence from the distant past, the usual practice is to adopt the modern observed rates of evolution and to extrapolate backwards in time. Despite fluctuating conclusions about the present rate of tidal dissipation, this process leads inexorably to the conclusion that the Moon was very close to the Earth about 2.5–1.5 × 10^9 years ago.

Such a close encounter conjures up planet-disrupting tides in which, to borrow a phrase from the Prayer Book of 1662, "the Earth shall melt away". Yet the geological evidence for this does not exist. Either the moon escaped unscathed or the close encounter occurred back in the darkest ages of the Earth. It is easier to dismiss the validity of the backwards extrapolation, for there is little reason to suppose that the dissipation rates have remained unchanged with time. Thermal evolution of the solid Earth, evolution of the oceans and the wandering of continents provide sufficient reason to modify the timescale by a factor of two or three.

It is better to follow the chemical arguments. A. E. Ringwood[3] has argued for many years that chemical evidence requires that the Moon formed out of the Earth from material evaporated from the mantle during the rapid accretion of the planet, aided by the gravitational energy of the impacting planetesimals that contributed to the construction of the Earth in the first place Various adaptations of this model are now becoming popular and there is little reason to adopt a starting model for the evolution of the orbital and rotational parameters of the Earth and Moon other than one in which the Moon was close to the Earth in the earliest days of formation. Any information on this evolution then becomes important in understanding the rates of energy dissipation and, by inference, the thermal evolution of the solid planet or the changing volumes and geometries of the oceans.

Different approaches have been used to quantify this evolution[2]. One approach is to model tidal dissipation in past ocean basins; another is to search the geological record of the Earth for traces of past Earth–Moon configurations. Growth cycles of corals and of molluscs provide some insight into these configurations during Phanerozoic time and the interpretations have received some confirmation from controlled experiments on their living counterparts[4]. Stromatolites, primitive sedimentary organisms from the Precambrian, have also allowed some, less confident, speculation. In both cases, the growth cycles of the organisms are assumed to be controlled by tidal, diurnal and/or seasonal factors during growth and it is also assumed that their record has been preserved intact so that these past cycles can be deciphered.

Now a new observation of past lunar–terrestrial geometries has been proposed. Periodic banding of inorganic material is known to occur in Precambrian time, most notably in the banded ironstones. Walker and Zahnle[1] in their new work suggest that these formations can establish the frequencies of some of the longer cycles in the Earth–Moon system. The banded iron formations of the Hamersley Basin in Western Australia, particularly the finely banded structure of the Weeli Wolli formation, provide the source of Walker and Zahnle's hypothesis. These bands are primary depositional features, believed to be precipitated from basin waters that were isolated from the oceans[5]. Their regular sequence indicates that their deposition was controlled by periodic natural environmental events. Superimposed on this fine structure are various other band structures, one of which occurs particularly regularly, separated by 23.3 (on average) of the finer bands[5]. Trendall[5,6] favours an annual frequency for the micro-bands, with deposition controlled by parameters such as water temperature, possibly with a biological involvement. This deposition sequence is then modulated or interrupted by processes of longer periodicity.

Trendall notes that the proposed periodicity of the mesoscale cycle is close to that of the double-sunspot or Hale cycle, although he points out that the absence of an 11-year cycle places this interpretation in some doubt. Note, however, that several indicators of modern climatic trends exhibit pronounced double-sunspot cycles and only weak 11-year cycles[7].

Other evidence for apparent solar periods in the geological record has recently been presented by Williams and Sonett in the form of sedimentary cycles in late Precambrian varves of South Australia[8], although here both the 11- and 22-year cycles were identified. The authors suggest their observations constrain models of the physics of the solar activity cycle.

Walker and Zahnle[1] offer a different interpretation. They suggest that the mesoscale bands are controlled by the lunar nodal cycle, which at present has an 18.6-year period. If correct, the banded ironstones, dated at about 2.5 × 10^9 years, provide a valuable constraint on the orbital evolution of the Moon. The authors conclude that a nodal period of 23.3 years at the time of the deposition requires that the Moon was at about 50 Earth-radii from the Earth, compared with the present distance of about 60 Earth-radii. Protagonists of early formation of the Moon who have been disturbed by the timescale problem can now rest in peace.

But the basic assumption made by Walker and Zahnle may provoke argument — an essential question is whether the nodal cycle is sufficiently significant to leave its mark on climate. Walker and Zahnle quote several analyses that purport to show that it does. But a solar influence may be more reasonable. For example, is there a similarity between the cycle of these mesoscale bands and the 23-year cycle found in the recurrence of prolonged droughts in North America[7]? Can severe evaporate concentration cause precipitation of the silica-rich mesoscale bands or can a change in wind patterns set up a new circulation system in the water body?

Walker and Zahnle do propose a test of their hypothesis. They suggest that some of the Milankovitch periodicities of orbital motions (periodicities that have a prominent role in modulating the ice age climate) will also have been different in the past from in the present and that this difference may be reflected in periodicities of the mesoscale bands. A macro-band structure has been noted in the banded iron formation, as well as a cyclicity of mesobands intermediate in scale between the macro- and meso-banding[5,6]. These cycles may offer a test of the new hypothesis, but it is unlikely that sufficient records exist. Alternatively, such a test may reveal some of the longer cycles such as the approximately 100- or 200-year cycles seen in modern climatic records[7]. Either way, further examination of the Weeli Wolli and similar formations is called for. ☐

1. Walker, J.C.G. & Zahnle, K.J. *Nature* **320**, 600 (1986).
2. Lambeck, K. *The Earth's Variable Rotation* (Cambridge University Press, 1980).
3. Ringwood, A.E. *Origin of the Earth and Moon* (Springer, Berlin, 1979).
4. Scrutton, C.T. in *Tidal Friction and the Earth's Rotation* (eds Bosch, P. & Sundermann, J.) 154 (Springer, Berlin, 1978).
5. Trendall, A.F. in *Iron Formations: Facts and Problems* (eds Trendall, A.F. & Morris, R.C.) 69 (Elsevier, Amsterdam, 1983).
6. Trendall, A.F. *Econ. Geol.* **68**, 1089 (1973).
7. Lamb, H.H. *Climate: Present Past and Future* (Methuen, London, 1972).
8. Williams, G.E. & Sonett, C.P. *Nature* **318**, 523 (1985).

Kurt Lambeck is Professor of Geophysics at the Research School of Earth Sciences, Australian National University, Canberra 2600, Australia.