19930009777
N93-18966

Variations of the Milankovitch Frequencies in Time.

Loutre M.F. and Berger A.

1 Pre-Cenozoic Times

The sensitivity of the amplitudes and frequencies in the development of the Earth's orbital and rotational elements involved in the astronomical theory of paleoclimates (eccentricity, obliquity and climatic precession), to the Earth-Moon distance and consequently to the length of the day and to the dynamical ellipticity of the Earth has been discussed for the last billions of years (Berger et al., 1989a,b,c; Berger and Loutre, 1991).

The shortening of the Earth-Moon distance and of the length of the day, as well as the lengthening of the dynamical ellipticity of the Earth back in time induce a shortening of the fundamental astronomical periods for precession (the 19-kyr and 23-kyr quasi-periods becoming respectively 12.6 and 14.3-kyr at 2 10^9 yr BP) and obliquity (the 41-kyr and 54-kyr quasi-periods becoming respectively 19.6 and 22.1-kyr at 2 10^9 yr BP) (Figure 1). At the same time, the amplitudes of the different terms in the development of the obliquity are undergoing a relative enlargement of about 50% at 2 10^9 yr BP but the independent term is increasing very weakly (less than 0.1%). In other words, the value of the obliquity, which lies within a range of 21.°7 to 24.°9 over the Quaternary was restricted to a range of 22.°5 to 24.°1 at 2 10^9 yr BP. On the other hand, the amplitudes in the development of the climatic precession do not change. Moreover, these changes in the frequencies and amplitudes for both obliquity and climatic precession are larger for longer period terms. Finally, the periods in the eccentricity development are not influenced by the variation of the lunar distance.

But the motion of the solar system, especially of the inner planets, was shown to be chaotic (Laskar, 1990). It means that it is impossible to compute the exact motion of the planets over more than about 100 Myr, and the fundamental frequencies of the system are not fixed quantities, but are slowly varying with time. As long as we consider the most important terms, the maximum deviation from the present-day value of the 19-kyr precessional period due to the chaotic motion of the solar system only does not reach more than a few tens of years around 80 Myr BP (Berger et al., 1991). Therefore the shortening of the obliquity and climatic precession periods is mostly driven by the change in the lunar distance and the consequent variations in the dynamical ellipticity of the Earth's angular speed.

At first sight, the deviation in the period for the eccentricity can be neglected, as the chaotic behaviour of the solar system implies a relative change of the main periods (404, 95 and 123 kyr-periods respectively) by less than 0.2%, 1.4% and 1.9% respectively, this maximum changes being achieved around 80 Myr BP. This implies, in particular, that the eccentricity periods used for Quaternary climate studies may be considered more or less constant for pre-Quaternay times and equal to their Quaternary values.

2 The Quaternary Period

The sensitivity of the frequencies of these astronomical elements to the dynamical ellipticity of the Earth has also been investigated for the Quaternary period (Dehant et al., 1990). According to the model used, the modification of the distribution of the masses on and inside the Earth during full glacial conditions has a weak influence on the moments of inertia of the Earth and consequently on the astronomical periods: more precisely the dynamical ellipticity of the Earth remains more or less constant for the isostatic equilibrium case (i.e. a subsidence of about 3/10 of the height of the ice sheet). For larger subsidences, the variation of the dynamical ellipticity of the Earth is positive and for smaller ones, it becomes negative, reaching 1.5% at the maximum. For a 1 % increase of the dynamical ellipticity of the Earth, the precessional quasi-periods (19 and 23 kyr) become 18.9 and 22.8 kyr while the quasi-periods of the obliquity (41 and 54 kyr) become 40.4 and 52.9 kyr.

3 Future research

- The determination of the Earth-Moon distance and/or the lunar recession rate for pre-Cenozoic times must be improved by taking into account the repartition and the displacement of the oceanic basins and of the continents in order to obtain a better time scale.
- A full model of the Earth interior would give more accurate values for the dynamical ellipticity of the Earth and the Earth's angular speed of rotation taking into account the repartition of the masses on and inside the Earth.
- The model used to compute the variation of the dynamical ellipticity of the Earth due to the waxing and waning of ice sheets could be improved by considering the

- geographical location and height of the ice sheets
- subsidence and rebound of the continents not covered by ice
- subsidence and rebound of the marine lithospere

- A model accounting for the transient response to the ice sheet loading, instead of the snapshot reconstruction as used in the present study where we considered only full (maximum) glacial conditions and plain interglacials, would allow us to simulate the time evolution of the global effects of the ice sheets formation and melting, taking into account lagging subsidence and rebound of the lithosphere.

- Improvements in the interpretation of past proxy data and refinement of the time scale would allow to provide an independent determination of the astronomical frequencies found in pre-Cenozoic time series, allowing to validate and calibrate the astronomical models.

4 References

Berger A., Loutre M.F. and Dehant V. , 1989a, Astronomical frequencies for pre-Quaternary palaeoclimate studies. Terra Nova, 1, 474-479.

Berger A., Loutre M.F. and Dehant V., 1989b. Influence of the changing lunar orbit on the astronomical frequencies of pre-Quaternary insolation patterns. Paleoceanography, 4(5), 555-564.

Berger A., Loutre M.F. and Dehant V. , 1989c. Milankovitch frequencies for pre-Quaternary. Nature, 342, pp. 133.

Berger A. and Loutre M.F., 1991. Astronomical forcing through geological time. In: Orbital forcing and cyclic sedimentary sequences. (P.L. de Boer, ed), Utrecht.

Berger A., Loutre M.F. and Laskar J., 1991. Stability of the astronomical frequencies over the Earth's history for paleoclimate studies. Science (in preparation).

Dehant V., Loutre M.F. and Berger A., 1990. Potential impact of the northern hemisphere Quaternary ice sheets on the frequencies of the astroclimatic orbital parameters. J. Geophys. Res., 95 (D6), 7573-7578.

Laskar J., 1990, The chaotic motion of the solar system. A numerical estimate of the size of the chaotic zones. Icarus. 88, 266-291.

Walker J.C.G. and Zahnle K.J., 1986. Lunar nodal tide and distance to the Moon during the Precambrian. Nature, 320, 600–602.

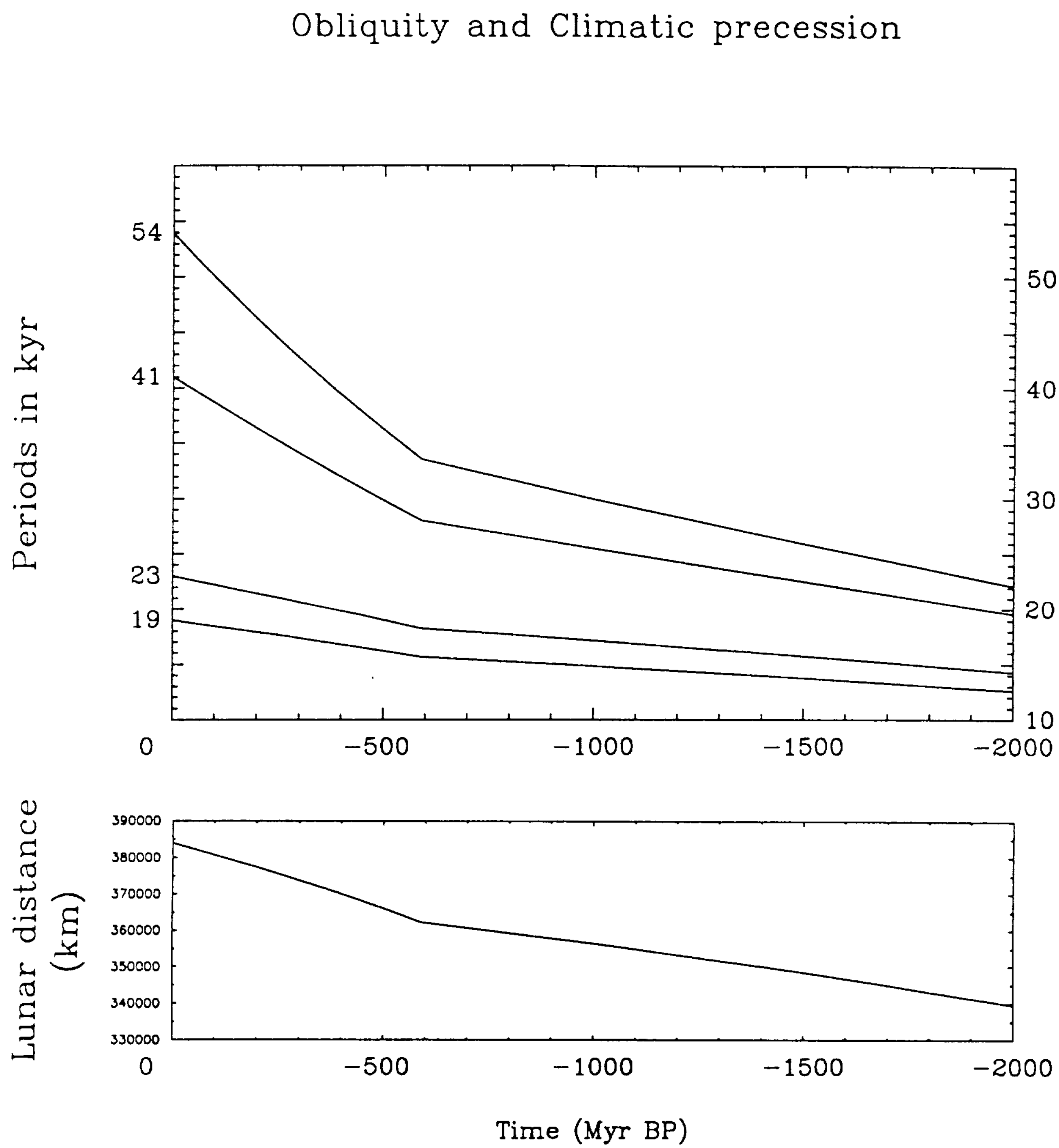

Figure 1: Estimated values of the periods of the orbital parameters (top) involved in the astronomical theory of paleoclimates considering the effect of the variations of the Earth-Moon distance (bottom) and of the Earth's figure and rotation (Berger and Loutre, 1991). It must be noted that the discontinuity in the rate of change of the astronomical periods reflects the artificial change in the value of the Earth-Moon recession rate taken to be 10^{-9} m s^{-1} for the last 590 Myr , and 0.43 10^{-9} m s^{-1} prior to 590 Myr BP (Walker and Zahnle, 1986; Berger and Loutre, 1991).