Crystal Enigma

SIR—In finding the atomic arrangements in crystals the amplitudes of the Fourier terms observed by X-ray diffraction must be combined with the correct phases to give a picture of the structure. Since this was first done by W.H. and W.L. Bragg in 1929, it has been recognized that centro-symmetric crystal structures, where the phases of the sine waves are either 0 or π, are far easier to handle than non-centro-symmetric structures, where general phase angles have to be found (nowadays by the methods of Karle and Hauptmann or by the introduction of heavy atoms as phase markers).

Protein crystals, containing as they do, L-amino acids, are always non-centro-symmetrical. But the total synthesis of protein molecules from their constituent amino acids is now possible so that, starting from D-amino acids and L-amino acids separately, it would be possible to make both D- and L-forms of the same protein of known sequence but unknown conformation. Co-crystallisation of equal numbers of D- and L-molecules might produce crystals of a racemate which could be centro-symmetrical with a consequent simplification in the process of solution.

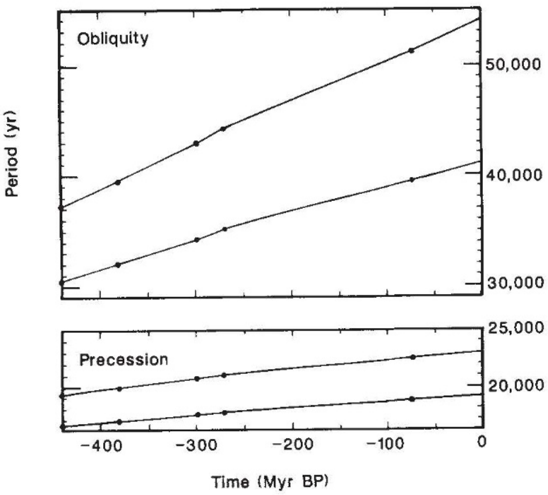
Note that the outcome of the Second World War turned on this issue, as the German Enigma coding machine was made centro-symmetrical for administrative convenience (coding and decoding procedures were then the same, and in a setting where typing in A gave B, then typing in B would return A). This weakness allowed M. Rejewski, J. Rózycki and H. Zygalski, and later others at Bletchley Park, an entry to the decipherment of Enigma, which perhaps ultimately led to military defeat of the Axis. Probably no crystallographers were involved on either side.

ALAN L. MACKAY
Department of Crystallography,
Birkbeck College,
Malet Street,
London WC1E 7HX, UK

Pre-Quaternary Milankovitch frequencies

SIR—According to the Milankovitch theory[1,2] external climatic forcing results from changes in the orbital parameters of the Earth's path around the Sun which affect the amount of solar radiation received at the top of the atmosphere. The main periods during the past 5 Myr of the three most important parameters, recalculated in ref. 3 are: eccentricity (a measure of the shape of Earth's orbit around the Sun) — 413, 95 and 123 kyr; obliquity (the tilt of the Equator on Earth's elliptical orbit around the Sun) — 41 and 54 kyr; climatic precession (a measure of the Earth–Sun distance at the summer solstice) — 23 and 19 kyr. Evidence of these periods has been found in sedimentary data recording the Quaternary climate[4,5].

Recent results from sediment records have shown that the pre-Quaternary climate was also dominated by components with periods ranging between 20 and 100 kyr (ref. 6). To relate this kind of periodicity to astronomical forcing, the frequencies of the latter must be calculated accurately. These can be obtained from a theory that describes the gravitational effects of the Sun, the Moon and the planets on the Earth's orbit. They include the effect of the Earth–Moon distance which is known to have changed during geological times and could affect the periods of astronomical forcing. Therefore, we must understand how the variations of the lunar orbit, and the related variations of the Earth's rotation and shape, can influence the Earth's orbital frequencies[7]. The complexity of the problem is increased by the interrelations between these parameters[8]: for example, the Earth's rotation rate is related to the Earth–Moon distance through tidal friction, and it influences the shape of the Earth through the centripetal force.



Estimated values of the periods of the orbital parameters involved in the astronomical theory of palaeoclimates, considering the effect of the explicit variations of the Earth–Moon distance and of the Earth's figure and rotation. (Dots represent computed values from the data.)

Precession and obliquity can be expressed as quasi-periodic functions of time[3] where the periods involved and the associated amplitudes are a function of the 'constant' of precession (this is not the case for the eccentricity). This 'constant' in turn depends on the three parameters just mentioned. Here we use Earth's rotation rate deduced from fossil corals or observations of ancient eclipses[9]. The associated variations of the other two parameters (the Earth–Moon distance and the Earth's shape) are also available in the literature[10–12].

With this whole set of data and appropriate models we can calculate the long-term variations of the main astro-climatic periods over the past 500 Myr (ref. 7). The figure shows that these periods have always been smaller than today's, their shortening becoming rather significant for epochs older than 100 Myr. Moreover, the effect is larger for the longer periods so that it may be impossible to distinguish between the '41,000-yr period of the obliquity' and the '23,000-yr period of the procession' in the Precambrian times.

The accuracy of our results is limited by the accuracy of the values used: an increase of the lunar recession rate by 50%, which is still plausible for 440 Myr BP, reduces the astronomical periods by a further 10%. On the other hand, our conclusions hold for a more accurate astronomical solution[13] as it seems that the astronomical frequencies considered here[3], remain of the same order of magnitude in the new solution. The chaotic behaviour of the solar system may, however, challenge our results for the remote past[14].

A. BERGER
M. F. LOUTRE
Institut d'Astronomie et de Géophysique G. Lemaître,
Université Catholique de Louvain,
2, Chemin du Cyclotron,
B1348 Louvain-la-Neuve, Belgium
V. DEHANT
Observatoire Royal de Belgique,
3, Avenue Circulaire,
B1180 Bruxelles,
Belgium

1. Milankovitch, M. *Kanon der Erdbestrahlung und seine Anwendung auf das Eiszeitenproblem, R. Serb. Acad., Spec. Publ.* (1941).
2. Berger, A. *Rev. Geophys.* **26**, 624–657 (1988).
3. Berger, A. *Nature* **269**, 44–45 (1977).
4. Hays, J., Imbrie, J. & Shackleton, N. *Science* **194**, 1121–1132 (1976).
5. Berger, A. *Quat. Int.* (in the press).
6. Fischer, A.G. *A. Rev. Earth planet. Sci.* **14**, 351–376 (1986).
7. Berger, A., Loutre, M.F. & Dehant, V. *Paleoceanography* (in the press).
8. Melchior, P. *The Tides of the Earth* (Pergamon, Oxford, 1988).
9. Stoyko, A. *Ann. Guébhard (Neuchâtel)* **46**, 293–316 (1970).
10. Lambeck, K. *The Earth's Variable Rotation: Geophysical Causes and Consequences* (Cambridge University Press, 1980).
11. Cazenave, A. in *Tidal Friction and Earth's Rotation II* (eds Brosche, P. & Sündermann, J.) 4–18 (Springer, Berlin, 1982).
12. Denis, C. *Geophys. J. R. astr. Soc.* **87**, 559–568 (1986).
13. Berger, A., Loutre, M.F. & Laskar, J. *Univ. Catholique de Louvain Sci. Rep. 1988 No. 13* (1988).
14. Laskar, J. *Nature* **338**, 237–238 (1989).