SUB-MILANKOVITCH PALAEOCLIMATIC EVENTS: THEIR RECOGNITION AND CORRELATION

Guest Editorial

Sub-Milankovitch climatic oscillations, too rapid and abrupt to be explained by orbital forcing, are important to our understanding of the stability of the global climatic system (Berger and Labeyrie, 1987). But while climatic variations over timescales between 10^2 and 10^4 years are indicated by proxy records ranging from ice cores to peat stratigraphies, we still lack a rigorous methodology for comparing and calibrating these different data sources. A fundamental difficulty is that it is difficult to know *a priori* if a particular climatic event was regional or global in extent. This debate has applied to the two most intensively researched sub-Milankovitch oscillations, the terminal Pleistocene Younger Dryas and the 'Little Ice Age'. The Younger Dryas stadial, for example, was originally considered to be restricted to north-west Europe, and explanations for its occurrence were conceived at a regional scale. However, evidence for its effects was subsequently found throughout the North Atlantic seaboard, and the event has since been recognised in sequences from the South China Sea to the Andes. Even though some earth surface systems were insensitive to its effects, the Younger Dryas is now considered to be the result of a perturbation to the global climate system during the last major deglaciation, rather than a regional phenomenon.

Sound intra- and inter-regional correlation is critical if we are to move from mere recognition to the more difficult issue of correctly identifying the cause(s) of sub-Milankovitch events, candidates for which include volcanism, variations in solar emissions and the switching on and off of deep ocean circulation systems (e.g. the salt oscillator model of Broecker *et al.*, 1990). Synchroneity, although important, is *on its own* usually a weak basis for correlation. For a start, natural archives recording past climate change almost always involve some degree of chronological uncertainty. Radiocarbon ages, for example, provide discontinuous time series which require assumptions to be made about intervening accumulation rates. Additionally, individual proxies have different response times to climate change. While tree-ring thicknesses reflect conditions for growth during a particular year, and hence provide a sensitive but 'noisy' record of climate, alpine glaciers have a lagged and smoothed response, and their histories of advance and retreat are dominated by longer periodicities of climatic change. Even if chronological difficulties can be overcome, correlation does not imply causation, especially if different climatic variables are involved. Although certainly linked, temperature and precipitation do not co-vary in a simple or easily predicted (or retrodicted) manner. Inter-regional teleconnections need to have some climatic basis – as with ENSO across the Pacific – if common causation is to be convincingly demonstrated.

It seems reasonable to suggest that the primary criteria for correlating records of Sub-Milankovitch climatic change are commensurability and coherence. The first of these simply means that *in the first instance* it is usually best to compare 'like with like', such as one tree-ring sequence with another one, and to demonstrate internal consistency and replicability before moving on to make comparisons between climate proxies. (This was the approach adopted for handling large palaeoclimate data sets by the COHMAP group (1988)). The second criterion complements the first by stressing the need for regional coherence in climate histories, before wider comparisons are made. A good example which incorporates both of these principles is the study of interstadials (500 to 2000 yr long) in Greenland ice cores, published by Johnsen *et al.* (1992). These sub-Milankovitch events, which occurred during the middle part of the last cold stage (oxygen isotope stage 3), were originally recognised in the Camp Century core, but it was only with their discovery in three other cores that it could be confirmed that they reflected regional climate fluctuations rather than local factors such as disturbed ice-sheet stratification.

In low-latitude continental areas the main effect of sub-Milankovitch climatic oscillations has been upon effective moisture balance, a subject discussed by Magaritz in a paper later in this issue. The record of precipitation minus evapotranspiration (P – E) is particularly clearly reflected in the water level and salinity of non-outlet lakes. For northern intertropical Africa, abrupt lake-level falls were shown by Street-Perrott and Roberts (1983) to have been regionally synchronous, with low-level (= arid) events occurring at ca. 10.5–10.0, 8.0–7.2 and 5.0–4.5 kyr (thousand radiocarbon years BP). Talbot (1982) even suggested that these events could be used as pan-African climato-stratigraphic marker horizons. The earliest of these regressional events was broadly contemporary with the European Younger Dryas stadial, while the middle one occurred at the same time as the final break-up of the Laurentide ice sheet over Hudson Bay. On the other hand, because these abrupt arid events were only known from tropical lakes, it was assumed that their immediate cause lay in a temporary suppression of the monsoonal circulation system (Roberts, 1990).

In fact, subsequent research has shown that similar, and in some cases, synchronous events also occurred in adjacent extra-tropical regions such as the Maghreb and the Near East. The records from lakes such as Tigalmamine in the Middle Atlas of Morocco and the Dead Sea in the Jordan rift are particularly significant because the general water-level histories of these lakes during the Holocene do not correspond with those from Africa's monsoonal sector (El-Hamouti *et al.*, 1989, Frumkin *et al.*, 1991). Instead, their effective precipitation signal has responded to the location and intensity of westerly depressions. In addition, because of their different response to orbital forcing, background lake levels in the circum-Mediterranean region have remained high during the second half of the Holocene, unlike those south of the Sahara. Consequently, lake regressional events are stratigraphically visible throughout the Holocene, and not only during its first part. These and other data from the tropics (e.g. de Deckker *et al.*, 1991) suggest that arid episodes have occurred approximately every 2 to 3 kyr during the late Quaternary, implying a periodicity for sub-Milankovitch events that is not regular but probably not random either (Roberts *et al.*, in press).

If the selection of palaeo-climatic records for correlation is partly based on judgement, then their evaluation is, almost of necessity, even more subjective. According to Popperian logic any records inconsistent with an existing framework for climatic change should cause us to reject that framework. The reality is, not unreasonably, rather different. An excellent example of why it is best to rely on a balance of evidence is provided by Gasse and Street's (1978) study of Holocene water-level fluctuations in a series of lake basins in the Ethiopian rift. Here it was possible to show that within a single climatic province, 'amplifier' lakes responded sensitively to abrupt Holocene hydro-climatic changes while groundwater-fed lakes responded hardly at all. Evidence for significant fluctuations in climate and regional water balance throughout the Holocene is thus increasingly persuasive, but if these changes are to be properly understood and explained, then rather greater rigour is going to be needed in their analysis than has been the case hitherto.

References

Berger, A. and Labeyrie, W. H. (eds.): 1987, *Abrupt Climate Change, Evidence and Implications*, Reidel, Dordrecht.

Broecker, W. S., Bond, G., and Klas, M.: 1990, 'A Salt Oscillator in the Glacial Atlantic? 1. The Concept', *Paleoceanography* **5**, 469–477.

COHMAP members: 1988, 'Major Climatic Changes of the Last 18,000 Years: Observations and Model Simulations', *Science* **241**, 1043–52.

De Deckker, P., Corrège, T., and Head, J.: 1991, 'Late Pleistocene Record of Cyclic Eolian Activity from Tropical Australia Suggesting the Younger Dryas is not an Unusual Climatic Event', *Geology* **19**, 602–605.

Frumkin, A., Magaritz, M., Carmi, I., and Zak, I.: 1991, 'The Holocene Climatic Record of the Salt Caves of Mount Sedom, Israel', *The Holocene* **1**, 191–200.

Gasse, F. and Street, F. A.: 1978, 'Late Quaternary Lake-Level Fluctuations and Environments of the Northern Rift Valley and Afar Region (Ethiopia and Djibouti)', *Palaeogeogr., Palaeoclimatol., Palaeoecol.* **24**, 279–325.

El Hamouti, N., Lamb, H., Fontes, J.-Ch., and Gasse, F.: 1991, 'Changements Hydroclimatiques Abrupts dans le Moyen Atlas Marocain depuis le Dernier Maximum Glaciaire', *C. R. Acad. Sci. Paris* **313**, sér. II, 259–65.

Johnsen, S. J., Clausen, H. B., Dansgaard, W., Fuhrer, K., Gundestrup, N., Hammer, C. U., Iversen, P., Jouzel, J., Stauffer, B., and Stefferson, J. P.: 1992, 'Irregular Glacial Interstadials Recorded in a New Greenland Ice Core', *Nature* **359**, 311–3.

Roberts, N.: 1990, 'Ups and Downs of African Lakes', *Nature* **346**, 107.

Roberts, N., Lamb, H., El Hamouti, N., and Barker, P.: in press, 'Abrupt Holocene Hydro-Climatic Events: Palaeolimnological Evidence from Northwest Africa', in Millington, A. C. and Pye, K. (eds.), *Effects of Environmental Change in Drylands*, J. Wiley.

Street, Perrott, F. A. and Roberts, N.: 1983, 'Fluctuations in Closed-Basin Lakes as an Indicator of Past Atmospheric Circulation Patterns', in Street-Perrott, F. A., Beran, M., and Ratcliffe, R. D. (eds.), *Variations in the Global Water Budget*, Reidel, Dordrecht, 331–345.

Talbot, M. R.: 1982, 'Holocene Chronostratigraphy of Tropical Africa', in Mangerud, J., Birks, H. J. B., and Jager, K.-D. (eds.), *Chronostratigraphic Subdivision of the Quaternary*, (*Striae* **16**), 17–20.

Department of Geography,
Loughborough University of Technology,
Loughborough, Leicestershire LE11, 3TU,
United Kingdom

NEIL ROBERTS