hancers into 'packaged' chromatin through the action of the *Polycomb* group of genes. This strategy restricts *Ubx* expression in the imaginal discs to the appropriate domain. Indeed, *cis*-acting *Polycomb* response elements in the upstream region of *Ubx* were described which repress the activity of adjacent genes over some distance.

The value of *Drosophila* as a general model for animal development was emphasized by some new findings. The orthologue of the PAX-6 (*smalleye*) gene of mouse is encoded by the fly gene *eyeless*, implying an unforeseen evolutionary relationship between the compound eye and the vertebrate eye (W. Gehring, Univ. of Basel). Screens for tumour-suppressor genes have identified interesting phenotypes (T. Xu, Yale Univ.). Also, the *gypsy* retrotransposon may function as a *bona fide* retrovirus, packaged into infectious virus-like particles (A. Bucheton, CNRS, Gif-sur-Yvette; V. Corces, Johns Hopkins Univ.). Perhaps humans, with their conspicuous lack of wings, should be considered as underdeveloped flies; however, that icon of homeotic transformation, the four-winged fly, is also incapable of flight. Attempts to correct this deficiency have been undertaken using more mutations in one locus than most geneticists use in a genome (*abx* bx^3 Ubx^{61d} *pbx iab-2*; E. Lewis, Caltech). Alas, this tribute to the hundredth year of homoeosis after Bateson was unsuccessful, but we look forward to the 1996 Crete meeting and a flying four-winged *Drosophila*. □

N. H. Brown is at the Wellcome/CRC Institute, Tennis Court Road, Cambridge CB2 1QR and the Department of Biochemistry, University of Cambridge, Cambridge CB2 1QW, UK. D. A. Hartley is in the Department of Biochemistry, Imperial College of Science, Technology and Medicine, London SW7 2AZ, UK.

PALAEOCLIMATOLOGY

Chill over the Cretaceous

Eric J. Barron

THE mid-Cretaceous period, about 100 million years ago, was far warmer than today and thus should be a good test of how well models of future climate can simulate conditions very different from the present day. Or so we thought. On page 453 of this issue, Sellwood *et al.*[1] challenge the evidence for extreme Cretaceous warmth, suggesting the need to re-evaluate past modelling efforts and to question whether the Cretaceous is a reasonable analogue for global change studies.

Much of the effort so far has been based on an early synthesis of the Cretaceous climate observations[2] indicating substantially warmer poles (mean annual temperatures above freezing) and small but significant increases in tropical sea surface temperatures. Like these earlier studies, Sellwood and colleagues' conclusions are based on oxygen isotope analyses of planktonic foraminifera, but they examine more locations, including more sites at lower latitudes, for a more specific time interval.

The results suggest that mean annual polar temperatures were near 0 °C, so some glacial ice could have formed, and that tropical sea surface temperatures were similar to modern values. This interpretation is very similar to the 'minimum' plausible warmth scenario of earlier Cretaceous climate reconstructions[2]. If the new results are correct, their reconstruction of Cretaceous temperatures has considerable significance.

First, the nature of tropical climate change is critical given the importance of the tropics in the global heat engine which drives the atmospheric circulation and the likely sensitivity of tropical life to a temperature change of even a few degrees. Most climate models predict that future tropical surface ocean temperatures will rise by about 2 °C for a doubling of carbon dioxide in the atmosphere. Similar model predictions result for the Cretaceous with higher CO_2 (see ref. 3). If Sellwood and co-workers are right, then either other (possibly unknown) climate forcing factors must have counteracted tropical warming, or our understanding of the climate system, as reflected in our ability to construct numerical climate models, is inadequate.

One well-known limitation of current climate models is inadequate treatment of the heat transport of the oceans. Most simulations of future and past climates are based on models which only consider the energy balance in the upper mixed layer of the ocean, lacking ocean dynamics or ocean heat transport. If the oceans transport more heat polewards, the result could be cooler tropical temperatures[3–5]. But we do not know that the oceans can play a different role in poleward heat transport, and other mechanisms may be required.

Second, we should look again at efforts to assess the sensitivity of the climate system to forcing factors such as carbon dioxide. For example, geochemical observations and models estimate that Cretaceous CO_2 concentrations were 4 to 8 times present-day values[6] — this, indeed, is a reason why the Cretaceous is so attractive to climate modellers. Using a 'warmer' estimate of the Cretaceous with warmer tropics and polar temperatures near 10 °C (global average temperature increase of 12 °C relative to the present day) would yield an average climate sensitivity to a carbon dioxide doubling of 3–6 °C. These values are on the upper end of the spectrum of climate sensitivity used in current assessments of the potential impact of human-induced global warming[7]. Of course, this is a crude analysis given that the sensitivity is not linear with respect to carbon dioxide concentration in the atmosphere. In contrast, the 'minimum' estimates of Cretaceous warmth are less than 6 °C, yielding an average climate sensitivity which must be closer to 1.5–3.0 °C for a doubling of carbon dioxide, on the lower end of CO_2 sensitivity estimates. This, of course, depends on the importance of other forcing factors and any uncertainty in the estimates of the level of carbon dioxide in the Cretaceous atmosphere.

The large number of differences between the past and the present day make it unlikely that any past climate can be a true analogue of future climes. This does not diminish the importance of the geological record in providing 'case studies' of global change, yielding valuable insights into climate change and climate sensitivity; but it shows that our ability to assess these critical aspects of the Earth system depend on our ability to reconstruct key past observations.

Sellwood and colleagues' interpretations are likely to be challenged. Do other time slices exhibit similar tropical temperatures or are tropical temperatures capable of change on timescales of millions of years through changes in ocean circulation? Are the limited data available dependent on local environmental conditions such as upwelling and is there substantial longitudinal variability? What is the true difference between surface temperature and the temperature at the depths in which the foraminifera lived? Still, they have undoubtedly given fresh life to the debate on climate and climate change. □

Eric J. Barron is at the Earth System Science Center, The Pennsylvania State University, 248 Deike Building, University Park, Pennsylvania 16802, USA.

1. Sellwood, B. W., Price, G. D. & Valdes, P. J. *Nature* **370**, 453–455 (1994).
2. Barron, E. J. *Earth Sci. Rev.* **18**, 305–338 (1983).
3. Barron, E. J., Peterson, W. H., Pollard, D. & Thompson, S. *Paleoceanography* **8**, 785–798 (1993).
4. Rind, D. & Chandler, M. *J. geophys. Res.* **96**, 7434–7461 (1991).
5. Covey, C. & Thompson, S. L. *Global planet. Change* **1**, 331–341 (1989).
6. Berner, R. A. *Nature* **358**, 114 (1992).
7. Houghton, J. T., Callander, B. A. & Varney, S. K. (eds) *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment* (Cambridge Univ. Press, 1992).