The erosive nature of the shoreline provides evidence that the lake height fell by about 50 cm only recently.

PAST CLUES TO FUTURE CLIMATE

by Carson Creagh

Henry Ford liked to bluster that history was bunk; that the past held no lessons for the present or the future. A self-made man who, it was said, worshipped his creator, he was intolerant of book-learning and uninterested in the science involved in the machine that made him a millionaire.

Ford would have been delighted by the vigorous anti-scientific tone of various recent assertions about climate change and the greenhouse effect.

Some people (many of them experts in their fields, although those fields do not happen to include climatology) claim that global warming is bunk. Yet even as they damn scientists as doomsayers, these commentators frequently betray a basic misapprehension of what science is about. They want it to be revealed truth, immutable and unarguable; they do not accept that science is dynamic, constantly evolving and refining its conclusions in the light of fresh information.

Since even the best science is something of a curate's egg, the debunkers can point to enough gaps in our understanding of climate change — the blank areas in our knowledge of planetary processes, the alarming differences between what global climate models are suggesting and actual field measurements, and the broad and occasionally bitter differences of opinion among scholars — to convince themselves that the whole egg is bad.

One field that has come under particular attack is palaeo-environmental research, which investigates the climate of the past and postulates possible futures based on the physical and chemical hints revealed in lake and ocean sediments, ice cores, pollen, fossils, tree rings and ancient river floods. Critics have claimed that past climates cannot be adequately described in a quantitative manner, or adequately represented over large geographical areas; that changes over long periods have no application to prediction; and that the past is unique, and cannot be used to indicate the future.

Researchers Dr Bob Wasson and Dr Terry Donnelly, of the CSIRO Division of Water Resources, have recently tested these objections against a rigorous re-examination of field data for Australia's palaeoclimatic record, and feel confident that the information obtained from local field studies not only deals with most criticisms, but also provides a valuable method of testing climate models that offer hope of predicting climate on a global scale. They answer the critics thus.

First, while they concede that quantitative records of past climates can never be simple to interpret, they point to rapid progress in interpretation that parallels improvements made in the general circulation models (GCMs) which portray the forces responsible for large-scale climate fluctuations. They say the interpretation of data from a range of sources has progressed to the point where palaeoclimatic analyses are accurate to within plus or minus one degree for mean annual temperatures and plus or minus 50 millimetres for mean annual rainfall. And the geographical spread over which the findings can be applied is increasing as more funding becomes available for field work.

KNOWLEDGE OF HOW CLIMATE HAS CHANGED OVER TENS OF THOUSANDS OF YEARS IN THE PAST IS GROWING RAPIDLY, AND PROVIDING USEFUL POINTERS TO THE FUTURE

Second, they argue that information on past climate changes can be of value if it shows, for example, whether the general rise in temperature that has occurred over the last century is similar to, or greater than, previous ones. Dr Roger Francey of the CSIRO Division of Atmospheric Research and colleagues have found that Tasmanian tree-rings show the temperature increase recorded over the last few decades, possibly driven by the enhanced greenhouse effect, is within the natural range of variability shown during the past 1000 years (see *Ecos* No. 68).

Third, they recognise that — to take one illustration — while the various interglacial periods (the intervals between Ice Ages or glacial maxima) may be similar in climatic terms, each has been characterised by a slightly different assemblage of plants. Such differences show that the past cannot be a perfect analogue of the future. This does not mean, however, that we cannot use what we know about the factors involved in earlier climates to provide clues about the future.

Australia has long posed problems for researchers hoping to reconstruct palaeoclimates, since its aridity and the poor preservation of pollen in inland sites limit how widely climate reconstructions can be applied. However, we have two major sources of accurate and useful information: lakes, bogs and swamps; and desert dunes.

In lake environments, sources of information about past climate include organic and inorganic material in beach and lake-floor sediments, microfossils such as crustaceans and the pollen of aquatic plants. Variations in water levels are the most directly useful indicators, since they reflect changes in the difference between rainfall and evaporation — which result from complex interactions between climate, vegetation (itself a reflection of climate), run-off and groundwater recharge.

To provide a benchmark against which to measure the way in which Australia's climate has changed over the past 30 000 to 40 000 years, thus providing a perspective on more recent changes, Dr Wasson and Dr Donnelly used detailed records collected by university and CSIRO scientists over many decades. Studies of sediment cores from Lake Keilambete in western Victoria and from the Willandra Lakes in south-western New South Wales established a sequence of high, low and intermediate water levels from about 40 000 to 15 000 years BP (Before Present). The Willandra Lakes, studied for decades by Dr Jim Bowler of the Museum of Victoria, are one of the few sites to provide a detailed record over a long period, with high lake levels — the result of large increases in rainfall — at about 30 000 years BP, subsequent oscillations and complete drying up some years 15 000 years later.

Dr Bowler, Dr John Dodson from the University of New South Wales and Dr Patrick de Deckker from the Australian National University analysed sediment and mineral deposits, pollen and microfossils to show that Lake Keilambete filled irregularly after 10 000 years BP, at the beginning of the Holocene, and reached its maximum depth (of about 30 metres) between 6500 and 5500 years BP. About 3000 years ago it became markedly shallower, then some 1000 years later rose again. It is intriguing to note that the lake, which at the beginning of this century was about 20 m deep, is currently only 10 m deep — as low as it has been in the entire Holocene record.

Lake Keilambete shown in March 1985 provides clear evidence of a former high lake level.

Trees in the foreground grow where water seepage occurs at the level of an old shoreline, formed when the lake was higher.

The researchers then compared the Willandra and Keilambete information with records from 37 lakes throughout Australia, including six in Tasmania. Lake records reveal roughly similar general patterns of climate change throughout the Holocene (see graphs on page 13) for Tasmanian lakes and mainland near-coastal lakes in Victoria, New South Wales, Queensland and Western Australia. However, these differ substantially from inland lakes in Victoria, New South Wales and South Australia which show a major rise in levels until 24 000 years BP, followed by a pattern of dry periods and rises, peaking at 4000 to 5000 years ago, some 2000 years later than at other sites.

Taken together, the records suggest a significant out-of-phase geographical relationship between coastal and inland sites that indicates a similarly unbalanced pattern of climate change. From Tasmania to northern Queensland, rainfall and evaporation reached a peak between 6000 and 7000 years ago — a time of low, but rising, lakes in the interior. In addition, a steady drop in lake levels in coastal South Australia and Victoria stands in stark contrast to rising levels from 20 000 to 14 000 BP in inland areas of those States. It seems that inland sites were still wet but drying at times when coastal sites were dry. Some of these differences could reflect the time groundwater levels in the interior of the continent take to respond to climate change, since many inland lakes are fed by groundwater.

Lake records — when compared with changes in dune building and decline, and with palaeoclimatic records from Antarctica and New Guinea — leave little doubt that very large climatic changes have indeed taken place over the past 30 000 years. The general picture is that Australia's climate was cool and wet prior to 25 000 BP, with deep water in many lakes. From then to the most recent Ice Age, at around 18 000 years BP, conditions were colder and drier, remaining arid in New Guinea and the Antarctic until 15 000 years BP .

Rapid warming seems to have taken place during 15 000–12 000 years BP, resulting in higher sea levels (see 'Preventing acid spills from farm land', *Ecos* No. 70) and an increase in rainfall. Around 6000 years ago, temperatures, rainfall and probably evaporation in Australia were higher than they are today —

precisely the conditions predicted by the global warming hypothesis.

Global circulation models are usually tested by seeing how well they simulate our modern climate. But if we want to know how well they simulate one likely to be substantially different from today's — an enhanced greenhouse climate — the sole test available is provided by past climates. If a GCM can successfully simulate both the cold, dry and windy climate of 18 000 years ago and the warm, wet one of 6000 years ago, we can have greater faith in its ability to simulate the future.

Dr Barrie Hunt and Mr Joseph Syktus, of the Division of Atmospheric Research, in conjunction with scientists from the Division of Water Resources and the Australian National University, are seeing how well CSIRO's own GCM can simulate the past. Their work is seen of such importance that it is being funded by the National Greenhouse Advisory Committee.

In essence, while we cannot test the accuracy of a predictive climate model until the phenomena it forecasts have come to pass, we can see how well it fits the currently known facts, and how well it 'predicts' the past. We can use large-scale analyses of a GCM to calculate what we already know has happened from finer-scale measurements: in this process we can use the model to find the best of a range of hypothetical explanations of what has occurred, honing the tools required if we are to predict future climates accurately.

One widely reported application of palaeoclimatic data in considerations of global warming concerns atmospheric CO_2 (and methane) readings for the last 500 years. The record which is based on gas bubbles, principally from Arctic and Antarctic ice cores, and on direct atmospheric sampling since the 1950s, has demonstrated a clear and rapid increase in both CO_2 and methane over the past 150 years or so — even though precise measurements of air samples only began 40 years ago. Scientists at the CSIRO Division of Atmospheric Research (as well as in many other institutions around the world) have turned to geological records — preserved in ice — to place their short instrument records in a more revealing context. (Without that context, for example, it would be very difficult to confirm that increases in greenhouse gases began with the Industrial Revolution.)

Palaeoclimatic records from sediments, ice cores and tree rings have also shown far more clearly than other sources the interplay between physical, chemical and biological processes in global climate systems. This information can be used to test how sensitively the world's climate reacts to changes in the composition of the atmosphere.

An examination by French and Russian scientists of CO_2 and methane in ice core samples from Vostok in Antarctica, and confirmed for the Northern Hemisphere by ice cores from Greenland, has revealed that a change in concentrations of greenhouse gases correlated with a global temperature increase of between 3° and 5°C during the late glacial (in other words, during the last deglaciation of the Earth). This correlation is, in fact, very similar to that predicted by GCM experiments involving a doubling of CO_2; different models have predicted a global increase in average temperatures of between 2·8° and 5·2°C following a doubling of atmospheric CO_2. The convergence provides an encouraging confirmation that general circulation models can simulate the sensitivity of our climate to a doubling of CO_2.

More on paleoclimatology

Palaeoclimate reconstructions for the last 30 000 years in Australia — a contribution to prediction of future climate. R.J. Wasson and T.H. Donnelly. *CSIRO Division of Water Resources Technical Memorandum* No. 91/3, 1991.

Summary lake level diagrams of the three major regions of eastern Australia