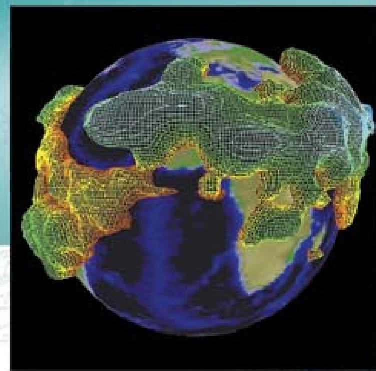
CLIMATE CHANGE



Fossil Thermometers for Earth's Climate

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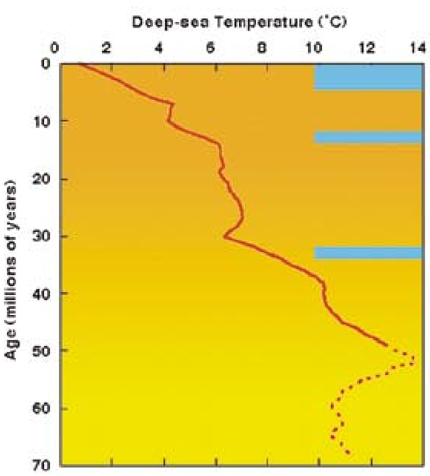
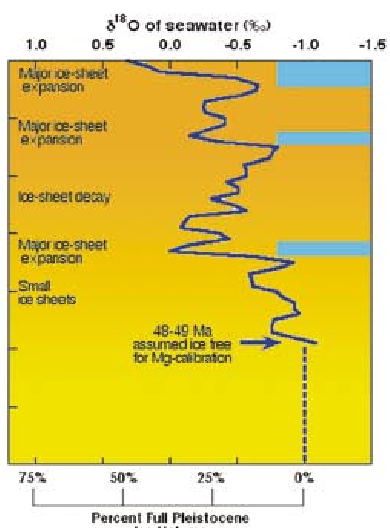
Cold-blooded reptiles living within the Arctic Circle, mangrove swamps along the south coast of England: We know that Earth's climate was much warmer than today in the Cretaceous and early Cenozoic time periods. A long-standing problem in Earth Sciences, however, has been to quantify exactly how much warmer. Matching up past temperatures with estimated levels of carbon dioxide should help modelers predict the effects of future global warming. The 'cleanest' overview of global temperature change on Earth over the past 100 million years comes from the deep oceans because here the signal is insulated from seasonal and other short-term 'noise'.

Until recently, our records of deep-sea temperature change relied almost entirely on the relative proportions of oxygen-16 to oxygen-18 in the calcite shells of fossil benthic foraminifera. Foraminifera are single-celled animals about the size of a pinhead that live on the sea floor and are found in the deep ocean sediments collected by the Ocean Drilling Program. This method works because the ratio of these two isotopes of oxygen incorporated into the fossil shell is dependent on the temperature at which the animal lived. But there is a problem. The ratio recorded by the fossil foraminifera is also sensitive to the ratio of oxygen-16 to oxygen-18 in the seawater, which in turn, shifts back and forth with changes in the global volume of ice on Earth. This change is because the lighter isotope (oxygen-16) is preferentially evaporated from seawater, transported to the poles where it falls as snow and is locked up in glaciers. In this way, growth of large icecaps will deplete average seawater of oxygen-16, making it relatively enriched in oxygen-18.





Deep-sea temperatures determined from the magnesium content of forminifera (above) and the ratio of oxygen-16 to oxygen-18 (δ^{18}O) of seawater which is a measure of global ice volume (right).

In a recent study we re-examined these same fossils for the trace amounts of magnesium (Mg) present as an impurity in their calcite ($CaCO_3$) shell (Lear *et al.* 2000). Foraminifera live today in many parts of the ocean, and we know that the amount of Mg impurity increases systematically with the temperature of the water in which they live but, crucially, is independent of global ice volume (Rosenthal *et al.* 1997). By applying the temperature-Mg relationship found in modern shells to the fossil shells, we were able to calculate the temperature of the deep ocean over the past 50 million years.

We then compared these Mg-temperatures to the existing record of oxygen-16 to oxygen-18 of the foraminifera shells, to calculate the ratio of the two oxygen isotopes in seawater over the past 50 million years. This process allowed us to calculate, for the first time, global ice volume over the past 50 million years. We found three distinct time intervals during which the oceans were suddenly depleted in the oxygen-16 isotope. These times must correspond to large and rapid growth of polar ice sheets, and are shown as blue shaded boxes in the figures. In fact, the timing of these events correlates with other evidence for ice growth, such as sea level falls and the occurrence of large rocks in deep-sea sediments dropped from icebergs far from land. Interestingly, the first of these ice-building events that happened 33 million years ago is not associated with a cooling of deep sea temperatures as recorded by the magnesium content of the foraminifera shells. Perhaps the Antarctic continent was already cold enough to support an ice sheet but too dry until 33 million years ago, when, for some reason, snow started to fall.