How to Make a Warm Cretaceous Climate

Computer modeling suggests that there must be more to the long slide from the balmy Cretaceous Period into the ice ages than the drifting of continents

As soon as it became obvious that the continents have been drifting across the globe for hundreds of millions of years, geologists and paleontologists began thinking about climate. The earth of the Cretaceous Period 100 million years ago was unaccountably warm, as it generally had been since the end of the last great ice age 140 million years earlier; perhaps the continents in their wanderings since the Cretaceous had upset some balance in the climate system that was essential to the maintenance of that ancient mild climate.

Such thinking seemed reasonable but was far from rigorously tested. Now, computer simulations of mid-Cretaceous climate support the importance of global geography with quantitative calculations. But so far, computer models have failed to warm Earth as much as it was warmed in the Cretaceous, suggesting that a single geographic factor or perhaps even a combination of them cannot totally explain long-term climate change.

Explaining Cretaceous climate has been difficult because it differed so from today's. Coral reefs for which warm water is essential ranged as much as 1500 kilometers closer to the poles than they do today, as did nonseasonal land plants. Deep ocean water that now hovers near freezing was 15° (Celsius) warmer, according to isotopic analyses. Alligators and crocodiles seem to have thrived at latitudes as far north as that of present-day Labrador. And there is no evidence of any permanent ice like that which today deeply buries Antarctica and Greenland. Eric Barron of the National Center for Atmospheric Research (NCAR) in Boulder has estimated from such data that the globally averaged temperature at the surface was at least 6° and perhaps as much as 14° warmer than today, when the average temperature of the surface is 15° above freezing.

Not only was it generally warmer during the Cretaceous, but it was particularly warmer in the polar regions. Barron has estimated that the difference between the temperatures at the poles and at the equator, which is now 41°, was no more than 26° in the mid-Cretaceous and may have been as small as 17°.

Explanations proffered for such a mild, equable climate have been reasonable but varied. Perhaps most popular was the idea that the position of the continents is crucial. Continents bunched in low latitudes near the equator, as Cretaceous continents tended to be, would allow warm ocean currents to carry heat poleward. High-latitude polar oceans, being less reflective than land, would also absorb more heat and further moderate climate.

As continents drifted poleward during the past 100 million years, the theory went, they disrupted poleward oceanic heat transport and substituted reflective, easily chilled land for absorptive, heat-retaining water. As cooling progressed, the land could accumulate snow and ice, creating an even more reflective surface. Overall, less of the solar energy falling in the polar regions would be retained and less tropical oceanic heat could travel poleward. Other geographical differences related to continental drift and plate tectonics were suggested as well to explain the warm Cretaceous, such as less land in the subtropics where highly reflective deserts can form.

> How did Earth retain more solar energy? How did a larger proportion of it reach the poles?

Barron and Warren Washington of NCAR decided to test these hypotheses by recreating the Cretaceous climate as best they could using a computer model. Barron and his colleagues and others have studied a succession of simpler models of the Cretaceous climate system, but he and Washington are the first* to use the complex sort of model used in the forecasting of the weather over a few days (*Science*, 1 April 1983, p. 39). These so-called general circulation models are balance sheets of solar radiation that keep track of this energy by simulating the entire climate system. Mathematical equations describing physical processes parcel out and transform the energy as it is absorbed at the surface, warms the atmosphere, drives global winds, creates storms, evaporates water that will form precipitation, is carried toward the poles, or is lost to space.

First, Barron and Washington compared the climates simulated by the NCAR Community Climate Model run under present-day geography and under Cretaceous geography. The model's Cretaceous world with its displaced continents, increased ocean area, lower mountains, and lack of permanent ice was indeed warmer than the simulated climate of the present but by only 4.8° rather than the required minimum of 6°. As required, the polar regions warmed more than the tropics.

But what aspect of Cretaceous geography caused even that much warming? To find out, Barron and Washington transformed the model's present-day geography step by step into the Cretaceous geography. To begin, they changed all of today's highly reflective permanent ice into ordinary land of the same elevation. The average global surface temperature rose 0.8°. Then they leveled the continents, and the global temperature rose another 1.1°. The largest change, a 3.1° warming, occurred when they moved the flattened continents back to their positions in the mid-Cretaceous, when the Atlantic Ocean was only beginning to open. Raising the sea level to flood part of central North America and much of North Africa, Europe, and the Near East actually cooled the climate 0.1°. Raising the continents to their more modest Cretaceous elevations drove the average temperature down 1.1°.

Thus, as suspected, geography was important, but no one aspect of it in this particular model seems to have been responsible for even the portion of the Cretaceous warming achieved in the model. Moving the continents around warmed the climate, but so did changing topography and ice cover. In fact, most of the Southern Hemisphere warming resulted from the darkening and lowering of Antarctica during its "deglaciation" rather than from any moving of the continents.

Even the effect of a single geographic element may not be that well understood. In the Cretaceous simulation, there was less land area between 45° and 80°N than in the simulation of the present due to shifted continental positions, and, as predicted by earlier hypotheses, the Cretaceous climate of the Northern Hemisphere was warmer. In the Southern Hemisphere, however, where land

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area *increased* between 35° and 65°S, climate was still slightly warmer. Barron and Washington suggest that perhaps the Southern Hemisphere did not cool as expected because only land-ocean changes at the highest latitudes, where both hemispheres had more ocean in the Cretaceous, affect climate.

Another intriguing result of the simulations was the failure of higher sea levels and the consequent flooding of continental interiors to change the simulated climate. A strong correlation had long been recognized between high sea levels and mild climates, especially in the mid-Cretaceous. Barron and Washington point out that the order of the steps by which they transformed present into Cretaceous geography may have been crucial to the effect of any one step.

Also, they are quick to point out that they are not duplicating Cretaceous climate, only conducting tests of the sensitivity of one climate simulation to geographic variations. Aside from not knowing the geography of the Cretaceous as well as that of the present, their pursuit of progressively more complex models has not yet brought them to the most realistic general circulation models, which themselves fall short of perfection. A major simplification of the present model is its ocean—it is a wetted surface having no currents and thus no oceanic heat transport.

The failure of the full Cretaceous simulation to achieve even the minimum required warming may mean that the model's simulations are inadequate in some vital respect, or that geographical variations alone are insufficient. Gerald North and David Short of the Goddard Space Flight Center, Greenbelt, Maryland, Thomas Crowley of the National Science Foundation, and John Mengel of Applied Research Corporation, Landover, Maryland, believe that Barron and Washington's model leaves out an important process—the changing seasons. Their simpler energy-balance model includes the seasons in a computer run of practical duration by giving up the realistic simulation of wind circulation.

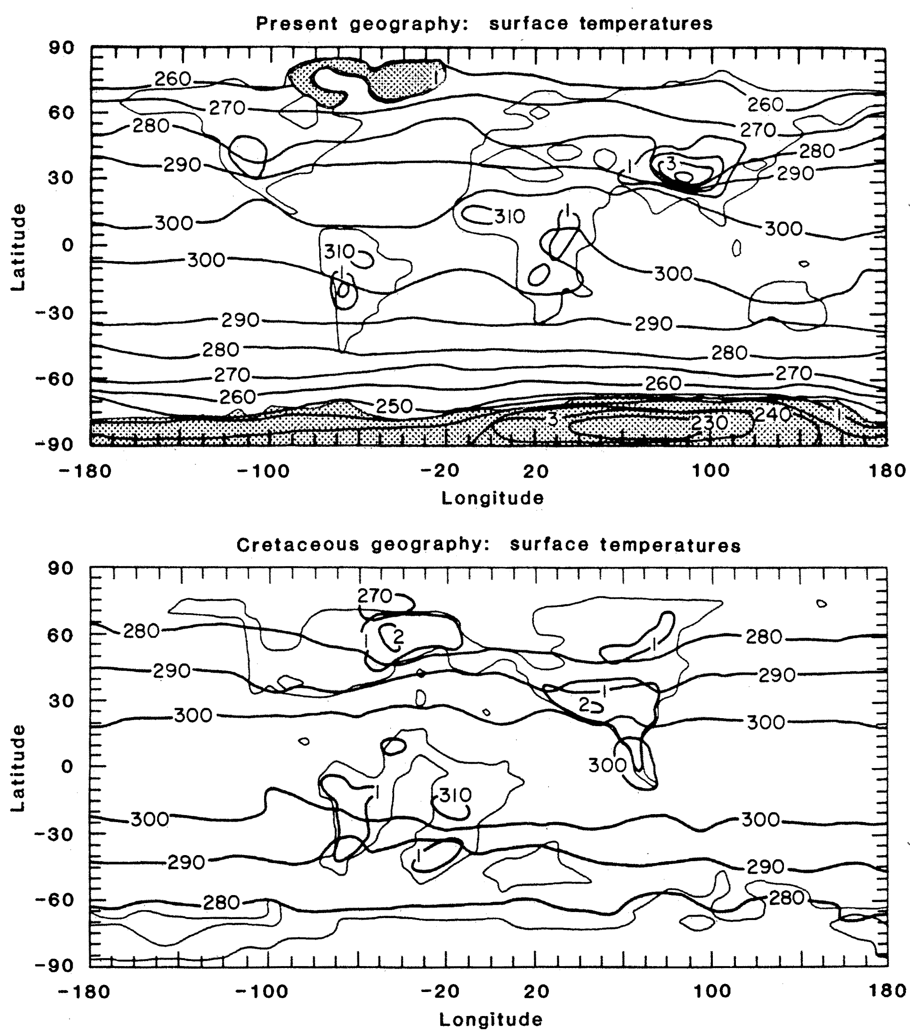
In their model, not just any continental land area at high latitude cools the climate. Large continents like Eurasia tend to heat quickly in the summer and become too warm for any snow to persist from year to year and form ice sheets that further cool climate. Smaller land areas, like Greenland or Antarctica, are more likely to become covered with ice. A shift in their model from present continental positions to those of the Cretaceous eliminates all permanent ice in the North Hemisphere.

Another group of modelers believes that long-term changes in the climate system cannot be understood without the inclusion of the effects of plate tectonics on geochemical cycles. Robert Berner of Yale University, Antonio Lasaga of Pennsylvania State University, and Robert Garrels of the University of South Florida have built a model of the flow of carbon through rocks, the ocean, and the atmosphere. The flows into the relatively small reservoir of atmospheric carbon dioxide from the huge carbon reservoirs in the ocean and rocks turned out to be highly sensitive to changes in the rate of sea floor spreading as well as the changes in sea level that must follow spreading rate changes.

Even if the spreading rate has decreased only 20 percent since the mid-Cretaceous (*Science*, 3 February, p. 472), the consequent reduction in volcanism driven by spreading and the increase in weathering of newly exposed continents could have reduced atmospheric carbon dioxide severalfold, according to the latest version of the model. The reduced effectiveness of the carbon dioxide greenhouse warming could account for about 5° of the Cretaceous warmth. The geochemical model's prediction of high carbon dioxide at times of high sea level is thus consistent with the observed correlation between warmth and high sea level.

Modeling of the Cretaceous climate must continue to be pursued with various models, both simpler and more realistic than Barron and Washington's present general circulation model. In the meantime, modelers will begin testing quantitatively hypotheses that purport to explain other turning points in climate evolution, such as the abrupt chilling of deep ocean waters about 38 million years ago or the spurt in growth of the Antarctic ice cap about 15 million years ago.

—Richard A. Kerr



Computer simulations of the past and the present

This computer model simulates the temperature changes due to geographic differences between the present and 100 million years ago in topography (contoured at 1-kilometer intervals), ice cover (stippled), continental position, and sea level (flooding of continents). The global average temperature in the Cretaceous simulation is 4.8° Celsius or 8.6° Fahrenheit higher. Temperatures are contoured in degrees Kelvin (0°C = 273 K). [Source: E. Barron and W. Washington]