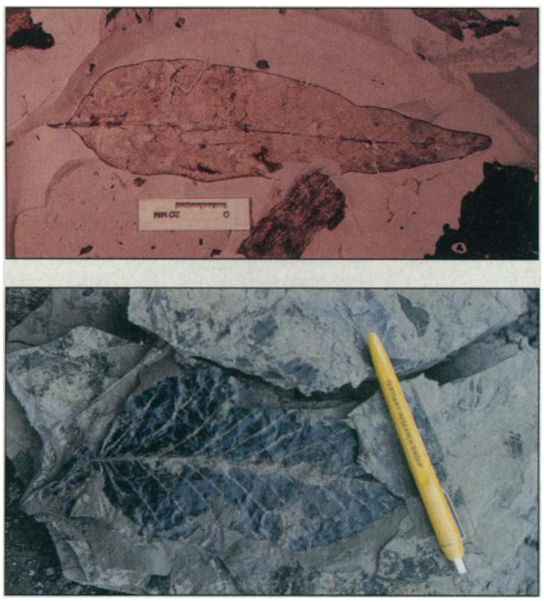
CLIMATE

Fossils Tell of Mild Winters In an Ancient Hothouse

Every winter, places like Fargo, North Dakota—deep within the continent and far from the moderating influence of the ocean—stand out on temperature maps as the sites of the harshest U.S. winter weather. According to computer models of climate, North Dakota and other continental interiors also had relatively harsh winters in the geologic past, even during periods like the early Eocene, about 50 million years ago, when global temperatures were the highest in the past 65 million years. But while the computers insist on harsh winters, Eocene fossils from continental interiors tell a different story: winters mild enough for crocodiles to roam through Wyoming and tree ferns to shade Montana.



S. L. WING

D. R. GREENWOOD

The edge tells the tale. Smooth leaf margins *(top)* point to a milder climate than toothed *(above)*.

The gap between fossils and computer models is nothing new. What is new is the attitude of paleontologists, who are fighting back at what they see as a dismissive response from the modelers. Paleobotanists Scott Wing and David Greenwood of the Smithsonian Institution's National Museum of Natural History have now gathered the existing fossil findings together and supplemented them with a new analysis of fossil leaves that also points to mild continental winters.

This concerted effort is having an effect. Computer modeler Lisa Cirbus Sloan of the University of California, Santa Cruz, concedes that the paleontologists "have a good story." She adds, "I don't think the models are completely wrong; they are getting an increasing number of things right, but we're still missing some factor." That gap, she says, could undercut faith in the ability of similar models to predict future climate change, as greenhouse warming strengthens. Says Sloan, "What we're learning is that the future could be quite different" than any existing model predicts.

To try to bring Sloan and her fellow modelers around, Wing and Greenwood decided to make a case that, as Wing puts it, "We have many lines of evidence and they all say the same thing." The fossil fauna records compiled by Wing and Greenwood include abundant signs of mild Eocene winters in continental interiors: cold-sensitive land turtles too large to burrow for protection during the winter, diverse communities of tree-living mammals dependent on year-round supplies of fruit and insects, and crocodile relatives, all found as far into the continental interior as Wyoming.

To make sure that one of these indicator species, the crocodilians, was actually adapted to the same mild climates as its present-day descendants, paleontologist Paul Markwick of the University of Chicago compiled a database of more than 1000 fossil crocodilian sites around the world. "I'm relatively confident in saying they followed the same climate trends" in the Eocene as they do today, he says. And if that's true, then the average temperatures during winter months in the Eocene, say Wing and Greenwood, were at least a few degrees above freezing, rather than the 3° to 10°C below freezing called for by the models—or roughly the same as the current winter regime.

The fossil plant data, Wing and Greenwood's specialty, also call for equable continental climate 50 million years ago. Palms, cycads (resembling a cross between ferns and palms), and tree ferns extended into Wyoming and Montana in the Eocene. All that is "very strong evidence" that cold-month mean temperatures were above 5°C, they say. These plants don't grow below those temperatures today because features such as soft, water-rich tissues and large, unprotected buds make them susceptible to freezing.

But Wing concedes that "it's very hard for modelers to deal with qualitative data." They "are used to dealing with numbers," so he and Greenwood set out to provide some, by quantifying the influence of climate on fossils. Refining an approach pioneered by Jack A. Wolfe of the University of Arizona, they took advantage of the fact that—for reasons that aren't always clear—leaf size, shape, and edge geometry vary with climate. In colder climates, for example, leaves tend to have toothed edges. Greenwood and Wing were able to quantify a relation between three leaf characteristics and cold-month mean temperature in a data set collected by Wolfe from a variety of modern climatic regimes. Applying the relation to Eocene fossil leaves, they found cold-month mean temperatures of 1°C to 8°C in Wyoming and Montana, cooler than some of the temperatures estimated from plant and animal species but still well above model predictions for the Eocene.

These results, which Wing and Greenwood will be reporting next week at Pennsylvania State University at a meeting on the Stratigraphic Record of Global Change, imply that the Eocene climate system was somehow able to carry heat into continental interiors to make up for the wintertime loss of solar radiation in mid and high latitudes. And that "keeps me going back to the model" to see if it can be made to match the fossil evidence, says Sloan. "You can make the [model winter] climate more moderate," she says, by raising carbon dioxide concentrations and having ocean currents carry more heat toward the poles, but "it doesn't come completely in line with the plant and animal data" without overheating the globe as a whole.

To meteorologist Brian Farrell of Harvard University, the failure of models to replicate the Eocene world is a sign that the overall circulation of the atmosphere had to be fundamentally different than it is today in order to distribute heat more evenly into continental interiors. Changes in one or more of several aspects of the atmosphere—such as the height of the stratosphere's base—might do the trick, he says, by leading to a simplified, more efficient circulation carrying heat away from the equator, one more like that on Venus.

Those are some of the atmospheric properties that models don't handle well, notes Farrell, so it might not be surprising that computers don't predict they will change by much in a greenhouse world. Perhaps, says Sloan, the models have been so thoroughly tuned to replicate today's climate that they are incapable of duplicating the hothouse of the Eocene—or of the future.

–Richard A. Kerr

Additional Reading

S. L. Wing and D. R. Greenwood, "Fossils and Fossil Climate: The Case for Equable Continental Interiors in the Eocene," *Phil. Trans. Roy. Soc. Lond.* **340**, in press (1993).