GLACIOLOGY

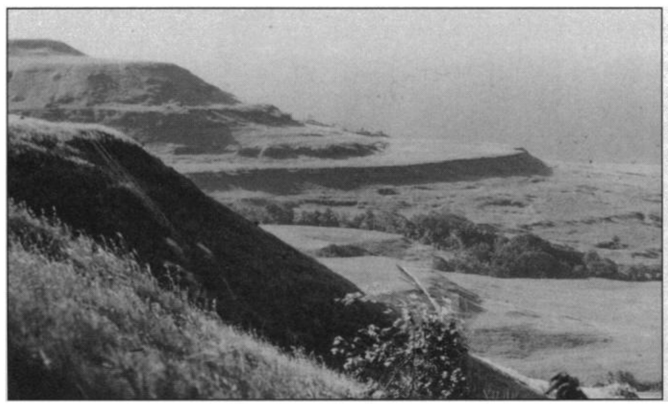
How High Was Ice Age Ice? A Rebounding Earth May Tell

Twenty-one thousand years ago a single great mound of ice rose over North America, from coast to coast and from far northern Canada down to the Great Lakes. Just how thick this Laurentide ice sheet was, no one is sure. There were no surveyors around in the Paleolithic, so today's ice-mappers have had to infer the height of the ice from traces left at the edges of the former ice sheet, along with guesses about how high the ice could have piled before flowing away under its own weight. The result: a picture of ice piled to an altitude as high as a respectable mountain—3.5 kilometers—across thousands of kilometers of land. But geophysicist Richard Peltier of the University of Toronto thinks it's time to cut this great ice sheet down to size.

On page 195 of this issue of *Science*, Peltier presents a different way of inferring ice sheet heights, based on the way Earth, which had been dented and squeezed by the weight of the ice, rebounded when the Laurentide ice melted. The result not only thins the ice sheet to a little more than 2 kilometers; it may also challenge a scenario in which the ice sheet shaped Ice Age weather patterns by sticking up into the prevailing westerly winds like a rock in a stream. "It seems very clear that everything done to mimic past [glacial] climate has to be redone," says Peltier. Paleoclimate modelers are already cranking up their computers, but other researchers are cautioning that Peltier may not have the final answer.

No one is questioning the key to Peltier's analysis—the fact that the weight of the ice reshaped the Earth. Given enough time, even "solid" rock is malleable enough that it can flow like water, and as the ice built up over thousands of years, the ground under it sank hundreds of meters. As the deep rock of the mantle flowed from beneath the ice-filled depression, it raised a bulge 100 meters high beyond the margin of the ice sheet. Even the tropics were deformed as the Northern Hemisphere ice and the ice sheet on Antarctica squeezed Earth between them. When most of the ice melted into the oceans between 20,000 and about 8000 years ago, Earth began to ease back to its pre-glacial shape.

A record of this rebound is found today on coastlines around the world, where changing sea level has cut series of terraces of different ages. Peltier has now turned that sea-level record into a measure of the weight that deformed Earth during the Ice Age. To do that, however, he had to take several factors into account. For one thing, beginning 20,000 years ago, sea level would have changed even if Earth's shape had stayed constant, because glacial meltwater was pouring into the ocean. For another, the rebound recorded by the sea-level changes depended not just on the weight of ice but also on the "stiffness" of the planet itself—essentially, how viscous the mantle rock is.



ARTHUR BLOOM/CORNELL UNIV.

Steps from the sea. On some coastlines, like this one in Papua New Guinea, past sea levels are recorded in wave-cut terraces.

Fortunately, there is an independent record of how much meltwater flowed into the oceans, derived from an isotopic signal in an ancient coral reef in Barbados (*Science*, 15 June 1990, p. 1314). That signal helped Peltier extract a record of Earth's changing shape from the chronology of sea-level change over the last 12,000 years. For the mantle viscosity, he drew on his own studies of how fast land that was once buried under the ice is rebounding. That's not a circular procedure, he says, because the rate of rebound is largely independent of the amount of ice and depends only on mantle viscosity. When Peltier cranked these factors into the model, the result indicated that North America is shrugging off the weight of far less glacial ice than had been thought.

Climate researchers are eager to work that diminished ice sheet into their own computer models to see whether they can still reproduce Ice Age climate conditions. In earlier simulations with a high Laurentide ice sheet, John Kutzbach of the University of Wisconsin, among others, had shown that the high plateau of ice neatly splits the jet stream into north and south jets, the southerly one guiding storms along tracks far south of today's to dump rain on the southwestern United States. That picture agreed with the evidence that large lakes existed during glacial times in the now-arid Southwest.

Kutzbach has just completed the first run of his model with Peltier's ice sheets included. He sees signs that the lower Laurentide ice sheet still splits the jet, though the jets rejoin faster than in earlier runs. And that, say researchers, is a hint that their basic understanding of Ice Age climate may hold up, even if Peltier turns out to be right.

But some geophysicists and glacial geologists are warning that climate researchers should not be in a hurry to accept Peltier's results. Geophysicists' doubts focus on his assumptions about mantle behavior. In his model, the mantle becomes only moderately stiffer with increasing depth. Kurt Lambeck of the Australian National University in Canberra, however, has studied rebound in regions that lay beneath smaller ice sheets than those Peltier studied and at sites that were never ice-covered. He has concluded, instead, that viscosity increases sharply with depth.

"The evidence one way or the other is pretty tenuous" about mantle viscosity, says John Wahr of the University of Colorado. "Peltier has been so prominent in this field that many people outside the field automatically accept his conclusions. Those conclusions may be right, but they're certainly not the unanimous opinion."

Glacial geologists also have reservations—about the model's implications for the history of ice in Antarctica. Peltier's model requires almost one quarter of Ice Age ice to have been stored in Antarctica until late in the deglaciation. But some glacial geologists don't see where all that ice would have fitted. As Arthur Dyke of the Geological Survey of Canada in Ottawa notes, "There's never been a consensus."

Peltier argues, however, that Earth's viscosity is not a crucial factor and that his model must be on the right track, because it stands up to a simple test. When he uses it to make predictions about sea-level change at sites that were ignored in tuning the model, the results closely match the actual record. The sea-level record in New Guinea, for example, shows that between 13,000 and 8000 years ago, the sea-level rise there ran more than 10 meters ahead of the rise at Barbados, which was one of the model's inputs. And that's just what his model predicts. "That's a beautiful verification of the theory," says Peltier. But many researchers say the most beautiful verification—models of the rebounding Earth by other groups that give the same answer—is yet to come.

–Richard A. Kerr