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WHAT CAUSES ICE AGES?

Blame it, perhaps, on the Himalayas. Or on the evolution of grasses

Seventy million years ago, the Earth was enjoying the greatest stretch of beach weather ever known. Dinosaurs tramped across Greenland. Palm trees swayed in the warm Canadian breezes. The ocean north of Siberia was almost suitable for skinny-dipping. Humidity and temperature were high all over the world and had been so, save a few interludes of relatively cool weather, for 500 million years.

Then something began to turn down the global thermostat. The mercury dropped, and soon ice sheets started to form at the South Pole. The drift toward the great Cenozoic Ice Age--which Earth is still in the throes of--had begun.

Scientists have long known about the giant ice sheets that the Cenozoic ushered in. Even in the mid-19th century they knew that glaciers had repeatedly raked swaths of Europe and North America in the not so distant past. Yet despite the efforts of marine geologists, atmospheric chemists, oceanographers, and more, no one knows what caused the ice ages. "We've been chewing on this problem for 30 or 40 years," says Alan Mix, an oceanographer at Oregon State University. "It's a killer." Adds Ralph Cicerone, dean of physical sciences at the University of California--Irvine, "It's embarrassing."

If they tried, scientists could hardly invent a more difficult mystery to crack. Most of the events in question took place tens or hundreds of millions of years ago. The shift in the Earth's climate was subtle: The planet is only 10 degrees cooler today than it was in the tropical period just before the Cenozoic. And the cooling was probably caused by factors only tangentially related to the climate systems of the planet. "The problem is like a Swiss watch, wheels within wheels," says Louis Derry, a geochemist at Cornell University. So perhaps it's only natural that even the best explanations for the ice ages are at once ludicrously complicated and yet probably far too simple to be true.

Scientists may not know the how or the why, but they do know the what of Earth's descent into the deep freeze. Sixty million years ago, the planet started to cool in earnest. Twenty-five million years later, Antarctica was buried under a thick sheet of ice; 18 million years after that, glaciers overran Greenland. Last of all, ice sheets invaded North America and Europe, retreated, advanced, retreated, and so on. Today, the planet is enjoying an "interglacial," one of the slightly warmer periods when the glaciers slink back to the poles.

Greenhouse in reverse. The cause of the ice ages is a remarkably consensus-free scientific topic, but on one point most researchers agree: The cooling that started 60 million years ago was caused by a drop in carbon dioxide in the atmosphere. Carbon dioxide is a so-called greenhouse gas: It traps sunlight close to the Earth, raising the planet's temperature. Less carbon dioxide in the atmosphere means colder weather.

Fine, but that only shifts the question: Why did carbon dioxide levels fall? The bizarre but leading theory is because two of the Earth's tectonic plates collided, forming the Himalayas.

While still in graduate school, marine geologist Maureen Raymo, now at the Massachusetts Institute of Technology, worked out a scenario that is widely cited in the scientific literature--both favorably and not. Raymo noted that the Himalayas are taller than any other mountain range on Earth and that they formed at nearly the same time as the start of the ice ages. Scientists know that carbon dioxide from the atmosphere combines with rain to make an acid that erodes rock; in the process, minerals such as calcium silicate in the rocks react with carbon dioxide, removing the gas from the atmosphere. Therefore, erosion on slopes as vast as the Himalayas', says Raymo, could reduce carbon dioxide levels enough to give the ice ages a push.

Raymo does have evidence for her theory, but she also admits that her idea has holes. Weathering on the scale she theorizes would devour so much carbon dioxide that soon there wouldn't be any left at all. Other scientists point to an opposite problem: The kind of minerals in the Himalayan rocks rarely consume carbon dioxide when they erode. The mystery of Cenozoic cooling has encouraged researchers to propose many other candidate culprits. One recent scientific paper also theorizes that the Himalayas are involved, but not through weathering. Instead, says the paper, the key factor is the tons of sediment shed by the mountains every year. The sediment runs into the Indian Ocean and buries large amounts of marine plankton and other plants. Entombed along with the plants is their carbon dioxide, meaning less carbon dioxide in the atmosphere and therefore less warming. "I would like to believe that we're right," says Derry, one of the paper's authors. Clearly many of his colleagues think he's wrong: Solutions championed by other scientists include the evolution of grasses, which happened at roughly the right time and would have stored large amounts of carbon dioxide in the soil; and weathering of the mountains in either New Guinea or Siberia.

Frozen north. There is equally great bafflement over the much more recent Northern Hemisphere glaciations--the events that scooped out the Great Lakes and carved Long Island. For most of the Cenozoic Ice Age, the polar regions were the only place to suffer heavy invasions of ice. But 2.5 million years ago, glaciers moved into Europe and North America. Eventually a mile-thick block of ice stretched from New Jersey to Indiana to Seattle, its huge weight causing the Earth's crust to sag. The glaciers have paid regular visits ever since, returning on a cycle lasting tens of thousand of years.

Scientists are satisfied they can explain what caused the timing of these local ice ages. The so-called Milankovitch model was first proposed by a Scotsman in the 1860s and developed by a Yugoslav astronomer-mathematician in the 1920s. As the Earth's orbit slowly changes, says the model, so does the pattern of the sunlight falling on a given spot on the globe (graphic, above). The changes in sunlight trigger the glaciers' advance and retreat. For evidence, Milankovitchers note that the amount of ice on the Earth over time nicely matches the record of sunlight changes caused by orbital changes.

The Milankovitch model is well accepted--as far as it goes. The problem is that the orbital changes in themselves are not big enough to make or to melt ice sheets. Orbital changes almost certainly serve as the glaciers' pacemaker; but something else must amplify its signal. Shifting ocean currents may play a part by redistributing heat around the planet. Another theory relies on glaciers' bruising effect on the Earth's crust. A continent burdened by a glacier sinks, lowering the elevation of the glacier's top surface. The loss of height warms the ice and makes it more prone to melt. Glacial sinking is one factor that could have worked along with shifting sunlight patterns to end a glacial period.

Researchers trying to understand the ice ages certainly don't lack for imagination. But creativity goes only so far in science, and what ice age scholars want now is cold, hard data. For example, there are no direct measurements of atmospheric carbon dioxide beyond 200,000 years ago. So even the assumption that carbon dioxide was higher before the great cooling "is based on modeling and wishes," growls Wallace Broecker, a top climate expert at the Lamont-Doherty Earth Observatory. Recent carbon dioxide levels are revealed by long cylinders of ice extracted from Antarctica. But there is no ice old enough to reveal the composition of the atmosphere millions of years ago, and researchers have no good candidate technique at hand.

Yet more data may not resolve the mystery. "Information is pouring in now, and it is not converging on a simple explanation," says Isaac Winograd, a hydrologist at the U.S. Geological Survey. In their gloomier moments, some scientists say the question of what caused the ice ages cannot be answered.

If the pessimists are correct, and scientists can't explain the Earth's past climate changes, they will be hard pressed to make confident predictions of the future climate. There is no doubt that the buildup of carbon dioxide caused by the burning of fossil fuels will cause the Earth to heat up--everything else being equal. The question is whether everything else really is equal. Until scientists can explain changes in Earth's climatic past, they cannot be sure they aren't overlooking factors that could either counteract a man-made warming--or amplify it. "The climate system has proved itself to be an angry beast," Broecker says. "We're prodding the beast, and we don't know what will happen."

From tiny perturbations mighty ice ages come

The advance and retreat of glaciers may be tied to ever so slight changes in Earth's orbit.

1. Tilt The tilt of Earth's axis varies from 22 degrees to 25 degrees over 41,000 years. The greater the tilt, the more summer sunlight falls on the poles, contributing to glacial retreat.
2. Wobble Earth wobbles like a top in a cycle that lasts 23,000 years, changing the fraction of sunlight that strikes each hemisphere.
3. Orbit The shape of Earth's path around the sun ranges from circular to more elliptical over 100,000 years. A circular orbit means less sunlight over the course of the year.

GRAPHS: Tilt exaggerated here to show effect; 11,500 years from now; Present day; Earth (present day); .1 percent more sunlight in this orbit; Sun; Earth (in 100,000 years)
Sources: Brown University, Lamont-Doherty Earth Observatory

PHOTO (COLOR): Global chill. Below, a glacier in Greenland. For now, the Earth is in a period of glacial retreat.

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By Traci Watson

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