Staggering Through the Ice Ages

What made the planet careen between climate extremes?

By RICHARD MONASTERSKY

Climate experts once viewed Earth as a well-mannered dancer moving to the stately and predictable beat of the ice ages. The world cooled and warmed with a slow, steady rhythm governed by the well-understood wiggles of its orbit. Vast ice sheets spread across the northern lands and then gradually retreated. Sea levels dipped and rose. Forests moved south and later returned. The changes kept a pace as measured as that of Earth's voyage around the sun.

But discoveries about the most recent ice age are transforming the image of a climatic waltz to something resembling a drunken lurch. During the last glacial epoch, Earth repeatedly swayed from extremely frigid conditions to warmth and back again with startling speed. As part of these shifts, the great North American ice sheet vomited huge numbers of icebergs that filled the North Atlantic.

The new revelations have left scientists reeling, because the steady orbital cycles thought to control the ice ages cannot easily account for the evidence of quick climatic jitters.

"It's clear that the climate theory is not complete. The quest is now to develop the rest of the theory to explain the shorter-term events that—when we look at them in the context of our lifespan—are much more dramatic," says Gerard Bond, a marine geologist at Columbia University's Lamont-Doherty Earth Observatory in Palisades, N.Y.

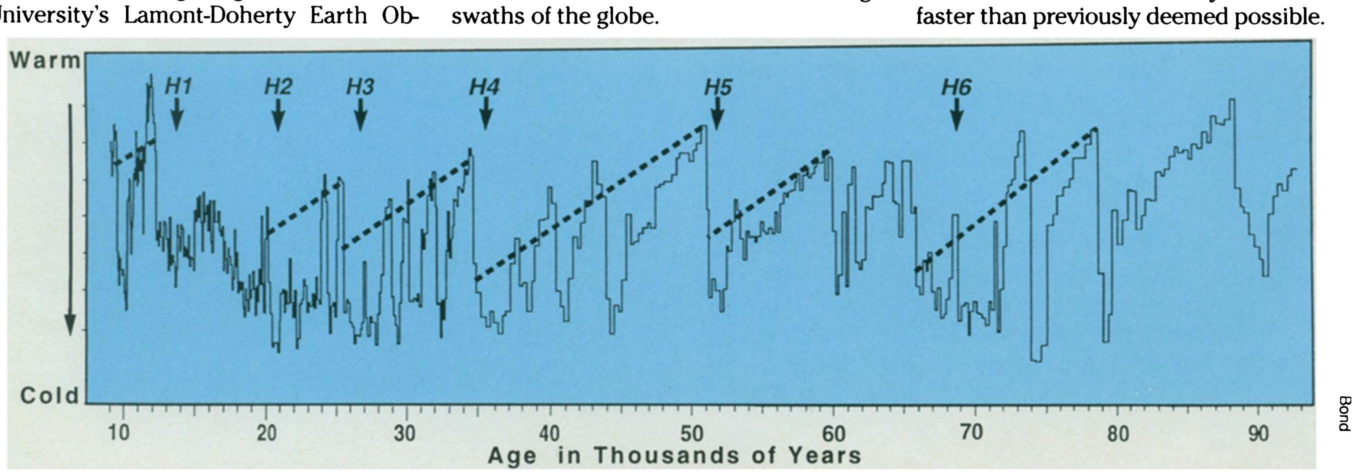
A sign in mud: When ice-age icebergs filled the Labrador Sea, they dropped light-colored rock fragments, which change the color of seafloor sediments from that region (arrow).

Without knowing what made the ice-age climate so intemperate, scientists cannot tell whether today's interglacial period is immune to the sudden swings so common when ice covered large swaths of the globe.

Much of the news about climate instability has emerged from two drilling projects in the middle of Greenland, where hardy crews bored through the 3-kilometer-thick glacial cap. Like counting tree rings, scientists can look back through the annual ice layers to trace how temperature, gas concentrations, and other factors varied during the last glacial epoch, which persisted from 115,000 until 10,000 years ago.

Although the term "ice age" conjures up a picture of unrelenting cold, temperatures during this period actually rose close to their interglacial values several times, only to plummet back toward full glacial conditions after a respite of a few hundred to a few thousand years. Willi Dansgaard of the University of Copenhagen and Hans A. Oeschger of the University of Bern in Switzerland first uncovered hints of these swings in Greenland ice cores drilled in the late 1960s and early 1980s. But the questionable quality of the oldest ice undermined confidence in their findings.

The two new Greenland cores, which match each other almost perfectly, provide dual confirmation that so-called Dansgaard-Oeschger events did indeed send temperatures bouncing up and down. In fact, the jumps from one extreme to the other occurred over decades, and in some cases over a few years—much faster than previously deemed possible.



Atlantic shivers: The European ice core records large swings in air temperature over Greenland during the most recent ice age. Dashed lines highlight cycles of successively weaker warmings, followed by large temperature peaks. During the coldest periods, known as Heinrich events (labelled H1 through H6), fleets of icebergs floated across the ocean.

But what does the weather over Greenland have to do with conditions in the rest of the world? As long as the evidence of climate blips remained confined to the top of Greenland, researchers could only speculate whether the fast shifts they detected there had affected other parts of the globe.

Unknown to the ice-core workers, however, a German oceanographer had already reported evidence that would draw the oceans into the picture. In 1988, Hartmut Heinrich, working in the eastern North Atlantic, described finding six unusual layers of seafloor sediments containing abnormally high percentages of rock grains.

To explain these bands, Heinrich, who works at the Federal Maritime and Hydrographic Agency in Hamburg, surmised that huge armadas of icebergs sailed across the Atlantic a half dozen times during the last ice age, dropping pulverized rock as they melted. The bergs apparently calved off of the Laurentide ice sheet, which covered Canada and parts of the United States.

Heinrich's discovery made few waves until 1992, when Lamont-Doherty's Wallace S. Broecker finally drew attention to the iceberg discharges and named them Heinrich events after their German discoverer. Bond, Heinrich, Broecker, and several others then demonstrated that the telltale sediment layers spread across much of the North Atlantic, from Newfoundland to Portugal, bearing witness to distinct iceberg flotillas 16,000, 23,000, 29,000, 39,000, 52,000, and 65,000 years ago.

The trail of debris pointed clearly to an origin along the Hudson Strait, north of Labrador, because sediments collected near there contained the greatest concentrations of rock fragments, with amounts decreasing to the east.

Last year, Bond and his colleagues married the disparate discoveries from the ocean mud and the Greenland ice. The Heinrich events, they noted, occurred during the coldest and longest spans of the Dansgaard-Oeschger cycles. Immediately after each iceberg discharge, air and sea temperatures jerked upward toward balmy conditions. Then the climate started the roller-coaster ride toward another frigid period.

Although the Heinrich events first seemed confined to the North Atlantic, their fingerprints are showing up in other parts of the world. George H. Denton of the University of Maine in Orono has tracked climate conditions in Chile by dating moraines—the rocky deposits left by receding glaciers. These moraines indicate that cold temperatures caused mountain glaciers to spread downslope at the same time as the three most recent Heinrich events, suggesting that western South America cooled in step with the North Atlantic.

Scrambling to explain Heinrich events, researchers have tended to seek answers in the regions they know best. Glaciologists first looked toward the Laurentide ice sheet, which spit out the icebergs that drifted into the cold waters of the North Atlantic. Douglas R. MacAyeal of the University of Chicago has theorized that ice sheets such as the Laurentide can grow unstable and pass through what he calls a binge-purge cycle of growth and collapse.

In this model, an ice sheet starts off stably frozen to the ground, building up layer upon layer. Eventually, the ice grows thick enough to insulate its base from the cold air temperature above.

As heat escaping from Earth warms the bottom of the sheet, the base melts, permitting the giant glacier to flow quickly across the land surface. Large fractions of the ice sheet plunge into the ocean in a Heinrich event, raising global sea level by 2 meters within the short span of a few centuries. Once thinned, the ice then refreezes to the ground and starts thickening until it next collapses.

When MacAyeal feeds rough estimates of ice-age atmospheric conditions into his binge-purge model, the Laurentide ice sheet produces Heinrich events 10,000 years apart, on average, in rough agreement with the actual cycle.

While the ice model appeals to glaciologists, some geologists who study seafloor sediments are looking for a broader explanation. In late May, at a meeting of the American Geophysical Union in Baltimore, Bond reported evidence that many different regions were discharging ice at about the same time as the northern section of the Laurentide ice sheet. Iceland and the southern lobe of the Laurentide also left their marks in the sediment layers of certain Heinrich events. According to Bond, MacAyeal's binge-purge model has a difficult time explaining why two very different parts of the Laurentide ice sheet, as well as the Iceland ice sheet, should have collapsed contemporaneously.

Denton's data from South America presents an even greater threat to the simple binge-purge model. "We have a tough time explaining one observation—that the effects of the Heinrich events appear to be felt globally, including in the Southern Hemisphere," says MacAyeal, who is now trying to alter the model. "The theoretical explanation of Heinrich events is

How stable is the current climate?

Compared to the wild temperature shifts of the most recent ice age, the steady conditions of the Holocene period—the last 10,000 years—seem boring. But that stability apparently made all the difference for human society. Only after climate quieted down did early agriculturists start domesticating crops and animals, sowing the seeds of the first civilizations.

Scientists originally thought that the relatively icefree Holocene world enjoyed some protection against the severe temperature swings seen during the last ice age. But European researchers undermined this comforting notion last year when they reported results from their ice core drilled through Greenland.

Looking within the deepest layers of ice, the scientists found evidence that the climate had gone through a series of malarialike fevers and chills during the previous interglacial period, the Eemian stage, lasting from 135,000 to 115,000 years ago (SN: 7/17/93, p.36).

Because the Eemian represents an analog of the Holocene, the ice-core evidence raised concern. To some, the findings suggested that even the modern climate might behave erratically if pushed far enough by greenhouse gas pollution.

In December, however, U.S. researchers raised a warning flag about the Eemian data. Their own ice core, drilled near the European camp in Greenland, contained folded and overturned layers near its base. Caused by ice flowing over Greenland's hilly topography, the folds essentially scrambled useful information about the Eemian stage in the U.S. core. The team wondered whether Eemian data in the European core suffered similar problems (SN: 12/11/93, p.390).

Although the European crew defended their original interpretations, they may soon have to recant some portion of their Eemian conclusions. U.S. scientists recently visited their colleagues across the Atlantic to examine the core in question for themselves.

They can't release their findings until European researchers have a chance to study the U.S. core this August, at which time the two groups will put together a joint statement. But those familiar with the controversy say the U.S. team found more evidence of folding in the European core than had previously been identified. Their work could invalidate some or all of the proposed temperature swings in the Eemian.

R. Monastersky

U.S. drill site.

Stay tuned for the sizzling conclusion to the ice-core drama.

—R. Monastersky

about to go through a sea change," he says.

The sea may indeed hold the answer, according to some researchers. Because Heinrich events dumped tremendous amounts of freshwater ice into the North Atlantic, they could have altered major ocean currents, thereby spreading their influence to other parts of the globe.

The North Atlantic occupies a critical climatic position. As warm water from the tropical Atlantic heads north, the surface layer cools and loses moisture through evaporation. The cold, salty water eventually grows dense enough to sink into the deep ocean, where it flows south and rounds the southern tip of Africa.

By carrying warmth from the tropics toward the poles, this conveyor-belt system of currents helps equalize temperatures in the modern world. But melting icebergs during the Heinrich events would have stalled the conveyor belt by adding freshwater to the North Atlantic, making the water too light to sink. With this major current slowed or even halted, heat would no longer have spread around the globe as efficiently as before, leading to a sharp cooling in regions distant from the tropics.

Such scenarios assume that discharges from the Laurentide ice sheet triggered global climate shifts. But Denton and others wonder whether this theory has it backward: a case of the tail wagging the dog. What if the globe cooled first, spurring the glacial advances in Chile at the same time as they caused Heinrich events in the North Atlantic?

If so, researchers must search for some factor that would cause the planet to warm and cool every 10,000 years or so. It might seem tempting to look for answers in the vagaries of Earth's orbit, a favorite explanation for the long-term ice-age cycle, and indeed some investigators are trying that path. But the shortest known orbital oscillation—the wobbling of Earth's spin axis—has a period of 20,000 years, apparently too long to explain the Heinrich events and the even more frequent Dansgaard-Oeschger swings.

Those seeking answers to the ice-age problem may have to shift their attention away from the polar regions toward warmer climes. Jerome Chappellaz of the Laboratory of Glaciology and Geophysics of the Environment, located in St. Martin d'Héres Cedex, France, and his colleagues put the spotlight on the tropics last year when they reported on a study of methane in the Greenland ice core. From 40,000 to 8,000 years ago, methane concentrations in the atmosphere jumped in concert with local Greenland temperatures, they announced in the Dec. 2 NATURE. Because tropical wetlands emitted much of the methane in the ice-age atmosphere, Chappellaz's team suggests that the lower latitudes may have triggered both the methane changes and the Greenland temperature rises.

Lamont-Doherty's Broecker also looks toward the tropics now. In the past, he viewed the Atlantic's conveyor-belt current as the cause of most climate flip-flops during the ice ages. But the newer evidence of worldwide temperature shifts has convinced Broecker that the tropical ocean might represent a critical and as-yet-overlooked force of change during the glacial epochs.

With so many new findings emerging each month, scientists are trying to make sense of the disparate evidence of ice-age lurches. In the back of their minds, they recognize that the ancient events bear on the pressing issue of global warming. Might the modern climate harbor an inherently unstable element that could trigger wild swings in response to the atmospheric buildup of greenhouse gases? Or was there something unique about the ice-age Earth—the existence of the Laurentide ice sheet for example—that made the climate so susceptible to major shifts during that period only?

Bond, for one, has little hope of a quick answer to the ice-age problem. "It's getting so complicated," he says, "I sometimes think we're going backwards." □