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On Thin Ice: Melting Patterns Across Time

by Katya Poltorak | February 2017

At first glance, the way ice forms doesn't seem like much of a mystery: water freezes when it gets cold and melts once it gets warm. However, the formation and loss of ice on our planet throughout its 4.53-billion-year history is a different story.

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With new tools at their disposal, geologists can now reconstruct this process in more detail than ever before. Three recent papers examine the patterns of ice sheet fluctuation on opposite sides of the world and focus on the two largest "storehouses" of ice on our planet—Antarctica and Greenland. The first two studies—both published in *Nature* in December 2016—provide new insight into the effects of past temperature changes on the Greenland ice sheet. Another recent study—published in the *Proceedings of the National Academy of Sciences (PNAS)* —shows that there have been times when Antarctica has warmed up more quickly than the rest of the world, and that this could happen again.

Frozen History

In discussing the global changes that took place thousands of years ago, geologists have developed a time chart that's important to understand. We are currently in the Quaternary Period, which started around 2,600,000 years ago and is still in effect. It is also known as the "last ice age"—a general category that includes several glaciation and interglacial epochs. The epoch we are currently in—the Holocene—began around 11,700 years ago, after the Pleistocene came to an end.

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Greenland's glaciers span 656,000 square miles. The total volume of the ice sheet is approximately 684,000 cubic miles. If all of this ice melted, sea levels around the world might rise by as much as 24 feet (about the height of a two-story house)!

Because ice sheets accumulate layer by layer, surface particles get captured and preserved as new surface layers form. As a result, "ice cores" that scientists obtain by drilling deep into the ice store thousands of years of climate history literally frozen in time. Trapped gases, for instance, reveal information about the composition of the atmosphere, while the ratios of certain elements can give clues about temperature shifts at different points in time.

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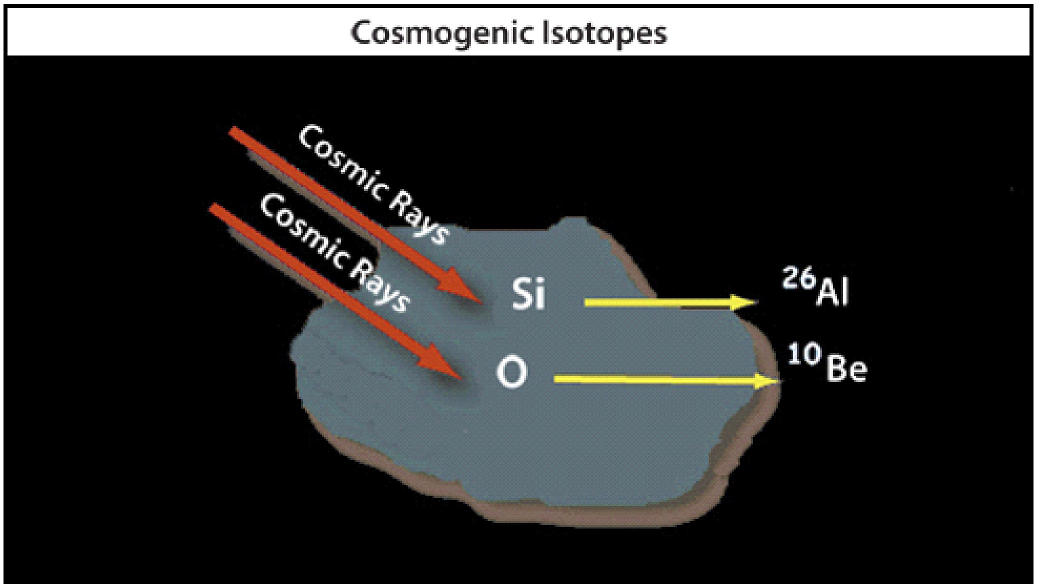
Valuable as they are, however, these frozen time capsules can be notoriously difficult to decipher. As glaciers get bigger, the friction created by the movement of ice sheets erodes the surface like a giant emery board. Because of this, there is a limit on how far down we can go to retrieve ice cores that remain readable.

Atoms Tell the Story

Why should we care? One of the two *Nature* studies—both of which focus on Greenland's glaciers—cut right to the chase in its first sentence. Spanning 656,000 square miles (1,699,000 sq km), "The Greenland Ice Sheet (GIS) contains the equivalent of 7.4 meters (24 feet) of global sea-level rise," the authors write. Its total volume of ice is mind-boggling: approximately 684,000 cubic miles (2,851,000 cubic km). To get a sense of just how big it is, consider that it is estimated that all 7.5 million humans now alive would be able to fit into just one cubic mile (4.16 cubic km) of space. If all of this ice melted, sea levels around the world might rise by as much as 24 feet (about the height of a two-story house)! Thus, as inhabitants of planet Earth, we definitely have a stake in the matter: knowing what will happen to all this ice—and how soon—is certainly in our best interests.

While past investigations concentrated on the ice itself, the two new *Nature* studies focused on the bedrock underneath it. In their analysis of the samples, both teams looked for isotopes of two elements: aluminum and beryllium. As you may know, an isotope is a rarer version of a particular element with a different number of neutrons. Since the number of protons in an atom—known as the atomic number—is what defines its "identity," isotopes have the same basic chemical properties as their "garden-variety" relatives. However, the shift in the number of neutrons gives an isotope a different atomic mass.



M. Bank

The aluminum and beryllium isotopes under study—beryllium-10 (^{10}Be) and Aluminum-26 (^{26}Al)—are commonly found in bedrock and have half-lives of 1.4 million years and 0.7 million years, respectively. Since these isotopes are created through direct contact with cosmic rays and the elements silicon and oxygen, their presence in a particular bedrock sample means that the sample had to have been exposed to the atmosphere directly, without an ice "buffer."

The key feature of radioactive isotopes is that they are unstable and gradually decompose. Since scientists know how long this takes for each atom, they can determine approximately when the decomposition began—and, as a result, estimate the age of the substance containing the isotope in question.

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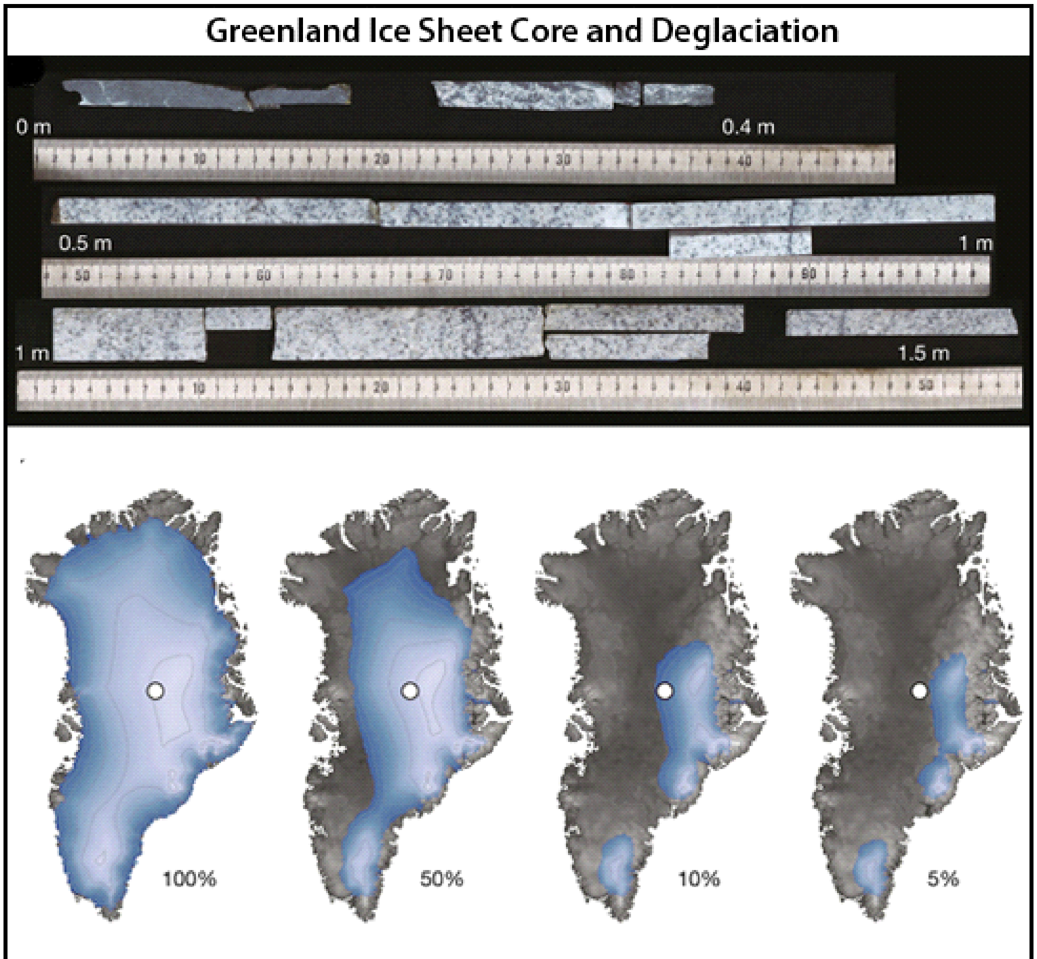
Fact or Fiction?

The story behind one of the *Nature* studies commences in 1993, when a team led by Joerg Schaefer began gathering data from bedrock underneath the Greenland ice sheet. Over the course of five summers, the scientists drilled through roughly 10,000 feet of ice and sediment and extracted samples that contained the two previously mentioned radioactive isotopes: ^{10}Be and ^{26}Al.



Schaefer, Joerg M., et al./*Nature*

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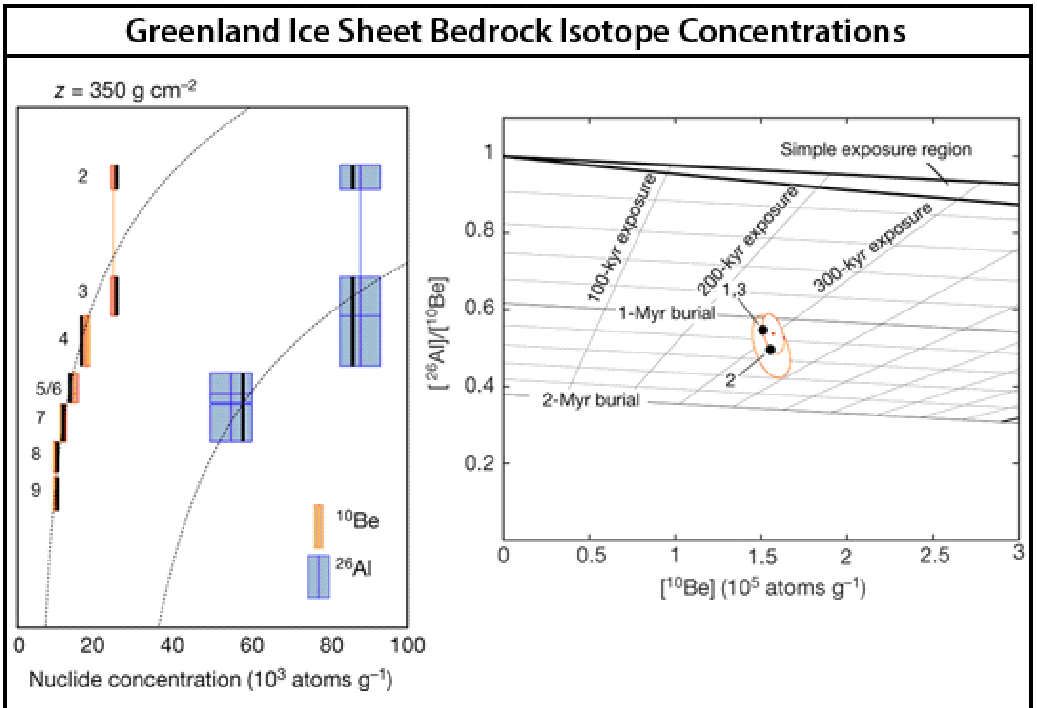
After measuring the concentrations of the two isotopes in the samples, Schaefer and his team used a mathematical model to conclude that Greenland had remained ice-free for at least 280,000 years. It had previously been widely thought that Greenland had been covered with ice throughout the Pleistocene and had been ice-free for anywhere from 20,000 years to 2 million years.



Schaefer, Joerg M., et al./*Nature*

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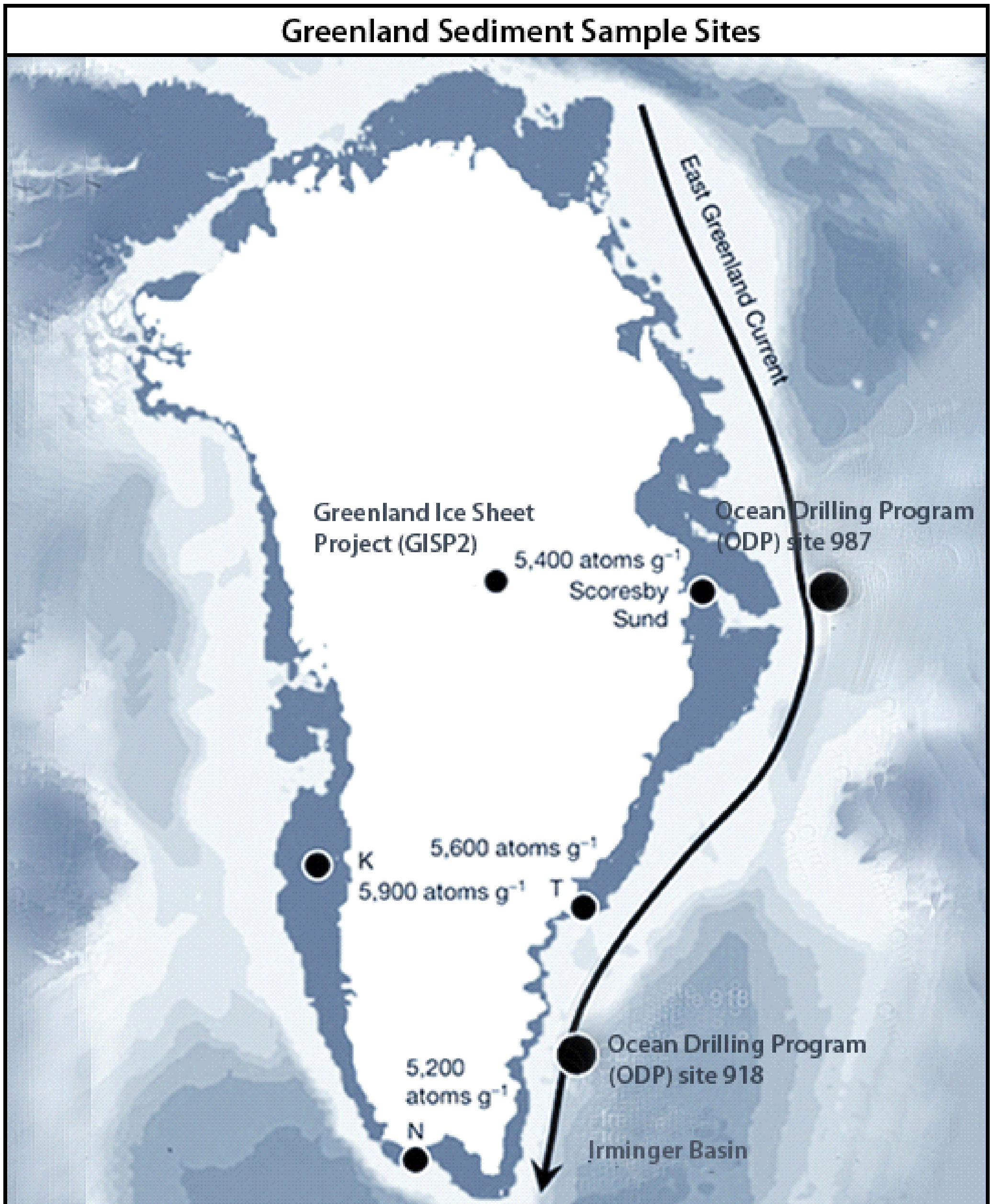
Does it really matter what happened so long ago? It certainly does. As Scripps Institution of Oceanography scientist Jeff Severinghaus told *ScienceDaily*, the study "challenges some prevailing thought on the stability of the ice sheet in the face of anthropogenic warming." As a result, "We can now reject some of the lowest sea-level projections, because the models underpinning them assume continuous ice cover during the last million years."

In other words, global climate change may have a more drastic effect on the melting of Greenland's ice—and the ensuing rise in sea levels—than had previously been widely assumed. As study co-author Richard Alley states, the researchers have not concluded "that tomorrow Greenland falls into the ocean. But the message is, if we keep heating up the world like we're doing, we're committing to a lot of sea-level rise."

Now You See It, Now You Don't

The second *Nature* study—led by University of Vermont geologist Paul Bierman—used similar methods to investigate the ice along Greenland's eastern coast. Like Schaefer, **Bierman** and his colleagues looked at radioactive isotope data from bedrock to uncover the history of Greenland's glaciers in an effort to help predict their fate. The scientists focused on the same isotopes—^{10}Be and ^{26}Al—found in marine sediment underneath the ice.

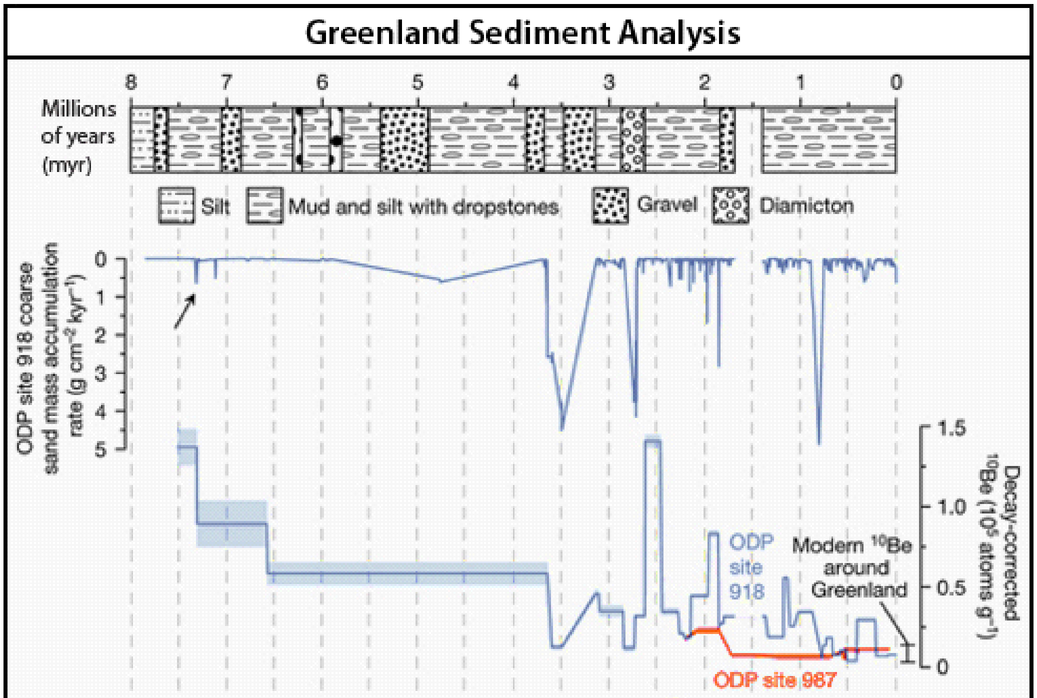


Bierman, Paul R., et al./*Nature*

Geologist Paul Bierman and his colleagues looked at radioactive isotope data from Greenland's glacial bedrock. The scientists focused on the same isotopes as in the other Greenland study—^{10}Be and ^{26}Al.

Based on the data they gathered, the scientists concluded that the ice sheet had been "persistent and dynamic" over the last 7.5 million years. As study co-author Jeremy Shakun explains in a press release, "an ice sheet has been in East Greenland pretty much continuously for seven million years...It's been bouncing around and dynamic—but it's been there nearly all the time."

How can something be both persistent and dynamic (in other words, both constant and changing) at the same time? While this description may appear self-contradictory at first, it refers to fluctuations in the size and span of the ice sheet, which, **Bierman** and his team concluded, was smaller in the early Pleistocene, but never disappeared completely. In the mid-to-late Pleistocene, however, deposition rates increased significantly and the ice sheet spread out into previously ice-free areas.



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The results that **Bierman** and his colleagues obtained might—at least at first glance—appear to contradict those reported by Schaefer. However, this is not necessarily the case. For one thing, Schaefer's team collected bedrock samples in one particular location in the middle of Greenland, while Bierman's team focused on a larger area along the eastern coast of the island. As **Bierman** himself explains, his study, as well as Schaefer's, both have elements of uncertainty: "Their study is a bit like one needle in a haystack...and ours is like having the whole haystack, but not being sure how big it is."

Moreover, the key message in Bierman's study is not exactly how and where the Greenland ice sheet fluctuated in size, but rather that its overall susceptibility to climate-related changes seems to be much greater than had been thought. As **Bierman** and his colleagues show, the expansion of the ice sheet in response to climate shifts demonstrates its sensitivity to changing conditions—which may have to be taken into account more and in making predictions about our planet's future.

Meanwhile, in Antarctica

Finally, a recent *PNAS* study provides new insight into the history of ice at the other end of the globe, in Antarctica. Study leader Kurt Cuffey, of the University of California at Berkeley, and his team obtained samples of ice from a spot where much snow had accumulated and which had a rich, 68,000-year-old climate record.

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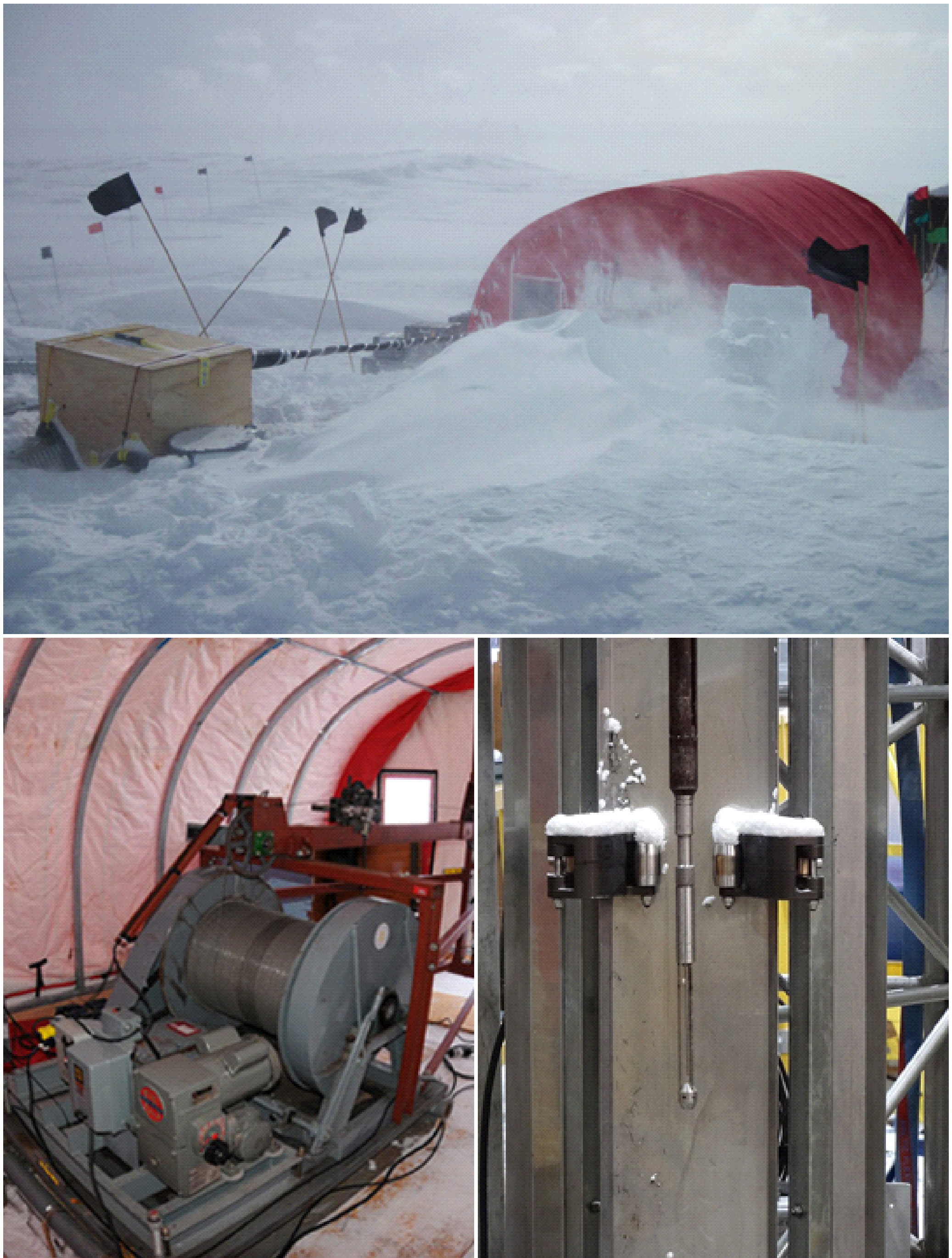
Kurt Cuffey, of the University of California at Berkeley, and his team obtained samples of Antarctic ice from a spot where large amounts of snow had accumulated and which had a rich, 68,000-year-old climate record.

Like Schaefer and **Bierman**, Cuffey and his team used isotopic data but combined it with measurements of temperature shifts across a borehole 3.5 km (a little over 2 miles) in depth to get a detailed picture of the region's climate history. The ice found at the bottom of the borehole was deposited about 70,000 years ago, while samples taken from about a sixth and a third of the way up were deposited about 50,000 and 20,000 years ago, respectively.

By combining isotopic with temperature data, Cuffey and his team were able to put together a more accurate "temperature history" of the continent while tracing the relationship between changes in temperature and the ice melting process with greater precision. The scientists determined that Antarctica finished warming between 20,000 and 10,000 years ago—several thousand years ahead of the Northern Hemisphere. Its temperature rise was also significantly steeper than that of the rest of the world: about 11 degrees Celsius (close to 20 degrees Fahrenheit) compared to about 4 degrees Celsius (7 degrees Fahrenheit) in other parts of the world.

Like Schaefer's study of Greenland ice, Cuffey's report shows that we can now narrow down the possible scenarios describing the effect of temperature changes on ice melting rates, eliminate climate models that are in conflict with the new information, and confirm those that are supported by the new data. One of the main contributions of his study is the new light it sheds on the phenomenon known as polar amplification. Geologists have known for a while that a change in temperature balance—for example, one caused by greenhouse gas emissions—tends to get exaggerated at the poles, which experience a greater shift than other parts of the planet. This effect has been observed at both poles in recent years, and seems to be stronger in Antarctica than in the Arctic for a number of reasons—such as certain aspects of ocean currents. And since we can now be reasonably sure that this is what led Antarctica to warm up so quickly in the past, we can expect a similar pattern to play an important role in the future.



University of California-Berkeley

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As Cuffey explains in a Berkeley press release, "If you look at the global climate models that have been used to analyze what the planet looked like 20,000 years ago—the same models used to predict global warming in the future—they are doing, on average, a very good job reproducing how cold it was in Antarctica. That is noteworthy and a confirmation that we know how the system works." What these models predict is that while temperatures around the globe will increase by about 3 degrees Celsius (around 5 degrees Fahrenheit) by 2100, temperatures in Antarctica are expected to rise almost twice as much!

Weeding Out False Leads

While the three studies approach the issue of ice melting from slightly different angles, several common features stand out. First and foremost, all three recognize the difficulties inherent to accurately assessing how ice sheets around the world changed in the past and how they might be expected to change in the future. In a blog entry on *Microbes Mind Forum*, Cuffey talks about the challenges of making accurate predictions: "For social-political reasons, glaciologists are expected to forecast the net rise of sea level by century's end." But, he continues, "The topic raises the question of how environmental scientists should respond to requests for quantitative forecasts when quantitative precision is illusory."

Another feature of all three studies is the effort taken to address theories that appear to be inconsistent with their findings. Taken as a whole, the studies reveal the power of combining multiple perspectives to shed new light on issues of grave concern to the future of our planet.

Discussion Questions

Why do you think the poles exhibit an amplification effect, with climate change occurring more dramatically there?

Besides the things mentioned in this story, what might you list as already apparent signs of climate change at the poles?

We draw a distinction between temperate and tropical zones. Do you think these zones are responding equally to climate change or not? What evidence can you find for your opinion?

Do you think the changes that are occurring will make further changes in the same direction more likely, or, on the other hand, will they make a swing back to an equilibrium state more likely? What reasons/evidence can you give for your opinion?

Journal Abstracts and Articles

(Researchers' own descriptions of their work, summary or full-text, on scientific journal websites.)

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global warming, ice cores, aluminum and beryllium isotopes, polar amplification, Antarctica, Greenland ice sheet,

Joerg Schaefer, Paul **Bierman**, Kurt Cuffey

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