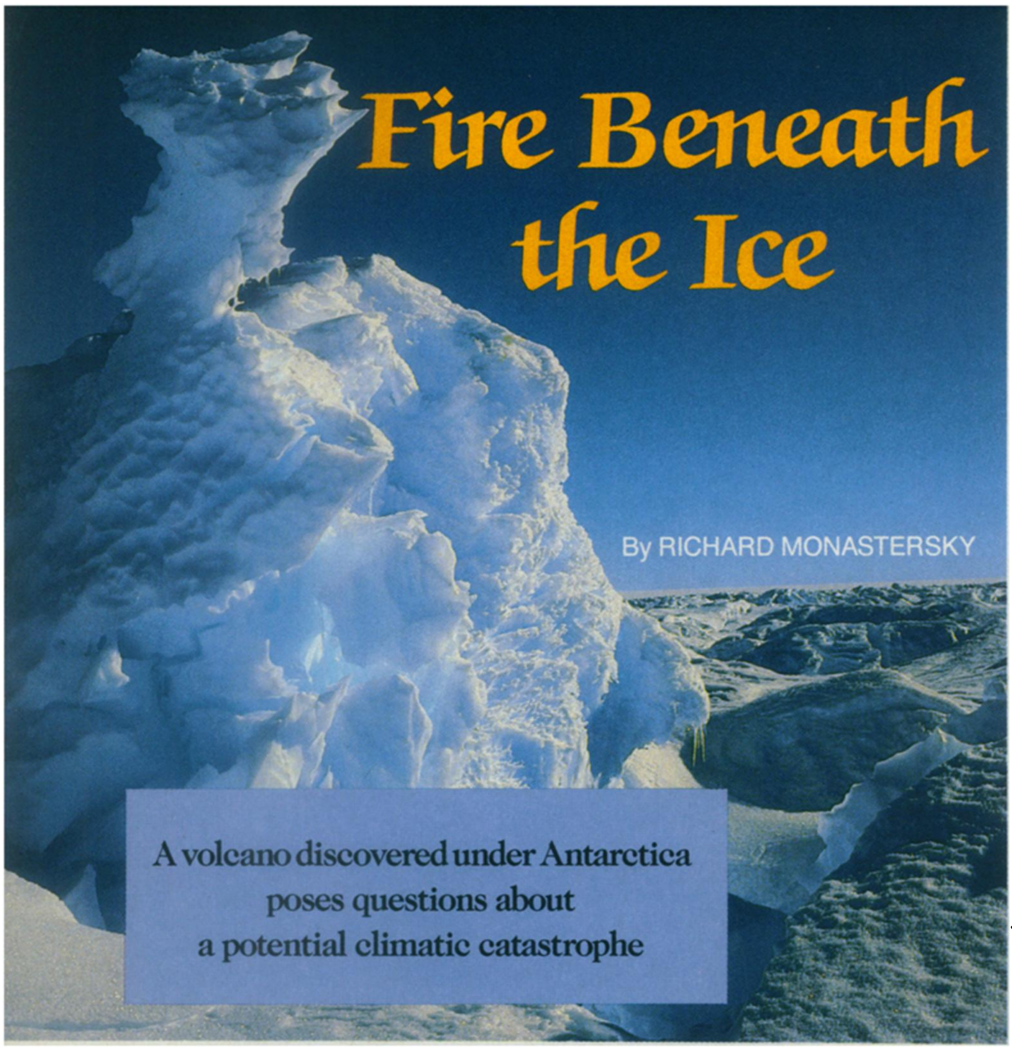
Fire Beneath the Ice

By RICHARD MONASTERSKY

A volcano discovered under Antarctica poses questions about a potential climatic catastrophe



Barclay Kamb, Caltech

Outside the window, snowflakes fly past in a horizontal stream, openly defying the force of gravity, while distant mountains disappear behind a lowering wall of clouds. The brewing storm will soon engulf McMurdo Station, temporarily halting all flights to and from this isolated research outpost on the coast of Antarctica. Inside the building, oblivious to the weather, Donald Blankenship and Robin Bell are biting their tongues as they meet with a group of reporters visiting the base.

The two geophysicists know they have a hot story, and like any discoverers, they can't wait to announce their finds. At the very least, their revelations provide a dramatic reminder that some corners of the planet remain totally unknown – no small feat in an age when even the summit of Mt. Everest is reachable by phone. More important, though, Blankenship and Bell's work carries implications for scientists wondering whether part of Antarctica's glacial cover will soon melt away, causing a rise in sea levels that would devastate the low-lying regions that shelter much of the world's population.

Blankenship, who hails from the University of Texas at Austin, can't keep a grin from creeping over his face as he launches into their tale. But he and Bell, from Lamont-Doherty Earth Observatory in Palisades, N.Y., take a decidedly roundabout route to the meat of the story, trying hard not to let the "V" word slip out lest they generate a flurry of publicity that would upset the academic journal considering whether to publish their research results. It is the middle of November, still months before their report will appear in print, so Blankenship and Bell back into their story, discussing only the barest details.

A great deal rides on that hoped-for journal article: The two scientists will soon request more funding from the National Science Foundation, where some have voiced skepticism about the way Blankenship and Bell study the Antarctic continent. For the past three southern summers, the two researchers have packed a small Twin Otter plane with an unusual assortment of surveying instruments and then spent hundreds of expensive air-hours ranging back and forth over a patch of frozen real estate roughly the size of Indiana.

Six years ago, while flying over a nearby region, Blankenship discovered hints of something unusual under a fast-moving section of the ice sheet, but he couldn't collect enough evidence to prove his hunch at the time. So he returned with Bell and the equipment necessary for surveying the icy landscape and the rock that lies hidden beneath.

Two of the instruments mounted on the Twin Otter focus on the ice, measuring its thickness and the elevation of its surface. The other pair of devices probes below the ice, gauging the magnetic strength and gravitational pull of the bedrock. This collection of extremely sensitive measurements is difficult to make from an airplane, so many scientists have questioned whether Blankenship and Bell's approach would pay off.

"If you had polled the community and asked whether they would succeed, most of us would have said no. They tried something that was technically very difficult and, on the face of it, very expensive," says Richard Alley, a glacial geophysicist at Pennsylvania State University in University Park.

Last year, though, Blankenship and Bell proved the skeptics wrong. On the final flight of the season, after months of cruising back and forth across the featureless ice sheet, they collected the evidence necessary to confirm what Blankenship had described in a field notebook five years ago with the word "volcano."

To an observer flying above it, the ice sheet at 81° 52.6′ S, 111° 18.1′ W offers no obvious clue that an active volcano seethes beneath. The ice in this region of West Antarctica measures almost 2 kilometers thick, forming an insulating blanket over whatever lies below. There are no great chasms in the ice, no fire or smoke spitting forth. But the instruments that Blankenship and Bell hauled down to the Antarctic have captured the unmistakable signature of a volcano, they say.

Radar reveals the profile of an isolated mountain rising steeply under the ice to a summit 650 meters above the surrounding bedrock. The magnetic measurements suggest that the mountain and its environs are rich in the mineral magnetite – a characteristic component of volcanic rocks. The gravity data, together with the radar findings, indicate that the buried peak has a cone shape, roughly similar to that of Mt. Fuji.

In form and composition, the mountain fits the description of a volcano. But there is more to the story. Blankenship and Bell claim not only that they have found a volcano under the ice, but also that the mountain is active, still erupting occasionally and growing.

When flying over the summit of the covered mountain, the researchers found a subtle circular depression in the surface of the ice sheet – a hole 50 meters deep and about 6 kilometers across. While not obvious, the depression shows up on data collected by a laser that shoots pulses downward to gauge the height of the ice surface.

"There's a lot of ice flowing into that hole, and that ice has to go somewhere.

There must be something removing mass from the bottom," Blankenship says. That ice-eater, he and Bell propose, is heat from an active volcano.

From the slope of the ice flowing into the hole, the researchers can estimate how fast the ice sheet is melting, which provides a portrait of the heat source underneath. They calculate that each square meter of rock beneath the depression emits about 10 to 50 watts of energy—a value roughly a thousand times that of the average continental crust. "That's really a lot. That's half a light bulb for every square meter," says Blankenship.

The two investigators can't tell when the volcano last came to life, but such heat values typify active volcanoes that have erupted in the past few centuries and could blow again at any time, Blankenship says. While such a blast would likely thin the ice substantially right above the volcano, it probably would not burn its way through the ice sheet, Blankenship says.

The perimeter of Antarctica has several active volcanoes, including Mt. Erebus, which made national news last month when researchers failed in their attempt to send a robot to the bottom of its crater. However, the volcano discovered by Blankenship and Bell is the first found under the ice that covers 98 percent of Antarctica, making it a find of considerable interest to glaciologists.

"It's very exciting. We're getting a picture of something we didn't know anything about," Alley says.

The newly detected volcano lies near the center of what is called West Antarctica, a collage of small crustal blocks that pasted themselves to the large East Antarctic continent at a time when dinosaurs lived there. West Antarctica figures prominently in modern climatic research because scientists in the 1970s proposed that the ice sheet covering this part of the continent is unstable and could split apart. The West Antarctic ice sheet is also the most temperamental on Earth; parts of it are changing far more rapidly than scientists had thought possible.

The volcano sits in a critical transition zone within West Antarctica. Uphill from this region, ice creeps slowly toward the coast. But just downhill from the volcano, the ice surges forward in fast-flowing currents called ice streams. These streams resemble huge glaciers, save that glaciers are bounded on either side by mountains, whereas ice streams are bordered by slower-moving ice.

Blankenship first came upon the idea that volcanoes exist below West Antarctica's ice cap in 1987, while studying a feature called Ice Stream B, one of five such streams that connect the interior of West Antarctica with the Ross Ice Shelf, a floating block of ice as big as Texas. Rivaling the world's greatest rivers in size, Ice Stream B measures about 50 kilometers across and 1 kilometer deep and runs for a distance of 500 kilometers. Parts of Ice Stream B flow at a clip of more than 2 meters per day, while ice along its banks crawls at only 2 meters per year.

Ice stream B and its four neighbors act as pipelines, draining ice from the stable center of West Antarctica to the Ross Sea, where it breaks apart to forms icebergs. Three additional major ice streams drain the other sides of West Antarctica. Because they are the most active part of the West Antarctic ice sheet, the streams have captured considerable attention from researchers wondering what the future holds for this part of the world.

While flying over Ice Stream B six years ago, Blankenship noticed a depression in the stream's surface, where large ice blocks had fallen into a hole. It was then that he first wondered whether a heat source below the stream could be melting the base of the ice sheet. Without any information about the ground below the ice, Blankenship could not test his idea. But the notion simmered in his mind.

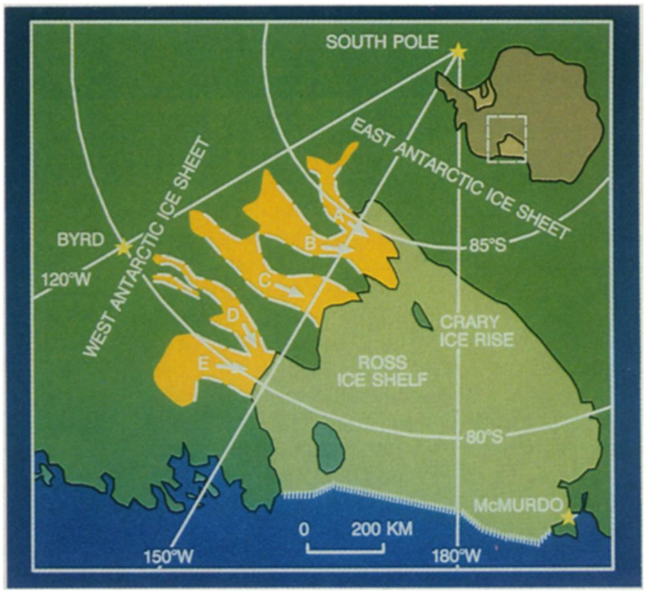
Though fresh out of graduate school in 1987, Blankenship was not a newcomer to the ice streams. He had made a name for himself a year earlier by discovering the critical feature that allows ice streams to flow so fast. Before then, most glaciologists had presumed that ice streams slide atop a layer of highly pressurized water separating the ice from the hard bedrock beneath, Blankenship says. But while conducting his dissertation work in Antarctica, the young geophysicist found evidence of a different lubricant under the ice.

Blankenship had originally intended to study crystal orientations in the deep ice by setting off explosions at the surface of the ice streams and recording the seismic vibrations that bounced off layers below. Yet the vibrations revealed something even more important — a 5-meter-thick layer below the ice sheet containing a soft material unlike ice or hard rock. Blankenship and his colleagues proposed that the soft layer consists of water-logged sediments called till that would reduce the friction between ice and bedrock. In the late 1970s, glaciologists had shown that till underlies a fast-moving mountain glacier in Iceland. But until Blankenship's work, nobody had suggested that a slurpy layer of sediments greases the underside of the huge Antarctic ice streams.

Three years later, researchers from the California Institute of Technology in Pasadena confirmed the till hypothesis when they drilled down into Ice Stream B and pulled up samples of water-logged sediments from beneath the ice. About as soft as toothpaste, this mixture of rocks and small grains was the long-sought lubricant under the ice streams.

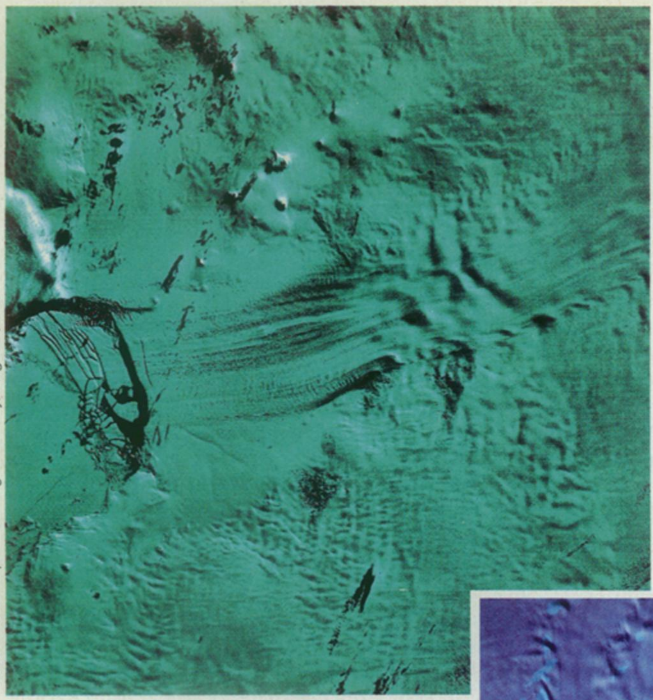
After that discovery, Blankenship began to wonder about the source of the till's water. Much of the ice sheet is thought to be frozen to the bedrock, or at least poorly lubricated. But Blankenship surmised that if volcanoes existed under the ice sheet, the entire region must be warmed by geothermal heat coming up through Earth's crust, which would melt the underside of the ice. To test his theory, he joined forces with Bell, who had experience in probing rocks with airborne instruments. Together, they put forward a proposal to survey the sub-ice geology using a suite of instruments that had never been combined before.

Although the Antarctic continent boasts the coldest temperatures on Earth, Blankenship and Bell had reason to suspect that volcanoes stew under West Antarctica's frozen blanket. Geologic evidence suggests that the western portion of the continent has rifted away from East Antarctica in recent geologic time, and the separation may be continuing today — an event that would thin the crust in a manner favoring the formation

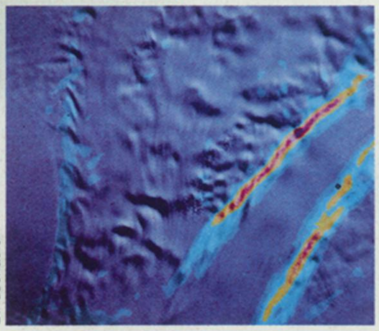


Five major ice streams, colored yellow, flow from the interior of the West Antarctic ice sheet into the Ross Ice Shelf. Ice resting on bedrock is dark green. Floating ice is light green. The Transantarctic Mountains separate the West Antarctic and East Antarctic ice sheets. McMurdo Station is the principal U.S. base.

Bindschadler



Baerbel Lucchitta/U.S. Geological Survey, Flagstaff, Ariz.



Bindschadler

Landsat satellite image captures an ice stream flowing into Pine Island Bay and calving into icebergs. Grounding line is midway through image. Ice on right rests on bedrock; ice on left is floating. Inset shows another stream, called Ice Stream D. Yellow and pale blue indicate borders where fast-moving currents shear past slow-moving ice sheet.

of volcanoes. Furthermore, the presence of active and formerly active volcanoes along the perimeter of the continent fits that geologic picture, hinting that others exist in the interior.

With that thinking, Blankenship and Bell traveled south with several colleagues, dragging 7,000 kilograms of equipment and 25 computers to their field camp in the flat white wasteland that characterizes most of the Antarctic continent. After one summer spent testing and a second summer searching, they finally detected a volcano. Their paper announcing the discovery appears in the Feb. 11 NATURE.

Blankenship and Bell believe the active volcano they identified has many neighbors under the ice streams and in the zone where the streams start. Pulling out a satellite image of some ice streams, Bell points to several circular features that she says look suspiciously like ice-covered volcanoes: "There are lots of really round forms on those images, and it's geologically difficult to make round things that are not volcanoes. Most things in geology are lines, not circles."

Take away the ice from West Antarctica, says Bell, and the crust beneath the ice streams might resemble that of the Basin and Range province of the southwestern United States, which the forces of plate tectonics have wrenched apart. The landscape in Nevada, Arizona, and New Mexico has numerous recently active volcanoes and a thin crust that readily conducts heat from the Earth's interior.

The new evidence collected by Blankenship and Bell suggests that West Antarctica also has a thin, hot crust, at least in certain places. Even more than the occasional volcanic eruptions, it is this pervasive geothermal heat that melts the base of the ice sheets, providing the water for the lubricating till beneath the ice streams, the researchers contend.

Although Bell mentions the idea of an iceless West Antarctica simply as an analogy, that image carries some chilling connotations for glaciologists. Of all the problems that might accompany a greenhouse warming, the collapse of West Antarctica's ice sheet stands out as one of the most calamitous. Should this frozen mantle melt, worldwide sea levels would rise by roughly 6 meters, enough to drown much of New York City, Los Angeles, New Orleans, Tokyo, Hong Kong, Bangkok, and many other heavily populated spots around the world.

According to glaciologists, the West Antarctic ice sheet has the potential to collapse because it rests on bedrock well below sea level, unlike the larger, stabler East Antarctic ice sheet, which sits atop rock that lies mostly above sea level. Right now, much of the West Antarctic ice sheet is not well lubricated and can move only slowly, whereas ice along the perimeter of the sheet forms floating shelves that do not touch the bedrock and are free to move. The border between these two regions is termed the grounding line, a feature that lies at the heart of the West Antarctic doomsday scenario.

If the grounding line began to retreat toward the interior of West Antarctica, it would release the brake on ice currently locked to its bed. The newly freed ice would flow faster toward the ocean, thinning the interior ice and causing the grounding line to retreat even faster. The process would accelerate, shrinking the ice sheet until it disintegrated completely, raising sea levels worldwide.

For many years, that scenario seemed a hypothetical one, with little basis in history. Traditional ideas about Antarctica have held that the ice sheets formed there millions of years ago and have remained in place ever since. Yet evidence reported in the last two years suggests that the West Antarctic ice sheet may have collapsed and then reformed in the not-too-distant geologic past, much more recently than scientists had previously believed (see p.107).

Looking forward in time, glaciologists have proposed several reasons why global warming could cause the ice sheet's grounding line to retreat. Some have focused on sea levels, which are currently rising by about 1 centimeter per decade and will probably rise even faster in the next century if the climate warms as expected. The swelling oceans could buoy the floating ice shelves, forcing the grounding line to pull inward and – potentially – starting the process of disintegration.

Others have wondered whether a global temperature rise could warm the waters circulating under the ice shelves – a shift that might thin these floating borders and then speed up the slow-moving inland ice. In fact, a small ice shelf along the Antarctic Peninsula disintegrated in the last two decades, apparently due to rising temperatures in the region.

Yet with all the concern about greenhouse warming, the specter of future climatic change may not represent the biggest threat to the ice of West Antarctica. Events that occurred thousands of years ago may exert the most influence on what the grounding line does today.

Glaciologists' calculations suggest that it takes more than 10,000 years for a climatic change in the atmosphere to seep through the thickest ice of West Antarctica. Therefore, the underside of the ice sheet may only now be reacting to the warming that took place at the end of the last ice age, about 10,000 years ago. In theory, once it reaches the base of the ice sheets, the warming should soften the ice, helping it flow faster and possibly setting off the catastrophic collapse.

"It may be that the trigger was already pulled and we have yet to see the result of it," says Robert A. Bindschadler of NASA's Goddard Space Flight Center in Greenbelt, Md. Bindschadler organized the West Antarctic Ice Sheet Initiative, a program aimed at studying the ice streams and the potential for ice sheet collapse. From recent work on the ice streams, glaciologists know these features are undergoing rapid changes: Some are speeding up, whereas others have stopped dead. Because of such events, researchers regard the ice streams as critical to understanding West Antarctica.

Blankenship and Bell believe their volcano discovery reveals an important clue about where the ice streams can form and where they can't. "The ice streams need a lubricant. They need material to make till: sediments from sedimentary basins and heat to make the water. Our hypothesis is that the onset of streaming is controlled by the geology," Blankenship says.

Last year, he and Bell found one of the two necessary ingredients when they located the volcanic evidence of abundant geothermal heat. In the last few months, they have detected signs of the sedimentary basins that presumably supply the other ingredient needed to create the ice streams.

These two factors, heat and sediments, may play a central role in the scenario of ice-sheet collapse, contend Blankenship and Bell. If geologic conditions do indeed anchor the ice streams, they would be unable to migrate farther inland as the grounding line retreats. The ice sheet may be stable up to a point – until the ice streams get so short that they can no longer buffer the thick interior ice from the ravaging effects of the ocean. No one knows what would happen if the ice streams were to disappear, but Blankenship and Bell think it would create an inherently unstable situation that could start the rapid disintegration of the ice sheet's interior.

Glaciologists know that the grounding line has retreated hundreds of kilometers since the end of the last ice age, when West Antarctica spread over an area half again as large as it does now. But they lack sufficient information to determine whether the retreat continues today or whether the grounding line has reached a stable point and will yield no further.

"What we need to establish is whether the retreat of the grounding line is continuing. If it is, then the scenario we describe is pretty critical. Those ice streams are very short compared to what they were in the past," Blankenship says.

With so many possible routes to an ice sheet collapse, should residents of Miami Beach or Bangladesh pack up and head for higher ground? Could catastrophe strike during our children's lifetime, or our grandchildren's?

Glaciologists are the first to admit they don't have an answer. Most researchers predict nothing dramatic will happen for at least the next hundred years and maybe many more. But they can't offer any certainty, because Antarctica remains largely unknown.

"We are in many ways a lot more ignorant than we'd like to be," Alley says.

Though the new discovery by Blankenship and Bell doesn't remedy that ignorance, it does offer some clues to what controls the ice sheets. Other researchers have not had time to consider the new findings, but Blankenship, Bell, and their co-workers believe their results indicate that the stability of West Antarctica ultimately depends less on the current climate than on the location of heat and sediments under the ice and the legacy of past climatic changes. They draw the ironic conclusion that the ice sheet could collapse regardless of whether governments curtail fossil fuel emissions in the next century.

"The failure of the ice sheets isn't necessarily controlled by what's happening on top – the climate," Bell says.

Weeks after her revelations at McMurdo that snowy day, Bell answers questions as she plays tic-tac-toe with her 5-year-old daughter at their home in the Hudson River Valley, which bears the scars of a thick ice sheet that covered this region during the last ice age. It's Christmas Eve, and this is the first time in the last three years that Bell will have spent the holiday with her family instead of halfway around the world. But this will be a short visit, because she returned from Antarctica only two weeks before and she must head back to the field camp the day after Christmas.

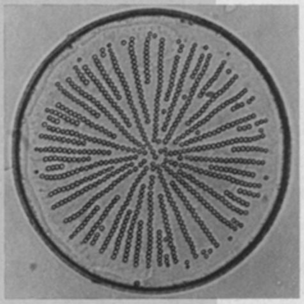
Losing game after game to her gleeful daughter, the distracted geophysicist focuses her attention on a discussion of ice sheet stability. Although the frozen blanket covering Antarctica has an air of permanence, it's clear that ice like this has come and gone many times during Earth's history. For evidence, Bell need look no further than outside her home window, at the maple trees whose roots seek a hold in the remains of ancient till left over from an ice sheet that vanished long ago. □

When Antarctica melted away

In the slang of the extreme south, the continent on the underside of the world is known simply as "The Ice." It's an apt name for a place where frozen water covers 98 percent of the land surface.

Earth scientists have traditionally regarded the Antarctic ice cap as a venerable, stable feature that has persisted for millions of years. But recent research suggests that Antarctica's icy mantle has passed through unstable periods, when large parts disappeared into the sea and then reformed.

During a project that drilled through the West Antarctic ice sheet, Reed Scherer of Ohio State University in Columbus found tiny fossils belonging to a species of one-celled, sea-dwelling algae that evolved 2 million years ago. The presence of these fossils under the ice sheet indicates that at the time such algae lived, open ocean existed in this part of West Antarctica, which suggests that the present ice sheet began growing less than 2 million years ago. Other fossil evidence hints that the ice sheet is probably less than 600,000 years old, contends Scherer, who is preparing to publish his results.



Fossil shell from a marine diatom found under Ice Stream B. This fossil and others indicate the West Antarctic ice sheet melted and reformed in recent geologic past.

Scherer

Scherer proposes that the West Antarctic ice sheet has formed and collapsed several times, which ties into concerns that global warming could cause the ice sheet to disintegrate in the future, raising worldwide sea levels by 6 meters. Douglas R. MacAyeal of the University of Chicago has created a computer model of West Antarctica that exhibits the kind of unstable behavior suggested by the fossil evidence, he reported in the Sept. 3, 1992 NATURE (SN: 9/26/92, p.207). The portrait of instability, however, clashes with the standard view that the West Antarctic ice sheet formed 6 million years ago and has remained in place ever since.

A similar type of debate rages over the history of the East Antarctic ice sheet, which is larger and more stable than its western counterpart. Canonical wisdom has held that the East Antarctic ice sheet formed roughly 14 million years ago, but fossils found in the mid-1980s indicated that trees and lakes existed in the interior of East Antarctica as recently as 3 million years ago. In the Oct. 29, 1992 NATURE, New Zealand and U.S. researchers supported that interpretation with dates on lava flows found with the fossils, which confirm that the fossils are only 3 million years old.

Although considered far less likely than a collapse of West Antarctica, the melting of East Antarctica would end in considerably greater devastation. Glaciologists calculate that such a meltdown would raise sea levels by a catastrophic 60 meters.

– R. Monastersky