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Freeze-Dried Findings Support a Tale of Two Ancient Climates

A surprising cache of ancient plant material adds evidence for divergent climate histories of the East and West Antarctic ice sheets over the past 14 million years

MCMURDO STATION, ANTARCTICA—Setting out on foot from camp on a clear, cold November day, three graduate students picked their way around the boulder-strewn flank of Mount Boreas, a naked butte in the Olympus Range of the Dry Valleys in Antarctica. The students had wandered 20 kilometers in search of glacial deposits or volcanic ash that would help them reconstruct the geologic history of this region 120 km from McMurdo Station. As they climbed over a pile of boulders, they spotted a low drift of white powder concealed in a depression.

At first, it looked like volcanic ash. But when they dropped to their knees and dug in with their fingers, they discovered papery layers of brown and white that resembled the stacked pages of a buried dictionary. Along the edges, inch-long fibers fluttered in the wind. The soft organic material was out of place in this sterile, stone-paved landscape. Once the trio had returned to camp, their microscopes revealed the brown and white layers to be desiccated slabs of an ancient lakebed that had been pried up by powerful winds. The white powder on the surface turned out to be thick deposits of diatoms. And the fibers were tiny brown stems and shriveled leaves.

The 2000 discovery, only now coming to light through a series of recent meeting presentations, represents the last gasp of a tundra ecosystem before it plunged 14 million years ago into a winter from which it has never emerged. It's one of several findings that point to an alpinelike ecosystem millions of years ago that has remained in a freeze-dried state ever since. "For 14 million years, presumably, they've been close to the surface," says paleoecologist Allan Ashworth of North Dakota State University (NDSU) in Fargo, who is coordinating analysis of the specimens. "If the climate had gotten warmer and wetter, microbes would have mined these deposits as carbon sources."

Juxtaposed against these f indings are results from two recent cores drilled into the seabed of McMurdo Sound, 120 kilometers from the Olympus Range. The analysis of the ANDRILL (ANtarctic geological DRILLing) cores, taken in the fall of 2006 and 2007, indicate huge fluctuations in temperature over the same period in that general region.

These findings appear to be contradictory at first glance, but in fact they buttress an evolving view among scientists that the two major features of the continent, the western and eastern ice sheets, have experienced vastly different climate histories. Data from the Dry Valleys reveals an East Antarctic Ice Sheet that is high, dry, cold, and stable, at least in its central area. And the ANDRILL cores suggest a more volatile West Antarctic Ice Sheet that is subject to the changing temperatures of the sea in which it wades. “It reaffirms the fragility of the West Antarctic Ice Sheet [WAIS] and the stability of the central part of the East Antarctic Ice Sheet,” says Peter Barrett, a sedimentologist at the Victoria University of Wellington (VUW) in New Zealand, who advised the ANDRILL project.

Those results also have major implications for what lies in store for the two ice sheets, which together cover more than 95% of the frozen land mass. Their fate represents a key element in any scenario about the long-term effects of global warming.

In fact, there’s so much at stake, and the fossil findings were so unexpected, that David Marchant, a geomorphologist at Boston University (BU), initially suspected a practical joke when his students asked him to look through the microscope. “I thought someone had snuck in grass from New Zealand,” he says. “It looked so fresh. As soon as I knew it was a real find, I thought this was among the biggest discoveries in the Dry Valleys, and maybe all of continental Antarctica, in the last decade.”

Freeze-dried samples

Adam Lewis, then pursuing his Ph.D. at BU under Marchant, had already spent several years studying glacial deposits in the Olympus Range. That work had given him a nodding acquaintance with dating them and allowed him to draw a general picture of past climates in the region. So although the withered roughage spotted by him and fellow grad students Jane Willenbring and Brett VandenHeuvel was novel, he immediately sensed its significance. “We knew it could be used to reconstruct temperature,” says Lewis. “We knew that we would be able to say, 15 million years ago, how warm it was in summer.”

It was some time before the graduate students could indulge their curiosity, however.

“We bagged it up, wrote down our notes, and made a little rock pile,” says Lewis, now on the faculty at NDSU. “Then we had to get back to work on glacial geology.” The group—Willenbring is now a postdoc at the University of Hanover, Germany, and VandenHeuvel is an environmental lawyer in Oregon—kept the f ind secret to prevent the site from being excavated before its stratigraphy was properly dated.

But Lewis returned 2 years later, and the story is now appearing in a series of recent presentations and upcoming publications. Lewis and Ashworth also star in a new documentary, *Ice People*, that describes their work in the Dry Valleys.

The shriveled fibers Lewis and his colleagues stumbled across were 14-million-yearold aquatic mosses whose leafy stems once undulated in shallow, lazy currents. When dunked in water, which Ashworth immediately tried with some of them, they reinflated and unfurled. “These things look like freezedried museum samples,” says Ashworth. The bodies of pea-sized freshwater seed shrimp, or ostracods, have also turned up with their soft mouth parts intact. A second lakebed, also in the Dry Valleys, offered up pollen, leaves, and twigs of southern beech—the twigs still composed of pliable, burnable wood. And lake sediments have coughed up megaspores of aquatic quillwort plants and fragments of insects, including a species of weevil.

These fossils paint a picture of an alpine lake dammed behind glacial moraines, surrounded by tundra and weather-beaten southern beech shrubs. The setting is similar to modern, above tree-line communities in New Zealand or Patagonia. The wide range of diatom species show that the lake didn’t dry up seasonally, says Alex Wolfe of the University of Alberta in Edmonton, Canada, who examined the diatoms: “It was a proper lake ecosystem.”

This spongy lawn of alpine tundra suggests an average summer temperature well above freezing, according to early results presented last summer by Marchant, Lewis, and Ashworth at the 10th International Symposium on Antarctic Earth Sciences in Santa Barbara, California. (More complete climate reconstructions are in press.) That’s at least 20°C warmer than current conditions, in which only a few minuscule nematodes, springtails, and mites eke out an existence below the surface.

Isotope analysis of volcanic ash sprinkled over one lakebed dates the tundra at 14.1 million years. Last November, Marchant and Lewis published geomorphic surveys suggesting that the Olympus Range shifted within a few hundred thousand years from warm, seasonally melting glaciers that fed lakes to dry-based glaciers that sublimated rather than melted. The dry glaciers have advanced and evaporated since then, but cosmogenic nuclide dating, which estimates the times that rocks on the surface have been exposed to cosmic rays, suggests that this landscape—perhaps the oldest on Earth—hasn’t tasted liquid water in the last 14 million years. “We’ll move a boulder, and we’ll think to ourselves, ‘Our ancestors were swinging in the trees, and that boulder was already there,’ ” says Lewis.

Cork in the bottle

While the portion of Antarctica on the other side of the Transantarctic Mountains stayed locked in the freezer for the last 14 million years, West Antarctica, which constitutes about a fifth of the continent, was having a much more on-again, off-again relationship with its ice. The two 1200-meter cores from the ANDRILL project provide a 20-million-year climate record. The 2006 core was of particular interest because it came from seabed beneath the northwest corner of the Ross Ice Shelf, a Spain-size slab of floating ice that feeds out of the West Antarctic Ice Sheet.

Glaciologists regard the Ross Ice Shelf as a barometer of the ice sheet's health. It buttresses the flow of major glaciers flowing out of WAIS, providing what some call "the cork in the bottle." Sea levels could rise by 5 meters were WAIS to melt. Satellite studies indicate that it is currently losing as much as 150 cubic kilometers of ice per year, and many observers consider it at risk for collapse because it slides on a bed that sits below sea level, where rising and warming seas could destabilize it. (All other ice sheets that survived the last deglaciation sit atop land.) The disappearance of the Ross Ice Shelf would lead to an acceleration of WAIS's glaciers and maybe major ice loss.

Alternating layers of diatoms and glacial debris from the ANDRILL cores revealed 60 cycles of advance and retreat of the Ross Ice Shelf over 14 million years, according to results reported last December. "The variation surprised us," says Timothy Naish, a paleoclimatologist at VUW, who co-led the 2006 ANDRILL effort and presented in April at the assembly of the European Geosciences Union in Vienna, Austria. Most striking of all was a 90-meter layer of green, diatom-rich sediment that evealed 200,000 years of biologically productive, ice-free sea starting 4.2 million years ago. "So as well as seeing variability," says Naish, "we're also getting this sense of extended periods when the West Antarctic Ice Sheet was very small, if not gone altogether."

For Lewis, an ice-free McMurdo Sound teeming with life at various points in the last 14 million years is consistent with having the Olympus Range maintained in a freeze-dried limbo if one factors in powerful katabatic winds screaming off the polar plateau. "There has to be a fairly big ice sheet perched right behind those mountains [in East Antarctica]," he says, "to blow all that cold air down the slope."

That the Ross Ice Shelf underwent major collapses rather than minor fluctuations is supported by glacial drop stones found in the 2006 ANDRILL core. The stones come from 300 kilometers south, where Byrd Glacier pours through the Transantarctic Mountains. Rocks scooped up by Byrd were delivered to McMurdo Sound because the Ross Ice Shelf bent the glacier's flow. But in sections of core showing open sea, rocks come from local sources. To Naish, it means that the Ross Ice Shelf was absent, or least too small to bend Byrd Glacier toward McMurdo.

The ANDRILL cores support a volatile view of West Antarctica and the Ross Ice Shelf that was emerging from earlier studies. In 1995, glaciologists drilled 1000 meters to the base of WAIS and found marine diatoms in the subglacial sediments. These diatoms, dated between 120,000 and 1 million years old, indicate an open sea and, hence, a major ice-sheet collapse.

Reed Scherer, the paleoecologist at Northern Illinois University in DeKalb who dated the diatoms, sees corroboration for WAIS collapse in other records. Beaches, corals, and water lines suspended in sea cliffs high above current water levels reveal major sea level spikes on at least three occasions during the time when Scherer's diatoms might have grown: at 125,000 years, 400,000 years, and 1.07 million years ago. The million-year-old event corresponds with an episode of open sea in the 2006 ANDRILL core. It also corresponds to a spike in 16O/18O ratios in marine cores worldwide, a sign that ice sheets had injected fresh water into the oceans, because ice sheets preferentially incorporate water molecules containing 16O over 18O.

One potential payoff from knowing Antarctica's history is a better understanding of how its ice will respond to global warming. The 90-meter segment of diatom-rich core that Naish helped drill in 2006 points to an open Ross Sea 4 million years ago, a time when marinecore records from other parts of the world suggest that CO_2 levels hovered around 400 parts per million, with global temperatures 3° to 4ºC warmer than today. Naish notes that those conditions correspond to optimistic predictions in last year's Intergovernmental Panel on Climate Change report of CO_2 levels in 2100. "If we can control our carbon emissions, we might be able to keep warming to 3ºC above present and stabilize CO_2 at 450 parts per million," he says. "But even at those levels, we don't have a West Antarctic Ice Sheet," implying that WAIS would disappear in the coming centuries.

Marchant and Lewis are already looking for fossils in other parts of the Dry Valleys. Ashworth advocates broadening the search to provide a more nuanced view of how Antarctica's two massive ice sheets have changed over time. For example, the East Antarctic Ice Sheet as a whole seems to have been stable over time. But some areas around its fringes sit on marine beds like WAIS does, and people would love to know more about the history of those areas. "All the way around the edge of Antarctica, you could have pockets of these fossils preserved," says Ashworth. "I've got this gut feeling that [more of] these deposits are going to be turning up." If he's right, what was once a rare discovery may someday become a standard tool for understanding the history of Antarctica's ice sheets and climate. **–DOUGLAS FOX**

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