MICROBIAL ECOLOGY

The Dark and Mushy Side of A Frozen Continent

Researchers are uncovering a wetter world under the Antarctic ice than they ever imagined. But it's far from clear which life forms call this extreme environment home

BIG SKY, MONTANA—Wetlands might seem incongruous in Antarctica's frozen wastes. But recent expeditions have uncovered a hidden landscape of lakes, marshes, and apparent rivers sandwiched between ice and rock. These vast wetlands, imprisoned under the ice, may even be teeming with life.

"There's water everywhere under there," says John Priscu, a microbiologist at Montana State University in Bozeman. At a meeting* here last month, Priscu and other experts compared notes on the latest tantalizing clues to what this unparalleled and largely unplumbed world might be like—and laid plans for exploring it.

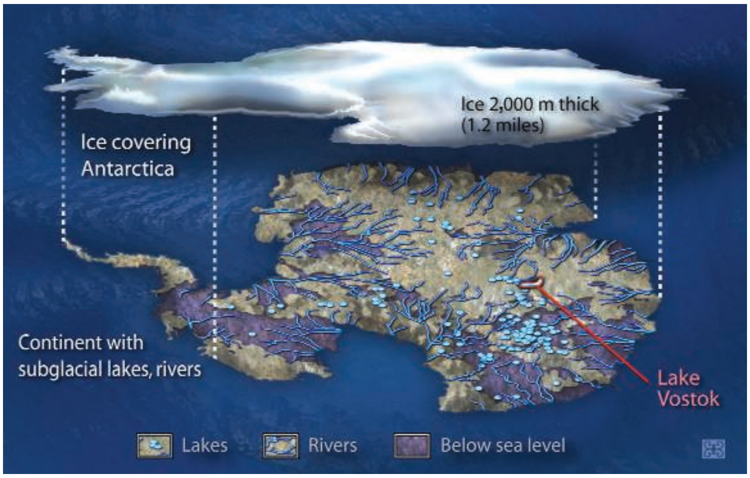
The first big plunge is likely to occur in Lake Vostok, the largest of Antarctica's 150-and-counting hidden lakes. A Russian-led team is preparing to penetrate and sample Vostok in 2009. The operation may help settle a point of sharp scientific dispute: whether the Connecticut-sized lake, overlain by more than 3.5 kilometers of ice, harbors microbial life. "We never thought life could exist down there," Priscu says. Now he's a believer. Other researchers are skeptics.

But experts concur that there's far more to Antarctica than meets the eye. "We're seeing a wide range of subglacial environments, from Lake Vostok to shallow, swampy environments," says Peter Doran, an earth scientist at the University of Illinois at Chicago. For now, the startling wetlands are terra incognita. Robin Bell, a geophysicist at Columbia University, says, "we've got a long way to go" before comprehending what's going on under the ice.

Peeking under the cover

The revelations about Antarctica's soggy, pitch-black underbelly have come mainly from drilling campaigns and radar mapping over the past decade. Drills that have bottomed out below the ice sheet have often hit water or warm, soft ice.

The ice blanketing the continent traps heat radiating up from Earth's core. That warmth, combined with intense pressure from the ice bearing down, allows water pockets under the sheet to keep their liquid form at normally freezing temperatures. All told, Antarctica's subglacial lakes contain around 10,000 cubic kilometers of water—about 10% of the fresh water in all the lakes elsewhere on Earth.



Water, water everywhere. An artist's rendition of aquatic Antarctica.

Antarctica's frigid water world is more dynamic than expected. Two recent studies found that some smaller subglacial lakes can roam around—they burst their banks and fill lower-elevation depressions. These findings hint at the existence of transient rivers, some as large, perhaps, as England's Thames—and raise the stakes on attempts to tap into the lakes. "We have to take a watershed approach," Doran says. If pollutants infiltrate a watershed, he says, "we may be contaminating things all the way downstream."

Although no subglacial lake has yet been pricked, researchers have drilled to within about 90 meters of Vostok's surface. Ice from this nether region is illuminating. When drilled down into from about 240 meters above the lake, the core changes from glacial ice, composed of compacted snow, to accretion ice, formed when Vostok water freezes to the ice sheet. Researchers have reported that accretion ice contains microbes that could be revived in the lab. Many scientists infer that these microbes were Vostok denizens, and other studies have shown that the microbes are close relatives of those found from Greenland to the Himalayas.

There are other signs of vitality as well. The sole sediment core under the ice sheet tested so far for microbes is brimming with life. In 2004, Brian Lanoil of the University of California, Riverside, and colleagues found that sodden soil under the Kamb Ice Stream in West Antarctica contained 10 million cells per gram—comparable to that of lake sediments found in temperate regions, and similar to sediments found under glaciers in New Zealand and Norway.

Glacial ice from the Vostok core is studded with modest numbers of microbes, around 100 cells per milliliter, according to studies led by Priscu and Brent Christner, a microbiologist at Louisiana State University in Baton Rouge. At the glacial-accretion ice transition, they reported last year in *Limnology and Oceanography*, the number rises to around 400 cells per milliliter. Accretion ice is also rich in organic carbon, Christner says. "This suggests that the lake is a source of both cells and organic carbon."

Other researchers think that the ice—and perhaps Vostok's waters—is largely sterile. Sergey Bulat, a molecular biologist at the Petersburg Nuclear Physics Institute (PNPI) in Russia, and his colleagues have also been probing the Vostok core for microbes and DNA. At the meeting, Bulat reported that his team often finds no cells in samples from both glacial and accretion ice, and never more than 20 cells per milliliter. (Bulat does put stock in one sign of life: His group has found that accretion ice contains DNA of bacteria similar to thermophilic species in vents on the ocean floor. Such microbes, he says, could be clinging to rocks around Vostok Lake and in lake sediments.)

The discrepancy between the Russian and U.S. cell counts could be due to different sampling techniques, says microbial ecologist Warwick Vincent of Laval University in Quebec, Canada. Whereas Bulat's team uses flow cytometry, Priscu and Christner count cells under a light microscope or scanning electron microscope. Or, says Vincent, "it could be that

* Subglacial Antarctic Lake Environments, 6–8 June.

CREDIT: ZINA DERETSKY/NSF

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there's a lot of heterogeneity in the ice core." Others argue that Priscu and colleagues have been led astray by an artifact. To keep the Vostok borehole from freezing shut, it's filled with drilling fluid. The hydrocarbons are a feast for bacteria. Says Christner: "We can think of the borehole as a 65-ton enrichment culture."

Irina Alekhina and her colleagues at the PNPI found that some microbes in the drilling fluid match species that Christner and others have found inside cores from Vostok and from the Taylor Glacier in Antarctica—microbes that they argued were native to the ice. The primary bacteria in the drilling fluid were Sphingomonas species, known contaminants of jet fuel—like the drilling fluid, mostly kerosene. "There is no indication for indigenous microbes," Alekhina concludes.

Priscu rebuts this by pointing to a study in Antarctica's McMurdo Dry Valleys in which his group found hydrocarbon-eating microbes. "The organisms are there in nature," Priscu says. "Just because we see it in the drilling fluid doesn't mean it's not native."

That debate notwithstanding, it's a mystery how microbes can survive deep in the Vostok core, which near the bottom could be 1 million to 2 million years old. If the cells had remained frozen all that time, "their genomes would accumulate enough damage that they would effectively be dead," Christner says. One microbial refuge might be the water channels between the ice crystals, says Buford Price, a physicist at the University of California, Berkeley. Christner and biophysicist James Raymond of the University of Nevada, Las Vegas, are testing whether the microbes are specially adapted to the cold life. Raymond found that one *Chryseobacterium* species from the Vostok core produces a protein that, in the lab, blocks ice-crystal growth. This suggests the bacteria are reshaping the ice around them to minimize damage, says Christner. The protein might work as antifreeze or as a seed for crystal formation to form an ice cocoon around the bacteria.

"This debate will not be resolved until Lake Vostok is sampled directly," says Vincent. When Russia breaks through, it will be like exploring a different planet. The drilling that has preceded this adventure has been "like putting pinholes in the continent," Priscu says. "We don't know what's on the bottom of that ice sheet." Well, we do know one thing: It's wet.

–MASON INMAN

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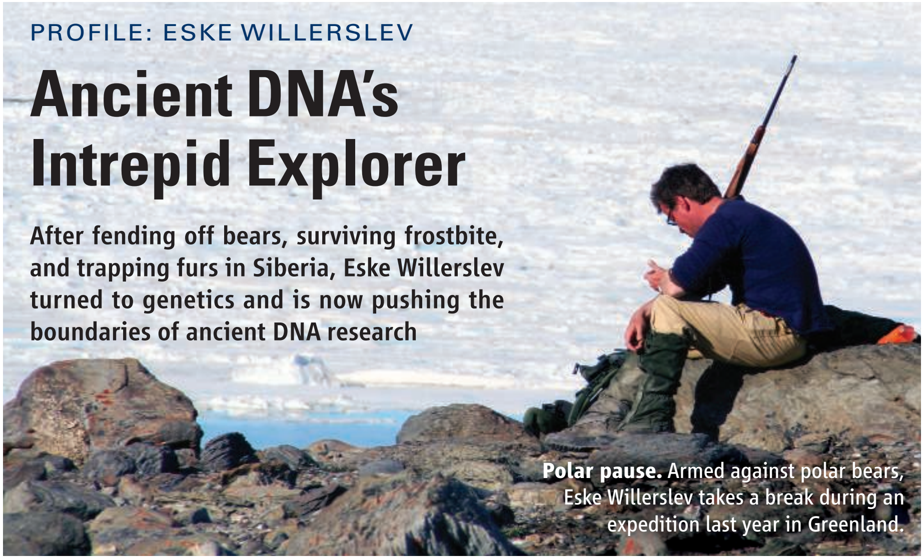
PROFILE: ESKE WILLERSLEV

Ancient DNA's Intrepid Explorer

After fending off bears, surviving frostbite, and trapping furs in Siberia, Eske Willerslev turned to genetics and is now pushing the boundaries of ancient DNA research



Polar pause. Armed against polar bears, Eske Willerslev takes a break during an expedition last year in Greenland.

CREDIT: SVEND FULLER

COPENHAGEN, DENMARK—In the basement of the Niels Bohr Institute in Copenhagen, Jørgen Peder Steffensen pulls a puffy pale blue parka over his t-shirt and shorts and steps inside a storage locker cooled to a constant –26°C. After digging through one of the hundreds of cardboard boxes stacked inside, the bearded climatologist lifts out a dirty, plastic-wrapped cylinder of ice about 55 cm long.

The frozen chunk was cut from the bottom of an ice core drilled through Greenland's ice cap in 1981 as part of a project to look at past climate. But this core bottom was considered too disturbed by the glacier above and too contaminated with silt and dirt from below to yield much information, says Steffensen. "I've taken care of this dirty, insignificant piece of ice for 26 years," he yells as refrigeration units thunder overhead. "It was only during discussions with Eske that we homed in on a use for it."

Eske Willerslev, the director of the Centre for Ancient Genetics at the University of Copenhagen, has spent the past 8 years teasing information about the distant past from discarded ice and even less likely places. Since first extracting DNA from glacial ice in 1999, the 36-year-old biologist has pioneered what he calls "dirt DNA"—the extraction and cloning of plant and animal DNA from just a few grams of soil and ice. In 2003, he redefined ancient DNA research when he extracted the 300,000- to 400,000-year-old DNA of mammoths, bison, mosses, and much more from small samples of soil he collected from the Siberian permafrost (*Science*, 18 April 2003, p. 407). It was the oldest DNA ever discovered by more than 200,000 years.

Not long after that, Willerslev began to wonder about the ignored ice core bottoms in the building his lab shared with Steffensen's climate research group. "I did the permafrost stuff, and then suddenly it hit me: Silty ice is icy permafrost, right?" Judiciously cutting and melting the core bottoms, Willerslev and his colleagues analyzed the resulting water for signs of DNA. What Willerslev found, and reports on page 111, broke his own record for the oldest DNA ever recovered, and promises to rewrite the history of Greenland's climate. His team identified and dated genetic sequences from coniferous trees, butterflies, beetles, and a variety of other boreal forest plants—traces of ancient forests that Willerslev says covered southern Greenland perhaps as far back as 800,000 years ago.

The results have impressed his colleagues in the close-knit, highly competitive ancient DNA research community. "To go from dirty water to a forest full of insects is pretty amazing," says Matthew Collins of the University of York in the U.K. "It's spectacular how far he appears to have gone back this time."

From fur-trapping to genetics

Willerslev and his identical twin Rane grew up reading about Danish legends such as Arctic explorer Knud Rasmussen and devouring *Buddy Longway*, a popular Belgian comic book that chronicled the adventures of a fur-clad American mountain man. "I always thought I was born 200 years too late," Eske says. "Exploring America in the beginning would have fit me perfectly."