PALEOBIOLOGY

Permafrost Comes Alive For Siberian Researchers

Long thought to be barren, the Arctic is yielding new information about life-forms on Earth—and the likelihood of finding similar organisms elsewhere

POINT CHUKOCHII, RUSSIA—Hydrologist Victor Sorokovikov yanks the threaded steel rods out of the hole in the tundra like a magician laboriously pulling one knotted handkerchief after another from a hat. The sun has broken through after several days of rain and snow, but even in August, drilling for microbes above the Arctic Circle is no picnic. With help from Dmitrii Fedorov-Davydov, a red-headed soil biologist with an encyclopedic knowledge of the tundra, Sorokovikov gives a final tug and the last hunk of metal emerges from a depth of 30 meters, its tip bearing a plug of what looks no more remarkable than frozen dirt.

But looks can be deceptive. The plug harbors millions of microbes that, once liberated from their Siberian prison, resume normal activity. This chunk of wind-blown sediment, deposited along the shores of Lake Yakutskoe 40,000 years ago and frozen ever since, may hold the key to understanding whether life could persist on Mars or other planets coated with permafrost. "If microbes can survive here for hundreds of thousands of years or more, why couldn't they survive on Mars?" asks expedition leader David Gilichinsky of the Russian Academy of Sciences' Institute for Basic Biological Problems in Pushchino, Russia.

Researchers gearing up for missions to Mars, Europa, and other cosmic bodies prepare by studying life in some of the harshest environments at home. Their venues range from ancient arctic permafrost and ice to antarctic lakes that haven't seen daylight for millions of years (see sidebar). But the work on the microbes themselves is proving far more interesting—and in some instances, disturbing—than scientists had ever imagined. "We're seeing things we've never seen before," says diatom expert Richard Hoover, astrobiology group leader at NASA's Marshall Space Flight Center in Huntsville, Alabama.

The first hints that permafrost may not be a sterile wasteland came in 1911, when Russian researchers reported that they had cultured bacteria from a mammoth unearthed in Siberia. Although many scientists suspect that modern bacteria had invaded the carcass, those findings—along with indications from later research that ancient permafrost soil may contain viable life—intrigued Gilichinsky, a geocryologist. In 1979 Gilichinsky, with microbiologists Dmitrii Zvaygintsev and Elena Vorobyova of Moscow State University, began hunting for microbes near where Russia's Kolyma River empties into the East Siberian Sea. His team quickly tapped a microscopic menagerie of bacteria, fungi, yeast, green algae, cyanobacteria, and mosses.

For years, however, he refrained from publishing out of fear that his group was inadvertently contaminating the samples. One reason for concern was the dearth of spore-forming bacteria, which cocoon themselves from freezes or droughts—the kind of hardy critters you'd expect to survive in frozen soil. So each year the researchers improved their equipment—settling on a dry drill that uses no chemicals or fluids—and refined their techniques, saving only the innermost core sections that never touch a septic surface. Gilichinsky's team is so careful, says Hoover, that "it would be hard to argue that what they're finding is a result of contamination."

Gilichinsky's group started publishing its findings in the mid-1980s, including a report of viable microbes from 3-million-year-old permafrost. Surprisingly, the scientists have found few microbes adapted to life in the cold. Aside from tending to be heavily pigmented, the ones they've dug up appear to be mostly run-of-the-mill species that survive in thin films of water that stay liquid even a dozen degrees below zero. Other strains may live in arctic cryopegs—underground marine ponds, tens of meters in diameter and a few

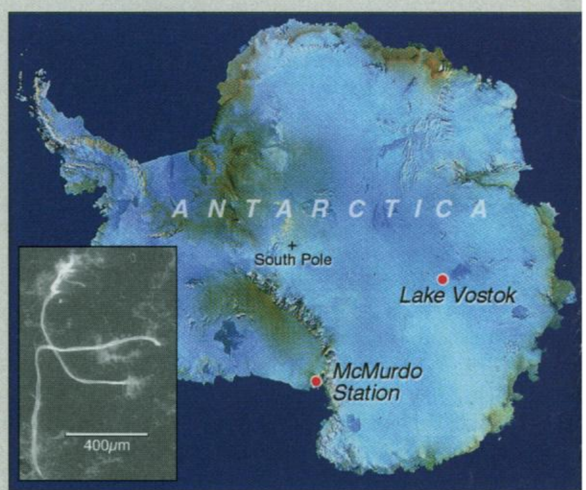
CREDITS: (INSET) R. HOOVER & G. JERMAN (NASA/MARSHALL SFC) AND M. IVANOV & S. ABYZOV (INSTITUTE OF MICROBIOLOGY, MOSCOW/RUSSIAN ACADEMY OF SCIENCES); (MAP) NATIONAL REMOTE SENSING LABORATORY/ SCIENCE PHOTO LIBRARY

Lake Vostok Probe Faces Delays

CAMBRIDGE, U.K.—Scientists have discovered tantalizing evidence that microbes are living under nearly 4 kilometers of antarctic ice, leaving them more eager than ever to explore a vast lake beneath the ice sheet. But a host of issues—including how best to probe for life, who should pay for the big-science project, and whether scientists should cut their teeth on smaller subglacial lakes—may delay any plunge into one of the world's most isolated ecosystems.

The scientific drumbeat to explore Lake Vostok began 3 years ago with a report that a body of water nearly the size of Lake Ontario lay beneath Russia's Vostok station in East Antarctica. Among those eager to tap into Vostok are space scientists, who see it as a good test-bed for a mission to search for life in an ice-covered ocean thought to exist on Europa, one of Jupiter's moons. At a meeting here earlier this week, 70 researchers from 14 countries argued that the exploration of a water body sealed from the rest of the world for millions of years should be a top priority for antarctic science. "If the point is only to test technology for a Europa mission, you might as well do that somewhere else" that's easier and cheaper, says glaciologist Dominique Raynaud, director of research for France's CNRS research agency. "But from what I have seen, I'm convinced the science is worth it." Adds Chris Rapley, director of the British Antarctic Survey, "It's one of the most high-profile and interesting projects of the next decade."

It's also expensive. Hopes that a Vostok mission could be mounted in 2001 for under $10 million (*Science*, 30 January 1998, p. 658) have been dashed as scientists learn more about the challenges it poses. The latest estimates indicate that developing the technology to avoid contaminating the lake and providing logistics for a full-scale Vostok mission could run $20 million or more, putting it beyond the reach of a single country. In addition, the U.S. planes needed for an expedition to the interior are already booked for the next few seasons ferrying construction materials for the new South Pole station. Seismic mapping surveys to pick a prime



Creature of the deep? Hoover and Abyzov found this and other unidentified filaments, possibly strands of a bacterial mat from the bottom of Lake Vostok that welled up and froze into the ice sheet.

meters thick, sandwiched between ice-hardened permafrost. Clinging to these life rafts, the microbes may derive nourishment from the ever-so-slow leaching of minerals and gases from the sediment into the water. But the Russian scientists, working with scientists at NASA and elsewhere, didn't think there were enough nutrients in these ponds for the microbes to reproduce and, thus, maintain a viable colony.

The biggest puzzle is how the microbes cope with DNA damage from background radiation. Radiation levels should have been high enough to kill off half the population in 200,000 years, prompting skepticism of Gilichinsky's initial reports of million-year-old microbes. But that calculation is based on the assumption that the microbes are in a resting state with no metabolic activity, and thus are not repairing their DNA. Gilichinsky believes that the microbes have sustained a modicum of unexplained metabolic activity—primarily to repair DNA and purge toxins—over the eons, although he admits he doesn't know how. Although the idea is far from proven, says Hoover, the permafrost findings show that "a lot of things scientists thought were constraints on microorganisms were simply wrong."

Raiding the ice box. David Gilichinsky (left) and team drill for ancient microbes in permafrost.

CREDIT: MUTSUMI STONE

The durability of the microbes raises the specter that the permafrost—a meat locker for countless carcasses of extinct mammoths and saber-toothed cats, not to mention a tomb for Stalin-era political prisoners and smallpox victims—could also harbor dangerous pathogens. During a visit to Siberia in 1990, Imre Friedmann of Florida State University in Tallahassee and a colleague came across a corpse, clothed like a native Yakutian, protruding from thawing permafrost. A local archaeologist, looking at the clothing, estimated that the person had died 100 to 300 years ago. "I immediately thought of smallpox, of course," says Friedmann. But "the body was buried fast and the matter forgotten." So far, says Gilichinsky, none of the microbes dug up at his site has resembled pathogens. Indeed, most bacterial pathogens—with anthrax a notable exception—do not develop durable resting forms, says Valery Galchenko of the Institute of Microbiology in Moscow. However, Gilichinsky's team has not sampled for viruses.

A more disturbing message has come from work on ice sheets. On one hand, scientists studying ancient microbes in the antarctic ice sheet have uncovered no lurking pathogens. Indeed, "we use masks to prevent *us* from contaminating the ice core," says Sabit Abyzov of the Institute of Microbiology. But in the July issue of *Polar Biology*, Scott Rogers of the State University of New York, Syracuse, and his colleagues report having detected RNA from the tomato mosaic tobamovirus in 140,000-year-old ice in Greenland. The RNA, more fragile than DNA, almost surely came from viral particles, although it's unclear if they are still infectious, says Rogers, whose group has also isolated more than 200 kinds of fungi, some 140,000 years old, from the ice. The find is not surprising, says Friedmann: Lacking an active metabolism, viruses "should be tougher survivors than bacteria." But it does raise the possibility that the ice sheets may serve as a viral reservoir that, with global warming, could continuously release ancient forms of microbes.

Gilichinsky doubts that his team will unleash any scourges, ancient or otherwise, but he's well aware of how his work can be misperceived. "Some religious people have come to me and said, 'If the organisms are dead, they are dead; we shouldn't bring them back to life' "—even though the microbes are, despite the odds, still alive. But Gilichinsky—who in 1991 kept working in Siberia despite news of the August putsch that toppled the Soviet government—has no plans to stop now. "It's important to at least know what is out there in nature," he says.

–RICHARD STONE

drilling spot could get off the ground within the next couple of years, but it may be 2004 or later before instruments reach the lake. Officials of NASA and the National Science Foundation (NSF) plan to meet next month to hash out a possible U.S. role.

Scientists hope that new data pointing to microbial life at Vostok will help them sell their governments on the importance of the mission. A joint French-Russian-U.S. program, which has spent a decade extracting ice cores at Vostok Station, stopped last year within about 120 meters of the lake after passing through 100 meters of refrozen lake water. Although the primary aim of the work has been to infer ancient climate patterns from the gases and particles trapped in the ice, scientists have also sampled the core for microbes. At the meeting, microbiologist John Priscu of Montana State University in Bozeman created a buzz with electron micrographs of what appear to be rod-shaped bacteria isolated from core samples of refrozen lake water. He's now analyzing DNA to try to classify the microbes.

Working on another piece of the same core, David Karl of the University of Hawaii, Manoa, ran a battery of tests to affirm life, such as measuring levels of ATP, an energy molecule vital to all known organisms, and tracing the incorporation of radiolabeled acetate into biomolecules. The sluggish biochemistry that his team saw, Karl says, "is consistent with a population growing very slowly." Although researchers were unable to detect any viruses, they confirmed the presence of bacteria, estimating that there are roughly 1000 cells per milliliter of meltwater. Sabit Abyzov of the Institute of Microbiology in Moscow and Richard Hoover of NASA's Marshall Space Flight Center in Huntsville, Alabama, who were not at the meeting, have also imaged what appear to be bacterial filaments and other microbes just above the lake.

With their appetites whetted, scientists want to know just how these and other lifeforms—if they are alive—can survive. But although further ice-core studies may give clues to which bacteria may colonize the ice-water interface, lake samples are needed to reveal what organisms, if any, live deeper in the water column or in the thick sediments coating the bottom. Despite the crushing pressures beneath the ice sheet, core studies suggest Vostok contains about as much dissolved organic carbon as do temperate lakes: "There's food down there," Priscu says. "I'd be very shocked if there is not microbial life," adds Jim Tiedje of Michigan State University in East Lansing.

Those who feel Vostok may be too ambitious have proposed starting with one of Antarctica's several dozen other subglacial lakes, including one under the South Pole that is 8 kilometers wide and at least 25 meters deep. "We should take into account all the possibilities," says Martin Siegert of the University of Bristol in the U.K., who is part of a team that has mapped many of the lakes but describes himself as "not anti-Vostok." But Erik Chiang of NSF, however, discounts any cost savings from such a mission, noting that the same technology would be needed to access either lake. If that's true, say most scientists, then Vostok's bigger potential scientific payoff should make it the preferred target. **–R.S.**