GLACIOLOGY

Russian Outpost Readies For Otherworldly Quest

VOSTOK STATION—In a dark storeroom carved into the antarctic ice at this remote outpost, Alexander Krassilev plucks what looks like a rolled newspaper wrapped in plastic from a wall lined with hundreds of cardboard cubbyholes. "This is some of the oldest ice on the planet," Krassilev says, gingerly cradling the opaque log in a hand heavily mittened against the chamber's constant –55 degrees Celsius. The ice sample started out as fresh snow 400,000 years ago; over the millennia, it was buried and crushed by another 3.5 kilometers of snow turned to ice. Trapped inside the ice are particles and gas bubbles that should reveal secrets of the Southern Hemisphere's ancient climate, and perhaps of the ice ages that periodically grip the entire globe. Krassilev offers his visitors a chance to hold this valuable key to Earth's past. "Don't drop it," he says lightly, his breath freezing into twinkling "diamond dust" that drifts to the packed-snow floor.

R. STONE

Vostok's ice man. Alexander Krassilev cradles a 400,000-year-old chunk of Antarctica's past.

The ice library that Krassilev, a drilling engineer from the St. Petersburg Mining Institute, has helped to build is the fruit of the most ambitious drilling project on the continent. From Russia's Vostok station—the coldest inhabited spot on the planet—researchers have extracted a frozen record that extends further back in time than any other ice core. The 120 meters of ice expected to be brought to the surface this season alone may represent as much as 100,000 years of supercompressed snowfall. Now this effort is about to end: Next month, drilling will stop after reaching a depth of about 3700 meters—just above the liquid surface of a lake the size of Lake Ontario, sandwiched between the ice sheet and bedrock.

The end of the drilling will leave Vostok station without a clear mission and with an uncertain future. There is a good chance that this aging and somewhat decrepit collection of buildings will be shut down for lack of funds, marking the end of Russia's continuous 40-year presence in the harsh antarctic interior—a tenure rivaled only by the U.S. base at the South Pole. "We can't say what will happen next year," says Nikolai Golosenko, Vostok's station chief in 1997.

But as the drilling winds down, researchers are eyeing a new project to take its place: exploration of the giant lake that now lies just beneath the drill bit. Isolated from the rest of the world for hundreds of thousands of years, Lake Vostok may contain exotic organisms adapted to its utter darkness. And because the lake resembles an ice-covered ocean thought to exist on Europa, one of Jupiter's moons, NASA is interested in joining the action. It is sponsoring an effort to design a probe that would penetrate Lake Vostok without contaminating it—an effort that would serve as a prelude to a mission to see if Europa harbors life. Researchers will meet in St. Petersburg, Russia, in March to plot strategy.

Vostok veterans see a fitting continuum between past exploits and this new challenge: Insights from the ice core may give hints about how Lake Vostok formed, says Vladimir Lipenkov of the Arctic and Antarctic Research Institute (AARI) in St. Petersburg. Deciphering the ice, he says, could be "a necessary relay between two great scientific endeavors: finishing the Vostok drilling and getting up steam for Vostok Lake." Exploration of the lake may not save Vostok station as a permanent base, however. The project, if it is given the go-ahead, could be accomplished from temporary buildings occupied for a few weeks a year. By the time it begins, sometime in the next decade, the old Vostok station could be buried in the drifts.

Core mission. The Soviet Union set up Vostok station in December 1957, during the International Geophysical Year—an event that many countries used as an excuse for establishing a toehold on the continent. The Soviets planted their flag at the south geomagnetic pole, at the time about 1300 kilometers from the geographic one. Since then, the Soviet Union has collapsed, and the shifting geomagnetic pole has wandered some 600 kilometers away. But Vostok has remained: a monument to perseverance staffed year-round, except for three winters when supplies ran short and the Russians had to evacuate the base.

For years, Vostok was renowned for the brutal monthlong overland traverse from the coast to the station, undertaken every December by snow tractor convoys carrying supplies for the coming year, and for the lowest recorded temperature on Earth's surface: –89.6°C (–128.6° Fahrenheit), set on 21 July 1983. *Vostochniki*, the scientists and staff members who get triple pay for the hardship assignment, have also gained fame for human drama. For instance, during the 1992 resupply traverse, with help days away, a man survived having his appendix removed under a local anesthetic.

Researchers have conducted a broad range of studies under these harsh conditions, including early groundbreaking studies of the polar magnetosphere. To most scientists, however, Vostok has become synonymous with the ice-coring program. The station sits atop a kilometers-thick ice sheet in East Antarctica that has accumulated over the centuries by just 1 to 2 centimeters a year, the rate of precipitation here. Drilling through this accretion provides a quick voyage through the continent's prehistoric climate.

The Soviet effort began in 1972; in 1984, another team joined in, led by Claude Lorius of the Laboratory of Glaciology and Geophysics of the Environment (LGGE) in Grenoble, France—which several years earlier had drilled a 900-meter core at Dome C, 600 kilometers from Vostok. Together, they drilled holes at Vostok more than 2000 meters deep and recovered an ice record extending back 160,000 years. Jean Jouzel of the French Atomic Energy Agency in Saclay and his colleagues then teased out the ice's climate secrets. They found, says LGGE director Dominique Raynaud, that the ice "exhibits in particular the remarkable correlation between greenhouse gases and past climate."

R. STONE

Tapping out. Vostok chief will oversee finale of world's deepest ice core.

To learn how global temperature has varied,

the researchers measured the ratio of deuterium to hydrogen, which in polar regions correlates directly to mean annual temperature: Because deuterium-containing heavy water doesn't evaporate as easily as water that contains ordinary hydrogen, a high level indicates a high global temperature. They also measured CO_2 trapped in bubbles in the ice. The findings dovetailed neatly: Carbon dioxide levels shot up at the end of the penultimate ice age, 140,000 years ago, and plunged at the start of the last one, about 100,000 years back. And about 10,000 years ago, as shallower ice cores in Antarctica and in Greenland have also shown, atmospheric CO_2 levels shot up again by almost 40%, a rise that may have helped end the last ice age. For the past 2 centuries, the Vostok core documented another rise of CO_2, this time because of human activity—evidence that became part of the scientific background to a climate treaty discussed in Kyoto last month.

As the Cold War thawed in the late 1980s, Russia invited U.S. researchers to join in further analysis of archived core samples and deeper ones expected from a new round of drilling. In exchange, the Russians asked for badly needed logistical support from the U.S. National Science Foundation (NSF)—flights to Vostok from McMurdo Station, the main U.S. antarctic base. Sending equipment and researchers from New Zealand to Vostok via McMurdo was much easier—and less harrowing—than by overland traverse.

Marine geochemists Todd Sowers of Pennsylvania State University in University Park and Michael Bender of Princeton were among the first to take up the invitation. They had developed a technique for comparing ice-core records in the Northern Hemisphere to those in the Southern Hemisphere based on the ratio of oxygen isotopes in air bubbles trapped in the ice. "It's a really exciting thing," says NSF glaciology program manager Julie Palais, that this technique "can help correlate the Vostok record to ice cores in Greenland." Comparisons have suggested that the Northern Hemisphere's climate has been more volatile than the Southern Hemisphere's, and that the onset—and end—of ice ages in the north triggered ice ages in the south.

In another north-south correlation, geologist Ed Brook of Washington State University, Vancouver, is working with Raynaud's group to compare rapid fluctuations in atmospheric levels of methane in the Vostok record to methane levels in Greenland cores and elsewhere, to clarify the role of this greenhouse gas in climate change. New ice-core projects at West Antarctica's Siple Dome—which gets about five times as much snow as Vostok, resulting in a more detailed climate record over the last 80,000 years to 100,000 years—and at Dome C, along with ongoing projects elsewhere on the continent (see table below), will also help researchers interpret the Vostok record.

Researchers had hoped that Vostok's last leg of drilling, which resumed on 20 December, would extend that record further back. But that is now in doubt. "Our main concern is that we found certain difficulties in penetrating warm ice," says Lipenkov, a glaciologist. Although ice near the surface is –55°C, geothermal heat rising from the bedrock has warmed ice near the core's bottom to about –6°C, and it's getting progressively warmer as drillers approach the lake. Lipenkov says that because of the warmth, the ice chipped off during coring probably melts and then refreezes, interfering with the drill head. He and others also worry that the slow sliding of the ice sheet over thousands of years has disturbed the lower ice layers and smeared the climate record. For the labs in France, Russia, and the United States that will decipher this climate record, the task could be like trying to interpret a garbled videotape played at fast forward. Indeed, "there are now serious doubts that the bottom ice contains climatic information," Lipenkov says.

ERIC BAKER

At the cutting edge. U.S. ice cores at Siple Dome should give sharper view of climate over last 100,000 years.

Another world. New prizes for science may wait below the ice, however, in Lake Vostok. With a surface area of some 14,000 square kilometers, Vostok is the largest of some 70 lakes underneath Antarctica's main ice sheet. It was discovered during airborne radio-echo surveys of the continent in the mid-1970s by Gordon de Q. Robin of the Scott Polar Research Institute in Cambridge, England, and his colleagues. Recent radio-echo and seismic surveys have found that Vostok is a body of fresh water, perhaps 600 meters deep in some places, with a thick sediment layer at the bottom.

Realizing their drill was approaching Lake Vostok, Russian scientists in 1994 asked the multinational Scientific Committee on Antarctic Research (SCAR) for advice on how to avoid contaminating the lake. The issue arose, in part, because the drill hole is filled with kerosene to prevent glacial ice from flowing like plastic and closing it up. "Drilling into the lake would badly contaminate the water and cancel any further studies," says LGGE's Jean Robert Petit. SCAR recommended that drilling stop at least 25 meters above the lake's surface, far enough to prevent seepage, experts estimated; Lipenkov says drilling is likely to finish closer to 100 meters from the surface.

Researchers are now exploring ways to design a probe that can examine the lake without contaminating it. One group taking up that daunting challenge is at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, which was stirred to action by images of Europa taken by the Galileo spacecraft 2 years ago. The images showed what appear to be vast ice floes similar to those in Earth's polar regions, and they revealed cracks in Europa's icy crust possibly made by heated ice or liquid water shifting below. After these revelations, other JPL researchers dropped by earth scientist Frank Carsey's office to talk about possible ways to penetrate Europa's ice sheet, estimated to be 2 to 20 kilometers thick. During the conversation, Carsey says, "I realized that going to Lake Vostok would be a definite benefit to somebody thinking about Europa."

JPL managers quickly agreed, giving Carsey and engineer Joan Horvath the go-ahead to begin planning an $8 million to $10 million Vostok mission. The JPL team started toying with the idea of using a cryobot: a robotic probe designed by Karl Kuivinen's group at the University of Nebraska, Lincoln, to melt its way into Greenland's ice sheet in summer 1996 to sample microparticles and test electrical conductivity. The tip of the cryobot,

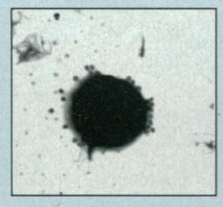
SELECTED ANTARCTIC ICE CORE PROJECTS

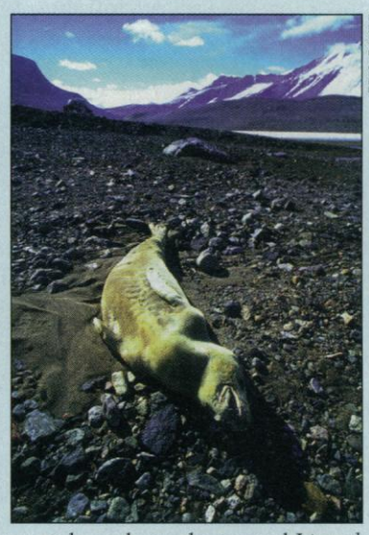
Project	Country	Elevation (m)	Core Depth (m) achieved	Core Depth (m) planned	Expected Time Record (years)	Status
Vostok	Russia/ France/U.S.	3488	3650	3700	500,000	Finishing 2/98
Dome C	European Union	3233	400	3250	250,000–500,000	Started 11/97
Dome Fuji	Japan	3810	2500	3090	200,000	Drill stuck
Siple Dome	U.S.	680	150	1000	80,000–100,000	Started 11/97

Exotic Marine Life in a Frigid Desert

TAYLOR VALLEY—As researchers gear up to explore Lake Vostok (see main text), they are speculating about the kinds of strange new creatures that might dwell in such a hostile environment, under nearly 4 kilometers of ice. They now have one intriguing candidate: mysterious viruses recently discovered in lakes in the McMurdo Dry Valleys.

The Dry Valleys—the continent's largest ice-free region—have long been regarded as one of the most extreme environments on Earth. Hurricane-force katabatic winds, which race unimpeded across the antarctic plateau, can whistle through here for days, polishing rocks into pyramid-shaped ventifacts and scouring the valleys of visible life. In the early 1970s, NASA prepared for its Viking missions to Mars by testing equipment in this rock-strewn wasteland.





CURTIS SUTTLE/UNIVERSITY OF BRITISH COLUMBIA

ERIC BAKER

Unearthly world. The inhospitable Dry Valleys are littered with mummified seals. But viruses, such as these appearing to attack a bacterium, thrive in the lakes here and may, perhaps, resemble extraterrestrial life.

But researchers soon realized that this unique desert ecosystem—the Dry Valleys get only traces of precipitation each year—may have another parallel to Mars: a series of perennially ice-covered lakes. Scientists have long speculated that Mars once had water and probably went through a phase where it had ice-covered lakes. "We started putting two and two together," says Bob Wharton, director of the Desert Research Institute (DRI), which runs a site here for the National Science Foundation's (NSF's) Long Term Ecological Research network. Antarctica's ice-covered lakes, he and colleague Chris McKay of the NASA Ames Research Center in Moffett Field, California, thought, might be a good model for martian lakes, prompting them to start an exobiology research program in the early 1980s.

Since then, biologists have been studying the relatively simple microbial food web that survives in the nutrient-starved lakes, consisting of bacteria, blue-green algae, phytoflagellates, and protozoa. Now, in four Dry Valley lakes, Wharton and his postdoc Ray Kepner have discovered a new ecosystem component: viruses. The viruses are so abundant, says Wharton, that "we think they are helping to control the microbial community." And they are a puzzle: So far the DRI team has detected only free-floating, extracellular viruses in the lakes. "The question is, 'What are the hosts for these viruses?' " asks Kepner.

Kepner first detected viruslike particles using a simple assay in two lakes during the 1995–96 field season. Last year, he brought samples back to the States and, with viral ecologist Curtis Suttle of the University of British Columbia, examined them under a transmission electron microscope. "Sure enough, we found viruses," Kepner says: icosahedral-shaped organisms similar in shape to viruses known to infect the kinds of microbes found in the lakes. "These are very intriguing findings," says NSF biology program manager Polly Penhale. The researchers have submitted their results to the journal *Limnology and Oceanography*.

Like the sunlight-deprived Dry Valley lakes, Vostok should have a similarly simple microbial food web whose species might also support viruses. Wharton thrills to the prospect of finding viruses that evolved in isolation in Lake Vostok for perhaps millions of years. "It's pretty exciting stuff," he says. Viruses in the Dry Valleys or in Vostok, if they exist there, may even resemble ancient martians. If organisms on the Red Planet were "relatively simple things well-adapted to the environment," he asks, "why wouldn't viruses have been a part of that as well?" Several billion years ago, says Dale Andersen, an astrobiologist at McGill University in Montreal, lakes similar to those in the Dry Valleys "may have been the site for life's last stand on Mars." –R.S.

shaped like a giant test tube, heats the ice; pipes inside the probe, which is connected to the surface by a coaxial cable, funnel the meltwater above it.

Any probe going through virgin ice would risk picking up bacteria and other microbes that live or lie dormant in the ice sheet and transferring them to the lake, however. "We fully appreciate that contamination is bad science," says Carsey. Not only for Vostok, but for Europa too: Exobiologists, who study possible life on other planets, "treasure the notion that Europa will be prebiotic," a chemical crucible that may resemble the Earth's oceans before life arose, says Carsey. Seeding such an environment with earthly organisms could alter the course of any future blossoming of life on Europa.

V. PAPITASHVILI

Relief column. The snow-tractor convoy arrived last month with supplies for what might be Vostok's last winter.

To avoid a biological calamity at Vostok, the JPL team has been working up designs to fit a cryobot with decontamination equipment. The simplest approach would be to attach a nozzle that bathes the cryobot in hydrogen peroxide, an oxidant that destroys microorganisms before breaking down to water and oxygen. "It's extremely benign material," says Carsey. However, it's unclear whether a hydrogen peroxide bath alone would be sufficient to kill off all life-forms hitching a ride on a cryobot. "We may have to augment that approach," says Carsey, who will be looking for new ideas next month in St. Petersburg.

That's not much comfort to environmental groups who have rallied opposition to NASA's plan. "Vostok's value to science is too important to be compromised for the sake of finding a method of exploring other planets," wrote the Antarctic and Southern

Ocean Coalition (ASOC) of advocacy groups in a letter to Carsey last August. The coalition urged JPL to consider other sites for a Europa analog mission. "It would be disastrous if they went ahead and contaminated the lake," says Beth Clark, director of the Washington, D.C.–based Antarctica Project and a co-signer of the ASOC letter.

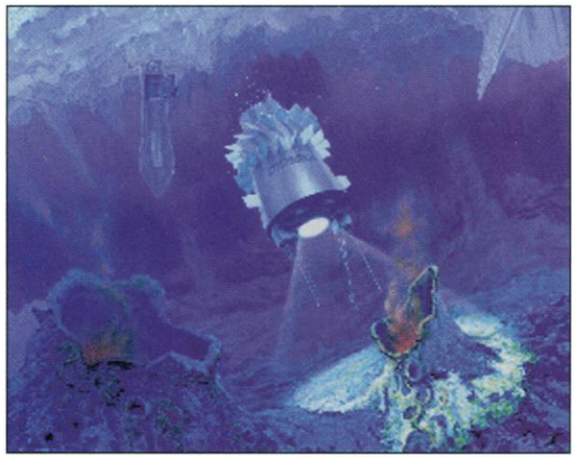
If they can overcome these hurdles, the JPL team next season plans to test a cryobot at the U.S. summer drilling camp at Siple Dome. If that goes well, in the summer of 2000 the researchers will have "a real dress rehearsal," Horvath says: They plan to send a cryobot through an ice shelf and into the Ross Sea.

Afterward, a run at Lake Vostok could come as early as 2001. The latest plan calls for blasting down to about 200 meters above the lake surface with a standard hot-water drill. (Because of the risk of contamination with kerosene, they would not use the existing drill hole.) "It would take a day or two to get down there" from the surface, Horvath says. Next, they would deploy a cryobot, about 3 meters long and 15 centimeters wide, that would melt its way into the lake on a one-way trip. After penetrating the lake, the cryobot would release a second robotic device: a hydrobot, a miniature underwater vehicle that will serve as a scout for the scientists monitoring it above.

The modest goal of the first run is to "find out what the heck is down there before investing in specialized instruments," says Horvath. The first hydrobot, she says, will probably be equipped only with a camera and perhaps an instrument for measuring biochemical signs of metabolic activity. Later versions could explore the water composition with miniature sensors—such as a mass spectrometer that fits in a coffee mug—that JPL is developing for planetary missions. But the initial priority, Horvath says, is to "see if there's anything alive down there."

Just how long any organisms may have been isolated in the lake is a subject of avid speculation. The last global warming that lasted long enough to melt Antarctica's ice sheets and expose Lake Vostok to daylight and fresh air occurred millions of years ago. But it's doubtful that organisms evolved in isolation that long. The oldest ice at the lake's surface is no more than a million years old—older ice has been squeezed out or has melted into the lake. Scientists suspect that this gradual mixing has provided a port of entry for microorganisms. Yeasts, unicellular algae, diatoms, and spore-forming bacteria "are seed material that might be going into this lake," says Peter Doran, a biologist at the Desert Research Institute in Reno, Nevada, who specializes in antarctic lake biology.

What actually could survive in the lake is another question. Researchers suspect that Lake Vostok has very few nutrients and is pitch dark, but the 100-meter-thick bottom sediments may help nourish organisms. "It will be a completely microbial food web," Doran predicts, consisting of bacteria, viruses, or other critters that don't depend on light. "You aren't going to find fishes swimming down there," he says. Still, says Desert Research Institute director Bob Wharton, "I would be really surprised if there wasn't life in that water."

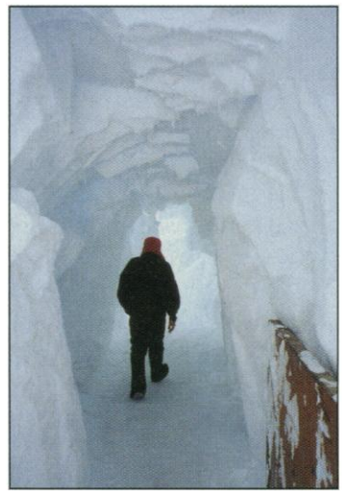


JPL

Strange new world. Hydrobot probing Lake Vostok's bottom, according to artist's rendition.

Researchers don't have to go far to get a better idea of what these life-forms might look like. Similar to Vostok is a series of perennially ice-covered lakes in the McMurdo Dry Valleys, a short helicopter ride from McMurdo Station. Microorganisms in these lakes, including mysterious viruses recently discovered there (see p. 660), may provide a preview of Vostok's menagerie.

Vostok's future. As they devise a strategy for exploring the lake, the JPL crew is working on the assumption that Vostok station won't be operating by the time they get there in 2001. Many of the station's current buildings are already almost completely covered by drifted snow and can be reached only through hand-shoveled tunnels. One key facility, a magnetics observatory, is buried under 3 meters of snow and has to be entered by a trap door. "I gathered there are quite a few other buried buildings out there, but people have forgotten where they are," says one foreign scientist who visited last year. Some doors are off their hinges and don't shut properly. While well-heated, the quarters for the 24 summertime researchers and workers and the dozen or so who will stay during the winter are cramped and aging. "There's a definite air of neglect about the place," says the scientist. "I'm filled with admiration—well, it's probably more like pity—for the men who spend an entire year there."



V. PAPITASHVILI

Losing ground. Snow tunnel is only way to reach this Vostok building.

An even bigger threat to the station than decay is the end of U.S. logistical support to Vostok, scheduled for next month, when the drilling ends. This season, NSF ran six flights to the station bringing personnel and vital supplies, from explosives to fresh food to alcohol. But without the drill project to support, says NSF Antarctica representative Dwight Fisher, "I don't think we'd fly there just to fly there"—particularly when flights will be at a premium in the coming years as work on the new South Pole station ramps up.

The Russian Antarctic Expedition (RAE) has pledged to keep Vostok operating through the next austral winter. After that, all bets are off. Russia is unlikely to keep the station supplied on its own, observers say. Short of cash to buy spare parts for its snow tractors, RAE has been running just one tractor traverse, instead of two, from its coastal Mirny station and has been forced to close Vostok two of the past four winters because the caravan could not bring in enough fuel. In what could be a bad omen, the vagaries of Russia's science funding have just claimed a new antarctic victim: The RAE plans to close its main base, Molodyozhnaya, in East Antarctica in a year or two.

Even if Vostok is shuttered, it could be reopened for the lake experiments. In that case, however, researchers probably will need a new building on site for controlling the cryobot and analyzing data. In addition, says Doran, "we will have to build new facilities, superclean facilities, if we do biological sampling." For Russian researchers eager to take part in the exploration of Lake Vostok, collaboration with JPL seems the best hope. "We are ready and glad to cooperate," says AARI's Sergey Verkulich, part of a group developing a Lake Vostok research plan. That may be just the ticket for ensuring Vostok station's survival—and Russia's presence in the antarctic interior—for years to come.

–Richard Stone