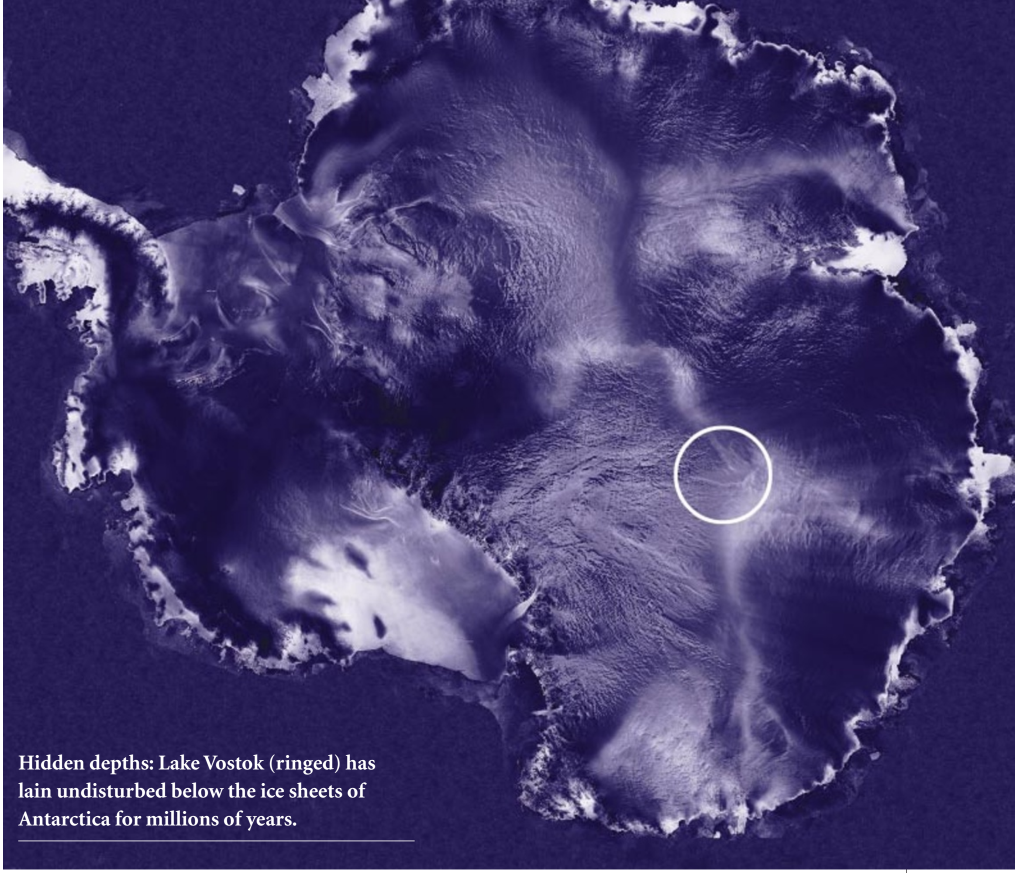
news feature

Life in the deep freeze

Unknown ecosystems and untapped records of the Earth's past may lie hidden in the lonely waters of Antarctica's Lake Vostok. But the lake's millions of years of isolation may be about to end, as Helen Gavaghan reveals.



Hidden depths: Lake Vostok (ringed) has lain undisturbed below the ice sheets of Antarctica for millions of years.

NASA

Had the biologists not intervened, a unique source of data might have been damaged for ever. Drilling innocently through the ice sheets that cover Antarctica, a team of climate researchers at first had no idea that they were also heading towards a valuable biological resource: a huge subglacial lake languishing in near-isolation some 4,000 metres below the ice.

The drilling started in 1989, when scientists based at the Russian Antarctic research station of Vostok launched a project to obtain information on the Earth's climate history from Antarctic ice crystals. But as evidence for the existence of the lake, now dubbed Lake Vostok, accumulated in the early 1990s, serious questions were raised about how deep the borehole should be.

To biologists, Lake Vostok offered potentially rich pickings. If it has remained isolated since the Antarctic ice sheet formed, perhaps as much as 20 million years ago, novel ecosystems may have developed in its waters. Sediment on the lake's floor could tell the history of that life, and of the ice sheet above it. But much of the biological value would have been lost if unsterilized drilling equipment had contaminated the lake's waters.

In 1995, biologists Cynan Ellis-Evans and David Wynn-Williams of the British Antarctic Survey in Cambridge attended a meeting at the nearby Scott Polar Research Institute, where researchers were discussing the drilling project. "We spent two days educating them about the potential biology of the lake," recalls Ellis-Evans. At the end of the meeting, the group reached a consensus that the drilling should stop before it reached the lake. It was duly halted in 1998, with the borehole some 120 metres from the lake's surface.

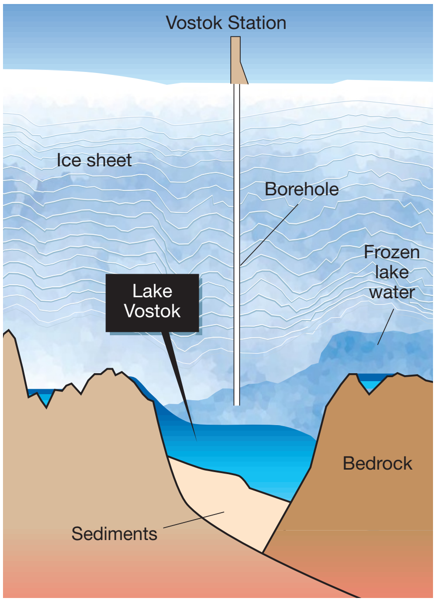
Curiosity about the lake and others in the area has grown since then, and ambitious plans to explore the area will soon be finalized. But although the case for halting the drilling was clear, deciding what to do next has proved to be far more complex. Antarctic exploration is expensive, and for a project on this scale, the needs of researchers from the different disciplines and countries involved have to be balanced. Even if funds can be raised and a consensus reached, the technological challenges of entering an almost pristine ecosystem without polluting it are considerable.

Breaking the ice

The job of overcoming these obstacles rests with an international, multidisciplinary team that is designing a strategy for exploring Vostok and other subglacial lakes in the east Antarctic. The group met for the first time in Bologna, Italy, last November, where it outlined a plan to access Lake Vostok at two places in three to six years' time[1]. Sediment would be recovered around three years later. Refined plans will be released at a meeting in Shanghai in July, and about 10 nations are expected to participate in the project.

Drilling through to Vostok remains "the jewel in the crown", says John Priscu, an ecologist at Montana State University in Bozeman, who chairs the exploration group. But the group's remit extends to all the subglacial lakes in the region, 86 of which have now been identified[2], although other large lakes may still await discovery. At the Bologna meeting, Ignazio Tabacco, a geophysicist from the University of Milan, presented evidence which suggested that some of the other known lakes may be linked together. The group might decide to enter one of these as a test run, but it is Vostok that is getting the lion's share of the attention. The lake has been mapped in far more detail than the others, and no larger body of subglacial water has yet been found in the region.

Formed in a geographical basin similar to a rift valley, Lake Vostok is at least 240 km long by 50 km wide. The latest depth analysis by Russian scientists, carried out by studying how the ice, water and lake floor reflect sound and radio waves, reveals a body of water that is up to 1,200 metres deep, and a lake bottom that is covered by sediments which can reach hundreds of metres in thickness[3]. Although the temperature of the lake is



The borehole beneath Vostok station extends into areas of frozen lake water.

ADAPTED FROM: M. STUDINGER/R. E. BELL/LAMONT-DOHERTY EARTH OBSERVATORY about −3 °C, it is prevented from freezing because of the extreme pressure generated by the weight of the ice sheet.

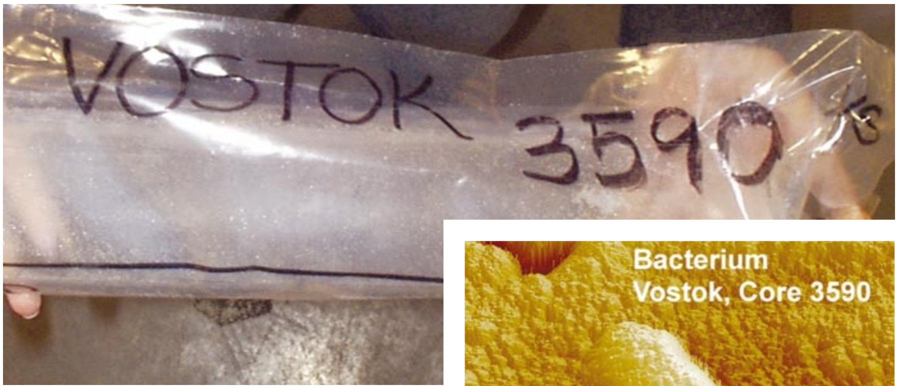
For Priscu and his fellow biologists, the lake's allure is its environment: total darkness, low nutrient levels, a pressure of 380 atmospheres and almost complete isolation from the atmosphere for millions of years. Life has been found in other harsh habitats, such as under Alpine glaciers and in geothermal springs. Biologists studying such areas always find something new, says Ellis-Evans. He cites the example of the enzyme *Taq* DNA polymerase, which was discovered in microbes living in the hot springs of Yellowstone National Park. Unlike most other enzymes, *Taq* DNA polymerase is stable at temperatures of around 70 °C. It now forms an important part of the polymerase chain reaction used to amplify DNA sequences in the laboratory.

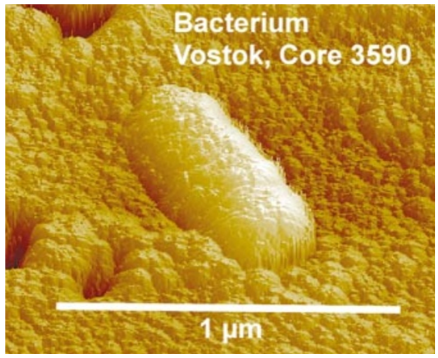
Life under a glacier

Already, there are hints that life may exist in Lake Vostok. The borehole that nearly reached the lake in 1998 was drilled to extract ice that originally fell as snow hundreds of thousands of years ago. But as the hole passed around 3,500 metres in depth, researchers noticed changes, such as the appearance of large ice crystals, in the ice they were recovering. Analysis of these samples suggested that they were frozen lake water.

The samples contained no climate information, but they did provide biologists with the first extracts from the lake itself. Two studies, published in 1999, revealed the presence of life, including organisms related to modern-day Actinomycetes and α- and β-proteobacteria[4,5]. Microbiologists have already been surprised by the unusual metabolic quirks shown by some α-proteobacteria[6] from other environments, which makes it likely that life in Lake Vostok will offer some interesting twists.

Based on the sample analysis, researchers estimated that the lake would contain a hundred thousand to a million microbes per millilitre[4]. But Priscu and, independently, Sergey Bulat of the Petersburg Nuclear Physics Institute, now say that levels may be as low as a few hundred per millilitre. An isolated Alpine lake, by comparison, might contain tens of millions of microbes per millilitre.





J. C. PRISCU

Signs of life: ice cores from deep within a borehole in Antarctica have yielded bacteria (right) which may have come from Lake Vostok.

Priscu cautions against relying too heavily on the ice samples, pointing out that microbes in the ice from the surface of the lake may not be typical of life elsewhere in the lake, or in the sediment. It is also possible that microbes may have been transferred to the ice from the drilling equipment, an effect that researchers try to minimize by working with samples from the centre of the ice core. But Bulat has studied the microbes found in the kerosene fluid used by the drill to deliver hydraulic power, and says that this fluid appears to be the source of at least some of the life found in the core.

Cold comfort

The small amount of ice that biologists currently have to work with also hampers the analysis. So a Russian proposal, made at the Bologna meeting, to drill another 50 metres into the existing bore is likely to find favour. But other issues remain unresolved. The microbes may, for instance, be entering the lake by sinking slowly through the ice sheet.

Starved of data from the water itself, researchers are currently trying to work out how life may have survived in the lake. Nutrients, for example, could be supplied by melting at the base of the glacier. Geologists believe that the bottom of the ice sheet is melting at the north end of the lake and freezing at the south. If this is correct, organic material, minerals and oxygen that have sunk through this glacier could be entering at the north of the lake. At the same time, friction between the water and sediment on the lake floor could release further nutrients into the water.

But any life that is present will still need an energy source to make use of these nutrients. With no light reaching the lake, the only source would appear to be the energy released by reactions involving the sulphides and the organic matter that are entering the lake. If so, the distribution of this matter by the circulation of water will have a big effect on the lake's ecosystem. Geothermal heating is likely to play a role in the circulation, although studies of the chemical composition of the lake ice have ruled out the possibility of major hydrothermal activity on the lake's floor[7]. Several models of the circulation, based on the likely heating and the density difference caused by the melting glacier, have been proposed, but only entry into the lake will determine which is correct.

How to reach the lake without contaminating it is another open question. Adapting technology used by the oil and gas industry in the Arctic seems the most likely alternative. At the Bologna meeting, Erik Blake of Icefields Instruments in Yukon, Canada, described how the drilling fluid is delivered through a ▶

J. R. PETIT/EXTRA-POL/EURELIOS

Core issues: samples of ice from below the Antarctic ice sheet await analysis at the Russian Vostok station.

ITALIAN ANTARCTIC PROGRAMME

Planning a breakthrough: the team plotting exploration of Vostok at last year's Bologna meeting.

tube that is slowly uncoiled as the borehole deepens. This prevents the fluid from coming into contact with the ice. Although the technology would have to be adapted for lake entry, the drill could pass through the Vostok ice sheet within six to eight days, says Blake.

The exploratory group also faces the problem of how to limit contamination from the drill-bit itself. Zero contamination is impossible, so the researchers are working to define an acceptable level of sterility for the drilling rig ready for the July meeting.

A drop in the water

They are also discussing how best to sample the lake water. Temperature, salinity and profiles of ion levels are likely to be the first measurements taken, and this will be done by stringing together several instruments and lowering them to the base of the lake.

Sample return will then follow. But designers of the instruments for this step face a tough task, as the borehole is likely to be no more than 10 centimetres in diameter. The large size of the lake and the low density of life within it mean that huge volumes of water need to be studied — an impractical proposition given the size of the borehole. Instead, researchers are considering lowering a pump into the lake, and retrieving the filter once a certain volume of water has been passed through it. In the long term, miniature remotely operated vehicles could be used. The technology to achieve this and the next step — drilling into the sediment on the lake floor — already exists, but several years of development will be needed to address the contamination issue and adapt it for use in Vostok.

For many researchers, recovery of sediment samples is the ultimate goal. A sediment core could, for example, shed light on the history of Antarctica's ice sheet. Some geologists contend that it has collapsed and reformed on one or more occasions during the past 20 million years. If they are correct, says Peter Barrett, a geologist at Victoria University of Wellington in New Zealand, cores from the lake floor will contain gravelly layers and rough surfaces resulting from the scouring of ice on the lake floor. The sediment interests evolutionary biologists as well, because it might contain a continuous record of the evolution of life in the lake.

Sediment samples could also clear up a problem in another discipline. Researchers modelling the Earth's past and future climate need an accurate measure of how global temperatures have changed over time. An important source of information is the ratio of two isotopes — oxygen-16 and oxygen-18 — in the shells of microfossils found in seafloor mud. The rate at which these isotopes are incorporated into the shells depends on the temperature of the surrounding water, so measuring the ratio of the isotopes reveals the temperature of the sea in which these creatures once lived.

But only recently formed fossils provide reliable data, because temperature is not the only factor that can increase oxygen-18 levels in the shells. Oxygen-16 evaporates more rapidly from water than its heavier sibling. At some periods during the Earth's history, a fraction of the evaporated oxygen-16 would have been trapped in polar snow rather than recycled into the oceans, further increasing the ratio of oxygen-18 to oxygen-16.

Weighty issues

Reliable temperature measurement depends on knowing how much each process contributes to the ratio. For the 18,000 years since the last ice age, researchers are confident that temperature accounted for roughly one-third of the oxygen-18. But, says Barrett, "the further back we go, the more ambiguity there is in interpretation of the oxygen-18 data".

Lack of knowledge about how much oxygen-16 was locked up in snow is one cause of the uncertainty, and one which a better knowledge of the history of the Antarctic ice sheet could help to rectify. So sediments from Lake Vostok could lead to a better record of the Earth's temperature history, and hence help to improve models of past and future climate.

With so much interesting work to be done, few would dispute the scientific value of entering Lake Vostok. But scientific consensus will not be enough by itself to get the project funded. When the interested parties sit down this summer, the degree and type of contribution that each could make are likely to be hotly debated. US involvement is essential, as the country currently runs the best-funded Antarctic research programme. Russian ownership of the Vostok base means that their contribution is equally vital.

The participants will have to dig deep, as Antarctic science does not come cheap. The US National Science Foundation, for example, allocated US$500,000 for an airborne survey of Antarctic lakes during the 2000–01 summer. Among other things, the money paid for a temporary camp near the Russian base. But after factoring in expenditure on aircraft, research stations, logistical support and data analysis, the total cost of the project rose by an order of magnitude. Exploration of Antarctica's lakes will cost tens of millions of dollars.

The researchers will also have to convince environmental activists that they have fully addressed the contamination problem. The Antarctic and Southern Ocean Coalition, an environmental pressure group, has in the past opposed entry into the lake. And although environmental assessments are carried out before any new Antarctic research project, nothing on this scale has been attempted before.

Antarctica will be in its dark, cold winter when the key scientific players unveil their plans for subglacial lake exploration this summer. By then, it will be over four years since drilling stopped just short of Lake Vostok's surface. If a deal can be struck, the freezing depths may at last yield their secrets. ■

Helen Gavaghan is a freelance journalist based in Yorkshire.

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M. STUDINGER

Which way is down? Signs at the Vostok station.