ANTARCTICA'S SECRET GARDEN

SAMPLES FROM A LAKE HIDDEN UNDER 800 METRES OF ICE CONTAIN THOUSANDS OF MICROBES AND HINT AT VAST ECOSYSTEMS YET TO BE DISCOVERED.

BY DOUGLAS FOX

John Priscu carries a sample from subglacial Lake Whillans.

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A cold breeze blew off the Antarctic plain, numbing the noses and ears of scientists standing around a dark hole in the ice. Flecks of ice crackled off a winch as it reeled the last few metres of cable out of the hole. Two workers in sterile suits leaned over to grab the payload — a cylinder the length of a baseball bat — dangling at the end of the cable. They used a hammer to chip away the ice and a blow drier to thaw part of the assembly. "Did it close?" asked the winch operator.

"Yeah," shouted John Priscu, a microbial ecologist from Montana State University in Bozeman. The cylinder rested heavily in his gloved hands — evidence that it had filled with water and sealed shut before its long journey to the surface. The fluid inside came from one of the most isolated bodies of water on Earth: Lake Whillans, trapped beneath 800 metres of ice just 640 kilometres from the South Pole. Hardly a word was spoken as Priscu hefted the vessel against his shoulder and shuffled into a metal shipping container, where the team had set up a cramped, makeshift laboratory.

That water, obtained on 28 January 2013, was the first sample ever retrieved directly from a subglacial lake. Although Priscu and other scientists had long yearned to explore Antarctica's hidden lakes and look for resident life, efforts to drill into them have been stymied by the threat of contamination, which would cast doubt on any life found and could introduce invasive organisms into the lake. Priscu and his team spent six years devising safe sampling procedures, and then had to surmount numerous logistical hurdles, such as transporting hundreds of tonnes of equipment to the remote site.

The researchers have been studying the samples since they reached the lake and have found that an abundance of life lurks beneath Antarctica's blanket of ice. In this week's issue of *Nature*[1], Priscu and his team report finding 130,000 cells in each millilitre of lake water — a density of microbial life similar to that in much of the world's deep oceans[2]. And with nearly 4,000 species of bacteria and archaea, the community in the lake is much more complex than might be expected from a world sealed off from the rest of the planet. "I was surprised by how rich the ecosystem was," says Priscu. "It's pretty amazing."

Samples from the lake show that life has survived there without energy from the Sun for the past 120,000 years, and possibly for as long as 1 million years. And they offer the first look at what may be the largest unexplored ecosystem on Earth — making up 9% of the world's land area. "There's a thriving ecosystem down there," says David Pearce, a microbiologist at Northumbria University, UK, who was part of a team that tried, unsuccessfully, to drill into a different subglacial body, Lake Ellsworth, in 2013. "It's the first time that we've got a real insight into what organisms might live beneath the Antarctic continent," he says.

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LIFE ON ICE

The ice above Lake Whillans is mind-numbingly flat, making it nearly impossible to imagine that anything unusual hides beneath it. I first travelled there in 2007 as a journalist covering a scientific expedition to the lake, which had been discovered earlier that year through remote satellite measurements. I returned in January 2013, embedded as a reporter with the team that Priscu led with two other scientists to sample the lake. That project, called Whillans Ice Stream Subglacial Access Research Drilling, involved collaboration between nearly two dozen researchers from 15 universities across five countries. The US National Science Foundation had invested roughly US$20 million in the effort, which included building a hot-water drill to get into the lake without contaminating it.

The idea that lakes might lurk beneath Antarctica's frozen cover was not widely considered until the 1990s, when ice-penetrating radar and seismic mapping yielded the first solid evidence of subglacial lakes. Nearly 400 are now known. They are fed by water that melts from the base of the ice sheet at rates of a few millimetres per year, caused by ambient heat from deep within the planet (see 'Invisible lakes').

Lake Whillans resembles nothing on Earth's surface. The weight of the ice forces the subglacial water upwards, causing the lake to sit at a slant on the side of a hill. It is a thin lens of water — only 2 metres deep and nearly 60 square kilometres in area — held in a pocket of low pressure created by the thinning of the ice sheet as it oozes over the hill.

The drill camp materialized on this lonely frontier in January 2013, when tractors arrived pulling shipping containers on massive skis. In their two-week journey from the coast, the tractors hauled 500,000 kilograms of gear and fuel, mobile labs, a machine shop and a hot-water drill that filled six cargo containers. Within two weeks, the camp was a noisy, industrial place, populated by three dozen people, a flock of tents flapping in the steady breeze and two roaring 225,000-watt generators. The polar summer resembled a mild winter in Minneapolis, Minnesota, with temperatures 5–15 °C below freezing.

It took seven days to drill through the ice sheet. To prevent contamination of the lake, the crew used ultraviolet radiation, water filtration and hydrogen peroxide to sterilize the machinery and the water used to bore through the ice. As the team neared the lake, progress slowed to a crawl when difficulty in steering the drill bedevilled the crew for an agonizing 36 hours.

At 7:30 a.m. on 27 January, a voice crackling through a handheld radio summoned me to the drill control room. Inside, six ice drillers in overalls stared at a computer screen showing a line shooting upwards on a graph, indicating that the water in the borehole had risen 28 metres, pushed up by a gush of water from the lake below. The lake was a balmy −0.5 °C, warmer than the drill camp that day.

The researchers pulled up the first sample the next day. Within minutes of raising the grey vessel, they decanted its contents: a honey-coloured broth that turned out to be richer in minerals than anyone had expected. The first cells were spotted several hours later under a microscope — green dots lit up by DNA-sensitive dye. Tests done over the next several days confirmed that those cells were alive. Twenty scientists and graduate students worked around the clock to collect 30 litres of water and several sediment cores from the lake. Before the hole froze shut, the team also measured the water chemistry in the lake and geothermal heat flowing up through the sediments. Sample boxes accumulated in a cave dug out of the snow on the edge of camp.

Over the past year, researchers have worked with those samples to assemble a portrait of life beneath the ice sheet. They have isolated and grown cultures of about a dozen species of microbe. And DNA sequencing has revealed signs of 3,931 species in all — many of them related to known microbes that break down minerals for energy.

Although contamination is always a concern, researchers not connected with the Lake Whillans project say that the sterilization precautions seem to have worked well. One sign is that the microbial density of the drilling water in the hole was 200 times lower than that of the lake samples, says Peter Doran, an Earth scientist at the University of Illinois in Chicago, who worked with the US National Research Council for ten years to develop guidelines for sampling Antarctic lakes cleanly. Doran was convinced by the evidence of diverse microbial life in the lake. "They found it in such a way that it can't be questioned. It's pretty iron-clad," he says.

VITAL SIGNS

Overall, life in Lake Whillans works much like ecosystems at the surface, but its deep denizens do not have access to sunlight and so cannot rely on photosynthesis for the energy needed to fix carbon dioxide dissolved in the lake water.

The genetic analyses by the team show that some of the lake's microbes are related to marine species that derive energy by oxidizing iron and sulphur compounds from minerals in sediment. But according to the DNA data, the lake's most abundant microbes oxidize ammonium, which is likely to have a biological origin.

"The ammonium is probably a relic of old marine sediments," says Priscu, referring to dead organic matter that accumulated millions of years ago when the region was covered by shallow seas rather than glaciers.

Only single-celled bacteria and archaea have turned up in samples from Lake Whillans — but the particular DNA tests used so far were not designed to detect other types of organism. This preserves the possibility that Lake Whillans might yet be found to harbour more complex life, such as protozoa — or even sub-millimetre animals such as rotifers, worms or eight-legged tardigrades, all known to live in other parts of Antarctica. Air bubbles in the overlying ice supply oxygen to the lake, so that is not a limiting factor. But the low rate of carbon fixation by microbes might provide too little food for multicellular life.

Lake Whillans receives about one-tenth the amount of new carbon per square metre per year as the world's most nutrient-starved ocean floors, which support sparse animal populations. Although the chances are slim that Priscu and his colleagues will find animals in Lake Whillans, they plan to look for them using better-tailored DNA assays. For now, the researchers are puzzling over the origins of the microbial residents of the lake.

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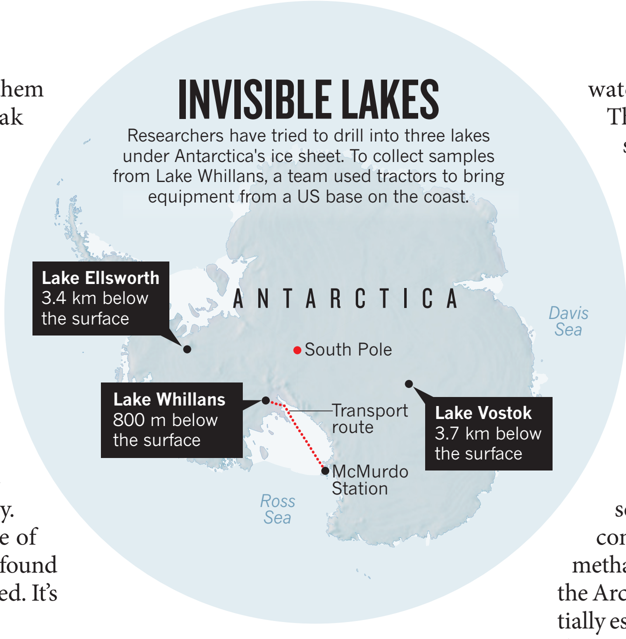
For a video of the Lake Whillans expedition, see:
go.nature.com/pb3jok



INVISIBLE LAKES

Researchers have tried to drill into three lakes under Antarctica's ice sheet. To collect samples from Lake Whillans, a team used tractors to bring equipment from a US base on the coast.

The big question is whether Antarctica's subglacial communities are made of 'survivors' or 'arrivers'.

Survivors would be the descendants of microbes that lived in the sediments when the area was covered by open ocean, as it has been periodically over the past 20 million years. Alternatively, Lake Whillans might be populated by wind-blown microbes — the 'arrivers' — that were deposited on the ice and worked their way down over 50,000 years as ice melted off the bottom of the glacier.

It is also possible that some organisms entered the lake more recently, carried in by sea water seeping under the ice sheet. Lake Whillans sits just 100 kilometres from the grounding line, where the ice sheet transitions from resting on ground to floating on the ocean. That line shifts as the ice thins and thickens, so it is possible that the lake exchanged water — and microbes — with the ocean during the past few thousand years, says Christina Hulbe, a glaciologist at the University of Otago in Dunedin, New Zealand, who has long studied that area of Antarctica.

Other findings from the lake samples have led to some tantalizing ideas. Traces of fluoride in its water offer possible evidence of hydrothermal vents in the area — rich sources of chemical energy that have the potential to support islands of exotic life, such as worms or heat-loving microbes. "It's probable that there are hydrothermal systems in there," says Donald Blankenship, a glaciologist at the University of Texas at Austin. The lake occupies a broad rift valley where Earth's crust has thinned, and radar surveys by Blankenship show putative volcanoes under the ice[3,4].

The results emerging from Lake Whillans could also shed light on how Antarctica influences the nearby ocean and even the entire world. If microbes beneath the ice sheet play an important part in altering the minerals in the sediments, as the latest data suggest, those organisms might supply iron to the subglacial waters that eventually reach the ocean. This process could provide an important source of nutrients to the chronically iron-starved ecosystems in the Southern Ocean[5], says Martyn Tranter, a marine biogeochemist the University of Bristol, UK.

In addition, the presence of small amounts of a chemical called formate in the water of Lake Whillans suggests the possibility that methane, a potent greenhouse gas, is produced in the deeper, oxygen-poor sediments beneath the lake. A 2012 study estimated that the sediments under the Antarctic ice sheet contain hundreds of billions of tonnes of methane — a reservoir equal to that stored in the Arctic's permafrost — which could potentially escape and exacerbate global warming if the ice retreats[6].

Lake Whillans provides only a local snapshot of life beneath the ice, and several teams are trying to fill in the picture by exploring other subglacial lakes. A Russian team is now analysing water from Lake Vostok, a lake in a deep tectonic rift in eastern Antarctica that is covered by 3.7 kilometres of ice. Researchers say that analysing those samples presents challenges because the water spent a year frozen in the bottom of the borehole before being brought to the surface. And as the ice was raised, it was exposed to the kerosene drilling fluid in the borehole.

Closer to Lake Whillans, Pearce and his colleagues attempted in 2013 to drill into Lake Ellsworth, which sits under 3.4 kilometres of ice in a glacial fjord, but they were forced to abandon the effort after difficulties arose with steering the drill.

With its thinner ice covering, Lake Whillans was an easier target than Ellsworth or Vostok, but it did not give up its secrets easily. The day after the first sample was retrieved, a camera lowered into the hole presented a mesmerizing scene as it neared the lake. Iridescent flakes of ice drifted upwards — a snow shower in reverse, and a sign that the hole was quickly refreezing. The scientists' instruments soon began to catch in the narrowing hole, forcing the drillers to pump in hot water to widen it. This tug-of-war lasted for four days before the team abandoned the hole to its inevitable fate, broke camp and flew their hard-won samples home. ■

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