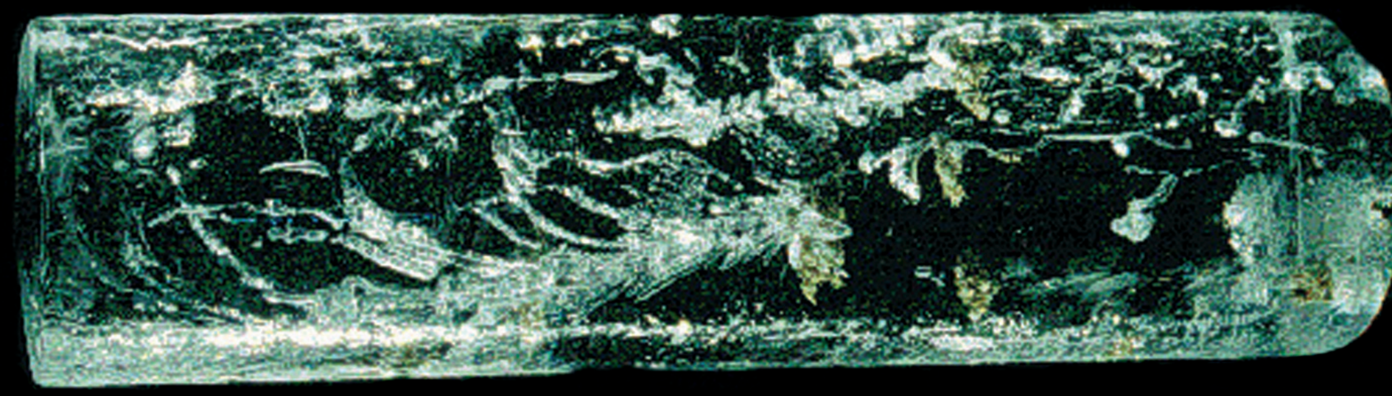
Antarctica: a last frontier for microbial exploration



▲ Microbial mats in ice from behind the Seuss Glacier near Lake Hoare. *Amy Chiuchiolo, Montana State University*

▶ A lake-ice core sample containing sediment and ice bubbles. *John Priscu*

Deep under the Antarctic ice lie huge bodies of water. **Brent C. Christner** and **John C. Priscu** believe that these lakes may contain some of the most unusual, extreme microbial ecosystems on Earth.

The realization that there was life on the Antarctic continent, other than that associated with the marine system, did not come to light until the seminal investigations initiated by the International Geophysical Year (IGY) in the late 1950s and early 1960s. These important pioneering studies reshaped our understanding of the potential for life in the coldest and driest desert on Earth. Research since these early IGY studies has revealed that large numbers of micro-organisms thrive in environments previously thought to be uninhabitable. Microbiological investigations conducted on deep ice cores and subglacial environments now support the notion that the Antarctic cryosphere may harbour some of the most unusual and extreme microbial ecosystems on our planet.

Lake Vostok

Subglacial Lake Vostok is by far the largest of the more than 140 subglacial lakes that have been identified thus far, with a surface area of more than 14,000 km^2, a depth in excess of 800 m, and a volume of ~5,400 km^3, making it one of the largest freshwater lakes on Earth. Despite surface air temperatures averaging −60 °C, the base of the East Antarctic Ice Sheet is near the pressure melting point of water (~−3 °C) owing to the combined effect of Earth's outward heat flux, the insulating properties of the overlying ice, and a reduced pressure freezing point resulting from the weight of the overlying ice sheet. The first indication that a lake existed beneath the East Antarctic Ice Sheet was based on anecdotal reports in the early 1960s by pilots with the Soviet Antarctic Expedition, who noted an extremely flat area near Vostok Station that could represent ice floating on water. These airborne observations were later confirmed by seismic data, radar profiles, and ice cores collected from the overlying ice.

The lake consists of a northern basin (water depth of ~500 m) and a larger southern basin (~800 m), which are separated by a bedrock sill. The variation in ice-sheet thickness between the north (~4,200 m) and south basins (~3,900 m) of the lake produces a 0.3 °C difference in the pressure melting point of water. This gradient results in glacial ice melting into the lake in the north, and refreezing (i.e. accretion) to the bottom of the ice sheet in the south, which has important repercussions to both horizontal and vertical circulation within the lake. Although lake water from Lake Vostok has not been directly sampled, the Russian Antarctic Expedition plans to penetrate the lake within the next 5 years. To date, all information on the microbiology of Lake Vostok is based on analysis of the basal portion of an ice core drilled at Vostok Station, which has provided seminal data to predict limnological conditions in the lake's surface waters. This ice, referred to as accretion ice, is comprised of water from the lake that has frozen to the bottom of the ice sheet.

Possible microbial life in the lake

While viable micro-organisms from the overlying glacial ice and in sediment scoured from bedrock adjacent to the lake must be regularly seeded into the lake, the question remains whether these or pre-existing micro-organisms (i.e. organisms that existed before Antarctica became glaciated about 13 million years ago) have established a flourishing community within Lake Vostok. Heterotrophic activity has been reported within melted samples of the accretion ice and amplification and sequencing of small subunit (16S) rRNA genes from extracted DNA and isolated cultures imply the lake is inhabited by bacteria related to the *Alpha-*, *Beta-*, *Gamma-* and *Deltaproteobacteria*, *Firmicutes*, *Actinobacteria* and *Bacteroidetes*. The average concentration of dissolved organic carbon, prokaryotic cells, and total dissolved solids in surface waters of the shallow embayment and open lake are predicted to be 86 and 160 µM, 150 and 460 cells ml^{-1}, and 1.5 and 34 mM, respectively. The input of organic carbon from the ice sheet has been estimated to be insufficient to support reproductive growth of the entire lake community, and a sustained ecosystem would require a supplemental chemical energy source residing in iron, sulfur and hydrogen redox couples.

Meltwater that enters the lake from the overlying ice sheet has about 10 times more gas than the accreted ice that leaves the lake, resulting in supersaturated gas concentrations within the lakewater itself. Calculations have revealed that Lake Vostok may have a dissolved oxygen concentration 50 times higher than that in the open ocean and contains much more oxygen in the form of air hydrates. Alternate electron acceptors, such as nitrate, are continually introduced into the lake through the melting of basal ice and sulfate is produced through the chemical weathering of sulfide minerals in the bedrock. Glacier flow results in the comminution of mineral matrices in the underlying bedrock, releasing carbonate, sulfide, iron and organic matter into the subglacial environment. Geochemical evidence implies that the microbial oxidation of metal sulfides in glacial flour occurs in oxic and anoxic glacier bed environments. Under oxic conditions, sulfide oxidation and heterotrophic activity will consume oxygen, eventually creating anoxia. Sulfide oxidation with Fe(III) as an oxidant can occur in the absence of oxygen, and sulfate reduction and methanogenesis are potential biogeochemical pathways for the anaerobic mineralization of organic matter. Thus, abiotic glacial geochemical processes may be sufficient to provide an energy source to microbes existing in Lake Vostok.

There has been speculation regarding geothermal energy input from high-enthalpy mantle processes or seismotectonic activity, which could introduce significant amounts of thermal energy and support an ecosystem similar to those found in deep-sea hydrothermal vents. However, since documented geophysical, glaciological processes could supply subglacial lake ecosystems with nutrient and redox couples for microbial metabolism, the search for viable subglacial communities need not be exclusive to environments with geothermal fluid or gas input.

Recent findings from subglacial environments

Knowledge of microbial life in subglacial ecosystems is limited due to sparse data resulting from the technological, financial and environmental challenges associated with sampling such cold and remote subsurface environments. Considerable progress has been made over the last 10 years in the exploration and study of subglacial environments, permitting a glimpse of the microbial life that exists under conditions of high pressure, cold temperature, low nutrient input and no sunlight. Estimates of the number of cells and organic carbon content in the Antarctic ice sheets and subglacial environs (4×10^{28} cells and 11×10^{15} g C) exceed that reported for the Earth's surface freshwater lakes and rivers (1.3×10^{26} cells and 1.2×10^{15} g C). These tentative estimates imply that the deep cold biosphere in Antarctica contains a previously unknown, but globally relevant pool of prokaryotic cells and associated organic carbon.

What next?

Future research of microbial ecosystems in subglacial lakes depends on a plan in which water samples are collected and returned to the surface. The overriding and limiting issues of this entire strategy are environmental concerns and the control of contamination in both forward and return excursions into the lakes. As such, it is of prime importance that environmental stewardship precedes all scientific endeavours. To this end, the Scientific Committee on Antarctic Research (SCAR) has established an international body of specialists to outline a detailed plan for eventual lake entry and sample return. This plan calls for the establishment of a network of instruments that gather limnological data continuously, collection of water samples for return to the surface, and recovery of deep sediment cores that can be used to reconstruct paleoclimatological, geological and microbial records for Antarctica. The next decade should prove to be an interesting time of microbial discovery for Antarctic science, one that follows the Antarctic tradition of melding interdisciplinary and international science. We can expect subglacial lakes to be at the forefront of such discovery since they remain one of the last unexplored frontiers on our planet.

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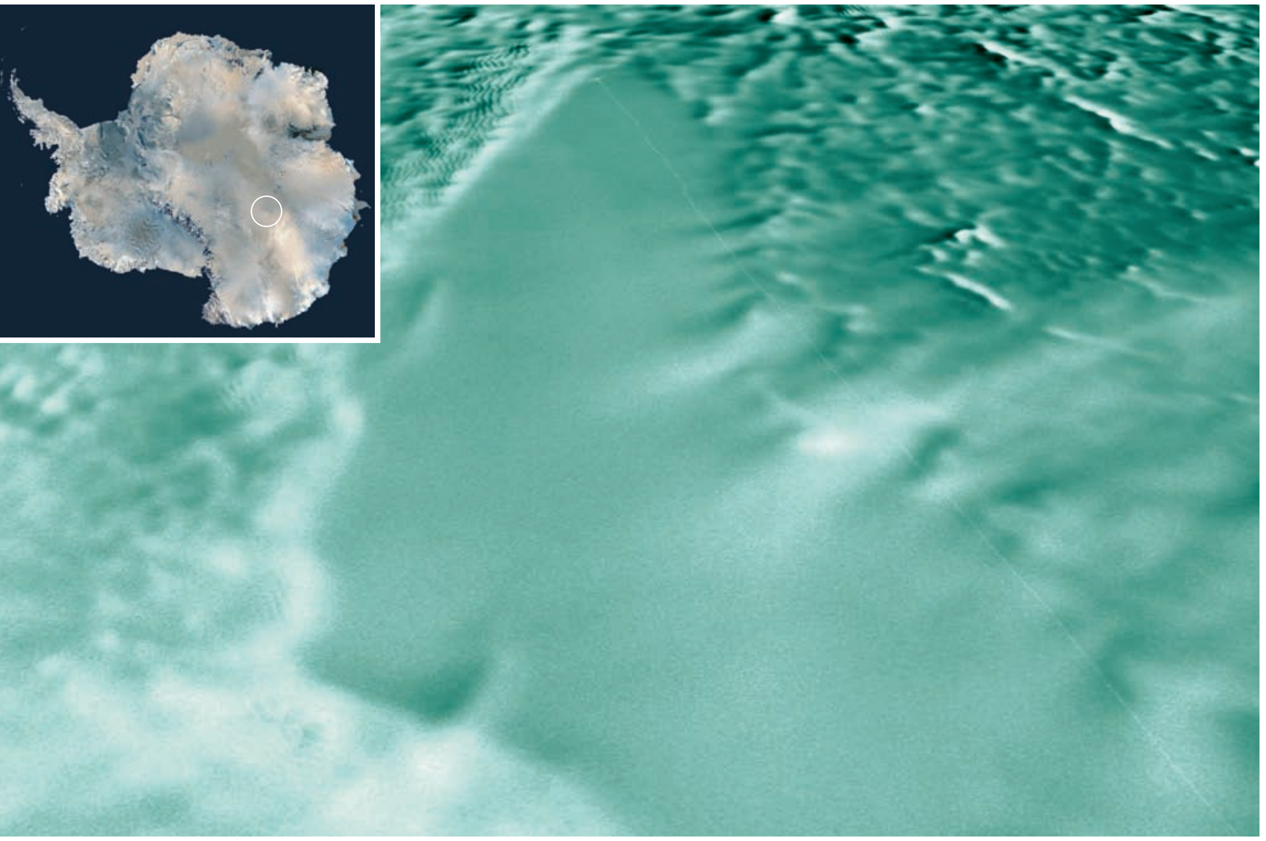
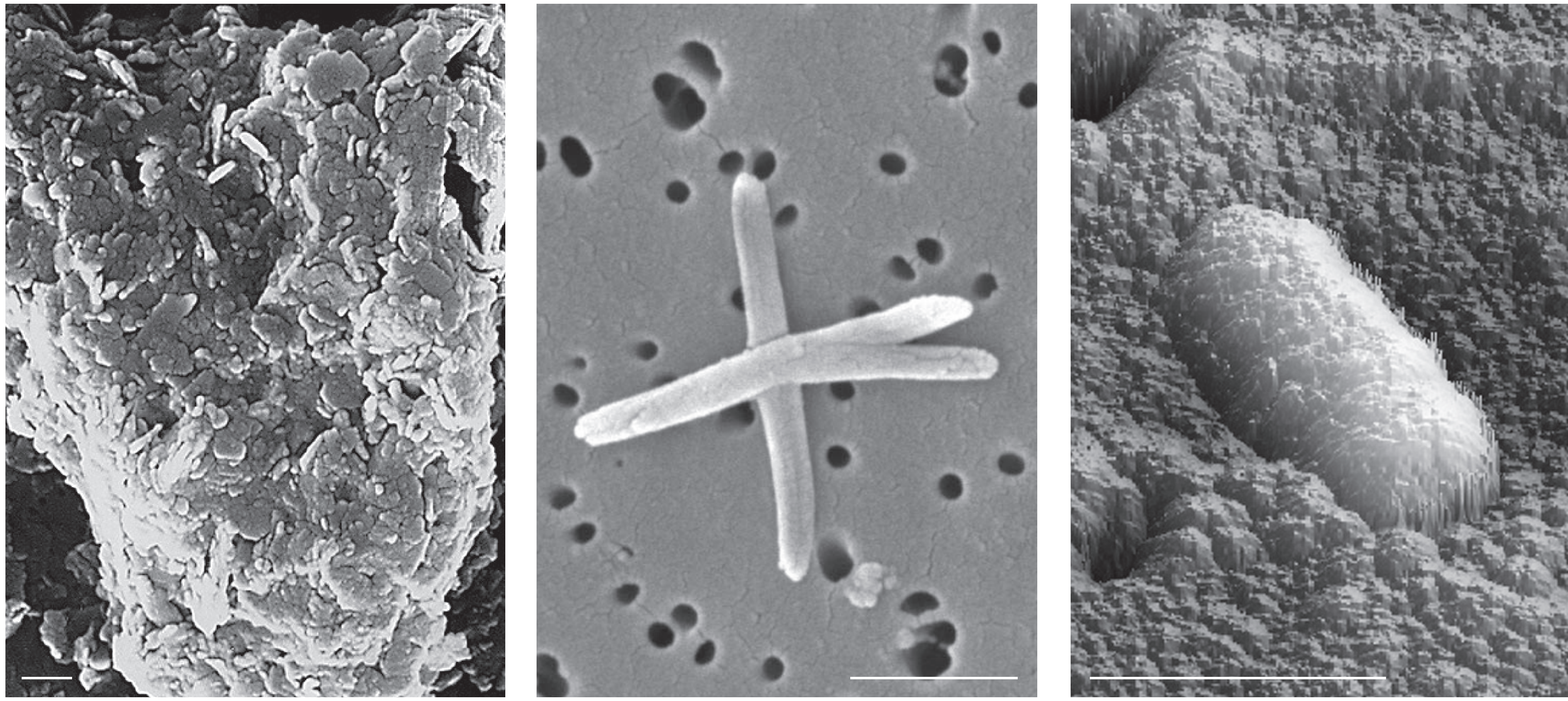


◀ Radar satellite image of the ice over Lake Vostok, Antarctica. The ice smooths out over the lake (centre), contrasting with the rough terrain of the ice over the surrounding mountains. The inset shows the approximate location of Lake Vostok. *Canadian Space Agency / Radarsat / NASA / Science Photo Library (inset NASA)*



▼ Scanning electron micrograph (left, centre) and atomic force micrograph (right) of microorganisms from Lake Vostok accretion ice samples from a depth of 3590 m. *John Priscu (left; Bar, 1 μm); Brent Christner (centre; Bar, 1 μm); John Priscu (right; Bar, 0.5 μm)*