EMBO reports

analysis

The cold side of life

The upcoming International Polar Year promises great advances in the exploration of the polar regions

Barren land covered with huge ice shelves, swept by merciless winds and entrapped by deadly cold seas: that is a common perception of the polar regions. However, this picture could not be more wrong, as both the Arctic and Antarctic are teeming with life that is extraordinarily adapted to the harsh conditions and which often exists at the edge of survival (Figs 1–4). There has been a growing interest in these psychrophilic organisms, and how they evolved to grow and proliferate at permanently cold temperatures (D'Amico *et al*, 2006). Yet, it is not only the life sciences that can gain important insights from studying biological communities at the poles. Understanding how polar ecosystems respond to rapid climate change is of global significance; there is evidence that organisms, oceans and the atmosphere in the polar regions interact strongly, influencing each other in complex ways and with potentially major consequences for climate.

Antarctic krill—a key component of many food chains in the Southern Ocean—are under increasing scrutiny for their possible impact on global warming. Krill feed on phytoplankton at the ocean's surface, and descend to deeper layers after each meal to excrete the remains of their food. Recent research suggests that krill feed several times a day, instead of only once as previously thought; this means that their faecal waste transfers a much larger amount of carbon to the ocean floor, equivalent to the annual emission of 35 million cars (Tarling & Johnson, 2006). By fixing CO_2 during photosynthesis, polar phytoplankton also contribute to the dynamics of carbon fluxes between the atmosphere, surface waters and deep ocean; the functioning of this physical–biological interface and how it is affected by climate change are under investigation.

Fig 1 | A jellyfish offshore of McMurdo Station, Ross Island. Photograph by Steve Clabuesch/US National Science Foundation.

The growing academic interest in the poles coincides with the launch of a milestone initiative, the International Polar Year (IPY), as "an intense, internationally coordinated campaign of research that will initiate a new era in polar science", according to its website (www.ipy.org). It is the fourth such undertaking since the first IPY in 1882 to 1883, and will run from March 2007 to March 2009 to allow researchers plenty of time and opportunities to work in both polar regions. "IPY will address and solve global scale problems through an enormous range of science," according to a press release from the British Antarctic Survey (www.antarctica.ac.uk), one of the main players in Antarctic research (British Antarctic Survey, 2006). "IPY has a rich array of dazzling projects in biology, ecology, physiology and so forth, that all fit under the general terms of life sciences," explained David Carlson, the Director of the IPY Programme Office. "Each of these projects represents three or more countries, 10–50 investigators, and major efforts in field observing or modelling."

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The IPY projects take a systematic approach, Carlson said, which is indeed required. For example, studying microbial ecosystems at the base of and within the

Fig 2 | Chinstrap penguins are about 68 cm (27 inches) tall and weigh about 4 kg (9 pounds). They are social animals and number about 5 million. Photograph by Zee Evans/US National Science Foundation.

Fig 3 | A crab-eater seal lounges on an ice floe near the Antarctic Peninsula. Crab-eaters are the most numerous seals in the world, with a population of more than 15 million. Although they do not eat crabs, they do eat krill and other crustaceans. They will reach a length of over 8 ft (2.44 m) and a weight of up to 500 lb (227 kg). Photograph by Jeffrey Kietzmann/US National Science Foundation.

cracks of floating sea ice in a complicated and highly unusual physical and biogeochemical environment requires a well-coordinated partnership between scientists looking at the biotic and abiotic components. "IPY goes after exactly these system-wide questions, in a way that perhaps one can't do without the stimulus of a once-in-50-years mega-programme," said Carlson. "Trying to understand the systems both in detail and on a global scale might still represent too large and too difficult a problem. Focussing on the poles gives us a start on this systematic approach that we eventually have to apply globally."

One of the most exciting areas of polar research—and a key IPY target—is the exploration of subglacial lakes in Antarctica. More than 145 of these water bodies have been spotted by airborne radar surveys, but some experts estimate their number to be more than 1,000, with many occurring along tectonic faults and depressions. Permanently covered by a thick layer of ice, the water remains liquid owing to a combination of high pressure and geothermal heating. These unique environments have been isolated for hundreds of thousands or even millions of years, experts believe, so any organisms within might be as alien as life from another planet.

The unquestioned star among these lakes is Vostok (Fig 5), named after the Russian research station situated nearby in East Antarctica. The lake is by far the largest in Antarctica—250 km long and 50 km wide, covering an area of 14,000 km^2 and up to 1,000 m deep—and its water lies beneath 4,000 m of ice. Although no water from Lake Vostok or any of the other lakes has yet been tested, scientists have sampled the 'accreted ice'—lake water refrozen to the underside of the ice sheet above. This was shown to contain small quantities of bacteria, and inorganic and organic growth nutrients (Siegert *et al*, 2001). John Priscu, at the Montana State University in Bozeman, USA, and other groups have demonstrated that microbes released from melted cores of accreted ice probes are viable and can be cultured (Siegert *et al*, 2001; Christner *et al*, 2001). Such findings have spurred great interest among biologists, as studying microorganisms from Vostok and other subglacial lakes could help to answer pertinent questions about how life on Earth—and perhaps other planets—evolved and adapted to extreme conditions.

Molecular profiling of microbes from accreted ice revealed close similarity with surface microbiota, suggesting either that bacteria within Lake Vostok do not represent an evolutionarily distinct subglacial biota or that microbes found in the probes originated from outside the lake and entered it through the deep glacial ice (Siegert *et al*, 2001; Christner *et al*, 2001). However, investigators believe that other microbes might exist within the lake that originated primarily from basal sediments and rocks, and might have been isolated long enough for significant evolutionary divergence to have occurred under unusual conditions. These include a saturating concentration of oxygen dissolved in the lake water, which might have forced organisms to evolve special adaptations, such as high levels of protective enzymes, to withstand oxygen stress.

Others maintain, however, that this view of Lake Vostok's inhabitants is inaccurate.

One international team, led by Sergey Bulat, a molecular biologist at the Petersburg Nuclear Physics Institute in Gatchina, Russia, isolated a single bacterial phylotype with "relevance to the lake environment" from accreted ice samples, suggesting that the water body itself should "be hosting a highly sparse life" (Bulat *et al*, 2004). Furthermore, the rare creature seemed similar to thermophilic bacteria found in hot springs, thus suggesting that the lake's microbial communities, if any, could have a chemolithoautotrophic ecology sustained by geothermal activity, similar to communities living near volcanic deep-sea vents on the ocean floor.

Hot or cold, the central problem is that there is no conclusive evidence that Lake Vostok supports life, and only direct samples from its water can solve the conundrum. Many fear, however, that shattering the last ice lens would inevitably contaminate the pristine and sealed microcosm, with unpredictable consequences. Russian researchers originally drilled down towards the lake for 3,623 m—enough to sample accreted ice that extends about 200 m above the water level—but stopped in 1998 under international pressure fuelled by environmental concerns (Fig 6). Recently, however, the Russians deepened the borehole to 3,650 m and successfully recovered 27 m of accreted ice. Now, they want to continue through the last 100 m of ice that divides the drill head from the lake's surface, which they plan to reach in late 2007 (Inman, 2005). Experts warn that the drilling apparatus used by the Russian team is not designed to minimize microbial contamination risks, and that the drill hole itself contains some 60 tonnes of antifreeze and kerosene that could pollute the lake.

Rendering the situation even more intricate, the US National Aeronautics and Space Administration (NASA; Washington, DC, USA) has expressed interest in Lake Vostok as an Earth-based laboratory for its research programme in astrobiology or 'exobiology'. From NASA's point of view, the conditions found at Lake Vostok are analogous to those on Jupiter's moon Europa, which contains vast oceans trapped under a thick layer of ice. In fact, Europa remains the most promising candidate for finding forms of life, if any exist, throughout the solar system. Working in Lake Vostok could help NASA's engineers to develop methods and technologies for drilling ice on Europa to search for extraterrestrial life, while avoiding interplanetary contamination. To that aim, NASA has been developing a special drill, which would use heat to melt the ice and penetrate the lake.

No laws can be enforced in Antarctica to stop the Russian plan, but intense discussion continues to address the value and feasibility of exploring Lake Vostok as well as other

Fig 4 | A snailfish, *Paraliparis devriesi*. Common inhabitants of deeper Antarctic waters, snailfish are characterized by a layer of jelly between the muscle and the skin. The jelly apparently derives from the blood and, according to various hypotheses, might have a buoyancy function, and roles in protecting the animal from ice crystals and in pressure adaptation. Photograph by Melanie Conner/US National Science Foundation.

Fig 5 | The ice above Lake Vostok is a smooth and featureless snowscape where any sense of scale or distance is lost. In 1983, the temperature at Vostok dropped to –89.2 °C, which is the coldest temperature ever recorded on Earth. With permission from Michael Studinger/Lamont-Doherty Earth Observatory.

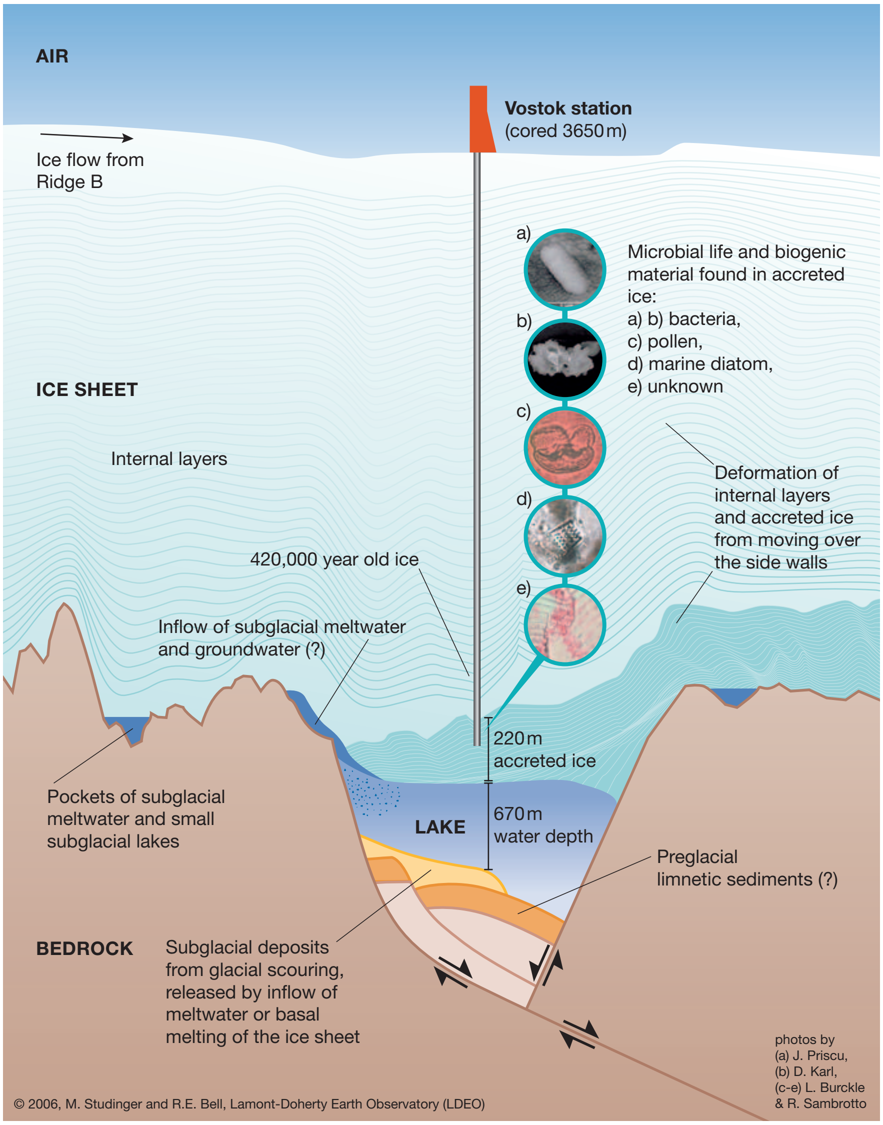

Fig 6 | A pictorial view of the subglacial Lake Vostok system. With permission from Michael Studinger/Lamont-Doherty Earth Observatory.

subglacial lakes. The Russians have filed an Initial Environmental Evaluation under the Antarctic Treaty—the main regulatory framework for research activities in Antarctica—to resume their drilling into Lake Vostok, which was followed by a draft Comprehensive Environmental Evaluation (CEE). The draft CEE was discussed by the Antarctic Treaty's Committee for Environmental Protection in 2003, and it was severely criticized by non-governmental organizations, research organizations and individual states, including New Zealand, Norway and France. As a result, Russia should have produced a revised version of the CEE addressing all comments before recommencing drilling, but these documents have not yet been presented. Even if Russia fulfils its duties as a signatory member of the Antarctic Treaty and submits its plans to the scrutiny of international scientists, it will remain the ultimate arbiter of Lake Vostok's future.

Joining the chorus of critics, the Antarctic and Southern Ocean Coalition (ASOC; Washington, DC, USA; www.asoc.org), a network of more than 150 conservation organizations, has expressed serious concerns about the Russian/NASA drilling plans at Lake Vostok and the reasons that feed them. "ASOC perceives that a form of 'hype' has been generated around the project that draws on more than just scientific interests," it argues (ASOC, 2002). "It has a lot to do with the perceived fundraising capabilities from a large-scale project linking 'sexy' topics like planetary research and the search for life in extreme environments to a vast, mysterious lake hidden under the East Antarctic ice sheet." To protect the long-term scientific and environmental value of Lake Vostok, the ASOC proposes that drilling should be postponed for an indefinite period, perhaps for several generations. "The current hype about Antarctica's hidden lake should not impel the Antarctic community to make a hurried decision with unpredictable, long-term consequences. Such decision-making will only compromise Antarctica's environment, along with its intrinsic wilderness values, for unnecessary short-term gain" (ASOC, 2002).

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Recent geophysical findings could help supporters of a cautious approach to the exploration of subglacial lakes. A British research team in Antarctica demonstrated the long-distance discharge of water from one subglacial lake to at least two others (Wingham *et al*, 2006). "Our observations conflict with expectations that subglacial lakes have long residence times and slow circulations, and we suggest that entire subglacial drainage basins might be flushed periodically," the investigators wrote. It is therefore possible that subglacial lakes are not isolated entities and playgrounds for separate microbial evolution, as previously assumed, which means that the accidental contamination of one lake could spread to others. "We note that *in situ* exploration of subglacial Antarctic lakes risks the rapid contamination of significant components of drainage systems," the authors concluded (Wingham *et al*, 2006).

"The new results underline the importance of extreme environmental caution in sampling the subglacial hydrosphere beneath the East Antarctic ice sheet," agreed Michael Studinger from the Lamont-Doherty Earth Observatory of Columbia University at Palisades, New York, USA. Adding to the complexity of the deep-water system, Studinger and colleagues have just reported the identification of two new subglacial lakes that are second in size only to Lake

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Vostok, and are located relatively close to it (Bell *et al*, 2006). "The size and origin of the two recently discovered large subglacial lakes suggest that these lakes are tectonically controlled. In contrast to the smaller and shallower lakes, tectonically controlled subglacial lakes are deep and quite old," said Studinger. "The tectonic control and longevity of these lakes suggests that they probably host a diverse ecosystem." The idea that subglacial lakes are interconnected by a hydrological network beneath the ice has existed for some time, but evidence to prove it was not available until now, Studinger added. He noted that the work by Duncan Wingham and others showed that these linkages exist, and that the flux of water beneath large continental ice sheets can be relatively fast and voluminous. "Model predictions of future sea-level rise have to take into account the lubricating effects of subglacial water on ice sheet stability and drainage, and the possible influx of large volumes of fresh water into the ocean," said Studinger.

Although the final programme of IPY scientific activities is not yet available, clearly a large part of it will be built on previous experiences. Among those is the work of a multi-disciplinary study of the microbial diversity in benthic microbial mats from freshwater and saline surface Antarctic lakes, MICROMAT (www.nerc-bas.ac.uk/mlsd/micromat). "What was 'special' to MICROMAT was the fact that bacteriologists, cyanobacteriologists, mycologists, protistologists and algologists were working for the first time on the same samples," said Annick Wilmotte, a microbiologist at the University of Liége, Belgium, and the project's coordinator. She added that MICROMAT revealed an unprecedented level of microbial diversity in Antarctic lakes, especially for bacteria and cyanobacteria, which raises questions as to how these communities have evolved and how their dispersal affects local biodiversity. As part of the project, a screening programme by pharmaceutical and academic partners indicated the presence of metabolites with significant biological activities, which has led to a renewed interest in the exploitation of Antarctic microbial diversity. Flavia Marinelli, from the University of Insubria at Varese, Italy, stated that several novel antibacterial, antifungal and antitumour compounds were isolated from bacteria, cyanobacteria and filamentous fungi, and are currently under investigation.

MICROMAT's promising results, Wilmotte hopes, will be extended during the next IPY, and will fertilize a new international project called Microbiological and Ecological Responses to Global Environmental Changes in the Polar Regions (MERGE). Briefly described as "an umbrella programme that aims to understand the responses of terrestrial, limnetic and supraglacial polar ecosystems to climate change" (IPY, 2005), MERGE will, among other tasks, study the polar microbial diversity of a large range of biotopes in both the Arctic and Antarctica, Wilmotte said.

Understandably, research at the poles is not an easy undertaking. The extreme weather conditions—howling winds and the coldest temperatures on Earth—present a major challenge to any scientific explorations, which is one of the reasons for the distinct international and collaborative spirit of polar research. No man's land thus becomes, to use a definition forged for Antarctica but also applicable to the Arctic, 'a natural reserve devoted to peace and science'. In addition to the hard science facts that the new IPY will produce, its long-lasting value will be calculated on the basis of its capacity to forge further research partnerships and to strengthen the alliance to conserve polar ecosystems.

REFERENCES

ASOC (2002) Options for Lake Vostok. Washington, DC, USA: The Antarctica Project.. www.asoc.org
Bell RE, Studinger M, Fahnestock MA, Shuman CA (2006) Tectonically controlled subglacial lakes on the flanks of the Gamburtsev subglacial mountains, East Antarctica. *Geophys Res Lett* **33:** L02504
British Antarctic Survey (2006) Countdown to International Polar Year. Press release, 14 Mar. www.antarctica.ac.uk
Bulat SA *et al* (2004) DNA signature of thermophilic bacteria from the aged accretion ice of Lake Vostok, Antarctica: implications for searching for life in extreme icy environments. *Int J Astrobiol* **3:** 1–12
Christner BC, Mosley-Thompson E, Thompson LG, Reeve JN (2001) Isolation of bacteria and 16S rDNAs from Lake Vostok accretion ice. *Environ Microbiol* **3:** 570–577
D'Amico S, Collins T, Marx JC, Feller G, Gerday C (2006) Psychrophilic microorganisms: challenges for life. *EMBO Rep* **7:** 385–389
Inman M (2005) The plan to unlock Lake Vostok. *Science* **310:** 611–612
IPY (2005) Full Proposals for IPY 2007–2008 Activities. Cambridge, UK: International Polar Year. www.ipy.org
Siegert MJ, Ellis-Evans JC, Tranter M, Mayer C, Petit JR, Salamatin A, Priscu JC (2001) Physical, chemical and biological processes in Lake Vostok and other Antarctic subglacial lakes. *Nature* **414:** 603–609
Tarling GA, Johnson ML (2006) Satiation gives krill that sinking feeling. *Curr Biol* **16:** R83–R84
Wingham DJ, Siegert MJ, Shepherd A, Muir AS (2006) Rapid discharge connects Antarctic subglacial lakes. *Nature* **440:** 1033–1036

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Defining species

The indirect impact of humans on biodiversity

For more than a century, Charles Darwin's theory of evolution has explained how new species appear on Earth. Driven by mutations, genetic recombination and selective pressures from new or changing environments, various subpopulations accumulate changes in their genomes until a new population eventually emerges that is sufficiently different—genetically and physiologically—from the original species, such that individuals from the two populations are reproductively isolated from each other. Until recently, most biologists subscribed to this linear view of evolution, succinctly expressed by the leading evolutionary biologist Ernst Mayr, who stated that "the living world is comprised of more or less distinct entities which we call species" (Mayr, 1957). However, recent work paints a more complicated picture of species differentiating, diverging, merging and reverting in response to environmental changes, which suggests that many of