Subglacial Lake Vostok (SW-1845)

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Abstract

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When Captain Robert F. Scott first observed the McMurdo Dry Valleys in December 1903, he wrote, “We have seen no living thing, not even a moss or a lichen…it is certainly a valley of the dead”. Eight years later, Scott's team reached the South Pole and his entry referencing conditions on the polar plateau read “Great God! This is an awful place”. Scott was unaware that life surrounded him in the dry valleys, and he also could not have realized that microbial life could exist miles beneath his feet in an environment sealed from the atmosphere by Antarctica’s expansive continental ice sheet. 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 in the late 1950’s and early 1960’s. Biological studies during this period were exploratory in nature, describing life forms and their habitat in terrestrial and surface lake environments. These important pioneering studies reshaped our understanding of the potential for life in the coldest, driest, and windiest place on Earth. However, it was not until about five years ago that microbiological evidence suggested that the Antarctic interior could serve as an environment for life, resulting from investigations conducted on a deep ice core from Vostok Station. These studies suggested that the cryosphere of Antarctica could support some of the most unusual and extreme microbial ecosystems on the planet. This information, coupled with the recent discovery of an extensive network of subglacial lakes beneath the East Antarctic Ice Sheet (EAIS), has changed our view of life in Antarctica. Although it is well documented and widely known that life exists in the permanently cold margins and marine environments of Antarctica, the cryosphere has traditionally been viewed as being devoid of life.

Subglacial Lake Vostok is by far the largest of the more than 140 subglacial lakes that have been identified thus far (IMAGE NUMBER 1), with a surface area of more than 14,000 km^2 and a depth in excess of 800 m, making it one of the largest lakes on Earth. The base of the central EAIS is relatively warm as a result of the combined effect of geothermal heating and the insulation caused by the overlying ~4 km of ice, despite surface air temperatures commonly below –60^{o}C. Lake Vostok has only recently become a focus of research, even though its presence was first noted in the early 1960’s when Soviet Antarctic Expedition (SAE) pilots observed an extremely flat area near Vostok Station that could represent ice floating over water. These airborne observations were soon confirmed by seismic data, radar profiles, and satellite images made near Vostok Station. The discovery of Lake Vostok and a number of additional subglacial lakes in central Antarctica during the early 1970’s went relatively unnoticed by the biological scientific community until the late 1990’s. However, curiosity about the nature of this environment and the potential existence of microbial life in subglacial lakes has recently intensified.

The site selection for Vostok Station by the SAE was truly fortuitous for subglacial lake research. Several deep ice cores have been extracted from the ice sheet at Vostok Station since drilling began in the mid-1960’s (the first 500 m deep borehole was made in 1965). The most recent and deepest (3,623 meters below the surface) ice core (borehole 5G) stopped ~120 m above the lake-ice interface, due to concerns of contaminating the lake. The upper 3310 m of the ice core has provided a detailed paleoclimate record spanning the past 420,000 years. Ice at depths between 3,310 and 3,538 m is deformed by contact with bedrock and does not contain useful paleoclimate data. The basal portion of the ice core from 3,539 to 3,623 m has a chemistry and crystallography distinctly different from the “normal” glacial ice above it. This basal ice has extremely low conductivity, large (up to 1 m) ice crystals, and numerous sediment inclusions. The mineral composition of ice-bound sediments below 3,539 m is dominated by micas and is clearly different than typical crustal composition and particles within the overlying glacial ice. The isotopic composition of this basal ice in concert with other data indicates that it formed by the refreezing (accretion) of Lake Vostok lake water to the underside of the ice sheet. Thus, there is ~ 210 m of Lake Vostok water frozen on the underside of the glacial ice beneath Vostok Station. Recent airborne radar surveys have shown that the accretion ice is dynamic and actually flows out of the lake on the downstream side.

The freshwater in Lake Vostok originates from the overlying ice sheet, which melts near the shoreline of the lake and at the ice-water interface in the north. Accretion to the base of the ice sheet occurs in the central and southern regions, removing water from the lake. As the accreted ice is essentially gas-free, the lake water is thought to have a relatively high dissolved gas content supplied from air bubbles released from the overlying glacial ice. Estimates on the gas content of Lake Vostok suggest that it could have an oxygen concentration 50 times higher than that in the open ocean. While it seems inevitable that viable microorganisms from the overlying glacial ice and in sediment scoured from bedrock adjacent to the lake are regularly seeded into the lake, the question remains whether these or pre-existing microorganisms have established a flourishing community within Lake Vostok. Evidence for the existence of geothermal activity is supported by the recent interpretation by French scientists of He^3/He^4 data from accretion ice. These data imply that there may be extensive faulting beneath Lake Vostok resulting in geothermal plumes entering the bottom of the lake in the southern part of Lake Vostok. If this emerging picture is correct, Lake Vostok could harbor an ecosystem fueled by geochemical energy much like that observed in deep-sea vent systems.

Due to concerns of contaminating these pristine subglacial environments and the current lack of an adequate sampling strategy to meet these needs, no direct samples have yet been obtained from subglacial lakes. Therefore, the accreted ice retrieved from Vostok Station has offered the only opportunity for microbial ecologists and geochemists to investigate material derived from a subglacial lake. Microbiological and molecular-based studies of accreted ice by 4 independent laboratories have indicated that these cores contain bacteria (IMAGE NUMBER 2). Metabolic and culturing experiments demonstrate that a portion of the assemblage becomes metabolically active upon melting and exposure to nutrients, suggesting Lake Vostok contains a viable microbial community. Molecular profiling of microbes within the accreted ice (by both culturing and direct 16S rDNA amplification) show close agreement with present day surface microbiota, consisting of phylotypes within the bacterial divisions Proteobacteria (alpha, beta, gamma, and delta), Low G + C Gram Positives, *Actinobacteria*, and the *Cytophaga-Flavobacterium-Bacteroides* line of descent. If microbes within the accreted ice are representative of the lake microbiota, this would imply that bacteria within Lake Vostok do not represent an evolutionarily distinct subglacial biota. The time scale of isolation within Lake Vostok (~20-25 million years) is not long in terms of prokaryotic evolution compared to their 3.7×10^9 year history on Earth. An alternative scenario is that glacial melt water entering the lake forms a lens overlying the Lake Vostok water column. If so, the microbes entrapped within accretion ice would likely have spent little time within the actual lake water itself (few, if any cell divisions occurring) before being frozen within the accretion ice. The microbes within the main body of the lake below such a freshwater lens may have originated primarily from basal sediments, rocks, and/or the preexisting environment before Lake Vostok became ice-covered. If so, their period of isolation may be adequate for significant evolutionary divergence, particularly given the potential selection pressures that may exist within this unusual subglacial environment.

Epifluorescence (of DNA-stained cells) and scanning electron microscopy have measured bacterial cell densities of 2.8 x 10^3 and 3.6 x 10^4 cells ml^{-1}, respectively, in Vostok accretion ice (3590 meters below the surface). Additionally, the concentration of dissolved organic carbon (DOC) in this core was measured at 0.51 mg l^{-1}. Based on these values and partitioning coefficients for the water to ice phase change, it is estimated that the water in Lake Vostok had bacterial cell concentrations of 10^5 to 10^6 ml^{-1} and a DOC concentration of 1.2 mg l^{-1}. Using data on the volume of the Antarctic ice sheet and subglacial lakes in concert with published bacterial volume to carbon conversion factors, the cell number and carbon content within the Antarctic ice sheet and subglacial lakes can be estimated, assuming that concentrations of bacterial cells and DOC in other subglacial lakes are similar to those estimated for Lake Vostok. Based on these calculations, subglacial lakes contain about 12% of the total cell number and cell carbon with respect to the pools associated with the Antarctic continent (e.g., subglacial lakes + ice sheet). The number of cells and prokaryotic cell carbon content for subglacial lakes plus the ice sheet (1.00 x 10^{26} cells; 2.77 x 10^{-3} Pg) approaches that reported for the Earth's freshwater lakes and rivers (1.3 x 10^{26}; 2.99 x 10^{-3} Pg), suggesting these environments contain nontrivial amounts of cells and carbon. These estimates of the number of prokaryotes and organic carbon associated with Antarctic subglacial lakes and glacial ice are clearly tentative and should be refined once additional data become available; however, they do imply that Antarctica contains an organic carbon reservoir that should be considered when addressing issues concerning global total carbon storage reservoirs and dynamics.

The seminal reports of life in subglacial Antarctic lakes have spawned many new ideas about how life evolved on our planet and others, how life adapts to extremely cold conditions, how ecosystems function beneath 4 km of ice, and has changed our view of the extent of Earth's biosphere. One new idea theorizes that microbes might thrive throughout most of the Antarctic ice sheet within intercrystalline veins. The veins, formed at junctions where three ice crystals meet, may offer a unique habitat for microbes in "solid" ice that has not yet been considered. These veins contain a relatively solute-rich solution that both lowers the freezing point and provides nutrition for microbial growth. This idea is supported by new data on the isotopic composition of gases within cores of Vostok glacial ice, which suggests biological modification. If it is eventually shown that such a microbial habitat does indeed exist in solid ice, then much of the Antarctic ice sheet may harbor active microbes, a notion previously unheard of. Important new information based on airborne radar surveys has shown that at least 140 more subglacial lakes exist beneath the EAIS. A great majority of these lakes exist near Dome C. These lakes, though not nearly as large as Vostok, are still substantial with at least one exceeding 500 km^2 in surface area. The density of lakes near Dome C, together with maps of bottom topography, implies that a hydrologically interconnected lake district may exist in this region of Antarctica. These lakes provide many new environments that presumably contain life in what was once thought to be an inhospitable environment.

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 endeavors, and that such an undertaking not be attempted until adequate sampling techniques are established. 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 paleoclimate and geological records for Antarctica. The next 10 years should prove to be an interesting time of 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.

(2069 words)

FURTHER READING:

Christner, B.C., E. Mosley-Thompson, L.G. Thompson, and J.N. Reeve. 2001. Isolation of bacteria and 16S rDNAs from Lake Vostok accretion ice. Environmental Microbiology 3:570-577.

Dowdeswell, J.A. and M.J. Siegert. 2002. The physiography of modern Antarctic subglacial lakes. Global and Planetary Change 35: 221-236.

Karl, D.M., D.F. Bird, K. Björkman, T. Houlihan, R. Shackelford and L. Tupas. 1999. Microorganisms in the accreted ice of Lake Vostok, Antarctica. Science 286:2144-2147.

Priscu, J.C., E.E. Adams, W.B. Lyons, M.A. Voytek, D.W. Mogk, R.L. Brown, C.P. McKay, C.D. Takacs, K.A. Welch, C.F. Wolf, J.D. Kirschtein and R. Avci. 1999. Geomicrobiology of subglacial ice above Lake Vostok, Antarctica. Science 286:2141-2144.

Priscu, J.C. and B.C. Christner. 2004. Earth's icy biosphere. In: A.T. Bull (ed.) Microbial Diversity and Bioprospecting. ASM Press, Washington, D.C.

Siegert, M.J., J.A. Dowdeswell, M.R. Gorman and N.F. McIntyre. 1996. An inventory of Antarctic subglacial lakes. Antarctic Science 8:281-286.

Studinger, M., R.E. Bell, G.D. Karner, A.A. Tikku, J.W. Holt, D.L. Morse, T.G. Richter, S.D. Kempf, M.E. Peters, D.D. Blankenship, R.E. Sweeney, and V.L. 2003. Rystrom, Ice Cover, Landscape Setting, and Geological Framework of Lake Vostok, East Antarctica, Earth Planet. Sci. Lett., 205 (3-4), 195-210.

Tabacco I.E. A. Forieri, A. Della Vedova, A. Zirizzotti, C. Bianchi, P. De Michelis, A. Passerini . 2003. Evidence of 14 new subglacial lakes in DomeC-Vostok area. Terra Antarctica Reports 8, 2003: 175-179.

IMAGE CAPTIONS:

IMAGE NUMBER 1: Locations of Antarctic subglacial lakes. Lakes discovered by Italian (blue triangles), Russian (red down white triangles) and UK-US-Danish (yellow triangles) teams are included (Lake Vostok is shown in outline). The ice-sheet surface is contoured at 500 m intervals. Reproduced from Priscu et al., "Subglacial Antarctic Lake Environments: International Planning for Exploration and Research", EOS, in press.

IMAGE NUMBER 2: Scanning electron micrographs of microbes in Lake Vostok accretion ice. Samples are designated by their depth of recovery from below the surface in meters and yellow arrows indicate prokaryotic cells. Melt water was filtered onto 0.2μm polycarbonate filters sputter coated with 10 nm Au-Pd and imaged using a cryogenic scanning electron microscope. Adapted from Priscu et al. 1999, Science, 286:2141-2144.