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Evolutionary Processes a Focus of Decade-Long Ecosystem Study of Antarctic's Lake Vostok

As scientists probe for life in new habitats and try to understand the processes that triggered the origin and guided the evolution of life on Earth, environments beneath large ice sheets are beginning to emerge as key ecosystems. Modern subglacial environments are analogues both for the icy moons of Jupiter and the environmental stresses that led to widespread evolutionary radiation following the Neoproterozoic "snowball" Earth.

The largest modern analogue to these distant systems is Lake Vostok, a great Antarctic subglacial lake, and the international science community is developing a plan to systematically survey and explore this complex system over the next decade. Approximately the size of Lake Ontario, Lake Vostok lies beneath the 4 km thick East Antarctic ice sheet (Figure 1). The lake is much deeper than Lake Ontario—remotely measured water depths reach 670 m.

The East Antarctic ice sheet flows across Lake Vostok and acts as a conveyor belt for both delivering and removing material. With this dynamic flux of material, the lake is an example of a complex system where the intersection of extreme geologic, geochemical, and glaciologic boundary conditions may be producing a unique and complex ecological niche.

Last year, a draft science plan was developed to study Lake Vostok. The science effort would include an initial planning and model development phase, paralleling technological enhancement to ensure the lake is not contaminated during the observation and sampling phases. This initial planning period would be followed by geophysical site surveys, in situ measurements, installation of long-term observatories, and recovery of samples from the base of the ice sheet, from the water column, and from the lake sediments and bedrock.

Clearly Visible from Space

Although over 70 lakes have been identified beneath the Antarctic ice sheet [*Siegert et al.*, 1996], Lake Vostok is the only lake large enough to be clearly seen from space. The flat ice surface over the lake, visible from space, results from floating of the ice sheet as it crosses the lake. Beneath the thick ice sheet, the lake rests in a deep, narrow depression, possibly a rift valley akin to the African Rift lakes.

Lake Vostok is located beneath the Russian research facility, Vostok Station. As a result, a wealth of information about the lake has been collected. The available data range from the results of seismic profiling experiments over the last 35 years to the Vostok ice core, widely held as the standard for atmospheric and climatic variability [*Petit et al.*, 1999]. The seismic data constrain the depth of the lake and confirm the presence of sediments in the lake floor. The ice core, the deepest yet recovered, provides a 400,000-year environmental record on conditions in the Lake Vostok region.

Evidence is mounting, both from remote sensing data and from the ice core, that the ice sheet does not passively traverse the lake, but dynamically interacts with the lake water (Figure 2). From airborne radar data, Siegert and Ridley [1998] demonstrated that the ice sheet first thins, then thickens, as the ice crosses the lake. These changes appear to be driven by the melting and refreezing processes at the base of the ice sheet.

Vostok ice core morphologic and geochemical evidence suggests that the basal ice did not result from the accumulation of surface snow, but rather formed from lake water freezing onto the ice sheet as it crossed the lake. Partial melting of the ice sheet will supply sediments, new water, microbes, and possibly gas hydrates to the lake. Together, the melting and refreezing process may also drive circulation within the lake. Samples of this basal ice are held at the National Ice Core Laboratory in Denver, Colorado.

Microorganisms to 3603 Meters

Careful analysis of the Vostok ice core by Russian scientists indicates that viable microorganisms are present to depths of 2400 m [*Abyzov*, 1998]. The presence of these microorganisms indicates that they may have been introduced into the lake from the overlying ice sheet. Similar viable microorganisms from 1 million year old Antarctic permafrost have been recovered, suggesting that prolonged preservation of viable microorganisms may be common in Antarctic habitats. Consequently, it is possible that microorganisms may be present in the liquid portion of Lake Vostok and other subglacial lakes.

However, the relative isolation from exogenous sources of carbon and solar energy, and the extreme physical and geochemical characteristics in Lake Vostok may have precluded the development of any functional ecosystem. In fact, subglacial lakes are expected to be oligotrophic habitats and may have the lowest nutrient levels and lowest standing stocks of viable organisms of any aquatic habitat on Earth. If the rift origin proposed by Russian scientists for Lake Vostok is correct, active geothermal vents could provide local sources of energy and growth-favorable temperatures analogous to environmental conditions surrounding deep sea hydrothermal vents [*Karl*, 1995]. More re-

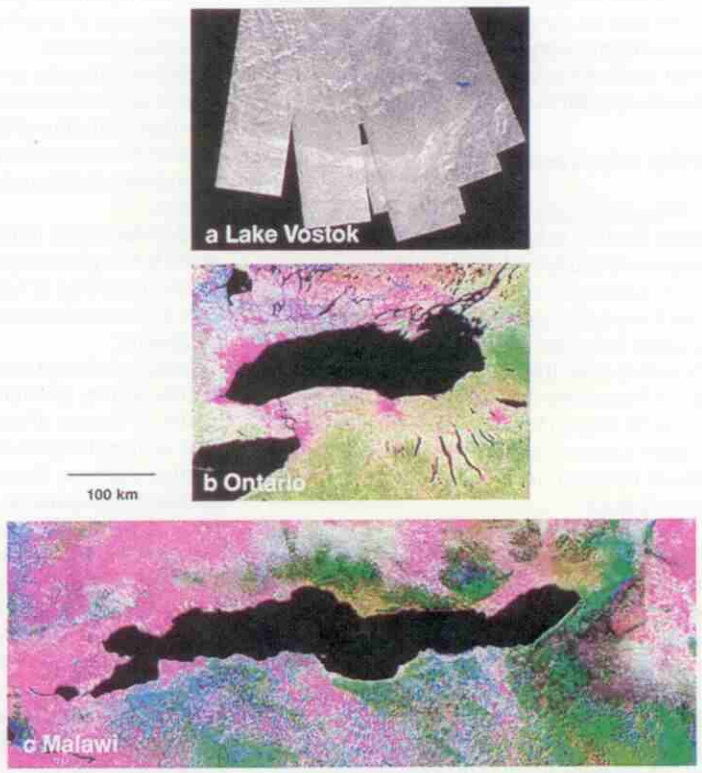


Fig. 1. Satellite images, all shown at the same scale, of a) Lake Vostok; b) Lake Ontario; and c) Lake Malawi.

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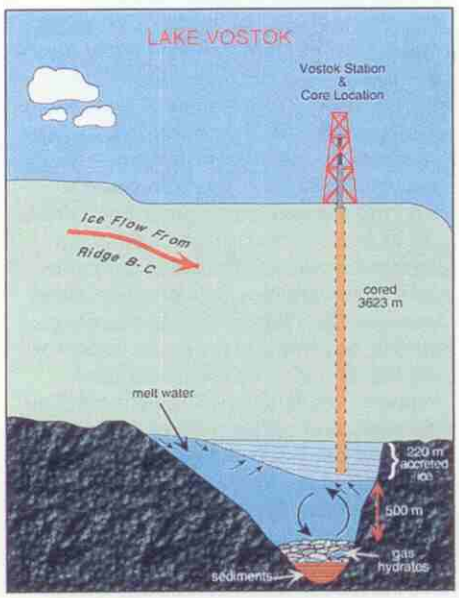


Fig. 2. Drawing of Lake Vostok indicating the ice flow over the lake near Vostok Station.

cent analysis of the ice core from depths of 3590 m and 3603 m have detected the presence of bacteria in ice that was accreted from Lake Vostok (Priscu and Karl, unpublished results).

Without direct measurements, one can only speculate on the possible presence of fossil or living microorganisms in the Lake habitat that has been isolated from external input for nearly 400,000 years.

Why Lake Vostok?

Why study Lake Vostok when there are at least 70 other subglacial lakes that could be explored? Studying Lake Vostok is technically and logistically difficult because of its thick ice cover and distance from major coastal Antarctic stations (Figure 3). Lake Vostok is over 1000 km from the National Science Foundation's (NSF) major research base, McMurdo Station. Other smaller lakes close to major bases including McMurdo and South Pole Stations would be logistically simpler to study.

But scientists agree that the initial target for studying subglacial environments should be the system most likely to support a stable microbial community. Small, shallow lakes beneath the ice sheet may have frozen solid during low stands of the ice sheet. Lake Vostok, because of its size and depth, probably remained liquid during changes in the Antarctic ice sheet volume. We understand much more about the ice sheet melting and refreezing processes over Lake Vostok than any other lake, and we have a solid local climate record for the last 400,000 years from the overlying ice core.

Lake Vostok is a unique focus for interdisciplinary studies and may be a unique region for detailed scientific investigation for a number of reasons. For one, the lake may be an active geological structure that could alter our understanding of the East Antarctic craton. For another, the lake may contain a sedimentary record of the Earth's climate, especially critical information on the initiation of Antarctic glaciation. Also, because of the possible presence of layered gas hydrates, the lake may be a previously undescribed extreme Earth habitat with unique geochemical characteristics. It may, as well, contain novel, previously undescribed, relic or fossil microorganisms with unique adaptive strategies for life. The lake also may be a useful Earth-based analogue and technology test bed to guide the design of unmanned, planetary missions to recently discovered ice-covered aquatic habitats on the Jovian moon, Europa.

History and Dynamics

The preliminary Lake Vostok science plan calls for an understanding of the history and dynamics of the lake's system as the culmination of a unique suite of geologic and glaciologic factors that may have produced an unusual ecological niche isolated from major external inputs and possibly dominated by the presence of stratified gas hydrates. Specific goals include:

- determining the geologic origin of Lake Vostok within the framework of improving the understanding of the East Antarctic continent and understanding the fundamental boundary conditions for a Lake Vostok ecosystem;
- developing an improved understanding of the lake's glaciologic history in order to understand the flux of water, sediment, nutrients, and microbes into a Lake Vostok ecosystem;
- characterizing the structure of the lake's water column, specifically evaluating the possibility of density-driven circulation associated with melting/freezing processes or geothermal heat, the potential presence of stratified gas hydrates, and the origin and cycling of organic carbon;
- establishing the taxonomic structure and functional diversity of any Lake Vostok biota, an isolated ecosystem that may be an analogue for planetary environments;
- recovering and identifying extant microbial communities and a paleoenvironmental record extending beyond the available ice core record by sampling the stratigraphic record both of the gas hydrates and the sediments deposited within the lake;
- ensuring development of appropriate technologies to conduct the experiments efficiently without contaminating the lake.

A preliminary timetable for Lake Vostok studies requires significant iteration with the Antarctic logistics operators, the interested U.S. agencies, and the international partners. The overall framework for the timeline allows an initial period of planning, modeling, and technological development. This planning period would be followed by ground and airborne site surveys, in situ measurements, and sample return. The airborne and ground-based site surveys would be used to identify locations for the initial in situ measurements and the long-term observatories. The first in situ measurements would include a vertical profile within the water column, microscale observations of the sediments, and careful measurements of the key interfaces, specifically the water/ice interface and the water/sediment interface. This initial measurement campaign into the lake would include the installation of a long-term observatory.

The following year would involve a targeted effort to obtain samples from within the lake, specifically samples of the basal ice, the lake water, and the hydrates, and samples of the surface sediments. Planning for a second long-term observatory would begin at this point as well. Following the installation of the second observatory, the research efforts would focus on the recovery of a sediment core from the lake. Throughout this project careful attention will be paid to developing the appropriate technology to sample the lake with minimum impact. Also, it will be important to have ongoing data exchange workshops and close international collaboration to ensure success.

A report on a workshop on Lake Vostok late last year, sponsored by NSF, is on the Web (http://www.ldeo.columbia.edu/vostok/). Hard copies can be requested from Margie Turrin (mkt@ldeo.columbia.edu). The workshop and report were sponsored and supported by NSF grant OPP-9820596 and

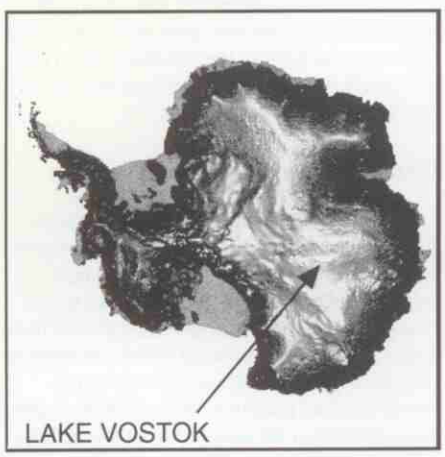


Fig. 3. European Remote Sensing (ERS-1) surface altimetry indicating location of Lake Vostok.

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References

Abyzov, S. S., I. N. Mitskevich, and M. N. Poglazova, Microflora of the deep glacier horizons of Central Antarctica (trans. from the Russian), *Microbiology, 67*, 451-458, 1998.

Karl, D. M., In *the microbiology of deep-sea hydrothermal vents*, edited by D. M. Karl, pp. 35-124, CRC Press, Boca Raton, Fla., 1995.

Petit, J. R., et al., Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica, *Nature, 399*, 429-436, 1999.

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

Siegert, M. J., and J. K. Ridley, An analysis of the ice-sheet surface and subsurface topography above the Vostok Station subglacial lake, central East Antarctica, J. *Geophys. Res., 103*, 10,195-10,208, 1998.