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LAKE VOSTOK

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Definition

Subglacial Lake. A lake covered by an ice sheet or glacier.

Introduction

Subglacial Lake Vostok is the largest of at least ~~275~~ subglacial lakes in Antarctica, and it was the first to be discovered. A lot of our knowledge about Antarctica, about the Earth's climate history, and about the subglacial lakes has been descended from the research station built at this location. This contribution summarizes some of the knowledge gained after more than 50 years of research in the heart of Antarctica, on top of, within, and below the ice.

On top of the ice: discovery

During the *International Geophysical Year*, the *Second Soviet Antarctic Expedition* encountered a quite plain area in the center of Antarctica. For the intended permanently manned station far away from any human settlement, airborne transport is indispensable, and hence this location was chosen to establish *Vostok Station*, on December 16, 1957. It is located close to the *Southern Pole of Inaccessibility* and the *South Geomagnetic Pole*. Many scientific experiments have been carried out at Vostok Station. Analyzing the results of seismic soundings, Soviet scientists had speculated about water beneath the 3,750 m thick ice sheet even in the 1960s. Further evidence of the existence of a lake was provided by radio echo sounding in the 1970s, which was confirmed later by satellite altimetry and seismic sounding (Kapitsa et al., 1996).

Subglacial Lake Vostok's area of about 16,000 km^2 can be estimated from airborne measurements and satellite imagery (Figure 1). The lake is surrounded by a bedrock-based ice sheet, and the ice flow approaches Subglacial Lake Vostok from Ridge B in the west, but is deflected southward over the lake (Figure 2). As the lake's surface is flat, it is reasonable to assume an isostatic equilibrium, that is, the ice floats on the water like an ice shelf. The observed ice surface slope over the lake is only 0.02%, leading to an elevation difference of about 50 m. However, because of the density differences between water and ice, surface ice slopes are enhanced approximately ten times at the lake–ice interface. This results in a lake surface elevation difference of about 500 m.

In the ice: drilling and indications of life

In the 1970s, Soviet scientists started to drill ice cores in the vicinity of their station. These early boreholes were less than 1,000 m deep, but nevertheless they provided a unique climate archive. Deeper cores were drilled in 1984 and in the 1990s. The deepest core reached a depth of 3,623 m and penetrated the boundary between meteoric ice and refrozen lake ice at 3,539 m. From this ice core, a climate archive dating back 420,000 years was revealed. According to the seismic soundings, the water interface below Vostok Station is about 3,750 m deep, which means that below Vostok Station a layer of about 210 m refrozen lake water exists (e.g., Jouzel et al., 1999). Today, the deepest borehole is less than 100 m away from the lake's surface.

Subglacial Lake Vostok is an oligotrophic environment: Temperatures of about $-3°C$, permanent darkness, low nutrient supply, and a supersaturated oxygen level provide a hostile environment, which has been separated from any atmospheric influence since the Antarctic Ice Sheet formed millions of years ago. However, analyses of the refrozen water reveal that potential nutrients and even viable microorganisms exist in Subglacial Lake Vostok (e.g., D'Elia et al., 2009). If this is verified in the future, a so far undiscovered ecosystem on Earth can be explored. Subglacial Lake Vostok may be an extraordinary example of how life may develop under such extreme conditions, and this nourishes speculations about extraterrestrial life on the ice-covered Jovian moon Europa in our planetary system.

Besides life in the lake water itself, remnants of preglacial life might be stored within the sediments at the lake's bottom – at least if the lake did exist before the ice sheet formed, which is still a matter of debate (Siegert et al., 2004). After the ice formed over the preglacial lake, the supply of light, oxygen, and nutrients from the atmosphere was intercepted, leading to mass extinction. If the sediments at the lake's ground are probed, a new climate archive will be opened and information about life million years before present will be available. However, it will be problematic to probe Lake Vostok without contaminating it. According to the *observer effect*, it is impossible to sample something without changing it. In the closed subglacial system, any contamination released by a drilling equipment will permanently and irreversibly modify the lake's composition. In this sense, Lake Vostok can be interpreted as a macroscopic example of the uncertainty principle.

Because of these well-founded worries of the scientific community against a probing, Russia agreed in the late 1990s to delay the penetration of the lake until further risk assessments have been made. It is undisputed that the Russians' drilling project does not violate the *Antarctic Treaty*. Therefore, they already have filed an *Initial Environmental Evaluation*, and only the obligatory *Comprehensive Environmental Evaluation* is pending. Hence, the drilling will be legitimate. The Russians are not the only ones who have interest in probing Lake Vostok. The American Space Agency NASA has announced that they would like to test their equipment to be used on missions to other planets and moons on Earth beforehand, and that Lake Vostok would be an ideal location for this. Meanwhile, a British consortium of scientists has launched an already accepted proposal to explore and penetrate a subglacial environment at the much more accessible and tiny Antarctic Subglacial Lake Ellsworth (e.g., Woodward et al., 2010) This has stirred the somewhat calmed plans to unlock Lake Vostok again: Despite the worries and protests of scientists (e.g., Hobbie et al., 2007) and the *Antarctic and Southern Ocean Coalition* (ASOC, an environmental organization), Russian scientists reinitialized drilling during the field season 2005/2006 with an overhauled equipment and stopped the drilling only a few tens of meters close to the lake. The Russian scientists claim that they are capable of sampling lake water without infecting it with modern microbes. However, this will be quite a task as their drilling hole is filled with kerosene and other noxious fluids necessary to prevent the borehole from refreezing or from closing due to pressure forces. Technical and legal reasons have postponed the penetration of the lake so far, but the Russians have announced that after 2010 they plan to go where no man has gone before (Schiermeier, 2008). Au2

Below the ice: modeling

The lake's area can be estimated from the surface topography, and a lot of valuable information about Lake Vostok can be gathered from the accreted refrozen lake water in the ice core. But until the lake is directly probed, detailed information about circulation and water mass exchange under the ice can only be derived from numerical modeling. From airborne gravity data and assumptions about the densities of ice, water, sediment, and rock, the lake's geometry and its water depth can be estimated (Studinger et al., 2004). In addition, seismic sounding can be used to constrain the derived geometry model (Filina et al., 2008). According to these studies, the lake's largest depth exceeds 1,000 m, the volume is about 5,000 km^3, and a sedimentary layer at the lake's bottom is several hundred meters thick.

The surface temperatures in central Antarctica are, on average, about $-65°C$ during winter, and even in the brief summer, they barely reach $-35°C$. This is well below the freezing point of water, and hence ice never melts in this region of the Earth – at least not at the ice sheet's surface. Nevertheless, water does exist in its liquid form below about 4,000 m of ice. At this depth, the freezing point of fresh water is about $-3°C$. A small geothermal heat flux of about 50 mW/m^2, as estimated for the area of Lake Vostok, is therefore responsible (and sufficient) for melting the ice's base. Additional hydrothermal energy sources are not expected to provide energy for the melting. The meltwater is collected in the topographic basin (a rift valley according to Bell et al., 2006) forming Lake Vostok.

With this valuable information, a lake-flow model can be set up to calculate the average water circulation, the basal mass (im)balance, and the distribution of melting and freezing at the lake–ice interface (Thoma et al., 2008). These simulations show a ceaseless melting-induced ice loss of about 5×10^{-2} km^3/a, which is not balanced by freezing, and a horizontal (vertical) water velocity on the order of 1 mm/s (10 μm/s). However, the modeled low vertical velocity is a spatial average; heating from below results in upwelling of plumes that rise significantly faster (about 0.3 mm/s) to the lake's surface (Wells and Wettlaufer, 2008). The combination of the modeled basal mass balance and ice flow information allows for estimating the distribution and thickness of the accreted ice at the ice sheet base from which samples have been drilled at Vostok Station. According to Thoma et al. (2010), about 65% of the lake–ice interface is covered with accreted ice (Figure 2).

Most probably, Lake Vostok is not an isolated lake but is connected to other lakes via a subglacial network like other lakes have proven to be before (Wingham et al., 2006; Fricker et al., 2007). The water collected in the Lake Vostok basin will finally reach the Southern Ocean. The age of the lake water is estimated to be between a few thousand years and more than 100,000 years, and a more recent model-based study (Thoma et al., 2010) indicates a mean water age of about 50,000 years. However, these timescales are short compared to the Antarctic Ice Sheet's age of several million years, which means that the lake water has been replaced several times since its inception.

Conclusions

After more than 50 years of research in the heart of Antarctica, some of Lake Vostok's mysteries are revealed (like the dimension of the lake), some are depreciated (like the theory of an isolated, sealed environment), but a lot is still unknown about the massive water basin beneath the 4,000 m thick Antarctic Ice Sheet. Within the next few years, we can expect more insights to be gained from the subglacial environment, perhaps by direct sampling through an access hole.

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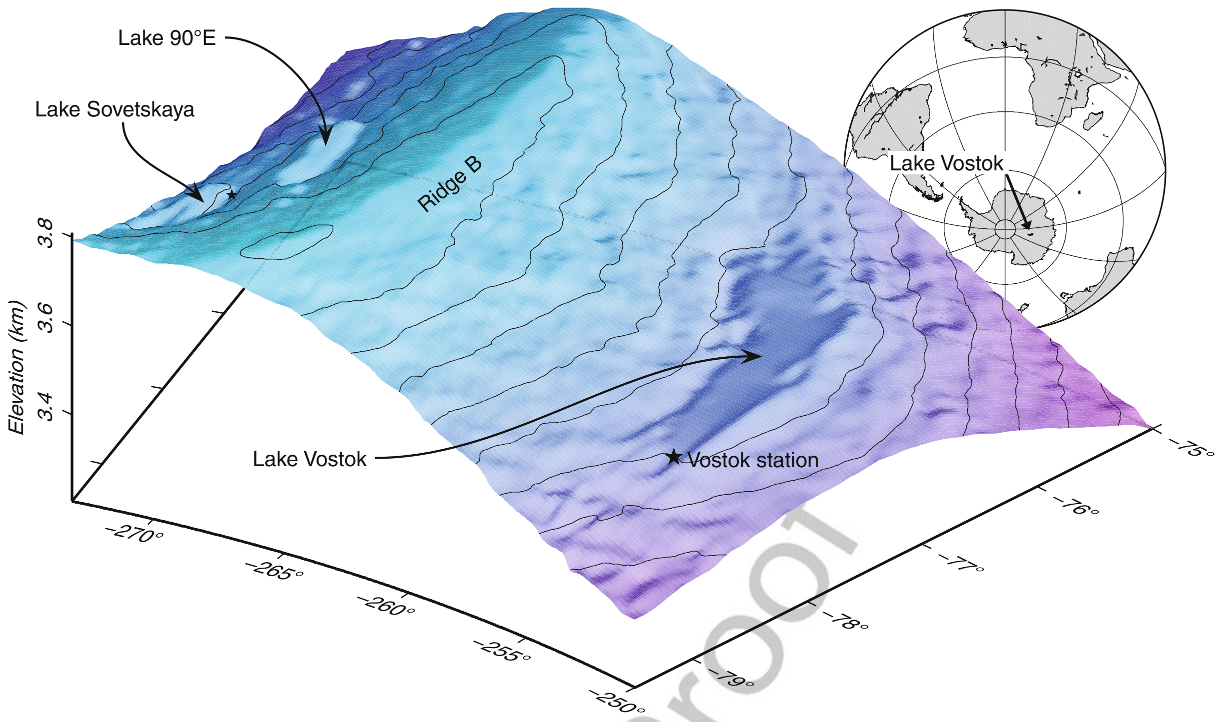
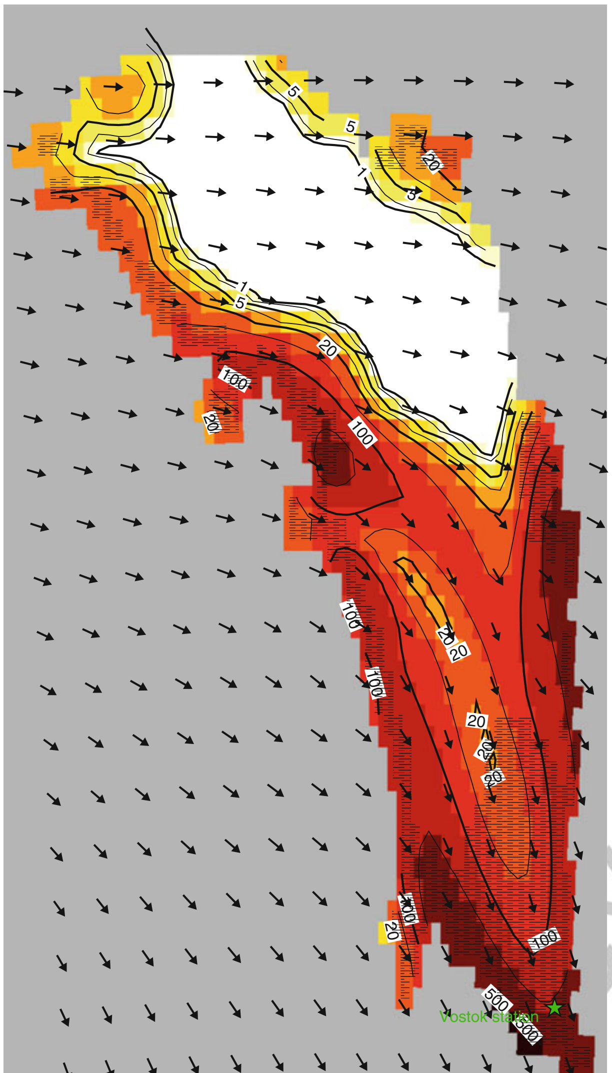
Cross-references

Antarctica
Basal Melting
Bed (Bottom) Topography
Bottom Melting or Undermelt (Ice Shelf)
Formation and Deformation of Basal Ice
Geothermal Heat (Flux)
Grounding Line
Ice Core
Ice Sheet
Ice Shelf
Lake Ice
Melting Point
Subglacial Drainage System
Subglacial Lakes



Lake Vostok, Figure 1 Lake Vostok, East Antarctica. Subglacial lakes can easily be identified by means of their flat ice sheet surface. Vostok Station is located in the southern tip of Lake Vostok. Two other major lakes can be identified across Ride B in central Antarctica: Lake 90° E and Lake Sovetskaya, named after another Russian Research station.



Lake Vostok, Figure 2 Accreted ice distribution and its thickness (m) at the lake–ice interface (indicated by *color*) and areas where freezing takes place (~~*white*~~ *shaded*). The surface ice flow direction (After Tikku et al., 2004) is indicated by *black arrows*.

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