Introduction

More than 70 subglacial lakes have now been identified by both airborne radio-echo sounding (RES) and satellite altimetry underneath the East Antarctic Ice Sheet. See Figure 1. The largest of these is Lake Vostok, located in the interior of the plateau of East Antarctica. It lies under 4 km of ice with an average depth of more than 500m. It measures 240 km long, 50 km wide and is 14,000 km2 in area, its water volume is estimated to be 2000 km3. These dimensions put it as one of the ten largest lakes in the world. It is theorized that the lake water is maintained in a liquid state by geothermal heating, pressure and insulation by the overlying ice. The presence of a layer of sediments on the lake bottom plus the findings of microbial forms in ice cores taken from above the lake suggest that life forms may yet be found that have been isolated from any outside interference for at least 1 million years.

Background/History

Vostok Station was built in 1957 by the Russians as a Cold War countermeasure to the activities of the American station at the South Pole. It was serendipitously situated over what has since been identified as Lake Vostok. The first inkling of lakes below the ice came from a Russian pilot, R. V. Robinson, who noticed flat areas over the ice sheet in 1961. He went so far as to describe these areas as "lakes" with "shorelines." (Siegert, 1999) Seismic studies being conducted near the station in 1964, led by the Russian scientist Andrei Kapitsa, were done solely to establish the thickness of the ice sheet. However, the information was not interpreted as a subglacial body of water and at the end of the field season, Kapitsa and his data went back to Moscow. It wasn't until three decades later that the print out of these seismic traces was re-examined by Kapitsa and his coworkers.

In the 1970s, scientists from the U.K., the U.S., and Denmark were collaboratively conducting radar scans of the plateau, also to establish ice sheet thickness. These studies were done with aircraft equipped with radar and could cover great distances efficiently. The echoes produced from these flights yielded several distinct signatures which were characteristic of subglacial lakes. These findings were reported in 1973. In 1977, Gordon Robin and Gordon Oswald of the Scott Polar Research Institute at the University of Cambridge "discovered" the existence of Lake Vostok still using the radio-echo sounding method. Since the advent of RES, another modality has been used which is even better suited for mapping subglacial lakes. This is satellite altimetry; employing satellites that beam radar down on the surface of the earth and record the topography. *"The first comprehensive survey of the Antarctic ice sheet, using the radar altimeter on the European Remote Sensing satellite, ERS-1, was undertaken in the early 1990s. Using this technique, Jeffrey Ridley (now at the U.K. Meteorological Office) and his colleagues established the shape of the flat region above Lake Vostok in 1993. They knew they were charting the deeply buried lake from space because the margins of the level area matched with the edge of the lake on cross sections generated with airborne radar."* (Ibid.)

It was this report which led to an immediate re-examination of the seismic data obtained by Kapitsa in 1964. He then published the first information about Lake Vostok in 1996. In the meantime, Russian glaciologists and climatologists had been drilling ice cores since 1989 over the lake to examine some 400,000 years of climate history. They had reached record depths of over 3,600 meters and it was here that they noticed peculiar changes in the size of the ice crystals. *"In the frigid heart of Antarctica, crystals of ice grow achingly slowly: at -55 C, 1 square millimetre of ice takes 10,000 years to form. Consequently, crystals in the ice core tended to be just a few centimeters across. But, suddenly, 3540 down metres, the drillers began pulling up huge crystals. 'There was one metre of core that was a single giant crystal,' says Petit, a member of the team. 'It was amazing.'"* (New Scientist)

The significance of this finding was that it indicated these ice crystals formed in relatively warm water, the researchers were looking at a 220 meter thick band of accreted lake water on the base of the ice sheet. See Figure 2. This discovery led to a halt in the drilling. Petit (Jean Robert Petit from the Laboratory of Glaciology and Geophysics of the Environment, Grenoble) as well as John Priscu (Montana State University) and David Karl (University of Hawaii) all presented their findings at an international conference on Lake Vostok in Cambridge, England. *"The accretion ice is comprised of a layer of dirty ice and a layer of 'gem ice'. Within this band of accretion ice are clues as to the nature of the ice and its contents. Things found and subsequently looked for in the accretion ice have been microbes, inorganic particles, gasses, ions, methane hydrates, geothermal activity clues and clathrates. (Clathrates are pea-sized super-compressed gas bubbles encased in ice – it is believed that 70% of gas entering the lake is bound up in clathrates with only 30% being in the water column. This makes the lake supercharged with gasses, like soda."* (Priscu)

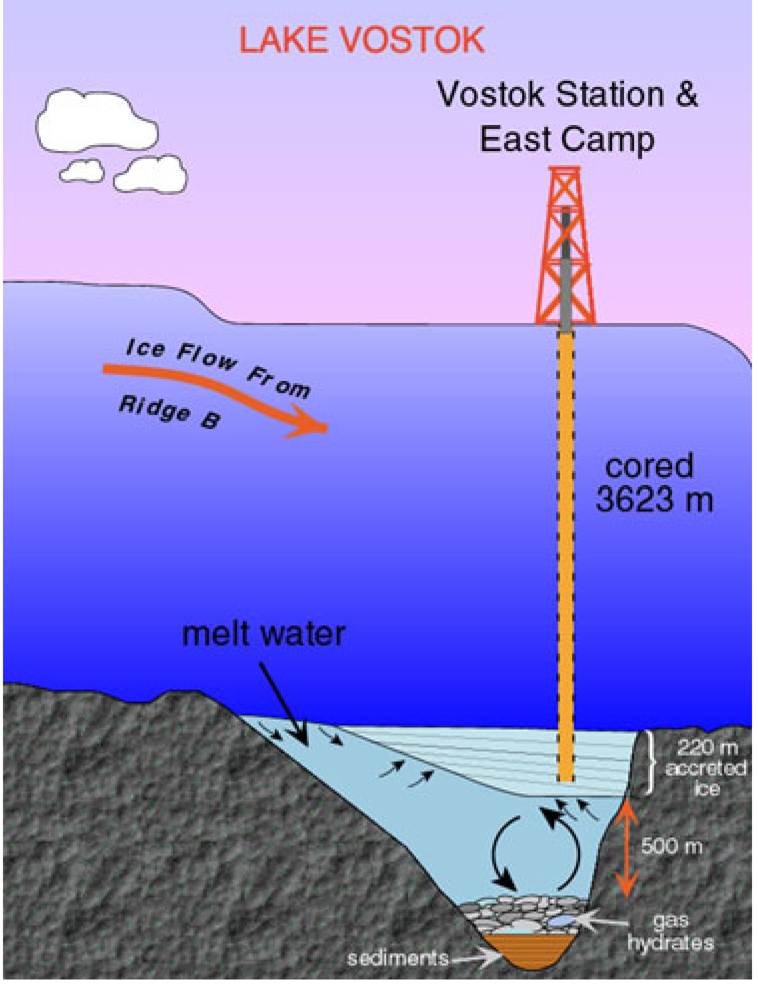


Figure 2. Conceptual drawing based on RES and seismic studies of the structures below the ice sheet at Vostok Station. From Robin Bell, Lamont-Doherty Earth Observatory, Columbia University.

Tectonic Setting

Based on limited geophysical data, it has been proposed that Lake Vostok "*occupies a structural depression such as a rift*" (Dalziel) such as Lake Baikal in Russia, Lake Tanganika in East Africa and Lake Malawi which is considered an active rift lake also in the East African Rift system. See Figure 3 on the following page for a comparison of Lakes Vostok, Ontario, and Malawi by satellite images. According to Dalziel, there are a number of tectonic possibilities that could explain the existence of this depression. The possible settings include:

- Intracratonic rift associated with extensional processes – similar to the lakes of the East African rift, Lake Vostok could occupy an Intracratonic rift valley. This could be an active system or one that is tectonically inactive.
- Rift resulting from a continental collision – where a rift and Intracratonic uplift associated with transmission of far-field stress into the interior of a continent as a result of continents colliding.
- Hot spot or mantle plume driven depression – reconstruction of plate tectonics suggest there may have been several of these under East Antarctica before the opening of the Southern Ocean basins.
- Glacial scour possibly eroding an older feature – while this could be an occurrence similar to the formation of the Great Lakes, tectonism may have also been at work.
- Meteor impact – the elongated depression of the shape of Lake Vostok could have been the result of a bolide then modified by later tectonism.

The lake bed could have been the result of any one of these processes and its age is also in question. One author postulates that the Vostok basin may have developed at about the time of the Lambert Graben (Rift) and the Gamburtsev Mountains, see Figure 4, which is thought to be at least 30 million years ago and possibly as much as 50 million years ago. It is with much more certainty that the permanence of the continental ice sheet occurred, a little less than 15 million years ago, and since this time Lake Vostok would have been completely covered by a thick sheet of ice. (Barrett) From this time on, the lake and whatever inhabitants that lived there, would have been shut off from the rest of the world.

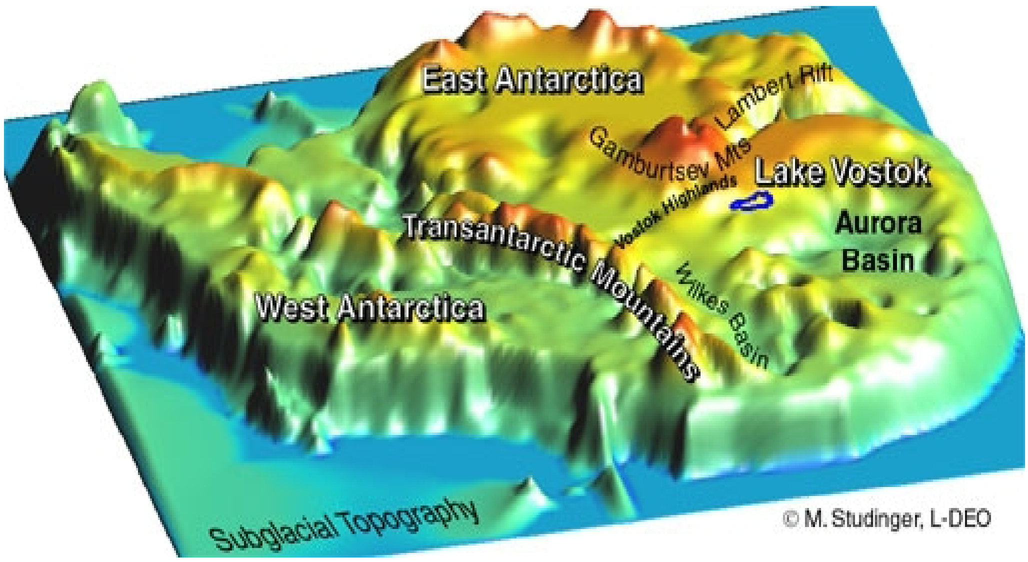


Figure 4

Life in the lake

Scientists have no way of knowing at the moment as to whether or not any organisms may still be alive in the waters of Lake Vostok but it is not an unreasonable assumption. There are numerous examples of organisms that live and thrive in conditions that are lethal to most cells. Organisms such as these are known as extremophiles. They range in habitats from undersea hydrothermal vents and hot springs, these are called “thermophiles” and “hyperthermophiles”; to the frozen regions of the Arctic and the Antarctic where such organisms are called “psychrophiles”. Still other extremophiles are found in hypersaline or hyperalkaline aqueous solutions. Thomas D. Brock, a microbiologist at the University of Michigan, reasoned from his years of investigations that ”*microorganisms would likely be found wherever liquid water existed*.” (Madigan and Mars) This same rationale is what researchers are taking into consideration with the waters of Lake Vostok.

In spite of the ”total *darkness, low nutrient levels*, [and] *a pressure of 380 atmospheres*” (Gavaghan, 2002) scientists such as John Priscu and others are hopeful viable life forms will be found in Lake Vostok. Both he and David Karl independently found examples of microbial life within samples of the ice core taken from 3590m and 3603 m respectively. These organisms recovered and identified by DNA fingerprinting techniques are related to modern day Actinomycetes and α- and β-proteobacteria. (Gavaghan, 1999) In addition to these species, viruses, fungi, yeasts, algae, and diatoms, some as old as 200,000 years, were also isolated. (BBC News, Priscu, 2003)

“*The founding populations (original inoculum) could come either from the rock or sediment prior to ice cover, or from microbes trapped in the ice that are slowly transported through the ice to the water. In either case, Lake Vostok microbes would have been isolated from their global relatives for at least 1 million years.*” (Tiedje)

Bell and her group have studied the ice sheet dynamics of the overlying ice at Lake Vostok (Bell *et al.*) They have concluded that the lake water residence time is roughly 13,300 years and that it takes from 16,000-20,000 years for the accreted ice to cross the lake and then exits along the southeastern lake margin. As this ice is moving across the lake, the basal ice will be melting at the rate of 1mm per year based on thermodynamic modeling. Even though the rate of sedimentation is quite low, the amount of sediments that have built up could be ten to hundreds of meters thick given that subglacial lakes may be millions of years old. However, no one has yet directly measured sediments on any subglacial lake. (Siegert, 1999)

It is possible that there may be biota buried even deeper in this basal sediment layer of Lake Vostok. If these are found, they may have evolved unique strategies for survival that are completely unknown since they could have been covered up prior to the formation of the lake which would be 35-40 million years ago. (Ibid)

Priscu warns that the microbes that were recovered in the core samples may well have been from contaminated drilling equipment (Gavaghan, 2002). This would seem unlikely as the sections of the ice cores that were used in the studies had had outer layers removed and these were checked for traces of kerosene. No kerosene was detected after the first 2 mm were removed (Mikucki, pers comm.). However, Sergey Bulat of the Petersburg Nuclear Physics Institute, says that some of the microbes found in the core samples were recovered from the kerosene used in drilling. (Gavaghan, 2002)

Mechanisms for life under the ice

Factors that could provide life sustaining scenarios are the dissolved organic carbon (DOC) concentration (Priscu *et al*, 1999); the potential use by the microbes of clathrates (gas hydrates) as an energy source (Tiedje); and the possibility of geothermal heating.

Priscu compared DOC concentrations of accreted ice and the water column from Lake Bonney to the DOC levels of ice core 3590. He then extrapolated those DOC levels to concentrations that could be expected within the water of Lake Vostok. He calculated these to be 1.2 mg/l, which is adequate to support microbial growth if their metabolism is heterotrophic (organisms which rely on an exogenous energy source) and this concentration is biologically labile. (Priscu *et al*., 1999)

From the earlier discussion of the tectonic setting of Lake Vostok it is not unlikely that geothermal heating is present to some extent. "S*ome rift valleys lack active volcanism, but nearly all show anomalously large amounts of geothermal heat ebbing upward from the interior of the earth. For Lake Vostok, such warming would be particularly important, because an enhanced supply of heat may lead to the circulation of geothermal fluids through the underlying bedrock, adding both warm water and leached nutrients to the lake."* (Siegert, 1999) It was subsequently shown that a major contribution by geothermal heating has been ruled out by studies of the chemical composition of the accreted ice (Jean-Baptiste, *et al*.)

Studies indicate that the ice sheet melts at its northern aspect of the lake and freezes at the southern aspect. "*If this is correct, organic material, minerals and oxygen that have sunk through this glacier could be entering at the north of the lake. At the same time, friction between the water and sediment on the lake floor could further release nutrients into the water*." (Gavaghan, 2002)

In spite of the extremes of the environment that would be found in this setting, researchers are confident that life forms will be found. In order to verify this, they need to obtain samples of the lake water and sediments.

Concerns

At the present time, drilling is still on hold while research and conjecture continue – as well as intense debate within the scientific community over what to do with Lake Vostok. The debate is whether or not to drill down into the waters of the lake. The stakes are huge.

The biggest concern by far is the possibility of forever contaminating the lake during the drilling process. The bore hole that is already there has been filled with a mixture of aviation fuel and Freon to keep this from refreezing. This amounts to 60 plus tons of drilling fluid. According to a comprehensive environmental statement presented by the Russians at the 23rd consultative meeting of the Antarctic Treaty in May of 1999, the "*report notes that the quantity of drilling fluid is too large to be removed, recycled, stored above ground, or transported away from the site. It should not, however, be allowed to penetrate into Lake Vostok, where it would pollute one of the last remaining pristine bodies of water on this planet. Calculations show that materials released into the Lake Vostok water column could circulate to the bottom of the lake within days and throughout the entire lake basin within decades*." (Vincent)

Another concern is the finding recently that the lake is super-saturated with oxygen and nitrogen. Chris McKay of NASA has warned that drilling into Lake Vostok "may result in a vigorous gas-driven flow if lake water is brought to the surface." (Field) Calculations of the gas levels dissolved in the lake are equal to 2.5 liters of gas per liter of water. This could lead to an explosion putting the drilling teams in danger. A means of averting this from happening is to fill the bore hole with a fluid that is at a higher pressure than the water. However, according to John Priscu, the fluid will need to be at a lower pressure in order to avoid contaminating the lake. The Russians are planning on drilling into the lake anyway and will try to adjust the pressure of the bore hole fluid as close as possible to that of the water in the lake to minimize the possibility of a blow-out. (Watson)

Implications

There are many reasons to want to study Lake Vostok. One is the prospect of being able to examine an ecosystem that has been isolated from the outside world for at the least a million years. This is a very novel opportunity that has scientists all over the world very excited. Another cause for excitement is the lure of bioprospecting. For biotech companies, extremophiles are highly sought for their genetic uniqueness and their abilities to function quite well in conditions similar to those processes used by industries and science. (Mackenzie) A "famous" example of one such find is the organism isolated from hot springs in Yellowstone National Park - the bacterium *Thermus aquaticus.* An extremozyme isolated from this organism, called *Taq* polymerase revolutionized the procedure of polymerase chain reaction (PCR) to amplify strands of DNA. (Madigan and Mars) This enzyme is able to withstand the high temperatures required in the thermocycling steps of PCR and has allowed this technique to be used in many scientific, medical, and forensic applications.

Bioprospecting, while it is an extractive process like mining, it removes information rather than a non-renewable resource; it uses small amounts of genetic material. This is where it becomes a debate within the debate. A great deal of money goes into the research and development of a product under investigation for biotech purposes. "*Biotech companies are increasingly looking to protect their investments by putting confidentiality clauses into the funding agreements that they strike with researchers and by patenting discoveries.*" (Mackenzie)

When the Antarctic Treaty was signed in 1959, it was with the intent that, among other things, Antarctica would be used for scientific research - the exchange of scientific information was to be promoted. The conditions under which scientists find themselves with biotech companies undermine these principles. In 1993, the Convention on Biological Diversity was adopted. "*Its introduction created the expectation that users of genetic resources share the benefits with others. But nothing in the Antarctic Treaty or any of the other conventions and protocols that govern activities on and around the continent outlines any benefit-sharing mechanism. And it's unclear whether present international rules governing the protection of intellectual property will help or hinder information exchange and benefit sharing.*" (Mackenzie) With no clear cut guidelines in place, the question of who will benefit from the discoveries that are likely to happen is yet unanswered. More discussion will therefore be necessary to sort this out.

Technologies

The general consensus with regards to the abilities to drill into the ice covering Lake Vostok is that the methods that are in existence at the moment are not capable of the task without considerable risk of contamination to the waters of the lake with either microbes from the surface or with drilling fluid.

There is, for the time being, international agreement that no drilling should take place until, and if, drilling can be achieved so that no contamination occurs. The Scientific Committee on Antarctic Research (SCAR) conducted a meeting in September 1999 to draw up a science plan with goals and recommendations for subglacial lake explorations. An offshoot of this SCAR meeting is the Subglacial Antarctic Lake Exploration Group of Specialists (SALE-GoS). This is an international group of scientists and experts who have since been conducting workshops at least yearly to review the "state of the art" of Lake Vostok and make recommendations to guide the research being conducted and proposed. Appendix 1 is a copy of their latest report and recommendations for subglacial lake explorations.

NASA's Jet Propulsion Laboratory (JPL) in California has been working on adapting technologies being developed for the Mars Exploration Technology Program for the possible use on the Jovian moon, Europa. Because of the likely similarities of environments, the robot design could be adapted for use to drill through the depths of ice here on Earth. Decontamination procedures and methods for characterizing microbial contamination are being evaluated.(Kern) It is hoped to couple these with the robotic probe, dubbed "Cryobot", being developed by NASA with assistance from engineers from the Norwegian Polar Institute, which uses hot water and gravity to move through ice, in conjunction with a second submersible robot deployed from the cryobot, called "Hydrobot". The hydrobot would explore the lake, and perhaps be able to collect water and sediment samples that could be returned to the surface for study (Siegert, 1999, Knight).

It was recently reported that Cryobot has completed a successful test run in the Arctic (Knight). Drilling techniques are being perfected in an ice environment similar to that over Lake Vostok but without the risk of polluting a unique habitat. Don Blankenship, a radar expert from the University of Texas, said “Lake Vostok is the crown jewel of subglacial lakes in Antarctica. I’m not sure we should learn to cut diamonds on the crown jewels.” (New Scientist) It would appear that his advice was heeded.

Conclusion

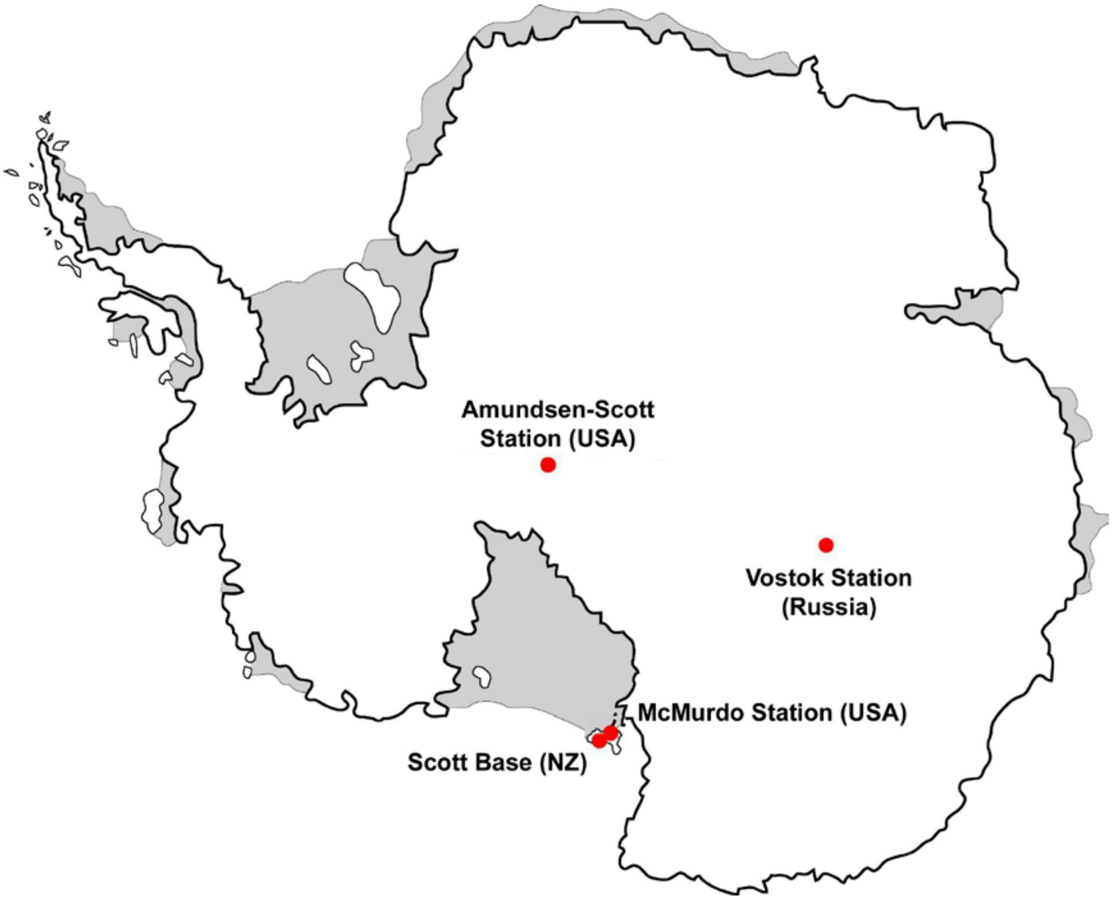
Lake Vostok is one of many subglacial lakes found in Antarctica yet it occupies a unique place in the scheme of things. It is the largest of any subglacial lake yet identified. It lies under 4 km of ice making it one of the deepest lakes known. It may be a reservoir of unknown life forms that have been able to evolve completely different means of survival. Its depths will hold insight into the earth’s past climate and tectonic history. Yet, because of its special status it has been put off limits to researches eager to unlock its secrets. There is no way to be certain about much of what is known of Lake Vostok as most of this information is speculation, extrapolation, or inferences. Until methodologies are perfected to ensure this body of water is not contaminated or polluted, that may be all that’s ever available.

Microbial Considerations of Lake Vostok

Abstract: Lake Vostok is one of more than 70 subglacial lakes found under the Antarctic ice sheet. It is of particular interest in that it is the largest one to be found, it was coincidently under the Russian research station Vostok, located in the central plateau of the East Antarctic Ice Sheet. Its existence was unknown until 1977 when airborne radio-echo soundings identified the lake. The shape was established by satellite altimetry in the early part of the 1990s which subsequently confirmed seismic data collected in the 1960s by the Russians for ice thickness studies.

. This lake is important as it may be a reservoir for unique microbial forms that have been filtering out of the overlying ice sheet as melting occurs. The sediments that may have pre-existed before the lake itself was formed have been covered by a permanent ice sheet for at least 15 million years. The sediments may therefore contain organisms that have had time to evolve completely different strategies for survival given the extremes of the environment. Ice core samples have been studied that are representative of accreted ice from the lake. These samples have revealed some microbial forms similar to members of certain modern day microbial families. Some have been found to be viable in ice core samples that are 200,000 years old. These organisms are thought to be different from those which may be found in the sediments.

Drilling into the lake was halted until further studies could be done to determine how best to enter into what is considered a unique and pristine environment. There is ongoing debate about the fate of Lake Vostok. Considerable impetus from the United States makes it the leading nation eager to sample the waters, though other countries are likewise interested in the potentials Lake Vostok has to offer. One of the goals of the US is to use Lake Vostok as a planetary analogue for future exploration of Mars and Europa. An international assemblage of scientists and experts, collectively known as the Subglacial Antarctic Lake Exploration Group of Specialists (SALE-GoS) is directly responsible for the stewardship of Lake Vostok and other Antarctic subglacial lakes. They will be guiding and directing the outcome of drilling projects into Lake Vostok.



Microbial Considerations of Lake Vostok

ANTA 502
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