Literature Review

Postgraduate Certificate of Antarctic Studies 12
2009/2010
University of Canterbury

Penetration of subglacial Lake Vostok through the existing holes - a good idea?

Matthias Wagner
Student-ID: 35267839
Date: 11/12/2009

Contents

1 Introduction

In winter 1958, the first drilling experiences for ice sheet exploration at Vostok Station, a Russian research station in Antarctica, took place. This was one year after the Vostok Station was established in 1957 during the International Geophysical Year. The existence of the subglacial lakes was unknown at that time for they were not discovered until the late 1960s. [19,21]

After coming to a depth of 52m in 1958, drilling was stopped for almost a decade until 1969. From then on, various holes were drilled and as a result thousands of meters of ice cores were recovered at Vostok Station. The drilling at borehole number 5G started on 20 February 1990 and it reached its record depth of 3650m in the summer season 2005/06. The data obtained by these ice cores revealed much information about the last 420,000 years. [21]

In the late 1960s due to seismic soundings water was assumed to be beneath the ice sheet. In the 1970s, an airborne radar mapping project driven by the US, UK and Denmark revealed flat reflections at the bottom of the ice sheet which also suggested water beneath it. The existence of Lake Vostok was first noted in 1973 by scientists of the Scott Polar Research Institute [15]. The full size of Lake Vostok, the biggest lake under the Antarctic ice sheet, was revealed by the European satellite ERS-1 in 1996 (Fig.1). Its surface covers an area of 14,000km^2 and it has a water volume of about 5400km^3. The size is comparable to Lake Ontario in North America. [15,19]

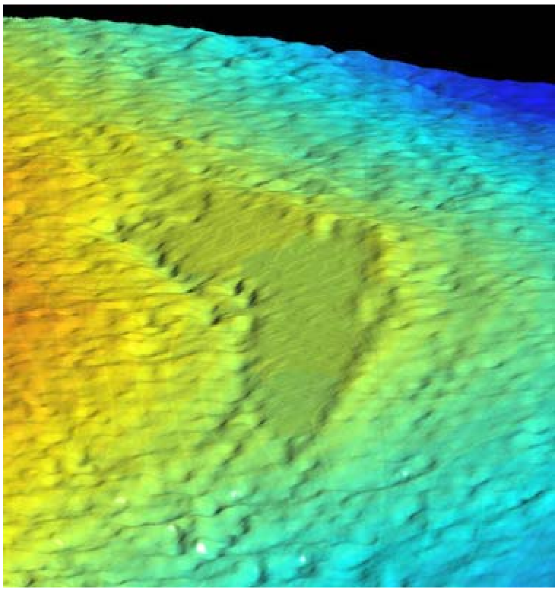

Fig. 1 Ice surface above Lake Vostok recorded by satellite ERS-1 [19]

During the drilling season of 1997/1998 at a depth of 3538m, the drill passed from meteoric ice into accretion ice which was formed by the freezing of subglacial lake water. Drilling was then stopped at 3623m, about 130m above Lake Vostok. In the probes of the frozen lake water evidence for microbial life and bacteria was found [4]. Nevertheless it is uncertain if any life could survive in the lake isolated from the atmosphere for several million years. [4,19,21]

Therefore scientists are highly interested in the exploration of subglacial lakes as nobody knows what really can be expected to exist in the lake water. The penetration of the lake to receive data is the only way to confirm or abandon any vague assumptions. This penetration has to be accomplished extremely carefully as different fluids from the drilling process, pollutants or other exchanges of alien material could harm the isolated environment. These therefore could cause reactions that cannot be undone and may lead to the extinction of possible life. [4,19]

2 Environmental Concerns

The subglacial lakes, being isolated from the atmosphere for millions of years, are supposed to have its own ecosystem [4]. Many of the lakes are connected to each other by subglacial streams. In order to receive data of the assumed ecosystem and the possible life in this hostile environment the lakes must be entered. This entry process however causes many concerns as the lakes environment could be harmed by this process. In the following the main concerns are presented.

Contamination of the lake

Analysis of accretion ice above Lake Vostok has given evidence of former microbal life in the lake. If different bacteria and single cell creatures have further developed to survive in extreme conditions there still maybe life in the lake water. By entering the lake with drills it is very likely that alien fluids, materials or gases will be inserted into the lake which could change the subglacial environment dramatically. This can lead to the destruction of an irrecoverable nature below the ice and extinction of assumed microbes. The highest efforts have to be made in order to protect the pristine environment of the subglacial lakes. [5,6,10]

Adverse environmental impact from drilling operations

Drilling is another impact to nature that has to be considered. If decisions are made to drill at sites that have not been established yet, heavy drilling equipment, fuel for energy supply and logistics, and the whole necessary infrastructure has to be installed at the specific location. Depending on the drilling mechanism, fluids will be needed that eventually can move along grain boundaries and form small tubes in the ice. These effects may cause pollution of ice and soil within an unpredictable big area around the drill site [7]. Other impacts can be exhaust gases from the generators or vibrations in the ice caused by the drilling frequency. With an increasing hole size, the footprint on the surface also becomes larger. [6,10]

Concerns about ecological danger from unknown bacteria to life on Earth

There are also concerns that lake water probes could release unknown bacteria or viruses that may harm life on Earth. Regarding this threat the risk already has been discussed at the XXIV Antarctic Treaty Consultative Meeting in 2001. In the frozen accretion ice that already has been recovered and examined no unusual species were found. The newly obtained water samples will be handled with great care, but any harm from microbal life is very unlikely. Also, due to an ice plug there will never be a direct connection of the lake to the surface. [9]

3 Drilling Technologies

For penetrating the Subglacial Antarctic Lake Environment (SALE) a “clean” drilling and sampling technology has to be found. Regardless of good intentions and the elegance of a solution on paper, the method of entering the SALE will be subjected to physical forces that may be difficult to predict exactly but must be prepared for a range of eventualities. Drilling technologies including wellbore control issues, wellbore sealing methods and sampling methods have to be compared and evaluated. [14]

In the following the four most suitable technologies for penetrating the SALE will be shown. There have been many comparable methods in use on projects in Antarctica, but most of them are not capable of drilling to a depth of almost 4000m which is necessary to penetrate lakes such as Lake Vostok. Other methods used in the past are very inefficient or unreliable compared to the described methods.

3.1 Ice Corers

Electrothermal Drill

Electrothermal drills are particularly suited for warm ice (more than -10ºC). The holes created are about 1-2mm larger than the drill so that the threat of getting stuck is kept to a minimum. Nevertheless antifreeze needs to be added to the melted water to avoid hole closures. The assembly of the Thermal Drill TELGA-14M, used for drilling the first 120m of the deepest hole 5G at Vostok Station is shown in Fig. 2. For power supply and lifting process it is connected to the surface with a cable (1). The thermal head (10) carves around the core which is stored in the core barrel (8). In comparison to the electromechanical drill, this process is very slow and needs a lot more energy although the drill itself is smaller. [2,9,21]

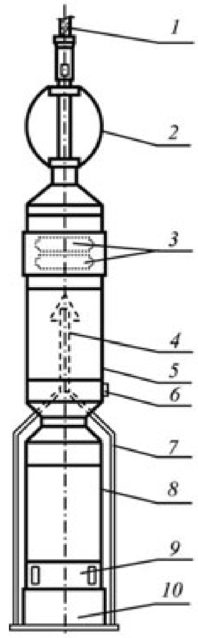

Fig. 2 Thermal drill TELGA-14M designed in Leningrad Mining Institute: 1. cable; 2. centering springs; 3. vacuum pump; 4. central water suction tube; 5. water tank; 6. valve; 7. water suction tubes; 8. core barrel; 9. core catcher; 10. thermal head. [21]

Electromechanical Drill

The electromechanical drill is also connected to the surface by a cable. Through its rotating tip it cuts out smooth ice cores with little thermal disturbance. It is very suitable for cold ice and is much faster than a thermal drill. Drilling warm ice however risks freezing of the drill. Also drilling fluids are necessary for washing away cutting chips and storing them in the chip chamber. The drill KEMS-132 was used to reach the record depth of 3650m in hole 5G-1 at Vostok Station. It is shown in Fig. 3. The anti-torque system (4) prevents the upper part of the drill from turning by holding on to the ice wall of the hole. This mechanism allows the drill head (10) build up the necessary torque for cutting the ice. The electromechanical drill was often used at various drill sites and a lot of experience could be gained. [2,9,21]

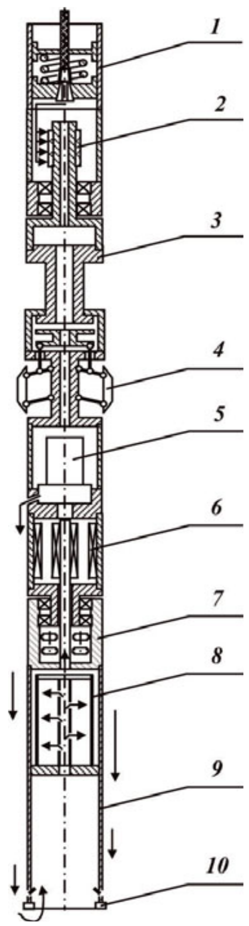

Fig. 3 Electromechanical drill KEMS-132: 1. cable termination; 2. electric chamber; 3. hammer block; 4. anti-torque system; 5. pump; 6. electric drive motor; 7. reducer; 8. chip chamber including chip filter; 9. core barrel; 10. drill head. [21]

3.2 Thermo-Probes

Thermo-Probes operate on the same principle as electrothermal drills (see Fig. 2) without collecting an ice core. They melt water at the bottom of the probe and slowly move down into the ice lowered by its own weight. The tether is unwound from the probe as it descends and melted water refreezes above the probe. Existing thermo-probes carrying measurement equipment are generally designed for one-way use, however, for sample retrieval returning probes could be designed using the same method of melting ice for going back. The advantage of those probes is that no antifreeze fluids are needed and the application therefore is very clean. Nevertheless, small particles in the ice could build up quickly in front of the melting head while descending making the probe very inefficient. It could even be stopped due to the heat insulation of the particles. Only operation in ice without impurities is reasonable. [2,14,20]

3.3 Hot Water Drills

Hot water drills use pressurized hot water to melt a hole into the ice. The nozzle is carried by a hose which can be descended in the melted hole. This is a very fast and efficient way to drill small holes into the ice. For larger holes, several hours are necessary as a lot of ice has to be melted. The hole is filled with melted water, balancing the glaciostatic pressure. Due to density variations in the ice, hole diameters can be very irregular. In cold ice, a lot of energy is needed for the melting process. The drilling process itself is clean, but the hole refreezes quickly after the drilling process has ended. For prevention of hole closure, antifreeze fluids have to be added causing the same environmental problems as in other drilling technologies. At the present time, a hot water drill has not penetrated the ice thickness yet, necessary for reaching most of the subglacial lakes. [2,14]

3.4 Coiled Tubing

The concept of a coiled tubing drill for ice (CTDI) combines the advantages of fast drilling and portable drill rigs with the advantages of a mechanical drill. The coiled tubing delivers the pressure of a high-pressure pump to a downhole steerable hydraulic motor that drives a cutting bit. An injector on the surface guides the tubing in and out the hole. A Sealing by a gel-pack or casing maintains the correct pressure in the hole (see Fig. 4). The operation fluid for the motor could be a non-freezing hydrophobic drilling fluid, water or possibly air. Cutting chips are washed to the surface with the driving fluid which is then filtered and reused making the drilling is a continuous process. The CTDI should be able to reach drilling rates of 40m/h. As mechanical and electrical power is available through the tube, different modules can be attached to its tip. The drill is suitable to drill through ice as well as through rock. Coiled tubing is a well established drilling process at many drill sites around the world. [2,3,14]

Disadvantages of the coiled tubing are the possibility of environmental contamination by drilling fluids and the needed sealing at the entry of the hole. Provisions have to be made to avoid leaking of the sealing in the firn ice. For some experiments, a hole diameter of up to 13cm is often to small to descend the necessary measuring equipment. No experiences have been made with CTDI so far. [2,3,14]

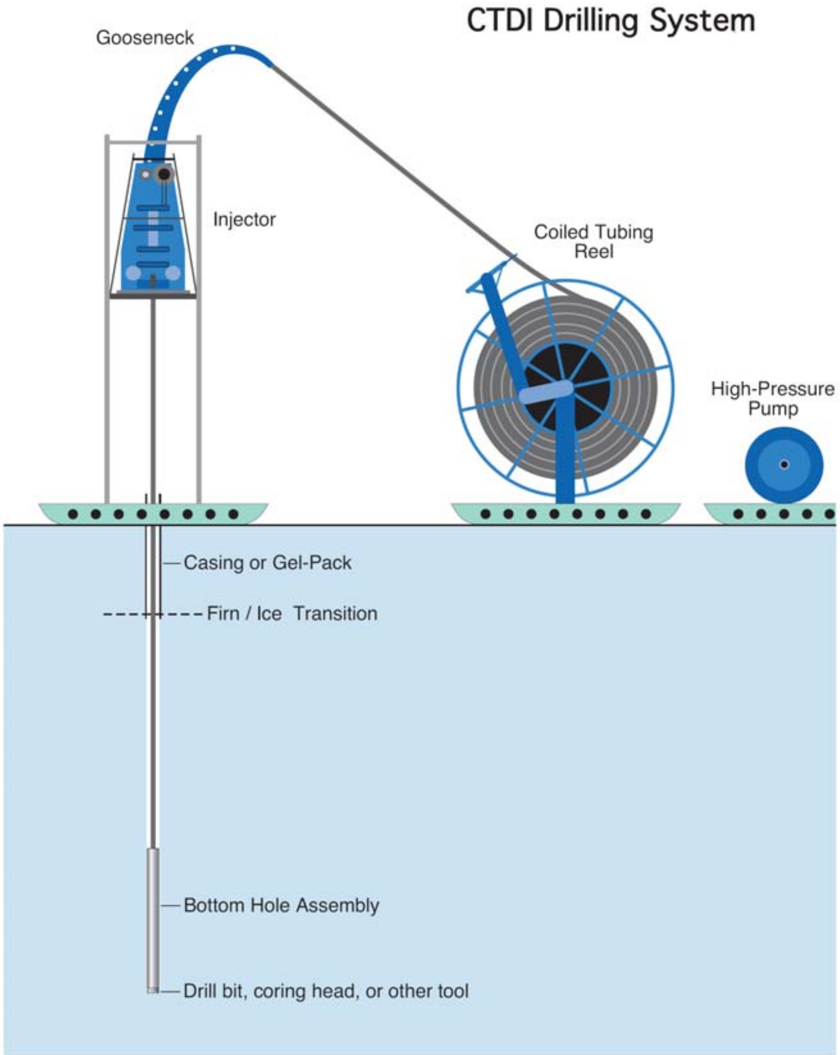

Fig. 4 Diagram of the main components of CTDI drilling system [3]

4 Penetration Proposal for Lake Vostok

Since 1998, a technique for entering subglacial Lake Vostok has been developed. The technique proposes that the lake shall be entered in three stages as described in Fig. 5. At first, the existing hole 5G-1 will be deepened to a depth of about 3720m, leaving a layer of about 30m between the lake and the hole. Then, a special tanker delivers environmentally friendly silicone oil to the bottom creating a 100m thick buffer layer. The silicone oil will be slightly heavier than the drilling fluid but lighter than water.[8,21]

In the second stage, a thermal drill with a diameter of 132mm and a small 2m long tip of only 50mm in diameter [8] will drill down until entering the lake water with its tip. On its way, possible residues of contaminated fluid will be decomposed by nozzle tip temperatures over 250°C [9]. The water can be examined or a probe can be taken before it is pulled up to a height of 30-40m above the lake again. It will stay there until the lake water, entering the hole up to the drill, is frozen. [8,21]

In the last stage the thermal drill will be pulled up after confirmation that the lake water is frozen. Then the electromechanical drill can be lowered again and take ice cores of the frozen lake water to about 10-15m above the lake surface.

Before starting the penetration of the Lake, Russia wanted to submit a finalized environmental evaluation to the Antarctic Treaty Meeting in April 2009 [17]. Due to a drill accident in 2007 and an unsuccessful recovery of the drill in season 2008/2009, the evaluation was not ready for submission at this meeting [11,12]. [8,21]

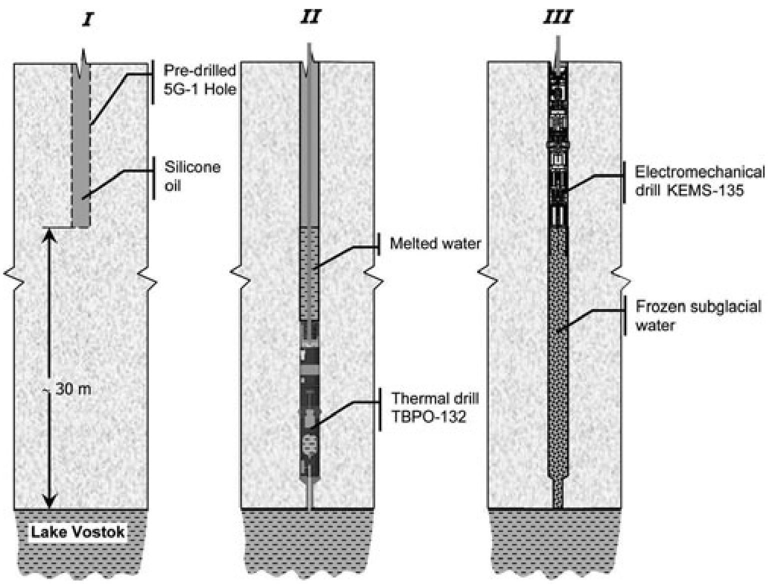

Fig. 5 Scheme of the three stages for penetration of subglacial Lake Vostok [21]

5 Discussion

The most important aspect of the penetration project of subglacial lakes is to avoid the pollution of the lake and the thereby possibly caused destruction of an existing ecosystem in the lakes. For a lake entry through the existing hole 5G-1 the biggest problem is the already present drilling fluids and antifreeze in the hole that cannot be replaced residue-free. The Russian penetration proposal through the hole would prevent the exchange of drilling fluids with the lake due to the silicone oil layer (see Fig. 5) and a sealing at the thermal drill developed for lake penetration. Regarding the proposal in detail there are still concerns that have not been mentioned. A malfunction of the thermal drill sealing would cause exchange of drilling fluids and lake water. Due to high pressure, water may stream out of the hole at the surface if no additional sealing is installed near the opening. Also, a complete destruction of drilling fluids at the bottom of the hole after lowering the thermal drill and before entering the lake has to be guaranteed.

Drilling to a depth of 30m above the lake surface can be risky as water veins are predicted to be up to 35m above Lake Vostok [16]. Through these veins fluid exchange could be possible and lead to a wide range of lake pollution. With the existence of water veins, the sealing of the thermal drill could not work to maintain the pressure difference between the lake and the borehole.

Drilling Technology

Regarding the four introduced drilling technologies, the core recovering technologies at Vostok Station have the disadvantage of not being one of the clean technologies. The holes are contaminated by the drilling fluids that keep them open. Due to these fluids a drill got stuck in 2007 while entering a cavern that was formed at the bottom of hole 5G-1 [13]. The drill was rescued and the accident was examined.

However, as these technologies have been applied for over 30 years now, drilling teams have got a lot of experience using them. They know which errors can occur and how to avoid them. Thermal probes are also well known but only suitable for clean ice and small depths. The other suggested drilling technologies haven’t been used for such operations yet. CTDI is still in the concept phase and hot water drills have never drilled to a depth of 4000m. Therefore problems and their solutions are still unknown.

Expenses

The possibility of an entry through the existing hole should not be abandoned. Drilling other “clean” holes at Lake Vostok or entering other subglacial lakes with the same thickness of the ice sheet above is a huge investment that has to be regarded in the decision. For new drill sites high expenses have to be made to install the necessary infrastructure and to run the logistics for equipment and personnel. Furthermore, the drilling process may take several seasons until the lake can be entered. Pentetrating the lake through the existing hole reduces the expenses as the infrastructure is already available.

Possibilities

Including some changes in Russia’s proposal, lake entry at Vostok Station can be a possibility with a minimum risk of lake water pollution. Adequate changes and additions are described in the following:

- To reassure a drilling fluid free environment beneath the silicone oil layer, the tip of the thermal drill should carry additional equipment to measure the existence of contaminants.
- The hole should only be drilled electromechanically to a minimum depth of 50m above the lake surface to avoid fluid exchange with water veins.
- Being the cleanest technology, a thermal probe which unwinds its tether should be used instead of the thermal drill. A return possibility for the probe can be included to receive a water sample. The ice behind the probe could refreeze before lake entry and build up a natural sealing much more reliable than a sealing at the drill. This would minimize the pollution hazard. Returning can be made possible by a second thermal head on top of the probe. [14,20]

The Lake

Through ice sheet movements and the freezing of lake water, research by R. E. Bell [1] has predicted lake water to be relatively young as a steady exchange occurs. Lake water is frozen and taken along by the ice sheet while melted water enters the lake on the other side. The lake is isolated and not interconnected to other subglacial systems. Therefore a possible pollution would not affect other subglacial ecosystems and only destroy a relatively young water environment. Nevertheless, very old creatures could have survived in the exchanging water. [1]

The aspect that Lake Vostok is the biggest lake beneath the ice sheet is mostly seen as an argument against entering the lake because of destroying the biggest subglacial system. The water volume as well could be seen as a positive aspect for the entry. A possible pollution by fluids or particles is very little in comparison to the whole volume. The pollutants will be distributed widely and would not be as dangerous as in a small environment due to a very little concentration. By pollution of other big systems in the world mankind has already experienced the impacts. Regarding oil spills on the ocean, many animals have died, but they haven't been exterminated. Besides that, the contamination would probably distribute in the top layer of the lake due to its density and would be carried out of the lake by freezing of the top layer. [9]

Furthermore, by intensive investigations and research Lake Vostok is the best known subglacial lake [18]. Research teams can be aware of certain circumstances that may occur while entering the lake. Also, if a test drilling would be successful in another lake, there can be still unexpected incidents at the second lake entry at Lake Vostok. Being the first entry can have a positive effect on the entry procedure as the drilling team will be better prepared for the unexpected.

6 Conclusion

Regarding all arguments, entering Lake Vostok through the existing hole 5G-1 could not only save a lot of additional expenses, but could also be a procedure with a minimum risk of pollution, if the progress is carefully supervised and certain changes are made to Russia's proposal. A thermal probe turns out to be the cleanest and safest way for the direct entry of the lake as a natural sealing builds up behind the probe. A test hole in another lake or a second cleaner drill at Lake Vostok is not essential. The impact of a new drill site on the surface also has to be taken into consideration. Lake Vostok itself is a good location for the first lake entry as it is the best known subglacial lake in Antarctica and facilities are already available. Being the first entry the executing research team will be very cautious to accomplish the project with success as there will be a big public interest.

References

[1] Bell, R.E., Studinger, M., Tikku, A.A., et al., Origin and fate of Lake Vostok water frozen to the base of the East Antarctic ice sheet. Nature, 416 (6878), 2002, S. 307-310

[2] Bentley, C.R., Koci, B.R., Drilling to the Beds of Ice Sheets: A Review. Subglacial Antarctic Lake Environment, 2006

[3] Clow, G.D., Koci, B., A fast mechanical-access drill for polar glaciology, paleoclimatology, geology, tectonics and biology. Nat. Inst. Polar Res. Mem., 56, 2002, S. 5-37

[4] D'Elia, T., Veerapaneni, R., Rogers, S.O., Isolation of microbes from Lake Vostok accretion ice. Applied and Environmental Microbiology, 74 (15), 2008, S. 4962-4965

[5] Hodgson, D.A., Roberts, S.J., Bentley, M.J., et al., Exploring former subglacial Hodgson Lake, Antarctica Paper I: site description, geomorphology and limnology. Quaternary Science Reviews, 28 (23-24), 2009, S. 2295-2309

[6] Jatko, J., Planning for Antarctic Subglacial Lake Studies: Science, Technology and Environmental Protection, in SCAR-COMNAP. National Science Foundation, Shanghai, China, 2002

[7] Jepsen, S.M., Adams, E.E., Priscu, J.C., Fuel movement along grain boundaries in ice. Cold Regions Science and Technology, 45 (3), 2006, S. 158-165

[8] Lipenkov, V., Russian Drilling And Surveys in the IPY, Arctic and Antarctic Research Institute, St. Petersburg, 2009

[9] N.N., Expert conclusion for the Project "Justification and development clean technology for penetrating the subglacial Lake Vostok (Antarctica)", in XXIV Antarctic Treaty Consultative Meeting. Russian Federation, St. Petersburg, Russia, 2001

[10] N.N., ASOC calls on Russia to re-consider penetrating the largest known subglacial lake. In: Appeal to the duma on Lake Vostok, Antarctica, (Hrsg.), The Antarctic and Southern Ocean Coalition, Washington DC, USA, 2008, S. 1-2

[11] N.N., Final Report of the Thirty-second Antarctic Treaty Consultative Meeting, Secretariat of the Antarctic Treaty, Baltimore, USA, 2009

[12] N.N., Results of Russian activities in the deep ice borehole at Vostok station in implementing the project of penetration to the water layer of the subglacial lake in the season of 2008/2009, in XXXII Antarctic Treaty Consultative Meeting. Russian Federation, Baltimore, USA, 2009

[13] N.N., Results of Russian activities in the deep ice borehole at Vostok station in implementing the project of penetration to the water layer of the subglacial lake in the season of 2008/2009, in XXXII Antarctic Treaty Concultative Meeting. Russian Federation, Baltimore, USA, 2009

[14] N.N., Subglacial Antarctic Lake Environments, Scientific Commitee on Antarctic Research, Bryan TX, USA, 2009

[15] Oswald, G.K.A., Robin, G.D.Q., Lakes beneath the Antarctic ice sheet. Nature, 245 (5423), 1973, S. 251-254

[16] Price, P.B., A habitat for psychrophiles in deep Antarctic ice. Proceedings of the National Academy of Sciences of the United States of America, 97 (3), 2000, S. 1247-1251

[17] Schiermeier, Q., Russia delays Lake Vostok drill, in nature publishing group. Macmillan Publishers New York, USA, 2008

[18] Siegert, M.J., Which are the most suitable Antarctic subglacial lakes for exploration? Polar Geography, 26 (2), 2002, S. 134-146

[19] Studinger, M., Subglacial Lake Vostok, Lamont-Doherty Earth Observatory of Columbia University, New York, 2008

[20] Ulamec, S., Biele, J., Funke, O., et al., Access to glacial and subglacial environments in the Solar System by melting probe technology. Re-views in Environmental Science and Biotechnology, 6 (1-3), 2007, S. 71-94

[21] Vasiliev, N.I., Talalay, P.G., Bobin, N.E., et al., Deep drilling at Vostok station, Antarctica: History and recent events. Annals of Glaciology, 47, 2007, S. 10-23