Pavel G. Talalay*, Alexey N. Markov, Mikhail A. Sysoev
Polar Research Center, Jilin University; No. 938 Ximinzhu str., Changchun City, Jilin Province, China, 130021; Tel/Fax +86 431 88502797
***Corresponding author**; e-mail: ptalalay@yahoo.com

NEW FRONTIERS OF ANTARCTIC SUBGLACIAL LAKES EXPLORATION

ABSTRACT. Antarctic subglacial aquatic environment have become of great interest to the science community because they may provide unique information about microbial evolution, the past climate of the Earth, and the formation of the Antarctic ice sheet. Nowadays it is generally recognized that a vast network of lakes, rivers, and streams exists thousands of meters beneath Antarctic Ice Sheets. Up to date only four boreholes accessed subglacial aquatic system but three of them were filled with high-toxic drilling fluid, and the subglacial water was contaminated. Two recent exploration programs proposed by UK and USA science communities anticipate direct access down to the lakes Ellsworth and Whillans, respectively, in the 2012/2013 Antarctic season. A team of British scientists and engineers engage in the first attempt to drill into Lake Ellsworth but failed. US research team has successfully drilled through 800 m of Antarctic ice to reach a subglacial lake Whillans and retrieve water and sediment samples. Both activities used hot-water drilling technology to access lakes. The main troublesome of the implemented and planned projects for accessing of Antarctic subglacial lakes is connected with the hydrostatic unbalance resulted in the upwelling of water into the hole with subsequent difficulties. The proposed RECoverable Autonomous Sonde 'RECAS' would measure and sample subglacial water while subglacial lake is reliably isolated from surface environment, and at the same time the sonde is able to measure geochemical signals *in situ* throughout the depth of ice sheet on the way to the bed. All process is going on in semi-automatic mode, and the estimated duration of subglacial lake exploration at the depth of 3500 m is 8–9 months. The general concept of the sonde as well as proposed power-supply and performance are given.

KEY WORDS: subglacial aquatic environment, environmental-friendly access technology, autonomous sonde

INTRODUCTION

Antarctica is the coldest, driest, and windiest continent, and has the highest average elevation of all the continents. About 98% of Antarctica is covered by the sheet of ice averaging at least 1,6 km thick; yet surprisingly, there is liquid water at the base of the Antarctic ice sheet. Russian scientist Peter Kropotkin first proposed the idea of fresh water under Antarctic ice sheets at the end of the 19th century. He theorized that the tremendous pressure exerted by the cumulative mass of thousands of vertical meters of ice could increase the temperature at the lowest portions of the ice sheet to the point where the ice would melt [Kropotkin, 1876]. 80 years later N.N. Zubov theoretically proved that there is a critical ice thickness, corresponding to the bottom temperature of ice sheet, equal to an ice melting point [Zubov, 1959]. In 1961, A.P. Kapitsa used Zubov's approach to suggest existence of liquid water lenses below the ice in central parts of East Antarctic Ice Sheet [Kapitsa, 1961]. The subglacial melting theory was further developed by soviet glaciologist I.A. Zotikov, who concluded that the water below the ice remains liquid since geothermal heating balances the heat loss at the ice surface (Fig. 1). According to his estimations the permanent rate of melting at the bottom of ice sheet is 1–4 mm/year [Zotikov, 1963].

Even though radar and seismic measurements have revealed water layer beneath the Antarctic ice sheet in 1970s [e.g., Oswald and Robin, 1973; Robin et al., 1977], these features had gone largely unnoticed by the broader scientific community for more than two decades. In 1996 an article in Nature written by Russian and British scientists reported that a huge lake existed beneath ~4 km of ice in East Antarctica in the region of Russian Vostok Station [Kapitsa et al., 1996]. It was concluded that the mean age of the water in the lake is about one million years. This article marked the beginning of modern Antarctic subglacial aquatic environment research.

Nowadays it is generally recognized that a vast network of lakes, rivers, and streams exists thousands of meters beneath Antarctic Ice Sheets. As of 2010, 387 subglacial lakes have been identified; this will increase as surveys improve spatial coverage [Wright and Siegert, 2011]. Estimates indicate that the total surface area of the subglacial lakes is nearly 10% of the ice sheet's base, and the volume of Antarctic subglacial lakes alone exceeds 10 000 km^3 [Dowdeswell and Siegert, 1999], with Lake Vostok (6100 km^3; Popov et al., 2011) and Lake 90°E (1800 km^3; Bell et al., 2006) being the largest.

Sealed from the Earth's atmosphere for millions of years, subglacial aquatic environment may provide unique information about microbial evolution, the past climate of the Earth, and the formation of the Antarctic ice sheet. The discovery of subglacial aquatic environments has opened an entirely new area of science in a short period of time. The next stage of exploration requires direct sampling of these aquatic systems [Talalay,

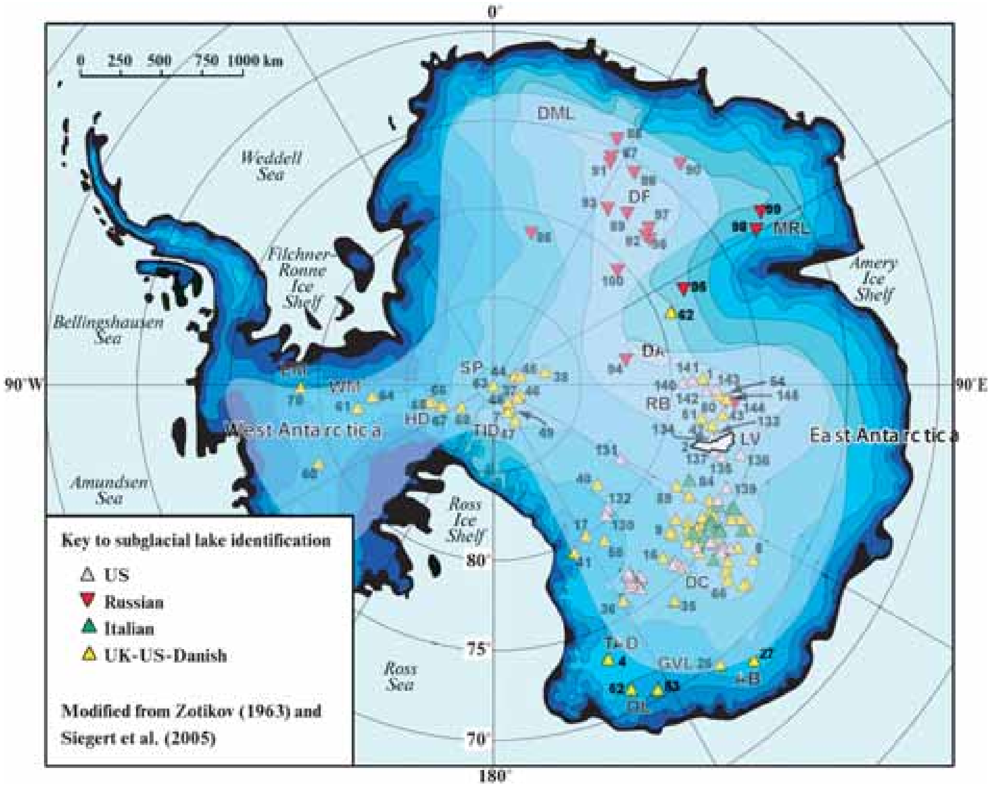


Fig. 1. Location of Antarctic subglacial lakes [Siegert et al., 2005] and bright spot area of bed melting accounting Earth geothermal flux 2,5× 10–6 kal×sm–2×sec–1[Zotikov, 1963]

2006]. The subglacial water most likely contains life, which must adapt to total darkness, low nutrient levels, high water pressures and isolation from atmosphere. It is obvious that *in situ* investigations should not contaminate these subglacial aquatic systems. This criterion makes sustainability of subglacial environment of chief importance.

BACKGROUND

The first project for penetration the Antarctic Ice Sheet to study the aqueous subglacial environment was proposed by A.P. Kapitsa and I.A. Zotikov in 1963 [Zotikov, 2006]. The project was based on a small nuclear power plant that would be lowered, as a part of hermetically sealed container, which would contain appropriate instruments and equipment. The nuclear power plant had to produce enough energy to melt ice down to the bottom of the ice sheet, and the resulting water would refreeze above the probe. Communication with the ice sheet surface is maintained by wireless means. This project was supported by the Atomic Energy Institute of the USSR Academy of Sciences which was ready to provide a small nuclear energy reactor of 100 kW, small enough to be installed in the 0,9 m diameter container. Fortunately, this project was never realized because Antarctic Treaty prohibits the disposal of radioactive wastes or nuclear plants in Antarctica.

In the following years dozen of deep drilling projects were completed in Antarctica in order to reach the ice sheet bed and to get opportunities for examining processes acting at the subglacial environment [Talalay, 2012b]. Even most of them have been succeeded at various sites of Antarctica, only three boreholes accessed subglacial aquatic system (Fig. 2).

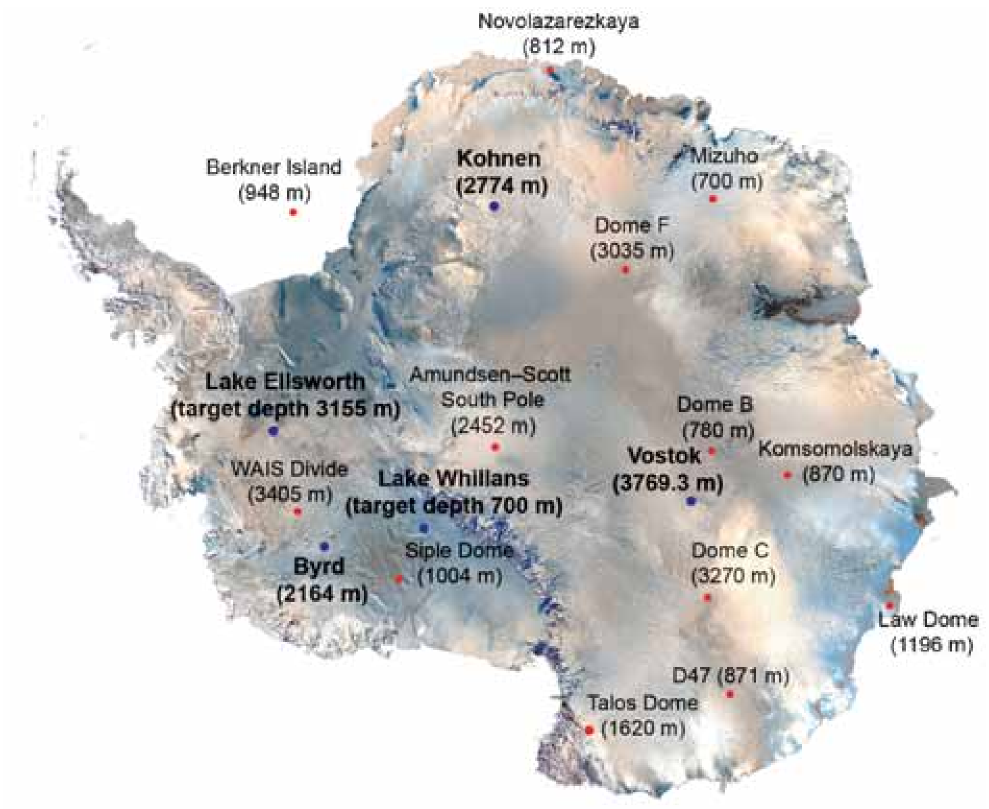


Fig. 2. Deep ice drilling sites in Antarctica (blue points mark boreholes that already reached or planned to reach subglacial aquatic systems)

Byrd Station. In 1967 and 1968 the USA CRREL electromechanical drill was used for coring at Byrd Station (80°01′S, 119°32′W, 1530 m a.s.l.), West Antarctica. At a depth of 2164,4 ma sudden decrease in power and a corresponding increase in cable tension indicated an abrupt change in material had been encountered by the cutting bit [Ueda and Garfield, 1970]. This was later concluded to be a layer of water estimated to be less than 0,3 m thick. During the time spent attempting to obtain a subglacial bedrock sample, the water which welded the hole mixed with the glycol solution used as drilling fluid in the lower part of the hole. Freezing out of the water created a heavy slush in the bottom 460 m of the hole. Within a few days, the slush became difficult to penetrate the drill, and further attempts to obtain a subglacial sample were terminated because of the possible loss of the drill. For the first time in the history of Antarctic exploration the existence of a water layer at the bottom of an ice sheet was proved experimentally. The near-bottom temperature gradient was estimated as 0,0325°C/m that gives the temperature at the ice sheet bed to be at pressure melting point of –1,5°C. No subglacial water samples were obtained at this time.

Kohnen Station. In 2001 within the framework of the European Project for Ice Coring in Antarctica (EPICA) the Kohnen station (75°00′S, 00°04′E, 2892 m a.s.l.) was established by Alfred-Wegener-Institute (Germany) in northwestern Dronning Maud Land as a logistic base for deep ice drilling activities. The estimate from radar soundings for bedrock depth was about 2780 ± 5 m [F. Wilhelms, personal communication].The near-bottom temperature log determined the temperature gradient as 0,0281°C/m that was extrapolated to the pressure melting point in 2790 m depth at 1,915°C, beyond ice thickness estimated by radar survey. Finally it was concluded that there is no melting at the bottom. In fact, in summer season 2006–2007 at the approach to the bed at the depth of 2774 m water started coming into the under-pressured hole with the flow rate of more than 1 l/min [Wilhelms, 2007]. The sample of refrozen water was recovered by special down-hole bailer (Fig. 3). Upon reducing the level of the drilling fluid, the water rose to 173m above the base. Unfortunately samples taken from the top of the column at the water-drill-fluid-interface were contaminated by the drill fluid (mixture of petroleum solvent Exxsol D40 with hydrochlorofluorocarbon HCFC-141b). It was decided not to re-drill the refrozen

Fig. 3. The first frozen samples of Antarctic subglacial water recovered at Kohnen Station, January 2007 [http://www.awi.de]

water column because of impossibility to get uncontaminated samples out of any deep ice coring hole that is stabilized by petroleum-based drill fluid.

Vostok Station. Deep drilling of a deep Hole 5G was started at Vostok Station (78°28′S, 106°48′E, 3488 m a.s.l.) in February 1990 [Vasiliev et al., 2011], six years before the large subglacial lake under the station was officially recognized [Kapitsa et al., 1996]. Twenty-two years later, in yearly February 2012, Russian researchers made contact with Lake Vostok water at a depth of 3769,3 m [Vasiliev et al., 2012; Talalay, 2012a]. The drill was rescued from rapidly rising lake water, but upon reaching the surface the whole drill was filled and coated with refrozen water ice (Fig. 4).Researchers predicted that the water would rise in the near-bottom part of the borehole, up to 30–40 m from the water table, but the first drill deployment in January 2013 found the top of frozen subglacial water at the depth of 3383 m [Press Relations Service of Arctic and Antarctic Research Institute, 10 January 2013] indicating that the water rose from the lake by 386 m. So, the pressure in Lake Vostok was much higher than expected that will need to be taken into consideration for future exploration.

A first analysis of the ice that froze onto the drill bit shows no native microbes came up with the lake water [Bulatet al., 2012]. It was preliminary concluded that the very uppermost layer of Lake Vostok appears to be "lifeless" so far but that does not mean the rest of it is.The microbes presented in the ice sample were fewer than 10 microbes/ml – about the same magnitude that would expect to find in the ultraclean room. Three of the four identified phylotypes was matched as contaminants from the drilling fluid, with the fourth unknown but also most likely from the surface.

The next stage of Lake Vostok sampling is planned for the 2012–2013 summer season by re-drilling of the frozen lake ice. It is likely that it will only be possible to re-drill upper 10–15 m of the frozen water because the main hole is inclined from the vertical by several degrees, and the re-drilled hole will deviate rapidly from the previous direction. Unfortunately, the technology used for the Lake Vostok access did not comply with the Comprehensive Environmental Evaluation [Water Sampling of the Subglacial Lake Vostok, 2002], and Lake Vostok was accessed using highly-toxic drilling fluid (mixture of kerosene with hydrochlorofluorocarbon HCFC-141b).When the subglacial water first entered the borehole, it contacted and mixed

Fig. 4. The refrozen Lake Vostok water recovered from the last run, February 5, 2012 [Credit: N.I. Vasiliev]

with the toxic drilling fluid. The subglacial water was almost certainly contaminated by the drilling fluid, and it is likely that it will be of no use for the investigation and identification of new forms of life within it.

LAST EVENTS AND NEAR FUTURE

During last decade researchers from all over the world suggested employing new methods to access Antarctic subglacial lakes and underlying sediments without undue contamination, obtain a variety of in situ physical, chemical and biological measurements and retrieve water and sediment samples [e.g. Blake and Price, 2002; Fleckenstein and Eustes, 2007; and others]. Most of them cannot be qualified as absolutely "clean" methods, and that is why they were not completed and/or financially supported. For example, autonomous cryobot designed by Jet Propulsion Laboratory (California Institute of Technology, USA) planned not to be retrieved after completing of the mission, and after certain time the probe would likely be destroyed by corrosion and contaminate the subglacial lake [Bentley et al., 2009].

Significant progress in the study of subglacial aquatic environments is now at hand with the initiation of two exploration programs likely to advance understanding of Antarctic subglacial environments over the next few years. Lake Ellsworth and Lake Whillan sprograms proposed by UK and USA science communities, respectively, anticipate direct access down to the lakes in the coming Antarctic seasons. Both activities have similar concepts, limits and performance.

Lake Ellsworth.UK consortium chose Lake Ellsworth (78°58′34″S, 90°31′04″W) as the best candidate to determine the presence, origin, evolution and maintenance of life in an Antarctic subglacial lakes. Lake Ellsworth is located in the center of the West Antarctic Ice Sheet, and the ice surface above the lake lies at approximately 1900–1925 m elevation [Proposed Exploration of Subglacial Lake Ellsworth Antarctica, 2012]. Due to radar survey the thickness of ice sheet in the region of proposed drilling site is 3155 m and the lake depth is 143 m. Minimal ice temperature is –32°C.

Hot water drilling system, designed by British Antarctic Survey, has been identified as the most effective means of obtaining rapid, clean access to Lake Ellsworth. The drilling concept is rather simple (Fig. 5): water is filtered then heated via a heat exchanger and pumped, at high pressure, through the drill hose to a nozzle that jets hot water to melt the ice. The hose and nozzle are lowered with the speed 0,5–1,0 m/s to form a straight

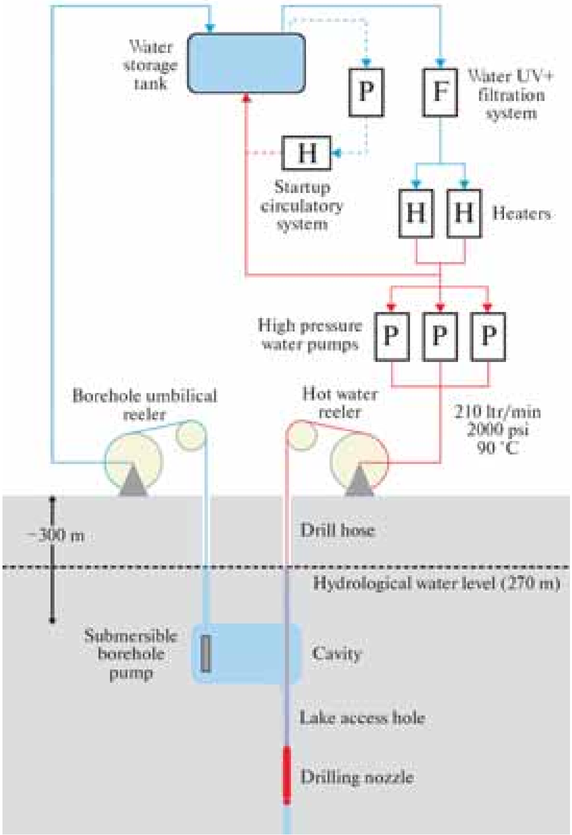


Fig. 5. Schematic diagram of the Lake Ellsworth hot water drill system (H – heaters, P – pumps, F – filters)[Proposed Exploration of Subglacial Lake Ellsworth Antarctica, 2012]

hole that will have a uniform diameter of 360 mm at the end of the drilling process. The water from the nozzle uses the melted hole as the return conduit. A submersible borehole pump installed near the surface, but below the lake's hydrological level (270 m below the ice surface), returns water to a number of large surface storage tanks, which are maintained at several degrees above freezing. The water is then reused by the hot water drill. A filtration and UV system will be used to treat drill water to remove suspended solid particles, including bacteria and viruses. The water will pass through a five staged filtration system utilizing spun bonded, pleated, and membrane filter elements with absolute micron ratings of 20, 5, 1 and 0,2, before being UV treated. This water is then heated to between 85°C and 90°C, and pumped down a single 3,4 km length of drill hose to a drill nozzle.

Creating the lake access hole into the lake will take around 3 days. Before reaching the lake, the water level in the hole will be drawn down a few meters below the hydrological lake level. This drawdown will prevent water from entering the lake. The refreezing time of 360 mm diameter borehole is estimated to be approximately 6 mm/h [Siegert et al., 2006] resulting in useable diameter of ~200 mm after a day from first access. Before the hole reduces to this size, both the water probe and a sediment corer will be deployed and retrieved.

In December 2012 a team of British scientists and engineers engage in the first attempt to drill through more than 3 km of Antarctic Ice Sheet into Lake Ellsworth but failed[1]. The first borehole was drilled to a depth of 300m and then the drill head left at that depth for 12 hours to create the cavity. The second, main borehole (located 2 m away from the first) was then drilled to 300 m depth and should have immediately connected with this cavity. This main borehole would then continue through the cavity and down to the lake while the first borehole would be used to recirculate water back to the surface using a submersible pump. For reasons that are yet to be determined the team could not establish a link between the two boreholes at 300 m depth, despite trying for over 20 hours. During this process, around 75,000 litres of hot water seeped into the porous surface layers of ice and was lost. The team attempted to replenish this water loss by digging and melting more snow but their efforts could not match the flow rate of the drill. The additional time taken to attempt to establish the cavity link significantly depleted the fuel stocks to such a level as to render the remaining operation unviable. On 25 December 2012 Martin Siegert, Principal Investigator of the Subglacial Lake Ellsworth experiment, confirmed that the mission to drill into the lake has been called off for Antarctic season 2012/2013.

Lake Whillans. The Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) project is a 6-year (2009–2015) integrative study of ice sheet stability and subglacial geobiology in West Antarctica, funded by the US National Science Foundation. Lake Whillans belongs to active subglacial lakes, which ice-surface is changed due to water volume fluctuations in subglacial basins [Fricker et al., 2011]. Subsequent studies with satellite altimetry have demonstrated that there are more than 120 such subglacial lakes in Antarctica. The ice-penetrating radar surveys showed that ice thickness above subglacial Lake Whillans is only 700 m and suggest that the depth of water in the lakes is less than 8 m even after lake drainage events.

In the same manner as Lake Ellsworth, WISSARD will use a hot water drill to clean access Lake Whillans with minimal chemical and microbial contamination to the pristine subglacial environment. The filtration and UV treatment system allows reducing microbial numbers to ~100 cell/ml within pumped into the hole hot water. The final filter size will be 0,2 mm. The drilling water will also be maintained at a temperature >90°C, which has been shown to significantly reduce the number of viable cells.

---

[1] http://www.ellsworth.org.uk/

The hot water drill, designed in University of Nebraska-Lincoln, will produce a borehole of at least 200 mm diameter (with future update to 800 mm diameter) that will remain open for ~8 days by periodical reaming. A variety specialized scientific instrumentation such as sub-ice robotically operated vehicle, modular oceanographic instruments, sediment samplers will be used in various combinations, depending on the mission and objective of each deployment.

In December 2012 the first testing of the hot water drilling system was carried out at a location Windless Bight near McMurdo. Then all equipment was moved 1010 km away by track-traverse across the Ross Ice Shelfto Lake Whillans[2]. On January 27, 2013 US research team has successfully drilled through 800 meters of Antarctic ice to reach a subglacial lake. Both water and sediment samples were collected from the lake. Water sampling tools deployed included a Niskin water sampler, which allows you to collect water samples at designated depths, an in situ McLane water sampler that concentrates water particulates on filters, and a CTD which measures Conductivity, Temperature and water Depth. Three different sediment sampling tools were used including a multi-corer, which collected three ~0,4 m cores each time it was deployed, a piston corer, and a larger percussion corer.

The main advantages of lakes Ellsworth and Whillans exploration methodologies are that equipment can provide samples of sub-glacial water and sediments as clean as possible from the present point of view, and the lake is accessed very fast. From the other hand there are numerous disadvantages of proposed technologies: (i) equipment is very expensive and heavy (<120 t); (ii) drilling access hole needs extremely high power consumption (2500 kW, ~25 l of gasoline per meter); (iii) access hole cannot be kept open more than 1–2 days without intensive reaming; (iv) the value of differential pressure while the lake is accessing is not predictable and is not regulated.

RECOVERABLE AUTONOMOUS SONDE RECAS

In 2012, Polar Research Center at Jilin University (China) undertook the development of RECoverable Autonomous Sonde 'RECAS', the design of which would measure and sample subglacial water while subglacial lake is reliably isolated from surface environment. At the same time the sonde is able to measure geochemical signals *in situ* throughout the depth of ice sheet on the way to the bed using embedded laser spectrometer. Generally, idea of RECAS design is based on the Philberth thermal probe that was used to measure temperature inside of an ice sheet [Philbert, 1976]. The outstanding characteristic of this probe was that the wire for the transmission of electric power to it and signals from it was twisted on the coil inside the probe, paid out of the advancing probe and became fixed in the refreezing melt-water above it. In 1968 two sets of the Philbert thermal probe were launched at Station Jarl-Joset, Greenland. The first probe drilled to the depth of 218 m, and the second one to the depth of 1005 m before the main heater broke down. Unlike the Philbert thermal probe, that was designed not to be recovered from the ice, the RECAS is able to move upwards.

General concept. The sonde is equipped by two hot-points with parabolic heating elements located on the bottom and top sides of the sonde (Fig. 6). The hot-point diameter is 150 mm, and diameter of the sonde body is 140 mm. The upper hot-point has a small central hole for cable sliding in it. The power of the each hot-point is ~5 kW, and the expected speed of penetration would be 1,7 m/h in pure ice at temperature –30°C accounting the efficiency of 0,75. To protect against re-freezing, the exterior cylindrical surface of the sonde is heated by special wired-in heating element with average power density 0,1 W/cm^2, and for the 4-m long sonde the side heating power is 1,8 kW.

The ~10%-portion of the melted water is pumped into the sonde through the small

---

[2] http://www.wissard.org/

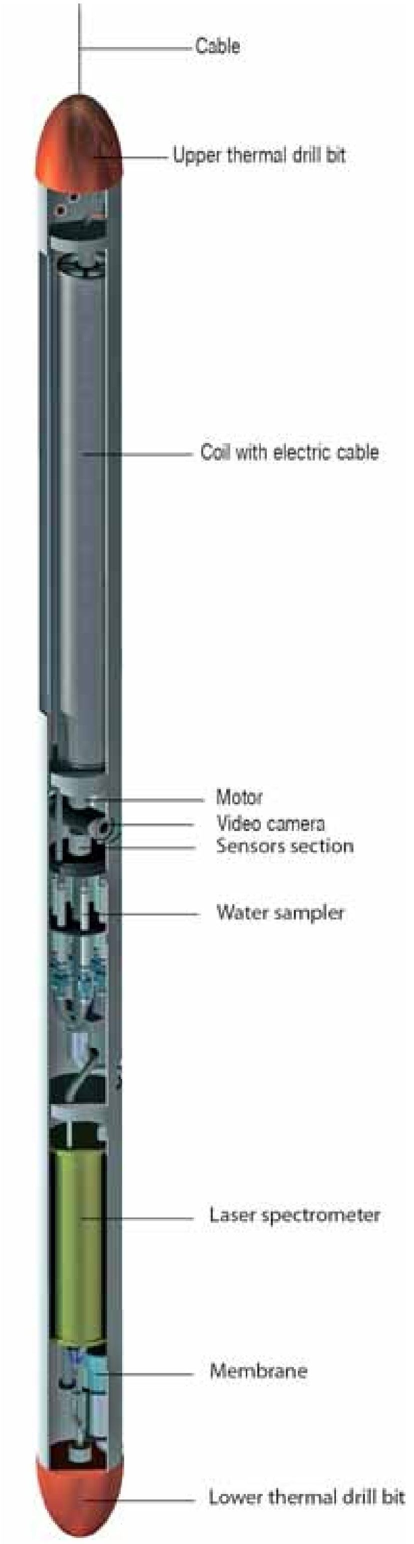


Fig. 6. Conceptual 3D-model of RECoverable Autonomous Sonde ,"RECAS"

hole located just above the lower hot-point. The gas dissolved in this water is separated in the membrane, and analyzed by embedded laser spectrometer. For this purpose, OF-CEAS spectrometer system patented by Interdisciplinary Laboratory of Physics (LIPhy), Grenoble, France can be used [Alemany et al., 2012]. This spectrometer is based on optical feedback cavity enhanced absorption spectroscopy technique, where a diode laser at 2,4 μm is injected into high-finesse (V-shape) optical cavity. Methane and water isotopes can be simultaneously analyzed with sensitivity of 1 ppm (for CH_4) and less than 1 ‰ (for δD of H_2O) over ~1 min integration time.

In the middle part of the RECAS twelve 120 ml titanium water sample bottles are installed. The bottle valves are actuated using magnetically-coupled electric motors enabling them to be opened and closed on the demand. Samples are maintained at pressure, enabling quantitative analysis of dissolved gases. The sonde is equipped by instrument chamber to measure inclination and azimuth of the borehole, pressure, temperature, pH, sound velocity, conductivity and other parameters. Video cameras and sonar provide additional information on the subglacial environment.

The coil with driven gear-motor section occupies the upper part of the sonde. The electric line for power supply and communication with down-hole sensors is twisted on the coil inside the sonde. It was proposed to design two modifications of the RECAS: one with the coil contains 1200 m of cable, and another one contains 4000 m of cable. To minimize size of the cable, the power is supplied at operating voltage of 3000–4000V DC, and then in the sonde it is transformed by voltage transformer. The cable consists from two signal lines 0,2 mm^2 and two coaxial power lines 2 mm^2. The outer diameter of the cable is in the range of 3–4 mm. The expected length of the coil with 1200 m cable is 1,3 m, and the length of coil with 4000 m cable is 4,3 m.

Pre-processed data from RECAS is transmitted to the surface computer system which transfers data to/from the internet using the Iridium modems via PPP to the Iridium ground-station, and with Short Burst Data messages. Data is automatically uploaded to webpages for human inspection, and SMS messages can be automatically sent to mobile phones to inform a human that manual intervention is required. It is possible to establish an SSH link to RECAS at any time within a few minutes.

Power supply. During moving down the RECAS highest power consumption is summarized from lower hot-point 5 kW, side heating 1,8 kW, upper hot-point 0,5 kW, coil motor 0,2 kW, sensors, down-hole computer, spectrometer, etc. 1 kW, electric losses in cable 1,5 kW; totally ~10 kW. During moving up the RECAS highest power consumption is summarized from lower hot-point 0,5 kW, side heating 1,8 kW, upper hot-point 5 kW, coil motor 0,5 kW, sensors and down-hole computer 0,4 kW, electric losses in cable 1,5 kW; totally ~9,7 kW.

The RECAS power supply should be able to provide electrical power for a full year without refueling or other intervention. The ideal power system will therefore be one that uses combination of (i) solar power during the summer, short-term electrical storage in the form of batteries, (ii) autonomous wind generators depending from site and capacity of wind, and (iii) automatically controlled diesel engines during the dark winter months.

Despite the extreme weather in Antarctica, the sun shines for extended periods through summer. Solar radiation vertical flux depends from the latitudes and as highest possible achieves 350 W/m^{2}and even more at the warmest December period. Roughly, the solar power can be converted by photovoltaic panels into electricity with an average efficiency of ~25% for polycrystalline silicon sells. At low temperatures the silicon solar cells are significantly more efficient, producing 5% more power for every 10°C drop in temperature. To put this into practical perspective, in order to meet the 10 kW electrical power supply, it would require something of 50–60 m^2 of photovoltaic panels. For example, the ConergyC167P panel with area 1,2 m^2 and nominal power output of 167 W at 25°C can be used as power supply [Lawrence et al., 2008]. Tests in Central Antarctica showed that each panel of this type produced a maximum of over 200 W and an average of ~2 kW×hr/day when the sun is above the horizon for greater than ~12 hours.

The autonomous wind generators could be a good alternative of renewable power supply, but their efficiency strongly depends from wind velocity. Tests with 1 kW wind generators (Raum, Hummer, and Bergey types) showed that turbine output power is in the 2,8-power-law relation with wind velocity, and 5 m/s wind speed gives only ~90 W of power [Allison et al., 2012]. If the site location is rather high on the Antarctic plateau that the katabatic winds will be relatively mild, this assumes low wind generator efficiency and implies large battery buffering.

The most reliable power supply is automatically controlled diesel engines, e.g. set of Hatz 1B30 diesel engines used by PLATO Antarctic site testing observatory [Lawrence et al., 2008]. The Hatz 1B30 is a compact, high efficiency, single-cylinder air-cooled diesel engine of 350 cc displacement with a maximum power output of greater than 1,5 kW at atmospheric pressure corresponding to the altitude of Antarctic Plateau. The engines are run on Jet-A1 aviation fuel. A bank of large fuel filters ensures a clean fuel supply for a minimum of one year between servicing. The fuel tank contains enough capacity for greater than nine months of continuous running and is also used to store heat from the engines to help regulate the internal temperature of the module. In addition, each engine is installed with its own bulk oil filtration and recirculation system in order to extend the required servicing interval.

Performance. All down-hole RECAS components will be sterilized by combination of chemical wash, HPV and UV sterilization

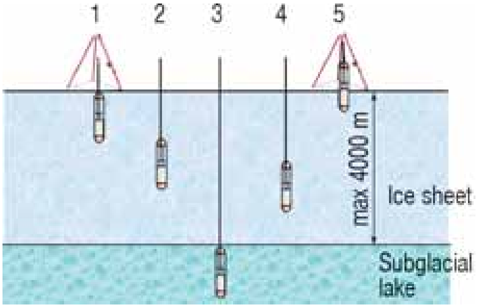


Fig. 7. RECAS subglacial access strategy (explanations are given in the text)

prior using. The working procedure is as follows (Fig. 7):

1. At the beginning of the summer season sonde is installed vertically on the surface of the Antarctic ice sheet above subglacial lake. All equipment is got into working trim, the bottom hot-point is powered, and the sonde starts to melt down to the ice sheet bed. The personnel leave the site, and all further operations are going on in semi-automatic mode.

2. The melted water does not recover from the hole and refreezes behind the sonde. Electric line for power supply and communication with down-hole sensors is released from the coil installed inside the sonde. Some of the melted water is pumped into the sonde. The gas dissolved in this water is separated through membrane and analyzed by embedded laser spectrometer. The penetration down to subglacial reservoir up to the depth of 3500 m should take about more 3–4 months.

3. Since the sonde enters into the subglacial lake, it samples the water and examines subglacial conditions (P, T, pH, sound velocity, and conductivity).

4. After sampling the motor connected with coil is switched on, and the top hot-point is put into action. The sonde begins to recover itself to the surface by spooling the cable and melting overlying ice with the help of the upper hot-point. The way to surface should take a bit longer time than the way down (~4–5 months).

5. Since 8–9 months from starting the sonde reaches the surface and waits the personnel for servicing and moving to the next site.

The RECAS is relatively cheap (10–20 times cheaper than penetration with hot-water drilling system), and small staff of 4–5 people can easily operate the sonde. The first laboratory tests of the RECAS units are planned for 2013, but the schedule of the field tests in Antarctica is open as the project did not get financial and logistical support in full.

CONCLUSIONS

As far as subglacial lakes and rivers were isolated from the exterior for thousands and millions years, they have to be extremely sensitive system. Currently, no clear protocols or standards for minimizing contamination have been established, although few initiatives to protect subglacial aquatic environments were formulated (e.g., Doran and Vincent, 2011).

The main troublesome of the implemented and planned projects for accessing of Antarctic subglacial lakes is connected with the hydrostatic unbalance resulted in the upwelling of water into the hole with subsequent difficulties. As the lake is connected with the surface via the borehole, there is no iron-clad guarantee that the modern microbiota do not get there. Moreover, open accessing of the isolated Antarctic subglacial water systems disturbs their thermobaric equilibrium state, thus changing the conditions of ice-water phase transition on the entire boundary between ice sheet and reservoir [Talalay and Markov, 2012]. This leads to formation of a new additional layer of accretion ice on the lower ice sheet surface.

Using of the recoverable autonomous sonde RECAS opens the new stage of Antarctic subglacial exploration because in this case subglacial water is reliably isolated from surface, and pressure in the lake does not influence the access technology. The sonde is able not only to measure and to sample subglacial water, but also to measure geochemical signals *in situ* using embedded laser spectrometer. The big advantage is that the RECAS is recoverable and can be used for many times. The potential drawback of the RECAR using is the impossibility of its recovery in the case of fail.

ACKNOWLEDGMENT

This paper describes the research done under "The Recruitment Program of Global Experts" (also called "The Thousand Talents Program") organized by the Central Coordination Committee on the Recruitment of Talents, China. The author thanks Victor Zagorodnov (Byrd Polar Research Center, the Ohio State University) for very constructive and pertinent remarks on RECAS design. ■

REFERENCES

1. Alemany, O., Chappellaz, J., Kerstel, E., Romanini, D., Cattani, O., Falourd S., Calzas M., Triest J., Lefebvre E., Possenti P., Duphil R., Piard L. (2012). The new SUBGLACIOR drilling probe. International Partnerships in Ice Core Sciences (IPICS). First Open Science Conference. 1–5 October 2012, Presqu'île de Giens, Côte d'Azur, France. Booklet of Abstracts. p. 165.

2. Allison, P., Auffenberg, J., Bard, R. and other 45 members of ARA Collaboration. (2012). Design and initial performance of the Askaryan Radio Array prototype EeV neutrino detector at the South Pole. Astroparticle Physics, Vol. 35, Issue 7, pp. 457–477.

3. Bell, R.E., Studinger, M., Fahnestock, M.A., Shuman, C.A. (2006). Tectonically controlled subglacial lakes on the flanks of the Gamburtsev Subglacial Mountains, East Antarctica Geophysical Research Letters, Vol. 33, L02504.

4. Bentley, C.R., Koci, B.R., Augustin, L.J.-M., Bolsey, R.J., Green, J.A., Kyne, J.D., Lebar, D.A., Mason, W.P., Shturmakov, A.J., Engelhardt, H.F., Harrison, W.D., Hecht, M.H., Zagorodnov, V.S. (2009). Ice drilling and coring. In: Drilling in Extreme Environments. Penetration and Sampling on Earth and other Planets. Eds: Bar-Cohen, Y., Zacny, K. WILEY-VCH Verlag GmbH & Co., KGaA, Weinheim, pp. 221–308.

5. Blake, E.W., Price, B. (2002). A proposed sterile sampling system for Antarctic subglacial lakes. Mem. Natl. Inst. Polar Res., Vol. 56, pp. 253–263.

6. Bulat S., Marie D., Petit J.-R. (2012). Assessing microbial life in extreme subglacial Lake Vostok, East Antarctica from accretion ice-lake water boundary samples. 12th European Workshop on Astrobiology, EANA'12. Stockholm, Sweden, October 15–17, 2012.

7. Doran, P.T., Vincent, W.F. (2011). Environmental Protection and Stewardship of Subglacial Aquatic Environments. In: Antarctic subglacial aquatic environments. Eds.: M.J. Siegert, M.C. Kennicutt II, and R.A. Bindschadler. Geophys. Monogr. Ser., Vol. 192, pp. 149–157.

8. Dowdeswell, J.A., Siegert, M.J. (1999). The dimensions and topographic setting of Antarctic subglacial lakes and implications for large-scale water storage beneath continental ice sheets. Geological Society of America Bulletin, Vol. 111, pp. 254–263.

9. Fleckenstein, W.W., Eustes, A.W. (2007). Proposed subglacial Antarctic lake environment access methodology. U.S. Geological Survey and The National Academies; USGS OF-2007-1047, Extended Abstract 033.

10. Fricker, H., Powell, A.R., Priscu, J., Tulaczyk, S., Anandakrishnan, S., Christner, B., Fisher, A.T., Holland, D., Horgan, H., Jacobel, R., Mikucki, J., Mitchell, A., Scherer, R., Severinghaus, J. (2011). Siple Coast subglacial aquatic environments: The Whillans Ice Stream Subglacial Access Research Drilling Project. In: Antarctic Subglacial Aquatic Environments. Eds.: M.J. Siegert, M.C. Kennicutt II, and R.A. Bindschadler. Geophys. Monogr. Ser., Vol. 192, pp. 199–219.

11. Kapitsa, A.P. (1961). Dynamics and morphology of ice sheet in the central part of East Antarctica. Transactions of Soviet Antarctic Expedition. Vol. 19, 93 pp. [in Russian].

12. Kapitsa, A.P., Ridley J.K., Robin G.Q., Siegert M.J., Zotikov I.A. (1996). A large deep freshwater lake beneath the ice of central East Antarctica. Nature, Vol. 381, pp. 684–686.

13. Kropotkin, P.A. (1876). Investigation of Quaternary Period. Notes of Russian Geographical Society. St. Petersburg, Vol. 7, 717 pp. [in Russian].

14. Lawrence, J.S., Allen, G.R. Ashley, M.C.B. and 33 others. (2008). The PLATO Antarctic site testing observatory. Proceedings of the Conference on Ground-Based and Airborne Instrumentation for Astronomy II. Eds: L.M. Stepp and R. Gilmozzi. Vol. 7012, art. no. 701227, pp. 701227-1–701227-12.

15. Oswald, G.K.A., Robin, G. de Q. (1973). Lakes beneath the Antarctic ice sheet. Nature, Vol. 245, pp. 251–254.

16. Philbert, K. (1976). The thermal probe deep-drilling method by EGIG in 1968 at Station Jarl-Joset, Central Greenland. Ice-Core Drilling: Proc. of the Symp. Univ. of Nebraska, Lincoln, USA, 28–30 Aug. 1974. Lincoln, USA. pp. 117–132.

17. Popov, S.V., Masolov, V.N., Lukin, V.V. (2011). Lake Vostok, East Antarctica: thickness of ice, depth of the lake, subglacial and bedrock topography. Snow and Ice, Vol. 1 (113), pp. 25–35 [in Russian].

18. Press Relations Service of Arctic and Antarctic Research Institute: Main operations of the Russian Antarctic Expedition during 04.01–10.01.2013. Arctic and Antarctic Research Institute, St-Petersburg, Russia, 10 January 2013, www.aari.nw.ru/news/text/2013/РАЭ100113.pdf [In Russian].

19. Proposed Exploration of Subglacial Lake Ellsworth Antarctica (2012). Final Comprehensive Environmental Evaluation. XXXV Antarctic Treaty Consultative Meeting, Working Paper IP-30, Agenda Item: CEP 6b, 86 pp.

20. Robin, G. de Q., Drewry, D.J., Meldrum, D.T. (1977). International studies of ice sheet and bedrock. Philos. Trans. R. Soc. London, Vol. 279, pp. 185–196.

21. Siegert, M.J., Carter, S., Tabacco, I., Popov, S., Blankenship, D.D. (2005). A revised inventory of Antarctic subglacial lakes. Antarctic Science, Vol. 17 (3), pp. 453–460.

22. Siegert, M. J., Behar, A., Bentley, M. et al. (2006). Exploration of Ellsworth Subglacial Lake: A concept paper on the development, organisation and execution of an experiment to explore, measure and sample the environment of a West Antarctic subglacial lake. Rev. Environ. Sci. Biotechnol., Vol. 6, pp. 161–179.

23. Talalay, P.G. (2006). Penetration into subglacial lakes: plans and reality. Nature. Vol. 9. pp. 45–53 [in Russian].

24. Talalay, P. (2012a). Russian researchers reach subglacial Lake Vostok in Antarctica. Advances in Polar Science. Vol. 23, No. 3. pp. 176–180.

25. Talalay, P.G. (2012b). Subglacial till and bedrock drilling. Cold Regions Science and Technology. [Accepted – in press].

26. Talalay, P.G., Markov, A.N. (2012). Ice mass balance and dynamics changing of Antarctic ice sheet as the result of open accessing of isolated subglacial reservoirs. International Partnerships in Ice Core Sciences (IPICS). First Open Science Conference. 1–5 October 2012, Presqu'île de Giens, Côte d'Azur, France. Booklet of Abstracts. p. 125.

27. Ueda, H.T., Garfield, D.E. (1970). Deep core drilling at Byrd Station, Antarctica. IASH Publication, Vol. 86, pp. 53–62.

28. Vasiliev, N.I., Lipenkov V.Ya., Dmitriev, A.N., Podolyak, A.V., Zubkov, V.M. (2012). Results and characteristics of 5Ghole drilling and the first tapping of Lake Vostok. Snow and Ice, Vol. 4 (120), pp. 12–20 [in Russian].

29. Vasiliev, N.I., Talalay, P.G., and Vostok Deep Ice Core Drilling Parties. (2011): Twenty years of drilling the deepest hole in ice. Scientific Drilling, Vol. 11, pp. 41–45.

30. Water sampling of the subglacial Lake Vostok (2002). Draft Comprehensive Environmental Evaluation. XXV Antarctic Treaty Consultative Meeting, Working Paper WP-019, Agenda Item: CEP 4c, 45 pp.

31. Wilhelms F. (2007). Sub-glacial penetration from an ice driller's and a biologist's perspective. Geophysical Research Abstracts, Vol. 9.SRef-ID: 1607-7962/gra/EGU2007-A-09619.

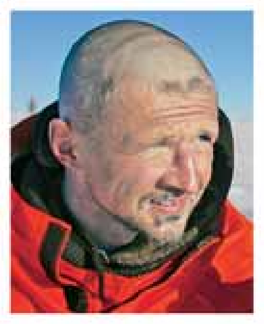
32. Wright, A., Siegert, M.J. (2011). The identification and physiographical setting of Antarctic subglacial lakes: An update based on recent discoveries. In: Antarctic subglacial aquatic environments. Eds.: M. J. Siegert, M. C. Kennicutt II, and R. A. Bindschadler. Geophys. Monogr. Ser., Vol. 192, pp. 1–7.

33. Zotikov, I.A. (1963). Bottom melting in the central zone of the ice shield on the Antarctic continent and its influence upon the present balance of the ice mass. Hydrological Sciences Journal, Vol. 8 (1), pp. 36–44.

34. Zotikov, I.A. (2006). The Antarctic Subglacial Lake Vostok: Glaciology, Biology and Planetology. Springer-Praxis Books in Geophysical Sciences. Praxis Publishing Ltd., Chichester, UK, 140 pp.

35. Zubov, N.N. (1959). Limits of thickness of sea ice and ground ice. Meteorology and Hydrology. Vol. 2. pp. 22–27 [in Russian].

Pavel G. Talalay graduated with honor from the Drilling Technology and Technique Department at the Leningrad Mining Institute and obtained Diploma of Mining Engineer in 1984. During the period from 1984 to 2010 he worked as engineer, senior engineer, researcher, associate professor, professor, head of the department at the Leningrad Mining Institute (since 1991 St. Petersburg State Mining Institute). He received degrees of Candidate of Technical Sciences in 1994, and Doctor of Technical Sciences in 2007. In 2010 he has got a grant from "The Thousand Talents Program" organized by the Central Coordination Committee on the Recruitment of Talents, China, and since September 2010 he has been engaged in research at the Jilin University as Professor of the College of Construction Engineering. Since December 2010 he became a director of the just-established Polar Research Center at Jilin University. His research interests are associated with different aspects of drilling technology in Polar Regions, especially on glaciers and ice sheets. He is the author of about 150 publications. Main publications: Fifty years of Soviet and Russian drilling activity in Polar and Non-Polar ice. A chronological history (2007, with coauthor); Twenty years of drilling the deepest hole in ice (2011, with coauthors); Subglacial till and bedrock drilling (2013, Vol. 86, pp. 142–166).



Alexey N. Markov graduated with honor from Leningrad Mining Institute as Mining Engineer - Geophysicist in 1986. In the period from 1986 to 1992 he worked as engineer of Antarctic Research Office, St.-Petersburg State Mining Institute. Afterwards up to 2010 he was leading engineer on logistics of the Center on Operative Management of Russian Antarctic Expedition. In 2010, he received his PhD from the St.-Petersburg State Mining Institute. Since December 2011 he works as Professor of Polar Research Center at Jilin University, China. He has more than 20 years of experience in the field of borehole logging in Arctic and Antarctic glaciers. His main scientific research refers to Antarctic ice sheet dynamics. Main publications: Features of dynamics East Antarctic Ice Sheet (2006, with co-authors); Specific Features of the Ice Dynamics in Eastern Antarctica (2006, with co-authors); Features of dynamic properties depending on depth and extension of East Antarctic Ice Sheet at the interval of depths of 0-450 meters (2008, with co-authors).

Mikhail A. Sysoev graduated in 2012 from Saint-Petersburg State Mining University as mining mechanical engineer. During the study several times he claimed first places in the International and All-Russian student CAD competitions. In 2012 he has got Chinese Government Scholarship for Master-degree studying in Jilin University, China. His research direction is focused on clean drilling and sampling of Antarctic subglacial aquatic ecosystems.