Arctic and Antarctic Research Institute

Russian Antarctic Expedition

Water Sampling of the Subglacial Lake Vostok

Final Comprehensive Environmental Evaluation

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Non-technical summary

The Comprehensive Environmental Evaluation "Water Sampling of the Subglacial Lake Vostok" was performed in order to determine the significance of the impact on the subglacial lake and the environment of the proposed technology of penetration to the subglacial lake surface using the existing deep ice borehole at the inland Vostok station. This activity addresses the scientific goal of collecting data on the origin, evolution and current state of the lake.

The proposed method for water sampling from Lake Vostok envisages using primarily the physical peculiarities of the state of the "ice sheet–subglacial Lake Vostok" system. The basic fact is that the ice sheet stratum is in the floating state with the pressure at the "ice-water" boundary corresponding to the ice column weight (overburden pressure). During ice drilling, the hydrostatic drilling fluid pressure in the borehole compensates the overburden pressure. Decreasing the drilling fluid quantity, it is possible to ensure undercompensation of overburden pressure, i.e. create such conditions when the water pressure in the lake at a given point will be greater than that of the drilling fluid column.

The authors of the Project consider that under such conditions, at the contact of the hole bottom and the lake surface, the drilling fluid will be forced out by lake water upward the borehole to a height corresponding to undercompensation of the overburden pressure. It is believed that penetration of the drilling fluid used to the lake can be excluded as it is hydrophobic and is much lighter than water. The drill will be extracted from the hole immediately after reaching the surface. It is obvious that lake water rising up the hole should freeze along the entire penetration height. After it freezes, the ice portion formed of the subsurface water layers of Lake Vostok is drilled again. Ice remaining below, which is formed of lake water, separates the bottom of the hole and the lake, i.e. prevents their possible connection. Thus, the proposed method will allow sampling of lake water without the direct incorporation of the drill and the measuring and sampling instruments to the lake.

This CEE presents a detailed description of the existing environmental state in the region, the characteristics of the drills, drilling fluids and the borehole over the entire ice sheet depth, physical-mechanical ice properties at the approach to the lake and the results of chemical and microbiological analyses of its composition. All possible risks related to the activity and the methods of their elimination and minimization were assessed. The proposed continuation of drilling in borehole 5G-2 (Vostok station, Antarctica) with water sampling (in the form of ice) is to be implemented at the end of the summer Antarctic season 2010–2011 and if necessary, the work will be continued during the season 2011–2012.

Like any other practical activity in Antarctica, continuation of drilling the borehole 5G-2 and penetration to the subglacial lake will obviously have an environmental impact. The evaluation performed indicates that it will inevitably include an insignificant influence by scale and duration on the atmosphere (evaporation of Freon 141b), on the ice sheet structure in the borehole 5G-2 and on the natural "lower ice surface–Lake Vostok surface" boundary.

The risks of contamination accompanying this activity that are primarily related to the presence of the drilling fluid in the borehole can be practically excluded during preparation and conduct of work.

Implementation of the proposed activity will require additional logistical support, which will insignificantly increase the current impact of the station activity on the glacial surface environment.

As follows from a comparison with the other methods of accessing Lake Vostok, the proposed activity of lake water sampling will be of a shorter-term and at a smaller scale and will have the least cumulative environmental impact in the Vostok station area, including the subglacial lake.

Based on the CEE performed, it is concluded that the impact of the considered activity on the environment of the station area, ice sheet and the lake is insignificant. The activity under consideration

can be conducted on condition of undertaking all measures envisaged to mitigate the environmental impact.

1. Introduction

Study of subglacial water environments of Antarctica was defined by the Scientific Committee on Antarctic Research (SCAR) as one of the leading direction of the studies of the region at the beginning of the 21st century. Creation of this direction and significant progress of achievements in this area is due to activities related to the subglacial Lake Vostok, which is located in the area of the Russian Antarctic station of the same name. An important advantage of Lake Vostok relative to the other subglacial water bodies of Antarctica is not only knowledge of the characteristics of this water body obtained by means of the methods of airborne and ground radio-echo sounding and geophysical modeling, but also availability at Vostok station of the deepest borehole in the world drilled in the continental ice sheet. At the time of preparing the Draft Comprehensive Environmental Evaluation for water sampling from the subglacial Lake Vostok (2002) the borehole depth was 3623 m and about 130±20 m of ice remained to the "ice-water" interface. This fact was decisive for developing an environmentally friendly technology to penetrate the lake water layer exactly through the existing ice borehole, which has all required logistical infrastructure at the surface.

In January 1998, as recommended by the international community, the Russian Antarctic Expedition suspended drilling of a deep ice borehole 5G-1 at Vostok after reaching a depth of 3623 m. Same year, the RF Ministry for Science and Technology announced open competition for developing an ecologically clean technology for water sampling from surface layers of subglacial Lake Vostok using the borehole 5G-1. The borehole was filled by vertical with a drilling fluid (kerosene-Freon mixture) for counteracting the "mountainous pressure" effect narrowing the borehole diameter at its bottom. As is known, "dry" drilling of boreholes in ice is possible only to a depth of 500 m, below this threshold the "mountainous pressure" effect will occur decreasing the diameter of the hole drilled and not allowing recovery of the drill to the surface. The drilling fluid should be non-freezing on the one hand, and on the other hand, its density should be equal to that of ice. It is known that the ice density is equal to 0.91 g/cm^3, therefore the density of the drilling fluid should be close to this value. After numerous laboratory studies a Freon/kerosene mixture was considered one of the best variants of such drilling fluid. The kerosene density is 0.78 g/cm^3 and the freon density is 1.04 g/cm^3, so a mixture of these two fluids in a specific concentration makes it possible to provide the required density of the drilling fluid. It was successfully used not only for drilling of the Russian ice holes in the Arctic and the Antarctic, but also by the European colleagues in deep drilling of glaciers in Antarctica and on Greenland Island. The technology for penetrating the water layer of Lake Vostok through the borehole 5G-1 was developed by specialists of St. Petersburg Mining Institute and the Arctic and Antarctic Research Institute in 1999–2000. In March 2001, this technology was approved by the RF State Environmental Expertise and was introduced by Russia at XXIV Antarctic Treaty Consultative Meeting (ATCM) in July 2001 in St. Petersburg (WP29 Expert conclusion for the Project "Justification and development of the ecologically clean technology for penetrating the subglacial Lake Vostok (Antarctica)".

In 2002 at ATCM XXV at the session of the Committee of Environmental Protection (CEP V) in Warsaw (Poland), Russia introduced the Draft CEE "Water sampling of the subglacial Lake Vostok" (WP19). To discuss it the Intersessional Contact Group was set up chaired by France. As a result, Russia presented at ATCM XXVI at VI session of CEP in Madrid (Spain) in 2003 the revised Draft CEE (WP01).

Comments on this document were presented in the ATCM XXVI Final Report, Madrid, Spain, 2003 in Annex E of the "Report of VI CEP", Appendix 2), which were as follows:

1. While the Committee recognized the importance of the long term science goals for subglacial lake exploration, the draft CEE provides insufficient consideration to reduce the potential environmental risks posed by the activity.

2. Insufficient information is provided on the special drilling fluid to support the conclusion that it is 'ecologically clean'.

3. The treatment of alternatives to the proposed activity is inadequate and should include alternative solutions.

4. The draft CEE does not adequately identify and discuss gaps in knowledge particularly as related to the question of the ice/water interface conditions and lake chemistry.

5. The draft CEE does not adequately address the risk of accidental release of drilling fluid into the lake and the potential consequences of this release.

6. Consistent with Annex 1, Article 3, paragraph 2(g), contingency plans should be developed to deal promptly and effectively with unforeseen impacts if the activities do not proceed as predicted.

Some comments could be answered only after resuming drilling in borehole 5G-1 for obtaining new data on ice core composition and structure. For this purpose the Russian Antarctic Expedition (RAE) prepared two Initial Environmental Evaluations (IEE) for continuing drilling operations: "Drilling of additional 50 m of deep borehole 5G-1 at Vostok station" and "Drilling of additional 75 m of deep borehole 5G-1 at Vostok station". After submitting the required documents to the Commission for consideration of activity of the Russian individuals and legal entities in the Antarctic Treaty Area and issuance of permits", RAE was granted the required Permits No. 025 in October 2004 and No.39 of 20.11.2006 to continue drilling in compliance with the procedures adopted in the Russian Federation. Drilling operations in deep borehole 5G-1 at Lake Vostok began again in late December 2004. As a result by 28 October 2007, the borehole depth was 3668 m. However a technical accident resulted in the drill loss at the borehole bottom. Attempts in the seasons of 2007–08 and 2008–09 to extract it were unsuccessful, and in January 2009 it was decided to bypass the accident segment by borehole deflection from the vertical. This methodology was developed at St. Petersburg Mining Institute and has already been successfully applied in Borehole 5G at Vostok station at a depth of 2243 m on 5 September 1992 after which the borehole was named borehole 5G-1 in Antarctica.

The deflection was started from a depth of 3590 m. The deflection angle was chosen so that the distance of the new borehole 5G-1 from the damaged drill at a depth of 3668 m was not less than 1.5 m. As of late January 2010, the depth of borehole 5G-2 was 3650 m. By that time new data on the ice core structure and the size of crystals forming it, gas content and concentration of the cells of living organisms in the ice core formed of the frozen lake water were obtained. The biological diversity of the drilling fluid and the properties of organosilicon fluid, which is planned to be used at the "kerosene-freon mixture" – lake water interface, was investigated. Foreign colleagues of RAE on Greenland Island and on the Queen Maud Land in Antarctica have obtained full-scale data on the environmentally friendly Russian technology proposed for water sampling from Lake Vostok. The answers to all comments of the international Antarctic community made at XXVI ATCM, 2003 in Madrid (Spain), were generalized and presented by the delegation of the Russian Federation at XIII CEP session of XXXIII ATCM in May 2010 in Punta del Este, Uruguay (WP-59 "Answers to the comments on CEE for "Water Sampling of the Subglacial Lake Vostok").

Paragraph 6, Article 3, Annex 1 "Comprehensive Environmental Evaluation" to the Protocol on Environmental Protection to the Antarctic Treaty reads that *"a final Comprehensive Environmental Evaluation shall address and shall include or summarize comments received on the draft Comprehensive Environmental Evaluation. The final Comprehensive Environmental Evaluation, notice of any decisions relating thereto, and any evaluation of the significance of the predicted impacts in relation to the advantages of the proposed activity, shall be circulated to all Parties, which shall also make them publicly available, at least 60 days before the commencement of the proposed activity in the Antarctic Treaty area".*

Given that the Russian Federation has completely answered all CEP comments on the Draft CEE "Water Sampling of the Subglacial Lake Vostok", this document based on the aforementioned Draft CEE is the final Comprehensive Environmental Evaluation of this activity. According to logistical assessments, the possibility of arranging penetration to the water layer of Lake Vostok through the borehole 5G-2 at

Vostok station with the aim of water sampling from the surface lake layer can be provided not earlier than late January – early February 2011.

2. Description of proposed activity

The Russian Antarctic Program plans to continue the super-deep drilling of the ice sheet and water sampling of Lake Vostok aiming at further scientific research.

Based on practical and economic considerations with respect to organization and logistics of drilling a new borehole, the Arctic and Antarctic Research Institute (AARI) and the St. Petersburg State Mining Institute (SPSMI) (TU) propose to use the already existing borehole 5G-2, special technical equipment and technology of environmentally safe water sampling for accessing Lake Vostok.

2.1. Characteristics of subglacial Lake Vostok

In the early 1990s, as a result of the analysis of satellite altimetry data, a flat subhorizontal ice plain was found to the north of the Russian Vostok Station and it was suggested that this plain is associated with the water surface of the same area. In summer of 1994, at a session of the Scientific Committee on Antarctic Research, held in Rome, A.P. Kapitsa made a report concerning the location of a large subglacial freshwater lake in this area. It was proposed to name it Lake Vostok. After this event, in 1996, this fact was thoroughly analyzed and compared with previously obtained seismic and radar data. This analysis supported the idea that this natural phenomenon existed. At the same time, beginning with the field season of 1995–1996, active and systematic study of this object was started by the Polar Marine Geosurvey Expedition within the framework of the annual Russian Antarctic research. The studies were carried out by remote geophysical methods, such as radio-echo sounding (RES) and reflection seismic sounding. The latter were carried out mainly over the lake surface [2–4]. Despite the tact that by now nearly 200 similar objects have been found, Lake Vostok is the biggest and the most studied lake in Antarctica.

During the first stage of the Russian studies Lake Vostok was totally contoured and its coastline was outlined on the general plan. According to the obtained data the coastline length makes 1030 km, including 70 km of islands; the water surface area makes 15.5 thousand km^2, exclusive 70 km^2 of island territories. It has been found that the water surface lies at absolute heights from about −800 m in the northern part to −200 m in the southern part relative to sea level. Its gradient makes up about 0.12°. At the time of study it was the first body of its kind, i.e. water reservoir with slope surface. In due time, this fact was widely debated.

In 2008, the second stage of the Russian studies of this area was over: comprehensive seismic research and radio-echo sounding aimed at mapping of Lake Vostok bottom and slopes was completed. By this time a total of 318 seismic soundings and 5190 linear km of radar echo-sounding survey were conducted. A sketch of the geophysics research can be seen in Fig. 1. The water body thickness was estimated by means of seismic measurements. The glacier thickness was estimated by radio-echo sounding due to reasonably consistent results of seismic and radar methods. Daytime surface (to determine location of the subglacial surface and lake bottom surface) was constructed from the most up-to-date ICESat laser altimetry data.

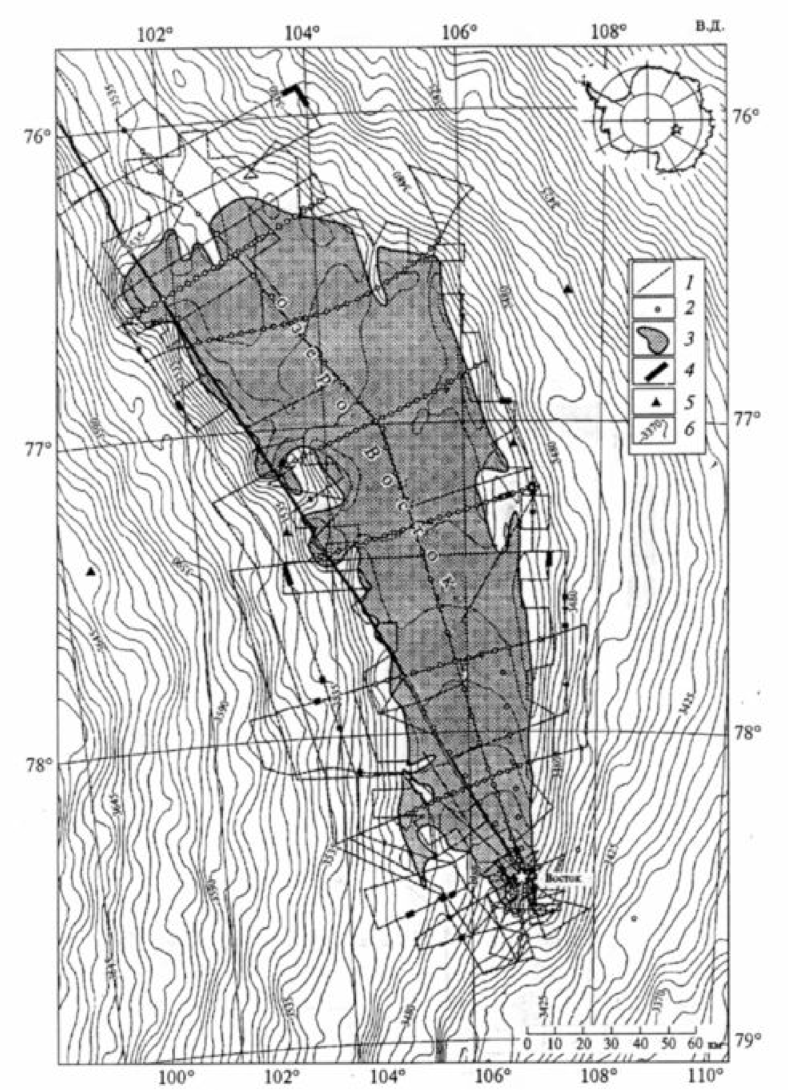

Figure 1

As may be inferred from Fig. 2, the thickness of sublacial Lake Vostok water layer averages about 410 m; water body volume – about 6343 km^3. In general plan the lake is divided in two, non equal in size parts. The first, southern part is deeper but smaller in size. It occupies an area of about 70×30 km. The prevailing thickness of water layer averages up to 800 m. The second northern part is relatively shallow. It occupies an area of about 180×60 km. The average thickness of water layer is about 300 m. A diagram-inset on Fig. 2 clearly demonstrates a relationship between the thickness of lake water layers and area coverage. A diagram shows two clearly defined peaks both of them corresponding to the prevailing water layer thickness of the shallow lake part.

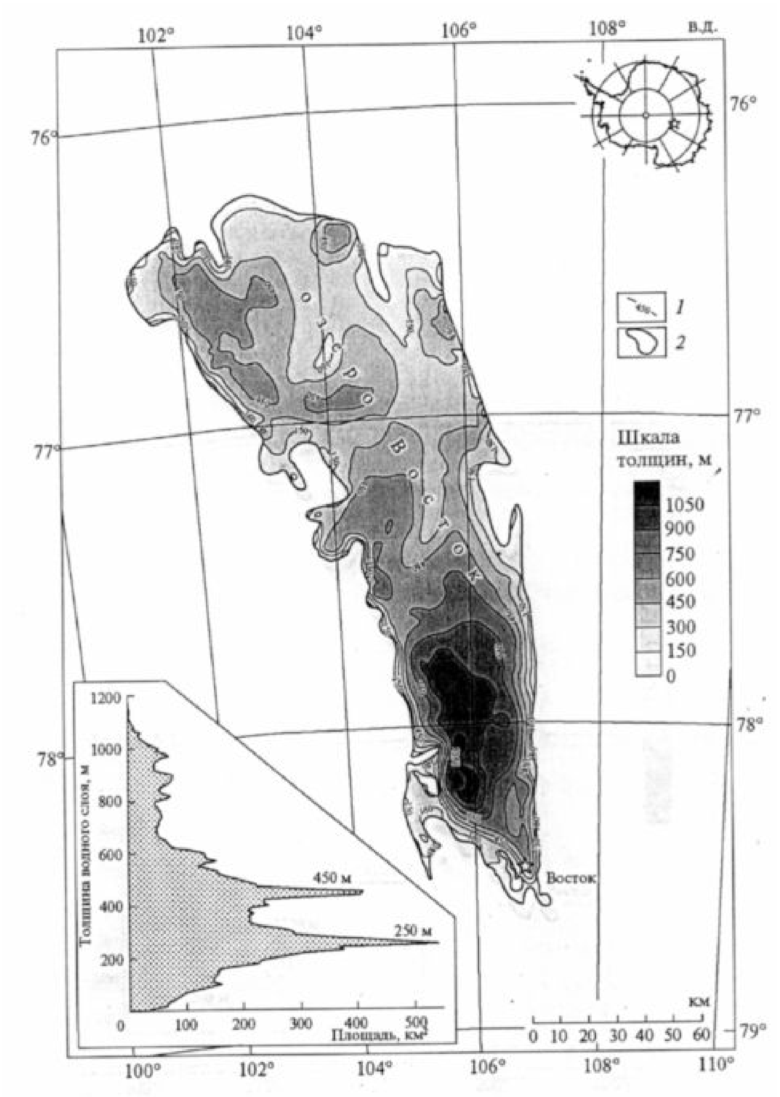

Figure 2

The above discussed thickness of Lake Vostok water layer is clearly representative of the lake bottom relief. The latter is shown in Fig.3. A number of geomorphologic features such as steep (over 15%) basin slopes, their significant height, sometimes more than 1500 m and quite sizable basin of 310×100 km, suggest this structure to be confined to deep-seated fault, as well as its relative juvenile geological age. Moreover, in the context of geomorphologic terminology, this structure should rather be named a trench (a long narrow steep-sided ditch), than a basin (a large bowl- or nearly bowl-shaped depression), since the ratio of its length to width is more than 3:1.

The natural part of trench Vostok generally presents a hilly plain with average absolute height of about -900 meters. The relative excesses are likely to be insignificant and do not exceed 100 meters with maximum gradient of 4°. The hilly plain occupies territory of 5800 km^2, which makes one third of all the territory (Fig.3) The first peak on the diagram of frequency relationship between Lake Vostok bottom relief heights and space occupied by them (diagram-inset on Fig.3) corresponds to specifically this area.

In the southern and north-western parts of trench Vostok there are two basins, clearly expressed in the relief. The first one is deeper and bigger in size (approximately 60×30 km). Its depth is about 400 m with average slope steepness of about 8°. The near-bottom part of basin is flattened, it is situated at absolute heights of about −1500 m. The third peak on the diagram corresponds to specifically this area (diagram-inset on Fig.3). The slope steepness is indicative of the tectonic genesis of this structure.

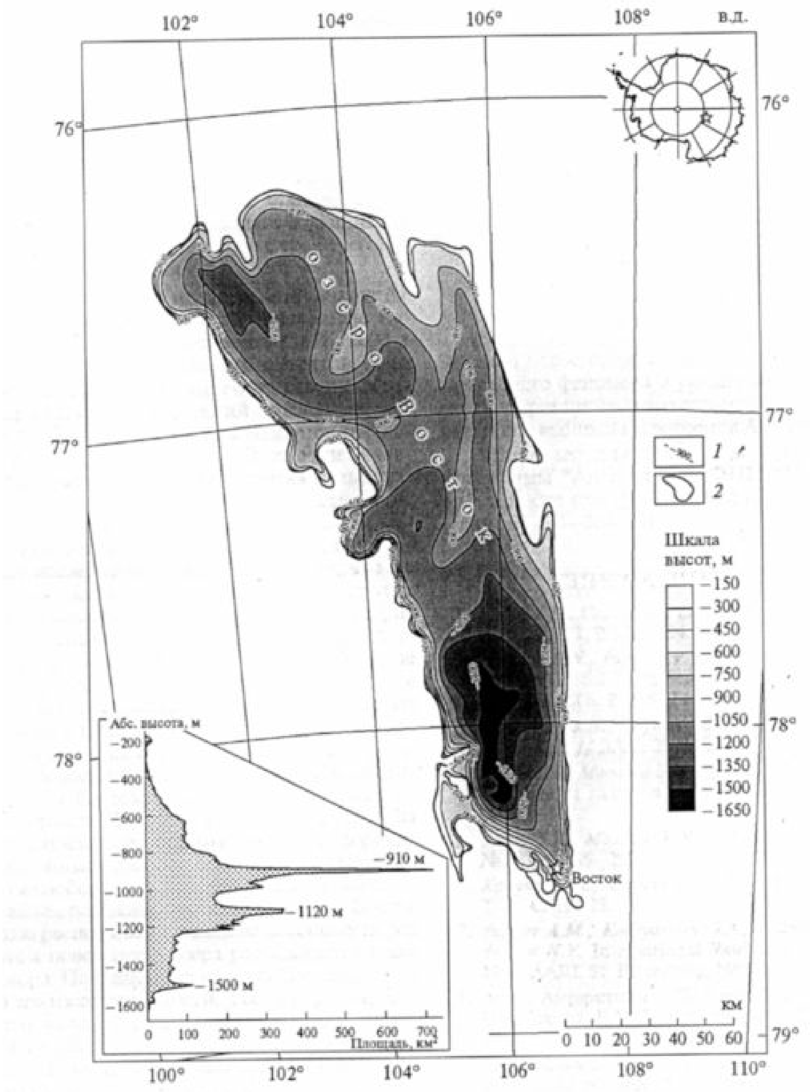

Figure 3

The second basin has a size of about 45×15 km. The relative excesses and gradients are also insignificant. The near-bottom part of the basin is situated at absolute heights of about −1150 m which corresponds to the second peak on the diagram. The question of isolation of subglacial Antarctic water bodies and, in particular, Lake Vostok, is considered to be a priority in connection with discussions on the lake penetration techniques in the near time. The concern of scientific community stems from the discovery of catastrophic subglacial flood occurrence. By now over 200 relatively small (up to several tens of kilometers in length) subglacial lakes were registered and from year-to-year their number is growing. For the major part of them no information on their coastline and water body amount is available.

In the course of Russian studies around Lake Vostok, numerous small subglacial water bodies were discovered. By 2008, their number amounted to 37 water bodies, of which 32 were discovered during the Russian radio-echo sounding investigations (Fig. 1) of late years. Linear dimensions of water bodies average to about 5 km. In the course of special study, in the lake southern part, a narrow extended 20 km-length fiord was discovered. However, a large body, both in the Russian and foreign research data points to the fact that at the moment Lake Vostok is isolated from the other similar objects. In particular, in 2000 the US scientists carried out an airborne geophysical survey. Intermediate routes were arranged at intervals of 7 km. But neither Russian data nor measurements obtained by the US colleagues point to the presence of Lake Vostok drainage system. In addition, the subglacial water bodies discovered around Lake Vostok are situated above its waterline. Thus, if even they are connected through watercourse, what seems contrary to all available data, the water would flow into the lake rather than the reverse. Moreover, research revealed that Lake Vostok water body is wholly located in the trench embedded in bedrock, and the lake surface is below sea level. The latter is also indirectly indicative of the lake isolation.

Thus, the scientific community concern over the possibility of Antarctic subglacial lake contamination during the penetration into the Lake Vostok through deep ice hole at Vostok station as a consequence of catastrophic flood from the lake, seems to be unreasonable.

Nonetheless the subject under discussion is of fundamental importance from both the scientific and practical points of view, and above all, in connection with penetration into the lake in the nearest future.

The fact, that no direct indications to the drainage system presence exist, on no account demonstrate the absence of the lake level fluctuations. It is quite natural that its depth was not constant at all times. During the Cenozoic orogenic phase and glaciation of this region, the trench Vostok and its mountain framing were subject to changes resulting in the amount of water in the lake. However, this is not relevant to the floods, since these phenomena reflect different natural mechanisms.

In spite of the great significance of the scientific data on Subglacial Lake Vostok characteristics obtained by means of remote techniques, the prime object of future research remains to be the water mass and bottom sediments of the lake. This problem is inextricably connected with the solving of engineering and technologic challenges of penetration into the lake water for its further research by variety of sounding and sampling probes.

2.2. History of ice sheet drilling at Vostok station. Background information

Drilling a deep borehole at Vostok station was first attempted in the 35th Soviet Antarctic Expedition (SAE) (1990) with the aim of reconstruction of paleo-climatic changes as early as the late 1960s. Deep drilling of the ice sheet at this station was started by specialists of the Leningrad (now St. Petersburg) Mining Institute in 1970. For this purpose different models of thermal and electrical-mechanical drills were used, methodologies of deep drilling were developed, types of drilling fluid were determined and different samples of auxiliary equipment were tested (winches, drilling rigs, etc.). By 1990, four deep boreholes of different depth and diameter were drilled at Vostok station. They were a necessary preliminary stage of implementing the major drilling project, which was initiated in 1990 in the 35th SAE. The borehole was named borehole 5G. Drilling was made by the thermal drills of the type TELGA and TBZS.

On 27 December 1991, the borehole 5G was drilled to a depth of 2503 m. During the recovery of the drill, it was stuck in the borehole, resulting in the increased loads at the drilling winch and a subsequent cable break. It was impossible to extract it, so at a depth of 2243 m on 5 September 1992 down-the-hole drilling began in order to avoid the accident segment of the borehole. From this time it was called borehole 5G-1.

During the 38th RAE (1993), the borehole 5G-1 reached a depth of 2755 m. Due to insufficient funding of the 39th RAE and some technical and organizational problems, the Vostok station was temporarily decommissioned and no drilling activities were hence carried out. During the 40th RAE (1995), drilling of borehole 5G-1 was resumed from a depth of 2755 m by the electrical-mechanical drill and without any complications the depth of the borehole 5G-1 has increased from 2755 m to 3109 m. After suspension of Vostok station during the 41st RAE (1997), no drilling operations were undertaken in the borehole 5G-1 in the wintering periods. In the seasons of the 41st, 42nd and 43rd RAE (1995–1996, 1996–1997 and 1997–1998), the borehole 5G-1 was run from a depth of 3109 to 3623 m, which is almost 600 m as deep as the maximum depths achieved by that time by specialists of EC countries (3032 m and 2953 m) and the USA (3057 m) in drilling the boreholes under more favourable conditions of Greenland. Drilling of boreholes by the EC specialists was stopped due to accidents in these depths. To compensate the overburden pressure, the EC specialists use a drilling fluid similar to that used by Russia. Its composition includes aviation fuel of JP-8 type as the main component and Freon F-141b as heaver. In 2005, drilling of glacier at Concordia Dome was stopped at a depth of 3270.2 m.

Drilling of borehole at Vostok station was performed in the framework of the Russian-French-US Program of Paleo-Climate Reconstruction from Ice Core Data. This project was finished in 1998 when the depth of borehole 5G-1 was 3623 m.

Drilling operations in the deep borehole 5G-1 on Lake Vostok began again in 2004. As a result, by 28 October 2007, the depth of the ice borehole was 3668 m. However a technical accident resulted in the drill loss at the borehole bottom. Attempts undertaken in the seasons of 2007–08 and 2008–09 to the extract the damaged drill from the borehole were unsuccessful, so in January 2009 it was decided to bypass the accident segment of the borehole using a method of deviating it from the vertical. This methodology was developed at the St. Petersburg Mining Institute and has already been successfully applied in Antarctica. The borehole deviation was started from a depth of 3590 m, which makes it possible to deviate from the location of the damaged drill by horizontal at a distance of 1.5 m. As of late January 2010, the depth of the new borehole called now borehole 5G-2, was 3650 m.

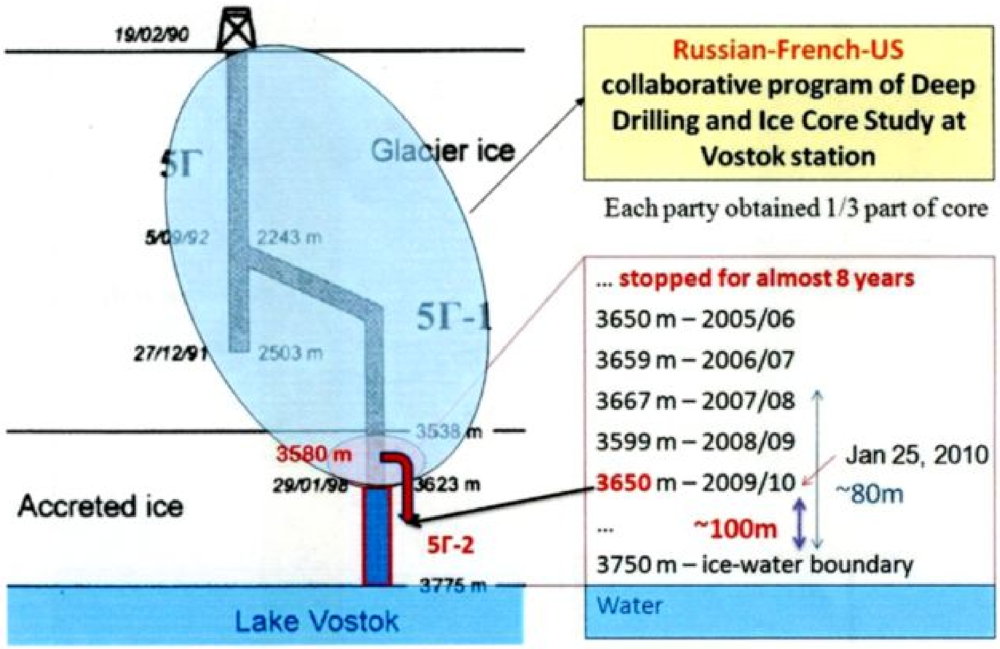

Figure 4

At present, the borehole 5G presents a complex multistage structure (Fig. 4). In the upper portion of the hole, a casing to a depth of 120 m is installed with an internal diameter of 165 mm. To a depth of 2200 m (the hole was run by a TBZS-152 thermal drill with an external diameter of 152 mm), the minimum borehole diameter is equal to 153 mm. The minimum diameter by depth intervals comprises: 2200–3095 m – 139 mm; 3095–3321 m – 138.4 mm; 3321–3500 m – 137.9 mm; 3500–3570 m – 136.2 mm; 3570–3650 m – 135 mm.

Before the beginning of drilling using a mechanical method, this borehole segment was enlarged to a diameter of 139 mm. In the process of drilling by a mechanical method (the maximum external diameter by bore bits of 135 mm), the drilled segments of the hole were periodically reamed resulting in a stepwise shape of the hole. The total volume of the drilling fluid (mixture of the aviation fuel TS-1, Jet-1A and freon F-141b) in the borehole comprises around 65 m^3. The drilling fluid level as of October 2010 is at a depth of 45 m, its average density equalling 928 kg/m^3. To a depth of 2200 m, the hole is practically vertical, then the deviation angle of the borehole axis from the vertical changes within 6 to 8°.

2.3. Technology of water sampling of Lake Vostok

In order to meet all ecological requirements for penetrating water of the lake, the authors of the Project propose to introduce some changes in the usual drilling methodology.

Significant experience of the team of drilling specialists gained in drilling the borehole 5G-1 has allowed developing and testing an environmentally clean drilling technology (both in terms of eliminating the adverse impacts on the ozone layer of the atmosphere and from the viewpoint of ice microbiology). The proposed method to access Lake Vostok envisages using primarily the physical peculiarities of the state of the "ice sheet–subglacial Lake Vostok" system. The basic fact is that the ice sheet is in the floating state with the pressure at the "ice–water" boundary corresponding to the ice column weight (overburden pressure). During ice drilling, the hydrostatic drilling fluid pressure in the borehole compensates the overburden pressure. Decreasing the drilling fluid quantity, it is possible to ensure undercompensation of overburden pressure, i.e. create such conditions when the water pressure in the lake at a given point will be greater than that of the drilling fluid column.

The authors of the Project consider that under such conditions, at the contact of the hole bottom and the lake surface, the drilling fluid will be forced out by lake water upward the borehole to a height corresponding to undercompensation of the overburden pressure. It is believed that penetration of the drilling fluid to the lake can be excluded as it is hydrophobic and is much lighter than water. The drill will be extracted from the hole immediately after reaching the surface. It is obvious that lake water rising up the hole should freeze along the entire penetration height. After it freezes, the ice portion formed of the subsurface water layers of Lake Vostok is drilled again. Ice remaining below, which is formed of lake water, separates the bottom of the hole and the lake, i.e. prevents their possible connection. Thus, the proposed method will allow sampling of lake water without the direct incorporation of the drill and the measurement and sampling instruments to the lake.

It is planned to realize this method of Lake Vostok access and study in several stages applying two types of the drill (electrical-mechanical and thermal) and two types of the drilling fluids (kerosene-freon mixture and silicon oil). The silicon oil will be used at the last stage of drilling by the thermal drill in order to increase the reliability of the water-drilling fluid interface in the borehole.

Drilling operations that were carried out by Denmark and Germany in different ice boreholes using a similar kerosene and Freon mixture as in the Vostok project, have demonstrated a possible unexpected contact of this fluid with the sub-glacial water masses. As a result of these contacts, the upper drilling fluid level in the borehole was rising to a height of the existing pressure undercompensation of this fluid to full pressure of ice strata above water. Analyses of the ice core from Greenland formed of frozen water that has risen upward in the borehole from sub-glacial aquatic systems showed that only the uppermost 10-cm section of the "fresh frozen" ice core was contaminated by the kerosene-Freon mixture. The lower layers of this core do not have any traces of contamination. So, an independent trial of the Russian technology was performed under full-scale conditions in Greenland with its results confirming correctness of theoretical estimates of the Russian specialists.

So, a possibility of using the Russian technology without its preliminary testing in small Antarctic subglacial lakes was demonstrated.

2.3.1. Parting drilling fluid

The silicone oils are specified as any of a number of polymers containing silicon atoms connected with the carbon atoms over atoms of the other elements (oxygen, nitrogen, sulfur, etc.). The silicone oils are hydrophobic and inert substances that are stable to water, air, oxygen, metals, wood, paper, plastics. The most suitable kind of silicone oils for the deep ice drilling are the low-molecular (or volatile) dimethyl siloxane oils (DSO's) that differ from other silicone, mineral and synthetic oils by the most little viscosity changes with temperature variation and also by volatility properties. The common chemical structure of DSO's is following:

$$(CH_3)_3 SiO - \left[-Si(CH_3)_2 O-\right]_n - Si(CH_3)_3 ,$$

where n is the average rate of polymerization (low-molecular DSO's have n ≤ 8).

DSO's are used in the industry as hydraulic liquids, lubricants, anti-adhesion coverings, foam breakers, cooling agents, dielectrics, etc. All companies that manufactured DSO's use their own trade name:

- **DC-200** by *Dow Corning Corp.* (USA);
- **KF96** by *Shin-Etsu Chemical Co.* (Japan);
- **MS-200** by *Midland Silicones* (United Kingdom);
- **Si** by *Siss* (France);
- **АК** by *Bayer* (Germany);
- **Lukosil M** by *Synthesia Kolin* (Czech Republic);
- **PMS** by *State Institute of Applied Chemistry* (Russia).

For distribution purposes DSO's are subdivided according to their viscosity (usually in centistokes at 20 or 25 °C), which considered to be the main working characteristic of the silicone oils. Low-molecular DSO's are clear, water-white, tasteless, odorless and neutral liquids.

The inertness of DSO's renders these fluids acceptable for use as ingredients of cosmetics, the prevention of human skin from chafing and as defoamers for food and beverages. There are no adopted workplace air DSO's contaminant levels specified for a normal 8-hour workday, 40-hour workweek, to which all workers may be exposed repeatedly without adverse effect. As a result, there are no recommendations for the control of workplace contaminant concentrations.

2.4. Stages and planning of the proposed activity

In accordance with the decision of V CEP on the Draft CEE "Water Sampling of the Subglacial Lake Vostok" (CEP V, 4b) taking into account the recommendations of SCAR (presented in the Information Paper of XXV ATCM IP55) and the comments of the Intersessional Contact Group (ICG) on the CEE consideration, the Russian Federation has introduced changes to the order of submission of documents and the initial calendar work plan. They were reported to CEP VI session held in the framework of ATCM XXVI in Madrid (Spain) in 2003 (WP1 "Water sampling of the subglacial Lake Vostok. Environmental Impact Assessment (revised draft Comprehensive Environmental Evaluation)". In discussing this document the CEP members have made some comments, which were included to the Final Report of ATCM XXVI in Appendix 2, Annex E "Report of CEP VI"

Some comments presented in the aforementioned document, could be answered only after resuming drilling in borehole 5G-1 for obtaining new data on ice core composition and structure. For this purpose the Russian Antarctic Expedition (RAE) prepared two Initial Environmental Evaluations (IEE) for continuing drilling operations: "Drilling of additional 50 m of deep borehole 5G-1 at Vostok station" and "Drilling of additional 75 m of deep borehole 5G-1 at Vostok station". In accordance with the obtained official Permits, stipulated by the rules of procedure for implementing the Protocol on Environmental Protection to the Antarctic Treaty to the Russian legislature, the RAE started realization of these Projects beginning from 2004. Based on the results of these and other studies, the Russian Federation has prepared and presented at ATCM XXXIII in 2010 in Uruguay the WP59 "Answers to comments on CEE for "Water Sampling of the Subglacial Lake Vostok". These answers served as a basis for preparation of the text of the Final CEE "Water Sampling of the Subglacial Lake Vostok".

2.4.1. Monitoring Program. Acquisition of additional necessary information to initiate the proposed activity: Continuation of drilling additional 50 m (from 3623 m to a depth of 3673 m) (2004–2010)

The Russian Antarctic Program undertakes the following measures to ensure monitoring of the characteristics of ice conditions at the borehole bottom with drilling new 50 m of the ice core at Vostok station that will minimize the risk of these operations:

Geophysical survey in the deep borehole which should include the borehole closure (deformation), ice temperature, fluid density and pressure controls;

Field observations and measurements of the ice texture and fabric in the fresh ice core, which would allow a timely detection of possible changes in the mechanical properties of ice related to ice permeability;

Develop contingency plan, which should be employed immediately in case the monitoring means indicate dangerous conditions (the conditions should be specified).

In compliance with the decision of V CEP (CEP V, 4b (5)), the Initial Environmental Evaluation (IEE) was performed for this stage.

2.4.2. First stage. Drilling of the borehole by electrical-mechanical drill from 3673 m to a depth of 3725 m (2010–2011)

Drilling of the bottom segment of the ice cover in the layer of 3725–3750 ± 20 m by a thermal drill for penetrating to the lake water layer (January–February 2011 or during the season of 2011–2012).

The first stage envisages additional drilling of about 100 m in the borehole 5G-2 by means of a coring electrical mechanical drill KEMS-132 and a complex of drilling equipment used here before. Considering the reliability and high efficiency of this equipment, its use appears to be completely safe in terms of ecology. In addition, it will allow extraction of approximately 100 m of the ice core from the ice sheet basal layers containing unique information on the lake evolution.

First, it is necessary to ensure the ecological safety of the lake–drill contact.

For this, prior to the second stage, it is proposed to introduce to the bottom section of the hole a new ecologically clean drilling fluid (neutral in respect to water and microorganisms). It can serve as a peculiar liquid plug about 25±20 m thick between the top and clean bottom sections of the borehole. The density of this buffer layer separating the bottom and the earlier used drilling fluid (a mixture of aviation kerosene TC-1 and freon 141b) should be higher than that of the drilling fluid of the main borehole but lower compared to lake water.

2.4.3. Second stage. Drilling of the borehole until the contact with the lake surface (2010–2011 or 2011–2012)

At the second stage (drilling of about 25±20 m of ice until the contact with the lake), it is planned to use a thermal drill with a stepped working body (TBPO-132) due to which a pilot- hole with a diameter 3–4 times as small as that of the main hole forms under the drill. During drilling, the overburden pressure undercompensation is maintained in the hole.

A thermal drill TBPO-132 consists of a pilot-chisel and a ring bit connected with the electrical power source, which heats them. The drill is also equipped with a pump and the feedback system sensors. The thermal drill similar to the electrical-mechanical drill is suspended in the borehole at a carrying cable. The rate of running of the last 25±20 m of ice until the contact with the lake is to be up to 3 m/hour.

Upon reaching the lake surface, the solid ice support under the bottom surface of the pilot-chisel will disappear causing a response of the contact sensor. The sensor signal will switch the packer that serves for isolating the near-bottom section of the hole from the rest of its volume. Drilling will be stopped simultaneously while the readings of sensors will allow us to evaluate the hydrostatic pressure difference in the hole and in the lake. When the pilot-hole bottom reaches the lake surface, three variants of the ratio of fluid column pressure near bottom P_f and water pressure in the lake P_l are possible: 1) $P_f<P_l$; 2) $P_f=P_l$; 3) $P_f>P_l$, with the first variant being the most likely and the second and third variants unlikely. At $P_f<P_l$, lake water will rise in the hole to a height h, corresponding to the pressure difference in the lake and the hole $\Delta\rho=P_f-P_l$. At thermal drilling, the working body should be in a constant contact with the bottom surface under the action of the force equal to some part of the drill weight. Thus, the direct water penetration from the lake to the hole is impossible. It can rise in the hole if the drill is raised above the bottom by a carrying cable or by the force that can occur at the moment of contact with the lake surface

due to a pressure difference if it is greater than the force pressing the drill to the bottom (the drill weight with deduction of the Archimedean buoyancy force).

At $P_f=P_l$, the lake water will rise in the hole at the drill raise with decreasing hydrostatic pressure of the drilling fluid, that is, the cable volume retrieved from the hole will be replaced by lake water.

At $P_f>P_l$, which is practically unlikely, at the pilot thermal chisel contacting the lake surface, the force P_o will act on the drill pressing it to the ring bottom of the hole. At disconnecting the power supply, the ring bit will be pressed against the bottom shoulder of the hole isolating it from the lake.

It will be further necessary to pump part of the fluid from the hole decreasing its level to such a value as to ensure inequality $P_f<P_l$. The situation will be reduced to the first variant and the retrieval of the drill from the hole will begin.

Thus, the thermal drill will perform a valve function ensuring the ecological safety of penetrating the lake disconnecting it and the hole at the moment of contact between the pilot thermal chisel and the lake surface.

To drill the last 25±20 m of ice until its contact with the lake, a thermal drill will be used without its detachment from the borehole bottom. At ice melting by the drill, the drill and the cable will be naturally cleaned from the drilling fluid by melt water whose column forms one more buffer layer below the organic-silicon fluid (polydimethylsiloxane – PMS).

After reaching the Lake Vostok surface (end of the second stage), the operation in the borehole will be stopped for the period of freezing of lake water introduced to the hole. Then, a portion of ice formed of lake water will be sampled by a coring electrical mechanical drill KEMS-132. The core will be retrieved observing all precautions to preserve the biological purity of its inner part by means of the method that has already been developed, repeatedly used and that has proved its reliability. The remaining ice will not be drilled ensuring complete isolation of the borehole from the lake surface.

Obviously, the most valuable material for future microbiological and other studies will be the lower section of the accreted ice column, which is the most free from alien admixtures entrapped by the water flow rushing to the hole from the lake.

2.5. Justification of the need and advisability of the proposed activity

The importance of study of Lake Vostok, which is the largest subglacial water body of Antarctica, is primarily related to the fact that it presents potentially a unique water ecosystem isolated from the Earth's atmosphere and the surface biosphere for at least 1 million of years. The extreme conditions that are characterized by high pressure, absence of light, the specific gaseous and chemical composition of water and prolonged isolation of Lake Vostok suggest a possibility for the occurrence and evolution here of the life forms significantly different from the forms known to modern science, preservation of relict forms and manifestation of other unknown evolution ways whose study will contribute to better understanding of the processes of life development both on our and other planets of the solar system. Significant lake dimensions (300×50 km with a water layer thickness comprising 1200 m) allow us to consider it as an Earth's analogue of the oceans that is believed to exist under the thick ice shells of Europe and Callisto – satellites of Jupiter. Thus, the area of Lake Vostok presents an interest as testing grounds for the methods of detection and study of life under the extreme (extraterrestrial) conditions. Along with this, the reconstruction of the occurrence and development of the subglacial Lake Vostok, establishment of its current parameters and the regime as well as the study of the composition of lake water and bottom sediments are considered at present as integral components of the study of geological history, glaciation and climate of Antarctica. The aforesaid explains an exclusive interest of the international scientific community to the study of Lake Vostok and predetermines the central place of this Project among the most significant scientific programs, which will be implemented in Antarctica during the next decades.

These studies will not be able to deny or confirm the hypothesis about the presence of some life forms. Thus, the objective of sampling lake water is one of the major issues ensuring progress in the study of nature of this unique body. To achieve this objective is the aim of using further the borehole 5G-2 – to continue drilling and sampling of lake water. At present, the borehole 5G-2 has already penetrated that part of the glacial strata that was most likely formed at freezing of lake water. Hence, further drilling, sampling and study of ice cores will provide new information on the origin and chemistry in the past of lake water and a possible existence of life in it. Penetration to Lake Vostok and sampling of water from its subsurface layer will allow us to obtain correct data on its modern state. In addition to their own value, these data will be invaluable for the development of subsequent technologies of direct studies of lake and its sediments and for updating the results of modelling and remote sensing studies.

2.6. Alternative types of activity

The alternative types of activity can be:

- apply the drilling technology without using the drilling fluid, for example, hot water;
- refuse from water sampling from Lake Vostok.

A method of ice sheet drilling by means of hot water (it is called “Fastdrill” in the USA) envisages drilling with a large rate and in the absence of using different hydrocarbon components. This technology cannot however be applicable under the conditions of Vostok station, as the required power for a constant hot water circulation in the ice borehole with a water temperature of about +90 °C allows drilling at a temperature higher than −35 °C. At Vostok, the year-round surface temperature of the ice sheet is −55 °C. Ice drilling at this temperature using hot water will require a power station with a capacity of several megawatts. Besides, vertical temperature convection at the contact of relict subglacial lake water with hot water from the borehole with a temperature of +90 °C will comprise many tens and even hundreds of meters. Microorganisms inhabiting these aquatic systems will be simply boiled in hot water. The more so as a possible diversity of microorganisms inhabiting the surface layers of the subglacial lake at using the non-core drilling is not known in advance. Of serious concern is the measurement accuracy of hydrophysical sensors lowered in the sounding complexes through hot water in the borehole, as the relaxation time of these sensors at unknown water temperature in situ in subglacial systems is practically not determined. Besides, the influence of temperature convection will significantly distort the real geophysical parameters. No other methods for ice sheet drilling and correspondingly penetrating the subglacial aquatic systems were developed and tested under the high-latitudinal conditions.

To refuse from water sampling will practically stop the scientific progress in investigating this unique natural phenomenon as an impossibility of applying the contact methods for the studies of water and bottom soil sediments will not provide an opportunity to answer many important question of current science.

The ecological cleanliness of the proposed Russian method has already been proved by the European colleagues during deep drilling of glacier on Greenland Island and therefore this method has a right for being implemented.

2.7. Response measures in emergency

The unforeseen circumstances in implementing the Project of penetrating the lake water layer through borehole 5G-2 could be an accidental penetration to the lake provided the glacial thickness is less than 3750 m (measured by radio-echo sounding and seismic methods). In this case, absence of organosilicon parting fluid at the “drilling fluid/lake water” interface is possible. However, as shown by operations in Greenland, potential contamination is possible only in the thin 10-cm layer within the borehole. In this case, lake water will rise upward in the borehole to a height of pressure undercompensation of the drilling fluid column. Glacier drilling under any circumstances is performed at the pressure undercompensation of 5–8 atm (with the drilling fluid depth by 50–80 m lower than the borehole upper level). Other emergencies in implementing this project, like the kerosene-Freon mixture release, etc. are not anticipated. No other technical mistakes in drilling the glacier are expected due to special additional measures undertaken for this operation at Vostok station. These are constant control of the technical equipment and monitoring the drilling fluid density and its upper level in the borehole.

2.8. Major expected results

Studies of deep boreholes at Vostok station and of the continuous ice core extracted from Vostok borehole, which age is greater than 500 kyr have already allowed us to obtain significant scientific results [6]:

- based on the ice core isotopic and glaciological studies, scientists of Russia (AARI, Institute of Geography of RAS), France (LGGE of the CNRS) and the USA (University of Miami) have established for the first time the cyclicity of climate change on Earth and identified four glacial and interglacial periods;
- methodology for aseptic microbiological sampling from the ice core was developed and tested at the level of scientific discovery of anabiosis duration of microorganisms of more than 200 kyr (SPSMI jointly with the Institute of Microbiology of RAS and AARI);
- data on the temperature regime of the glacial cover were obtained for the first time in central Antarctica and were used as a basis of mathematical modeling of the heat-mass transfer processes in the glacier.

Studies in the area of geophysics, glaciology, paleoclimatology and microbiology will permit us to collect numerous materials of unique significance for the world science.

2.9. Area of proposed activity

The activity will be undertaken at the Russian inland Vostok station located on the plain snow surface of the ice sheet in East Antarctica (78°28' S, 106°48' E) at an elevation of 3488 m above sea level. At the present time, the area of station facilities occupies an area of around 25600 m^2. The main structures include: office-living house, mess-room, DES-garage-bath-house, new and old drilling complexes, balok[1] of emergency DES and three baloks for storage of food products. The buildings and baloks are interconnected. Their location corresponds to the wind rose. In the dark time, the station is illuminated by searchlights. The main station buildings have a compact arrangement (at the site 130×130 m in size), which saves the strength of people at moving over the station but at the same time, contributes to snow drifts. Many buildings are now under the snow: magnetic pavilions, “Dumand” balok, the US ice core storage complex, house No. 1 (old Vostok) that existed from the time of establishing the station, Astronomic Geodetic Point (AGP) center and several balok structures [7].

To undertake studies under this Project, the Vostok station has the following facilities:

- a drilling complex including a drilling house with a rig and a set of ground equipment;
- a glaciological laboratory equipped with necessary facilities and instrumentation for the studies of the extracted ice core;
- a specially equipped ice core storage space providing its long-term preservation at a constant below zero temperature;
- living and auxiliary premises

To undertake a complex of studies, 14 to 25 people can be accommodated at the base depending on the season. There are 5 diesel-generators 100 kW each. From 1970, 5 holes 15–18 cm in diameter and a depth between 500 to 3668 m were drilled. In accordance with the Project, it is proposed to continue drilling by a 4-people team.

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[1] Balok is kind of a wooden shed or hut, which can be mounted on vehicles including sledge and easily transported to the required locality.

2.10. Types of expected production and domestic waste and methods of their utilization and removal

It is noted that operations connected with this Project will not cause a significant increase in waste generation, since they will be carried out in the planned regime of station activity without increasing the facilities and logistics activity.

During drilling operations, a two-component fluid consisting of aviation kerosene TS-1 and Jet-A with addition of heaver – Freon F-141b for additional borehole plugging-back and at the final stage, inert polydimethylsiloxane oil to prevent penetration of hydrocarbons to the sampling zone will be used.

There will be no extraction of the drilling fluid and formation of its waste during the operation period. Insignificant by quantity waste from servicing the equipment (rags, plastic and paper) will be removed in accordance with the existing instructions.

2.10.1. Oil and oil-containing mixtures

The formation of these wastes due to the proposed activity is not envisaged by the technology.

The station waste hydrocarbon materials and fuel remains unsuitable for further use will be transported to Mirny station.

2.10.2. Sewage water

The proposed activity will not influence the increase of sewage water production.

The main sources of sewage water are the bathhouse (together with a laundry), the mess-house including the galley and the office-living premises. Sewage is pumped out via the heated pipes to deep pits that are melted in snow. Upon their fill up, new pits are melted in snow. Their depth is about 20 m and the diameter is 3 m.

2.10.3. Garbage (including solid kitchen waste)

The combustible wastes produced will be burned in the incinerator.

3. Description of the environment in the operation area

Vostok station is located on the plain snow surface of the glacial plateau in East Antarctica (78°28' S, 106°48' E) at a height of 3488 m above sea level. The least distance from the coast is 1260 km, from Mirny station – 1420 km and from the South Pole – 1253 km. The ice sheet thickness in this area is 3750 m and the thickness of the snow-firn strata is about 120 m. The glacier bed beneath the station is at a mark of about 200 m below sea level.

3.1. Glacial cover in the borehole area

As follows from the data of geophysical and glaciological studies, the upper portion of the ice sheet at the drilling site of borehole 5G-2 is comprised of a 100-m snow-firn layer overlying the monolithic ice strata. It is composed of the "interglacial" and "glacial" seams of ice types differing in the grain size and orientation of their crystallographic axes. In the upper portion of the section, these differences are quite insignificant, however at depths greater than 2700 m the "interglacial" and "glacial" ice seams differ significantly by their structure and mechanical properties [8]. In addition, at the 3310–3370 m depth range, some indications of tectonic inconsistency in the bedding of strata were observed. At the 3460–3538 m range, there is layered ice, which is characterized by alternating layers of fine- and coarse-grained ice. Finally, the basal ice layer detected below the 3538 m mark and traced to the borehole bottom (3650 m) is formed by giant-grained ice (ice crystals greater than 1 m in diameter). This ice contains rare scattered small inclusions (1–6 mm in diameter) presenting concentrations of clayey particles of morainic origin. According to [8], the structure of basal ice indicates its stationary state and a congelation origin, i.e. the ice forming during the process of water freezing. This fact is confirmed by the results of isotopic studies of the ice core specimens. The ice flow above the lake in the Vostok station area is directed south-eastward. The presence of a basal layer of stationary ice in the lower ice section suggests that the ice sheet here beds predominantly on the underlying mountain rocks, whereas the dissected subglacial bed relief presents a hindrance to the lower layers of the glacial strata. The maximum shear deformations occur within the higher layer (3460–3540 m). Beginning from these depths and higher, the ice strata are involved into motion whose rate at the ice sheet surface comprises about 3 m/year [9].

Large dimensions and depths of the lake are direct evidence that the total transport of melt water entrapped in the basin by the ice cover can be zero or close to constant. At the bottom ice sheet surface at the ice-water phase divide, the ice melting/accretion rate can differ in different parts of the lake both in value and sign. This rate at the divide is determined by the local vertical heat flux that consists of geothermal and climatic components.

Calculations showed a decrease of 100–150 m in the ice sheet thickness in the lake area during the global cooling events in the past due to a significantly reduced atmospheric precipitation [10].

At the present time at an average pressure at the ice-water divide estimated as 340 bars the freshwater freezing temperature is assumed to be −2.6 °C, while the corresponding optimal value of the current ice sheet thickness was determined to be 3776±3 m. Based on seismic sounding data, the ice thickness at this location is 3750 m. The difference of 26 m is equivalent to the offset of the lake water freezing point from −2.6 °C to −3.1 °C, which is less likely.

According to studies of the ice core from the deep borehole at Vostok station, it is known that the upper 3540 m of the ice sheet overlying the stationary basal ice layer is subjected to intense displacement and deformation heating in the contact zone. Based on the vertical temperature distribution measurements in the ice sheet (in the borehole) and climatic reconstructions from isotopic ice composition data, the heat flux, ice sheet thickness and bottom ice melting/accretion rate were estimated. They have revealed that the best coincidence of the calculated and measured temperatures for the present conditions can be obtained at the bottom heat flux of 0.036±0.006 W/m2 that produces the average water rate freezing of

1.1±0.6 mm/year [11]. This is in agreement with the results of structural ice core studies according to which the 220-m basal layer is represented by congelation ice that was formed from water freezing to the bottom ice surface.

3.1.1. Characteristics of the current state of borehole 5G-2

The drilling of borehole 5G-1 was interrupted at the end of the seasonal operations of the 43rd Russian Antarctic Expedition (RAE) in January 1998 when the borehole depth comprised 3623 m, which is approximately by 130 m higher than the “ice-lake water” interface. After the end of drilling, the borehole was suspended. The drilling operations in this borehole were resumed in the season of 2004–05 and were continued in the subsequent seasons. In January and in October 2007, there were two technical accidents at the bottom of borehole 5G-1 leading to a loss of the drills. While it was possible to eliminate the consequences of the January accident and the drill broken away from the power cable of the drilling complex was recovered to the surface, all attempts undertaken in the seasons of 2007–08 and 2008–09 to extract the drill separated from the borehole bottom depth of 3668 m were unsuccessful. So in late January 2009 it was decided to begin a new deviation from borehole 5G-1 from a depth of 3590 m. The choice of this horizon was determined by the need of collecting the repeated ice core specimens from 3604–3609 m horizons, in which the increased concentrations of mineral particles were found. The new borehole was called borehole 5G-2. In the end of the season 2009–2010 its depth was 3650 m. The present design of borehole 5G-2 is presented in the figure in Annex 1. The total volume of the drilling fluid in the borehole is about 65 m^3. The drilling fluid level is at a depth of 40 m and its average density is equal to 928 kg/m^3. The difference between the overburden pressure of the ice strata and the hydrostatic pressure of the drilling fluid is about 0.1 MPa. The rate of the borehole narrowing in the bottom area at the existing undercompensation of the overburden pressure is not greater than 0.1 mm/year. The borehole head has been sealed. The borehole is practically vertical to a depth of 2200 m, then the deviation angle of the hole axis from vertical comprises 6 to 8°.

3.1.2. Crystallographic and structural properties of lake ice with respect to its permeability for the drilling fluid

Studies of the ice core extracted from borehole 5G-2 have revealed that at a depth of 3538 m in the Vostok station area there is an interface between glacier ice of atmospheric origin and accretion ice formed as a result of Lake Vostok water freezing to the ice sheet bottom [7, 8]. Lake ice has a coarse-grained crystalline structure with a random orientation of c-axes. The average crystal size is about 25 cm in diameter whereas in some horizons the diameter of the crystals is greater than 1 m [7, 8].

As a result of studies of the crystalline structure of the ice core samples from horizons of 3553 and 3610 m made by the method of x-ray diffraction measurements, it was established that lake ice is characterized by an almost perfect crystallographic structure and a low density of lattice dislocations ($<108\ m^{-2}$) [9]. These data indicate absence of deviatoric stresses in ice and also point to a perfect structure of ice crystals excluding a possibility for the drilling fluid (kerosene/freon F-141b mixture) to diffuse through the ice lattice.

However, it is known that at high temperatures (beginning from ~6 °C below the ice melting point), a quasi-liquid film forms at the ice-grain boundaries. The thickness of this film at the triple junctions of ice grain increases up to several tens of microns close to the melting point. Thus, triple junctions form in polycrystalline ice a system of connected microscopic veins through which (under the action of pressure and/or concentration gradient) liquid water and soluble impurities including the borehole fluid, can migrate. A theory of diffusion of soluble impurities through a vein system is given by Rempel et al. [10]. Applying theory [10] to the conditions (ice temperature, grain size) appropriate to the near-bottom strata of the ice sheet at Vostok, one can calculate that the total penetration depth of the drilling fluid from the borehole to ice (also in the direction towards the ice-sheet bottom) will be less than 1 m over the first millennium. Thus, a possible penetration of the drilling fluid from the borehole through ice to Lake Vostok is practically excluded provided that ice bedding deeper than the current borehole bottom (3650 m) has a structure similar to that observed in the investigated section of the lake ice core (3538–3650 m).

3.1.3. Probability of changes in physical and structural properties of lake ice (towards its permeability increase) within a depth range from 3650 m (current borehole bottom) to 3750 m (estimated depth of ice-water interface)

The lake ice properties determining its permeability for the borehole fluid may change with depth as ice becomes younger near the ice formation zone. An analysis of isotope data from the lake ice core has revealed that the mechanism of ice accretion near Vostok station is related to thermohaline circulation in the lake being thus similar to the mechanism of water freezing to the ice shelf base [11, 12]. In particular, it was shown that frazil ice plays a significant role in accretion of lake ice. The crystals of frazil ice form due to super-cooling of melt water, which rises along the inclined ice ceiling of the lake from a zone of subglacial melting in the north towards a zone of ice accretion in the south of the lake. The consolidation of originally loose layer of frazil ice crystals accumulating under the ice-sheet base occurs as a result of slow freezing of host water. According to the isotope data, the frazil ice forms 42 to 70 % of the total volume of newly accreted lake ice.

By analogy with sea ice accreting at the ice shelf base, it is reasonable to suggest that young lake ice has a fine-grained structure with a grain size not greater than some millimeters in diameter [13]. Such structure increases ice permeability as a rule, especially at the annealing temperatures typical in the ice overlying the accretion zone. Interpretation of data obtained from thin-section, chemical and x-ray diffraction studies of the available ice core leads to a conclusion that after its formation, the lake ice experiences an abnormal grain growth under the prolonged annealing conditions [9]. We do not know at present at what distance from the ice-water interface the formation of this secondary lake ice structure characterized by a negligible low permeability for the borehole fluid (see above) is completed. As a reliable estimate a distance of 25 m from the ice-sheet bottom can be taken. The calculated temperature at this depth is equal to 0.5 °C below the melting point [4], while the ice age exceeds 2 kyr [4, 14], which is more than sufficient for the secondary structure formation.

In summary, within overall uncertainties of the aforementioned estimates, the 3725 m depth should be considered as a lower boundary to which the ecologically safe conditions of ice drilling with a conventional electromechanical drill are assured. Continuation of drilling below a 3725 m depth should be considered as the beginning of Lake Vostok entry and thus requires employment of new equipment and technology specifically designed for this operation.

3.2. Climate of the area

The mountain part of the ice sheet with marks of more than 2000–3000 m belongs to the climatic area of Central Antarctica. The ice sheet is covered with snow, which never melts the year-round. The atmospheric mass above the ice sheet compared to the coastal areas of Antarctica is distinguished by high transparency and dryness of air. The total solar radiation is very large. It equals 1.26 GJ/m^2 in December and is 80% comprised by direct radiation. The annual surface radiation balance at the station is equal to 0.08 GJ/m^2. Intense cooling of air occurs above the Antarctic Plateau with strong surface temperature inversion developed during the entire year. Winter lasts for 6 months (April–September) and summer for two months (December–January) with duration of transient seasons also for two months (spring – October and November and autumn – February and March). The geographical location of the station, features of the underlying surface, solar radiation regime and atmospheric circulation govern the general climate severity. Here, throughout the winter, the air temperature is extremely low. The mean annual air temperature at the station is −55.4 °C. A typical feature of annual air temperature variations is the absence of a pronounced minimum during one of the winter months. The development of active meridional atmospheric circulation in Antarctica leads to advective warming and appearance of “warm centers” above the continent in the middle of winter. Advection of warm air masses to the continent in winter can account for the fact that according to multiyear data, the temperature of four winter months (April-June, September) is the same and of two colder months (July, August) differs only by 1–2 °C. This characterizes the phenomenon of “the winter without pronounced centers”. In spite of steady air temperature variations in winter, the coldest month is August (with an average multiyear temperature of August close to −70 °C), when the atmospheric cooling above the continent lasting the entire polar night achieves its peak at the end of it. However, the absolute temperature minimum at the stations in the center of the ice sheet is always recorded in July. On July 21, 1983, the absolute minimum of surface air temperature on Earth equal to −89.2 °C was recorded. In spring, especially with the onset of polar day, there is a steady and large air temperature increase by absolute values. From September to December, the mean monthly air temperature increases two-fold. However, in spring, the temperature is quite low, its average value comprising −50 °C. The temperature is naturally the highest in the middle of the polar day in summer (December-January), never dropping below −36 °C, on average, for a month, but although not exceeding −30 °C. The highest temperature is observed in the third 10-day period of December and in the first 10-days of January indicating a direct relation to the Sun's height above the horizon. The absolute maximum recorded at Vostok station is equal to −13.6 °C. The air temperature in summer is twice as high as in winter. From summer to autumn, a rather sharp cooling occurs and during the autumn months (February, March), a constant and significant temperature decrease continues. The average temperature of the autumn months is low (−50.8 °C) being equal to the temperature of the spring months. The average annual air temperature from year-to-year varies compared to multiyear temperature within 3.5 °C. The annual amplitude at the time of observations is equal to 35.7°, with the absolute amplitude comprising 75.6°. The diurnal temperature variations are usual on average for a year with the maximum in the daytime and minimum at night. In winter, the diurnal variations are practically absent as the difference between the temperature at the observation hours is not greater than the accuracy of its measurements. Mean quadratic deviations of mean monthly temperatures in some years from their multiyear averages are small comprising ±1 °C in the summer months and ±4 °C in winter. The fact that the greatest air temperature fluctuations occur during the colder period of the year and the smallest are recorded in summer emphasizes once again the significance of the interlatitudinal air mass exchange in winter and the dependence of summer temperatures on the solar radiation regime. A large number of observations clearly show a regular feature, namely, the decrease of temperature with decreasing pressure whereas its increase is accompanied with increasing atmospheric pressure.

At Vostok station, due to its location at a large height (3488 m above sea level), the pressure is very low and comprises 624.2 mb, on average, for a year. The annual variations have their maximum in the summer and the minimum in late winter (September). Climate is also distinguished by extremely low air humidity. The water vapour pressure in summer comprises only 0.29 hPa, and on average for a year it equals 0.07 hPa.

An insignificant amount of moisture in the atmosphere is attributed to negligible evaporation from the glacial cover due to the absence of free moisture supply at the surface and low air temperature. In the annual variations of absolute humidity, the maximum is observed in summer and the minimum in winter. The average annual relative humidity at the station is 71%. It is maximum in summer (73%) and minimum (69%) in winter.

There are pronounced variations of the frequency of occurrence of clear and overcast sky at Vostok station. The frequency of occurrence of clear sky is the highest in winter (60%) and the lowest in summer (30–40%). The cloudiness is weak with cirri (Ci) and cirrostratus (Cs) clouds prevailing. The total cloudiness is small (3.4 points for a year). If cloudiness is considered by seasons, then the largest cloudiness (3.8 points) is observed in spring and the least (3.2 points) in winter.

The wind regime is characterized by weak catabatic west-southwesterly winds with the mean annual speed of 5.4 m/s. The annual speed variations have two maximums – in September–October and in March. There is a direct relation between the direction of catabatic wind and that of the ice sheet slope at Vostok station. The inland Vostok and Sovetskaya stations are situated at the opposite slopes of the meridional rise. The air sinks from the glacial ridge along its slopes towards the Vostok station in the west-southwest direction and towards the Sovetskaya station in the east-southeast direction. As can be seen, the wind directions at these stations differ approximately by 140°, i.e. they are almost opposite. The frequency of occurrence of catabatic winds during a year comprises 60–80%. Cyclones (obviously very weak) sometimes penetrate the station area both from the Indian and the Pacific Ocean sectors of the Antarctic. In the event of a cyclone arriving from the Ross Sea, the cyclonic winds coincide with the westerly winds prevailing at the station while at the south-southwesterly winds, the cyclonic weather features are clearly pronounced. The cyclones of the Indian Ocean sector of the Antarctic also bring the cyclonic weather to the station but with the easterly winds. Their speeds are attenuated by the opposite catabatic winds and are hence small. The probability of storm winds (with a speed > 15 m/s) at Vostok station is small. The maximum speeds recorded at gusts comprise 23 m/s in summer, 23 m/s in autumn, 27 m/s in winter and 32 m/s in spring. The frequency of occurrence of calms is less than 1%.

The frontal cloudiness carrying precipitation penetrates very rarely to the area of Vostok station. Clouds are depleted in moisture in these cases and snowfalls are of little intensity. The annual sum of atmospheric precipitation falling out only in the solid form is about 25–50 mm. Up to 98% of the entire mass of precipitation fallout here is comprised of columnar skeletal ice crystals of prismatic shape. The inland area is characterized throughout the year by the fallout of small ice crystals at clear sky ("ice needles"). The deposition of such ice crystals was recorded at Vostok station for 247 days, on average, for a year. The occurrence of ice crystals at clear sky is due to sea air flowing to the inner areas of the cold continent in heights of about 500–100 m above the ice cover in its central parts, supersaturation of air by several tens of percent relative to ice and its sinking due to downward motions. Supersaturation of air results from radiation cooling with its advance inland. The ice crystals originate above the central areas of the ice sheet in a relatively warm isothermal layer above the surface inversion. At Vostok station, the isothermal layer in July was located approximately between the levels of 650 and 550 hPa. The ice crystals also form fog and haze typical of the central areas of Antarctica. The transparent ice fog occurs at a weak wind and quite often simultaneously with the fallout of ice needles from the atmosphere. There are about 35 days with ice fog, on average for a year, such days in summer being few. The ice haze is also observed with the intense fallout of ice needles being observed more frequently than fog up to 150 days a year. The snowstorms in the station area are rare due to weak winds, their frequency of occurrence with drifting snow comprising not more than 15% for a year. In summer when the snow surface is covered with the radiation crust, even the wind with a speed of 10 m/s does not cause the snow transport. Practically the entire annual amount of deposited snow presents a winter layer. This is a thin layer several centimeters thick comprised of small crystals and their fragments, which is much less dense than in the other areas due to weak local winds. Since in summer the snowfalls are rare, predominantly the finest sublimation ice crystals falling out from the atmosphere at clear sky are deposited at the surface. They deposit in a thin loose layer easily moving with weak winds, evaporate and melt under the action of intense solar radiation. At noted above, radiation crusts, single and multiple are common at the surface marking the summer season in the annual core of layers. The main amount of snow is accumulated during the cold time of the year from May to October. The accumulation of atmospheric precipitation is within 2–3 g/cm^2 a year. The area adjoining the station presents a level snow plateau with small soft piles of blown snow with a height up to 20 cm. At the surface of the snow cover, space micro-particles deposit with different intensity and periodicity. Airflows bring micro-particles of Earth's origin (volcanic dust, spores and pollen of plants, microorganisms, chemical compounds and microelements) as well as anthropogenic particles (compounds of sulfur, nitrogen, carbon, decay products of thermonuclear explosions, etc.) from the other continents and the oceans.

Different optical phenomena such as halos, crowns and columns and optical illusions are typical of the atmosphere in the Vostok station area. The halos are observed both in summer (around the Sun) and in winter (around the Moon) on average 60 days a year. The crown forms as a rule only around the Moon in winter. There are 7 such days on average for a year. The columns around the Sun are very rare (one day on average for a year). The polar night lasts almost four months from April 24 to August 20 [7].

3.3 Geophysical data on the area of Lake Vostok and the adjoining territories

Lake Vostok is located at the margin of the ancient (Pre-Cambrian) Antarctic shield developed under the glacial ice of East Antarctica in the sector between 0° to 90°–110° E. The currently available structural and geophysical data on this region suggest that Lake Vostok is confined to the inland rift zone comparable by its crust structure and tectonic location with the rift structures of other continents (for example, such as the rifts of East Africa, Lake Baikal and St. Lawrence Lakes). Typical characteristics that serve as a basis for such suggestion include the length and width of the depression of Lake Vostok comprising more than 300 km and 50–80 km, respectively, according to geophysical and satellite altimetry data; morphology of the coastal slopes presenting steep bedrock cliffs (escarps) with an amplitude of up 1000 m; [16]; strong negative gravity anomalies in the free air reduction from −60 to −105 mGl [17], on whose basis the model of the upper Earth's crust section is constructed where the basement is submerged by 3–5 km (Fig. Annex 11) and the vault structure of the surrounding regional relief with average heights of 500–1000 m.

The accurate spatial location and the length of the rift zone remain uncertain due to insufficient morphological and geophysical data, however, by analogy with similar structures, it can be assumed that the depression of Lake Vostok presents only a fragment of a more extensive rift zone. Gravimetric data [17] (Vostok–Komsomol'skaya–Sovetskaya line) indicate a possible continuation of the rift troughs to the west-northwest of Lake Vostok (at least to 95° E) with the change of its strike approximately at 60°.

In the regional respect, the lineament identified is in good agreement with the general morphological and tectonic structure of the eastern margin of the Antarctic shield displaying a spatial and genetic unity with the extensive rift zone of Prydz Bay–Lambert glacier and its supposed extension in the eastern foot of the Gamburtsev Mountains. The existence of linear depressions (Grabens) at the foot of the Gamburtsev Mountains is confirmed by calculations of the magnetic active basement depths that show in some places (the survey covered only some foot fragments of the Gamburtsev Mountains) its submergence to 3–8 km (see Fig. 18), whereas the bedrock relief is located here approximately at sea level [19]. A lengthy valley where the basement is 2–5 km high was also revealed in the central part of Gamburtsev Mountains (approximately along 77° E), probably defining one more branch of the general rift system (Fig. Annex 10). Thus, all this system can in total present the largest inland rift belt similar by the scale of manifestation of destructive processes with the rift belt of East Africa (Fig. Annex 13). If this is so, then one can expect the existence within the supposed belt of a range of subglacial (freshwater) lakes located in the depressions of the rift structures.

The assumption of the age of origin and the history of development of the rift zone of Lake Vostok and its possible continuation are based on the general knowledge of tectonic evolution of East Antarctica and other Gondwana continents. If from the beginning of glaciation in East Antarctica in the Late Eocene (ca. 40 millions of years BP) most of the crystalline shield was overlapped by a thick glacial cover, as is assumed by many investigators, then sedimentation in Lake Vostok was very slow and hence the main strata of sediments had accumulated at the earlier time. The main phase of the Earth's crustal extension resulting in the development (reactivation) of the rift zone of Lambert glacier and East Gondwana break-up is dated by the age of 145–130 million years. This event probably accounts for the formation of the entire assumed rift belt of the Antarctic shield including the depression of Lake Vostok with the dominance of sediments of the corresponding age within it. The morphology of Lake Vostok (Fig. Annex 12) and the vault character of the adjoining generalized relief indicate a likely development of modern (neotectonic) processes in the lithosphere of the entire region. This is indirectly confirmed by the presence of the Gaussberg volcano of the Pleistocene age on the Davis Sea coast located within the supposed rifting belt.

Geophysical data both within the lake itself and in the surrounding territories are important for understanding the tectonic nature of Lake Vostok. In 1989, the Polar Marine Geological Expedition (PMGRE) onboard IL-18D aircraft carried out a complex of aerogeophysical studies in Central Antarctica. The data obtained were processed again in 2000 within the framework of the present Project and served as a basis for constructing a map of the magnetic active basement surface of Central Antarctica.

During the period 1961 to 1964, gravimetric observations were performed along some sledge-tractor traverses in the area of Lake Vostok that have revealed the presence f high amplitude negative anomalies of the gravity field [17], however, no efforts to process these materials in the context of the Earth's structure modeling were undertaken until now as the lake morphology, which makes a significant contribution to the anomalous field was unknown [4]. New data of PMGRE on the bedrock relief depth within Lake Vostok allow us to perform necessary calculations and make (most general so far) conclusions on the deep structure of this region.

Materials of aeromagnetic surveys are usually a source of information on the distribution of magnetic active sources in the section of the Earth's upper portion. Mass calculations of depths to the anomaly forming objects-sources allow obtaining some understanding about the morphology of the magnetic active basement in the absence of seismic data, which can be in the first approximation identified with the crystalline basement (for Central Antarctica with the basement of the East Antarctic craton). Calculation of parameters of the magnetic sources for Central Antarctic areas is the only information not only about the possible location of the crystalline basement surface, but also about the presence or absence of sediments.

Analysis of the data obtained and their correlation with the subglacial relief of this region have allowed us to reveal the segments of basement submergence and large faults in the Earth's crust. Linear basement submergence zones (with a bedding depth of more than 2–3 km) can be interpreted as rift graben probably forming one system with the Lake Vostok Graben.

3.4. Peculiarities of the gas regime of Lake Vostok as related to the problem of lake penetration

As a result of the intense water exchange between Lake Vostok and the overlying ice sheet [15], there occurs a net transfer of the atmospheric air (in the form of gas hydrate) through the ice-sheet thickness to the lake water [2]. The thermodynamic conditions of Lake Vostok (pressure >33 MPa, temperature of about −3 °C) are within the stability field of mixed air-clathrate-hydrate and of mixed hydrates of other gases (methane, carbon dioxide, etc.), which are probably present in lake water. Due to this, gas cannot exist in the lake as a free phase (gas bubbles) [2]. The increase of concentration of dissolved gases accumulating in lake water is limited by the equilibrium solubility of these gases in the presence of a mixed gas hydrate whose composition as shown by the results of gas analyses of the lake ice core should be close to the air hydrate composition [16]. According to the results of calculations the upper bound of the concentration of dissolved atmospheric gases in the lake is 3.55 g l^{-1} (2.25 g N_2 l^{-1}+1.3 g O_2 l^{-1}) [2, 17], which is two orders of magnitude as high as the concentrations of these gases in water under normal conditions. Further accumulation of gases above this bound would force the mass of the hydrate phase in the lake to increase.

The planned penetration to Lake Vostok will be made at an insignificant and transitory pressure disbalance between water in the lake and the drilling fluid in the borehole: it is proposed to decrease the borehole fluid pressure in order to allow lake water advection to the borehole. Since even this reduced pressure will be much higher (by a factor of ~3) than the dissociation pressure of air hydrates, there will be no significant changes in the thermodynamic equilibrium of gases dissolved in water (no generation of bubbles, etc.). Until complete freezing of lake water that has risen to the borehole, the diffusion of dissolved gases from lake water to a buffer liquid initially depleted in gases relative to lake water is possible.

3.5. Water salinity of Lake Vostok

The estimates of subglacial water electrical conductivity based on radio-echo sounding data [25] indicate that the subglacial lakes of Antarctica including the largest of them Lake Vostok, present fresh water bodies. On the other hand, an intense water turnover in the ice sheet – Lake Vostok system [33, 26], including melting of glacial ice in the north of the lake, water circulation in the lake itself, ice accretion in the south an finally, export of lake ice outside the bounds of the lake depression due to ice sheet movement (Fig. Annex 12), suggest a gradual saturation of the subglacial ice with admixtures that are contained even in very small quantities in the melting glacial ice. This occurs as a result of admixtures being replaced by ice crystalline lattice at water refreezing. Even a minimum difference in the salinity of melt water and resident water of the lake can have serious consequences for circulation in the subglacial water body [27, 28]. Thus, the difference in salinity, which is equal only to 0.03 ‰ will cause the same water density gradient, which occurs due to the existing difference of 0.3 °C between the water crystallization temperatures at the typical points of subglacial melting and accretion. The chemical analysis of ice core samples from the borehole 5G-1 revealed that the concentration of main ions (SO_4^{2-}, Cl^-, Na^+, Mg^{2+} and Ca^{2+}) in the upper layer of lake ice (3538–3609 m) is on average two orders of magnitude as high as in the lower layer (bedding deeper than 3609 m), and one order as high as the maximum concentration of these admixtures in the atmospheric ice layers formed during the glacial periods. Such distribution of admixtures is obviously caused by the presence of frozen water pockets in the 3538–3609 m layers and related mineral inclusions of subglacial rocks.

Calculations have showed that the total concentration of soluble admixtures in water of the subglacial Lake Vostok is within 0.1 to 1 ‰, which corresponds to the level of mineralizing of fresh natural water. However, the concentration of soluble admixtures in melt glacial water discharged to the lake in its northern part is only 0.001 ‰. As indicated above, even such an insignificant difference in water salinity generates a density gradient sufficient for the ascending motion of lighter melt water along the ice roof of the lake rising from north to south. Another important result of the melt water rise along the bottom ice sheet surface is that admixtures coming to the lake through the ice sheet including the microbial material are transported directly to the place of lake ice accretion under the conditions of restricted mixing with resident water of the lake. Due to this, the composition of lake ice accreting in the area of borehole 5G-21 at Vostok station reflects to a greater extent the composition of this subsurface "conveyor" (melt water) than the properties of deeper lake layers.

3.6. Microbiological studies of deep horizons of the ice sheet

Study of microorganisms of the basal zone of the Antarctic ice sheet at Vostok station is of great interest since relict forms of microorganisms could be preserved in these layers formed of subglacial lake water. Such studies can also serve as an important stage in developing the methodological approaches for future studies of glacial features encountered in space – ice covered seas on Jupiter's satellites, polar caps on Mars, etc.

First microbiological studies of glacial basal layers adjoining the subglacial Lake Vostok were carried out in 1999–2000. They revealed that microorganisms of mixed origin area present in the congelation ice zone [29, 30].

The bacterial cells in the studied horizons of the glacial cover numbered hundreds in 1 ml of melt water (Table 3.4.5.1).

Table 3.4.5.1 – Number of bacterial cells in the studied horizons of the glacial cover

Horizon, m	Number of cells in 1 ml of melt water
3002	170
3025	190
3049	170
3078	100
3099	190
3139	430
3151	1740
3178	480
3201	270
3225	530
3252	120
3274	380
3299	860
3325	90
3344	620

However, within these values, there were variations between 90 to 1740 cells in 1 ml of melt water. Analyzing data in Table 1, it is noted primarily that within the depth interval of 3002 m to 3099 m corresponding to the coarse-grained ice formed in the interglacial epoch, the numbers of microbial cells were the lowest between 90–190 ml^{-1}. In deep horizons – from 3139 m to 3225 m corresponding to a fine-grained ice zone formed in the glacial period, the numbers of microorganisms varied to a greater extent between 270 to 530 ml^{-1}, and even to 1740 ml^{-1}, being on average 2–3 times as high as in the previous layer. These conclusions confirm that the numbers of the cells of microorganisms and the quantity of admixtures brought from the surface of continents and oceans to different glacial strata horizons depend on climatic conditions that existed on Earth at the time of the Antarctic ice sheet formation. An increase in the numbers of cells with depth from 20 ml^{-1} to 860 ml^{-1} was noted in the samples from a relatively thin layer (32–3299 m) formed during the preceding glacial epoch. And finally in depths of 3325 and 3344 m located at a comparatively close distance from each other, a rather sharp difference in the concentration of cells (between 90 to 620 ml^{-1}) was observed. This is probably related to the fact that these horizons are in the zone (3310–3370 m), where the tectonic disconformity indications in the bedding of ice layers were noted, which in the opinion of V. Ya. Lipenkov and N. I. Barkov reflect the shear displacement of ice that probably disturbs the initial distribution of microbial cells.

At direct microscopy of preparations in the luminescent and scanning electronic microscopes, microorganisms morphologically similar to modern forms and belonging to different taxonomic groups both prokaryotes and eukaryotes were detected. In all 15 samples studied from horizons between 3002 m to 3344 m, similar to the overlying layers of the ice sheet, cocci and small rods of different shape. In some horizons, filaments of Actinomycetes, yeast cells and hyphae and conidia of fungi were observed. There is a special group of large rods of different shape that judging by morphology, can belong to different species of soil bacteria. These rods were detected predominantly in the 3274 m and 3299 m horizons, i.e. in the zone of shear displacement of ice and could get to it from bedrock. In all samples along with the cells of bacteria, cyanobacteriae and unicellular algae were detected (Fig. in Annex 15). The most widespread were the so-called Coccolithophoridae. Similar to the overlying horizons, diatoms predominated among the remains of unicellular organisms found in the ice samples.

The numbers and the morphological diversity of microbial cells matched to a great extent the quantity of admixtures, predominantly of organic nature indicating that the ingress of particles and microorganisms to different horizons of lake ice was regulated by the same processes. However, the correlation between the microbial cells and suspended matter in this zone was less pronounced compared to the main glacial strata.

In some horizons, microorganisms that were quite rarely encountered in the main ice sheet strata were observed. These were primarily large bacteria morphologically similar to caulo-bacteria and budding forms (Fig. Annex 14).

In all horizons unicellular micro-algae predominantly diatoms were observed in large or smaller numbers. Most of micro-algae encountered in basal horizons were similar to those revealed in the main ice sheet strata. In addition, in the upper part of the zone, fragments of silicic skeletons of diatom algae were found (Fig. Annex 15).

3.7. Viability of bacterial cells

Studies of viability of bacterial cells that were in the frozen state for tens of thousands of years were carried out using the material obtained from different horizons of the ice strata of Antarctica between 708 m to 2974 m. The analysis of the results has revealed that the temperature factor has a great influence on the breeding activity of bacterial cells that have preserved viability at their further incubation; it was found that a greater increase in the numbers of bacteria activated after anabiosis occurs at a temperature of 20, 25 and 28 °C compared to a temperature of 15 °C. The results indicate that mesophyllous forms prevail among the bacteria that have preserved viability.

Microorganisms introduced to the glacial strata horizons both with atmospheric precipitation and freezing of lake water were conserved for tens and hundreds of thousand years. Part of them has preserved not only the integrity of cells but also viability due to transition to the dormant state. Penetration of microorganisms from the lower layers of the ice sheet to the zone of accreted ice with melt water was not favorable for all microbes. The processes of watering of living cells contributed to their awakening from anabiosis and set the problem of choosing the strategy for further existence. Far from all were capable to survive under the new specific conditions that were often accompanied with a periodic change of the liquid and solid water state. This is indicated by the presence of a much greater number of cells with a weak or almost absent fluorescence after their staining with fluorescamine. The loss of brightness of fluorescence is predominantly related to the decrease of the quantity of proteinaceous substance in them. While in the main glacial strata horizons bacteria with a weak fluorescence comprised approximately 40–50%, in the zone of accreted ice, their quantity increased to 70–80% and even more in some horizons. Among the prokaryote forms with a weak fluorescence in the zone of lake ice, there were some cocci and rods, some cells of cyanobacteria and representatives of the Genus Cytophaga, among the eukaryote forms – yeast cells and hyphae of fungi. In most cells morphologically similar to cyanobacteria, their own red fluorescence typical of them was absent. To check the assumption about the preservation of viability by bacteria, the samples in the ice sheet zone under study from horizons of 3541 m, 3544 m and 3576 m in the form of melt water were placed to a thermostat. Periodical determination of the numbers of bacterial cells has revealed that in two days after cultivating at 28 °C, the concentration of cells in the sample from a horizon of 3541 m increases two-fold compared to the initial one and in 5 days four-fold, which is shown in Table 3.4.6.1.

Table 3.4.6.1 – The increase of the numbers of cells of microorganisms after incubation of melt water samples

Horizon, m	**Temperature, °C**	**Number of cells in 1 ml of melt water**			
		Initial	**1 day**	**3 days**	**5 days**
3541	28	200	450	740	900
3544	20	300	5000	2900	–
3576	20	280	3200	5200	–

At the incubation of samples from horizons of 3544 m and 3576 m at lower temperature (20 °C), the numbers of microbial cells grow more actively increasing by the third day of cultivating 10-20-fold. The data obtained indicate that viable cells of microorganisms are present in this zone.

3.8. Molecular-biological studies of microbial diversity in Lake Vostok accretion ice

The molecular biology study of microbial contents of the Lake Vostok accretion ice (originating from lake water: type I – shallow depth bay and type II – open water) was conducted in the Petersburg Institute of Nuclear Physics (PNPI, St Petersburg, RAS). Because of very low DNA contents revealed in a preliminary trial the PCR-based (Polymerase Chain Reaction) methods were correspondingly advanced to detect 2–8 cells in 1 ml of melt water by using semi-nested PCR schemes and broad-range (16–17 of more than 20 bacterial divisions) updated degenerate primers for representatives of three Kingdoms of Life – Prokaryote, Archaea and Eukaryote (only Fungi). The target for PCR was V3 variable region of bacterial and archaeal 16S rDNA and ITS region of fungal nuclear rDNA. For example, the new bacterial primers allow us to match most of known bacteria.

A molecular biological analysis of lake ice I (samples from the 3546, 3571 and 3604 m depths) has revealed absence of the known representatives of cyanobacteria (the most ancient of Kingdom of Bacteria), archaea and fungi. For fungi, the same result was obtained during the study of one sample of lake ice type II (3619 m). However, under the special ("non-specific") conditions of PCR with "archaeal" and "fungal" primers, the DNA of unknown origin was discovered in some samples. One sample of such a DNA (3571 m) has shown a distant relation to the known sulfite-reductases of bacterial origin whereas up to now we cannot identify the other DNA clones (3604 m).

Detailed studies were made on the samples of lake ice I from 3551 and 3607 m depths. To make the findings confident 6 databases of potential contaminants were established. As a result, the overwhelming majority of the bacteria found in these samples were recognized as contaminants. Only three bacteria (their fragmented 15000 years-old DNA), all from 3607 m sample, have passed all controls and can be considered as true representatives of Lake Vostok microbiota. All these bacteria (three different species) proved to be related to chemolithoautotrophs and mesothermophiles, whose representatives were found in hydrothermal vent areas and fields in oceans and continents at temperatures up to 40–60 °C (Fig. 5). The first species (Hydrogenophilus thermoluteolus) represents microorganisms discovered in hot springs

(Japan, Izu district and USA, Yellowstone) and deep mines (Japan) and capable to oxidize hydrogen in the presence of carbon dioxide as a source of carbon. The second species is related to thiosulfate-oxidizing hydrothermal vent strains isolated from the Galapagos hydrothermal system. The third species is related to uncultured bacterial strains of OP11 division isolated from deep-sea (2 km) sediments of the hydrothermal Guaymas basin (Gulf of California, Mexico) which contains sulfides-sulfates and methane in anaerobic and organic carbon rich environment and from deep-sea (4 km) sediments of the Izu-Bonin trench (Japan Islands).

Based on the results, we suggest that Lake Vostok microbiota is probably concentrated in its bottom sediments especially in the area of deep crust faults where water can be heated geothermally and be realizing through cracks into the open lake (frazil ice) due to weak episodic seismotectonic events. Rare bacterial findings in lake ice can be explained by both possible DNA (cells especially) degradation in the oxygen saturated lake water (as supposed now) and low probability for life in open lake due to high oxygen tension which is known to be toxic in general.

The microbiological (microscopy) studies of lake ice were conducted at the Institute of Microbiology (INMI, Moscow, RAS) using ice core samples retrieved from 3541–3611 m depths. It was shown that microorganisms – representatives of both Prokaryotes and Eukaryotes, are present in all samples. Their numbers and morphological diversity were non-uniform at different horizons and correlated to some extent with the presence different ice-entrapped organic and inorganic impurities. Part of observed biological objects including bacteria, micro-algae and pollen of higher plants were morphologically similar to the objects earlier detected in the main ice sheet strata while others were detected for the first time.

In the INMI special experiments using radio-isotopic labels and incubation at 15–28 °C were also conducted to find in the lake ice viable cells. As a result, such cells were revealed in several samples which disagree with molecular biology results mentioned above. The same was shown by epifluorescent microscopy – viable cells were counted up to 30–40%, however, their amount was lower in lake ice as compared to glacial ice sheet. A higher lake water temperature and alternating melting-freezing processes may not contribute to good preservation of glacier-released cells. To prove the data obtained new ice core samples for microscopy will be decontaminated and treated in special super-clean conditions worked out for molecular biology studies.

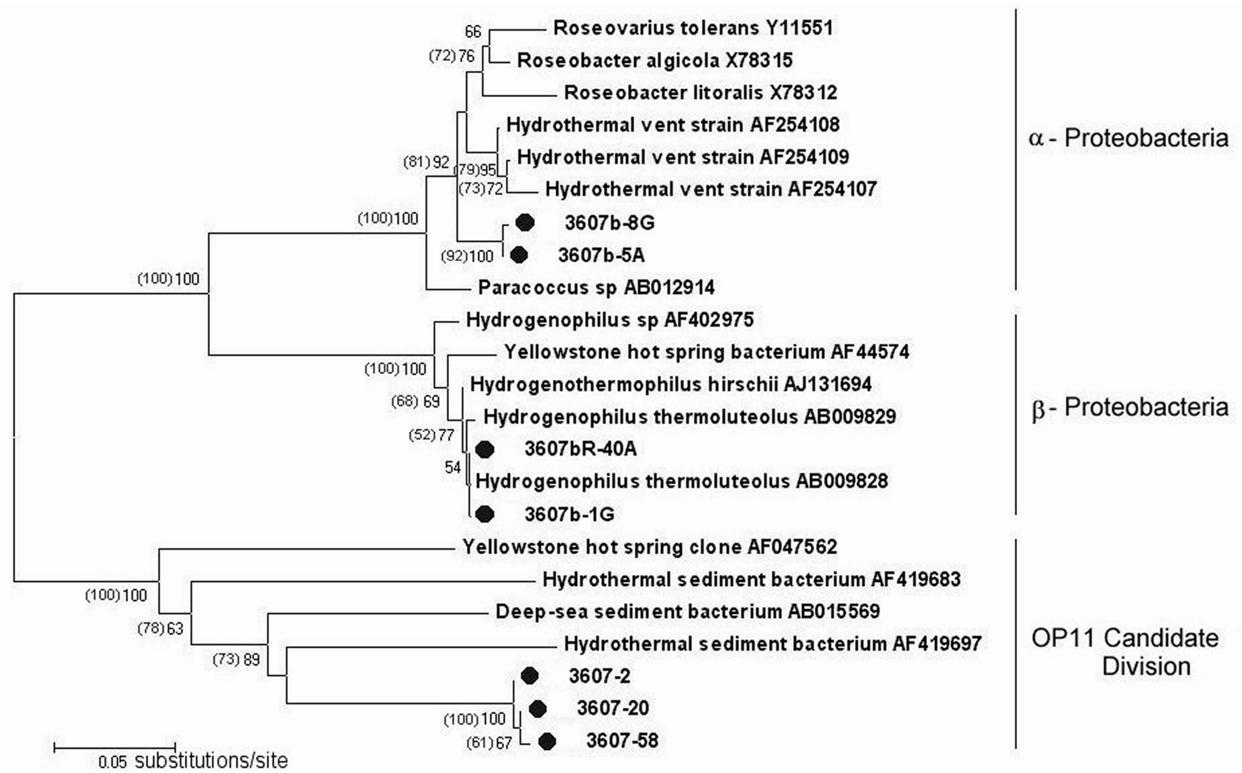

Figure 5 Phylogenetic analysis of the clones from the Lake Vostok ice core sample from a depth of 3607 m

3.9. Biota in the activity area

Due to the absence of necessary conditions to support inland life and a significant remoteness from a shore, there are no native animals and plants at the Vostok station area. However, microorganisms (bacteria and fungi) which are ubiquitous are present for sure due to their stratospheric transfer with atmospheric masses and human activity (transport vehicles etc.).

3.10. Bacterial diversity of the Vostok borehole drilling fluid

As shown above, the chemical composition of the drilling fluid of borehole 5G-2 presents a complex mixture of different types of aviation kerosene (TC-1, JET-A etc.) (saturated hydrocarbons with a chain length of more than 10) and freons (4 and 141B) at the ratio 5:1. The aviation kerosene can also contain branched and aromatic hydrocarbons. Many different bacteria are known to degrade or decompose kerosene and oil products (Tables 3.4.8.1–3.4.8.3).

Given the low temperatures of the environment and a long-term history of the real mixture formation in the borehole, such a mixture cannot be simulated under laboratory conditions. Thus, the investigation of microbial diversity of the drilling fluid collected from different borehole horizons (in a range of 110 m to 3600 m) presents a unique study of the environment.

The molecular biological analysis of the original Vostok drilling fluid (4 samples from depths of 110 m, 2750 m, 3400 m and 3600 m) has revealed the following.

Based on the analysis of 33 clones from ribDNA library eight bacteria in total were identified. It is noteworthy the drilling fluid from different horizons contained different bacteria. Even the samples from adjusted horizons (3400 m and 3600 m) were differing by species contents.

At present, the data obtained indicate that the Vostok drilling fluid contains 4 major bacterial species:

- In the upper horizon of glacial ice (110 m) – unknown (80–81% homology) representative of *Desulfobacteracea* (delta-Proteobacteria) which capable to oxidize sulfates and decompose benzenes contained in oil and its products. An evaluation titre of these bacteria in the sample comprises more than 4.7×10^{3} cells per ml.
- In the lower horizon of glacial ice (3400 m) – *Sphingomonas natatoria* (alpha-Proteobacteria) which can degrade kerosene. The evaluation titre of these bacteria in the sample comprises more than 1.0×10^{4} cells per ml.
- In the lake ice horizon (3600 m) – two species, one presents a closely related species of *S. aurantiaca* group (alpha-Proteobacteria) which can degrade kerosene while the second is closely related to a human pathogen *Haloanella gallinarum* (CFB group of bacteria). The evaluation titre of these bacteria in the sample comprises more than 2.7×10^{3} cells per ml and more than 5.4×10^{3} cells per ml, respectively.

In addition, 4 more bacteria (as single clones) were detected in the samples. They represent human pathogens and saprophytes (for example, Staphylococcus cohnii of gram-positive bacteria and a clone related to Haemophilus influenzae of gamma-Proteobacteria) as well as soil-born bacteria (rhizosphere of agricultural plants and timber-destructors). The presence of these bacteria is complicated to explain and is now considered as a random contamination of the drilling fluid itself upon its sampling from a borehole or processing for DNA extraction.

In general, of 4 major bacteria detected in the drilling fluid, only three can be involved in kerosene degradation (refer to Tables 3.4.8.1–3.4.8.3). The fourth microbe – a human pathogen, should be considered as a kerosene contaminant by human.

Table 3.4.8.1 – Bacteria degrading "kerosene" in soil

Division	Organism
Alpha-Proteobacteria	Sphingomonas sp.
Beta-Proteobacteria	Alcaligenes spp
Gamma-Proteobacteria	Pseudomonas sp Stenotrophomonas maltophilia + fungus (Penicillium janthinellum)
Firmicutes (Actinobacteria)	Mycobacterium sp Rhodococcus erythropolis (R. spp) (Nocardiaceae)
Firmicutes (Bacillales)	Paenibacillus spp

Table 3.4.8.2 – Bacteria degrading "kerosene" in freshwater and sediments

Division	Organism
Beta-Proteobacteria	Azoarcus sp (Rhodocyclus group)
Delta-Proteobacteria	Syntrophus spp+ archaeon (Methanosaeta spp – Euryarchaeota)
WS1-WS6 divisions	10 of 94 (11%) sequence types
OP5, OP8, OP10, and OP11 divisions	21/94 (22%)
10-well recognized divisions	63/94 (67%)

Table 3.4.8.3 – Bacteria degrading "kerosene" in seawater and sediments

Division	Organism
Alpha-Proteobacteria	Lutibacterium anuloederans (Sphingomonadaceae)
Beta-Proteobacteria	Unidentified
Gamma-Proteobacteria	Cycloclasticus spirillensus (C.sp) Vibrio, Pseudoalteromonas, Halomonas Marinomonas and Neptunomonas naphthovorans (Oceanosprillium)
Delta-Proteobacteria	Desulfosarcina, Desulfonema, Desulfococcus
Firmicutes (Actinobacteria)	Rhodococcus spp (Nocardiaceae)
Firmicutes (Bacillales)	Paenibacillus naphthalenovorans (P. spp)
Cytophaga-Flavobacterium- Bacteriodes	Unidentified
Green non-sulfur bacteria	Unidentified
Holophaga-Geothrix-Acidobacterium	Unidentified

3.11. Anthropogenic load on the environment of the area

A long-term existence and operation of the station has obviously introduced some changes to the wilderness of the environment of this Antarctic area. The greatest changes were introduced to the relief and structure of the glacial surface over an area of around 0.4 km2 within which the station structures are located. Appearance of these structures and the support of life activity of the expeditions have resulted in the natural redistribution of snow (formation of snowdrifts) and snow withdrawal to obtain water. As a result of the annual clearing of snowdrifts using bulldozers, the Vostok station is located now in a trough of artificial origin with a depth of about 3 m.

Due to DES operation, galley, use of transport vehicles, residence of investigators, appearance of waste, etc., the station obviously has its own microclimate and microbiota. However, due to severity of natural conditions, their spreading is restricted to living, auxiliary and research structures and the sites of waste disposal.

Beginning from 1970, drilling and ice core sampling from deep boreholes is made at Vostok station. During this time, 5 main boreholes with a diameter of 15-18 m and a depth of 500 to 3623 m were drilled. The presence of the boreholes changes the ice sheet structure at the drilling points. In order to prevent closure of the boreholes under the action of overburden ice pressure, they were filled with a non-freezing drilling fluid comprised of a stable mixture of aviation kerosene TS-1 and Freon in the proportion 1:5 (from 1995, less dangerous and permitted Freon 141b is used). After the end of drilling operations, the boreholes were decommissioned, but the drilling fluid was not extracted from them. In general, the total volume of the drilling fluid conserved in the boreholes comprises about 140 m3.

4. Analysis of the environmental impact

4.1. Identification of impact sources

In order to analyze the environmental impact of the Project for penetrating the subglacial Lake Vostok, it is necessary to identify the impact sources among the types of activity used by the impact agents characterizing them and assess the significance of impact on the environment of the areas of activity (impact).

4.1.1. Impact agents

An impact agent presents an object, product or result intrinsic to man activity, which interacts with the environmental objects (components, values).

The main agents of anthropogenic impact are typically subdivided into physical (causing visual, thermal, electromagnetic, mechanical and other physical change of different media); chemical (connected with pollution of different media by fuel, chemical substances, domestic and production waste and life activity products); and biological (connected with incorporation of alien flora and fauna and microbes by man resulting in the increased mortality in the local populations and the disturbance of the existing natural structure and webs in the ecosystems).

The environmental impact agents include:

- Atmospheric emissions (gases emitted to the atmosphere, including exhaust gases, aerosols, dust, etc.);
- Waste (introduced to the environment – waste water, technological and food wastes, garbage);
- Fuel (including other liquid hydrocarbons used for non-scientific purpose – result of refueling of transport vehicles, etc.);
- Chemicals (chemical substances including drilling fluids introduced ton the environment);
- Representatives of non-native flora and fauna (introduced to the environment as a result of activity)* if such are present;
- Microorganisms (introduced to the environment as a result of activity);
- Noise (noise from activity – running engines, equipment, human voices, etc. propagating to the environment);
- Type (making a visual impact on animals and the aesthetic values of landscape, etc.)*;
- Mechanical disturbance (physical interaction with the environment inherent to the activity – as a result of movement of transportation vehicles, equipment and man in the environment);
- Heat (heat from power plant generators, transport, heaters, etc. dissipated to the environment as a result of activity);
- Electromagnetic emission (electromagnetic emission from powerful generators, antennas, etc. dissipated to the environment as a result of activity)*;
- Light (light emission from powerful searchlights, lighters dissipated to the environment as a result of activity)*.

*) Note. Environmental impact agents marked by * are not taken into account in further EIA analysis as they do not interact with the environmental compartments under consideration (components and values).

4.1.2. Types of activity

All types of activity used in the Project can be subdivided into two groups:

A. Project support operations (on the ice sheet surface)

Airborne transport operations

Ground-based transport operations

Activity at the station

Drilling unit operation maintenance

B. Penetration to the lake (inside the glacial strata)

Drilling of glacial strata

Contact with the lake surface

4.1.3. Areas of the activity (impact)

Identification of the areas of activity (impact) as NRA, RA or CIA is performed on the basis of the current environmental state descriptions presented in sections 2, 3

It is noted that for a subsequent determination of the impact significance, it is necessary to take into account the current environmental state of the area of activity (impact), i.e., to determine whether the activity is undertaken in the station area – non-recoverable area (NRA), or in a remote area of field studies or logistics operations – recoverable (partly) areas (RA) or in the intact territories (in this case, inside the ice sheet) of Antarctica – conventionally intact areas (CIA).

It is obvious that a similar impact of one and the same activity cannot inflict significant damage to the environment in the NRA (for example, in the station territory where the environmental components have been already irreversibly changed) and irreparable damage in the intact virgin area.

A specific feature of this Project is conduct of work on the glacial surface in the NRA (Vostok station) with penetration to the intact environment of the subglacial lake (CIA) that has a different ecosystem and a special environment. That is why the main aim of the Project of penetration is to ensure a minimum risk of producing an impact on the lake and its ecosystem.

Thus, the areas of activity (impact) can be unambiguously divided into the:

surface areas of logistics operations – NRA: Vostok station, “Mirny–Vostok” route (no deviations of the traffic from the route and any operations related to this Project are planned; and

site of the proposed borehole run from the existing bottom to the “ice-water” divide inside the virgin glacial massif – CIA.

For the analysis of the environmental impact of activities, methods employed earlier for the EIA both in the Antarctic and the Arctic were used, in particular, a matrix evaluation method. The matrices are presented below in the form of Tables 4.1.1–2 on two groups of the types of activity used in the Project of penetration to the lake.

Table 4.1.1 – Logistics operations (operations at the surface)

Impact agent / Activity Type	Atmospheric emissions	Wastes	Fuel	Chemicals	Microbes	Noise	Mechanical disturbance	Heat	Activity (impact) area
Airborne operations	×	–	–	–	–	×	–	×	Vostok station area (NRA)
Ground-based vehicle operations	×	×	–	–	×	×	×	×	Vostok station area (NRA) and “Mirny-Vostok” route area (RA)
Activity at the station	×	×	×	–	×	×	×	×	Vostok station area (NRA)
Drilling unit operation maintenance	×	–	–	×	–	×	–	×	Vostok station area (NRA)

Table 4.1.2 – Penetration to the lake (operations inside the glacial strata)

Impact agent / **Activity Type**	**Drilling fluid**	**Microbes**	**Noise**	**Mechanical disturbance**	**Heat**	**Activity (impact) area**
Glacial strata drilling	×	×	–	×	×	Borehole 5G-1 and a restricted ice massif surrounding it
Contact with the lake surface	×	×	–	×	×	A restricted lake surface area at the “ice – water” boundary

The cross in the table cell (×) denotes that the *type of activity* under consideration is identified as an *impact source*, i.e. it has an inherent corresponding *impact agent* on the environment of the *area of activity (impact)*. It is important to note that one *type of activity* may have several *impact agents*. Thus, one and the same *impact agent* can be inherent to different *types of activity*, which is necessary to take into account during the subsequent determination of the *impact significance* in case of coincidence of one and the same *area of activity (impact)*.

As can be seen from the tables, most types of activity do not produce the presented *impact agents*, i.e. they are not the *impact sources* and do not participate in further analysis.

As can be seen from the Tables, all types of activity have the impact agents under the consideration, which identifies tem as the environmental impact of the corresponding areas of activity (impact).

4.2. Analysis of significance of the anticipated environmental impact

The analysis of determining the *impact significance* from performing the types of activity identified as the *impact sources* was also performed using a matrix method.

The cross in the cells of matrices presented below in the form of Tables 4.2.1–5 denotes those *impact objects* (environmental components, environmental and scientific values) that are subjected to the corresponding *(impact) agent* from the corresponding *impact source* (type of activity). The cross absence indicates that the *impact agent* under consideration does not have any influence on the *impact object*.

The impact significance is determined given the environmental state of the area of activity, which is mainly defined as a *non-recoverable area (NRA)*. The assessment criterion is “a minor or transitory impact”.

Table 4.2.1 – Airborne operations (NRA, RA)

Impact agent / Impacted Object	Atmospheric emissions	Noise	Heat	Impact significance
Air	×	–	×	Less than a minor or transitory
Snow	×	–	–	Less than a minor or transitory
Ice	–	–	–	NO Impacts

Table 4.2.2 – Ground-based vehicle operations (NRA)

Impact agent / Impacted Object	Atmospheric emissions	Fuel	Noise	Mechanical disturbance	Heat	Impact significance
Air	×	–	–	–	×	Less than a minor or transitory
Snow	×	×	–	×	×	Less than a minor or transitory
Ice	–	–	–	–	–	NO Impacts

Table 4.2.3 – Activity at the station (NRA)

Impact agent / Impacted Object	Atmospheric emissions	Waste	Fuel	Microbes	Noise	Mechanical disturbance	Heat	Impact significance
Air	×	-	-	×	–	–	×	Impact from the activity at the station is within the existing impact scale and is not beyond the limits of the present changes of environmental parameters of NRA
Snow	×	×	×	×	–	×	×	
Ice	–	–	×	–	–	×	–	

Table 4.2.4 – Drilling unit operation maintenance (NRA)

Impact agent / Impacted Object	Atmospheric emissions	Waste	Fuel	Microbes	Noise	Mechanical disturbance	Heat	Impact significance
Air	×	–	–	–	–	–	×	Less than a minor or transitory
Snow	–	–	–	–	–	–	–	NO Impacts
Ice	–	–	–	–	–	–	–	NO Impacts

Table 4.2.5 – Glacial strata drilling (CIA)

Impact agent / Impacted Object	Drilling fluid	Microbes	Mechanical disturbance	Heat	Impact significance
Ice microbiota	–	× (–)	–	–	Less than a minor or transitory
Ice chemistry	–	–	–	–	NO Impacts
Ice structure	–	–	×	–	Less than a minor or transitory
Lake water	–	–	–	–	NO Impacts

Table 4.2.6 – Contact with the lake surface (CIA)

Impact agent / Impacted Object	Drilling fluid	Microbes	Mechanical disturbance	Heat	Impact significance
Water and ice microbiota in the contact zone	–	–	–	–	NO Impacts
Water and ice chemistry in the contact zone	× (–)	–	–	–	Less than a minor or transitory
Lake ice surface	–	–	–	–	NO Impacts
Lake water	–	–	–	–	NO Impacts
Lake bottom	–	–	–	–	NO Impacts

4.3. Anticipated impact on environmental compartments

4.3.1. Direct impact and contamination risks

The following risks appear during drilling operations: 1) loss of the drilling equipment in the borehole; 2) penetration of the drilling fluid to the lake.

Impact: influence of the drilling fluid on the environment. The drilling technology of a deep borehole 5G envisages application of the drilling fluid consisting of the aviation fuel TS-1 and Freon 141b as heaver. The greatest danger for the environment is related to Freon losses as a more volatile and active substance.

Freon 141b is delivered to the station in sealed drums and its losses during transportation and storage are practically excluded. The technological losses in the process of drilling can be divided into two portions: evaporation of the drilling fluid from the surface in the borehole and fluid, which is carried to the surface in the process of round-trip operations.

The technological process and the design of the borehole 5G ensure a minimum loss of the drilling fluid including Freon). The upper part of the borehole passing through the snow-firn zone is overlapped by the plastic casing excluding any losses of the drilling fluid in it. The lower (200–300 m above the bottom) and the upper (200 m) segments of the borehole are filled with the drilling fluid with a relatively low level of Freon. The fluid density on these segments is not greater than 900 kg/m^3. Freon and kerosene are added separately to the borehole. Pure Freon is delivered to the borehole to the chosen horizons by a special device while kerosene is poured from the surface contributing to a decreased Freon concentration at the drilling fluid surface. At the beginning of the drill run, the drill is filed at the surface by a practically pure kerosene, which is delivered to the bottom as the design of the drill does not allow the fluid circulate over it in the process of round trip operations.

At the drill recovery, the carrying cable extracts about 40 liters of the drilling fluid from the hole, whose density corresponds to an average density of the drilling fluid in the upper 100 m in the borehole. Together with cuttings, around 35 liters of fluid is extracted from the near-bottom zone in the sludge trap. The fluid flowing from the cable and the drill is collected to trays from which it is again poured to the borehole.

To assess the losses of the drilling fluid during the season of the 43d RAE, the drilling group has carried out a complex of geophysical observations including regular measurements of the density of the fluid extracted from the borehole and fluid depth, fluid sampling from different horizons and temperature measurements along the entire borehole drilled.

The fluid extracted from the borehole with the carrying cable and in the drill remains in the open containers at the drilling site for about an hour. After that at the beginning of the next run it is poured to the hole with the descent of the drill. At first, the fluid has a temperature of about −40 °C and then at pouring to the hole about −20 °C. Over 10 hours the fluid density decreased by around 10 kg/m^3. It is obvious that with increasing temperature Freon will evaporate more quickly from the fluid. Assuming that Freon evaporates uniformly with time, we obtain that approximately 0.2 kg can evaporate from 80 liters of the drilling fluid.

Then the total irrevocable losses of the drilling fluid during a run (round trip operations) will be about five liters, or 1 kg of Freon 141b. Given the losses due to evaporation from the extracted drilling fluid, we have 1.2 kg of Freon per run.

Impact: change of the glacial structure along the borehole 5G-2 below a depth of 3650 m. At continued drilling from the bottom of borehole 5G-2 to the lake surface in the basal glacial horizons, the drill will run additional 100 m. The total volume of the extracted ice cores for investigation (at their diameter of 105 mm) will be around 1.2 m^3. At the end of drilling in newly formed ice of lake water (see section 2.2), it is possible to apply two methods for prevention of lake contamination: 1) penetrate the lake again and make lake water rise in the borehole by 20–30 m: 2) stop re-drilling in several meters from the “ice–lake water” boundary. In the former case, upon terminating all work in the borehole the drilling fluid will be in depths between 3650 to about 3725 m, while the borehole length remaining to the boundary with the lake surface will be obstructed by ice formed of the frozen lake water. In the second case, there will be several meters of newly formed between the drilling fluid column and the lake surface.

Impact: disturbance of the natural “glacial base-lake surface” boundary at the borehole drilling point. At penetrating the lake, water will rush upward the borehole 5G (see section 2.2). The height and the volume of water introduced to the borehole will depend on the given undercompensation pressure of the drilling fluid (for example, 20 m at undercompensation of 2 bars). It is obvious that extraction of about 1.5 m^3 of water from the subglacial lake with a depth of hundreds of meters and an area of more than 10000 km^2 will not influence the change of thermodynamic conditions of the equilibrium state of the “ice sheet–subglacial lake” system, i.e., it will not change the depth of the “ice–water” boundary and the course of the accretion processes at this boundary.

At the moment of penetrating the lake and water rushing upward in the borehole, an increased water flow in the subsurface lake layer will also occur. Given small water volumes extracted from the lake, this impact will be very short (probably, minutes) and of a local character (real influence over a distance of about 10–20 m) and should not change the pattern of natural circulation of lake water.

Contamination risk: loss of the drilling equipment in the borehole. In the process of borehole drilling by a mechanical or thermal methods, emergency situations are possible. Their causes can be divided into two main types: technological and technical. The main technological causes include the disturbance of the borehole sides and of the drilling process. The technical causes include equipment failures (both on the surface and in the borehole).

In case the drill is stuck, the minimum loss is to leave the drill in the borehole. Then the borehole is deflected from the drill that has failed and drilling is continued. This can be, however, achieved if the possibility of cutting the carrying cable directly at the place of its fixation in the drill is envisaged or if there is a safety element in the upper part of the drill, which is destroyed at a specific cable tension force. Otherwise, there is a large probability of the cable tearing off near the surface at deflecting roller or the winch drum. At such tearing off of the carrying cable, the hole is lost completely.

Contamination risk: Drilling fluid penetration to the lake. As shown above, the probability of the drilling fluid penetration directly to the lake (upper water layer) is quite small. If this still occurs, then kerosene will bring (to the surface lake layer) about 10^3–10^4 of cells of at least two main species of bacteria found in the lake ice horizon (kerosene-degrading *Sphingomonas aurantiaca* and a human pathogen *Haloanella gallinarum*) for each milliliter of the fluid. Both bacteria are heterotrophic.

Three indirect evidences (from data of lake ice study) indicate the absence of plankton bacteria in the upper freshwater lake layer:

- Molecular-biological studies (rDNA amplification) have not still revealed any bacteria that can be unambiguously attributed to lake water;
- Very low values of dissolved organic carbon (DOC less than 20ppb C) are insufficient to support the growth of heterotrophic bacteria;
- High existence of oxyphyle (at a high oxygen pressure) autotrophic forms of bacteria unknown to science cannot be denied.

In case of the drilling fluid penetration to the lake, the following events are presented for the revealed “kerosene” bacteria and “biota” of the lake:

- The drilling fluid (kerosene proper) will oxidize completely for a short time;

- “Kerosene” bacteria will be inactivated by the lake conditions (oxygen excess, no organic matter) and “burn” shortly.

Thus, a less than a minor and transitory impact of the drilling fluid and bacteria it contains on the biota of the upper water layer of the lake is expected on condition of an insignificant (relative to the lake water volume) amount of this fluid penetrating the lake.

4.3.2. Possible indirect impact

Environmental impact during the logistics supply of the proposed activity. To implement the proposed activity will require logistics support, i.e. it will cause some increase of anthropogenic impact on the Vostok station area. This impact will be produced for several Antarctic summer seasons when a 4–6 people glaciological-drilling team will stay and work at the station. Since it is planned to use the Vostok station during these years as a logistics base for conducting other research studies, this activity will produce only an additional and in general insignificant environmental impact. The impact components will be addressing the life support issues of the glaciological-drilling team: supply with the food products, extraction and melting of snow for water supply, supply and consumption of additional diesel fuel, running diesels for power supply of the living premises and the drilling installation and appearance o additional life activity waste. It is noted that all aforementioned environmental impact factors are within the usual level of operations for life support at Vostok station.

Impact on the environment of the results of the proposed activity after its termination. After completing all planned operations (borehole 5G-2 drilling, lake penetration, repeated drilling of ice formed of lake water), the borehole 5G-2 will be suspended. The extraction of the drilling fluid from the borehole does not appear advisable in terms of ecology due to the following considerations: 1) This is about 60 t of stable mixture (containing Freon) that is difficult to divide into components for re-use; 2) Transportation of this mixture from the station will require shipment and subsequent consumption of a large quantity of fuel being in itself quite long and complicated; 3) Environmentally safe storage of such quantity on the surface in the station area is now practically impossible.

So, at the present time, storage of the drilling fluid in the borehole itself is most safe for the environment. Theoretically, it is possible to remove most of the drilling fluid by its partial pumping from the first upper hundred meters of the borehole. Due to undercompensation of the overburden pressure there will be narrowing of the deeper part of the borehole and the drilling fluid will be squeezed upwards up to the level of overburden pressure compensation. Data were obtained in practice that at the undercompensation of the fluid column in 100 m, narrowing of the borehole in the deeper ice sheet layers will occur with a rate of 2 mm a year. That is, at maintaining such undercompensation, the lower ice layers of the borehole will merge in 70 years. This physical phenomenon can be used in the future for extracting the drilling fluid from the deep layers of the borehole.

4.3.3. Cumulative impact

Continuation of drilling of the borehole 5G-2 and penetration to Lake Vostok with sampling will impact all environmental compartments at Vostok station: the atmosphere, microclimate and surface relief of the area, glacial strata and, probably, the subglacial lake surface (see sections 3.1 and 3.2). However, this impact will be insignificant and if compared with other options for achieving the proposed scientific objective – minimum.

The contamination risks of continued drilling of borehole (a brief exit to the lake of equipment or penetration of the drilling fluid) will accompany by all means any other variant of accessing the lake by drilling. To exclude the risk of the drilling fluid leak to Lake Vostok is possible only by using the robotic technology (cryobot and hydrobot) [12]. On the other hand, this technology of penetrating the lake envisages leaving the cryobot and the hydrobot in the lake, i.e. there is not even a risk, but a direct non-exclusive and long-term impact on the lake ecology.

The activity at Vostok station will be carried out in the area, which belongs to the category of *non-recoverable area (NRA).* The logistics operations related to continuation of activity in the borehole will be only part of the anthropogenic load on the Vostok station area during the periods of seasonal activity. It is obvious that in case of using the borehole, drilling equipment of the station and the existing life support conditions here, the total environmental impact of the proposed activity will be much less compared to drilling a new borehole in the station area and the subglacial Lake Vostok.

The scales and general duration of the total environmental impact of the proposed activity are determined not only by the specific measures planned but also by the peculiarities of natural conditions of the Vostok station area. As can be seen from section 1.1, the distinguishing features of these conditions are the absence of water in the liquid phase at the surface and in the glacial strata, which reduces significantly the intensity and the extent of the area of man influence on the territories adjoining the station. In fact given the severe conditions and the ice flow rates the impact made will be restricted to the station area at the surface and to the borehole in the glacial strata for the nearest hundreds of years. In addition, considering the ice flow features and a tendency for ice accretion at the bottom glacial surface, it can be assumed that the results of the proposed activity (borehole, drilling fluid) will not impact the ecology of Lake Vostok. Moreover, the main part of the borehole with the drilling fluid will be offset beyond the lake boundaries.

4.4. Anticipated impact on the aesthetic and wilderness values of the environment

Drilling and ice core recovery from the borehole 5G-2 has changed the vertical ice sheet structure at the borehole location. At suspending the borehole, its impact will be restricted to the drilling fluid influence on the ice sides of the hole. During a long period of time, the location of the area of this impact will change. Part of the borehole with the drilling fluid (up to a depth of about 3500 m) will be offset in the southeastern direction exiting the boundaries of the subglacial Lake Vostok in 2000 years. Part of the borehole with the drilling fluid (3500–3650 m depths) will probably remain above the lake for several tens of thousand years.

4.5. Anticipated impact on the areas of scientific, historic and cultural significance

The presence of the borehole 5G-2 in the glacial strata disturbing the natural ice structure will not allow the repeated drilling of the ice strata in order to obtain ice cores or enter Lake Vostok at a distance of 100 m from the borehole head.

The ice core extracted from borehole 5G-2 is of unique value for paleoclimatic reconstructions both for the given Antarctic region and on a global scale. In accordance with the existing rules, this ice core after sampling is subdivided into several segments that are studied in many laboratories of the world. It is important that some part of the ice core remains as a reference collection in the core storage at Vostok station. Thus, future studies of the ice sheet characteristics in the Vostok station area will not require drilling a new borehole with core sampling, i.e., the influence of the existing borehole 5G-2 on future glaciological activities in the vicinity of the Vostok station will be practically zero.

4.6. Unavoidable impact at continuation of drilling the borehole 5G-2 and penetration to Lake Vostok

Conduct of the proposed activity will inevitably have the following environmental impacts:

- change of the ice sheet structure at the drilling point of the existing borehole 5G-2 from a depth of 3650 m and to the lake surface (a total of about 100 m);
- short-term exposure of the natural “ice base–lake surface” boundary with its subsequent formation at lake water freezing in the borehole 5G-2;
- extraction from the surface lake layer beneath the borehole 5G-2 of about 1.5 m^3 of water for its sampling in the form of ice cores;

- retrieval to the surface and evaporation to the atmosphere of about 60 kg of Freon 141b during drilling operations;
- total impact on the Vostok station area due to the delivery here, living and work of 4–6 specialists for several summer Antarctic seasons as well as to the delivery to the station of an insignificant quantity of drilling equipment components.

4.7. Risk of the impact of lake microorganisms on the human health and the environment

Referring to the problem of a possible ecological danger of exposing the relict Lake Vostok to present-day life on Earth, it is noted that:

First, the lake water sample collected in the form of an ice core will be in the hands and under control of competent investigators.

Second, according to the calculation data of the Project authors, a prolonged contact of the lake surface with the borehole is excluded due to the ice plug at the borehole bottom.

4.8. Proposals for mitigating the environmental impact

In the framework of the Project of penetrating to the subglacial lake, two components of one complex of measures to ensure the ecological safety of drilling operations should be subjected to a careful analysis:

- technological component determined by application of different drilling fluids and use of mechanical and thermal drilling methods;
- engineering components determined by design parameters of the drilling equipment applied.

Technological measures. Before the direct access to the lake, an intermediate buffer fluid layer is created that should mitigate a possible risk of lake contamination. The main measure of a technological character excluding the possibility of the drilling fluid penetrating the lake is to create the drilling fluid pressure in the near-bottom zone of the borehole smaller than the water pressure in the lake. This is possible only by providing a sufficiently high accuracy of measurement of the drilling fluid pressure in the borehole. As estimated by the Project authors, the accuracy of pressure measurements at present is not less than ±0.9 bars. To increase the accuracy of measurement of the drilling fluid is the most important reserve in ensuring ecological safety of operations.

Engineering measures. The design parameters of the thermal drill to be used at the second stage of lake access allow us to exclude the drill exit to lake water and penetration of the drilling fluid from the borehole to the lake.

Upon reaching the lake surface, it is proposed to create the conditions for lake water incorporation to the hole after which the drilling operations are stopped until the complete lake water freezing in the borehole. Then, ice sampling from lake water by the electromechanical drill KEMS-132 will be carried out.

Part of ice near the boundary with the lake will not be drilled in order to ensure the isolation of the borehole from the lake and to prevent possible adverse environmental consequences. This fact is a very important aspect in the studies planned and this variant is the most preferable.

To ensure a guaranteed ecological purity of Project implementation, it is desirable to make a preliminary check of the developed technologies and drilling equipment before penetrating Lake Vostok under the field conditions to exclude possible failures.

The main source of Freon losses in the process of drilling and lowering-recovery operations is the drilling fluid remaining in the sludge or flowing from the cable, the drill and the measurement instruments. To reduce these losses it is planned to use a centrifuge for further drilling activities that will separate the sludge and the drilling fluid. At present such device is used for drilling a deep borehole at Dome C in Antarctica under the EPICA Project. In this manner more than 90% of the fluid can be separated from the sludge. The remaining kerosene is easily separated at melting the sludge, but Freon will go to the atmosphere. Thus, the Freon losses will be decreased to 0.6 kg a run during subsequent measurements and monitoring observations in the borehole.

4.9. Gaps in knowledge

To fill the gaps in our knowledge is possible only by the direct studies of the lower ice strata layers at the contact with the Lake Vostok surface, penetration to the lake and sampling its water, this being the scientific goal of the proposed activity.

5. Conclusions

The proposed continuation of drilling in the borehole 5G-2 (Vostok station, Antarctica) and penetration to Lake Vostok with water sampling (in the form of ice) is planned for the summer Antarctic seasons from 2010 to 2011 and if necessary in the season of 2011–2012. This activity aims to achieve a scientific objective of obtaining data on the origin, evolution and current state of the lake.

The method and technology proposed for this are based on current knowledge about the state of the "ice sheet–subglacial lake "system, physical laws and long-term practical experience of drilling deep boreholes at Vostok station.

Like any other practical activity in Antarctica, continuation of drilling the borehole 5G-2 and penetration to the subglacial lake imply an environmental impact. An evaluation performed indicates that it will inevitably include an insignificant influence by scale and duration on the atmosphere (evaporation of Freon 141b), on the glacial structure in the borehole 5G-2 in depths of more than 3650 m (about 100 m of additional drilling) and on the natural "lower ice surface–Lake Vostok surface" boundary.

The risks of contamination accompanying this activity that are primarily related to the presence of the drilling fluid in the borehole can be practically excluded during preparation and conduct of work.

Conduct of the proposed activity will require additional logistics support, which will insignificantly increase the current impact of the station activity on the glacial surface environment.

As follows from a comparison with other methods of accessing Lake Vostok, the proposed activity of lake water sampling will be of a shorter-term and at a smaller scale and will have the least total (cumulative) impact on the environment in the Vostok station area, including the subglacial lake.

Based on the Final CEE performed, it is concluded that the significance of the impact of the proposed activity on the environment of the station area, ice sheet and the lake is no more than a minor. The activity under consideration can be conducted on condition of undertaking all measures envisaged to mitigate the environmental impact.

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7. ATCM documents

Protocol on Environmental Protection to the Antarctic Treaty (signed on October 4, 1991 in Madrid, Spain)

Guidelines for Environmental Impact Assessment in Antarctica (Resolution 4 (2005)ATCM XXVIII-CEP VIII, Stockholm

XXII ATCM/IP 66, Application of the "minor or transitory impacts" criterion of EIA in different regions of Antarctica, submitted by Russia

XXIII ATCM/IP 73, Deep Borehole 5G1. Current Environmental State and Perspectives (Vostok Station), submitted by Russia

XXIV ATCM/WP 29, Expert conclusion for Project "Justification and development of ecologically clean technology for penetrating the subglacial Lake Vostok (Antarctica)"

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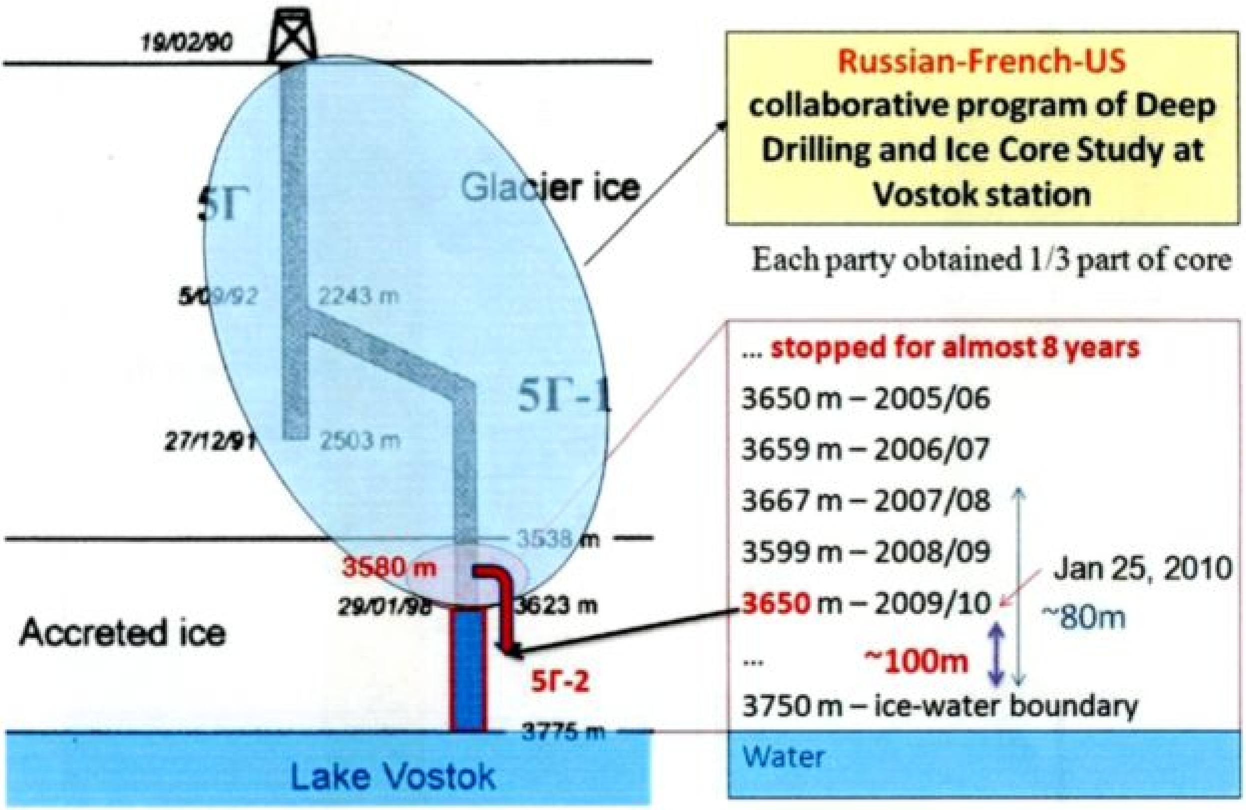
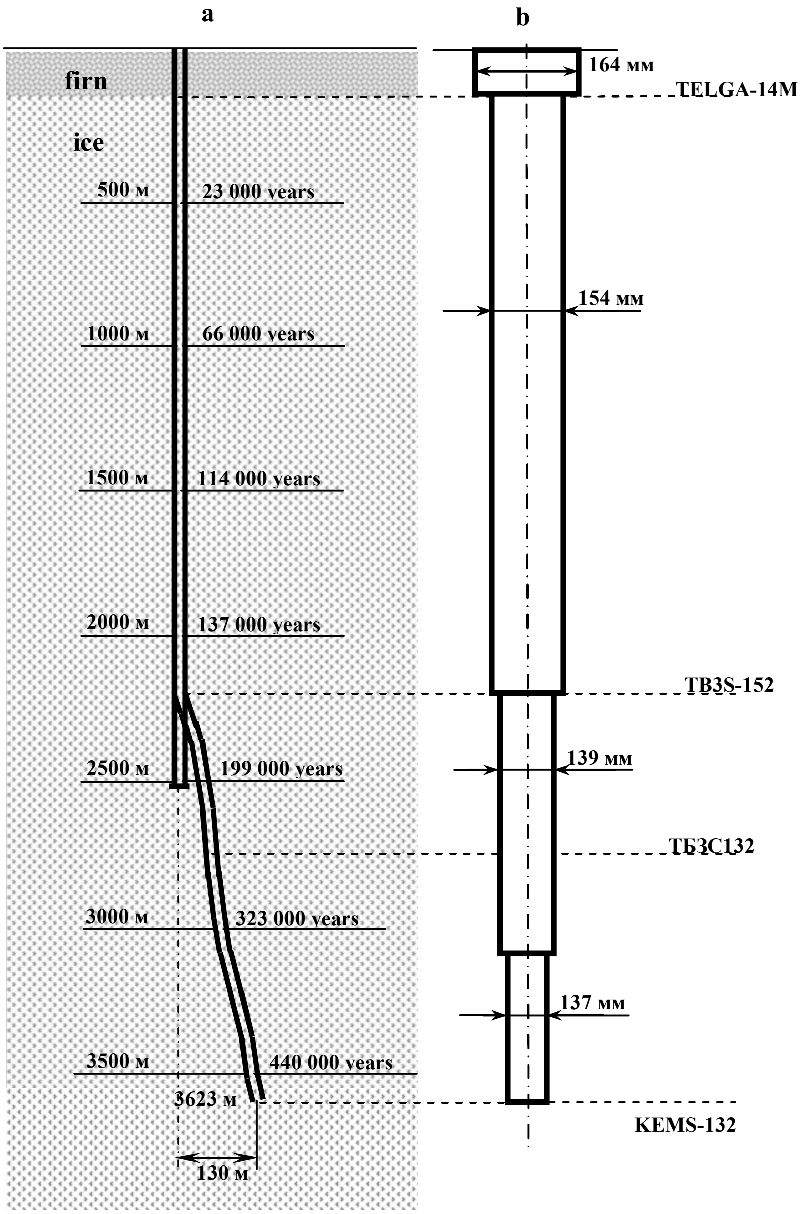
9. ANNEXES

ANNEX 1. Borehole 5G

A. New section of borehole 5G (5G-2) at Vostok station (scheme)

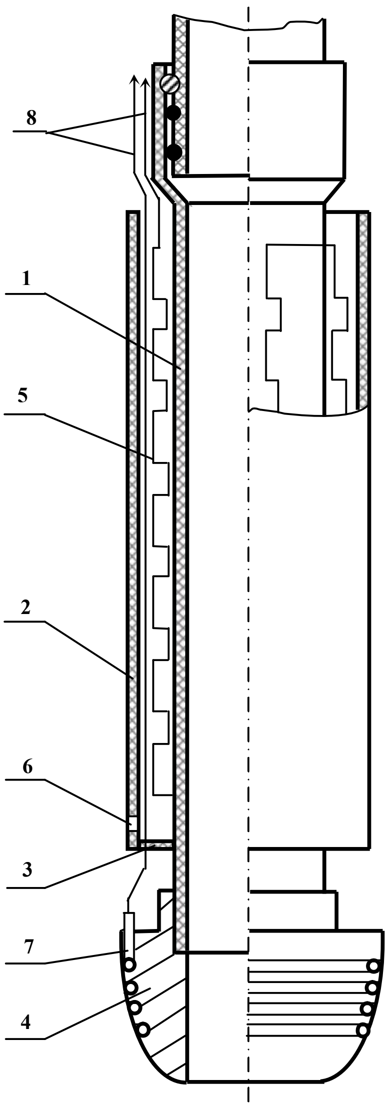


B. Borehole 5G (5G-1) at Vostok station (scheme)



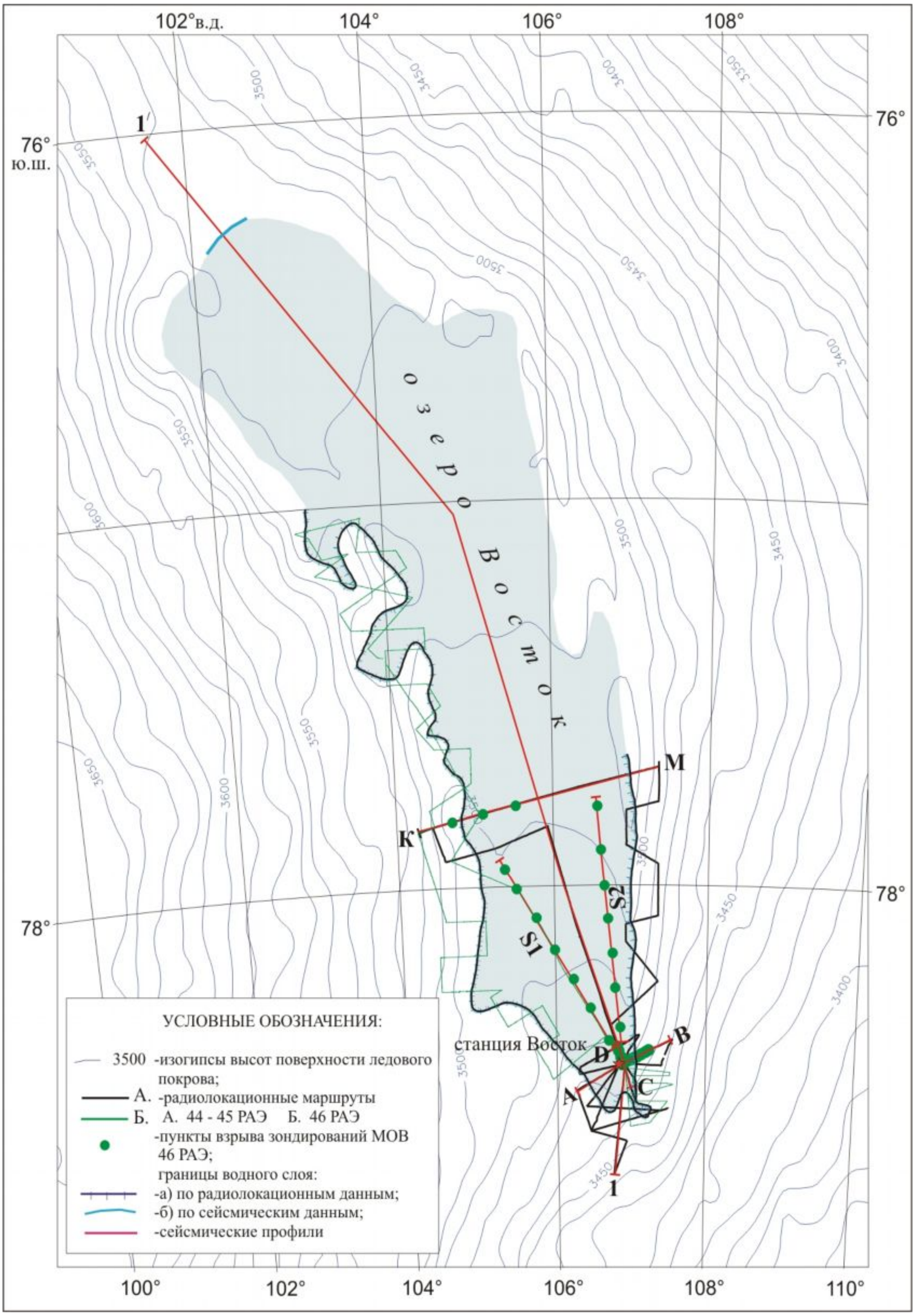
a – borehole profile with indication of depth and age; b – borehole design with indication of the types of corers used (electrical thermal- TELGA, TB3S; electrical-mechanical – KEMS).

ANNEX 2. Lower casing section

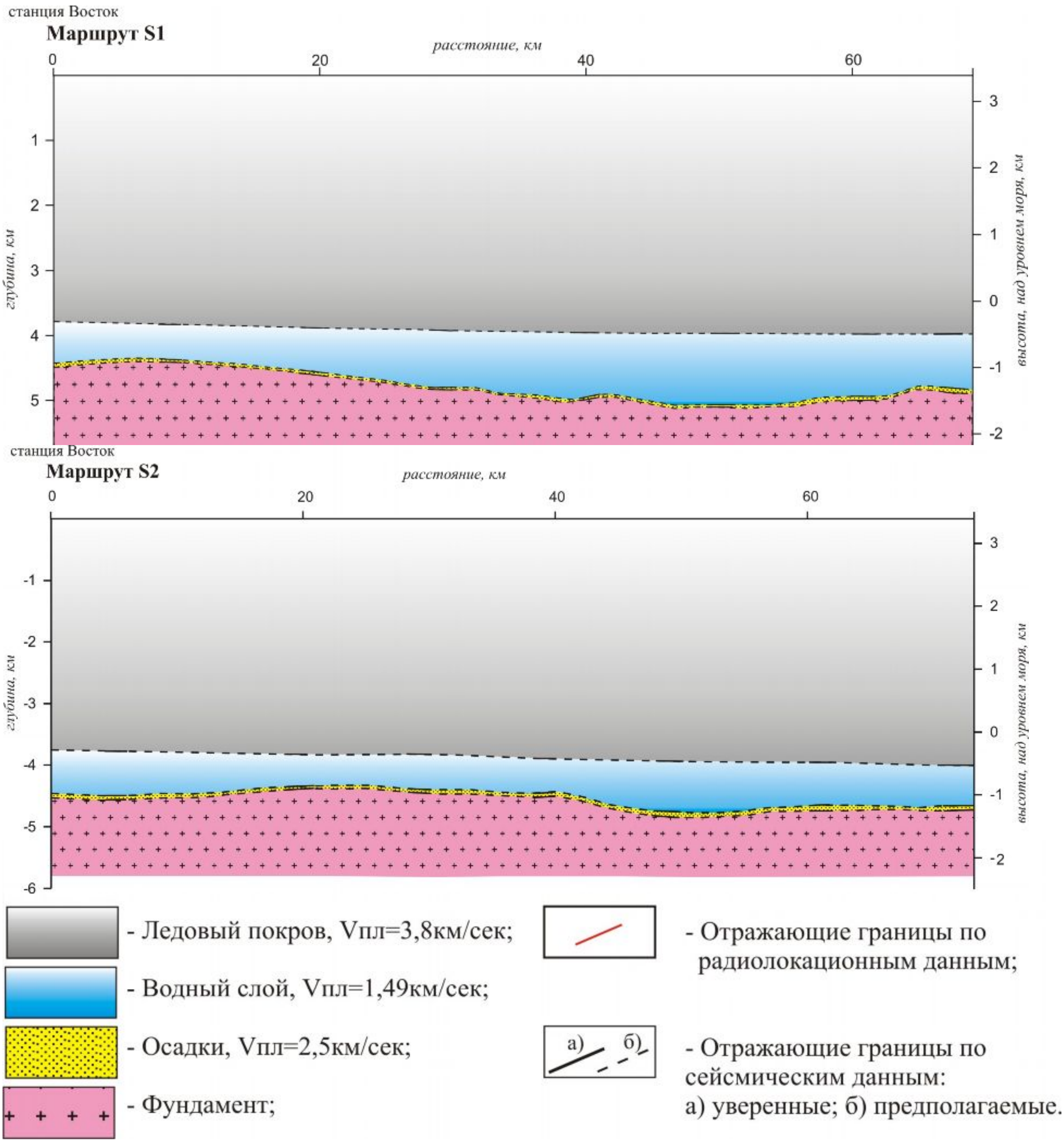


1-Inner tube, 2- external tube, 3- bottom, 4-aluminum shoe, 5-nichrome spiral, 6-holes, 7 - heating element, 8-wires.

ANNEX 3. Diagram of geophysical studies in the Lake Vostok area



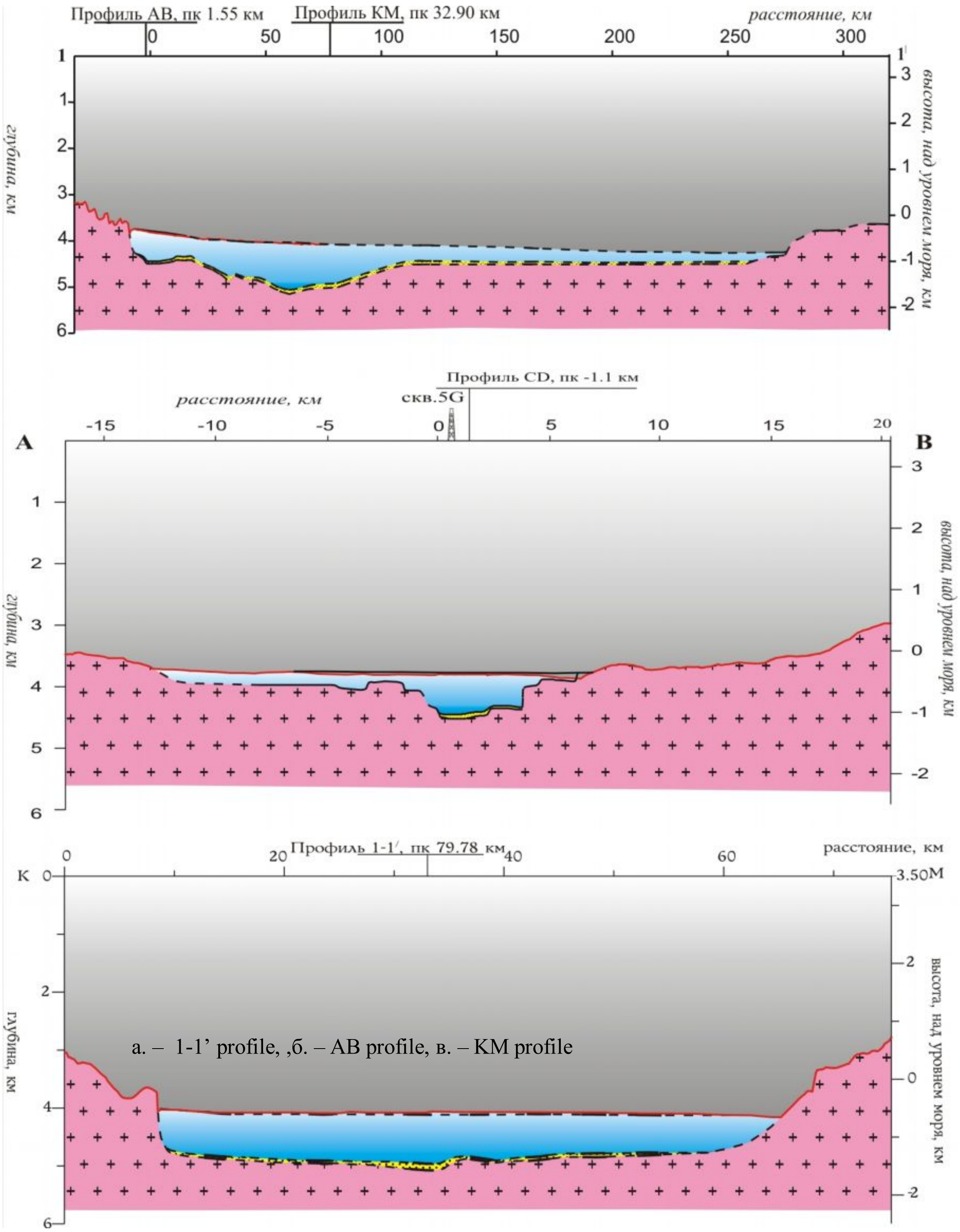
ANNEX 4. Geophysical sections along S1 and S2 lines



Ice cover,
Water layer,
Sediments,
Basement

Reflecting boundaries from radio-echo sounding data
Reflecting boundaries from seismic data
a) assured; b) assumed

ANNEX 5. Complex geophysical sections



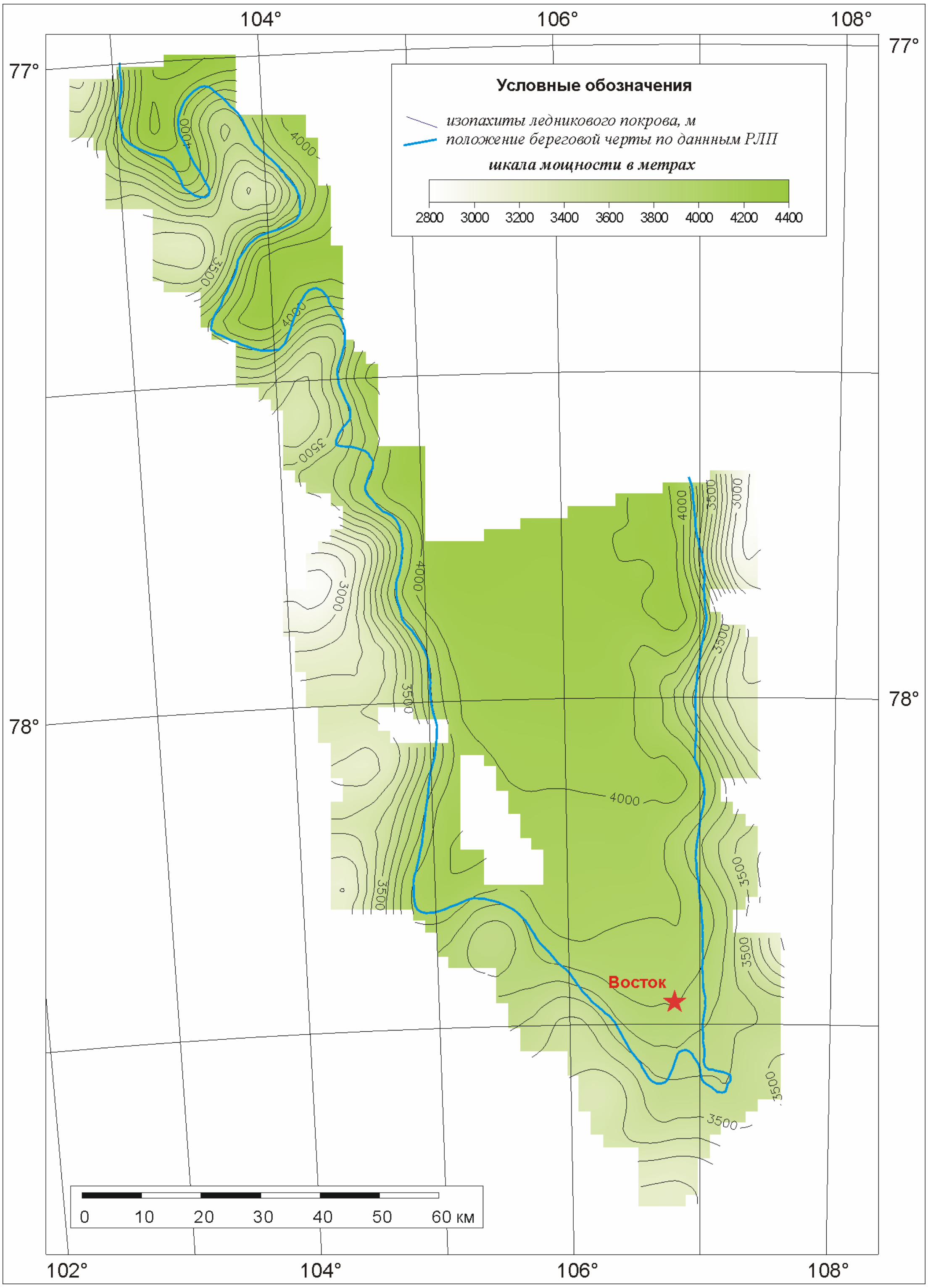
а.

б.

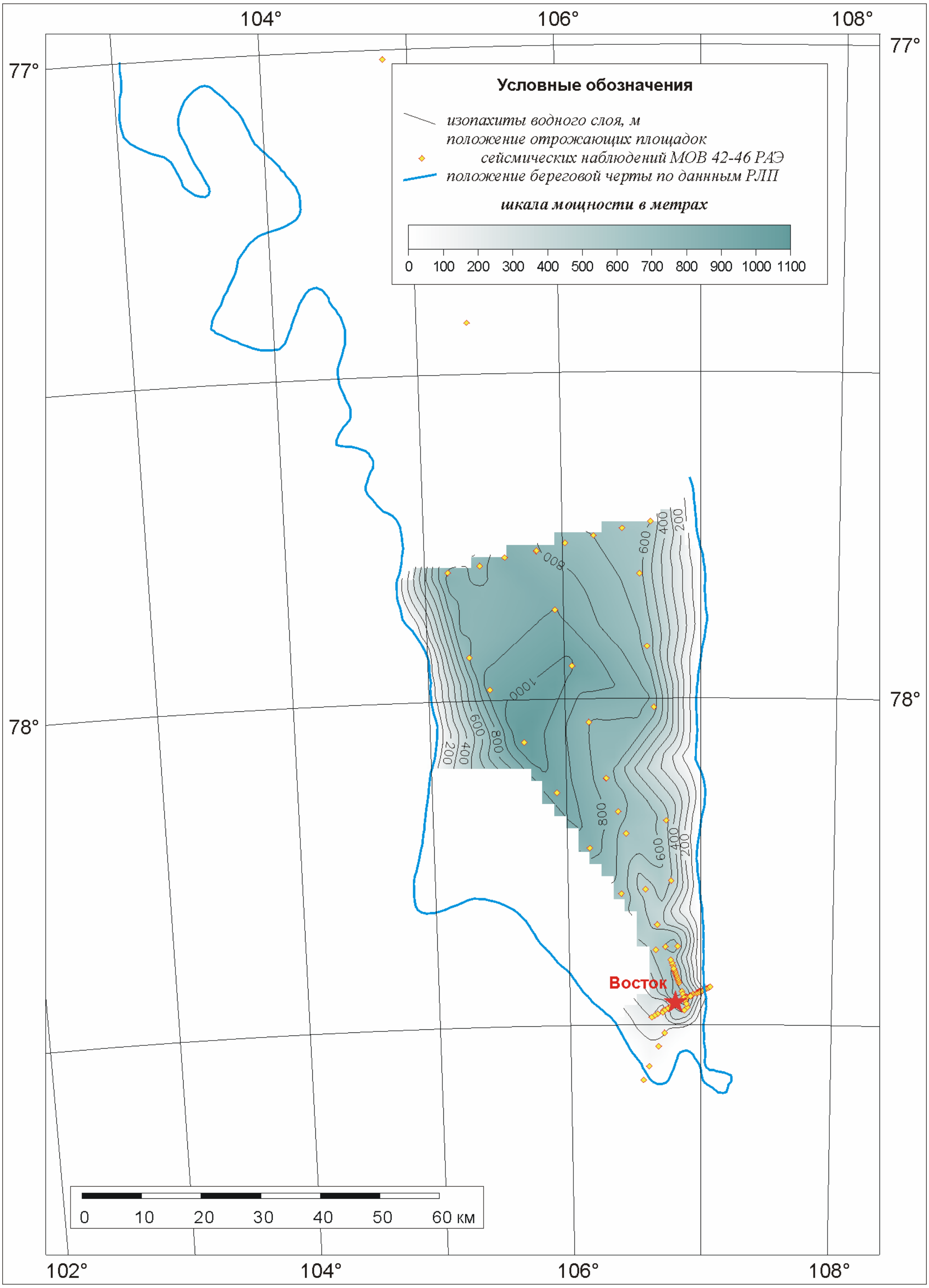
в.

а. – 1-1' profile, ,б. – AB profile, в. – KM profile

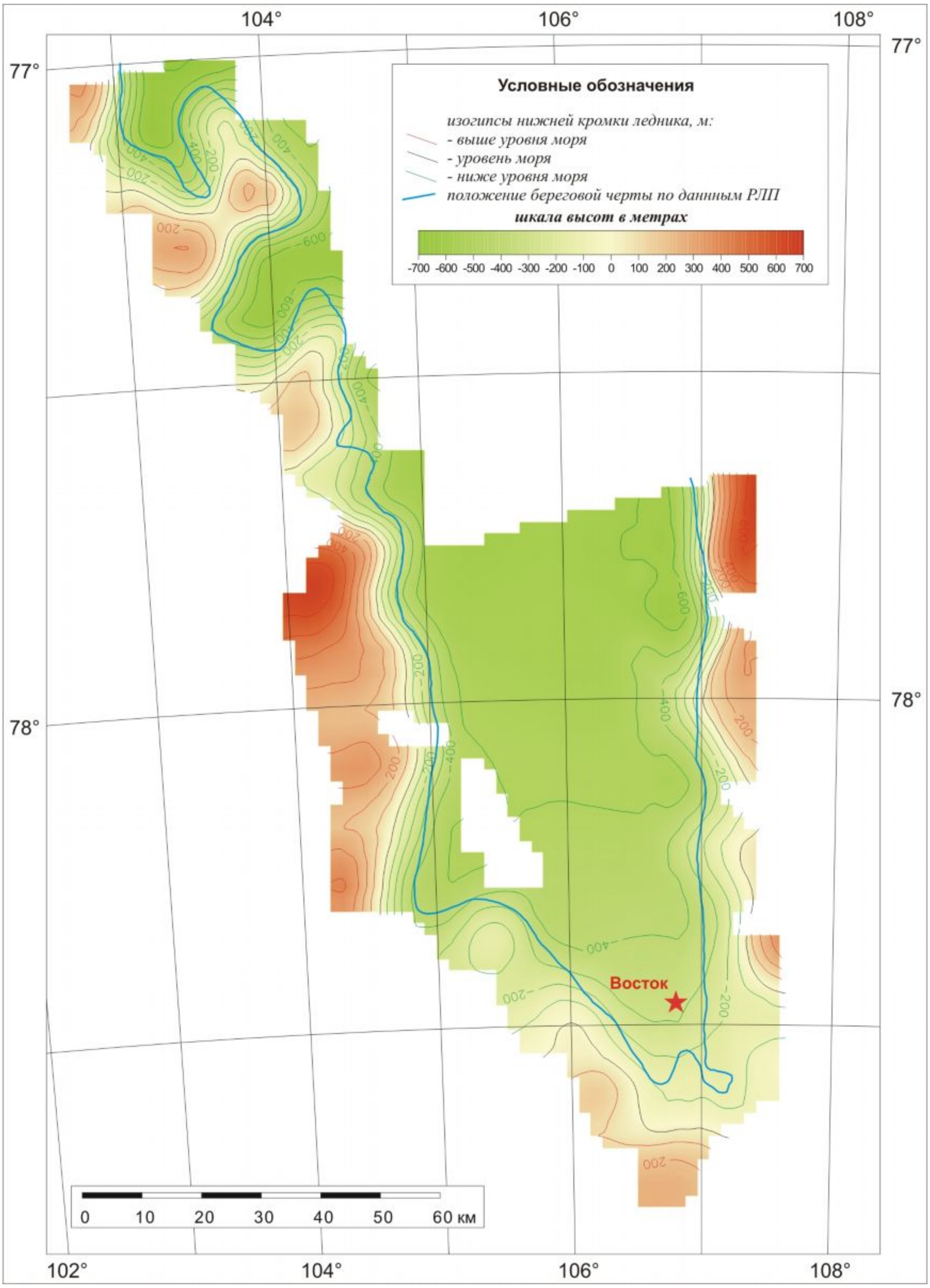
ANNEX 6. Ice sheet thickness based on RES and RSS data



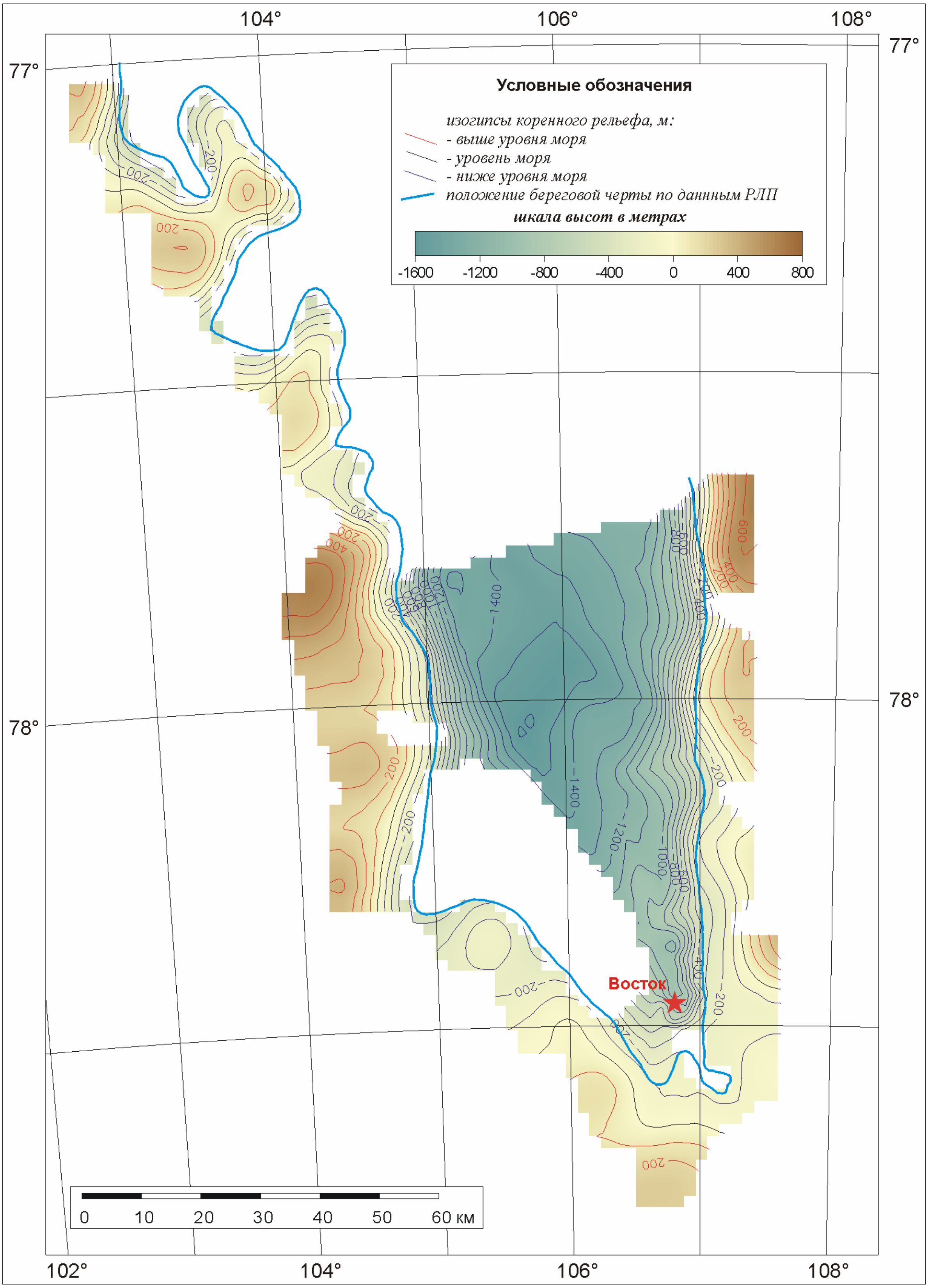
ANNEX 7. Water layer thickness based on RSS data



ANNEX 8. Bottom ice edge location based on RES and RSS data



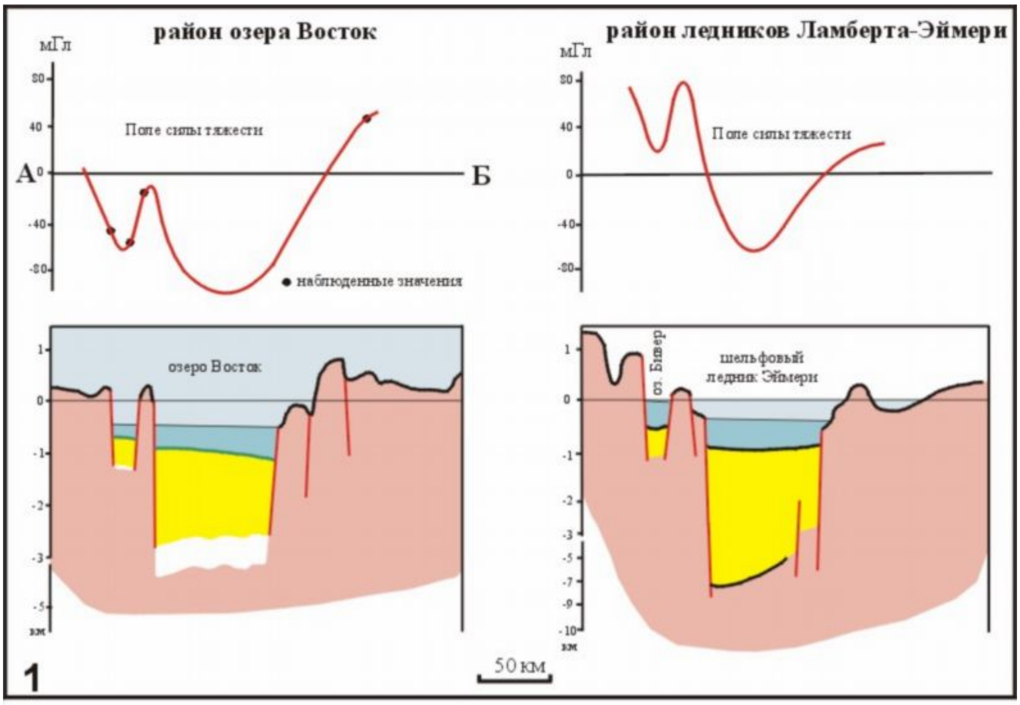
ANNEX 9. Bedrock relief from RES and RSS data

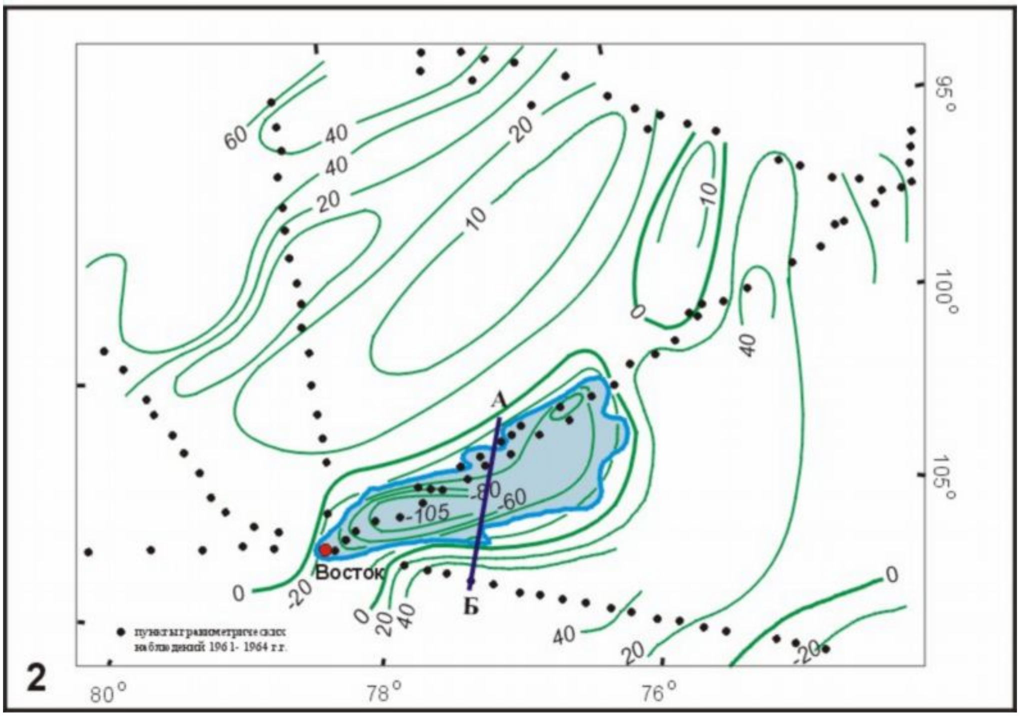


ANNEX 10. Map of magnetic active basement surface

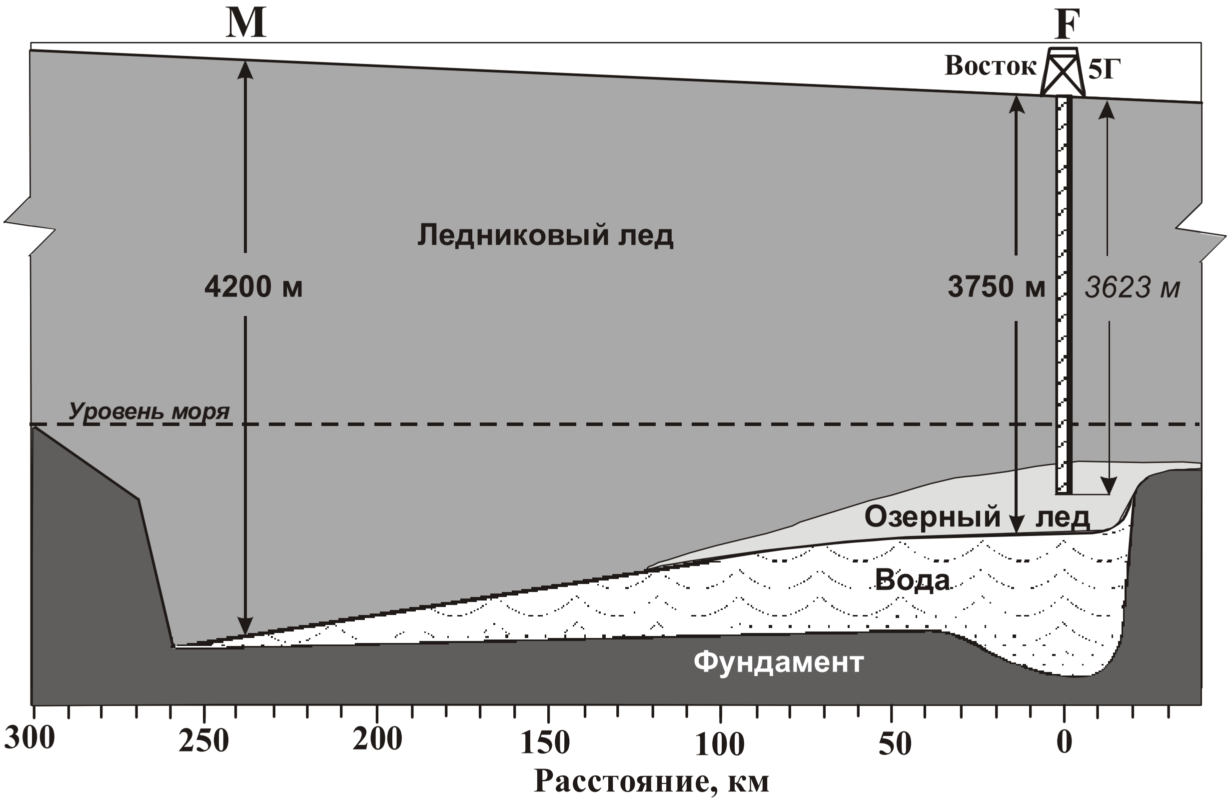
ANNEX 11. Models of the upper Earth’s crust

structure in the area of Lake Vostok and Lambert-Amery ice shelves (1) and diagram of the anomalous gravity field (reduction in free air) of Lake Vostok area based on 1961-1964 studies (2)





ANNEX 12. Schematic section of the Antarctic ice sheet along the long axis of Lake Vostok

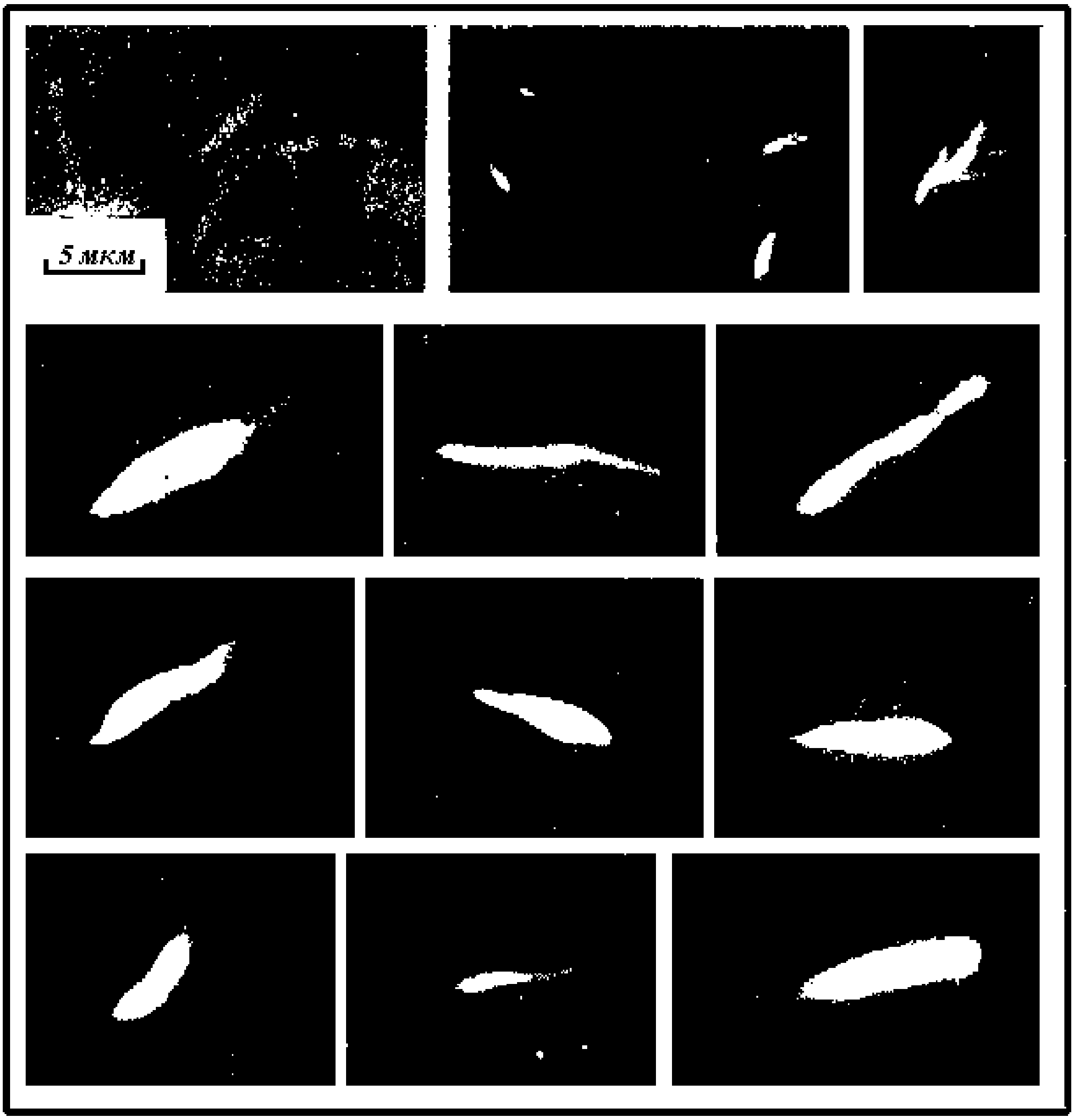


M and F – typical points in the northern (melting zone) and southern (accretion zone) lake areas. /29, 30, 20, 31, 32/.

ANNEX 13. Rift zones of East Africa and East Antarctica

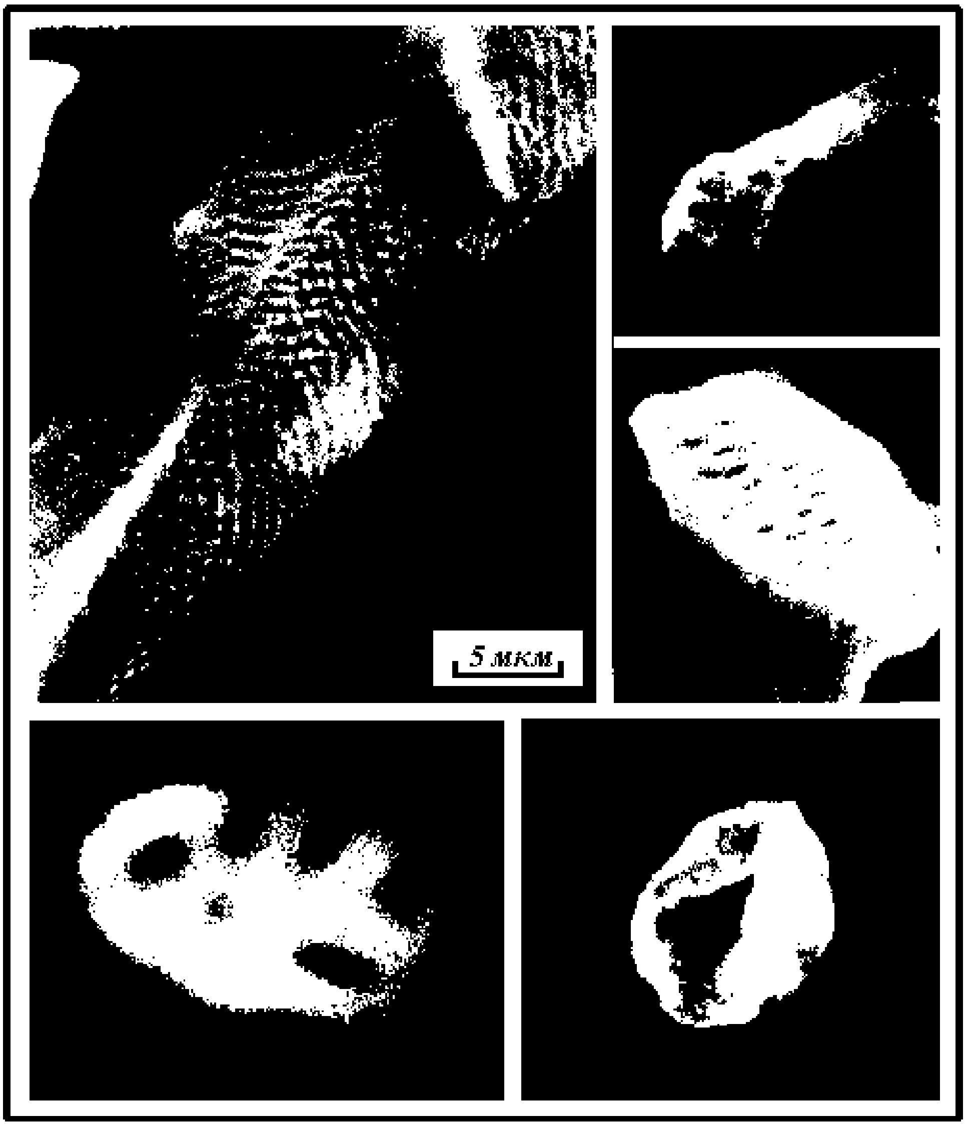
ANNEX 14. Bacteria observed predominantly in the accretion ice zone

(luminescent microscopy)



ANNEX 15. Fragments of diatom skeletons detected for the first time in the accretion ice zone

(luminescent microscopy)



Annex 16. Comments on Draft CEE “Water sampling from the subglacial Lake Vostok” amd answers to them

In 2002 at ATCM XXV in Warsaw (Poland), Russia has introduced the Draft CEE “Water sampling of the subglacial Lake Vostok” (WP-19). To discuss it the Intersessional Contact Group was set up chaired by France. As a result, Russia presented at ATCM XXVI in Madrid (Spain) in 2003 the revised Draft CEE (WP-01).

Comments on this document were presented in the ATCM XXVI Final Report, Madrid, Spain, 2003 in the Annex on the CEP Report.

Some comments could be answered only after resuming drilling in borehole 5G-1 for obtaining new data on ice composition and structure. Drilling operations began again in 2004, and by 28 October 2007, the borehole depth was 3668 m. However a technical accident resulted in the drill loss at the borehole bottom. Attempts in the seasons of 2007-08 and 2008-09 to extract it were unsuccessful, and in January 2009 it was decided to bypass the accident segment by borehole deflection from the vertical. This methodology was developed at St. Petersburg Mining Institute and successfully applied in Antarctica. The deflection was started from a depth of 3590 m in 1.5 m from the accident segment. As of late January 2010, the depth of borehole 5G-2 was 3650 m. The obtained results could not be currently used in the final CEE in order to present it according to CEP regulations at CEP XIII in Uruguay in 2010. Russia has prepared the following answers to CEP comments to be discussed by the international Antarctic community.

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1 While the Committee recognized the importance of the long term science goals for subglacial lake exploration, the draft CEE provides insufficient consideration to reduce the potential environmental risks posed by the activity.

Studies of ice cores from borehole 5G-1 and 5G-2 at Vostok station carried out in 2004 to 2010 and results of similar drilling operations in the north of Greenland Island (Denmark) and on Queen Maud Land in East Antarctica (Germany) showed the structure of lower ice layers of lake origin in the ice sheet to be comprised of large very hard ice crystals, which do not create any conditions for drilling fluid spreading from the borehole downward or towards lateral sides. Such crystalline structure is likely to be caused by physical water freezing peculiarities at a pressure of about 375 atm. Drilling performed by Denmark and Germany in different ice boreholes using the drilling fluid with similar composition as in Vostok project (kerosene and Freon mixture) has demonstrated a possible unexpected contact of this fluid with sub-glacial water masses. As a result, the upper drilling fluid level in the borehole was rising to a height of the existing pressure undercompensation of this fluid to full pressure of ice strata above water. Analyses of the ice core from Greenland formed of frozen water that has risen upward in the borehole from sub-glacial aquatic systems showed that only the uppermost 10-cm of the “fresh frozen” ice core was contaminated by the kerosene-Freon mixture. The lower layers of this core do not have any traces of contamination. So, an independent test of the Russian technology was performed under full-scale conditions in Greenland. Study of microbial diversity of the kerosene-Freon mixture from borehole 5G-1 at Vostok station showed the species composition of bacteria inhabiting this mixture to absolutely differ from that revealed in the ice cores and cannot introduce additional problems to determinations of species diversity of micro-organisms. The kerosene-Freon layer in the borehole serves as a real biological protection from biological material transportation from the borehole surface by drilling equipment and the cable. So, the risks of potential contamination of lake relict water using the proposed Russian methodology are reduced to a minimum.

2 Insufficient information is provided on the special drilling fluid to support the conclusion that it is 'ecologically clean'.

Technology of penetrating the sub-glacial Lake Vostok envisaged introducing an organic silicone fluid (organosilicic oil) to the lower part of borehole before the direct contact of the kerosene-Freon mixture with surface lake water. Different properties of this fluid were investigated in detail and presented in the paper prepared at St. Petersburg Mining Institute by Dr. P.Talalay "Characteristics of behavior in the environment and toxicological properties of dimethylsiloxane oil products", introduced many times at different international conferences on ice drilling.

Silicone oils present hydrophobic and inert substances, stable to water, air, oxygen, metals, wood, paper and plastics. This product type is manufactured in the USA, Japan, Great Britain, France, Germany, Czech Republic and Russia and has everywhere its own trademark. There are no time restrictions for personnel handling silicone oils as there is no proof of their harmful influence on human organism.

Study of microbial diversity of silicone oil showed absence of bacteria inhabiting it in the Antarctic ice cores.

3 The treatment of alternatives to the proposed activity is inadequate and should include alternative solutions

As alternative solutions, a rapid ice drilling technology "FASTDRILL" (USA) is considered. This technology cannot be applicable at Vostok station, as the required power for a constant hot water circulation in the ice borehole with a temperature of about $+90^{o}$ C allows drilling at a temperature higher than -35^{o}C. At Vostok, the year-round surface temperature of the ice sheet is -55^{o} C. Ice drilling at this temperature using hot water will require a power station with several megawatts capacity. Vertical temperature convection at the contact of relict subglacial lake water with hot water from the borehole with a temperature of $+90^{o}$ C will comprise many tens and even hundreds of meters. Microorganisms inhabiting these aquatic systems will be simply boiled. Of serious concern is the measurement accuracy of hydrophysical sensors lowered in the sounding complexes through hot water in the borehole, as the relaxation time of these sensors at unknown water temperature in situ in subglacial systems is practically undetermined. No other methods for glacier drilling and correspondingly penetrating the subglacial aquatic system were developed and tested under the high-latitudinal conditions.

4 The draft CEE does not adequately identify and discuss gaps in knowledge particularly as related to the question of the ice/water interface conditions and lake chemistry.

Knowledge gaps noted in 2003 about the ice/water interface conditions and chemical and microbiological composition of surface water of Lake Vostok were to a great extent eliminated for the past 7 years. The final answer can be given only after penetration. Nevertheless it is already obvious that ice formed of frozen lake water directly contacts its surface layer. Information on ice structure at the glacier bottom is given in 1. Data on the hydrochemical analysis of ice cores from lower horizons of borehole 5G-1 were obtained as a result of special analyses at the Laboratory of the University of Venice (Italy). They were presented at different international forums and published in scientific journals. An analysis of the gaseous content of specimens from the lower ice core layers showed an extremely high oxygen concentration, which most likely testifies to oversaturation of surface lake water layers with dissolved oxygen. This creates "cold reactor" conditions, under which oxygen burns the living cells. The microbiological analyses of ice from the lower part of borehole 5G-1 showed the concentration of living cells to be ultimately low, comprising 1 to 10 cells in 1 ml indicating an extremely low biological activity in the surface water layer of Lake Vostok. These results were also presented at different international forums and published in scientific editions.

5 The draft CEE does not adequately address the risk of accidental release of drilling fluid into the lake and the potential consequences of this release.

Data on the ice structure in the 3623 – 3668 m layer indicate a complete absence of any capillary channels in the lower glacier layers through which the drilling fluid could spread downwards. This makes the assumed risk of an accidental kerosene-Freon mixture release into the lake surface water quite baseless. The contact area of this mixture with water will be restricted by borehole diameter (132-137 mm). The mixture is a hydrophobic liquid and does not mix with water. Being lighter (density of 0.91 g/cm³) than water, the drilling fluid will always be above water. A hypothesis of the presence of flood systems in subglacial aquatic media is soundless for Lake Vostok, as the lake water body is entirely within the shores formed by mountain rocks and not by glacier. Besides, Lake Vostok does not have any systems of channels connecting it with the other subglacial water systems. The latter data were obtained from ground-based radio-echo sounding fully contouring the lake coastline.

6 Consistent with Annex 1, Article 3, paragraph 2(g), contingency plans should be developed to deal promptly and effectively with unforeseen impacts if the activities do not proceed as predicted.

Unforeseen circumstances in implementing the Project of penetrating lake water through borehole 5G-2 could be an accidental penetration to the lake provided the glacial thickness is less than 3750 m (measured by radio-echo sounding and seismic methods). In this case, absence of organosilicon parting fluid at the “drilling fluid/lake water” interface is possible. As shown by operations in Greenland, potential contamination is possible only in the thin 10-cm layer within the borehole. In this case, lake water will rise upward in the borehole to a height of pressure undercompensation of the drilling fluid column. Glacier drilling under any circumstances is performed at the pressure undercompensation of 5-8 atm (with the drilling fluid depth by 50-80 m lower than the borehole upper level).

Other emergencies in implementing this project, like the kerosene-Freon mixture release, are not anticipated. No other technical mistakes in drilling the glacier are expected due to special additional measures undertaken for this operation at Vostok station. These are constant control of technical equipment and monitoring the drilling fluid density and its upper level in the borehole.

Annex 17. Permit No. 067 for the activity of the Russian individuals and legal entities in the Antarctic Treaty Area

Утверждено
приказ Росгидромета
от 07.12.99 г. № 139

**ФЕДЕРАЛЬНАЯ СЛУЖБА РОССИИ
ПО ГИДРОМЕТЕОРОЛОГИИ И МОНИТОРИНГУ ОКРУЖАЮЩЕЙ СРЕДЫ
(РОСГИДРОМЕТ)**

Серия **РАЗРЕШЕНИЕ** № 067

**на деятельность российских физических и юридических лиц
в районе действия договора об Антарктике**
(южнее 60 град. южной широты)

Действительно с „01" декабря 2010г.
по „01" марта 2012г.

Настоящим разрешается ГУ "Арктический и антарктический научно-
(организация,
Исследовательский институт" Росгидромета (ГУ "ААНИИ")
учреждение,
199397, г. Санкт-Петербург, ул. Беринга, 38
юридический адрес или ф., и., о.,

№ паспорта для физических лиц)

осуществлять Отбор проб воды подледникового озера Восток
(вид деятельности)

с 01 декабря 2010 года по 01 марта 2012 года
(период выполнения деятельности)

в районе Центральная Антарктида
(район, место, объект проведения деятельности)

в соответствии с 1. Письмом ГУ "ААНИИ" от 10.11.2010 № 16-3-144а
(документы, в рамках которых осуществляется деятельность)

1. 2.Положительным заключением экспертной комиссии Минприроды России
(Приказ от 26.03.2001 № 257)

2. ~~3. Выводами КООС (Заключительный отчет КООС XIII, Уругвай, 3-7 мая 2010г.)~~

3. ~~4. Протоколом заседания Комиссии от 12.11.2010 № 30~~

Условия Соблюдение требований Протокола по охране окружающей среды
(условия выполнения деятельности, ограничения)
к Договору об Антарктике, рекомендаций, изложенных в оценке воздействия
на окружающую среду

*Руководитель Федеральной службы России
по гидрометеорологии и мониторингу
окружающей среды*

А.В.Фролов
(подпись)

Дата выдачи
„23" ноября 2010

М. П.

МПФ Гознака. 2000. Зак. 20-4621.