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GEOETHICAL PROBLEMS OF DIRECT ANTARCTIC SUBGLACIAL LAKES ACCESS

Abstract *Opened in the end of 20th century numerous sub-glacial water reservoirs of Antarctica among which the largest formation is subglacial the Lake Vostok finding in area of the Russian research station with the same name. The Antarctic subglacial lakes and, first of all Lake Vostok, are unique objects for studying of history of development of our planet, at least, during an order of 15 million years or more. Experimental conditions of their existence assume preservation possibility here relic forms of the life which studying will promote the best understanding of developments of life as to ours, and on other planets.*

The program of Deep Ice Coring at Vostok station in Antarctica is carried out since 1969 and provides reception of fundamental knowledge of a deep structure and evolution of a glacial cover and sub-glacial water at the central part of East Antarctica. Within the limits of realization of this program deep ice drilling with full ice core recovery and complex researches of core and an ice formation around hole were carried out. Recently the project of complex research of sub-glacial lakes is realized.

The successful decision of these tasks demands not only high professionalism but use of ecological and fundamental principles of geoethics in respect to wildlife objects live and inorganic nature.

The discovery of the subglacial Antarctic lakes is already recognized as one of the most significant geographic revelations in 20th century. Lakes beneath the Antarctic ice sheet were first reported from airborne radio-echo sounding (RES) records by Oswald & Robin (1973). Analysis of RES and seismic investigations high-accuracy satellite radar altimeter data resulted that the Antarctic ice sheet is underlain by an extensive, complex and dynamic water system, which encompasses the largest wetland on Earth, at least hundreds of lakes, drainage pathways, and deep groundwater. Right now nearly 400 subglacial lakes have been identified, and the total surface area of the subglacial lakes has been estimated at nearly 10 % of the ice sheet's base. (Fig. 1).

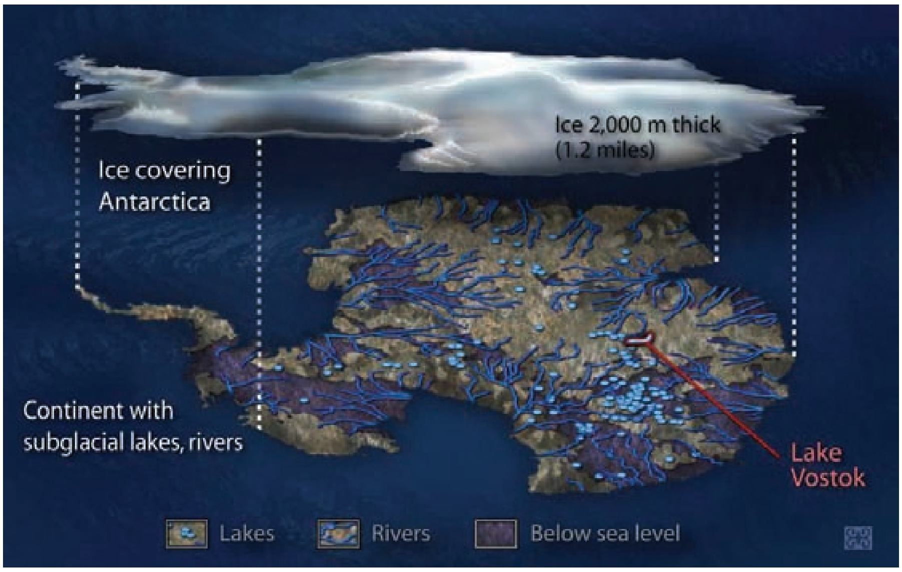

Fig. 1. Antarctic subglacial hydrology compiled by Zina Deretsky, NSF [http://www.nsf.gov/news/mmg/media/images/AntarcticLakes_h.jpg]

Distribution and dynamics of subglacial water is of inherent importance to understanding the Antarctic continent, its ice sheet, and its connectivity to the global climatic, geochemical, and biologic systems. The important stage of subglacial lake investigation were made by Laurence Gray and his colleagues from Canada Centre for Remote Sensing (Ottawa) who discovered active subglacial lakes with changeable surface elevation and hydrological parameters.

The Soviet Antarctic research station Vostok was founded at the center of the East Antarctic Ice Sheet (78°28'S, 106°48'E, 3488 m.a.s.l.) in 1957 (Fig. 2). This place turned out to be the coldest on Earth; the lowest reliably measured temperature of -89.2°C was recorded on 21 July 1983. In addition, by good fortune Vostok was set above the southern end of the largest subglacial lake in Antarctica, discovered in 1996 by Russian and British scientists [Kapitsa et al., 1996].

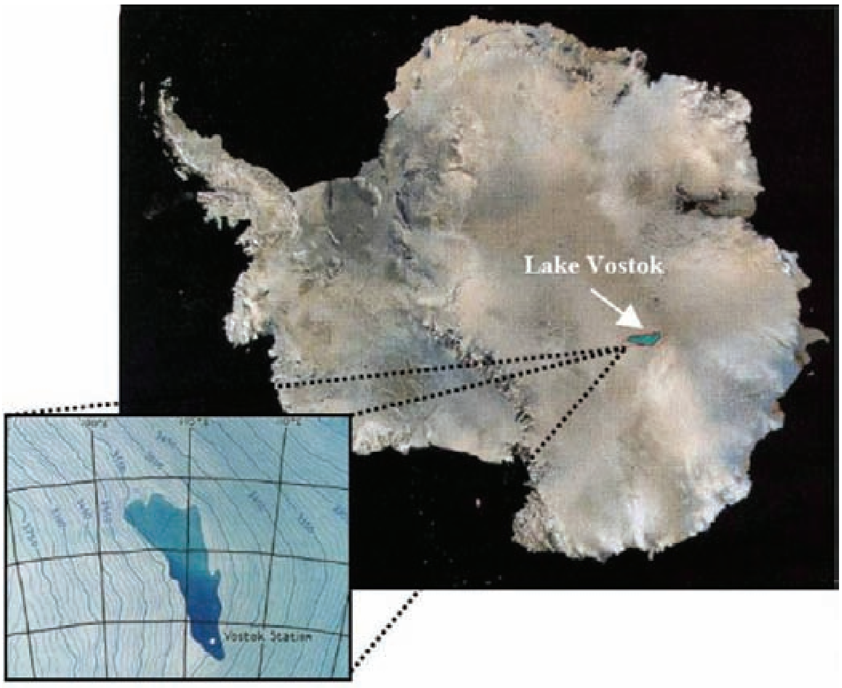

Fig. 2. Location of Vostok station and Lake Vostok [from Siegert, 1999]

With dimensions 280 km × 50 km and water depth reaching 1200 m, Lake Vostok (Fig. 3) buried beneath 4 km thick East Antarctic ice sheet is the largest subglacial lake identified by radar surveys in Antarctica [Siegert et al., 2005]. The origin, evolution and the present-day state of Lake Vostok system are closely related to the tectonic evolution, the climatic history and the development of the ice cover of Antarctica. The lake represents an old (Late-Jurassic-Early Cretaceous) rift structure bounded by deep faults and, as an old and deep tectonic lake isolated from the surface biota for millions of years, has the greatest potential for harboring ancient life [Priscu et al., 2005]. A success in searching for life in Lake Vostok environments (accretion ice – lake water – sediments) could yield exciting exobiological findings and have important methodological and motivational implications for exploration of extra terrestrial icy systems. Thus, if life is able to exist in the depths of Lake Vostok, then life may exist on Europa and other extreme environments elsewhere in the solar system.

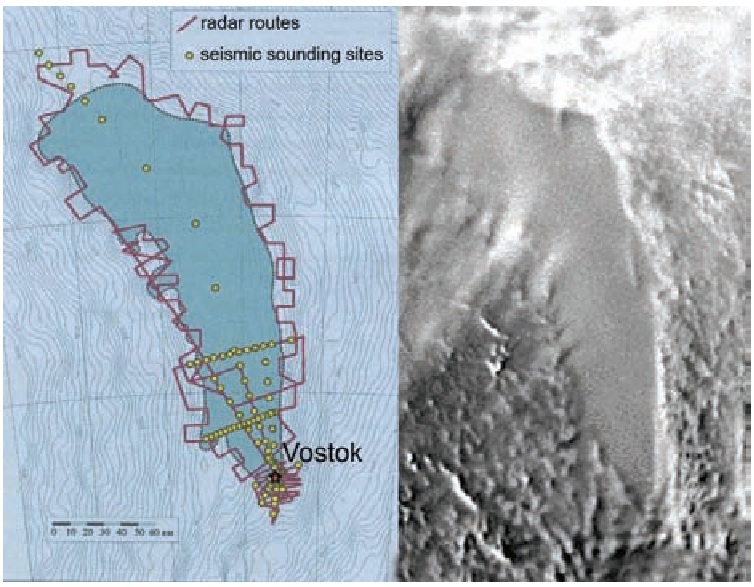

Fig. 3. Lake Vostok topography according to geophysical data (at the left) and Antarctic surface in the region of Vostok from ERS-1 radar altimeter data (at the right)

Since 1999, the Russian studies of Lake Vostok have been carried out in the frame of the Federal Targeted Program "World Ocean", subprogram "Antarctica", project 4 "Deep ice coring, paleoclimate research and subglacial Lake Vostok exploration". The long-term program covers the period to 2012. The field operations are under responsibility of the Russian Antarctic

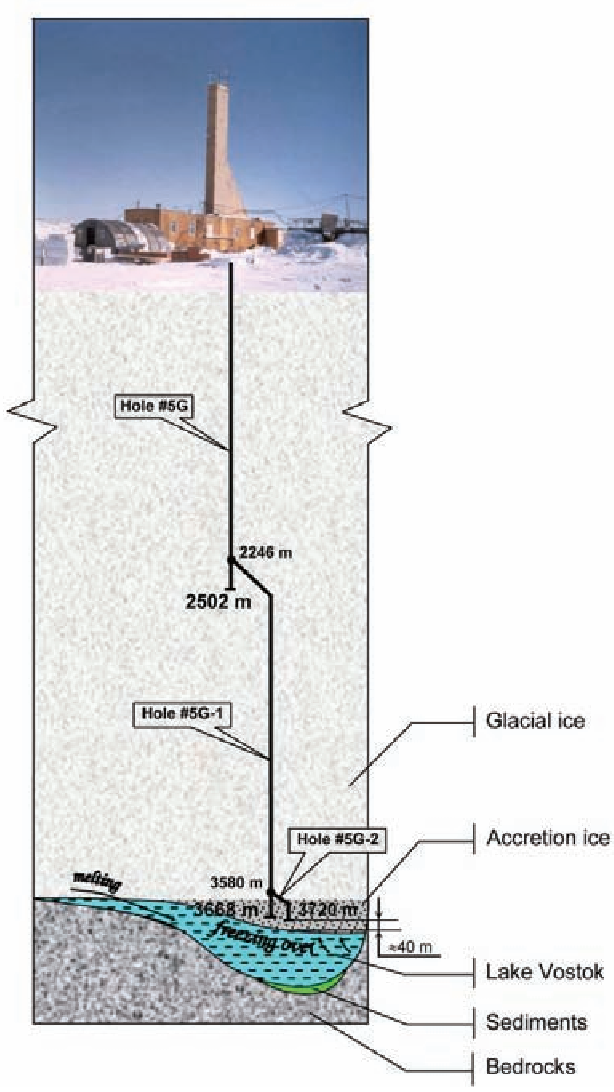

Fig. 4. Schematic drawing of deep Hole #5G

Expedition. The multi-disciplinary project is being implemented by a consortium of 9 Russian research institutions. Preparations for the exploration of subglacial lake Vostok are now well advanced anticipating direct lake access within the next 1-2 years.

Deep ice core drilling at Vostok station began in 1970. In the 1970s a set of open uncased holes were drilled by a thermal drill system suspended on cable. The deepest dry hole in ice reached 952.4 m (Hole #1, May 1972). It was concluded that for drilling at greater depths it is necessary to prevent hole closure by filling of the borehole with a fluid. Thus, from 1980 on new thermal and electromechanical drill systems working in fluid were used. Two boreholes reached depths of more than 2000 m. Hole #3G-2 was deepened to 2201.7 m depth in 1985 (Kudryashov, 1989) and Hole #4G-2 to 2546.4 m depth in 1989 (Kudryashov et al., 1994).

Drilling a new deep Hole #5G started in February 1990. The hole was deviated twice because of stuck tools (Fig. 4). In the summer season of 2010-11 the Hole #5G-2 reached the depth of 3720 m [Lipenkov, 2011]. From independent data sources, the ice-water interface at Vostok is at a depth of 3760±15 m [Popov et al., 2000; Masolov et al., 2001] and the remaining ice thickness between deep hole and the lake equals about 40 m.

The deepest portion of the ice core (from 3539 m to 3720 m) has a chemistry, isotopic composition, and crystallography distinctly different from the overlying glacial ice. Geochemical and physical data indicate that it originated from the accretion of subglacial lake water to the underside of the ice sheet (Jouzel et al., 1999). Together with data on ionic chemistry, these ice core data favor an origin of the lake ice by frazil ice generation in a supercooled water plume existing in the lake, followed by accretion and consolidation from subsequent freezing of the host water.

Microbiological studies of the Vostok glacial and accreted ice have indicated that low, but detectable, concentrations of prokaryotic cells and DNA are present (Bulat et al., 2004). Many of the bacterial cells are associated with non-living organic and inorganic particulate matter.

In recent years, advances have been made in understanding and predicting the physical and chemical environment of Lake Vostok based on modeling efforts that set boundary conditions for various attributes. Future studies of the subglacial water properties and searching for ancient life are now important parts of the project at Lake Vostok.

The subglacial water most likely contains life, so that any in situ investigations should not contaminate the lakes. This constraint makes an environmentally sensitive lake-penetration of chief importance. In fact two times the subglacial water was reached by deep holes at Byrd station (2164 m, 1969) and base Kohnen (Fig. 5, 2774 m, 2006). In both cases there were no any special environmental preparations to access water. Therefore the relict water had welled up into the holes and contacted with the toxic drilling fluid.

The specific properties of ice and subglacial water systems demand not only new non-traditional drilling and sub-glacial lakes access technologies but using of the geoethical methods which include the following steps:

1.Estimation of the geodynamic stability of the object to the technological impact.

2. Selection of the main sources of the technological environmental impact.

Fig. 5. Refrozen water from the last run at Base Kohnen

3. Developing of the environmental-friendly investigation methods and selection of the highly protected natural objects.

The ecological sense of the geoethical principles leads to the limitation of the actions for geological investigations. Pollution of Antarctic Region is dangerous particularly because nature recovery takes much longer time than in regions with temperate and open climate. At first the strategy of Antarctic environmental control was declared in Declaration of Stockholm UN Environmental Conference in 1972. On 4 October 1991 high significance of these aspects was confirmed in the signing of the Protocol on Environmental Protection to the Antarctic Treaty [Antarctica Agreements, 2010]. The Article 3 of the Protocol declared: “The protection of the Antarctic environment and dependent and associated ecosystems … shall be fundamental considerations in the planning and conduct of all activities in the Antarctic Treaty area.” The Protocol entered into force on 14 January 1998 following ratification by all Antarctic Treaty Consultative Parties.

The philosophical sense of geoethics is wider. It could be formulated as difference between social and antisocial actions for geological investigations with respect to biocenosis. Social actions are considered to keep integrity, stability and beauty of biocenosis, and, vice verse, all that hinder this belongs to antisocial actions.

Even the recent deep drilling projects has been succeeded at various sites of Antarctic ice sheet, the drilling technology is plenty harmful for Antarctic environment. Currently there are no references of environmental monitoring on the deep drilling projects carried out in inland of Antarctica and historically follow up studies have not been conducted on the impacts of past drilling operations.

Environmental hazard sources of drilling technology are: 1) drilling fluids; 2) drilling and auxiliary equipment; 3) drilling cuttings; 4) transportation facilities; 5) petroleum, oil, and lubricant; 6) power station and diesel power lines; 7) spills and wastes.

Formerly utilized drilling fluids are considered as very harmful agents for Polar Regions environment because they can contaminate in large quantities air, surface and near-surface snow-firn layers, ice cuttings, subglacial water resources [Chistyakov, 2005]. Interactions of the drilling at inland on the Antarctic ice sheet with surface or air biota are impossible or unlikely, but the possibility of impacts to subglacial water biota from drilling fluid can occur almost at any inland drilling site. Effects of drilling fluids are particularly important if fluid is to be left in the hole. Because of the movement of the ice, fluid in the hole will eventually reach the sea after a period of many thousands of years.

Since 2004 an international scientific community is discussing the problems of the deep drilling technology within International Partnerships in Ice Core Sciences (IPICS). Two IPICS Workshops (Algonkian Regional Park, 2004 and Brussels, 2005) and Steering Committee business meetings (Vienna, 2008 and Corvallis, 2009) declared that searching of the new drilling fluid is the most important task of ice core drilling technical challenges. Members of IPICS concluded: “The identification of a non-toxic, non-flammable, density appropriate, hydrophobic, inexpensive, envronmentally friendly and readily available fluid(s) with predictable performance characteristics has become somewhat of a Holy Grail in the ice-drilling community." [IPICS, 2004].

Several projects of subglacial lakes environment access technologies were proposed by Russian, UK, USA and other science communities. They have different concepts, limits and performance. But all of them cannot be qualified as ultra-clean technologies and intelligent choice from geoethics point of view.

The penetration of the Lake Vostok will be performed in coming summer season with technology developed in St.-Petersburg State Mining University and Arctic and Antarctic Research Institute in the frame of the project "Justification and development of the ecologically clean technology for penetrating the subglacial Lake Vostok (Antarctica)" funded by the Ministry of Science and Technology of the Russian Federation [Verkulich et al., 2002]. On the first stage an ecologically inert hydrophobic liquid (e.g., polydimethylsiloxane) will be injected to the hole bottom (Fig. 6). In a second stage, the access to the lake will be completed with the coreless thermal drill. This will allow lake water to enter into the hole and to fill up its lower 30–40 meters. On the third stage the frozen lake water will be sampled with electromechanical drill to a level of about 15–20 m above the ice-water interface.

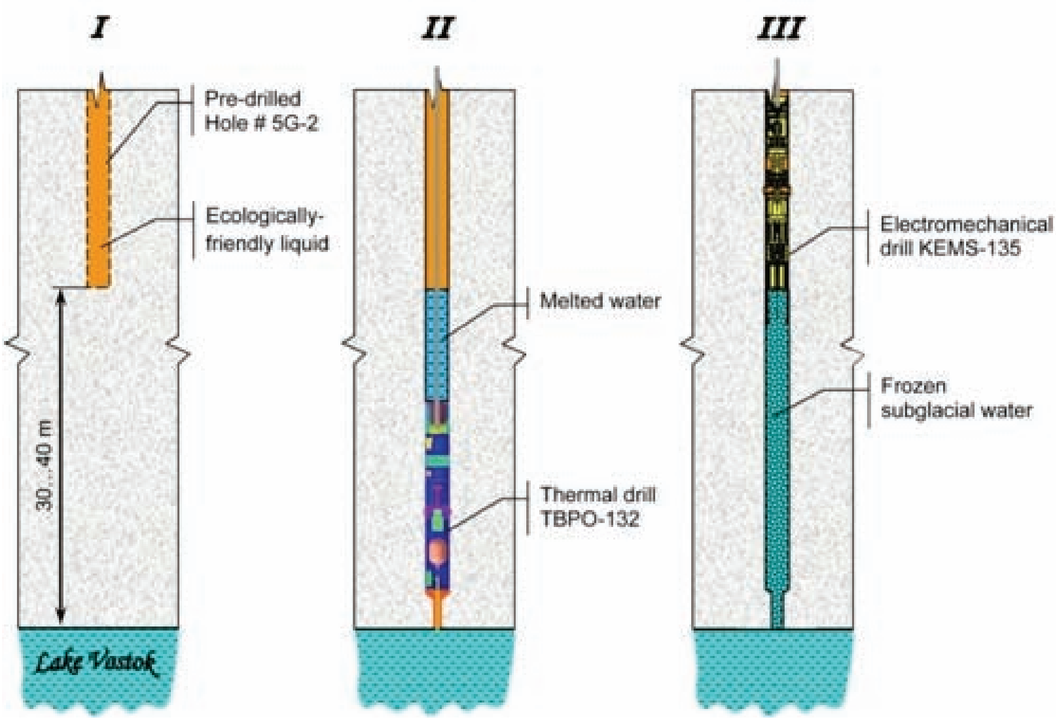

Fig. 6. Scheme of penetration and sampling of sub-glacial Lake Vostok

Nevertheless, kerosene used as a base of drilling fluid in the Hole #5G is a high environmental risk material since, in the event of a spill, it has a long residence time, particularly in cold environment. There is a risk of slight mixing between drilling fluid, hydrophobic liquid and melted water. In this case some amount of kerosene can penetrate into subglacial water. In the water environmental the concentrations of aromatics containing in kerosene more than 1 mg/m^3 cause the poison effects to microorganisms.

We can point out other disadvantages of this project: 1) the composition and quantity of the inert hydrophobic liquid are not chosen yet; 2) there are not adequate physico-mathematical model of the subglacial water welling up into the hole; 3) the sealing of the hole using subglacial water freezing is not proved; 4) the danger of gas hydrates dissociation in frozen-on ice is not estimated.

UK and USA preparations for the exploration of subglacial lakes are now well advanced, with two major programmes (Lake Whillans and Lake Ellsworth) anticipating direct lake access within the next 2-3 years [Blake, 2011]. Both projects is planned to be accessed by hot-water drilling system that should melt the hole of near 36 cm in diameter (Fig. 7). All melted water is filtered to 0.2 micron and go through UV treatment. After lake access the probe capable of measuring and sampling the water column and sediment is lowered into the access hole. During sampling the hole filled by water should be keep open and the technical details of the probe recovering to the surface is not clear. Such technology cannot provide isolation of subglacial water from the surface.

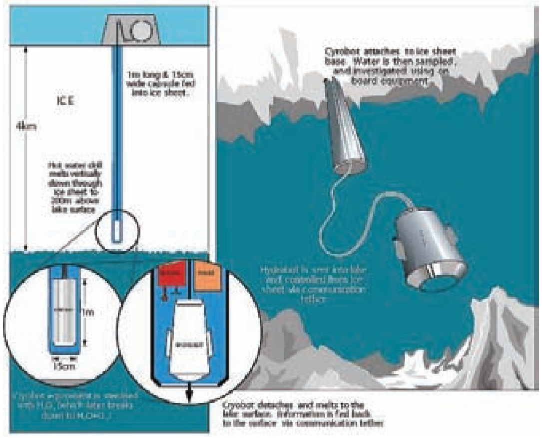

Fig. 7. *Scheme of penetration and sampling of subglacial lakes using hot-water drilling technology*

So, the risk of subglacial microbiota poison from drilling technology should be totally excluded. Hopefully, planning exploration of subglacial lakes will prevent contaminating the waters and will give the unique chance to use geoethical principles for such investigations.

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