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Proposal for penetration and exploration of sub-glacial Lake Vostok, Antarctica

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Abstract: According to directions issued by the Ministry of Science and Technology of Russia to the Arctic and Antarctic Research Institute and St. Petersburg Mining Institute, a new project has been launched with the aim to develop technology for the ecologically safe *in situ* exploration of sub-glacial Lake Vostok (Antarctica). In this paper we propose our current approaches to accessing the lake and sampling its water using the deep Hole 5G-1 at Vostok Station.

It is proposed that by maintaining the hydrostatic pressure at the hole bottom slightly lower than pressure of the overburden ice it would be possible to allow lake water to enter the hole and to freeze in it at a certain distance from the bottom after the drill reaches the ice—lake water interface. Then the re-frozen ice in the bottom part of the hole could be cored again in order to obtain lake water samples. The new thermal drill TBPO-132 and drilling operations which are necessary for the proposed method realization, are described.

1. Introduction

Discovery of sub-glacial Lake Vostok and growth of knowledge about it within the last decade were possible due to glaciological, microbiological, geophysical and satellite radar altimeter investigations, and numerical modeling (Jouzel *et al.*, 1999; Kapitsa *et al.*, 1996; Karl *et al.*, 1999; Lukin *et al.*, 2000; Priscu *et al.*, 1999; Ridley *et al.*, 1993; Salamatin *et al.*, 1998; Siegert and Ridley, 1998; Siegert *et al.*, 2000; Wüest and Carmack, 2000). They allowed us to specify the following parameters for this unique water body; area: 14000 km^2, length: 285 km, average width: 60 km, maximum depth: 800 m, ice cover thickness: 3700–4200 m, and maximum bottom sediment thickness: 330 m. It is assumed that the lake is fresh water one, that it is millions years old, that there is water circulation, and that it likely contains microorganisms. However, our understanding of the lake environment can not be confirmed or clarified unless *in situ* measurements and sampling are performed.

With this goal, and according to the directions issued by the Ministry of Science and

Technology of Russia to the Arctic and Antarctic Research Institute (AARI) and St. Petersburg Mining Institute (SPMI), a new long-term project was launched in 1999 with the aim to develop techniques and procedures for the ecologically safe lake penetration and exploration with the possible employment of the deep Hole 5G-1 at Vostok Station. In this paper we propose our approaches to access the lake and sample its water without contamination.

2. Lake Vostok and Hole 5G-1

Ice coring in the deep Hole 5G-1 at Vostok Station, situated above the southern end of the lake (Fig. 1a, b), was stopped in January 1998 at a depth of 3623 m (Fig. 1c). Multi-disciplinary studies of the ice retrieved (Jouzel *et al.*, 1999; Petit *et al.*, 1999), revealed paleoclimatic records for the past four glacial-interglacial periods, and established the existence of accreted basal ice at a depth of 3538 m and down to the hole bottom (Fig. 1c). This ice is believed to form the rest of glacial section that confirmed by the modeled tendency of the lake water re-freezing (with a rate of 1.1 ± 0.6 mm/year) at the ice—water interface at the southern lake end (Salamatin *et al.*, 1998). According to Popkov *et al.* (1999), and Lukin *et al.* (2000), the interface is located at a depth of 3750 ± 30 m, some 130 m below the bottom of Hole 5G-1. They also determined that the water layer and bottom sediments in the vicinity of the hole reach ~670 m and ~90 m thickness, respectively (Fig. 1c).

The hole itself, with internal diameter over 137 mm, is vertical from the glacial surface to 2200 m depth, but below this it deviates up to 6–8 degrees. When drilled, the hole was filled with aviation fuel TC-1 and freon 141B as a densifying agent (applied to maintain pressure compensation). At present, the hole contains 60 m^3 of drilling fluid with an average density of 928 kg/m^3, which fills it up to a depth of 95 m (Fig. 1c). The actual difference between the ice pressure and drilling fluid hydrostatic pressure is about 0.1 Mpa. This pressure difference leads to hole diameter contraction at a rate of about 0.1 mm/year.

3. Technology of penetration in and exploration of Lake Vostok

The proposed method to access Lake Vostok and to sample its water is based on "ice sheet—lake" system properties which are presently accepted: 1) the pressure at every point of the ice—water interface is equal to the weight of the floating overburden ice due to the closed state of the system; 2) there is re-freezing of lake water at the ice—lake interface in the southern part of the lake. It is proposed that by maintaining the hydrostatic pressure at the bottom of Hole 5G-1 slightly lower than pressure of ice it would be possible to allow lake water to enter into the hole and to freeze in it at a certain distance from the bottom after the drill reaches the ice—water interface. Then the re-frozen ice in the bottom part of the hole could be cored again in order to obtain lake water samples.

These seemingly simple procedures turn out to be difficult because of the presence of the potentially-contaminating drilling fluid that must not enter the lake. For this reason, we plan to maintain appropriate conditions in the hole prior and during the realization of our method, and to use the new equipment.

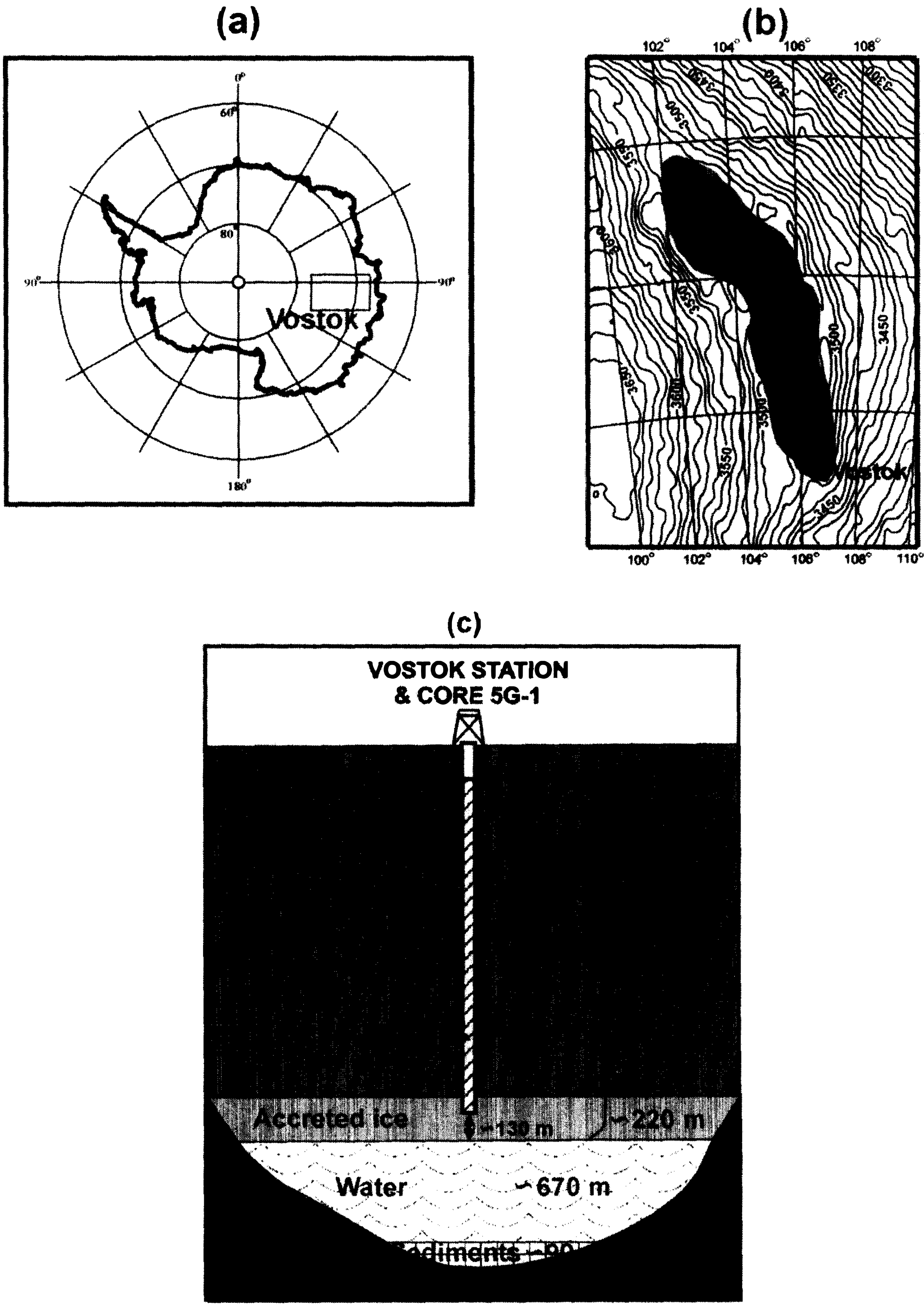

Fig. 1. *(a, b) Location of Vostok Station and Lake Vostok.*
(c) Summary on the deep Hole 5G-1 and Lake Vostok in the vicinity of Vostok Station.

3.1. Necessary conditions and equipment

Before penetration into the lake, an additional 100 m will be cored in Hole 5G-1 (Fig. 2). This can be accomplished with electromechanical drill KEMS-135, which has been successfully employed here (Kudryashov *et al.*, 1994, 2002). Stopped at a safe distance from the lake (~30 m), this operation should provide information on the lake history from the study of the resulting ice records. It will also make possible geophysical measurements in the immediate vicinity of the lake that may give additional information on the remaining part of undrilled ice (thickness, thermal-physical properties, etc.).

The next operation is the delivery of new liquid (presumably silicon oil) to the hole bottom by a special device (tanker). It is anticipated that, being heavier than the drilling fluid and lighter than water, this hydrophobic liquid will create a 100 meter-thick "buffer layer" of ecologically-friendly fluid at the bottom part of the hole (Fig. 2). The last operation prior to penetration into the lake is maintainance of hydrostatic pressure in the hole (P_{hole}) lower by ~0.3 Mpa than the pressure in the lake (P_{lake}) by removing excess volume of drilling fluid.

Drilling up to the ice—water interface will be carried out by thermal drill TBPO-132 (Fig. 3), which is now in being built at AARI and SPMI with using the previous experience (Kudryashov *et al.*, 1991). The drill of 6–7 m total length and 132 mm main outer diameter, includes: a heated pilot drill bit of 2 m length and 50 mm diameter (1), heated ring drill bit with truncated cone form (2), packer (3), pressure sensors (4, 5, 6), valve (7), pump (8) with a driving motor (9), electronics package (10), electrical compartment (11), hole bottom load sensor (12), cable lock (13), cable (14) with moveable bushing (15) and spring (16), and contact sensor (17). The contact sensor consists of a stock (18), sensing elements (19, 20), and spring (21). The drilling procedures will be controlled from the surface by operators using a control desk with sensor readings and information on drill system characteristics.

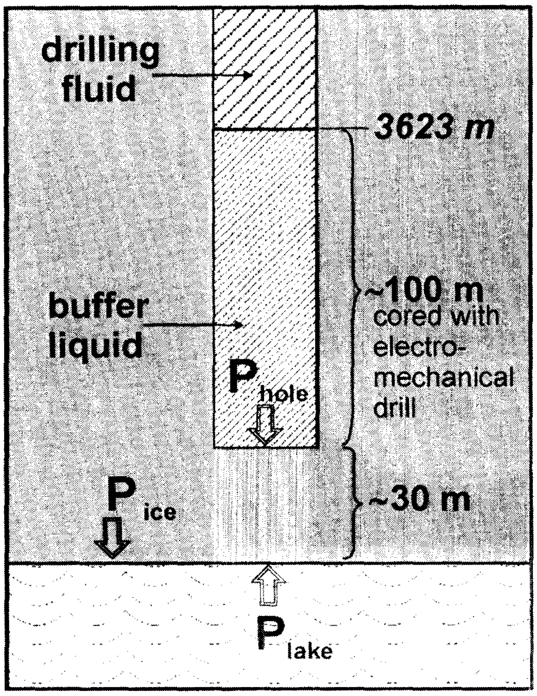

Fig. 2. Schematic of conditions in the near-bottom part of deep Hole 5G-1 before the penetration into Lake Vostok.

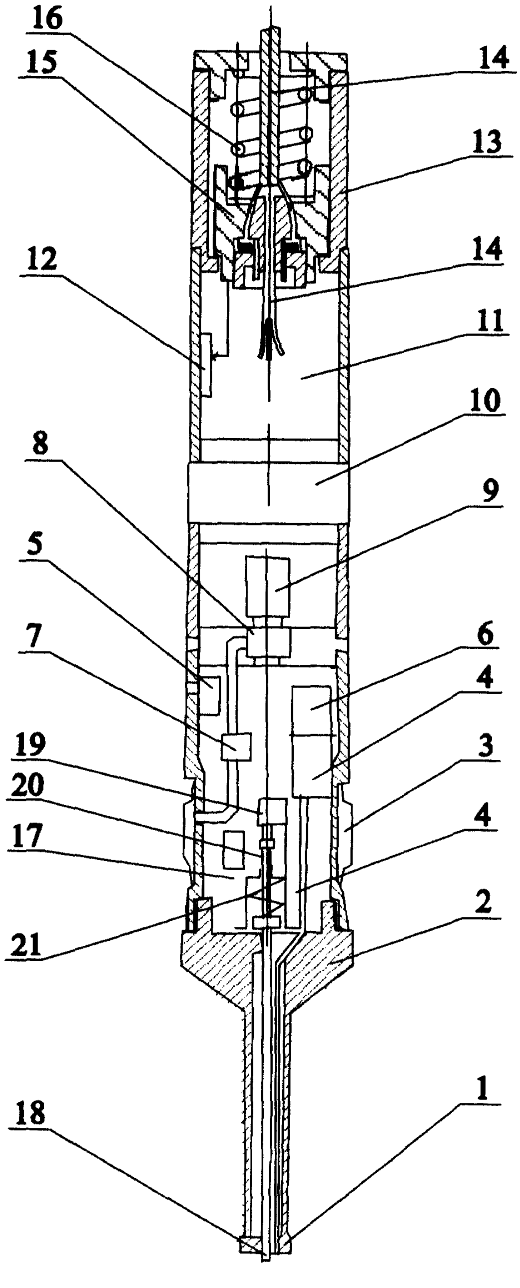

Fig. 3. Schematic of the thermal drill TBPO-132: 1-pilot drill bit, 2-ring drill bit, 3-packer, 4, 5, 6-pressure sensors, 7-valve, 8-pump, 9-driving motor, 10-unit of electronics, 11-electrical compartment, 12-sensor of the load on a hole bottom, 13-cable lock, 14-cable, 15-moveable bush, 16-spring, 17-contact sensor, 18-stock, 19, 20-sensing elements, 21-spring.

3.2. A scenario of the lake access and its water sampling

Thermal drilling of the remaining part of ice by the TBPO-132 drill will be carried out in one operation with an average advance speed of about 4 m/hr. The drill will create a narrow lower hole of ~50 mm diameter and ~2 m length followed by a conical form hole, and then by upper hole having the main drill diameter (~132 mm). During the process, the drill will be cleaned by the produced melt water, which will provide an additional ecologically-friendly layer separating the hole bottom and silicon liquid (Fig. 4a).

At the moment the tip of pilot drill bit touches the ice—water interface (Fig. 4a), the stock loses ice support and is pushed down by the spring, thus tripping the sensing elements and contact sensor. A signal from the latter arrives, via the electronics, to other drill

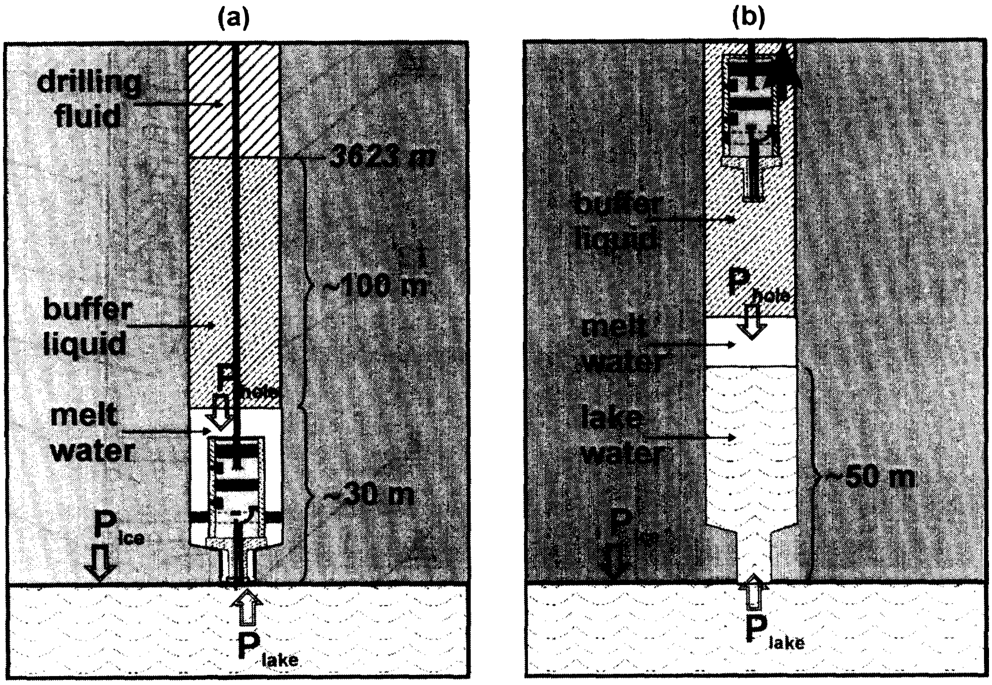

Fig. 4. Schematic of the project realization at the moment the drill tip touches the ice-water interface (a) and during the drill lifting (b).

components and to the control desk at the surface. In response, the packer is automatically turned on, and drill heating and movement are stopped: these actions should stop drilling and isolate the hole from the lake immediately (Fig. 4a).

The ensuing operation will depend on the readings of the pressure and contact sensors, permitting us to estimate the actual difference between pressure in the hole (P_{hole}) and in the lake (P_{lake}). In the most likely event that $P_{hole} < P_{lake}$ by the appropriate magnitude, the packer is released while the drill is lifted-this would allow lake water to enter and form a column in the hole (Fig. 4b). We suppose that the lake water flow will be rather slow because of small difference between P_{hole} and P_{lake} (~0.3 Mpa), heavy weight of the fluid and drilling equipment in the hole (~50 tons), and narrow space between the walls of drill and hole. Obviously, the lake water intrusion will follow mainly to the volume of the lifted drilling equipment, and a rate of this intrusion will decrease sequentially to zero value because of the same decreasing in the P_{hole} and P_{lake} difference. These processes should exclude the possibility of catastrophic lake water blowout and mixing of fluids and lake water in the hole due to a resonance effect. The height of the lake water column in the hole (40-50 m) is regulated then easily by the addition or removal of drilling fluid.

The situation with $P_{hole} > P_{lake}$ could result from an error in the preliminary calculations for the pressure and in turn may arise from unknown physical properties of the "ice sheet—lake" system. In this situation, simultaneously with touching the ice—water interface, the truncated cone form drill bit should be pressed against the ice in the narrowed section of the hole (Fig. 4a). Both the packer and the drill body will serve to isolate the lake from the hole. Then drilling fluid is withdrawn from the hole until the condition with $P_{hole} < P_{lake}$ is achieved. Operations then proceed as described above.

There is also a theoretical possibility also that water conduit, existing in the ice and connected with the lake, can be met during thermal drilling. In this case, the contact of the pilot drill tip with such a conduit will signify the lake access, and the above-described operations will proceed.

The preliminary results of numerical modeling, being carried out in SPMI and based on the known features of the ice sheet thermal regime at the southern end of the lake (Salamatin *et al*., 1998), show us that the entered lake water will freeze in the hole within one day. Once geophysical investigations, equipped by forward-looking sonar system or other facilities, confirm that the freezing in the hole is finished, coring of frozen lake ice can be made with the electromechanical drill KEMS-135 down to the horizon 10–15 m above the ice—water interface. This will allow sampling the lake water and will prevent any contamination of the lake.

4. Conclusions and future activity

The proposed technology may be considered as a concept for the ecologically safe penetration and pilot exploration of Lake Vostok, which enable progress in reconstruction of the lake history, elucidation of the thermal and physical conditions at the ice—lake water interface, and estimation of the chemical, isotopic, biological and other properties of the lake water surface layer.

Realization of the proposed technology seems rather simple in technical and logistical aspects. However, there are several major issues, which have to be resolved before the employment of this technology on Lake Vostok.

One of such issues is the execution of numerical modeling of thermal drilling process by the TBPO-132 drill. This should help us to estimate the possibility of complete collapse of the ice structure below the ring drill bit during the last phase of the thermal drilling.

Another issue is further improvements in the proposed technology. They include the development of procedure for the drilling/sampling equipment sterilization, the choice of the specific "buffer liquid" type, and the equipment of the TBPO-132 drill with additional systems. As an example, the water-sampling system can be installed here allowing us both to get some lake water at the moment of penetration (first sterile sampling), and to compare characteristics of this single sample with those investigated on the frozen lake ice. The last action looks very important because our technology does not guarantee the absolute absence of chemical, isotopic and biological changes, which may occur in the frozen lake water through its cross-contamination by drilling equipment/fluids or during its freezing in the hole.

The third issue is testing of the proposed technology. It should be carried out in the laboratory conditions and then in the field (on ice shelves or small sub-glacial lakes), and provide an information on improvements in technology and equipment, which are required for the ecologically safe and technically effective penetration and exploration of Lake Vostok.

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References

Jouzel, J., Petit, J.R., Souchez, R., Barkov, N.I., Lipenkov, V.Y., Raynaud, D., Stievenard, M., Vassiliev, N.I. and Vimeuz, F. (1999): More than 200 m of lake ice above sub-glacial Lake Vostok, Antarctica. Science, **286**, 2138–2140.

Kapitsa, A., Ridley, J.K., Robin, G. De Q., Siegert, M.J. and Zotikov, I. (1996): Large deep fresh-water lake beneath the ice of central East Antarctica. Nature, **381**, 684–686.

Karl, D.M., Bird, D.F., Björkmann, K., Houlihan, T., Shackelford, R. and Tupas, L. (1999): Micro-organisms in the accreted ice of Lake Vostok, Antarctica. Science, **286**, 2144–2147.

Kudryashov, B.B., Chistyakov, V.K. and Litvinenko, V.S. (1991): Bore-hole Drilling in the Condition of Rock Aggregate Changes. Leningrad, Nedra, 1–295 (in Russian).

Kudryashov, B.B., Vasiliev, N.I. and Talalay, P.G. (1994): KEMS-112 electromechanical ice core drill. Mem. Natl Inst. Polar Res., Spec. Issue, **49**, 138–152.

Kudryashov, B.B., Vasiliev, N.I., Vostretsov, R.N., Dmitriev, A.N., Zubkov, V.M., Krasilev, A.V., Talalay, P.G., Barkov, N.I., Lipenkov, V.Ya. and Petit, J.R. (2002): Deep ice coring at Vostok Station (East Antarctica) by electromechanical drill. Mem. Natl Inst. Polar Res., Spec. Issue, **56**, 91–102.

Lukin, V.V., Masolov, V.N., Mironov, A.V., Popkov, A.M., Popov, S.V., Sheremetyev, A.N., Verkulich, S.R. and Kuz'mina, I.N. (2000): The results of geophysical research of the subglacial Vostok lake (Antarctica) for the period 1995–1999. Problemy Arktiki i Antarktiki (Problems of Arctic and Antarctic), **72**, 237–248 (in Russian).

Petit, J.R., Jouzel, J., Raynaud, D., Barkov, N.I., Barnola, J.-M., Basile, I., Benders, M., Chappelaz, J., Davis, M., Delaygue, G., Delmotte, M., Kotlyakov, V.M., Legrand, M., Lipenkov, V.Y., Lorius, C., Pepin, L., Ritz, C., Saltzman, E. and Stievenard, M. (1999): Climate and atmospheric history of the past 420,000 years from the Vostok ice core. Nature, **399**, 429–436.

Popkov, A.M., Verkulich, S.R., Masolov, V.N. and Lukin, V.V. (1999): Seismic section at Vostok station area, Antarctica—results of studies in 1997. Mater. Glyatsiol. Issled. (Data Glaciol. Studies), **86**, 152–159 (in Russian).

Priscu, J.C., Adams, E.E., Lyons, W.B., Voytek, M.A., Mogk, D.W., Brown, R.L., Mckay, C.P., Takacs, C.D., Welch, K.A., Wolff, C.F., Kirshtein, J.D. and Avci, R. (1999): Geomicrobiology of sub-glacial ice above Lake Vostok, Antarctica. Science, **286**, 2141–2144.

Ridley, J.K., Cudlip, W. and Laxon, S.W. (1993): Identification of subglacial lakes using ERS-1 radar altimeter. J. Glaciol., **39**, 625–634.

Salamatin, A., Vostretsov, R., Petit, J., Lipenkov, V. and Barkov, N. (1998): Geophysical and paleo-climatic implications of the stacked temperature profile from the deep borehole at Vostok Station, Antarctica. Mater. Glyatsiol. Issled. (Data Glaciol. Studies), **85**, 233–240 (in Russian).

Siegert, M.J. and Ridley, J.K. (1998): An analysis of the surface and sub-surface topography of the Vostok Station sub-glacial lake, central East Antarctica. J. Geophys. Res., **103**, 10195–10207.

Siegert, M.J., Kwok, R., Mayer, C. and Hubbard, B. (2000): Water exchange between the sub-glacial Lake Vostok and the overlying ice sheet. Nature, **403**, 643–646.

Wüest, A. and Carmack, E. (2000): A priori estimates of mixing and circulation in the hard-to-reach water body of Lake Vostok. Ocean Modelling, **2**, 29–43.

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