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Lakes of the Bunger Hills (East Antarctica): chemical and ecological properties

ABSTRACT: The results of chemical and biological analyses of lake water samples, taken in the Bunger Hills during January—March 1987 by the participants of the 32-nd Soviet Antarctic Expedition from the new seasonal station „Oasis-2" (66°16'S and 110°45'E) are presented. It was discovered that the sea contributed considerably to the formation of intraoasis isolated reservoirs. The water of the epishelf lake — Transkripcii Bay — consists of two layers: upper freshwater (0,3—1,0‰) and lower salt water (19‰); the bottom water contains H_2S. The phosphate concentration varied from 3—8 mg l^{-1} in freshwater lakes to 37 mg l^{-1} in Rybij Chvost Bay (Pass Cove), where the high concentration of chlorophyll „a" (up to 10 mg l^{-1}) was found.

Key words: Antarctic, Bunger Hills, limnology.

Introduction

The scientific interest in Antarctic lakes has remarkably increased since the early seventies. This is explained by rich paleoevidence they contain. The lakes are formed during Pleistocene and Holocene on the bedrock, earlier covered by the glacier. These lakes are very sensitive to the changes of the latter. Since 1983 the Arctic and Antarctic Research Institute (Leningrad) has carried out a long-term Antarctic Lake Programme aimed at the investigation of their contemporary regime and at their relationship with the glacier and ocean. Full-scale observations are carried out on the lakes which have been poorly (or not at all) investigated earlier: in 1983—84 the lakes of the Bunger Hills

(Klokov, Kaup and Loopmann 1985, Kaup et al. 1988), in 1983—84 and 1984—85 Beaver and Radok Lakes (Piskun and Klokov 1986, Word et al. 1986) were studied. In January 1987 limnological observations were resumed in the Bunger Hills area, where a new Soviet seasonal station („OAZIS-2") at 66°16'S, 100°45'E was constructed. The paper discusses the chemical composition and biological properties of the water bodies.

Investigated area

Bunger Hills oasis is an ice-free area with the coordinates of its center being 66°10'S and 101°00'E, of the surface of 952 km^2 (Korotkevič 1958). In the central part of the oasis there is the largest local sea inlet Kakapon Bay with an

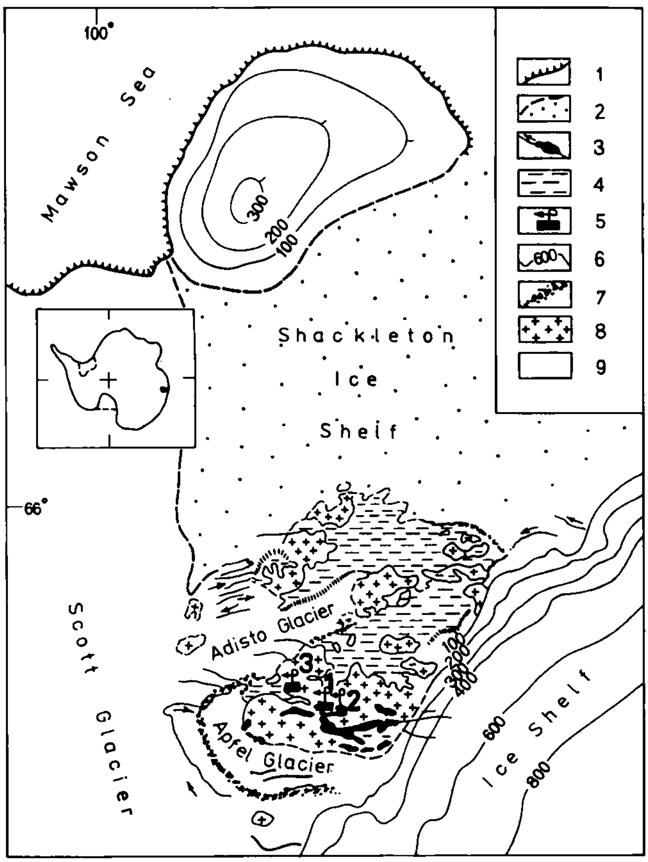

Fig. 1. The region of Bunger Hills 1 — coast line; 2 — shelf ice border; 3 — lakes and streams; 4 — sea inlets; 5 — scientific stations: 1 — „Oasis-2" (SU), 2 — „Dobrowolski" (Poland), 3 — „Edgeworth David" (Australia); 6— altitude lines; 7 — moraine; 8 — ice-free territories; 9 — continental glacier.

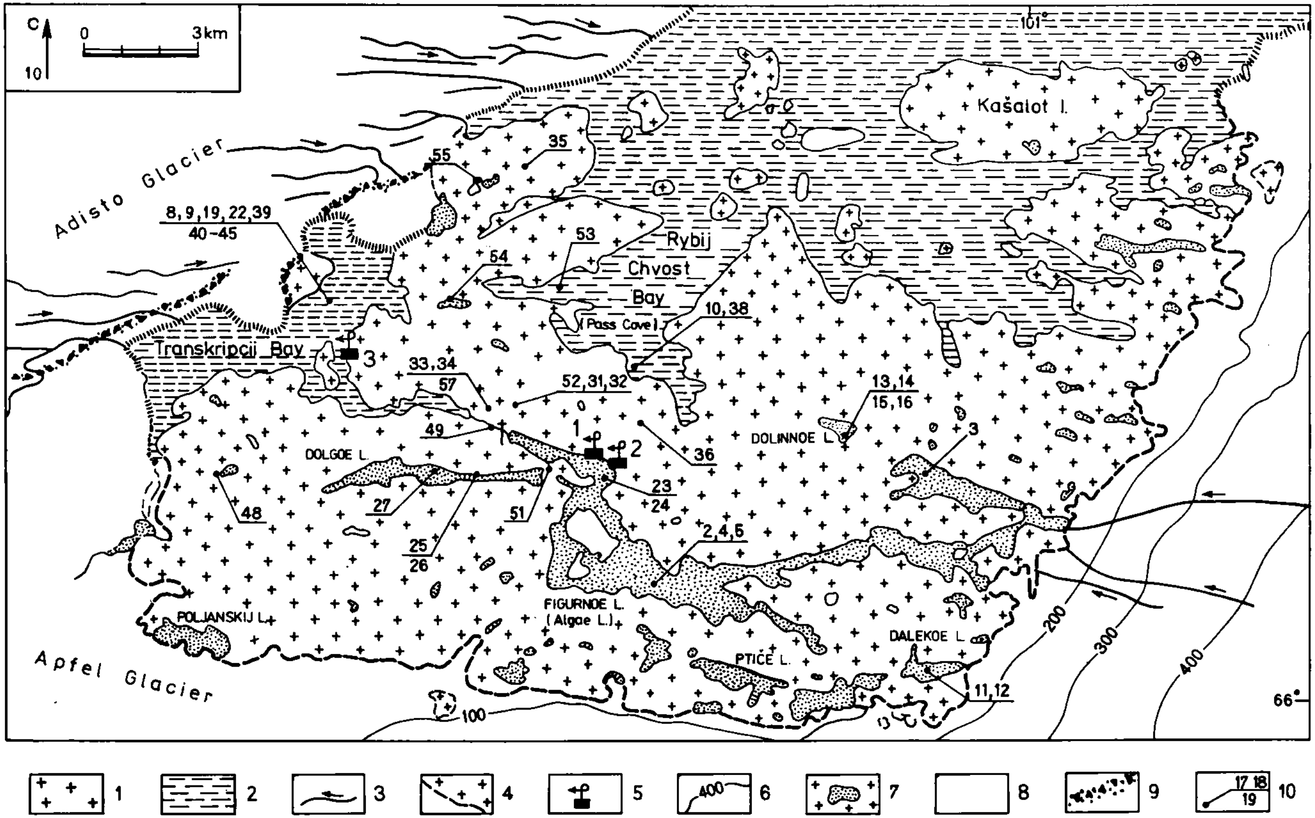

Fig. 2. The location of water samples for chemical analysis in Bunger Hills (numbers correspond to sample numbers in Tab. 1) 1 — ice-free territory; 2 — sea inlets; 3 — streams; 4 — border of continental glacier; 5 — scientific stations: 1 — „Oasis-2" (SU), 2 — „Dobrowolski" (Poland), 3 — „Edgeworth David" (Australia); 6 — altitude lines; 7 — lakes; 8 — continental glacier; 9 — moraine; 10 — sample numbers.

area of more than 400 km^2. This inlet is bounded by the bare bedrock and moraine material up to 10—12 km in width. There are numerous large and small islands in Kakapon Bay (Fig. 1).

The largest area of the icefree bedrock (263 km^2) is located in the southern part of the oasis and borders on the Adisto Glacier in the west, on Apfel Glacier in the south and on the continental ice slope in the east (Fig. 2). The surface of this part is rather low with a maximum altitude of 165 m above sea level, the relief is not much pronounced. Ranges of smoothed hills and several shallow valleys are extending from east to west and to north-west. Few valleys are connected with sea inlets and form narrow bays of fjord-type like Rybij Chvost Bay (Pass Cove). Hundreds of large and small lakes are located in the valleys and land depressions. The total area of the lakes is about 36 km^2 covering 6—7% of the oasis bedrock. Professor E. S. Korotkevič was the first to describe the physiographic conditions in Bunger Hills (1958) on the basis of observations made in the area in 1955—57. On the basis of meteorological obsevations Rusin (1961) has shown that the local climate is milder compared to that at the same latitudes at the Antarctic coast. The annual net radiation balance is positive, constituting 35—40 Kcal cm^{-2}. Mean annual air temperature is $-9{,}1°C$. The ground temperatures are above freezing point during four months. The low air humidity (the lowest registered value was 12 per cent) results in high potential evaporation which is estimated as 450—600 mm per year.

The abundance and diversity of lakes are the most typical features of the local landscape. The discoverer of the oasis U.S. pilot D. E. Bunger named the area in 1947 „a land of blue and green lakes" (Byrd 1947). However, though the water bodies attracted the attention of the scientists visiting the area, systematic limnological observations were not carried out. Scarce data on chemical and biological properties of the lakes were obtained during the IGY and afterwards (Vinogradov 1957, Korotkevič 1958, Grigor'ev 1960). An attempt to summarize the data on the lakes of Bunger Hills was made by Wiśniewski (1983).

Methods

The samples were taken and soundings were carried out from January 19 to March 15, 1987 in the southern part of the Bunger Hills area; observations were made either from the ice or from the boat. More than 20 water bodies were studied. The paper discusses the results of the analysis of water samples from 11 lakes, isolated from the melt water inflow, 2 lakes with the melt water inflow, i.e. Figurnoe Lake (Algae Lake) and Dolinnoe Lake, and from sea inlets, namely Transkripcii Bay and Rybij Chvost Bay (Pass Cove). Water samples were taken with plastic bathometers and stored in the polyethylene bottles. Samples for the main ion analysis were sealed in bottles and stored in a cold room with the temperature not higher than 5°C. The analysis of main ions was performed after the expedition in the Institute of Geography and Geoecology of the GDR Academy of Sciences in Leipzig by R. Zierath. Kations were determined by atomic absorption spectrophotometry (Mg, Ca) and flame emission photometry (Na, K). For the anions (Cl, SO_4) different analytical methods were used, depending on the concentrations of the anions (Kaup et al. 1988). The carbonates (HCO_3, CO_3) were titrated in the field with HCl. The pH was determined shortly after sampling by means of glass electrodes. The dissolved O_2 was measured in situ by means of the OXYMET instrument constructed in the Tallin Polytechnic Institute. The total mineralization was measured in the field. The total phosphorus and nitrates were determined by routine spectrophotometric techniques with the „SPECOL" spectrophotometer which was also used for the determination of the chlorophyll „a". Magnesium carbonate was used against acidification, the filters were extracted with acetone. The well-known formula were used.

Results

Total mineralization and main ions. The chemical composition of waters corresponds to the conditions of water body formation and to their subsequent water exchange. The transit-flow lakes such as Figurnoe and Dalekoe Lakes are slightly mineralized (17—18 mg l^{-1}), the prevailing ions are Na, Ca, Cl, SO_4. The stability of the chemical composition of the water in Figurnoe Lake reflects a strong vertical and horizontal mixing in the lake (Tab. 1). The lower values of the main ions in lakes show their feeding regime determined by the glacier melting and a long period of the positive water balance. The effect of sea salts on the lake water chemical composition is not detectable.

The water bodies isolated from the glacial melt water inflow display a remarkably higher mineralization and the prevailing ions are Na and Cl (the lowest mineralization of about 110 mg l^{-1} was measured in Dolgoe Lake, the highest values (22‰) were measured in an unnamed lake — sample number 54). As a rule no vertical gradients of ions were found. The lakes of this group are subdivided into lakes with melt water and those which are filled with sea water. Such differences are clearly reflected in Fig. 3. The points which are very closely concentrated near the sea water points show the marine origin of the lakes with sample numbers 35, 54, 55. The ionic relation Mg/Ca is between 2,2 and 23 in these lakes which is unusually high for the continental waters. Thus, a significant influence of the sea is very probable during the formation of these lakes. It is possible that they were separated quite recently from Kakapon Bay, resulting from the isostatic uplift of the continent in Holocene. Such lakes with light mineralization and ionic ratios typical of marine water are found in

Table 1

Hydrochemical characteristics of water bodies of Bunger Hills; (ions concentrations in mg l^{-1}; x— not determined).

Water body	Sampling site	Depth (m)	Na	K	Ca	Mg	Cl	So_4	$CO_3 +$ HCO_3	pH	Conductivity	Sampling date
Lakes with glacial melt water through flow												
Figurnoe (Algae) Lake	23	0,5	4,0	0,7	3,1	1,0	8,1	5,5	2,9	7,3	38	01.03.87
	2	1	3,5	0,7	3,0	0,8	6,5	5,0	x	7,2	31	13.03.87
	3	36	3,5	0,6	3,1	0,8	8,0	7,5	3,8	7,3	31	06.03.87
	24	40	4,0	0,7	3,0	0,8	7,6	9,0	3,3	7,2	36	01.03.87
	4	80	3,0	0,5	3,1	0,8	6,7	9,0	x	7,1	31	13.03.87
	5	134	3,0	0,6	3,1	0,8	5,0	5,0	x	7,0	31	13.03.87
Dalekoe Lake	12	0,5	2,0	0,7	1,6	0,7	5,0	5,0	2,1	6,9	19	12.03.87
	11	40	1,5	0,6	1,6	0,6	3,3	5,0	1,8	6,9	16	12.03.87
Isolated lakes of glacial origin												
Dolgoe Lake	25	0,5	32,0	2,9	9,0	6,5	47,0	6,0	12,6	8,0	193	20.02.87
	26	30	32,9	2,9	8,5	5,3	70,0	5,0	11,5	8,1	192	20.02.87
	27	60	33,0	3,0	8,5	5,5	52,0	6,0	11,8	7,7	200	20.02.87
Dolinnoe Lake	13	1	150,0	20,0	23,0	36,0	490,0	8,5	49,0	8,6	857	05.03.87
	14	10	150,0	20,0	23,0	35,0	230,0	9,5	48,0	8,6	885	05.03.87
	15	30	160,0	20,0	28,0	39,0	295,0	9,5	49,0	8,5	1000	05.03.87
	16	38	160,0	30,0	30,0	39,0	285,0	8,0	46,0	8,5	985	05.03.87
Unnamed Lake	48	0	150,0	10,0	16,8	17,5	210,0	7,0	26,4	8,3	715	21.01.87
Isolated lakes of sea origin												
Zapadnoe Lake	57	0	200,0	20,0	10,5	23,0	405,0	33,0	x	8,0	1170	19.01.87
	33	2,5	1600,0	95,0	55,0	150,0	2070,0	120,0	43,0	8,6	6640	09.03.87
	34	4,5	1600,0	95,0	60,0	145,0	2740,0	120,0	43,0	8,7	6420	09.03.87

Vostočnoe Lake	52	0	1700,0	40,0	60,0	145,0	2990,0	135,0	x	8,6	6450	19.01.87
	31	2	1700,0	95,0	55,0	170,0	2350,0	120,0	50,0	8,8	7140	09.03.87
	32	5	1750,0	100,0	60,0	185,0	3100,0	135,0	50,0	8,8	5710	09.03.87
Srednee Lake	36	0	12500,0	615,0	275,0	1180,0	19200,0	1680,0	8,6	7,7	31760	08.02.87
Unnamed lakes	54	0	8500,0	438,0	50,0	1155,0	20480,0	2210,0	28,0	8,1	37990	08.02.87
	55	0	320,0	20,0	18,5	36,0	735,0	46,0	8,6	7,7	1865	08.02.87
	35	0	300,0	20,0	9,0	32,0	635,0	37,0	7,0	7,6	1570	10.02.87
Sea inlets												
Transkripcii Bay	39	2,8	100,0	20,0	5,1	8,1	230,0	15,0	2,4	7,2	490	11.02.87
	40	5	230,0	20,0	10,0	20,0	460,0	33,0	1,4	7,4	1230	11.02.87
	41	10	250,0	20,0	11,5	28,0	605,0	34,0	1,4	7,4	1430	10.02.87
	43	30	280,0	30,0	11,5	26,0	570,0	41,0	1,8	7,8	1390	11.02.87
	8	50	520,0	31,0	11,5	26,0	545,0	36,0	x	7,8	1390	11.02.87
	19	88	650,0	50,0	25,0	50,0	1010,0	72,0	3,4	6,6	2855	09.02.87
	9	89	1210,0	69,0	40,0	53,0	1150,0	81,0	x	x	2998	09.02.87
	44	93	7100,0	390,0	270,0	650,0	12340,0	1110,0	36,0	7,3	24630	09.02.87
	45	99	7750,0	375,0	595,0	905,0	16000,0	660,0	43,0	7,4	32120	09.02.87
	22	104	9600,0	475,0	410,0	860,0	16000,0	1220,0	49,0	7,5	30540	09.02.87
Rybij Chvost Bay (Pass Cove)	10	0,5	4600,0	265,0	140,0	375,0	8430,0	525,0	13,8	8,6	16420	27.02.87
	38	5	8250,0	415,0	520,0	875,0	16350,0	1260,0	29,0	8,4	34300	27.02.87
	53	33	8925,0	475,0	410,0	1010,0	18145,0	1675,0	31,0	7,7	37270	01.02.87
Temporary inter-lake streams												
Streams	51	0	33,0	2,9	7,0	5,5	46,0	12,0	11,6	7,8	195	27.01.87
	49	0	5,0	0,6	3,2	1,1	7,8	5,5	3,7	7,1	x	28.01.87
Precipitation												
Region of „Mirnyj" stat.		0	1,04	0,16	0,067	0,20	0,74	0,17	x	5,8		1970—79[a)]

[a)] according to Ščerbakov, Mel'nikov and Petrov (1984).

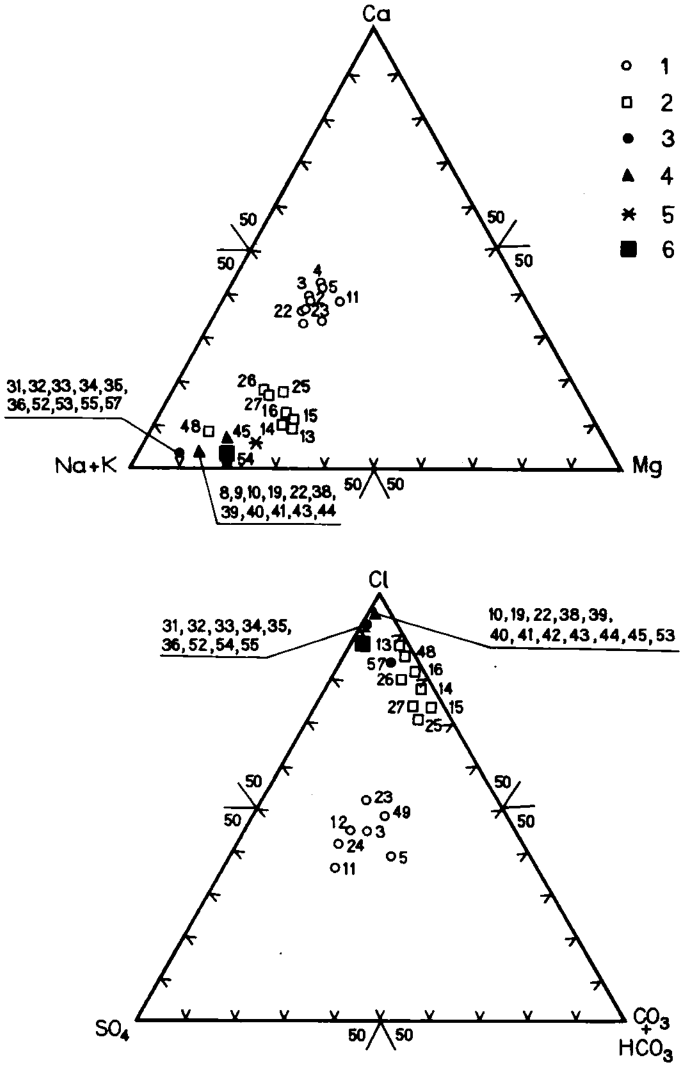

Fig. 3. The chemical composition of waters in Bunger Hills (equiv. in %) 1 — lakes with glacial meltwater throughflow; 2 — isolated lakes of glacial origin; 3 — isolated lakes of sea origin; 4 — sea inlets; 5 — precipitation (Ščerbakov, Mel'nikov and Petrov 1984); 6 — seawater. The numbers correspond to the sample numbers in Tab. 1.

Vestfold Hills (Burton 1982) and around Lutzow-Holm Bay (Torie et al. 1977). Their ages are estimated to be about 6000 years.

Dolgoe and Dolinnoe Lakes and the one without name with sample number 48 are separated from the glacial melt-water inflow quite recently, this resulted in volume decrease and mineralization which is 5 times larger due to its longer isolation from the Figurnoe Lake system. The source of contemporary feeding of these lakes, i.e. the local snow fields, is also of different importance, since the valleys of both lakes are differently oriented with relation to the prevailing winds and snow storms. The main ionic ratios in the waters of these lakes correspond to those of precipitation (see Fig. 3). The lower content of SO_4 could be explained with freeze up and crystallization of Na_2SO_4 in the littoral part of the lakes. These salts are accumulated in deeper parts of the lakes. The vertical profiles of salinity in sea inlets are substantially different. The water of Transkripcii Bay consists of two clearly different layers. The higher layer with the salinity of 0,3—1,0°/₀₀ has the thickness of 88 m in the central part of the Bay. The salinity grows with the depth up to 11°/₀₀ at 93 m and 19°/₀₀ at 104 m (bottom). A similar salinity distribution pattern was detected in Beaver Lake (Piskun and Klokov 1986). The lower salt water layer in Traskripcii Bay is different, it is anaerobic (all samples taken under the halocline contained H_2S). It is probable that the canals in the Adisto glacier which connect this bay with the Kakapon Bay, are situated above the halocline (both bays have similar tides).

There is no freshwater layer in the Rybij Chvost Bay and the salinity grows from 9°/₀₀ under the ice to 18,6°/₀₀ near the bottom. Here the connection with the ocean is obviously more free than in Transkripcii Bay and the ocean water is diluted with the fresh water inflow and melting of icebergs.

The ionic ratios of the waters of the Transkripcii Bay are similar to the seawater (except ratio Cl/SO_4) and are not much changing with depth. The waters of Rybij Chvost Bay have clearly oceanic origin. The water type in both bays is Na—Cl.

pH—value. The waters of Bunger Hills show neutral or weak alkaline reaction. Since the mean annual pH of the precipitation of this region is 5,8 (Ščerbakov, Mel'nikov and Petrov 1984), the increase of pH in lake waters results obviously from the leachout of bedrock and moraine. A pH value of about 6,9 was found in lakes with glacial feeding i.e. Figurnoe, Dalekoe and Burevestnik Lakes. In the first lake after releasing from the ice cover the water had pH of 7,2—7,4. In the brackish lakes Vostočnoe and Zapadnoe the pH values were 8,6—8,8, in other lakes, isolated from glacial melt waters the pH was 7,6—8,3. In the Rybij Chvost Bay the pH was 7,7—9,3, the highest value coincided with the maximum of chlorophyll amount and, consequently, with the intensive uptake of CO_2 from the water in photosynthesis. In the Transkripcii Bay the pH was 6,6—7,8, the minimum was recorded at the depth of 88 m, at the border of the aerobic and anaerobic zones, and is related to the oxidation of the H_2S.

$$H_2S + 2\,O_2 = SO_4^{2-} + 2\,H^+$$

Dissolved oxygen. In the water bodies completely or partly ice-free the O_2 content was measured to be near the saturation. In the station bay of Figurnoe Lake (Algae Lake) the content of O_2 before the noon were somewhat lower than in the afternoon, as a result of photosynthesis. Except of the lower layer in the Transkripcii Bay, there were no anaerobic conditions in water bodies. Under the ice cover there was normally a supersaturation with O_2. In the water of lake Dolinnoe O_2 saturation was 118%, in the Vostočnoe, Zapadnoe and Srednee lakes it was 122, 122 and 125%, respectively. But in Dalekoe lake on 12 March at 2 pm there was only 93—96% of saturation with O_2. In the lower part of Rybij Chvost Bay considerable oversaturations (109—153%) were registered once more correlated with intensive phytoplankton development in this bay.

Nutrients. In the Antarctic continent the nutrients originate mostly from the precipitation. In 5 samples of fresh snow, gathered from February to March, there was 4—16 mg P l^{-1} of total phosphorus and 2—10 mg P l^{-1} of ionic phosphorus. These values are about 2 times higher than in Schirmacher Oasis (Kaup 1984, 1988). The mean value of nitrites 0,8 mg N l^{-1} corresponds to that in the precipitation in the Schirmacher Oasis and mean valus of nitrates 11 mg N l^{-1} are about 3 times lower.

In waters of the majority of lakes quite low concentration of phosphates (3—8 mg P l^{-1}) and nitrates (2—5 mg N l^{-1}) were met, the concentrations of total phosphorus often exceeded 10 mg P l^{-1}. Quite high concentrations of phosphorus and nitrates were met in the sea inlets. In Rybij Chvost Bay the concentrations of total phosphorus reached 37 mg P l^{-1} and of nitrates 186 mg N l^{-1} (Tab. 2). Such data show that the primary part of phosphorus is less bounded by planktonic cells and dissolved organic material. The strong impact of seawater, enriched with nutrients, is also to be seen. The concentrations of phosphorus and nitrates in the upper part of Transkripcii Bay are comparable with those in lakes of oasis, but reached high values of phosphorus (up to 850 mg P l^{-1}) near the bottom. Here the phosphates are entering into the water from the anaerobic sediments.

The concentrations of silica in lake waters of Bunger Hills are mostly from several to 10 mg Si l^{-1}. In lakes isolated from the glacial melt-water inflow the concentrations up to 20—30 mg Si l^{-1} do not show a strong leachout from bedrock and moraine.

Chlorophyll „*a*". The majority of the lakes observed show very low concentrations of chlorophyll „*a*". The lowest values of about 0,1 mg l^{-1} were found in the beginning of February in Lake Figurnoe, later on they had increased up to 0,2 mg l^{-1} in the middle of March. In Lake Dolgoe the values of 0,1—0,4 mg l^{-1} and in Lake Dolinnoe of 0,3—0,6 mg l^{-1}, in the brackish lakes Zapadnoe, Vostočnoe and Srednee they were 0,7—1,0 mg l^{-1}. Quite high values (1,8—3,2 mg l^{-1}) for the Antarctic ultrafresh water lakes were found in Lake Dalekoe. The development of phytoplankton is here probably stimulated with the inflow of nutrients with the glacial melt-water.

Quite low concentrations of chlorophyll „*a*" were recorded in the main part of Transkripcii Bay, about 0,1—0,3 mg l^{-1} (Tab. 2). But the Rybij Chvost Bay had a very high productivity and the concentration of chlorophyll „*a*" was here

Table 2
Hydrological data on some chosen water bodies of Bunger Hills; (x not determined)

Depth (m)	T (C)	Salinity ( )	PO_4-P (mg l^{-1})	NO_3-N (mg l^{-1})	O_2 (mg l^{-1})	Chlorophyll „a" (mg l^{-1})
			DOLINNOE LAKE, 5 March 1987			
1	1,9	0,53	5	4,5	13,0	0,26
5	2,2	0,54	5	5,2	13,2	0,26
10	2,4	0,54	6	4,8	12,8	0,29
20	2,8	0,54	5	4,8	13,2	0,25
30	4,8	0,57	5	5,0	13,3	0,48
38	5,6	0,58	4	5,0	13,0	0,59
			RYBIJ CHVOST BAY, 27 February 1987			
0,5	0,2	9,00	5	7,1	17,8	6,98
5	0,0	17,20	1	6,5	20,8	9,65
10	0,3	17,20	6	6,9	18,7	2,80
20	−0,9	18,60	37	186,0	15,3	0,94
			TRANSKRIPCII BAY, 11 February 1987			
3	x	0,27	8	13,1	x	0,14
5	0,4	0,61	6	9,8	x	0,13
10	0,3	0,73	6	4,6	x	0,19
20	0,3	x	8	3,8	x	0,08
30	0,3	0,75	6	2,4	x	0,27
50	0,4	0,75	8	3,5	x	0,12
88	0,0	1,00	16	2,4	x	x
93	−0,1	1,00	648	3,3	x	x
99	−0,2	18,60	752	6,1	x	x
104	−0,3	19,00	848	0,0	x	x

1—10 mg l^{-1}, i.e. of 1—2 orders of magnitude higher than in Figurnoe Lake. It seems, that the melt water with the abundance of nutrients favour the development of sea diatoms here.

Zooplankton and benthos. Small (about 1 mm) orange coloured copepod crustaceans were found in the majority of the above mentioned water bodies of oasis (excluding brackish lakes Vostočnoe, Zapadnoe, Srednee). Caught with plankton net, they were found to grow in quantity towards the bottom. Probably this crustacean was *Acanthocyclops mirny* (Boruckij and Vinogradov 1957), discovered already in 1956.

At the bottom of Rybij Chvost Bay at the depth of 11 m the diver G. A. Kadačigov has found a very rich bottom fauna, consisting of sea-urchins, sea-stars, oligochaetes, sponges and bivalves. Meadows of red algae were also met. Fishes of at least 2 different species were caught and a Weddell seal was met on the ice cover in the middle of March. The further study of samples of flora and fauna will probably help to estimate how long the relative isolation of the sea inlets of Bunger Hills has lasted and how this isolation has influenced the diversity of water organisms.

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Streszczenie

Praca zawiera wyniki hydrochemicznych prób wody jazior oazy Bunger Hills, pobranych w okresie od stycznia do maraca 1987 r. przez uczestników 32 Radzieckiej Ekspedycji Antarktycznej do nowej, sezonowej stacji „Oazis-2" (66°16'S, 110°45'E). Okazało się, że wody morskie miały znaczny udział w formowaniu się izolowanych obecnie zbiorników oazy. Wody epi-szelfowego zbiornika wodnego — Zątoki Transkripcii — składa się z dwu warstw: górnej, słodkowodnej (0,3—10‰ S) i ddolnej, słonowodnej (19‰ S); woda przydenna zawiera H_2S. Zawartość fosforanów wahała się od 3—8 mg l^{-1} w jeziorach słodkowodnych do 37 mg l^{-1} w Zatoce Rybij Chvost (Pass Cove), gdzie stwierdzono też wysoką zawartość chlorofilu „a" (do 10 mg l^{-1}).