

Organic Compounds in the Snow–Ice Cover of Eastern Antarctica

I. A. Nemirovskaya

Shirshov Institute of Oceanology, Russian Academy of Sciences, Nakhimovskii pr. 36, Moscow, 117997 Russia
e-mail: *nemir@geo.sio.rssi.ru*

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Abstract—This paper presents data on the concentration and composition of organic substances, lipids, and hydrocarbons, in the snow–ice cover of fast ices and continental lakes of Antarctica. It was shown that organic compounds were accumulated in the layers with the most intense autochthonous processes (mainly at the snow–ice and ice–water boundaries). These zones remain active at a biogeochemical medium even at low temperatures. The maximum content of organic compounds (10–20 times that of the snow–ice cover of other regions) and a sharp change in the proportions of their migration forms in the ice volume were detected in the regions of penguin colonies (fast ice at Buromsky Island and a lake in Haswell Island). The content and composition of hydrocarbons in Antarctic ices were compared with those of Arctic ices.

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INTRODUCTION

Snow and sea ice have been subject to extensive studies, primarily because they are important agents transporting various compounds from shore regions to the open ocean. It was shown [1] that falling snow efficiently removes aerosol material from the atmosphere. Ice captures chemical elements and components of natural and anthropogenic origins and transports them from inner shelf areas into the open ocean. The investigation of organic compounds in the Arctic region (Franz–Victoria trough, Barents Sea; Mendeleev Rise, Arctic Ocean) showed that their content and distribution are controlled by the character of formation and circulation of air masses and ice drift [2, 3]. These studies were continued in the snow–ice cover of the fast and lake ices at the regions of the following Russian Antarctic stations (Fig. 1): Molodezhnaya, Cosmonaut Sea; Progress, Prydz Bay, Commonwealth Sea; and Mirnyi, coastal part of the Davis Sea during Russian Antarctic Expeditions 46 and 48 in April–May 2001 and March–April 2003, respectively, and cruises 17 and 18 of the R/V *Akademik Fedorov*. The goal of this work was to evaluate changes in the content and composition of organic compounds [lipids, aliphatic hydrocarbons (AH), and polycyclic aromatic hydrocarbons (PAH)] during the growth of fast ices of various types and in the snow–ice cover of Antarctic continental lakes. Such data are also important for the investigation of the global carbon cycle and for the determination of the background concentrations of compounds of natural or anthropogenic origin.

In contrast to the Arctic, sea ice plays a smaller role in the Antarctic sedimentary process, because the source areas of sedimentary material are blocked by ice

walls bounding the Antarctic ice sheet [1]. Unlike Arctic pack ice, the major portion of Antarctic sea ice forms seasonally. The removal into the ocean of considerable amount of snow, which does not melt owing to low air temperature, results in the formation of a slush layer on the sea surface, up to several tens of centimeters thick [4]. The slush is accumulated on the sea surface, freezes, and transforms into young ice, an aggregate of crystals with parallel axes containing brine droplets and pockets. The first ice crystals form on the open water surface at a temperature of -1.8°C . These crystals impart “oily” properties to the water, and such an ice is therefore referred to as a grease. Pancake ice or nilas is formed subsequently depending on the presence or absence of waves on the sea surface. By growing fast, ice is formed, and the thickness of the ice cover increases. The nonuniform distribution of snow on the ice surface and processes of seawater infiltration result in the development of ice layers with peculiar crystal structures and physical and biological properties, which must influence the content and composition of organic compounds in the snow–ice cover.

METHODS

Special care was taken to prevent contamination [2, 3] during the sample collection and analysis (207 samples). Ice cores were recovered in snow–ice plots using a manual titanium ring borer ($d = 14.5$ cm) and cut with a saw taking into account their structure. The blocks of the cores were placed into special tanks. In order to obtain large amounts of water, 10–15 cores were simultaneously thawed for 2.0–2.5 days.

The samples of ice slush and nilas were collected using a special triangular net screen (pore size of

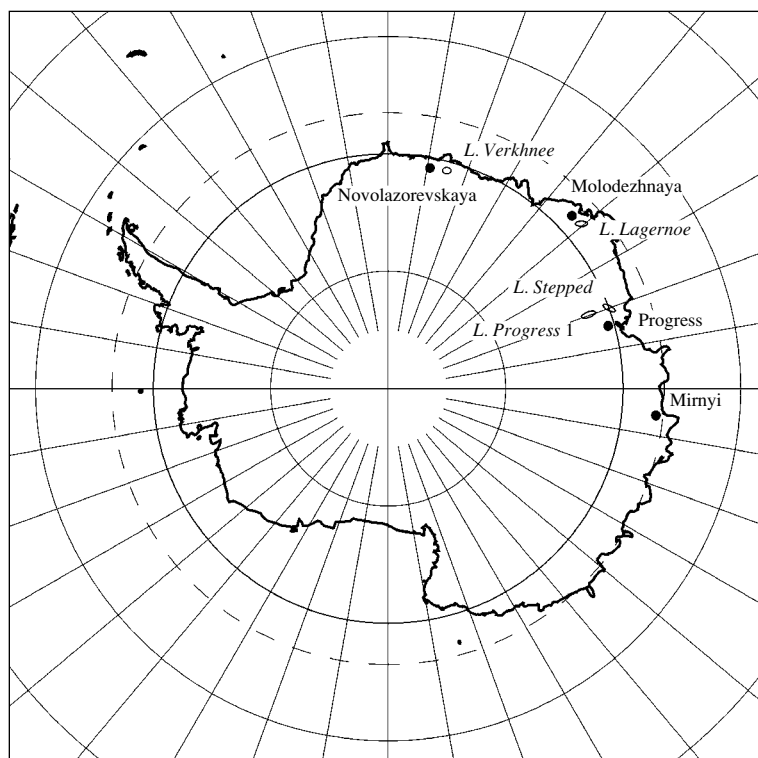


Fig. 1. Location of the main sites studied in Antarctica.

1 mm²), which was recommended for the sampling of the surface microlayer [5]. The melt water was treated by the same procedure as the snow samples.

Lipids were extracted with chloroform. The concentration of lipids (before silica-gel column chromatography) and aliphatic hydrocarbons (after silica-gel column chromatography) were measured by IR spectroscopy on an IR-435 Shimadzy instrument (Japan). A mixture of 37.5 vol % isooctane, 37.5 vol % hexadecane, and 25 vol % benzene was used as a standard. It was prepared from an ampoule of the standard GSO 7248-96 solution provided by AOZT Ekros. The contents and properties of alkanes were measured by capillary gas chromatography on a TBT chromatograph (France) using squalane as a standard (Laboratory of the Chemistry of Oceans, Shirshov Institute of Oceanology, Russian Academy of Sciences; analyst V.I. Perypkin). The concentrations and compositions of PAH were determined by high performance liquid chromatography (HPLC) on a Milikhrom instrument (Russia) equipped with a KAKh-4 reversed-phase C₁₈ column. An acetone–water mixture (75 : 25) was used as an eluent. The measurements were performed at 254 nm. The identification was conducted from the time of release of individual polyarenes obtained from a laboratory of the Environmental Protection Agency (USA). The following unsaturated arenes were identified: phenanthrene (Ph), anthracene (A), fluoranthene (FL), pyrene (P),

triphenylene (TR), chrysene (CR), perylene (PL), and benzo(a)pyrene (BP).

RESULTS AND DISCUSSION

Snow

The snow collected from the fast ice of the Prydz Bay showed AH contents below the detection limit of the analytical method (Table 1) and lower than in the Arctic Ocean at the region of the Mendeleev Rise, where the AH concentration was 3 µg/l in the dissolved form and 1 µg/l in the suspended form [3]. It is obvious that a negligible amount of AH is supplied from the atmosphere with snow. The Antarctic atmosphere is characterized by a very low content of terrigenous aerosol [1]. Because of this, AHs occur mainly in dissolved forms despite their low solubility. The snow of the coastal areas of Antarctica is usually contaminated by sea salts supplied from seawater [6] and, to a lesser extent, by specific Antarctic flora and microorganisms. The eolian input of terrigenous organic compounds (remnants of higher terrestrial plants) from America and Africa is negligible [7].

However, their content in the snow on fast ice at the region of the Mirnyi station increased after a strong snowfall and became higher than that of the surface water (Table 1, Fig. 2a). The amount of transported snow at a wind velocity of 12–15 m/s may be as high as 800 kg per meter per hour [6]. The seasonal fast ice of

Table 1. Concentrations of organic substances and suspension in various forms of sea ice

Description	Horizon, cm	Suspension, mg/l	C _{org} , µg/l	Lipids, µg/l	AH, µg/l	Lipids, µg/mg susp	AH, µg/mg susp
<i>Molodezhnaya Station, 67°34' S; 46°05' E</i>							
<i>Cosmonaut Sea, Alashev Bay, April 24, 2001</i>							
Slush		1.6	180	149	81	93.1	50.6
Subice water		1.3	160	94	63	72.3	48.5
<i>Progress Station, 69°22' S; 76°23' E</i>							
<i>Commonwealth Sea, Prydz Bay, May 2, 2001</i>							
Nilas		1.7	60	21	7	12.4	4.1
Subice water		1.0	50	12	3	12.0	3.0
<i>Mirnyi Station, 66°31' S; 92°55' E</i>							
<i>Davis Sea, April 3–5, 2003</i>							
Slush		1.4	560	77	19	54.2	13.4
Pancake ice		0.4	183	52	13	123.8	31.0
Nilas	0–10	0.6	300	62	12	103.3	20.0
Subice water		0.2	80	28	5	121.7	21.7
<i>Progress Station, 69°13' S; 76°18' E</i>							
<i>Commonwealth Sea, Prydz Bay, April 29, 2001</i>							
Snow	0–10	1.8	30	3	0	1.7	0.0
Ice	0–10	6.8	280	46	11	6.8	1.6
	20–30	2.3	480	121	13	53.1	5.7
	30–40	1.7	720	118	38	70.2	22.6
Subice water		1.3	60	14	3	10.7	2.3
<i>Mirnyi Station, 66°31' S; 92°55' E</i>							
<i>Davis Sea, May 13, 2001</i>							
Snow	5–15	2.6	80	15	8	5.8	3.1
Ice	0–15	5.5	100	29	4	5.3	0.7
	15–33	4.8	40	44	7	9.1	1.4
	33–48	7.8	270	98	10	12.5	1.3
	Subice water		2.0	30	6	4	3.1
<i>Davis Sea, May 17, 2001</i>							
Snow	5–15	2.4	535	10	2	4.1	0.8
Ice	0–10	8.9	392	46	7	5.2	0.8
	10–20	37.1	1086	40	9	1.1	0.2
	20–37	9.0	1090	77	16	8.6	1.8
	37–52	41.4	240	54	8	1.3	0.2
	Subice water		3.4	110	9	3	2.7
<i>Progress Station, 69°37' S; 74°13' E</i>							
<i>Commonwealth Sea, Prydz Bay, March 23, 2003</i>							
Snow	5–15	0.4	280	16	1	45.7	2.9
Firn	15–35	12.0	130	13	1	1.1	0.1
Ice	0–30	2.0	665	94	3	47.7	1.5
	30–125	1.2	246	191	14	161.9	11.9
	125–155	3.4	2256	213	24	62.1	7.0
Subice water		1.6	89	70	9	43.2	5.6

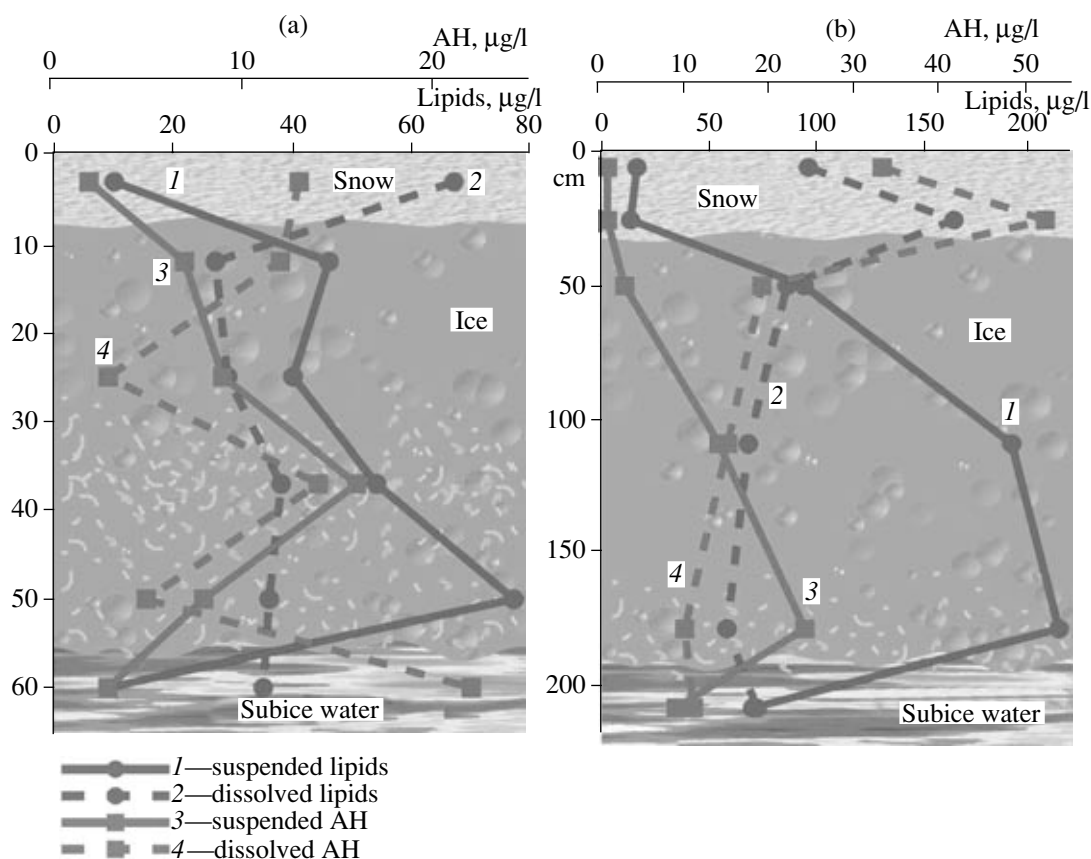


Fig. 2. Relationships of (1, 3) suspended and (2, 4) dissolved (1, 2) lipids and (3, 4) aliphatic hydrocarbons in the snow-ice cover of fast ice: (a) region of the Mirnyi Station, May 17, 2001; and (b) region of the Progress Station, March 23, 2003.

Antarctica is thinner than Arctic multiyear ices. When a thick snow cover forms on its surface, the ice submerges in response to snow loading. As a result, the upper snow layer is permeated with seawater (snow salinity is 28–30‰) and populated by marine plankton organisms (diatoms). The formation of an upper layer enriched in algal biomass is a phenomenon characteristic of only Antarctica. Such ice is referred to as infiltration. During warming, these organisms begin to reproduce rapidly, forming accumulations tens of times greater in number and biomass than those in the subice water [8], which is obviously favorable for the generation of organic compounds.

We also managed to sample snow from the surface of Antarctic lakes, the areas of subglacial ice melting. Very low concentrations of hydrocarbons were detected in such snow samples from the regions of conserved stations (Fig. 3). The meteorological conditions of the Antarctic ice sheet efficiently prevent the penetration of marine aerosols and continental dust formed by rock disintegration into its interior regions [1]. The resumption of human activity at the Progress station in 2003 had almost no effect on the AH concentrations in the snow-ice cover of lakes Crystal and Stepped compared with 2001 (Table 2).

However, a sharp increase in the concentration of organic compounds was observed in snow from an ice barrier at the region of unloading of equipment for the Novolazorevskaya station from the R/V *Akademik Fedorov* and, especially, near the station in the snow-ice cover of Lake Verkhnee. The snow of Lake Verkhnee contained 102 and 222 μg/l of dissolved and suspended AH, respectively (Table 2); the composition of lipids was relatively enriched in AH, which is characteristic of oil-contaminated regions [9]. This could be related to the activity of the station, because pollution with petroleum products was detected in some soil samples containing up to 30 000 μg/g of AH, as compared to the background content of 10–20 μg/g of dry mass. Furthermore, the pH value of the snow from Lake Verkhnee and the ice barrier was 4.95–4.97, which is lower than the pH of snow from other lakes (5.03–8.04). It is suggested [6] that hydrogen ions account for 38% of the bulk ionic composition of Antarctic snow, and the meltwater of Antarctica can be considered as a very weak solution of natural acids (mainly, H₂SO₄ and HNO₃) with minor amounts of neutral salts. Therefore, the decrease of pH values in populated areas is indicative of pollution, because acid rains show pH of 4.0–4.5.

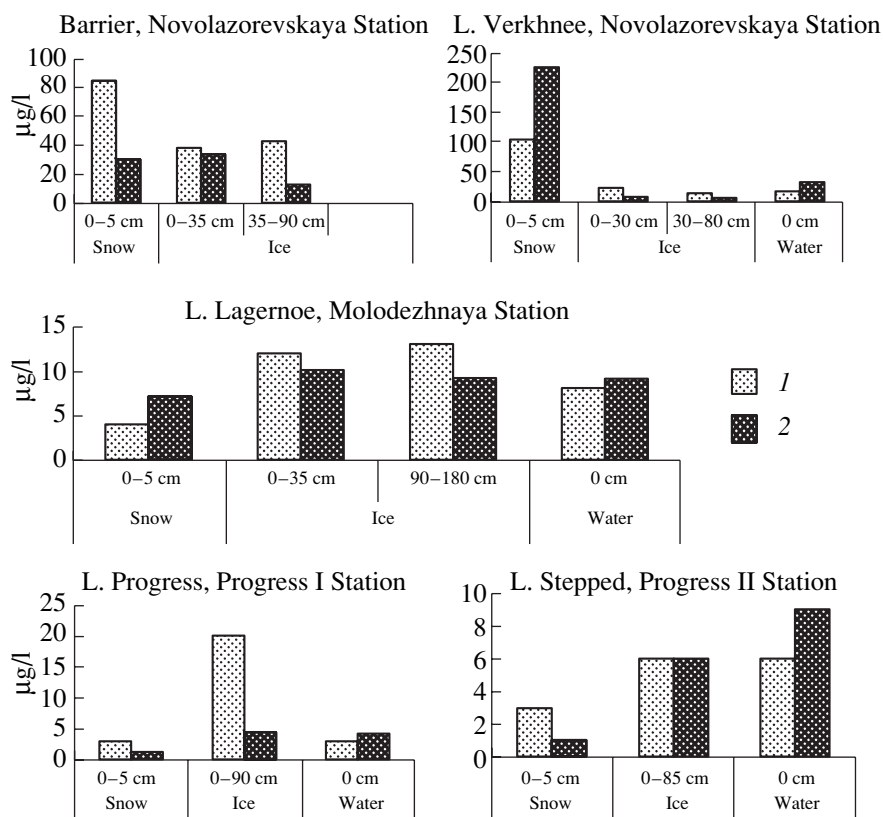


Fig. 3. Distribution of (1) dissolved and (2) suspended AHs in the snow-ice cover of Antarctic lakes in 2001.

In addition, this region is affected by the aerosol flow from the Schirmacher Oasis, which results in the enrichment of Lake Verkhnee snow in suspended material up to 4.36 µg/l. In contrast, snow from the lakes of conserved stations showed much lower suspended matter content (0.04–0.45 µg/l), and its composition was dominated by the component of marine genesis (diatom algae). According to our data, distribution patterns of alkanes in the snow were dominated by biogenic compounds with a maximum at *n*-C₁₇ (Fig. 4). The role of terrigenous homologues in the composition of AH was negligible, owing to the absence of plants in the Antarctic continent. The odd to even alkane ratio (CPI) ranged from 1.0 to 1.1. The concentrations of phytane and pristane are practically identical (Pr/Pf = 1.1–0.9), and *n*-alkanes prevailed over *iso*-alkanes (C₁₇/Pr = 1.3–2.3 and C₁₈/Pf = 1.7–2.0).

Ice

As can be seen from Table 1, the analyzed compounds are concentrated in suspensions from young ice in comparison with seawater (Fig. 5). The concentration factor in the ice slush is 7.5 for C_{org}, 2.8 for lipids, 3.8 for AH, and 6.2 for a suspension. The ratio of suspended and dissolved forms for AH and lipids is AH_s/AH_d = 2.25 and L_s/L_d = 2.30. It is evident that dur-

ing the formation of slush, organic compounds are extracted from the oceanic surface film (SML), which is enriched in all elements compared with subsurface seawater [9]. This is especially true of hydrophobic low-solubility compounds showing high affinities to the interface boundaries water-atmosphere and water-solid suspended particles.

The concentrations of the analyzed compounds in the pancake ice and nilas are also higher than in the subglacial water (Fig. 5). The formation of young ice is accompanied by the capture or filtration of suspension into the ice layer from water, which results in the mechanical concentration of suspension and an increase in the content of suspended particles of the compounds considered. In the case of surface waves, water softens ice and exerts two effects on its structure: increases the number of canals and capillaries in the ice and increases their diameter, which intensifies exchange processes between water and ice [4]. An increase in the diameter of canals at the lower boundary of ice increases water flow into the ice, which becomes higher than the brine discharge. Because of this, at a seawater salinity of 33.7‰, the salinity of pancake ice and nilas is 32.9‰ and 21.3‰, respectively. This process promotes an increase in the abundance of dissolved organic compounds in the pancake ice and nilas compared with slush.

Table 2. Concentrations of organic compounds ($\mu\text{g/l}$) in the snow-ice cover of Antarctic continental lakes

Sample	Horizon, cm	Form	Lipids	AH	AH, % of lipids	Sample	Horizon, cm	Form	Lipids	AH	AH, % of lipids
<i>Novolazorevskaya Station, 70°46' S, 11°50' E</i>											
April 2001, Lake Verkhnee						February 2003, Lake Verkhnee					
Snow	0–10	Dissolved	124	102	82.3	Water	Surface	Dissolved	65	40	61.5
		Suspended	335	222	66.3			Suspended	59	25	42.4
Ice	0–30	Dissolved	59	22	37.3	<i>Lake Stantsionnoe</i>					
		Suspended	12	7	58.3						
	30–80	Dissolved	37	13	35.1	Ice	0–10	Dissolved	33	23	69.7
		Suspended	27	6	22.2			Suspended	95	81	85.3
Subice water		Dissolved	55	17	30.9		10–20	Dissolved	10	6	60.0
		Suspended	68	33	48.5			Suspended	22	9	40.9
<i>Ice barrier, unloading of equipment from the R/V Akademik Fedorov, Novolazorevskaya Station</i>											
April 2001						February 2003					
Snow	0–20	Dissolved	130	84	64.6	Firn	0–27	Dissolved	45	12	26.7
		Suspended	76	30	39.5			Suspended	22	6	27.3
Ice	0–30	Dissolved	83	37	44.6		27–140	Dissolved	38	24	63.2
		Suspended	59	33	55.9			Suspended	17	6	35.3
	30–70	Dissolved	68	42	61.8	Subice water		Dissolved	91.9	35.7	38.8
		Suspended	30	12	40.0			Suspended	94.2	39.8	42.2
Subice water		Dissolved	66	41	62.1						
<i>Molodezhnaya Station, Lake Lagernoe, 67°34' S, 46°05' E</i>											
April 2001						March 2003					
Snow	0–15	Dissolved	14	4	28.6	Snow	0–10	Dissolved	25	6	24.0
		Suspended	24	7	29.2			Suspended	17	11	64.7
Ice	0–90	Dissolved	40	10	30.0	Ice	0–27	Dissolved	38	12	31.6
		Suspended	31	13	32.3			Suspended	26	5	19.2
	90–180	Dissolved	34	13	38.2		27–255	Dissolved	100	33	33.0
		Suspended	25	9	36.0			Suspended	37	3	8.1
Subice water		Dissolved	44	8	18.2	Interglacial water		Dissolved	22	5	22.7
		Suspended	46	9	19.6			Suspended	34	12	35.3
<i>Progress Station, 69°22' S 76°23' E</i>											
April 2001						March 2003					
<i>Lake Progress (Crystal)</i>											
Snow	0–10	Dissolved	21	3	14.3	Snow	0–10	Dissolved	27	1	3.7
		Suspended	3	1	33.3			Suspended	36	3	8.3
Ice	0–90	Dissolved	36	10	27.8	Ice	0–90	Dissolved	12	2	29.7
		Suspended	26	7	26.9			Suspended	22	8	35.0
Subice water		Dissolved	15	3	20.0	Subice water		Dissolved	11	3	29.7
		Suspended	16	4	25.0			Suspended	20	4	30.0
<i>Lake Stepped</i>											
Ice	0–85	Dissolved	28	7	25.0	Snow	0–10	Dissolved	38	6	15.8
		Suspended	20	6	30.0			Suspended	20	5	25.0
Subice water		Dissolved	21	6	28.6	Ice	0–90	Dissolved	37	11	29.7
		Suspended	45	9	20.0			Suspended	40	14	35.0
							Dissolved	37	11	29.7	
							Suspended	30	9	30	
<i>Mirnyi Station, 69°37' S, 92°55' E, April 2003</i>											
Snow	0–5	Dissolved	35	11	31.4	Snow	0–5	Suspended	39	7	19.9
<i>Lake, Haswell Island</i>											
Snow	0–10	Dissolved	31	2	6.5	Ice	40–55	Dissolved	210	2	1.0
		Suspended	34	3	8.8			Suspended	340	11	3.2
Ice	0–15	Dissolved	712	88	26.4	Ice	55–70	Dissolved	427	93	21.8
		Suspended	390	154	39.5			Suspended	260	103	39.6
Ice	15–40	Dissolved	232	3	1.3	Subice water		Dissolved	1001	590	58.6
		Suspended	512	24	4.7			Suspended	572	210	36.7

The Antarctic fast ice shows a heterogeneous structure [10], which results in variable concentrations of the analyzed compounds from layer to layer (Fig. 2). A characteristic feature of Antarctic fast ice is the development of diatoms both on the lower and upper ice surfaces [8]. Because of this, the concentration of organic matter may increase in the upper zones of ice compared with snow (up to a factor of 5 for bulk lipid content and 5.5 for bulk AH).

Fast ices (Table 1) show a synchronous change in the concentrations of lipids and AH: $r_{\text{lipid-AH}} = 0.73$ ($n = 18$). The abundance of dissolved organic matter is much less variable than that of suspended particles, which are enriched in the brown diatom layer. In particular, in the lower layer of the fast ice of the Prydz Bay (near the Progress station), the content of organic compounds in the suspension was 8–13 times higher than that of the subice water. It is evident that the high metabolic activity of diatom algae in ices with a developed system of capillaries and sink channels is favorable for the accumulation of suspended organic matter in this layer. The biogenic character of organic matter is supported by the composition of alkanes, which are dominated by light autochthonous homologues C_{17} – C_{20} (Fig. 6): $\Sigma(C_{16}$ – $C_{22})/\Sigma(C_{23}$ – $C_{40})$ ranging from 1.7 to 5.1. The growth of ice during our investigations at the Mirnyi station caused an upward migration of the diatom layer, and the concentration of AH in the layer 20–37 cm was higher than in the boundary zone adjacent to subice water (samples collected on May 13 and 17, respectively; Table 1).

The lake ices also showed considerable variability in the concentration of organic compounds between various parts of ice cores (Table 2). In particular, in the upper dull layer (0–14 cm) of fine-grained ice from Lake Stantsionnoe (Novolazorevskaya station), the content of suspended AH (81 $\mu\text{g/l}$) was 9 times higher than in the lower gray layer (14–22 cm). It is conceivable that the concentration of organic compounds in particular layers was related to the influence of meltwater transporting suspended mineral particles into the lakes [1].

Drilling at Lake Lagernoe (Molodezhnaya station) did not penetrate the full thickness of the ice cover (ice core was 255 cm long, and water-filled pockets 1–4 cm in size were encountered during drilling). This core contained abundant bubbles (1–5 mm in size) and cavities (3–5 cm) and consisted of two layers. The layer between 0 and 27 cm was dull white, and the layer of 27–255 cm was grayish in color. The bulk concentration of organic compounds (dissolved and suspended) showed an almost twofold increase at the transition from the upper to lower layer (from 64 to 107 $\mu\text{g/l}$ for lipids and from 17 to 38 $\mu\text{g/l}$ for AH). Their content decreased in interglacial water: 56 $\mu\text{g/l}$ for lipids and 17 $\mu\text{g/l}$ for AH.

The highest concentrations of organic compounds, 10–20 times greater than those measured in sea and lake ices, were observed in the region of penguin colo-

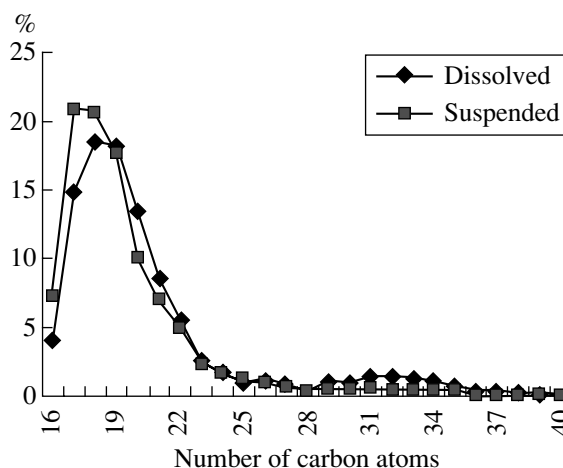


Fig. 4. Distribution of dissolved and suspended alkanes in the snow of Lake Verkhnee (April 2001).

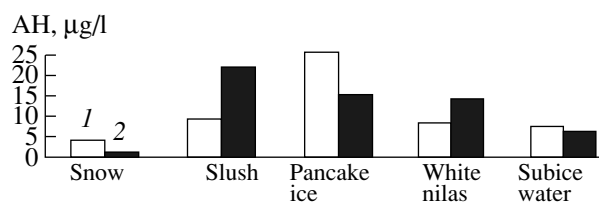


Fig. 5. Relationships of (1) dissolved and (2) suspended aliphatic hydrocarbons in various forms of fast ice, snow, and subice water (April 2003).

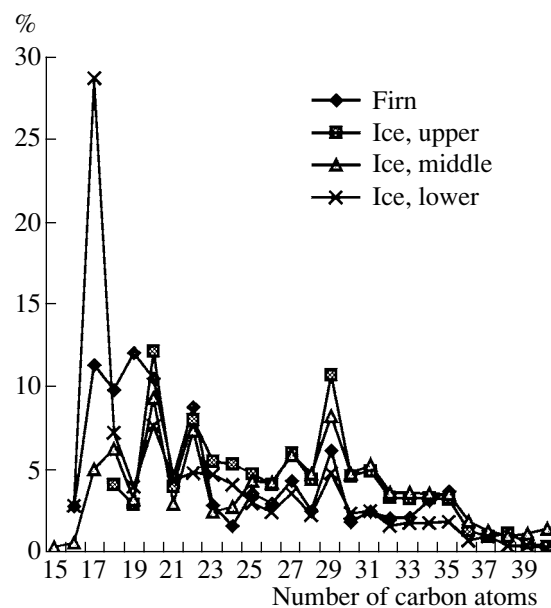


Fig. 6. Distribution of alkanes in the snow-ice cover of fast ice (Prydz Bay, Commonwealth Sea) in April 2001.

nies at the Mirnyi station: in the fast ice of Buromsky Island and an epishelf lake in Haswell Island, which was formed through the melting of glaciers and storm-related splashing of saline water (Table 2). The mechanisms of their migration changed abruptly from layer to

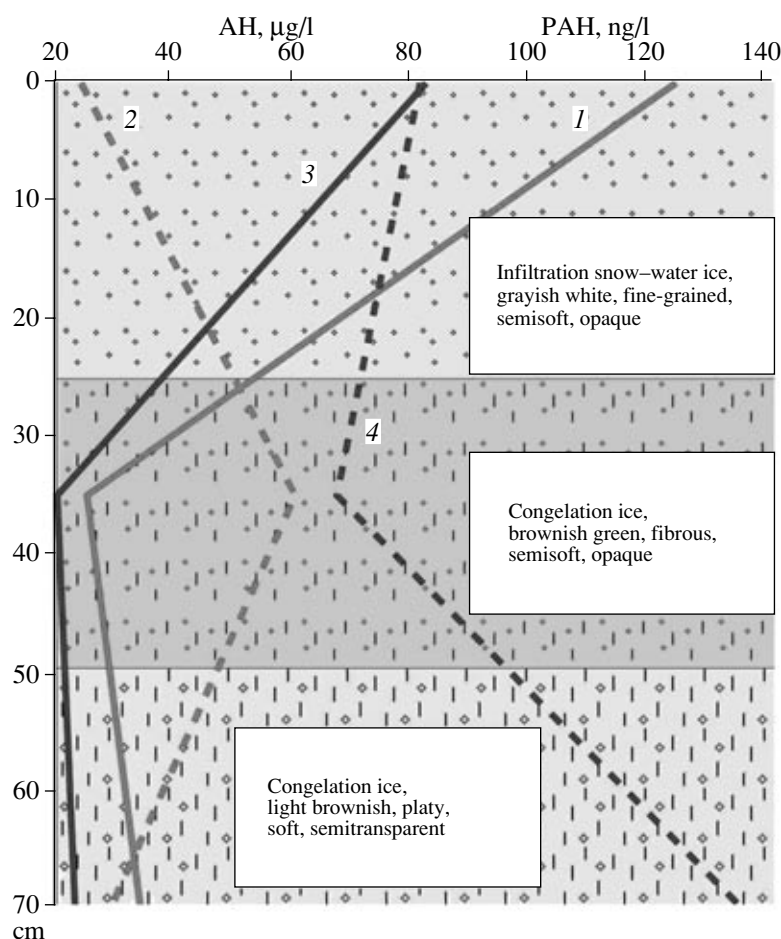


Fig. 7. Distribution of (1, 2) aliphatic hydrocarbons and (3, 4) polycyclic aromatic hydrocarbons in (1, 3) dissolved and (2, 4) suspended forms in an ice core from the region of Buromsky Island.

layer in the ice volume. In contrast to other fast ices, the maximum contents of lipids and AH in the ice cores from the region of Buromsky Island (Fig. 7) were confined to the surface layer containing penguin excrement rather than to the brownish-green layer enriched in algae. This snow-water ice layer was characterized by the prevalence of dissolved organic compounds over suspended ones. However, suspended organic compounds prevailed already in the middle brownish-green layer (by a factor of 6 for lipids and 2.5 for AH). The fraction of AH in the composition of lipids was rather low, which is usually typical of freshly synthesized organic matter. The youngest lower ice layer contained almost equal amounts of suspended and dissolved forms of lipids and AH. The light-brown color of the lower part of the core is indicative of the initial stage of the development of algae, owing to which this ice layer is enriched in organic compounds compared with the subice water but to a lesser extent than the middle layer.

A similar distribution of organic compounds with the maximum content of dissolved forms in the upper layer was observed in the ice of the Haswell Island lake (Table 2). The concentration of dissolved AH (500 $\mu\text{g/l}$)

related to natural processes under eutrophic conditions in the water of this lake appeared to be an order of magnitude higher than the MAC for petroleum hydrocarbons. It is obvious that the penguin excrement served as a feeding medium for the formation of AH.

Rather high concentrations of lipids and AH were also detected in the moss collected at the region of Lake Haswell (1378 and 109 $\mu\text{g/l}$, respectively; Table 3). However, similar concentrations were also observed in the moss and lichen at Lake Stepped, where penguins were not present. This is probably related to the fact that lichens have no root system and feed only on eolian materials, i.e., they accumulate organic compounds from air. Under severe Antarctic conditions, they show high biological activity providing normal life processes resulting in the formation and accumulation of chemical compounds [10]. The organic compounds accumulated by mosses, lichens, and algae decompose extremely slow under low-temperature conditions. They form an upper humus-rich soil horizon, where the contents of lipids and AH varied within the ranges 140–200 and 12–30 $\mu\text{g/g}$, respectively (Table 3).

Table 3. Concentrations of organic compounds ($\mu\text{g/g}$) in soil, lichens, and mosses

Site	Object	C_{org}	Lipids	AH	%		
					lipids in C_{org}	AH in C_{org}	AH in lipids
<i>Progress Statio</i>							
Shore of Lake Stepped	Lichen	141800	1219.9	311.7	0.9	0.022	25.6
	Moss	145500	904.1	109.8	0.6	0.007	12.1
	Soil	3800	145.5	29.9	3.8	0.78	20.5
<i>Mirnyi Station</i>							
Shore of Lake Haswell	Moss	239600	1377.6	108.8	0.57	0.04	7.9
	Soil	4200	197.7	12	4.7	0.28	6.1

Trace concentrations of PAH were found in the snow-ice cover of Antarctica. Phenanthrene, fluoranthene, and chrysene (up to 10 ng/l in total) were only detected among polyarenes from the slush and pancake ice. Trace concentrations of PAH were measured in the upper and lower layers of the fast ice. The only exceptions were ices sampled near penguin colonies, where the total contents (suspended and dissolved) ranged within 24–160 ng/l at Buromsky Island and 15–251 ng/l at the lake of Haswell Island. However, polyarenes from these sites were also represented by low-molecular-weight homologues. Compounds with higher molecular masses (for instance, benzo(a)pyrene) were never detected.

Thus, our investigations demonstrated that the formation of Antarctic ices was accompanied by both the accumulation of organic compounds from water and their biosynthesis within the ice. It was shown that owing to the high biological activity of ice algae, the concentrations of chlorophyll *a* and C_{org} in fast ice may be very high (210 and 6000 $\mu\text{g/l}$, respectively [11]).

During the initial stage, the mechanical concentration of suspended matter prevails over the accumulation of organic compounds in slush. Because of this, when recalculated to one milligram of suspension, their contents were higher in the pancake ice and nilas than in slush (Table 1). Despite the rapid growth of newly formed ice, its biogeochemical constituents show minor changes during the initial stage of development. In particular, the concentration of chlorophyll *a* increases significantly on the third day, when environmental conditions in the lower layers concentrating unicellular algae become favorable for cell development [11]. The gradual increase of biomass up to 0.23 $\mu\text{g/l}$ (chlorophyll *a* content) begins only on the eighth day.

The accumulation of suspended compounds in a marine environment is limited to expelling organic molecules to the surface of sorbents, and the intensity of sorption is controlled by sorbate-sorbent hydrophobic interactions [12]. This process is widespread both in Antarctic and Arctic ices. It was noted that newly formed ice from the Novaya Zemlya region might concentrate suspended particles by a factor of 2–3 and

organic matter by a factor of 5 [13]. However, Antarctic ices are poorer in organic compounds than Arctic ices. For instance, the concentration of AH in the ices of the Franz-Victoria trough (averaging 123 $\mu\text{g/l}$ [2]) and the Mendeleev Rise (averaging 64 $\mu\text{g/l}$ [3]) were six and three times higher, respectively, than in the fast ice of Antarctica (averaging 22 $\mu\text{g/l}$). This is most likely related to the differences between the young ices at a nascent stage of the biogenic formation of organic matter and the multiyear pack ices in which these processes are much more extensive. The growth and development of ice are accompanied by changes in its physical structure and, consequently, in the producing characteristics of ice flora and its species composition [14]. In addition, while the composition of AH was dominated by allochthonous alkanes in the Arctic [2], only autochthonous alkanes occur in Antarctica, and the composition of PAH is dominated by low-molecular-weight homologues, i.e., the hydrocarbons of the Antarctic snow-ice cover are strongly different in composition from Arctic hydrocarbons.

The ices of lakes Glubokoe, Lagernoe (Molodezhnaya station), and Stepped (Progress station) were characterized by the development of organisms and showed an increase in the concentration of organic compounds at the ice-water boundary (Table 2). Despite their low biologic productivity, these lakes are centers of life [10]. Numerous copepods and rotifers were found in the water beneath the ice of Lake Stepped.

Phytoplankton and marine organisms contribute significantly to the formation of the composition of organic compounds in ice suspension [11, 14]. In addition to AHs, which are synthesized by phytoplankton, PAHs are generated both at the ice-water boundary, which was observed in multiyear Arctic ices [3], and in the snow-ice layer. It is believed that PAHs are formed mainly during the combustion of various fuels and during the slow (millions of years) aromatization in geochemical processes of such widespread natural compounds as sterols and triterpenes [15]. The detection of such considerable PAH amounts in both pack and seasonal ices suggests that they form rather rapidly even under high-latitude conditions. Even at low tem-

peratures, ices exhibit catalytic properties, and, contrary to the widely accepted opinion, many intense biochemical processes occur in ice (e.g., oxidation and hydrolysis) [11, 16].

CONCLUSIONS

The Antarctic snow cover is characterized by low concentrations of organic compounds (concentrations of AH and PAH are close to the detection limits of analytical methods) both on fast and lake ices, which is related to the low content of terrigenous aerosols in the Antarctic atmosphere. The only exceptions are snow immersed in seawater, which showed AH contents of up to 8 µg/l, and snow from the region of the Schirmer Oasis (Lake Verkhnee, Novolazorevskaya station) containing up to 220 µg/l.

Lipids and AHs are accumulated in fast ices at the snow–ice and water–ice boundary zones. These zones (especially water–ice) remain active biological media even at low temperatures, and autochthonous processes occurring in them promote the formation and accumulation of organic compounds. However, their concentrations are lower than those of Arctic ices.

A specific feature of Antarctic lake ice is the low content of suspended organic compounds compared with the dissolved forms over the whole core length. This feature is due to the low content of suspended material. The role of suspended AH forms increases in ices and, especially, in the water of subglacial lakes, where the development of algae was observed (for instance, in Lake Stepped).

The maximum concentrations of organic compounds and sharp changes in the proportions of their migration forms were established in the snow–ice cover and subice water at the areas of penguin colonies (fast ice of Buromsky Island and the lake of Haswell Island). In addition to AH, the concentrations of low-molecular-weight arenes also increase.

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