ISSN 0001-4370, Oceanology, 2015, Vol. 55, No. 4, pp. 508–520. © Pleiades Publishing, Inc., 2015.
Original Russian Text © N.A. Belyaev, M.S. Ponyaev, A.M. Kiriutin, 2015, published in Okeanologiya, 2015, Vol. 55, No. 4, pp. 563–576.

MARINE CHEMISTRY

Organic Carbon in Water, Particulate Matter, and Upper Layer of Bottom Sediments of the Central Part of the Kara Sea

N. A. Belyaev, M. S. Ponyaev, and A. M. Kiriutin
Shirshov Institute of Oceanology, Russian Academy of Sciences, Moscow, Russia
e-mail: belyaev@ocean.ru
Received April 22, 2013

Abstract—Based on data obtained in the course of the 59th cruise of RV *Akademik Mstislav Keldysh*, the content of organic carbon was determined in water (dissolved organic carbon, DOC), particulate matter (particulate organic carbon, POC), and bottom sediments of the Yenisei estuary and of the central part of the Kara Sea during the summer–autumn season of 2011. The decisive impact of the waters of riverine runoff upon the variability of DOC and POC concentrations in the marine aquatic area is shown. POC enrichment in the autochthonous component is revealed for the frontal zones, as well as the increase of DOC concentrations in the area of the northern extremity of the Novaya Zemlya Islands. The distribution map of organic carbon (C_{org}) in the upper layer of bottom sediments of the central part of the Kara Sea is plotted on the basis of the analysis of the authors' and published data. A pronounced enrichment of the thin upper layer (0–0.5 cm) of bottom sediments in organic carbon (>20%) is registered at most of the stations and depends neither on lithological composition of sediments nor on the location of sampling sites.

DOI: 10.1134/S0001437015040013

INTRODUCTION

The program of the studies of carbon cycle in the Kara Sea in the course of the 59th cruise of RV *Akademik Mstislav Keldysh* was drawn in view of the oceanological, biological, and geochemical conditions revealed by surveys in 2007 [13]. The authors, being members of this expedition, aimed to explore the main features and factors determining the distribution of organic matter (OM) in the Kara Sea system. The analysis of samples collected in the Yenisei River estuary and in the central part of the Kara Sea allowed us to compare the obtained results to the preceding data on the west of the sea and Ob Bay. The focus of the studies on OM variations in different barrier zones (water–bottom and mixing zones) made it possible to localize the processes of OM transformation. The present report considers the supply of organic carbon (OC) in dissolved and particulate forms with riverine runoff, as well as the variability of OC concentrations in the zone of marginal filter and in the water–sediment system. The location of stations in the selected sections allows one to trace the path of organic carbon (C_{org}) from the supply with riverine runoff to the burial at the foot of the continental slope. The sections and sampling sites are shown in Fig. 1. The Yenisei section (Fig. 1, I) along with the cross-section of the eastern branch of the St. Anna Trench (Fig. 1, II) form a submeridional profile intersecting the area of the inner shelf and reaching the continental slope. The section at the northern extremity of the Novaya Zemlya Islands (Fig. 1, III) encloses the treated area from the north, and the Taimyr section (Fig. 1, IV) marks the propagation of the riverine runoff eastwards along the coastline of the Kara Sea.

MATERIALS AND METHODS

Seawater, particulate matter, and bottom sediments were sampled and prepared using the standard procedure described, e.g., in [1, 7]. The usage of a multicorer allowed one to exclude any disturbance of the surface layer of bottom sediments. In total, 91 samples of seawater and 157 samples of bottom sediments were collected at 22 stations and examined for contents of organic carbon.

The main improvement of the treatment procedure of the collected matter compared to the preceding methods of analyses [1] consisted in the exclusion of drying of the samples to determine the content of C_{org} and carbonate carbon (C_{carb}) in the samples of particulate matter and bottom sediments. The lyophilization of deep-frozen samples immediately before analysis allowed the minimization of changes in OM composition for sample preparation, unification of procedures of sample preparation for particulate matter of seawater and bottom sediments, as well as to reliably determine OM concentrations and composition in the much watered upper layers in the cores of bottom sediments (the warp and subwarp).

The content of C_{org} and C_{carb} was determined by means of a TOC-Vcph analyzer equipped with a SSM 5000A device (Shimadzu Co.). The measured concentrations of dissolved organic carbon were within 0.05–

25000 mg C/L; the volume of the injected sample amounted to 100 μL. The concentrations of carbon in the bottom sediments were measured within 0.05–30 mass % (per dry mass) from weighed samples of 100 mg. The range of measured concentrations of particulate organic matter amounted to 5–10000 μg C/L. Device error was 1%. The reproducibility of the results of analyses was within ±5%. The analyzer was calibrated before the treatment of the analyzed series using standard samples of bottom sediments (SDO2, SDO1, and SDO3). To verify the procedure of lyophilic drying of the samples, some samples of bottom sediments collected during the 54th cruise of RV *Akademik Mstislav Keldysh* were examined repeatedly. The results of these repeated tests fell into the confidence interval of 5%.

One must note that the quantitative determination of a content of particulate matter requires nuclear polycarbonate filters of a 0.45 μm pore diameter, whereas the content of carbon is determined by means of glass-fiber Whatman GF/F filters of 0.7 μm conventional pore size. Resulting from the difference in shapes and diameters of the pores in filters, the obtained DOC content in particulate matter (Table 1) is not a strictly valid quantity but represents regularities of C_{org} content in the composition of particulate matter.

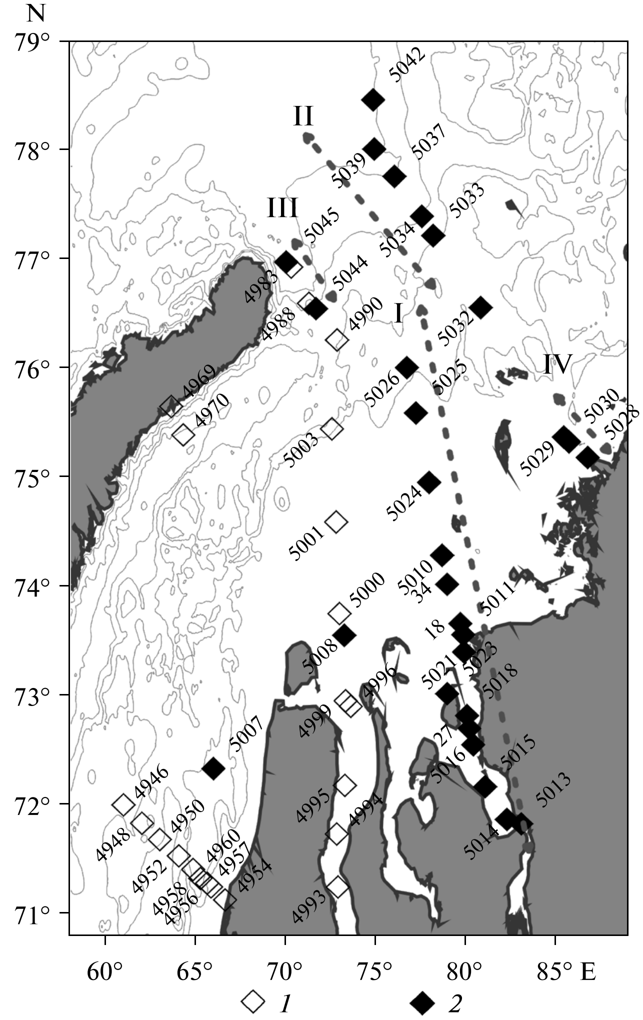

Fig. 1. Location scheme of the sampling stations: *1*—AMK-54 cruise, September 2007; *2*—AMK-59 cruise, September 2011. I—Yenisei section; II—cross-section of the eastern spur of the St. Anna Trough; III—the section at the northern extremity of the Novaya Zemlya Islands; IV—Taimyr section.

RESULTS AND DISCUSSION

Dissolved and particulate organic carbon. The results of analyses for DOC and POC in seawater are presented in Table 1. Data on mass concentrations of particulate matter were presented by Kravchishina [4]. The maximum concentrations of both DOC and POC (10.8 mg/L and 566 μg/L, respectively) were registered at the origin of the marginal filter of the Yenisei river at station 5015, with the maximum in the freshwater surface layer for dissolved OM and in the salinized near-bottom layer for particulate OM. The minimum DOC content was found at the northern extremity of the Novaya Zemlya Islands (0.77 mg C/L, station 5044); the POC content was minimum at the eastern branch of the St. Anna Trough in the layers of 110–150 m (22 μg/L, station 5042). The surface water layer contained on average 4.5 mg/L of DOC (the number of analyses $n = 22$, $\sigma = 2.3$ standard error) and 188 μg/L of POC ($n = 25$, $\sigma = 118$). The near-bottom layer contained 3.1 mg/L of DOC ($n = 19$, $\sigma = 2.4$) and 145 μg/L of POC ($n = 21$, $\sigma = 144$). The averaged content for all the treated samples amounted to 3.4 mg/L of DOC ($n = 69$, $\sigma = 1.99$) and 129 μg/L of POC ($n = 77$, $\sigma = 110$).

The concentrations of organic carbon in the layers of bottom water collected from the tubes of the multicorer varied within wide ranges of 74–3290 μg/L for POC and 0.89–12.03 mg/L for DOC. One must note that whereas the DOC concentrations in the layer of bottom water in general were not too different from those in the corresponding near-bottom layer, POC concentrations in bottom waters exceeded those in near-bottom water by an order of magnitude. This may be partly caused by the sediment roiling under sampling. However, the difference in chemical composition of the OM of particulate matter of the bottom layer from both the OM in near-bottom layers and that of the warp [7] allow the assumption of the permanent occurrence of a POC-enriched bottom layer.

Most treated stations (15 out of 22) were located along the Yenisei Gulf to the eastern branch of the submeridional profile of the St. Anna Trough. The auxiliary sections were also executed from the Taimyr Peninsula to the origin of the eastern branch (3 of 22 stations) and from the northern extremity of the Novaya Zemlya Islands to the central part of the trench (2 of 22 stations).

Table 1. The content of dissolved and particulate organic matter in the central part of the Kara Sea

Station no.	Depth, m	Layer, m	Salinity, psu	DOC, mg C/L	Particulate matter			DOC/POC
					μg C/L	mg/L	POC/PM, %	
5007	138	0	24.0		164	0.43	38	
		135	34.6		137			
		Bott.		12.03				
5008	22	Bott.	31.8	5.81	3290			2
Yenisei section								
5013	30	0	0.1	7.85	394	2.55	15	20
		27.5	0.1	7.95		3.95		
		Bott.		6.88	518			13
5014	10	2	0.0	7.96	407	2.93	14	20
		8	0.1		187	1.81	10	
5015	14	0	0.5	10.78	345	2.73	13	31
		12	21.0	4.69	567	10.31	5	8
		Bott.	23.4	4.78	1569			3
27		0		7.19	381	2.05	19	19
5018	22	0	15.8	5.11	279	1.15	24	18
		6	24.9	3.27	153	0.97	16	21
		14	28.3	4.77	171	1.53	11	28
		20	31.1	3.25	367	5.53	7	9
		Bott.	31.0	2.26	2906			1
5021	34	3	17.1		363	1.04	35	
		31.5	31.5	1.91	283	7.63	4	7
5011-2	36	0	13.6	4.72	311			15
		5	14.1		238	1.27	19	
		12	29.7	2.39	224	0.51	44	11
		25	31.3	3.42	246	1.20	21	14
		33.5	32.4	2.12	151	1.73	9	14
		Bott.	32.5	1.57	2207			1
5023	29	2–2.5	16.5	4.55	120	0.82	15	38
		5	25.0	4.59	121	0.83	15	38
		22	31.9	2.74	83	0.80	10	33
		27	32.1	4.49	127	2.50	5	35
		Bott.	32.1	1.65	640			3
18		0		3.53	188	0.78	24	19
34		0		3.90	150	0.81	18	26
5010		0	26.2	4.94	152	0.44	35	32
		5	26.3	5.81	96	0.31	31	61
		10	26.3	3.23	141	0.35	40	23
		20	31.2	2.28	82	0.58	14	28
		27.5	32.1	2.06	149	2.06	7	14
		Bott.	32.2	1.88	2538			1

Table 1. (Contd.)

Station no.	Depth, m	Layer, m	Salinity, psu	DOC, mg C/L	Particulate matter			DOC/POC
					μg C/L	mg/L	POC/PM, %	
5025	47	0	22.9	3.36	118	0.47	25	28
		45	33.5	1.33	46	0.71	7	
		Bott.	33.5	1.54	74			21
5026	62	0		2.99				
		2	24.2	3.24	113	0.34	33	29
		6	25.3	2.88	80	0.40	20	36
		20	32.9	1.77	65	0.16	41	27
		60	34.0	1.11	45	0.38	12	25
		Bott.	34.0	1.40	1251			1
Cross-section of the eastern spur of the St. Anna Trench								
5032	59	1.5	28.7	2.24	72	0.28	25	31
		16	32.9	1.12	44	0.29	15	26
		40	33.7	4.71	37	0.17	21	126
		56	34.,04	7.64	37	0.42	9	208
		Bott.	34.0	4.58	684			7
5033	122	2.5(0)	27.3	2.48	79	0.31	26	31
		9.5	27.6	2.79	84	0.37	23	33
		55	34.2		38	0.26	15	
		120	34.4	1.23	37	0.36	10	33
		Bott.	34.4	3.35	974			3
5034	219	1	31.3		74	0.26	29	
		15	32.9		40	0.16	25	
		110	34.7		38	0.22	17	
		215	34.9		63	0.35	18	
		Bott.	34.9	3.83	2705			1
5039	361	1	31.6	2.54	63	0.16	39	40
		20	34.4	2.29	49	0.29	17	46
		150	34.8	3.62	31	0.31	10	116
		355	34.9	1.26	37	0.25	15	34
		Bott.	34.9	1.37	1270			1
5042	465	1	32.2	3.62	66	0.15	44	55
		9	33.3	3.95	65	0.15	42	60
		35	34.4	2.81	43	0.13	33	65
		100	34.9	3.04	22	0.10	22	139
		280	34.9	1.10		0.12		
		460	34.9	3.25	34	0.27	12	97
		Bott.		0.89				

Table 1. (Contd.)

Station no.	Depth, m	Layer, m	Salinity, psu	DOC, mg C/L	Particulate matter			DOC/POC
					µg C/L	mg/L	POC/PM, %	
Stations at the northern extremity of the Novaya Zemlya Islands								
58(5044)		0		5.81	135	0.51	27	43
5044	150	2(0)	33.2		124	0.35	35	
		4	33.2	2.89	120	0.28	42	24
		110	34.6	1.31	46	0.12	37	29
		147	34.8	0.77	45	0.26	18	17
		Bott.	34.8	2.28	620			4
5045	530.5	7	33.6	1.05	77	0.13	58	14
		20	34.3	1.15	58	0.15	40	20
		100	34.9	1.07	34	0.13	26	32
		527.5	34.9	1.40	35	0.15	24	40
		Bott.		1.12				
Taimyr section								
5028	40	1	18.2	3.98	141	0.82	17	28
		8	21.5	3.92	103	0.65	16	38
		20	31.8	2.21	44	0.19	23	50
		38	33.4	1.55	104	0.90	12	15
5030	41	0.5	25.5	3.33	126	0.58	22	27
		3	28.2	5.02	69	0.71	10	73
		14	30.6	2.61	59	0.21	28	44
		38	33.5	3.06	131	0.90	15	23
5029	54	0(1.5)	29.1	2.36	52	0.24	22	45
		8	29.2	1.96	56	0.31	18	35
		51	33.7	1.29	63	0.92	7	21

The data on mass concentrations of particulate matter by Kravchishina [4]; bott.— water sampled from the multicorer tube.

The Taimyr section is characterized by DOC and POC values close to average for the sea (2.8 mg/L of DOC and 86 µg/L of POC; $n = 11$). The degree of increase of the concentrations of particulate organic carbon near the coasts is caused in the surface layer by the supply of Yenisei waters, and by the probable processes of coastal abrasion and roiling of bottom sediments in the near-bottom layer. This correlation is slightly pronounced and has nearly no effect on the variability of DOC concentrations. The increase of POC concentrations is caused by the transfer of terrigenous matter and confirmed by the decrease of OM content in particulate matter of both the near-bottom and surface layers.

Applying the data obtained during the 54th cruise of RV *Akademik Mstislav Keldysh* [1], schemes of the distribution of DOC and POC content in the surface, subsurface (~20 m), and near-bottom layers were drawn (Fig. 2). Despite the differing structures of water circulation in the Kara Sea in 2007 and 2011 [14], one may compare two different types of the supply of terrigenous organic matter with the runoff of the Ob and Yenisei rivers. As noted by [1], the occurrence of a horizontal marginal filter was shown for the Ob River. Extending far northwards, the weakly desalinized waters of riverine runoff containing much DOC flow here onto the underlying seawaters. The hydrodynamic mixing (in the horizontal zone of high gradients of salinity) results in intense coagulation and flocculation of DOC. This causes the new formation of POC and increases its concentration in underlying layers. Hence, the enrichment in dissolved organic matter of the riverine runoff in surface layers (Fig. 2a) and in particular OM in near-bottom layers (Fig. 2c) is traced. As a result, the zone of terrigenous OM accumulation in bottom sediments is projected onto the entire area of the inner shelf. The Yenisei estuary is characterized by the occurrence of a classic system of a marginal filter as described in [9]. In the course of field surveys in 2011, a more complicated structure was registered through several hydrochemical parameters for the estuarine frontal zone consisting of the vertical and horizontal mixing zones [10]. In this case, the bulk of particulate OM was precipitated in the estuarine zone (Fig. 2c) and the remaining part was propagated in the upper layer and little affected the underlying layer (Figs. 2a, 2b).

The salinity dependence of DOC content (µM C/L, stations 5013–5026) in the waters of the Yenisei Gulf is shown in Fig. 3a. The inverse linear dependence of DOC content on salinity was revealed by [19] for the seasons of 1979, 1999, and 2000 for both the Ob and

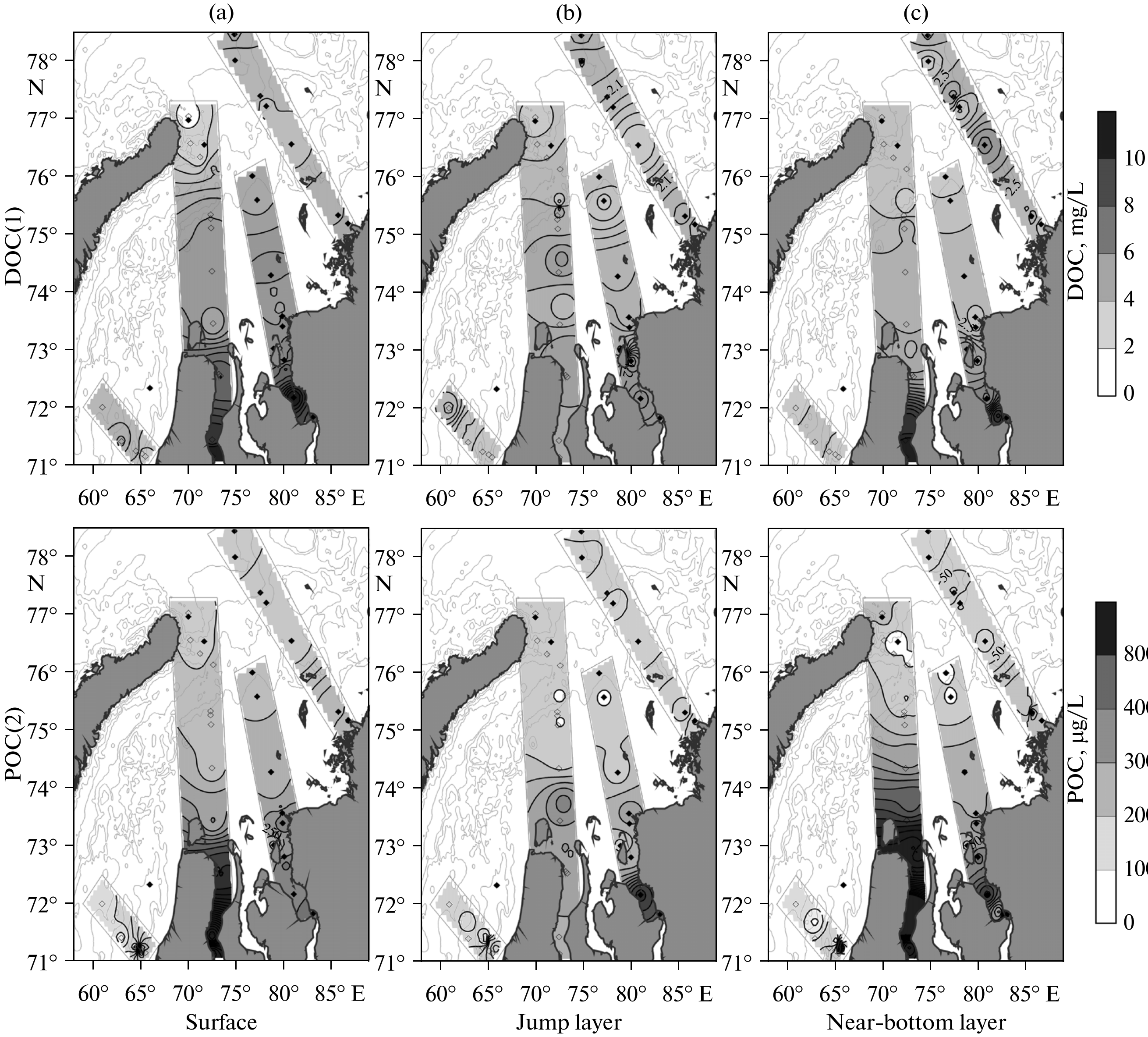

Fig. 2. Schemes of the distribution of dissolved (*1*) and particulate (*2*) organic carbon (DOC and POC, respectively) in the surface (a), subsurface (~20 m, b), and near-bottom layer (c).

Yenisei rivers and confirmed by [1] for 2007. The equation $Y = -17.4X + 715$ obtained for all the DOC samples of surface waters collected in 2011 and marked with black rhombs in Fig. 3a shows the stable correlation between the POC concentration and salinity ($r^2 = 0.85$). If calculating including the samples from near-bottom layers of the stations 5013–5026 at the inner shelf (Fig. 3a, white squares), the correlation is still high but decreased ($r^2 = 0.79$) owing to the points above the trend line (the dotted contour, stations 5010, 5018, 5011-2, and 5023). These points are located at the upper boundary of the marginal filter and associated with the zones of biological fronts. The calculated value of the DOC content in the Yenisei waters by the survey data of 2011 amounted to 715 μM C/L and fell within the ranges of values determined before by [19] (560, 740, and 679 μM C/L in 1997, 1999, and 2000, respectively). The volume of riverine runoff in 2011 as well did not exceed the annual average values [12].

The diagram of the relationship between POC concentrations and salinity for all the examined samples collected at the inner shelf (stations 5013–5026) is presented in Fig. 3b. The approximation of all the available data with logarithmic dependence gives no positive result ($r^2 = 0.24$). If the points within the dotted area of high POC content are excluded, the application of the equation for the salinity dependence of POC ($Y = -58.6\ln X + 262$) results in positive correlation ($r^2 = 0.91$). Hence, the given equation represents the minimum possible POC concentrations for the

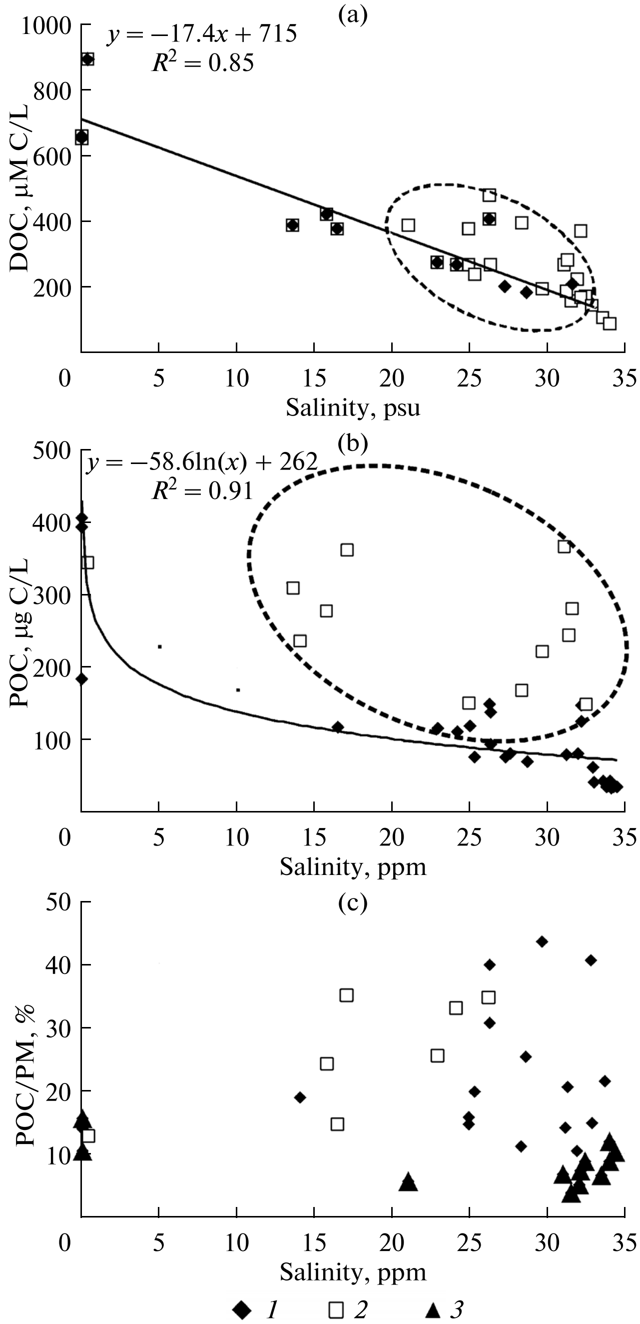

Fig. 3. Graphs of salinity dependence. DOC (a): *1*—surface samples; *2*—the samples of all the layers of the section; POC (b): *1*—all the samples of the section; *2*—the samples from the stations of the frontal zone; C_{org}(part)/PM ratio, % of dry particulate matter (c): *1*—all the samples of the section; *2*—the samples from the stations of the frontal zone; *3*—near-bottom layers.

defined values of salinity, marks POC precipitation, and excludes the new formation of POC. The analysis of the field of values constituted by the excluded points (white squares) shows that all these values are related to the stations 5018, 5021, and 5011-2. These stations are located in the zone of high gradients of the surface salinity which first decreases from 18 psu near the station 5017 to 0.8 psu between stations 5018 and 5019, decreasing afterwards to 24.3 psu at station 5021 [14]. The excess of the true registered POC concentrations over the theoretical curve is as high as 500% for the stations 5018, 5021, and 5011-2, at ~250% on average. The character of propagation of the Yenisei waters and the location of the considered section allow one to note that all these stations are located in a zone of severe hydrological fronts formed under the interaction of the freshwater runoff adjoining to the coasts of Taimyr Peninsula and moderately desalinized waters of the Kara Sea shelf [14]. In terms of the salinity dependence of total concentration of particulate matter, the excluded points are not dropped out of the general data set.

The salinity dependence of the POC–particulate matter ratio for the Ob and Yenisei estuarine zones was considered in [2]. The curve of salinity dependence of C_{org} distribution in particulate matter (% C_{org} per dry mass) for the stations of the inner shelf is given in Fig. 3c. The analysis of this ratio for near-bottom samples (black triangles in Fig. 3c) shows the depletion of particulate matter composition in OM. This effect is characteristic for all the seasons of surveys in the estuaries of the Ob and Yenisei rivers [2]. The data allowed us to ascertain that the particulate matter (PM) in surface layers of the "abnormal" stations (white squares) is enriched in organic constituents, and such samples show a salinity range characteristic for the biotic part of the marginal filter [8].

The increased OM content in the composition of particulate matter was registered in most layers at stations located in the northwest of the considered region (stations 5044, 5045, 5039, and 5042). These stations are also characterized by an increase of the proportion of dissolved relative to particulate OM. During surveys from 2007, the maximum OM content in particulate matter was registered in the same area as well at station 4983 of just the same location as station 5045. The minimum OM fraction in the suspension is revealed at a number of near-bottom depth levels and stations of the colloid and gravitational part of the marginal filter. As a result of bottom elements being stirred up by tidal and slope currents, the particulate matter of near-bottom depth levels approaches bottom sediment matter in composition [2]. In the area of the marginal filter, the delivered masses of the mineral suspension significantly exceed the organic suspension, despite significant POC concentrations.

Hence, the enrichment of particulate matter in the organic component is registered in clearly definite areas of the considered region: in the extreme northwest area, bordering the zone of the supply of Atlantic waters, the Novaya Zemlya upwelling, and ice melting, as well as in the Yenisei estuary in the zone belonging to biotic part of the marginal filter [8].

The outer zone of the Yenisei marginal filter is characterized by a complicated structure. Along with the processes of horizontal and vertical mixing, the inflows of desalinated waters both above and below the layer of pycnocline were revealed. This zone shows the highest gradients of the values of surface salinity being as high as 13.9 psu/mile at stations 5022–5011 [14]. The area of stations 5016–5010 is characterized by maxima of mesoplankton biomass per 1 m^2 of the surface, reaching the highest values at station 5021, and of an abundance of marine phytoplankton species in the surface water layers of stations 5010 and 5019 [6]. This area is also characterized by increased chlorophyll concentrations [17]. Thus, the increased POC concentrations at the stations located in the biotic part of the marginal filter (stations 5018–5011-2) may be ascribed to newly formed particulate matter of autochthonous origin.

The increased content of both phyto- and zooplankton in the extreme northwestern area including the stations 5044, 5045, 5039, and 5041 was found at station 5044. The increase of chlorophyll content in seawater was also seen at this station [14]. The location site of station 5044 was characterized by increased concentrations of DOC and POC. This station also shows a pronounced increase of the proportion of dissolved relative to particulate matter, as well as excesses of DOC and POC in upper layers compared to the calculated conservative values. This allows the assumption that OM concentration increase mainly results from registered increased productivity of plankton communities.

One must note that the growth of phyto- and zooplankton biomass registered at stations 5033–5035 and caused by the structural transformation of the communities in the slope frontal zone [15, 16] was not reflected in the variations of DOC and POC concentrations. This is probably related to the distinct localization of the biological front at station 5035 characterized by a pronounced growth of chlorophyll concentrations in the surface layer [17].

The content of C_{org} in the upper layer of bottom sediments. The concentrations of C_{org} in the samples of the upper layer of bottom sediments from the surveyed area are presented in Table 2. The map of C_{org} content in the upper layer of bottom sediments (Fig. 4) was drawn based on the authors' data of two expeditions (41 stations) [1] and the information by Carbon database (over 600 stations) [18]. To create the map, carbon content was averaged for the upper 5-cm layer of bottom sediments at the treated stations and information from the database was verified.

It was confirmed that the concentrations of organic carbon are closely related to the grain-size composition of sediments (Fig. 5, [3]). The minimum concentrations are associated to sands and sandy siltstones located above the 50-m isobathic line. The increased content is characteristic for the accumulation zones of aleuropelite matter located in estuarine areas and in the sedimentation depot at the middle part of the St. Anna Trench. The content of C_{org} in siltstones of the Novozemel'skii Trough is lower in general than that in aleuropelites of the St. Anna Trough but exceeds the carbon content in the sands of the beginning of the continental slope.

The maxima of C_{org} content in the Yenisei profile (Fig. 5, 1b) were registered in aleuropelites of the estuarine area at the zone belonging to the gravitation part of the marginal filters (station 5018, 2.4% of C_{org} per dry mass on average). One must note that the accumulation of finer aleuropelite matter and increased content of organic carbon in bottom sediments exactly coincide with the projection of marginal filter onto the bottom in summer–autumn time. No peak increase of runoff during the flood season was revealed for the sedimentation of the OM-enriched fine-grained matter outside the estuarine zone. Thus, one may suppose that sediment matter supplied by waters of spring flood is not buried in the nearby shelf zone but transferred with flood waters to deeper areas of the Kara Sea shelf.

The other maximum of C_{org} content belongs to the intermediate depot of sedimentation in the transient area of the St. Anna Trench at the northern extremity of the Novaya Zemlya Islands deeper than 150 m. Sediment matter is supplied there not only from the Kara Sea basin but also from the northeast of the Barents Sea [5]. The redeposited sandy sediments at a depth of 30–50 m are characterized by decreased C_{org} concentrations (e.g., 0.4% of C_{org} at station 5032).

A topical problem in the studies of the carbon cycle is the OM transformation at the water–sediment interface. The variations in OM concentrations and composition were noted by [6]. However, an incidence of this effect was not characterized. The thorough separation of the bottom sediments cores in the course of sampling allowed the determination of enrichment degrees of upper layers of the sediments in organic matter.

The enrichment of warp and subwarp layers (0–0.1 and 0.01–0.5 cm, respectively) in organic carbon relatively to the average C_{org} content in the upper (5-cm) sediment layer was found in most of the examined samples (Fig. 5a). The increase of C_{org} concentration is commonly registered in the subwarp layer (Table 2), shifting sometimes to the warp. The enrichment of these layers in C_{org} relatively to average C_{org} content over all the stations amounted to 21% ($r^2 = 23\%$) for the Yenisei section and 49% ($r^2 = 52\%$) for the Ob section. The maximum values were as high as 80% in the sands of the Yenisei estuarine zone (station 5014) and 150% in the sands of the Ob River mouth (station 4994). This effect is registered in all the types of sediments (sands, aleuropelites, and claystones), being not localized in any area of the considered basin and characteristic for the entire surveyed region. This layer is also characterized by the occurrence of the maximum biomasses of microorganisms, the growth of their integrated activity, and the changes in isotope and chemical composition of molecular markers [7]. Hence, one may assert that the processes described above are characteristic not only for the stations considered by [7] but also for the entire surveyed

Table 2. The content of C_{org} in bottom sediments

Station no.	Depth, m	Lith. layer, cm	Layer, cm	C_{org}, %
5007	138	0–0.5	Warp	1.42
		0.5–6	0.5–1	1.75
			2–6	1.71
		6–33	6–8	1.74
			8–13	1.73
			13–20	0.12
			20–33	1.37
5008	22	Warp	Warp	1.73
		0.1–5	0.1–0.5	1.14
			0.5–1	1.96
			1–5	1.31
		5–22	5–10	1.03
			10–15	1.18
			15–22	1.11
5010	28	0–1	Warp	1.69
			0.1–0.5	2.08
			0.5–1	1.49
		1–5	1–2	1.52
			2–5	1.57
		5–33	5–10	1.81
			10–15	0.88
			15–20	1.09
			20–25	1.39
			25–33	1.53
5013	28	Warp	Warp	0.73
		0–5	0–1	0.62
			1–5	0.51
		5–12	5–12	0.44
		12–16	12–16	1.16
		16–25	16–20	0.17
			20–25	0.24
5014	4	0–1	Warp	1.07
			0–1	0.47
		1–13	1–5	0.61
			5–13	0.61
5015	7.8	0–1	Warp	2.80
			0.5–1	2.66
		1–10	1–2	2.30
			2–5	1.42
			5–10	2.45
		10–32	10–15	2.24
			15–20	2.38
			20–25	3.45
			25–32	2.55

Station no.	Depth, m	Lith. layer, cm	Layer, cm	C_{org}, %
5016	13.0	0–0.5	Warp	2.23
			0–0.5	2.20
		0.5–4	0.5–4	2.10
		4–28	4–10	1.96
			10–15	2.03
			15–20	1.89
			20–28	1.81
5018	11.7	0–2	Warp	2.42
			0–2	2.40
		2–32	2–5	2.34
			5–10	2.27
			10–15	2.38
			15–20	2.16
			25–32	2.56
5011-2	31.7	0–1	Warp	1.55
			0–1	1.52
		1–3	1–3	1.33
		3–28	3–5	1.46
			5–10	1.32
			10–15	1.20
			15–20	1.27
			20–28	1.13
5021	31.0	0–5	Warp	2.17
			0–1	1.89
			1–5	2.01
5023	27.0	0–1	Warp	0.32
			0–1	0.17
		1–5	1–5	0.25
		5–10	5–10	0.63
		10–12	10–12	0.45
5024	33.7	0–1	Warp	0.47
			0–1	0.59
		1–5	1–5	0.46
5025	48.0	0–1	Warp	0.61
			0–1	0.40
		1–6	1–2	0.46
			2–6	0.45
		6–16	6–10	0.35
			10–16	0.29
5026	62.0	0–2	Warp	1.14
			0–1	0.85
			1–2	0.85
		2–28	2–5	0.77
			5–10	0.65

Table 2. (Contd.)

Station no.	Depth, m	Lith. layer, cm	Layer, cm	C_{org}, %
			10–15	0.69
			15–20	0.64
			20–28	0.66
5028	34.5	0–3	Warp	1.44
			0–1	0.99
			1–3	0.77
		3–8	3–8	0.82
5030	41.0	0–5	Warp	1.12
			0–1	1.39
			1–5	0.99
		5–20	5–20	0.69
5032	54.0	0–1	Warp	0.54
			0–1	0.39
		1–2	1–2	0.48
		2–21	2–5	0.38
			5–10	0.29
			10–15	0.35
			15–21	0.62
5033	118.0	0–5	Warp	0.86
			0–1	0.83
			1–2	0.81
			2–5	0.17
		5–6	5–6	0.68
		6–28	6–10	0.48
			10–15	0.53
			15–20	0.56
			20–28	0.84
5034	216.0	0–2	Warp	1.43
			0–1	1.31
			1–2	1.63
		2–4	2–4	1.36
		4–29	4–10	1.24
			10–15	0.95
			15–20	0.77
			20–29	0.74
5037	317.0	0–5	Warp	1.85
			0–2	2.42
			2–5	1.33
		5–8	5–8	1.23
		8–26	8–26	
5039	362.0	0–2	Warp	1.89
			0–1	1.81
			1–2	1.79
		2–5	2–5	1.51
		5–9	5–9	1.07
		9–30	9–15	1.21
			15–20	1.42
			20–25	1.19
5042	470.0	0–4	Warp	1.56
			0–1	1.61
			1–4	1.41
		4–7	4–7	1.42
		7–30	7–10	1.49
			10–15	1.69
			15–20	1.51
			20–25	1.58
			25–30	1.83
5044	154.0	0–3	Warp	0.91
			0–1	0.83
			1–3	0.86
		3–12	3–7	0.62
			7–12	0.75
5045	537.0	0–0.5	Warp	1.59
			0–0.5	2.41
		0.5–2	0.5–2	1.50
		2–28	2–5	2.25
			5–10	2.13
			10–15	2.01
			15–20	2.00
			20–25	2.08
			25–28	2.15

Lith. layer is a layer of sediment distinguished by lithological parameters in view of the lithological description.

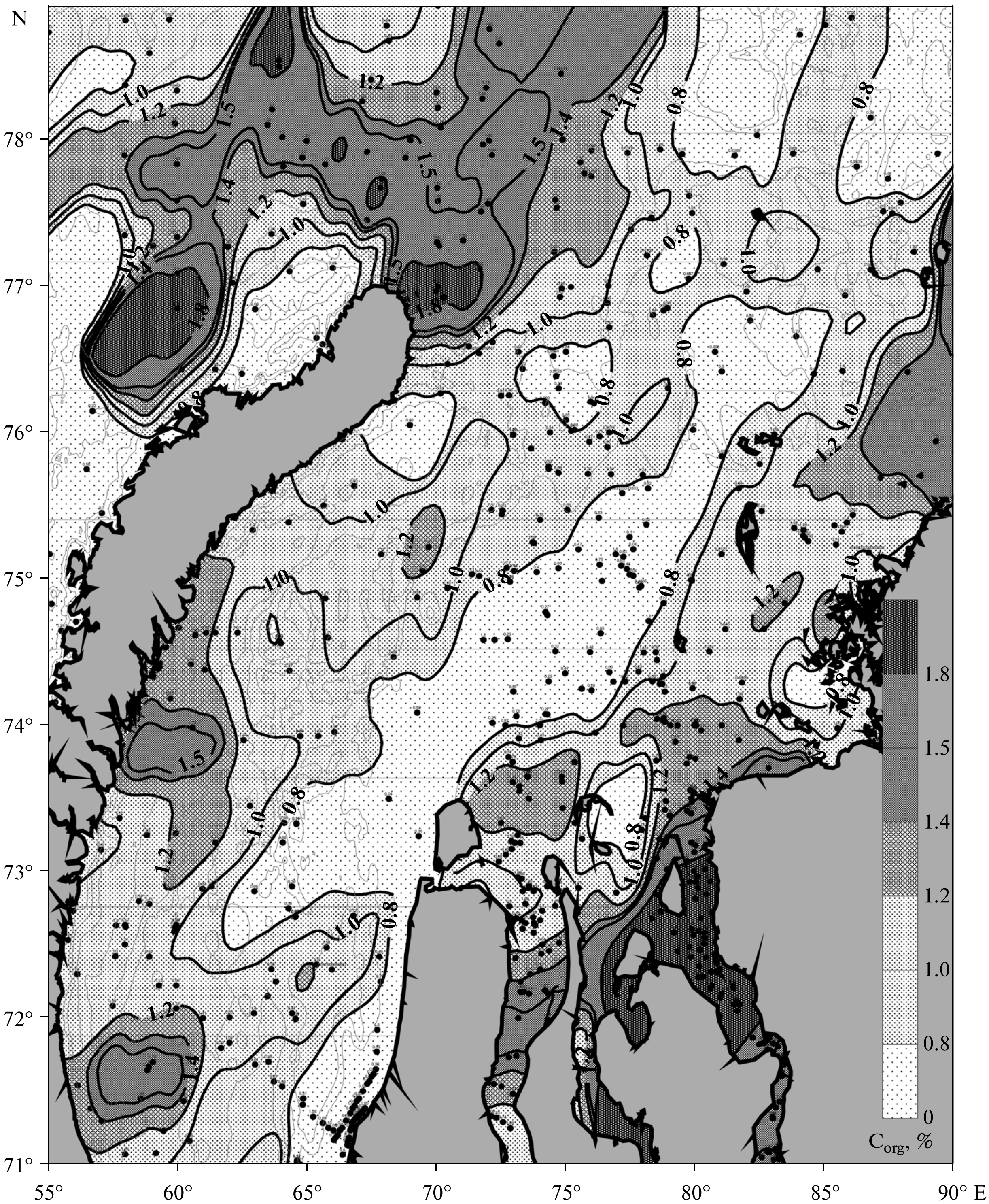

Fig. 4. Map of C_{org} distribution in the upper layer (0–5 cm) of bottom sediments.

aquatic area. The question of the seasonal variability of C_{org} concentrations in the surface layer of 0–0.5 cm is still open. All the examined samples were collected during the summer–autumn season long after the completion of the spring peak of phytoplankton bloom [11]. The increase of carbon content may be caused by seasonal localization of the supplied autochthonous OM in the upper layer of sediments and the subsequent biogeochemical transformation of the OM. To reveal the seasonality in the processes of OM transfor-

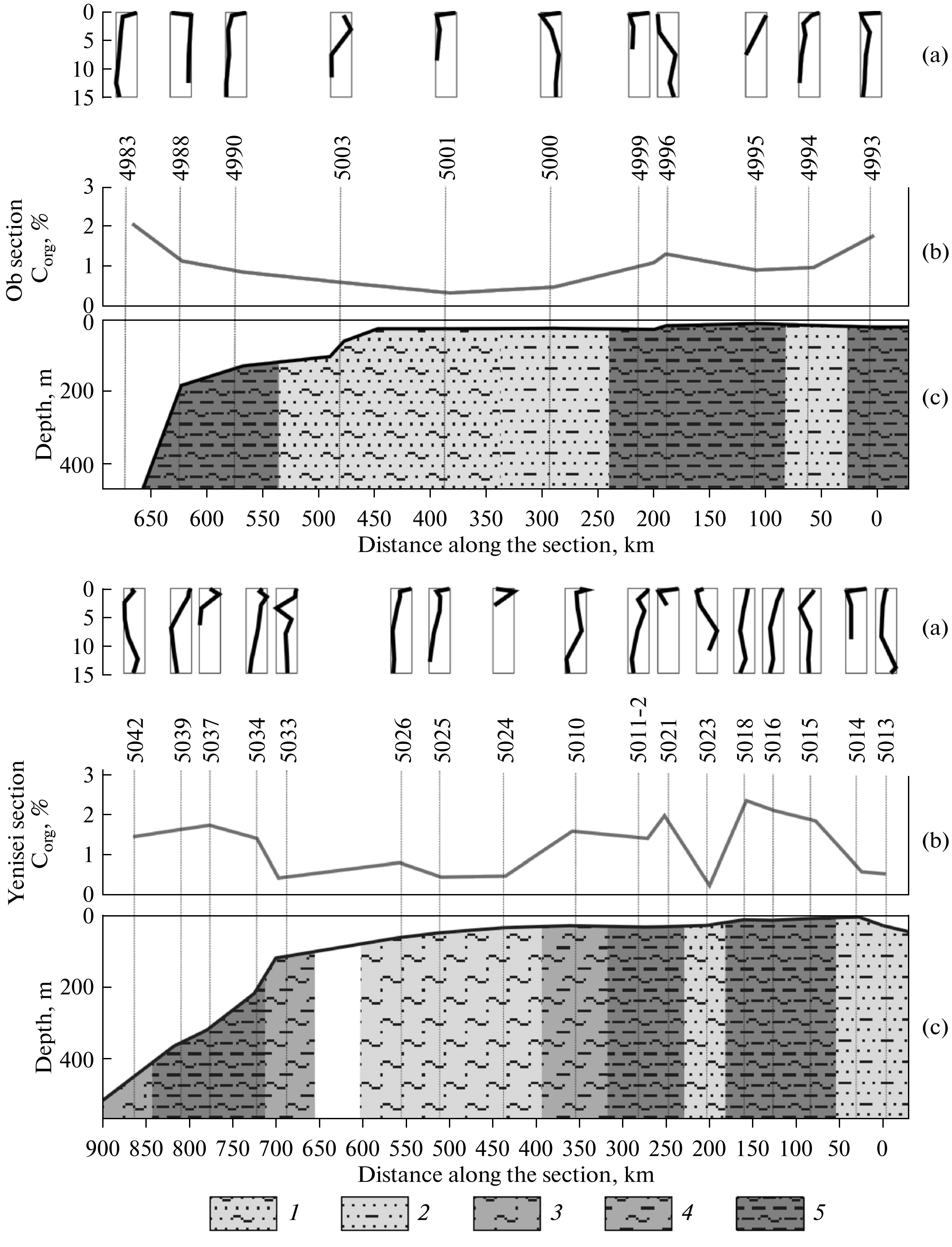

Fig. 5. (a)—relative vertical variations of C_{org} content along the core of bottom sediments; (b)—C_{org} distribution in the upper layer of bottom sediments over the section; (c)—the bottom profile and grain-size characteristics of a sediment; *1*—silty sand; *2*—clayey sand; *3*—sandy siltstone; *4*—clayey siltstone; *5*—aleuropelite.

mation in the upper layer of sediments, as well as the regional features of sedimentation and of initial stages of diagenesis, the surveys at the late winter season are required, which would allow one to make a conclusion on the permanent or temporary occurrence of the greatly reactive transformation zone.

CONCLUSIONS

The distribution of POC in the Kara Sea is closely related both to the propagation of the waters of riverine runoff and to local variations in plankton abundance. The highest POC concentrations were registered in the waters of gravitation part of the marginal filter at the outlet of the Yenisei Gulf (stations 5007–5015). The most pronounced enrichment of particulate matter in organic components was characteristic for the biotic part of marginal filter (stations 5010, 5018, 5011-2, and 5021) [8] and for the area of inflow of Atlantic waters and of the Novaya Zemlya upwelling (stations 5039–5045). The enrichment of particulate matter in the autochthonous component is closely related to the registered maxima of plankton abundance in the frontal zones revealed by the expedition.

The distribution of DOC in surface waters shows the conservative mode; the concentrations are varied under the mixing of riverine and marine waters. An excess of DOC concentrations compared to the calculated conservative values was found in the near-bottom layers of stations 5010, 5018, 5011-2, and 5021 associated to the zones of biological fronts. An increase of both DOC and POC concentrations within the water mass which marked the zone of increased biopoductivity was registered in the northwestern area of the surveyed region at the mixing zone of the Kara Sea waters and those of the Central Arctic Basin.

The correlation of OC content in bottom sediments and their grain-size composition is confirmed. The increased OC content was registered in aleuropelite sediments of the zones of riverine estuaries and in local depots of sedimentation at the St. Anna Trench. The increased OC concentrations were found in redeposited sands embedded about 50-m isobathic line.

The enrichment of the upper thin layer of sediments (the warp and subwarp) in organic carbon was revealed. The increase of OC content in the surface layer of sediments is characteristic for all the types of sediments over the entire surveyed region. The analysis of vertical distribution of carbon in the upper layer of bottom sediments localizes distinctly the water–sediment barrier zone in the upper layer being thinner than 1 cm.

ACKNOWLEDGMENTS

The authors are grateful to M.D. Kravchishina for the granted data on mass concentrations of particulate matter [4], to all the scientific staff of the expedition, to M.V. Flint and A.Yu. Lein personally for their valuable advises and criticism, as well as to the crew of RV *Akademik Mstislav Keldysh* for their permanent assistance. We are especially grateful to E.A. Romankevich for consulting and determining the direction of the research.

The study was carried out within state order no. 0149-2014-0036. Analytic processing was carried out with the support of the RF government (grant no. 14.Z50.31.0012).

REFERENCES

1. N. A. Belyaev, V. I. Peresypkin, and M. S. Ponyaev, "The organic carbon in the water, the particulate matter, and the upper layer of the bottom sediments of the west Kara Sea," Oceanology (Engl. Transl.) **50** (5), 706–715 (2010).
2. V. V. Gordeev, *Geochemistry of the River-Sea System*, Ed. by A. P. Lisitzin (Izd. I.I. Matushkina, Moscow, 2012), pp. 284–288.
3. V. A. Kosheleva and D. S. Yashin, *Bottom Sediments of the Arctic Seas of Russia*, Ed. by I. S. Gramberg (Russian Scientific Research Institute of Ocean Geology, St. Petersburg, 1999), p. 112.
4. M. D. Kravchishina, A. Yu. Lein, I. N. Sukhanova, V. A. Artem'ev, and A. N. Novigatsky, Okeanologiya (Moscow) (in press).
5. M. A. Levitan, Yu. A. Lavrushin, and R. Stein, *History of Sedimentation in the Arctic Ocean and Subarctic Seas* (GEOS, Moscow, 2007) [in Russian].
6. A. Y. Lein, N. A. Belyaev, and M. D. Kravchishina, "Isotope markers of organic matter transformation at the water-sediment geochemical barrier," Dokl. Earth Sci. **436** (2), 214 (2011).
7. A. Y. Lein, P. N. Makkaveev, M. D. Kravchishina, et al., "Transformation of suspended particulate matter into sediment in the Kara Sea in September of 2011," Oceanology (Engl. Transl.) **53** (5), 570–606 (2013).
8. A. P. Lisitzin, "Marginal filter of oceans," Okeanologiya (Moscow) **34** (5), 735–747 (1994).
9. A. P. Lisitzin, V. P. Shevchenko, M. E. Vinogradov, et al., "Flows of sediments in the Kara Sea," Okeanologiya (Moscow) **34** (5), 748–758 (1994).
10. P. N. Makkaveev, Z. G. Melnikova, A. A. Polukhin, S. V. Stepanova, P. V. Khlebopashev, and A. L. Chultsova, Okeanologiya (Moscow) (in press).
11. P. R. Makarevich, "Annual succession of pelagic phytocenosises of estuarial ecosystems of the northern Russian seas," Al'gologiya **18** (4), 386–392 (2008).
12. *Review of the Environmental Pollution Degree in Russian Federation in 2011*, Ed. by Yu. A. Izrael', et al. (Rosgidromet, Moscow, 2012), p. 19.
13. "Special issue," Okenologiya (Moscow) **50** (5), (2010).
14. P. O. Zavialov, A. S. Izhitskiy, A. A. Osadchiev, V. V. Pelevin, and A. V. Grabovskiy, Oceanology (Engl. Transl.) (in press).
15. E. G. Arashkevich, "A report of the group studying zooplankton," in *Scientific Report of the 59th Cruise of R/V Akademik Mstislav Keldysh, September 12 – October 7, 2011*, Archive of the Shirshov Scientific Research Institute of Oceanology (IO RAN), vol. 2.
16. I. N. Sukhanova, "A report of the group studying phytoplankton," in *Scientific Report of the 59th Cruise of R/V Akademik Mstislav Keldysh, September 12 – October 7, 2011*, Archive of the Shirshov Scientific Research Institute of Oceanology (IO RAN), vol. 2.
17. A. B. Demidov, S. A. Mosharov, and P. N. Makkaveev, Okeanologiya (Moscow) (in press).
18. E. A. Romankevich and A. A. Vetrov, *Carbon Cycle in the Russian Arctic Seas* (Nauka, Moscow, 2001) [in Russian].
19. H. Kohler, B. Meon, V. V. Gordeev, et al., "Dissolved organic matter (DOM) in the estuaries of Ob and Yenisei and the adjacent Kara Sea, Russia," in *Siberian River Run-Off in the Kara Sea*, Ed. by R. Stein, et al. (Elsevier, Amsterdam, 2003), pp. 281–308.

Translated by A. Rylova