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OCEANOLOGY

Freshwater Sources in the Bays of Yuzhnyi Island of the Novaya Zemlya Archipelago according to Isotopic (δD, $\delta^{18}O$) Data

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Abstract—An isotope–geochemical study was performed on the waters of Abrosimov and Stepovoi bays along the southeastern coasts of the Novaya Zemlya Archipelago. The waters considered were freshened by several sources: the continental river runoff, the regional atmospheric precipitation, and the waters supplied from the archipelago. The contributions of these freshwater constituents appeared to be different for surface and subhalocline waters. It was shown that the surface waters were freshened with the local runoff from the archipelago, whereas those situated under the halocline were affected by a mixture of the Ob and Yenisei waters along with thawed riverine ice. The supply of the constituents mentioned into aquatic areas of the bays was determined by the global circulation of the Kara Sea waters freshened in turn with those of the continental runoff as well.

Keywords: oxygen and hydrogen isotopes, salinity, seawater, Arctic, Kara Sea, freshening, Novaya Zemlya Archipelago

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INTRODUCTION

The Kara Sea, separated partially by the Novaya Zemlya Archipelago, is the most freshened one among the Russian Arctic seas with as high as 40% content of freshwater in the surface layers [1]. The global freshwater source in the Kara Sea is the runoff of the great Siberian Ob and Yenisei rivers [2]. The two-component mixing of riverine waters supplied with the continental runoff and modified Atlantic waters of the Barents Sea origin is traced from the riverine estuaries as far as the central part of the sea [1, 3, 4]. The regional atmospheric precipitation [4] may be considered as a permanent source of the Kara Sea freshening along with atmospheric precipitation of high latitudes detected in low-freshened waters of the bays of Severnyi Island researched formerly by the authors [5].

In moving off the continent and approaching the coast of Novaya Zemlya Archipelago, the freshening processes in the Kara Sea waters are supplemented with local freshwater sources of seasonal watercourses and glacial thawed water supplied from the coasts of the archipelago [5]. The main freshwater sources for Severnyi Island are glacial thawed waters and, to a smaller degree, the summer atmospheric precipitation [7]. Since Yuzhnyi Island is characterized by the absence of upland and covering glaciation [8], one may suppose that the main contribution to local runoff from the island should be provided exclusively by seasonal atmospheric precipitation.

As the Novaya Zemlya Current is propagated from north to south along the entire eastern coasts of the archipelago [6], one may assume that the bay waters of both Severnyi and Yuzhnyi islands are characterized by the same freshwater sources. However, their contribution into the spatial distribution within the water masses in the bays may be different for each of the islands. The present study aimed to reveal the sources of freshening components along with the peculiarities of their spatial distribution within the water mass in the bays of Yuzhnyi Island of Novaya Zemlya Archipelago. The isotope geochemistry of oxygen and hydrogen was selected as the technique for study of the representativeness in terms of the processes of seawater freshening [9, 10]. The waters of Abrosimov and Stepovoi bays constituted the subject of this study.

MATERIALS AND METHODS

The samples for study were collected in vertical profiles of the stations located in the bays and bay out-

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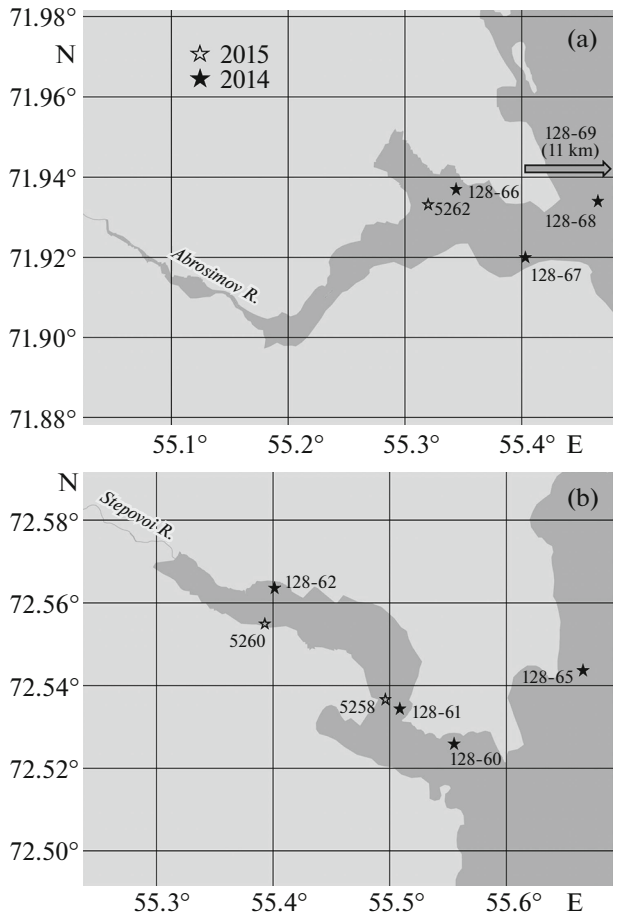

Fig. 1. The location of sampling stations in (a) Abrosimov and (b) Stepovoi bays of Yuzhnyi Island of the Novaya Zemlya Archipelago.

lets (Fig. 1) during the cruises of R/Vs *Professor Shtokman* and *Akademik Mstislav Keldysh* over the Kara Sea in 2014 and 2015, respectively. The samples in Stepovoi Bay were collected at six stations in ~10-m intervals (stations 5258 and 5260 of 2015 as well as stations 128-60, 128-61, 128-62, and 128-65 of 2014; see Fig. 1). The samples in Abrosimov Bay were collected at five stations (station 5262 of 2015 as well as the stations 128-66, 128-67, 128-68, and 128-69 of 2014; Fig. 1) in ~5-m average intervals. The sampling was carried out with bottle samplers of an SBE 32 set; the water temperature and salinity were measured using an SBE 19plus CTD probe.

The isotope analysis of oxygen was carried out by the CF IRMS procedure using a DELTA V+ mass spectrometer (Thermo Co., Germany) equipped with a Gas Bench II peripheral unit. The isotope analysis of hydrogen was carried out by the reduction of water samples on hot chromium (H/Device) and subsequent analysis with a DELTAplus mass spectrometer (Thermo Co., Germany). The δD and $\delta^{18}O$ values of water samples were calibrated in the V-SMOW–V-SLAP scale using the appropriate international standards. The accuracy of determination of the $\delta^{18}O$ and δD values amounted to ±0.05 and ±0.03‰, respectively.

CHARACTERISTICS OF THE BAYS

Stepovoi and Abrosimov bays are located on the eastern coast of Yuzhnyi Island of the Novaya Zemlya Archipelago. Stepovoi Bay, situated 70 km to the north of Abrosimov Bay, is a bight elongated deep into the island for 11 km to the northwest, with the maximum 1.8 km width at the inlet (Fig. 1a). The bay consists of two basins: the deeper (60 m) inner one and the central part of 35–45 m depth. The basins are separated with a threshold uplifted to the depth of 25 m. A similar threshold separates the central basin of the bay from the open sea; Stepovoi Bay is characterized by the discharge of numerous brooks and the Stepovoi River. Abrosimov Bay (Fig. 1b) cuts for 6 km into the coast of Yuzhnyi Island and has a width of 2 km at its widest part. The bay is subdivided into two bights (northern and southern). The bay is shallow (≈10 m average depths), and the open part is as deep as ≈20 m. Numerous brooks and the Abrosimov River are discharged into the bay [11].

RESULTS

Compared to North Atlantic waters circulating over the Barents and Kara seas (S ~ 34.90 PSU; [1, 4]), the waters of the treated stations were freshened at all the sampled depths and the average salinity of bay waters amounted to 32 ± 4.2 PSU at all of the depths. The maximum salinity of 34.58 CPU was registered in the waters of the station 128-69 located at the maximum seaward distance from the coasts of Abrosimov Bay (sampling of 2014). The minimum salinity of 26.85 PSU was characteristic for stations 5258 and 5260 in Stepovoi Bay (sampling of 2015). In both of the bays, the waters of surface layers were subjected to the maximum freshening, whereas the near-bottom waters showed a salinity of 33 PSU or more.

The behavior of the $\delta^{18}O$ and δD values was similar to that of salinity. The least values were registered in the most freshened waters of the surface layer in Stepovoi Bay and amounted to –2.8 and –21.5‰, respectively. No pronounced freshening took place that year in Abrosimov Bay, and the $\delta^{18}O$ and δD values in the waters of the surface layer amounted to –0.13 and –1.90‰, respectively. The waters of both bays surveyed were not considerably freshened as well in 2014, and the $\delta^{18}O$ and δD values varied in narrow ranges from –0.8 to –0.2 and from –6 to –3‰, respectively. The maximum $\delta^{18}O$ and δD values were registered in the near-bottom waters of Abrosimov Bay in 2015: +0.27 and –1.59‰, respectively. Thus, the $\delta^{18}O$ and δD values in Stepovoi Bay varied from –2.82 to

+0.12 and from –21.5 to –2.4‰, respectively (35 samples). These values in Abrosimov Bay varied from –0.88 to +0.27 and from –6.9 to –0.4‰, respectively (23 samples).

DISCUSSION

Considering the isotope composition–salinity relationship, the authors used the δD value for measuring to a better relative accuracy against that of $\delta^{18}O$ applied commonly in oceanological studies [1, 3, 9]. The freshwater components were identified by means of analysis of the data concerning the calculation lines. Each of these latter corresponded in δD–*S* coordinates to the mixing of one of the freshwater components and the waters of Atlantic origin [5]. Figures 2a and 2b show the mixing lines for all the potential freshening sources of isotope parameters.

Under the specific wind conditions, westward propagation would be possible not only for the Ob and Yenisei estuarine waters but also for riverine ice [2]. The isotope characteristics of the Ob and Yenisei estuarine waters were determined previously by extrapolation to zero salinity of the data for the waters of the center of the Kara Sea [4]. The isotope parameters of riverine ice were calculated using the appropriate fractionation coefficients of oxygen and hydrogen isotopes in the water–ice system: α(D) = 1.0211 and $\alpha(^{18}O)$ = 1.0029 [12].

The freshwaters supplied from the coasts of the Novaya Zemlya Archipelago during the summer season when the samples were collected might be constituted by thawed glacial waters and summer atmospheric precipitation. Severnyi Island is characterized by the prevalence of glacial waters in the runoff from the archipelago with a minor contribution (25% or less) of summer atmospheric precipitation [7]. The main source of local watercourses on Yuznhyi Island is the local atmospheric precipitation. The ranges of the $\delta^{18}O$ and δD values in the atmospheric precipitation over the area considered were evaluated using the GNIP database [13]. Since the Atlantic air masses passing over Northern and Central Europe, Scandinavia, Svalbard, and (partially) Iceland were the main sources of atmospheric precipitation over Novaya Zemlya Archipelago [7], the authors used the data by the stations of Ny Aalesund (Svalbard), Reykjavik (Iceland), and Amderma (the Kara Sea coasts). In our view, the ranges obtained should characterize both the local runoff from Yuzhnyi Island and the atmospheric precipitation falling in summer in the Novaya Zemlya region.

The data obtained for the bay waters of Yuzhnyi Island constitute two groups of points in Fig. 2a within the salinity ranges of 31–32 and 32–34.5 PSU (groups I and II, respectively). Group I includes the waters from shallow depths characterized as a rule by waters of the upper mixed layer: up to 13–17 m at stations

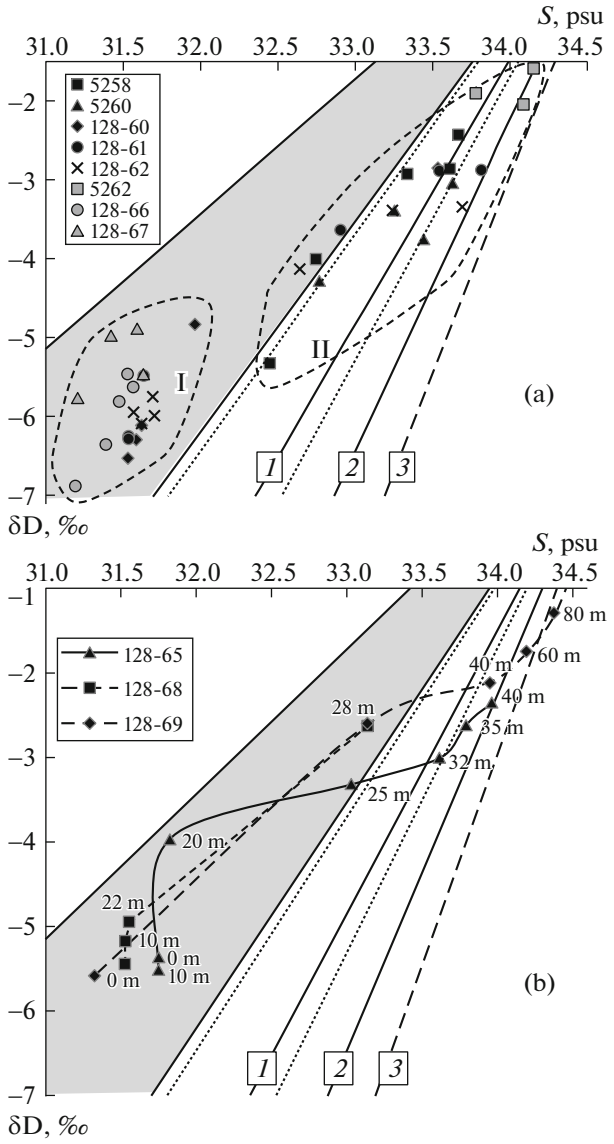

Fig. 2. The data obtained for (a) the waters of the stations in the bays of Yuzhnyi Island of the Novaya Zemlya Archipelago and (b) the remote stations in the Kara Sea in δD–*S* coordinates. The black and gray markers are for the stations in Stepovoi and Abrosimov bays, respectively. The lines *1*, *2*, and *3* show the mixing of the marine component of Atlantic origin with the waters of the Ob River, Yenisei River, and regional atmospheric precipitation, respectively. The dotted lines are for the mixing of the marine component with thawed ice of the associated river. The shaded area shows the seawater mixing with the summer atmospheric precipitation falling over the Novaya Zemlya region.

128-67 and 128-66 in Abrosimov Bay and up to 20 m at stations 128-60, 128-61, and 128-62 in Stepovoi Bay. Related to the calculation lines, group I is situated in the field of mixing seawaters with summer atmospheric precipitation falling over the archipelago. This freshwater constituent might be supplied to the upper layers of bay waters by both the local runoff from

Yuzhnyi Island and immediately as atmospheric precipitation. The contribution of the atmospheric component into surface waters of the bay amounted to 8–15%.

Group II consists of the points for the waters sampled at depths over 20 m in 2015 at the stations 5258 and 5260 in Stepovoi Bay along with station 5262 in Abrosimov Bay, as well as at stations 128-60, 128-61, and 128-62 in Stepovoi Bay in 2014. Related to the calculated mixing lines, this group of points is situated within the area characteristic for the mixing of Atlantic waters and the freshwater component of continental origin: the Ob and Yenisei estuarine waters along with thawed riverine ice. The total contribution of the freshwater components amounts to 2–5% for the waters of this group. Most likely, these waters are supplied into the bays of Yuzhnyi Island under circulation of the Kara Sea waters freshened generally to about the same degree by the riverine continental runoff [1]. The increasing effect of the local atmospheric component with the decrease of salinity is traced in the waters of this group.

The general trend as such is shown by the waters of stations at outlets of the bays (stations 128-65, 128-68, and 128-69). The lines of δD variations with depth for these stations are seen in Fig. 2b. The waters of all the stations are characterized by a similar distribution of the role of freshening components with depth. The freshening of surface layers is caused by local atmospheric precipitation, whereas the deeper waters are characterized by an increase of the influence of remote freshwater sources (the riverine runoff and regional atmospheric component).

Unlike Severnyi Island, subhalocline waters of the bays of Yuzhnyi Island showed no occurrence of the atmospheric component characteristic probably of the polar current waters supplied to Novaya Zemlya Archipelago from higher latitudes through the St. Anna and Voronin trenches [5]. Near-bottom waters of the Yuzhnyi Island bays are freshened with the components of continental runoff (the Ob and Yenisei estuarine waters along with riverine ice) supplied by the East Novozemel'skoe Current transferring the Kara Sea waters desalinated by the continental runoff along the Novaya Zemlya coasts from north to south [6, 15]. No surface plumes of riverine waters were registered for Yuzhnyi Island, unlike the bays of Severnyi Island where, in particular, a surface plume of the Ob estuarine waters was found on Sedov Bay in 2015 [5]. However, the propagation of riverine plumes as such towards Yuzhnyi Island must not be ruled out, e.g., owing to the same Novozemel'skoe Current; nevertheless, this was not confirmed by the authors' surveys of 2014–2015.

The absence of the contribution of a glacial component into the local runoff from the archipelago determines the specificity of isotope characteristics of surface waters in the bays of Yuzhnyi Island. Stepovoi and Abrosimov bays are freshened exclusively by the summer local atmospheric component, which is capable of freshening the surface waters of bays both by the immediate discharge of summer precipitation over the aquatic areas and by the runoff from the archipelago.

CONCLUSIONS

The aquatic areas of the bays of Yuzhnyi Island of the Novaya Zemlya Archipelago, similarly to those of Severnyi Island, are freshened with waters supplied from both local and remote sources. The contributions of these sources are different for the surface and subhalocline waters of the bays of Yuzhnyi Island. The main specificity of surface waters in Stepovoi and Abrosimov bays consists in the absence of components such as glacial runoff and riverine plumes. The key freshwater component in the bays is the summer atmospheric precipitation constituting the runoff from the archipelago. Subhalocline waters in the bays of Yuzhnyi Island are freshened with the components of the continental runoff supplied to the coasts of the archipelago with the Kara Sea waters freshened integrally by the Ob and Yenisei estuarine waters along with thawed riverine ice.

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