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Some aspects of the nutrient geochemistry of Novaya Zemlya rocks

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Abstract. The primary sources of nutrients in the Arctic are river runoff and remineralization processes. However, the local characteristics of coastal ecosystem functioning are strongly influenced by the supply of nutrients from glacial meltwater, particularly in regions where glacier-fed streams interact with the bedrock. In this study, we tested the hypothesis that rocks which form the bedrock of glacial streams, such as sandstones, siltstones, shales and carbonates, can serve as significant sources of nutrient elements (notably nitrogen and silicon) for coastal ecosystems. Laboratory experiments involving the exposure of representative rock samples to distilled water for up to 30 days demonstrated a measurable increase in nutrient concentrations. The observed leaching rates for nitrate nitrogen and dissolved silicon reached up to 7.9 micromoles per square meter per day and 30.7 micromoles per square meter per day, respectively, in the most reactive samples (these were sandstone from Stepovogo bay and siltstone from Blagopolychia bay). The results indicate that the release of nutrient elements from glacial bedrock, particularly during periods of enhanced meltwater runoff, can contribute significantly to the balance of nutrients and primary productivity of Arctic coastal ecosystems.

Keywords: Novaya Zemlya, Kara Sea, rocks, nutrients, stream runoff

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Introduction

Novaya Zemlya is an archipelago located in the Russian sector of the Arctic between the Barents Sea and the Kara Sea. Due to the changing climate, significant changes have been taking place in the ecosystem of the Arctic seas in recent years: the area of long-term ice has been significantly reduced [1, 2], the ice age and thickness of the seasonal ice cover have been decreasing [3], and the influence of Atlantic water mass inflows has been increasing [4, 5]. According to [6], the retreat of outlet glaciers to the Novaya Zemlya archipelago has significantly accelerated in the last two decades, with a reduction in glacier area of 1,000 km^2 since the end of the 20th century, and a reduction in ice volume of 380 km^3. Thus, it is evident that Novaya Zemlya serves as an indicator of climate changes in the Arctic. Climate change is leading to a fundamental restructuring of the hydrological and, consequently, biogeochemical conditions of Arctic ecosystems [7–9]. Glaciers play a particularly important role in global biogeochemical processes. As a result of physical and chemical weathering, they release significant amounts of dissolved substances and solid particles into coastal zones [10, 11]. According to existing studies [12–16], glacier retreat increases the concentrations of biogenic compounds, as well as organic matter, in rivers fed by glacial meltwater [17]. Parallel investigations in Tempelfjorden Bay (Svalbard Archipelago) [18] have shown that carbonate rocks composing the shoreline represent a significant source of not only nutrient elements but also heavy metals to the aquatic ecosystem. Research in northern Sweden (Karkevagge area) has demonstrated that metamorphic rocks, particularly crystalline schists, serve as a source of inorganic nitrogen for regional water bodies, including the rivers and lakes of Lapland [12].

During field investigations in the biohydrochemistry laboratory, IORAS, of streams in the bays studied, elevated concentrations of nitrate nitrogen and dissolved silica were detected compared to the average values for the Kara Sea. The mean nitrate concentrations in the streams during each study period significantly exceeded the mean values observed in the surface waters of the Kara Sea (0.5–1 μmol); a similar excess was also recorded for dissolved silica concentrations (the mean value for the Kara Sea is about 8 μmol). The data were previously published in the articles [19–21]. The averaged results for each bay are presented in Table A.1.

There is a lack of data on the lithology of Novaya Zemlya bays in the global scientific literature. The inaccessibility of the archipelago has so far prevented shedding light on the lithological structure, composition, and age of the archipelago’s rocks. The absence of lithological data made it impossible to explain the peculiarities of the biogeochemical structure of the archipelago's bays. This became possible within the framework of the comprehensive program “Ecosystems of the Siberian Arctic Seas”, which was launched in 2007 under the guidance of Academician M.V. Flint [22, 23].

The aim of this study is to describe the lithological and chemical features of rock samples forming the shores of the Novaya Zemlya Archipelago. Using experimental investigations of field material, we seek to determine the influence of the composition of the bedrock on the qualitative and quantitative characteristics of the fluxes of nutrient elements (nitrate nitrogen, dissolved silica). The patterns observed are used to explain the high concentrations of nutrient elements in Novaya Zemlya streams.

Material and methods

As shown in Figure 1, the study area is located in Novaya Zemlya.

The coastal zone of the Novaya Zemlya Archipelago and the surfaces of small islands represent a terraced plain, bounded by a coastal escarpment. As one moves inland from

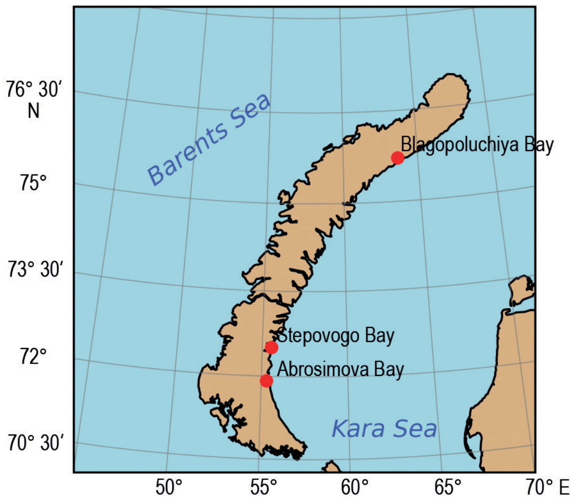

Fig. 1. Location of the study area on Novaya Zemlya Archipelago

Рис. 1. Местоположение района исследования на архипелаге Новая Земля

Fig. 2. A typical landscape on Novaya Zemlya. Photo by Gennady V. Borisenko

Рис. 2. Типичный ландшафт Новой Земли. Фото Г.В. Борисенко the coast, the coastal plain transforms into a denudation plateau characterized by absolute elevations ranging from 200 to 500 meters above sea level.

The general topography of Novaya Zemlya is defined by the presence of a mountain ridge, which is divided by transverse through valleys into separate tectonic blocks. Most of the elevated relief elements are completely devoid of vegetation and represent a typical Arctic desert. The vegetation of the Arctic tundra is mainly localized in the coastal zone and river valleys [24].

A typical landscape of Novaya Zemlya is shown in Fig. 2. The ground is mostly covered by tundra vegetation—mosses, lichens, with patches of bare rock and gravel. Watercourses are usually fed by melting snow and ice, and their banks are often muddy, lined with stones and sparse vegetation.

In the coastal zone and marine inlets, the surface layer is mainly composed of sandy deposits underlain at a depth of 12–20 meters by clayey rocks. Granulometric analysis shows a predominance of fine and very fine sand fractions.

The primary material for this study consisted of a collection of rock samples obtained during expeditionary work in the water areas of three bays of the Novaya Zemlya Archipelago: Blagopoluchiya, Stepovogo and Abrosimova. The geological material was collected as part of the Kara Sea Expedition led by Academician M.V. Flint, within the research project “Ecosystems of the Russian Arctic” (research ongoing since 2007).

Field investigations were carried out in 2019–2020 during the RV Akademik Mstislav Keldysh expedition through specialized shore landings in the study area. The expedition included single-day routes to glacial formations for the purpose of collecting geological samples at predetermined coordinates.

The research methodology included the preparation of an experimental setup using a rock sample placed in a hermetically sealed vessel with a volume of 3.3 liters, filled with distilled water. During the experiment, the system temperature was kept constant at 4 °C as this temperature is typical of the natural conditions observed in Novaya Zemlya during the summer period. The measurements were performed according to the following scheme: regular monitoring of dissolved silicon and nitrate nitrogen concentrations was carried out at intervals of 3.5–7 days (0.5 weeks). At each sampling point, changes in the volume of the aqueous medium were recorded, and the accuracy of measurements was controlled, including corrections for losses during sampling. The addition of mercury chloride was necessary to preserve the samples and to prevent the influence of microbiological processes on the parameters studied. We are aware that $HgCl_2$ may also affect certain chemical reactions, for example, by interacting with specific components of the sample. The duration of the experiment was 30 days (5 weeks) from the start of sample exposure to the final measurement. All the procedures were conducted in accordance with standard hydrochemical analysis methods adopted in the laboratory.

The determination of nitrate nitrogen was performed no later than 12 hours after sampling. The colorimetric method for determining the mass concentration of nitrate nitrogen is based on the reduction of nitrates to nitrites in cadmium columns. Analyses were carried out onboard the research vessel laboratory within 12 hours of sample collection. For calibration, standard solutions (SS) with a nitrate ion concentration of 1 mg/cm^3 were used. The measurement wavelength was 543 nm.

The determination of dissolved inorganic silicon (silicates) was carried out in accordance with [25]. For calibration, State Standard Samples (GSO 8212-2002) with a silicate ion concentration of 1 g/cm^3 were used. The measurement wavelength was 810 nm.

For analysis, an X-ray fluorescence spectrometer PW 2400 (Philips Analytical, 1997) and SuperQ software (PANalytical, 2009) are used, as well as approved methodologies and state standard reference materials. Samples are dried, ground to a powder, pressed into pellets or subjected to induction fusion to obtain glass beads. The pellets/glass samples are analyzed in the spectrometer according to the manufacturer's recommendations and approved methodologies. The mass fractions of elements are determined based on the intensity of radiation. Calibration is performed using state standard reference materials. Data processing is carried out using SuperQ, and the results are expressed as mass percentages of oxides or elements. The value of 9.9 ppm is the detection limit for trace elements. The leading XRF expert is Anton Igorevich Yakushev, a certified expert in XRF and a research fellow at the Laboratory of Mineral Matter Analysis.

The determination of total nitrogen and carbon in the rock samples studied was performed using a modern CHNS-O analyzer ECS 4024, based on the Dumas method. The instrument possesses broad analytical capabilities, allowing the determination of CHNS-O concentrations in the range from 200 ppm to 100 % for sample masses from 10 μg to 100 mg. High measurement accuracy is ensured at less than 0.2 % relative to the certified standard, with an error not exceeding 0.1 % of the certified standard. The TCD detector is characterized by a low detection limit in the range of 1–5 μg. The elemental analysis standard of acetanilide had the following parameters: ω(C) 71.09 %, ω(H) 6.71 %, ω(O) 11.84 %, ω(N) 10.36 %. The combustion temperature was 960 °C.

The surface area of the rock samples was measured manually using ImageJ software. The measurement procedure involved outlining the sample boundaries on digital images and calculating the enclosed area in square millimeters, following established protocols for image-based morphometric analysis [26].

Results and discussion

The geological structure of the eastern coast of Novaya Zemlya includes rocks ranging from Late Cambrian in the northeast to Early Permian in the central and southern parts. It is characterized by the presence of the following main stratigraphic units [27–30].

In this analysis, four groups of rocks were identified: Carbonate, Sandstone, Shale, and Siltstone. Carbonate rocks are characterized by very high contents of calcium ($CaO \approx 39$ %) and strontium ($Sr \approx 693$ ppm), while having low concentrations of silica ($SiO_2 \approx 25$ %), alumina ($Al_2O_3 \approx 0.8$ %), and iron oxide ($Fe_2O_3 \approx 2$ %). Sandstones display moderate levels of silica ($SiO_2 \approx 30$ %), alumina ($Al_2O_3 \approx 3.7$ %), and iron oxide ($Fe_2O_3 \approx 3.4$ %), along with comparatively high barium ($Ba \approx 118$ ppm) and zinc ($Zn \approx 112$ ppm). Shales and siltstones are rich in alumina ($Al_2O_3 \approx 13$ %), iron oxide ($Fe_2O_3 \approx 6$ %), potassium oxide (K_2O up to 3 %), and silica ($SiO_2 \approx 67–68$ %), but contain very little calcium ($CaO < 0.5$ %) and strontium ($Sr \approx 60–68$ ppm). In general, the main distinctions between these groups lie in the proportions of calcium, strontium, and silica, as well as the presence of clay-related components, which are most pronounced in shales and siltstones.

A complete summary of the major and trace element composition of all samples analyzed by X-ray fluorescence analysis (XRF), is provided in Appendix Tables A.2–A.7.

Blagopoluchiya Bay

A diverse assemblage of rocks was identified in Blagopoluchiya Bay. The area is dominated by polymictic (quartz, potassium-sodium feldspar, illite, plagioclase) siltstones and sandstones, which exhibit a variety of grain sizes — from fine- to coarse-grained —

and complex cleavage structures, including intergranular and aggregate types, with features such as slumping folds, wavy and parallel cleavage, and micromullions. Several sandstones and siltstones display significant carbonate content, either within the matrix or as replacement features, and some contain fragments of carbonate rocks and fossil remains. Layers of siliceous-clayey shale are also present, with certain varieties containing ferruginous concretions. Additionally, thin interlayers of clayey siltstone and occurrences of stylolite-like structures were observed. The presence of conformal and clayey cement, as well as evidence of secondary processes such as carbonatization and the filling of cracks with fine-crystalline quartz, further underscore the complex diagenetic history of these sedimentary formations. Overall, the lithology of Blagopoluchiya Bay reflects a dynamic depositional environment with significant mineralogical and textural heterogeneity.

The rock samples were collected from Devonian and Carboniferous deposits. The samples were presumably collected from the boundary and/or deposits of the Rogachevskaya and Milinskaya formations of the Lower Carboniferous C_1rg+ml (C_1t+s) from the limbs of the Ukromnaya Anticline (see Fig. 3).

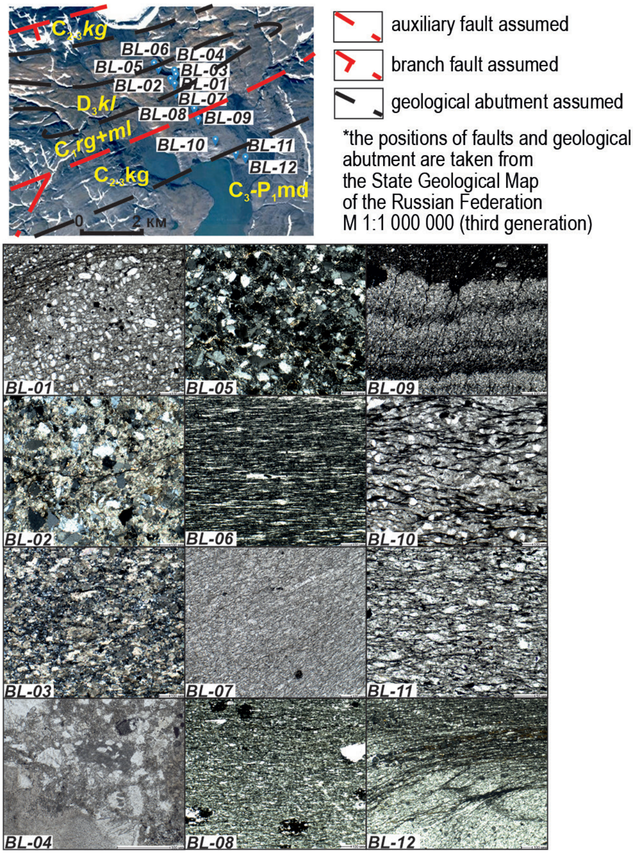

Fig. 3. Sampling locations and structural types of rocks in Blagopoluchiya Bay (see details below in Table 1)

Рис. 3. Места отбора проб и структурные типы пород в заливе Благополучия (подробности см. в таблице 1)

Table 1

Descriptions of rock samples of Novaya Zemlya bays in thin sections

Таблица 1

Описания образцов горных пород исследуемых заливов в тонких шлифах

Sample / Образец	Описание	Description
BL-01	Алевролит полимиктовый глинистый кливажированный (складка оползания, межагрегатный кливаж агрегатного типа грубоволнистый редкий в центральной части, на крыльях проникающий планетарный с наложенным постепенным кливажем плойчатости), николи //	Polymictic clayey cleavage siltstone (slumping fold, interaggregate cleavage of the aggregate type, coarsely wavy, rare in the central part, penetrating planetary on the wings with superimposed gradual cleavage of flatness); nicols //
BL-02	Песчаник полимиктовый тонко-мелкозернистый карбонатизированный со стилолитоподобным редким межзерновым кливажем, с тонкими прослоями алевролитов глинистых, николи x	Polymictic fine to close-grained carbonated sandstone with rare stylolitelike intergranular cleavage, with thin interlayers of clayey siltstone; nicols x
BL-03	Карбонатизированная порода, возможно по глинисто-кремнистому сланцу, николи x; вторая разновидность – глинисто-кремнистый сланец (на рисунке не представлен)	Carbonated rock, possibly after clayey-siliceous shale; nicols x; the second type is clay-siliceous shale (not shown in the figure)
BL-04	Песчаник полимиктовый разнозернистый с обломками карбонатных пород и остатков организмов, николи //	Polymictic inequigranular sandstone with fragments of carbonate rocks and remains of organisms; nicols //
BL-05	Песчаник полимиктовый тонкозернистый алевритовый с конформным и глинистым цементом с трещинами, выполненными мелкокристаллическим кварцем с наложенной карбонатизацией (кливаж межзерновой редкий грубый ветвящийся), николи x	Polymictic fine-grained silty sandstone with conformal cement and clayey cement with cracks filled with fine-crystalline quartz with superimposed carbonatization (intergranular cleavage is sparse, coarse, branching); nicols x
BL-06	Кремнисто-глинистый сланец, николи //	Siliceous-clayey shale; nicols //
BL-07	Карбонатная порода замещения, николи //	Carbonate replacement rock; nicols //
BL-08	Кремнисто-глинистый сланец с ожелезненными конкрециями, николи //	Siliceous-clayey shale with ferruginous concretions; nicols //
BL-09	Алевролит полимиктовый кливажированный (межзерновой кливаж проникающий частый параллельный, микромуллионы), николи //	Polymictic cleavage siltstone (intergranular cleavage is penetrating, frequent, parallel, micromullions); nicols //
BL-10	Песчаник полимиктовый алевритовый кливажированный (межзерновой кливаж грубоволнистый частый извилистый сопряженный), николи //	Polymictic silty cleavage sandstone (intergranular cleavage is coarsely wavy, frequent, sinuous, conjugate); nicols //

End of table 1

Окончание табл. 1

Sample / Образец	Описание	Description
BL-11	Алевролит полимиктовый кливажированный (межзерновой кливаж проникающий волнистый сопряженный), николи //	Polymictic cleavage siltstone (intergranular cleavage penetrating wavy conjugate); nicols //
BL-12	Алевролит полимиктовый кливажированный (межзерновой кливаж проникающий частый параллельный), николи //	Polymictic cleavage siltstone (intergranular cleavage penetrating in frequent parallel); nicols //
3C-01	Песчаник полимиктовый мелко-тонкозернистый с конформным цементом с хлоритом и кальцитом замещения слоеватый, николи //	Polymictic fine-to close-grained sandstone with conformal cement with chlorite and replacement calcite, layered, nicols //
3C-02	Алевролит полимиктовый глинистый с хлоритом и кальцитом замещения кливажированный (межзерновой кливаж агрегатного типа, проникающий, извилистый, резкий), николи //	Polymictic clayey siltstone with chlorite and replacement calcite, cleavage (intergranular cleavage of the aggregate type, penetrating, sinuous, sharp), nicols //
3C-03	Песчаник полимиктовый мелко-тонкозернистый с конформным цементом с хлоритом и кальцитом замещения слоеватый, николи x	Polymictic fine- to close-grained sandstone with conformal cement with chlorite and replacement calcite, layered, nicols x
3A-01	Песчаник полимиктовый средне-мелкозернистый с конформным цементом с хлоритом слоеватый, николи x	Medium-fine-grained polymictic sandstone with conformal cement with chlorite, layered, nicols x
3A-02	Песчаник полимиктовый тонко-мелкозернистый с конформным цементом с хлоритом и кальцитом замещения слоеватый, николи x	Fine-to-close-grained polymictic sandstone with conformal cement with chlorite and replacement calcite, layered, nicols x
3A-03	Песчаник полимиктовый тонко-мелкозернистый с конформным цементом с хлоритом и кальцитом замещения слоеватый, николи x	Fine-to-close-grained polymictic sandstone with conformal cement with conformal cement with chlorite and replacement calcite, layered, nicols x

Stepovogo Bay

The rock samples were collected from the deposits of the middle submember of the Belushskaya Formation, Lower Permian (P_1bl2, P1u). The samples are represented by sandstones with interlayers of siltstones (see Fig. 4). The sandstones are polymictic (quartz, potassium-sodium feldspar, illite, plagioclase, fragments of effusive rocks and clay shales), fine- to very fine-grained, aleuritic, and clayey, with conformal cement containing chlorite and replacement calcite, and are layered. The siltstones are polymictic, clayey, with chlorite and replacement calcite. All varieties are cleaved to varying degrees. The cleavage is predominantly intergranular and aggregate-type; in siltstones, it is penetrative, sinuous, and sharp (see Fig. 4, sample 3C-02), while in sandstones it is coarsely wavy, frequent, and sinuous. Such deformation textures of clastic rocks develop under low- and medium-temperature conditions (up to 300–350 °C) [31].

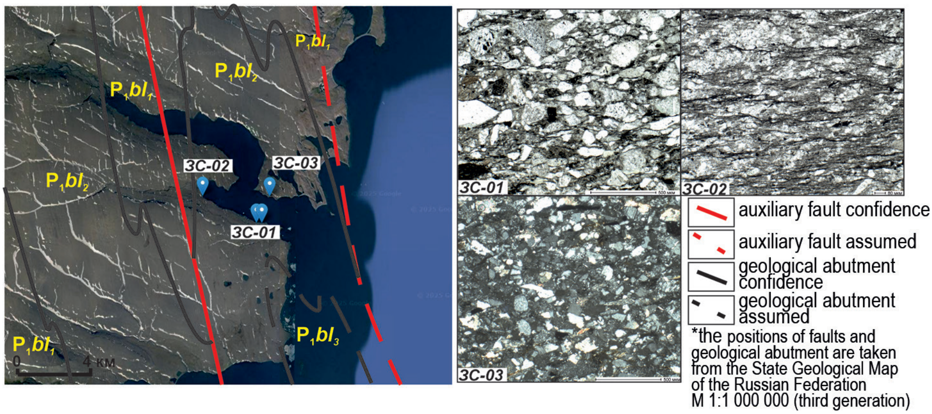

Fig. 4. Sampling location and structural types of rocks in Stepovogo Bay, see details in Table 1

Рис. 4. Место отбора проб и структурные типы пород в бухте Степового, подробности см. в таблице 1

Abrosimova Bay

The rock samples were collected from the deposits of the Belushskaya Formation, Lower Permian (P_1bl, P_1u), and are represented by sandstones with interlayers of siltstones (see Fig. 5). The sandstones are polymictic (quartz, potassium-sodium feldspar, illite, plagioclase, fragments of effusive rocks and clay shales), ranging from fine- to medium-grained, with conformal cement containing chlorite and replacement calcite, and exhibit bedding. The conformal nature of the boundaries is often traced by fine-grained clayey and carbonaceous material. Overall, these rocks are similar to those of Stepovogo Bay, but differ mainly in grain size.

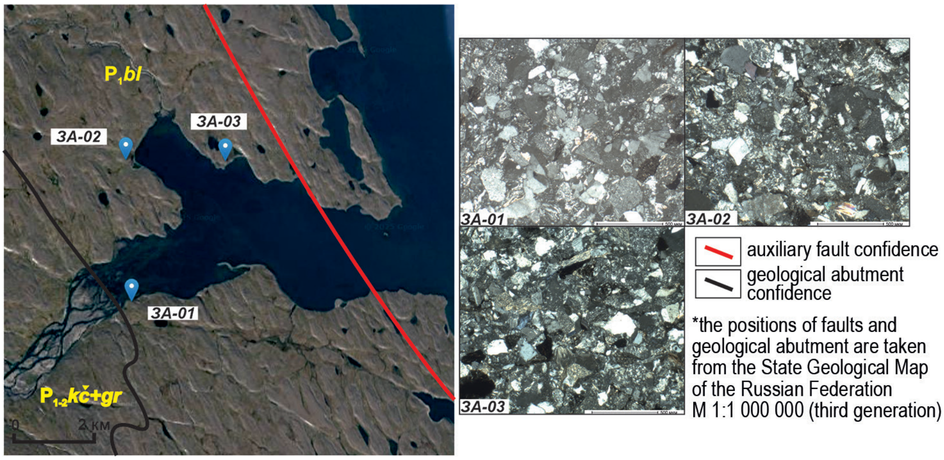

Fig. 5. Sampling location and structural types of rocks in Abrosimova Bay, see details in Table 1

Рис. 5. Место отбора проб и структурные типы пород в бухте Абросимова (подробности см. в таблице 1)

An unsupervised clustering algorithm implemented in Python was used to identify relationships between different rock samples, based on their elemental composition data. Prior to analysis, the data for each sample were normalized using the StandardScaler function. Hierarchical clustering was performed using Ward's method with the Euclidean distance metric, and the results were visualized as dendrograms. This approach made it possible to evaluate the relationships between the samples and to partially confirm the geological boundaries between them, although some uncertainty remains due to the inherent imprecision of these boundaries. In particular, in the dendrogram, sample BL-06 appears as a distinctly separate group alongside the 3A and 3C samples, further supporting the similarity between the 3C and 3A series (see Figs. 6, 7).

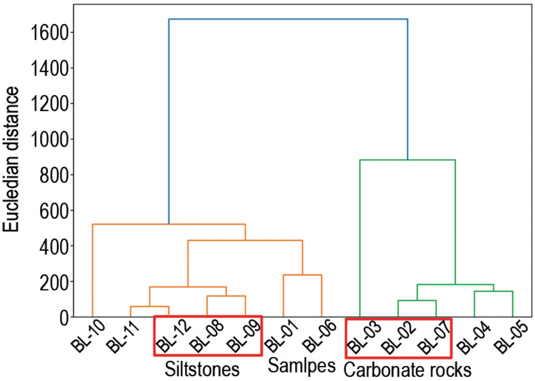

Fig. 6. Dendrogram of samples from Blagopoluchiya Bay; the clustering based on chemical composition corresponds to the age of the samples. Rock types outlined in red indicate those with the highest nutrient element release activity (see below)

Рис. 6. Дендрограмма образцов из залива Благополучия; кластеризация на основе химического состава соответствует возрасту образцов. Породы, выделенные красным цветом, обозначают те, которые обладают наибольшей активностью по высвобождению биогенов (см. ниже)

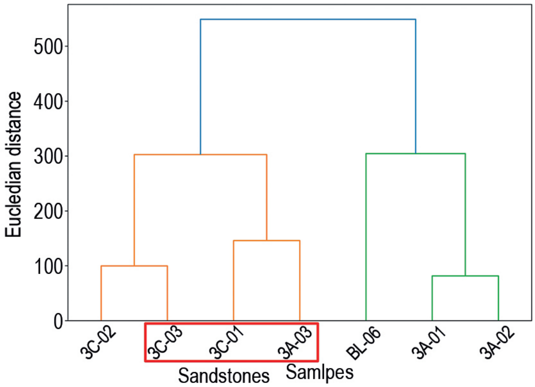

Fig. 7. Dendrogram of samples from Stepovogo Bay and Abrosimova; the clustering based on chemical composition corresponds to the type of the samples. Rock types outlined in red indicate those with the highest nutrient element release activity (see below)

Рис. 7. Дендрограмма образцов из заливов Степового и Абросимова; кластеризация на основе химического состава соответствует типу образцов. Породы, выделенные красным цветом, обозначают те, которые обладают наибольшей активностью по высвобождению биогенов (см. ниже)

Overall, the clustering generally reflects the grouping of the rocks to particular groups (such as sandstones, siltstones, and shales). However, in some cases, this clustering is disrupted, which can be attributed to the fact that rock types are, in general, quite similar in their chemical composition. Additionally, some of the samples are located at the boundaries between different geological ages, which may also contribute to the observed uncertainty in their classification.

C/N Ratio

In this study, the total nitrogen and carbon contents in the rock samples were analyzed (see Fig. 8).

The carbon-to-nitrogen (C/N) ratio is an important indicator in geochemical and ecological studies as it provides insights into the sources and potential reactivity of organic matter within rocks and sediments. In particular, the C/N ratio helps distinguish between organic carbon, which can serve as a nutrient source for microorganisms, and inorganic (carbonate) carbon, which is generally not bio-available. At moderate C/N ratios, where the carbon is not predominantly associated with carbonates, the presence of organic carbon indicates the potential for microbial activity and nutrient cycling within the rock or sediment. Organic carbon, when accessible, supports the growth and metabolism of microbial communities, influencing biogeochemical processes such as mineral weathering, nutrient release, and the overall productivity of the ecosystem. Therefore, analyzing C/N ratios allows the evaluation of the nutrient potential of the rocks and their capacity to support microbial life [32, 33].

Analysis of the content distribution showed that for nitrogen (N) concentrations of 0.02–0.06 %, the carbon content (C) varies from 0 to 2.44 %; for N concentrations of 0.00–0.01 %, the C content is 5.74–12.26 %. Thus, the observed values can be explained

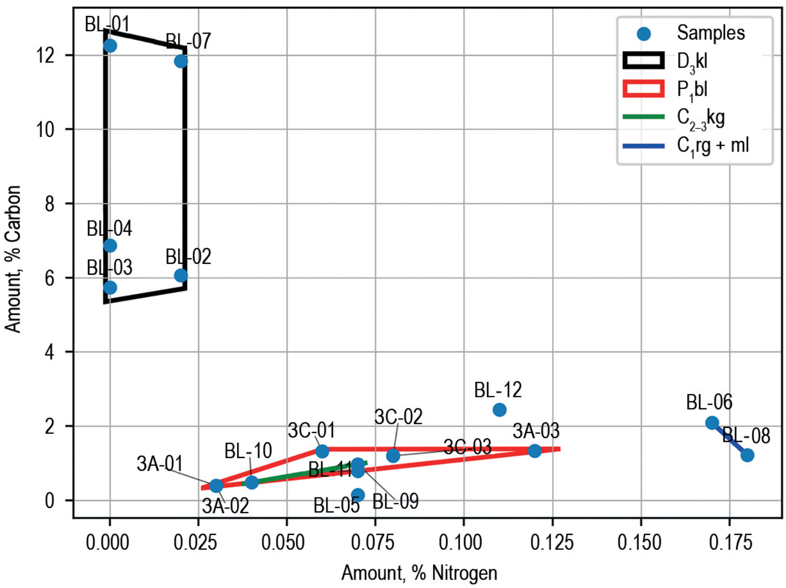

Fig. 8. Scatterplot of nitrogen versus carbon content in the rock samples

Рис. 8. Диаграмма рассеяния содержания азота по отношению к содержанию углерода в образцах пород by the incorporation of carbon into the crystal lattice of carbonate minerals. In sample BL-01, the CaO content is 0.23 %, while those of Al_2O_3 and SiO_2 are high (10.84 and 71.34 %, respectively); carbon may also be incorporated into the mineral lattice.

Analysis of the nitrogen and carbon content data reveals notable differences among the samples studied. The shale samples BL-12 and BL-09 exhibit relatively elevated nitrogen contents (0.11 % and 0.07 %, respectively) and C/N ratios of 22.93 and 13.47. These values suggest the presence of organic matter that could serve as a nutrient source for microorganisms, as the C/N ratios fall within the range commonly associated with organic carbon of mixed origin [32, 34]. The moderate carbon content in these shales (BL-12: 2.44 % C, BL-09: 0.97 % C) further supports the potential for microbial activity.

In contrast, the carbonate samples BL-07 and BL-03 show a different pattern. BL-03 contains a high amount of carbon (5.74 %) but has undetectable nitrogen, resulting in a C/N ratio of zero. BL-07 also demonstrates high carbon content (11.84%) with extremely low nitrogen (0.02 %), yielding an anomalously high C/N ratio (640.55). These features are typical of carbonate rocks, where carbon is primarily present in inorganic (carbonate) form, which is not available as a nutrient for microorganisms [35]. The lack of nitrogen indicates a scarcity of organic matter in these samples.

The polymictic sandstone samples 3A-01 and 3A-03 display moderate nitrogen values (0.03 % and 0.12 %, respectively) and carbon contents (0.40 % and 1.33 %), with C/N ratios of 12.42 and 11.51. These ratios indicate the presence of organic matter that could potentially be bioavailable, supporting a moderate nutrient status for microbial communities in these rocks.

The plot (Fig. 8) presents the relationship between nitrogen and carbon content (in amount percent) for different rock samples, with the groups highlighted by colored contours. Most of the samples are clustered at low nitrogen concentrations (below 0.1 %) and show a wide range of carbon contents. The group delineated by the black contour (D_3kl) displays high carbon but very low nitrogen content, characteristic of carbonate rocks, which typically contain inorganic carbon and minimal organic nitrogen. In contrast, the red and green contours (P_1bl and $C_{2–3}$kg) enclose samples with low to moderate carbon and higher nitrogen values, suggesting a greater presence of organic matter, likely associated with siltstones and sandstones. Notably, samples BL-06 and BL-08 (connected by the blue line, C_1rg + ml) are distinct, exhibiting the highest nitrogen concentrations among all samples, which may reflect a significant contribution of organic-rich material or unique lithological characteristics. Overall, the plot highlights pronounced differences in carbon and nitrogen content among the lithological groups, corresponding to variations in their potential for nutrient release.

In summary, the shale samples (BL-12 and BL-09) and polymictic sandstones (3A-01, 3A-03) contain organic carbon and nitrogen in proportions favorable for microbial utilization, while the carbonate rocks (BL-07, BL-03) are dominated by inorganic carbon and lack significant nitrogen, making them much less favorable as nutrient sources for microorganisms.

See the results in Table A.8.

Experimental studies of the nutrient signal from rocks

A series of hydrochemical analyzes was conducted as part of the experimental investigation of the nutrient activity of the rocks studied. The experimental procedures are detailed in Materials and methods.

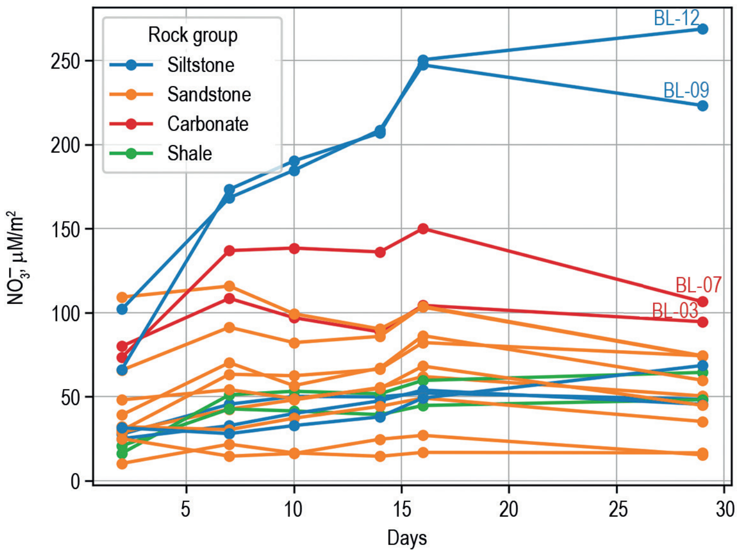

Fig. 9. Dynamics of dissolved nitrate nitrogen concentration in water for samples from the Novaya Zemlya bays: BL — Blagopoluchiya Bay series, 3C — Stepovoy Bay series, 3A — Abrosimova Bay series

Рис. 9. Динамика концентрации растворенного нитратного азота в воде для образцов из бухт Новой Земли: BL — серия залива Благополучия, 3С — серия залива Степового, 3А — серия залива Абросимова

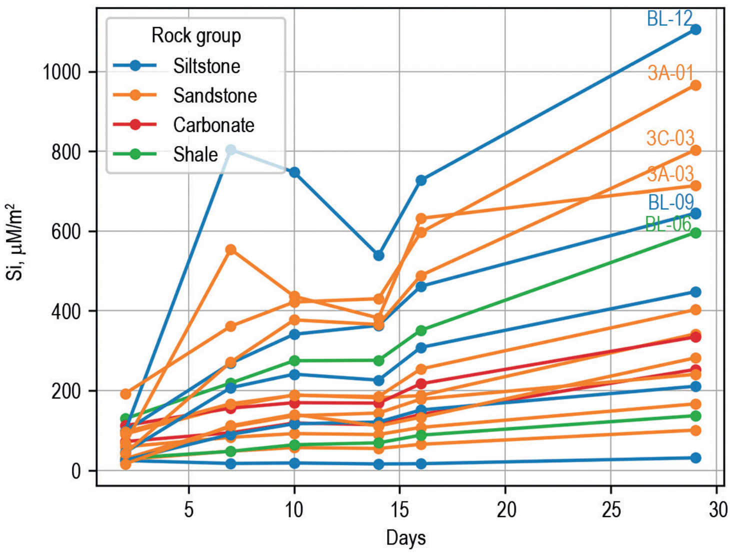

Fig. 10. Dynamics of dissolved silicon concentration in water for samples from the Novaya Zemlya bays: BL — Blagopoluchiya Bay series, 3C — Stepovoy Bay series, 3A — Abrosimova Bay series

Рис. 10. Динамика концентрации растворенного кремния в воде для образцов из заливов Новой Земли: BL — серия залива Благополучия, 3С — серия залива Степового, 3А — серия залива Абросимова

Changes in the concentrations of nutrient elements in water are shown in the following graphs. Since the samples differed in size, the data obtained were normalized to the premeasured area of the samples (see Materials and Methods). The graphs of nitrate nitrogen (μmol m^{-2}) and dissolved silicon (μmol m^{-2}) are presented in Figs. 9 and 10.

In general, samples in the BL series (Blagopoluchiya Bay) demonstrate higher concentrations and rates compared to the 3C (Stepovogo Bay) series. The 3C group shows a general trend toward low concentrations and slow growth. Notably, the highest nitrate nitrogen activity is observed in siltstone and carbonate rock samples. For dissolved silicon, the highest release rates are also observed in siltstone and siliceous-clayey shale samples.

At the end of the experiment, it was found that samples BL-01, BL-05, and BL-12 were covered with ochreous films of iron(III) oxide, and native mercury was detected in the columns during nitrate analysis. This may be related to the addition of mercury chloride at the beginning of the experiment to reduce microbiological activity. The addition of mercury chloride most likely led to the formation of hydrochloric acid solution and a series of chemical reactions, such as the decomposition of calcite upon the appearance of hydrochloric acid solution during the dissolution of mercury chloride in water; a decrease in pH and the oxidation of Fe^{2+} to Fe^{3+} at an alkaline barrier formed as an alkaline film on the surface of calcite crystals. As a result, samples BL-01, BL-05, and BL-12, which contain ferrous iron, became covered with ochreous films. The reduction of mercury to its native state was promoted by the reduction of organic matter, the content of which is apparently highest in samples BL-06 and BL-08.

Table 2

Mean output rates of nutrient elements from rock samples

Таблица 2

Средние скорости выноса биогенных элементов из образцов горных пород

Sample Name	Group	Mean Rate per Day (Si), $\mu mol \cdot m^{-2} \cdot day^{-1}$	Mean Rate per Day (NO_3^-), $\mu mol \cdot m^{-2} \cdot day^{-1}$	Mean Rate per Day (Si), $mg \cdot m^{-2} \cdot day^{-1}$	Mean Rate per Day (NO_3^-), $mg \cdot m^{-2} \cdot day^{-1}$
3A-03	Sandstone	30.65	4.61	0.86	0.29
3A-01	Sandstone	22.10	1.00	0.62	0.06
BL-09	Siltstone	18.62	7.89	0.52	0.49
BL-12	Siltstone	17.81	11.02	0.50	0.68
3C-03	Sandstone	16.64	0.65	0.47	0.04
BL-06	Shale	11.44	1.27	0.32	0.08
3C-02	Siltstone	9.95	1.20	0.28	0.07
BL-05	Sandstone	8.19	0.00	0.23	0.00
BL-10	Sandstone	7.66	2.91	0.22	0.18
3C-01	Sandstone	7.58	0.34	0.21	0.02
BL-07	Carbonate	5.87	1.94	0.16	0.12
BL-11	Siltstone	5.82	1.40	0.16	0.09
3A-02	Sandstone	3.81	0.74	0.11	0.05
BL-03	Carbonate	2.89	0.08	0.08	0.00
BL-08	Shale	2.89	2.19	0.08	0.14
BL-04	Sandstone	2.65	1.89	0.07	0.12
BL-02	Sandstone	1.58	1.82	0.04	0.11
BL-01	Siltstone	0.00	0.74	0.00	0.05

Table 2 presents the mean production rates of nutrient elements — specifically silicon (Si) and nitrate (NO_3^-) — from various rock samples grouped by lithology (sandstone, shale, carbonate). For each sample, the mean daily Si and NO_3^- release rates are reported in units of micromoles per square meter per day (μmol·m^{-2}·d^{-1}).

The three samples with the highest mean rates of Si output are 3A-03 (Sandstone) with 30.65 μmol·m^{-2}·d^{-1}, 3A-01 (Sandstone) with 22.10 μmol·m^{-2}·d^{-1}, and BL-09 (Siltstone) with 18.62 μmol·m^{-2}·d^{-1}. For nitrate (NO_3^-), the highest mean output rates were observed in BL-12 (Siltstone) with 11.02 μmol·m^{-2}·d^{-1}, BL-09 (Siltstone) with 7.89 μmol·m^{-2}·d^{-1}, and 3A-03 (Sandstone) with 4.61 μmol·m^{-2}·d^{-1}. These samples show the highest nitrate release rates among all the rock samples analyzed.

The influence of nitrogen in rocks on local element cycles can be quite significant. It has been established that elevated nitrogen content in aquatic and soil environments is associated with the weathering of primary rocks. According to available data, the average nitrogen content in terrestrial rocks is 1.27 ± 1 mg N per kilogram [36]. The total nitrogen stock in sedimentary rocks is estimated at $7.5 \cdot 10^{20}$ grams [37]. During rock weathering, nitrogen is released, increasing its availability to living organisms and affecting biogeochemical cycles.

Nitrogen is generally not measured in rocks due to the widely held assumption that nitrogen concentrations are insignificant and due to the lack of a universally accepted standard method for analyzing the form and concentration of nitrogen in mineral fractions of rocks and soils. As a result, the nitrogen biogeochemical cycle is rarely considered in a geological context. Nitrogen is present in kerogen (a stable organic substance in rocks), ammonium or nitrate salts. Sedimentary rocks, for example, serve as a long-term reservoir for about 20 % of global nitrogen, but their weathering rates and nitrogen content vary by orders of magnitude [38, 39].

Geological nitrogen has been shown to contribute to the saturation of nitrogen in ecosystems (more nitrogen than is required by biota), leading to elevated concentrations of nitrates in surface and groundwater [40, 41]. Geological nitrogen may be a significant source of nitrate for both groundwater and surface water [42, 41, 43]. The main source of nitrogen in silicate rocks is believed to be from sedimentary rocks [44]. Ammonium content in metamorphic micas in France ranges from 120 to 500 mg/kg in muscovite and from 300 to 1500 mg/kg in biotite [45].

A 30-day laboratory experiment showed that the weathering of local rocks in the West Fork of the Gallatin River watershed, Montana, releases significant amounts of nitrate, matching elevated levels of nitrate in area streams. Isotopic analysis suggests that mineral dissolution in rocks and soils is a key natural source of stream nitrogen in this region [46].

In comparison with previous studies, the current results demonstrate comparable values. For example, in the study [19], the flux of nutrient elements was estimated at 0.04–0.18 mg m^{-2} day^{-1} for nitrate nitrogen and 0.16–0.24 mg m^{-2} day^{-1} for silicon. None of the Novaya Zemlya rock samples in this study exhibited higher nutrient output rates than those reported for Svalbard rocks, which reached up to 0.64 mg m^{-2} day^{-1} for NO_3^- and approximately 2 mg m^{-2} day^{-1} for Si.

Rocks 3A-01, 3A-03, BL-09 demonstrate a high level of nutrient element release due to several key features of their composition and structure. Firstly, their polymictic nature means they are composed of a wide variety of minerals and rock fragments, which broadens the spectrum of nutrient elements (such as Ca, Mg, Fe, and others) available for release.

Secondly, the presence of easily soluble cements—specifically chlorite and calcite—facilitates the rapid mobilization of these elements when the rocks undergo weathering or interact with water. Chlorite provides iron and magnesium (and sometimes manganese), while calcite is a source of calcium, all of which are essential nutrients.

In addition, the fine- to medium-grained texture of the sandstones and the fine-grained nature of the siltstone result in a high specific surface area, which accelerates chemical weathering and the release of elements. The layered structure and pronounced cleavage (particularly in the siltstone) enhance the permeability and porosity of these rocks, allowing water to circulate more freely and extract soluble components more efficiently. Features like micromullions further increase the contact surface, promoting even more intensive leaching.

Overall, the combination of diverse mineral composition, easily dissolvable biogenic minerals, high porosity and permeability, and a well-developed surface area explains why these rocks exhibit such high levels of nutrients release.

Sample BL-12 is a polymictic cleaved siltstone, with various stages of micromullion formation along cleavage zones. The polymictic composition includes quartz, feldspars, and micas, which release silicon during weathering. Cleavage and micromullions increase the contact area of rock with water, accelerating leaching. Micromullions form channels for fluid migration, transporting dissolved Si and N. Diagenetic processes, such as secondary cementation by carbonates or silica, contribute to the accumulation of nitrogen-containing compounds, which are released during weathering.

Organic matter present in shales and siltstones releases nitrogen in the form of ammonia or nitrates during decomposition. The high microporosity of clay matrices and cleavage fractures creates reservoirs for the accumulation of elements, which are rapidly released during hydrolysis. The geochemistry of iron, associated with redox conditions, activates nitrification/denitrification processes for nitrogen and the dissolution of silica.

The concentrations of nutrients in watercourses are influenced not only by the underlying bedrock of the catchment, but also by soil characteristics. However, little is known about the soils of Novaya Zemlya along the eastern coast. The soils of Blagopoluchiya Bay exhibit typical features of the High Arctic tundra, such as low fertility, weak profile development, predominance of mineral horizons, and a close relationship with microrelief and moisture conditions [47]. In contrast, the soils of Stepovoy and Abrosimov Bays are richer and contain higher amounts of organic carbon, which may result in higher levels of biological activity. The soils of the southern section are represented by lithosols, while those of the northern section are predominantly petrozems. In the soils of the southern section, the occurrence of rough-humus (AO) horizons is greater than that of gray-humus (AY) and humic-dark humus (AH) horizons [48]. Gray-humus horizons are found in both the northern and southern sections with similar frequency and exhibit a moderately developed, weakly fine-crumb or granular structure due to the high content of organic carbon (Corg: 5–7 %). This, in turn, can promote the mobilization of stored carbon and nitrogen. However, the underlying bedrock plays a major role in the formation of elevated concentrations of nutrients under conditions of poorly developed soil cover, as observed in Blagopoluchiya Bay.

Overall, the results of our study are consistent with the findings of [19]; the leaching rates we obtained are of the same order—on average, 5 micromoles of nitrogen and 10 of dissolved silicon (samples from Blagopoluchiya Bay were used). In [19], rocks from Svalbard were also studied, and their leaching rates were found to be three times higher than those of the rocks from our study. Some differences may be attributed to the different experimental conditions—in the study 19, the experiments were conducted at a temperature of 20 °C, whereas in our study the temperature was 4 °C.

Conclusion

Climate change in the Arctic is accelerating, leading to increased temperatures, reduction in sea ice extent, and the rapid retreat of glaciers [1, 3, 6]. These processes are expected to result in greater glacial meltwater discharge and, consequently, increased fluxes of dissolved and particulate materials into adjacent marine and freshwater systems [11, 5].

Our study demonstrates that the bedrock of Novaya Zemlya can act as a significant source of nutrients, particularly nitrogen and silicon, which have the potential to alter the hydrochemical profiles of the surrounding water bodies. Experimental results indicate that certain rock types — especially those with polymictic composition and reactive mineral cements — exhibit enhanced release rates of nutrient elements under simulated weathering conditions.

Analysis of the nitrogen and carbon content in the samples studied reveals substantial variability. The highest nitrogen concentrations were observed in siltstone and polymictic sandstone samples (0.03–0.12 % N). These rocks also display moderate C/N ratios (11–13) and carbon contents ranging from 0.40 % to 1.33 %. Such values indicate the presence of bioavailable organic matter, which can serve as a nutrient source for microbial communities and promote biogeochemical cycling.

Sand- and siltstones demonstrate a high level of nutrient element release due to several key features of their composition and structure. Their polymictic nature means they are composed of a diverse assortment of minerals and rock fragments, broadening the spectrum of nutrient elements (such as Ca, Mg, Fe) available for release. Additionally, the presence of easily soluble cements—particularly chlorite and calcite—facilitates the rapid mobilization of these elements during weathering. Chlorite supplies iron and magnesium (and sometimes manganese), while calcite is a source of calcium, all of which are essential for ecosystem productivity.

The results of the experimental leaching tests further support these findings. Among all the samples analyzed, siltstones exhibit the highest mean output rates of nitrates. Specifically, the mean daily release rates for nitrate reach up to 8 μmol m^{-2} day^{-1}.

It is important to note that the contribution of nutrients from bedrock to the coastal waters of the Arctic remains largely unquantified. However, such nutrient inputs can play a critical role in supporting primary production, particularly during the summer months when surface waters often experience a deficit of essential nutrients. In summary, projected climate-driven increases in glacier melt and runoff, combined with the nutrient-releasing potential of Novaya Zemlya rocks, are likely to significantly impact the biogeochemical characteristics of adjacent aquatic systems in the future.

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Некоторые аспекты геохимии питательных элементов пород Новой Земли

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Расширенный реферат

В статье представлены результаты исследования геохимических особенностей горных пород архипелага Новая Земля и их вклада в формирование питательного режима прибрежных арктических экосистем. В условиях ускоренного таяния ледников, вызванного климатическими изменениями, все большее значение приобретает роль талых вод, выщелачивающих биогенные элементы из коренных пород. Авторы проверяют гипотезу о том, что осадочные породы (песчаники, алевролиты, сланцы и карбонаты), формирующие берега ледниковых потоков, могут служить источником азота и кремния для прибрежных вод.

В ходе полевых работ в 2019–2020 гг. в заливах Благополучия, Степового и Абросимова были собраны образцы пород, относящихся к девонским, карбоновым и пермским отложениям. В лабораторных условиях (температура 4 °C, дистиллированная вода, 30 дней) оценивалась скорость вымывания нитратного азота и растворенного кремния. Наибольшие скорости выноса зафиксированы для алевролитов и песчаников: до 7,9 мкмоль·м$^{-2}$·сут$^{-1}$ по азоту и 30,7 мкмоль·м$^{-2}$·сут$^{-1}$ по кремнию.

Анализ элементного состава (методом рентгенофлуоресцентной спектрометрии) и содержания общего азота и углерода (методом Дюма) показал, что наиболее активные в плане высвобождения биогенов породы характеризуются:

– полимиктовым составом (разнообразие минералов — кварц, полевые шпаты, слюды, обломки эффузивов и сланцев);

– наличием легкорастворимых цементирующих минералов (хлорит, кальцит);

– высокой удельной поверхностью и развитой трещиноватостью (кливаж, микромуллионы), способствующей интенсивному выщелачиванию;

– умеренным содержанием органического вещества с C/N-отношением 11–23, указывающим на биодоступность азота.

Установлено, что концентрации нитратов и кремния в ручьях Новой Земли превышают фоновые значения для акватории Карского моря, что подтверждает значимость литогенного источника питательных элементов. В условиях слаборазвитого почвенного покрова (особенно в заливе Благополучия) именно коренные породы играют ключевую роль в формировании гидрохимического состава речного стока.

Полученные данные свидетельствуют о том, что в условиях усиления ледникового стока из-за потепления климата вынос биогенов из пород Новой Земли может существенно влиять на первичную продуктивность прибрежных арктических экосистем, особенно в летний период, когда поверхностные воды испытывают дефицит питательных веществ.

Ключевые слова: Новая Земля, Карское море, горные породы, биогенные элементы, сток ручья

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Appendix A. Chemical Data Tables

Table A.1

Summary of nitrate (NO_3^-) and dissolved silicon (Si) concentrations in streams of the Novaya Zemlya bays (all concentrations in μM)

Таблица A.1

Сводные данные по концентрациям нитратов (NO_3^-) и растворенного кремния (Si) в ручьях заливов Новой Земли (все концентрации приведены в мкМ)

Bay	Year	NO_3^- Range, Mean (μM)	Si Range, Mean (μM)	Sampling Date
Blagopoluchia	2007	1.12–8.82, 2.93	28–36, 32.6	13–15.09
	2013	3–4.48, 3.7	6–42, 29	13–16.09
	2014	3–8, 5.25	7–27, 14.4	29–31.08
	2016	0.6–10.8, 6.5	2.9–36.74, 27.5	31.07–02.08
	2017	1–11, 5.46	2–46, 26	25–26.09
	2018	0.14–11.2, 3.27	10–46, 19.3	09–11.09
	2020	2.5–5.19, 3.5	1.6–6.93, 3.1	07–10.09
Abrosimova	2014	1.4–11.4, 6.13	6.76–14.05, 10.8	06.09
	2015	12.7–13.7, 12.5	16–37.8, 24.2	03.10
	2016	5–16, 9.5	12–41, 26.5	15.08
	2019	2.2–8.7, 4.9	16–28, 21.6	24.07
Stepovogo	2013	0–9, 3.4	15–80, 40	19.09
	2014	1.75–38, 6.63	1.75–38, 24	04.09
	2015	2–10, 8.81	6.72–39, 22	02.10
	2019	3–5.4, 4.12	23.4–33.5, 28	26.07

Table A.2

Major oxide composition (%) of rock samples from Blagopoluchiya Bay

Таблица A.2

Содержание основных оксидов (%) в образцах горных пород из залива Благополучия

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	LOI
BL-01	71.34	0.63	10.84	5.53	0.010	1.67	0.23	2.22	1.44	0.08	1.51	4.36
BL-02	17.54	0.27	3.61	4.47	0.146	4.75	36.60	0.88	0.34	0.11	1.70	29.49
BL-03	48.25	0.06	0.87	3.19	0.076	2.24	23.63	0.09	0.04	0.06	0.39	20.95
BL-04	29.56	0.26	2.28	2.69	0.099	3.54	34.01	0.76	0.12	0.10	0.44	26.05
BL-05	0.27	0.02	0.29	0.24	0.035	0.57	54.48	0.06	0.03	0.04	0.02	43.90
BL-06	74.21	0.77	11.58	2.84	0.014	0.58	0.47	1.86	2.10	0.04	0.18	5.17
BL-07	1.35	0.07	0.72	0.80	0.083	0.33	53.76	0.09	0.05	0.04	0.02	42.65

Окончание таблицы А.2

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	LOI
BL-08	62.61	0.94	14.19	9.15	0.213	2.48	0.53	1.17	2.57	0.10	0.03	5.79
BL-09	65.01	1.00	16.53	5.14	0.030	2.06	0.17	0.80	4.20	0.07	0.02	4.76
BL-10	72.65	0.61	8.54	6.08	0.112	2.35	3.12	0.68	1.32	0.11	0.04	4.18
BL-11	63.65	1.03	15.36	6.56	0.030	3.30	0.14	0.91	3.55	0.08	0.02	5.15
BL-12	68.06	0.90	13.17	5.54	0.032	3.06	0.24	0.87	2.92	0.12	0.05	4.83

Table A.3

Trace element concentrations (ppm) in rock samples from Blagopoluchiya Bay

Таблица А.3

Концентрации микроэлементов (ppm) в образцах горных пород из залива Благополучия

Sample	Cr	V	Co	Ni	Cu	Zn	Rb	Sr	Zr	Ba	Cl
BL-01	106	117	21	32	24	34	56	159	205	264	87
BL-02	42	42	9.9	30	9.9	18	17	348	27	61	209
BL-03	12	12	9.9	11	9.9	27	9.9	1054	9.9	24	9.9
BL-04	33	29	9.9	9.9	9.9	19	9.9	466	35	34	119
BL-05	9.9	9.9	9.9	9.9	9.9	25	9.9	349	9.9	27	70
BL-06	164	286	9.9	30	17	19	89	69	181	342	9.9
BL-07	9.9	9.9	9.9	9.9	9.9	21	9.9	332	9.9	19	195
BL-08	148	240	9.9	59	25	61	109	49	195	538	9.9
BL-09	127	263	11	54	15	23	160	34	222	462	43
BL-10	71	119	21	43	16	386	50	43	183	348	9.9
BL-11	115	216	13	56	18	28	146	35	205	593	81
BL-12	119	182	9.9	54	9.9	28	110	43	202	591	56

Table A.4

Major oxide composition (%) of rock samples from Stepovogo Bay

Таблица А.4

Содержание основных оксидов (%) в образцах горных пород из залива Степового

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	LOI
3C-01	61.06	0.86	14.77	6.97	0.107	4.34	1.64	3.19	1.32	0.191	0.08	5.21
3C-02	59.39	0.90	15.86	7.60	0.090	4.49	0.95	2.81	1.90	0.193	0.19	5.34
3C-03	58.85	1.03	15.95	8.03	0.098	4.90	0.54	2.88	1.96	0.181	0.02	5.27

Table A.5

Trace element concentrations (ppm) in rock samples from Stepovogo Bay

Таблица А.5

Концентрации микроэлементов (ppm) в образцах горных пород из залива Степового

Sample	Cr	V	Ni	Cu	Zn	Rb	Sr	Zr	Ba	Pb	As	Cl
3C-01	301	172	104	58	104	37	165	179	415	18	15	50
3C-02	239	187	108	78	139	53	124	186	702	18	9	54
3C-03	291	198	106	89	120	49	111	195	632	15	4.9	92

Table A.6

Major oxide composition (%) of rock samples from Abrosimova Bay

Таблица А.6

Содержание основных оксидов (%) в образцах горных пород из залива Абросимова

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	SO_3	LOI
3A-01	68.73	0.69	12.45	6.11	0.060	3.74	0.57	3.10	0.98	0.157	<0.01	3.23
3A-02	67.33	0.76	12.47	6.44	0.074	3.71	1.17	3.06	0.98	0.174	0.01	3.61
3A-03	58.16	1.02	15.90	9.07	0.121	4.56	0.31	2.44	2.07	0.203	<0.01	5.88

Table A.7

Trace element concentrations (ppm) in rock samples from Abrosimova Bay

Таблица А.7

Концентрации микроэлементов (ppm) в образцах горных пород из залива Абросимова

Sample	Cr	V	Ni	Cu	Zn	Rb	Sr	Zr	Ba	Pb	As	Cl
3A-01	287	154	87	35	85	28	122	148	241	11	4.9	78
3A-02	356	173	91	35	86	30	143	153	270	10	8	65
3A-03	282	209	116	124	148	53	92	201	498	28	4.9	52

Table A.8

Nitrogen and Carbon Content in Samples

Таблица А.8

Содержание азота и углерода в образцах

Sample name	mg N	Amount% N	C/N Ratio	mg C	Amount% C
BL-01	0	0	0.00	5.336	12.26
BL-02	0.006	0.02	400.15	2.515	6.06
BL-03	0	0	0.00	3.004	5.74
BL-04	0	0	0.00	2.843	6.87
BL-05	0.033	0.07	2.16	0.071	0.15
BL-06	0.073	0.17	12.09	0.881	2.09
BL-07	0.008	0.02	640.55	5.391	11.84
BL-08	0.121	0.18	6.66	0.807	1.22
BL-09	0.038	0.07	13.47	0.513	0.97
BL-10	0.021	0.04	10.65	0.220	0.48
BL-11	0.039	0.07	11.93	0.463	0.79
BL-12	0.054	0.11	22.93	1.244	2.44
3C-01	0.032	0.06	23.03	0.726	1.32
3C-02	0.045	0.08	15.61	0.706	1.21
3C-03	0.043	0.08	15.97	0.684	1.20
3A-01	0.016	0.03	12.42	0.194	0.40
3A-02	0.022	0.03	11.97	0.259	0.39
3A-03	0.058	0.12	11.51	0.670	1.33