ГЛЯЦИОЛОГИЯ И КРИОЛОГИЯ
GLACIOLOGY AND CRYOLOGY OF THE EARTH

Оригинальная статья / Original paper
https://doi.org/10.30758/0555-2648-2026-72-1-85-112
УДК 551.34

Permafrost on Severnaya Zemlya Archipelago and Wiese Island, Russian High Arctic

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Abstract. Climate conditions largely control the properties and distribution of permafrost. Its sensitivity to warming makes it a valuable indicator of ongoing climate change. This is especially true for High Latitudes, where climate warming accelerates at the highest rates worldwide. However, little is known about permafrost conditions, its properties and features on the High Arctic Islands, the northernmost land where permafrost occurs. For the first time, the present study summarizes Soviet literature data, recent drilling and other observation data of periglacial landforms, ground temperatures, cryostratigraphy and ground ice properties (including stable water isotope data, partly obtained during the Arctic Century Expedition in 2021) on the Severnaya Zemlya Archipelago and adjacent Wiese Island in the Russian High Arctic. The study provides baseline information on High Arctic permafrost to encourage and promote further investigations of the state and dynamics of warming permafrost.

Keywords: Russian High Arctic, Severnaya Zemlya, Wiese Island, Arctic permafrost, active layer, ice wedge, frost blister

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For citation: Demidov N.E., Rachkova A.N., Guzeva A.V., Gunar A.Yu., Kozachek A.V., Krasilnikov S.S., Sekisov N.L., Tchikhatchev K.B., Ugryumov Yu.V., Opel T., Meyer H., Wetterich S. Permafrost on Severnaya Zemlya Archipelago and Wiese Island, Russian High Arctic. *Arctic and Antarctic Research*. 2026;72(1):85–112. https://doi.org/10.30758/0555-2648-2026-72-1-85-112

Received 21.12.2025 **Revised 01.03.2026** **Accepted 05.03.2026**

Многолетняя мерзлота на архипелаге Северная Земля и острове Визе

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Аннотация. Климатические условия в значительной степени определяют распространение и характеристики многолетней мерзлоты. Чувствительность мерзлоты к потеплению позволяет рассматривать ее как важный индикатор происходящих изменений климата. Это особенно актуально для высоких широт Северного полушария, где скорость климатического потепления наибольшая на планете. Мерзлотные условия островов в высокоширотной Арктике — самых северных участков суши, где встречается многолетняя мерзлота, — остаются слабо изученными. В настоящей работе для архипелага Северная Земля и близлежащего острова Визе впервые обобщены данные исследований советского времени вместе с результатами недавних работ, включавших бурение, наблюдения за криогенными формами рельефа, температурой пород, изучение криостратиграфии и содержания стабильных изотопов воды, данные по которым частично получены во время экспедиции “Arctic Century” в 2021 г. Представленная работа закладывает основу для дальнейшего исследования современного состояния и динамики мерзлоты в высокоширотной Арктике.

Ключевые слова: Российская Арктика, Северная Земля, о. Визе, многолетняя мерзлота, сезонно-талый слой, полигонально-жильный лед, наледный бугор

Для цитирования: Demidov N.E., Rachkova A.N., Guzeva A.V., Gunar A.Yu., Kozachek A.V., Krasilnikov S.S., Sekisov N.L., Tchikhatchev K.B., Ugryumov Yu.V., Opel T., Meyer H., Wetterich S. Permafrost on Severnaya Zemlya Archipelago and Wiese Island, Russian High Arctic. *Проблемы Арктики и Антарктики*. 2026;72(1):85–112. https://doi.org/10.30758/0555-2648-2026-72-1-85-112

Поступила 21.12.2025 **После переработки 01.03.2026** **Принята 05.03.2026**

Introduction

Since the archipelago (Fig. 1) was discovered in 1913, large-scale geological, physiographic, hydrometeorological and glaciological studies have been carried out on

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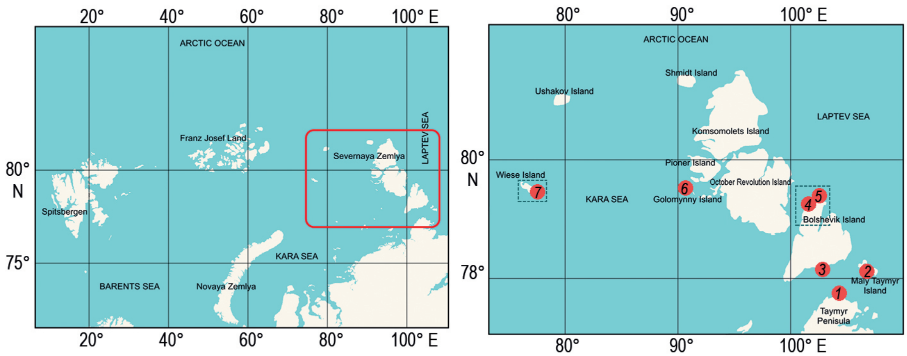

Meteorological stations:
1 — Taymyr Peninsula, Cape Chelyuskin, *2* — Maly Taymyr island, *3* — Bolshevik island, Bay Solnechnaya, *4* — Bolshevik island, Cape Baranova ice Base, *5* — Bolshevik island, Cape Peschany, *6* — Golomynny island, *7* — Wiese island

Fig. 1. Location of the Severnaya Zemlya Archipelago and surrounding islands showing the position of the study sites on Bolshevik and Wiese islands (dotted frames; see Fig. 2), and the meteorological stations referred to in the study

Рис. 1. Расположение архипелага Северная Земля и окружающих островов с указанием местоположения участков исследований на островах Большевик и Визе (пунктирные рамки; см. рис. 2), а также метеорологических станций, упомянутых в исследовании

Severnaya Zemlya, while Wiese Island has largely remained unstudied since its discovery in 1930. On Severnaya Zemlya, distinct permafrost research, if any, has so far been only sporadic. Studies of seasonal thawing and cryogenic processes on October Revolution Island are among the few works published in Russian [1–3]. However, the results of these studies are too insufficient to give even a preliminary idea of the large-scale permafrost conditions of the archipelago, primarily due to the lack of data on the temperature of the frozen strata and their thickness. The geocryological map of the USSR at a scale of 1:2 500 000 shows the regional ground temperature characteristics of the permafrost based only on theoretical calculations[1]. Meanwhile, from a natural-scientific point of view, the study of the Severnaya Zemlya Archipelago is of interest if one is to understand the specifics of permafrost formation under extremely severe High Arctic climatic conditions.

To study the permafrost conditions of Severnaya Zemlya and to establish permafrost monitoring, fieldwork, including drilling of boreholes, was carried out in 2021 in the north of Bolshevik Island close to the research station Cape Baranova Ice Base (Fig. 2*a*). In a physio-geographical context, the other islands of the Kara Sea, including Wiese Island, although not part of the Severnaya Zemlya Archipelago, are referred to as the Northern Land Province of the Arctic desert zone [4]. In 2023, a permafrost observation point was established on Wiese Island as part of the Russian National System of Background Permafrost Monitoring [5].

The present study aims (1) to summarize and make available previously conducted permafrost studies to identify permafrost characteristics in comparison to other high-latitude regions of the Earth and (2) characterize for the first time the current permafrost conditions of Severnaya Zemlya and Wiese Island for the first time based on newly obtained data.

1 Kondtrateva K.A. Severnaya Zemlya (to the Geocryological Map of the USSR, scale 1:2.500.000). *Merzlotnye issledovaniya = Permafrost Research.* 1982;20:84–96. (In Russ.).

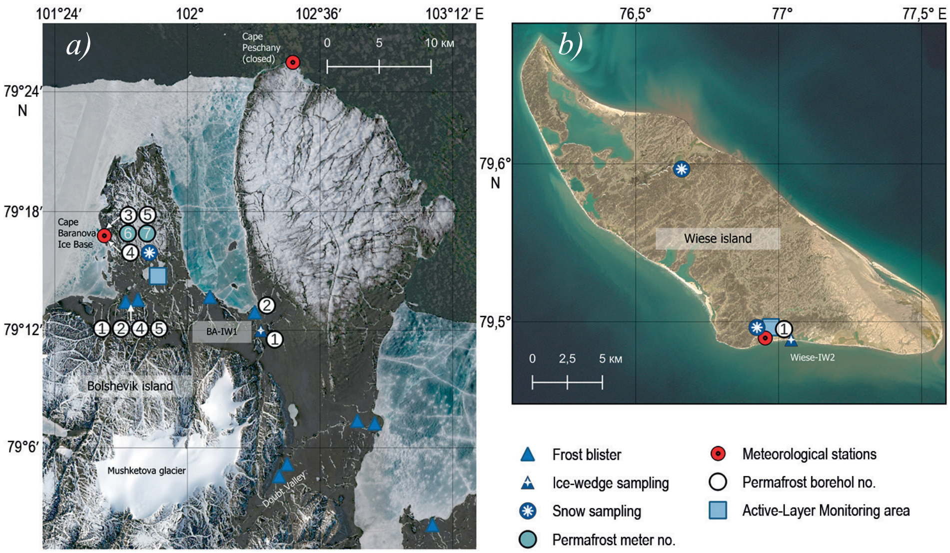

Fig. 2. Sampling and observation points (*a*) on Bolshevik Island near the Cape Baranova Ice Base on Bolshevik Island (Sentinel-2 Quarterly mosaics, 1 July 2021), and (*b*) on Wiese Island (Landsat image, 8 June 2024)

Рис. 2. Точки отбора проб и наблюдения (*a*) на острове Большевик в районе «Ледовой базы Мыс Баранова» (мозаика снимков Sentinel-2, 1 июля 2021 г.) и (*b*) на острове Визе (снимок Landsat, 8 июня 2024 г.)

Study region

Severnaya Zemlya Archipelago

The Severnaya Zemlya Archipelago consists of four large islands — October Revolution, Bolshevik, Komsomolets and Pioneer — and many small islands between 77°55′ and 81°16′ N (see Fig. 1). The relief of the archipelago is plateau-like and low-hilly. The maximum relief marks are confined to glacial domes. The bedrock base of the glaciers reaches heights of up to 800 m (Tumannye Mountains, October Revolution Island). In the river valleys, Quaternary sediment sections up to 70 m thick are known [6]. However, the Quaternary sediments only play a minor role, as the surface morphology consists mainly of rock covered by thin cryo-eluvium. Only the accumulative marine Quaternary terraces at the northern part of Bolshevik Island near Cape Baranova and Cape Peschany and in the northern part of Komsomolets Island near Cape Arctic, as well as on the western end of October Revolution in the area of the Uzkiy Gulf cover considerable areas[2]. The bedrock on Bolshevik Island and in the eastern part of October Revolution Island is mainly represented by Proterozoic-Lower Paleozoic metamorphic rocks crushed into steeply dipping folds and ruptured by granitoid intrusions, while the western parts of October Revolution, Komsomolets islands and Pioneer Island is mainly formed by folded Ordovician, Silurian and Devonian sedimentary rocks. Cenozoic deposits represent the northern part of Komsomolets Island.

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2 *Geological map of Severnaya Zemlya, scale: 1:1 500 000*. Moscow: Ministry of Geology of the USSR; 1967. (In Russ.).

Due to its offshore location, the climate of Severnaya Zemlya is less continental than that of the Taymyr Peninsula to the south, but more continental than that of the western sector of the Russian High Arctic. Marine climate features are most pronounced in the north-western part of the archipelago due to westerly air transport. The interaction between cold air masses from the inner Arctic, continental air masses from Siberia and relatively warm and humid masses from the North Atlantic intensifies cyclonic activity here. Another climate-forming feature of the archipelago (especially for its western part) is the inflow of advective heat from sea waters from the Atlantic and continental rivers. Heat transfer from the sea causes relatively warm winter air temperatures on Severnaya Zemlya, while relatively cool summer air temperatures result from the buffering effect of sea water and sea ice. According to meteorological observations since 2013 at the research station Cape Baranova Ice Base, the average monthly temperature is consistently above 0 °C only in July, while in August and June there are years when it can be below 0 °C [7]. The average monthly temperature of winter months is in the range of –30 to –15 °C.

About half of the archipelago's territory is covered by ice caps. According to the drilling data of the largest glacier on the archipelago on Komsomolets Island, the Akademii Nauk (AN) ice cap, the ice thickness reaches 761 m [8]. Direct glacier mass-balance measurements and further mapping revealed that the glaciation significantly decreased in the 20th century [9; 10]. The glaciers largely determine the distribution and regime of the rivers on Severnaya Zemlya. The rivers are mainly fed by melting glaciers and snow [6]. In winter, all the rivers are frozen to the bottom. The river valleys are canyon-shaped; only the largest rivers of the archipelago have flat-bottomed valleys with terraced slopes. There are about 30 lakes on the archipelago with a mirror area of more than 1 km^2. Small thermokarst lakes are common on marine terraces.

The vegetation cover is exceptionally scarce, as the archipelago belongs to the Arctic desert zone [4], although in favorable areas in the southern part of the archipelago, Arctic tundra vegetation occurs, forming a cohesive network hosting small reindeer populations. The altitudinal belt is manifested in the fact that the vegetation is poorer on the elevated inner plateaus, with only small areas covered with mosses and lichens.

Wiese Island

Wiese Island (79°29' N, 76°59' E) is located 265 km west of Severnaya Zemlya in the Kara Sea. It is 36 km long and up to 11 km wide (see Fig. 1). The climatic conditions here are generally similar to those of Severnaya Zemlya. Distinctive characteristics of Wiese Island are the absence of glaciation, the low-lying, gently hilly relief with absolute elevations up to 22 m above sea level[3], and the prevalence of sandy deposits. The fine-grained Lower Cretaceous sands that form the island have horizontal bedding and many nodules in the form of interlayers and large spherical contractions of dense rocky soils [11]. In the island’s eastern part, the lower terrace is composed of Quaternary deposits. As a permafrost monitoring station was being established in 2023, more than ten reindeer antlers were found on the surface and in the gullies. The position of these finds and their distance to the meteorological station rule out the possibility of the antlers being moved by the dogs belonging to the station. Further surface features on Wiese Island are rare boulders of igneous rock. The hills are intersected by narrow troughs, which in summertime carry water. Closed troughs fill with meltwater and form small lakes, which

3 *Topographic map of USSR 1:200 000. T-43 IV, V, VI, Polar station Wiese*; 1957. (In Russ.).

dry-up during the summer period. The coastal zone exhibits some lagoons filled with salty water and dissected by sand and stone spits from the sea.

The island's vegetation is sparse, reaching about 50 % coverage, and mainly composed of mosses and lichens, while grass is rare.

Material and methods

Fieldwork

Permafrost drilling was carried out by the UKB-12/25 (Vorovskiy Machine Factory, Ekaterinburg, Russia) dry drilling machine using core barrels ranging from 108 to 73 mm in diameter [12]. As the cores were retrieved, photo documentation of the cores, sampling, description of lithology and cryostructures took place. Drilling of frost blisters was carried out using Kovacs core and auger samplers (Kovacs Enterprise, LLC, USA). Cryopeg brines originated from the boreholes and were collected in plastic bottles and transported at approximately 0 °C to laboratory for analysis. For temperature measurements in the borehole #1 on Bolshevik Island, thermistor chains were installed using equipment from MSU-Geophysics LLC (Russia) and from Marlin-Yug LLC (Russia) in borehole #1 on Wiese Island (see Fig. 2), which measure temperature with a resolution of 0.01 °C and accuracy of ±0.1 °C. Both loggers collect temperature measurements at 6-h intervals. Observational data from Wiese Island borehole are transferred automatically using a satellite-based data transmission system and data from borehole on Bolshevik Island are collected manually during occasional visits.

Air temperature and soil temperature data at the meteorological stations were obtained from the Federal Service for Hydrometeorology and Environmental Monitoring[4]. Measurements of the seasonal active-layer thickness (ALT) were carried out at the end of the thawing period using a metal gauge on a 50 by 50 m site with a 5 m spacing. Furthermore, ALT measurements were complemented by AM-21 type permafrost meters (Ecolog-Yug LLM, Russia; see Fig. 2), which record the freezing depth of distilled water in a rubber tube immersed in the ground. On Bolshevik Island, wedge-ice samples were obtained by excavation in a pit and on Wiese Island sampled in a coastal exposure (see Fig. 2). At both locations the upper 5 cm of ice was moved away by hammer and chisel to ensure uncontaminated ice samples. Oriented ice blocks with approximate dimensions 10×10×20 cm crossing the wedge growth direction were cut and transported at subzero temperature to the laboratories. In August 2021, a snow patch was sampled in a 5 cm resolution for stable isotope analysis in a 100 cm deep snowpit at Wiese Island in the framework of the Arctic Century expedition. In September 2023, samples of freshly fallen snow were collected in sealed plastic tubes in the vicinity of weather stations on Bolshevik and Wiese islands (see Fig. 2). After collecting and until laboratory analyses, the samples were stored at sub-zero temperatures.

Analytical work

The ice (or moisture) content of the sediments was determined by the weight method in 53 samples expressed as weight percentage (wt%). An Agilent 720-OES (Agilent Technologies, Inc., USA) inductively coupled plasma optical emission spectrometer was used to analyze the cation content (Na^{+1}, K^{+1}, Mg^{+2}, Ca^{+2}) in eight samples of cryopeg brines, and anions ($Cl^{–}$, $SO_4^{2–}$, $HCO_3^{–}$) were determined titrimetrically.

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[4] Roshydromet. All-Russian Research Institute of Hydrometeorological Information — World Data Centre. 2024. Available at: http://aisori-m.meteo.ru/waisori/ (accessed: 28.05.2024). (In Russ.).

In total, 32 samples originated from one excavated horizontal ice-wedge profile 1 (combined BA-IW1-01 and BA-IW1-02 sample sets; Table S2). Profile 1 was taken frozen in two blocks, which remained frozen upon laboratory analysis. After manual cleaning, both blocks (each ca. 15 cm wide) were sub-sampled at 1.5 cm resolution in the cold lab (–4 °C). In this study we measured and considered additional 14 samples from a second horizontal ice-wedge profile 2 (combined BA-IW1-03 to BA-IW1-08 sample sets; Table A.2). A second ice wedge (Wiese-IW2, n = 6) on Wiese Island and four snow samples from Wiese (n = 1) and Bolshevik (n = 2) islands, and Cape Chelyuskin (n = 1), Taymyr Peninsula were analyzed using a Picarro L2120-i analyzer of the Climate and Environmental Research Laboratory (CERL, AARI, St. Petersburg, Russia) with an analytical precision of ±0.08 ‰ for $\delta^{18}O$ and ±0.4 ‰ for δD.

The stable oxygen ($\delta^{18}O$) and hydrogen (δD) isotope ratios of BA-IW1 wedge-ice and snow samples from the 2021 Arctic Century expedition (n = 20, from a 100 cm snow pit on Wiese Island) were determined at the ISOLAB facility of the Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research in Potsdam (Germany), using a Picarro L2130i cavity ringdown spectrometer (CRDS) with an analytical precision of ±0.08 ‰ for $\delta^{18}O$ and ±0.5 ‰ for δD. Stable water isotope ratios are reported in per mil (‰) versus Vienna Standard Mean Ocean Water (VSMOW2). The deuterium excess *d* was calculated as $d = \delta D - 8 \cdot \delta^{18}O$ [13].

Results

Recent regional climate warming

Data from seven meteorological stations on Severnaya Zemlya and its islands and continental surroundings allow us to analyze trends and variabilities of the almost century-long mean annual air temperature (MAAT) and annual precipitation records. The fluctuations of MAAT at the meteorological stations were synchronous (Fig. 3). The difference in absolute values of MAAT between the stations during most of the observation period was within 2 °C. The cooling trend in the first half of the observation period was replaced in the mid-1970s by a more pronounced trend of mean annual air temperature increase. The MAAT on the westernmost Wiese Island is slightly higher than that on Golomyanny Island and on northern Taymyr (Chelyuskin station). MAAT calculated according to the WMO standard[5] for the thirty-year periods from 1961 to 1990 and from 1991 to 2020 increased by 2.6 °C on Golomyanny Island, by 3.0 °C on Wiese Island and by 2.0 °C on northern Taymyr (Chelyuskin station) corresponding to an increase rate of the MAAT rise of between 0.07 and 0.1 °C per year. In 2021, the MAAT at the meteorological stations were –12.1 °C on Golomyanny Island, –12.4 °C on the Cape Baranova Ice Base, –11.4 °C on Wiese Island and –12.1 °C on northern Taymyr (Chelyuskin station). Mean annual precipitation calculated for 1991–2020 at the meteorological stations are as follows: Wiese Island 205 mm, Golomyanny Island 180 mm, northern Taymyr (Chelyuskin station) 212 mm. The meteorological stations do not show any clear trends in MAP. Concerning the influence of precipitation on the ground-temperature regime on Severnaya Zemlya, the following features are noteworthy: the overwhelming majority of precipitation falls as snow, snow thickness is generally low while snow density is high. The duration of the snow cover, as well as unevenness in distribution depends on the relief [1].

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5 *WMO guidelines on the calculation of climate normal. № 1203*. Geneva: WMO; 2017.

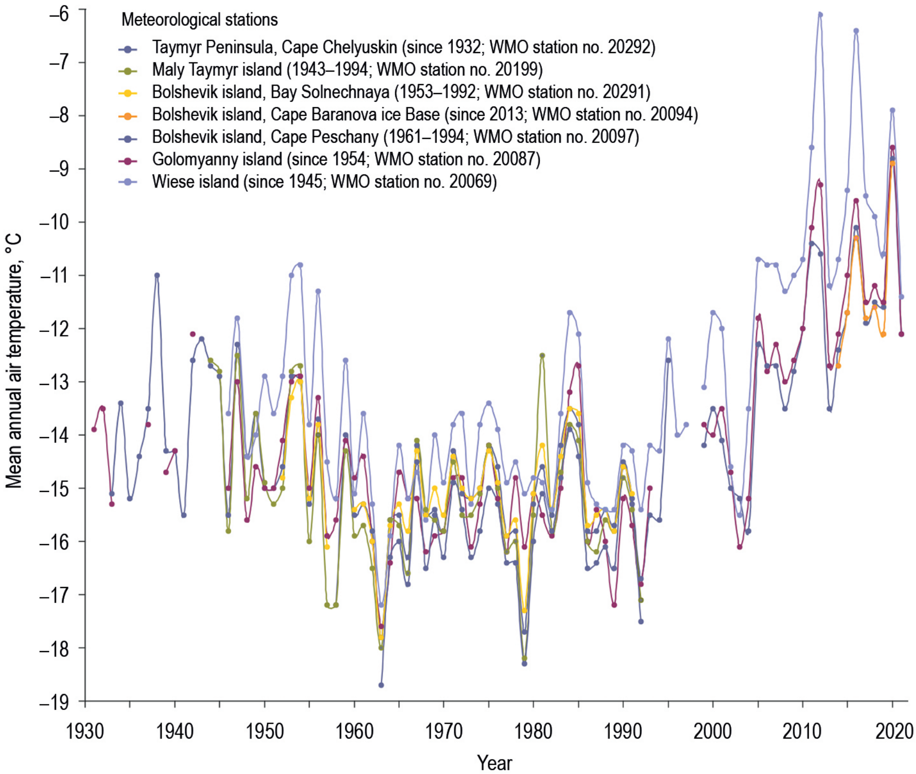

Fig. 3. Change of the Mean Annual Air Temperature (MAAT) over the last nine decades in the Severnaya Zemlya Archipelago and adjacent areas (see Fig. 1)

Рис. 3. Изменение среднегодовой температуры воздуха за последние девяносто лет на архипелаге Северная Земля и прилегающих территориях (см. рис. 1)

In the seas surrounding Severnaya Zemlya, there is a well-pronounced trend of changes in ice conditions. The ice-cover extent of the northeastern part of the Kara Sea and the western part of the Laptev Sea decreased by 14 and 8 %, respectively, in the 30-year period between 1986–2015 compared to 1956–1985 [14].

Permafrost temperature, thickness and seasonal thawing

The mean annual ground temperature (MAGT) at the meteorological stations on Golomyanny and Wiese islands and at Cape Chelyuskin since 1989 are shown in Figure 4.

In 1989, the MAGT at all the three observation sites were in the range of –14 to –13 °C and increased progressively to –10 to –9 °C in 2018, corresponding to a temperature increase rate of 0.14 °C per year. According to the measurement data in borehole #1 on Bolshevik Island (Fig. 5), the mean annual ground temperature within the layer of seasonal temperature variation at a depth of 9.5 m was about –9.8 °C in 2022–2023.

According to measurements in 2023–2024 in borehole #1 on Wiese Island at a depth of 19 m corresponding to the depth of zero annual temperature amplitude, the temperature is –10.4 °C. Thus, the characteristic range of modern MAGT in the layer of seasonal temperature ranges from about –10 to –9 °C. The mean annual air temperatures are only slightly lower than the MAGT. The difference between MAAT and MAGT does not exceed

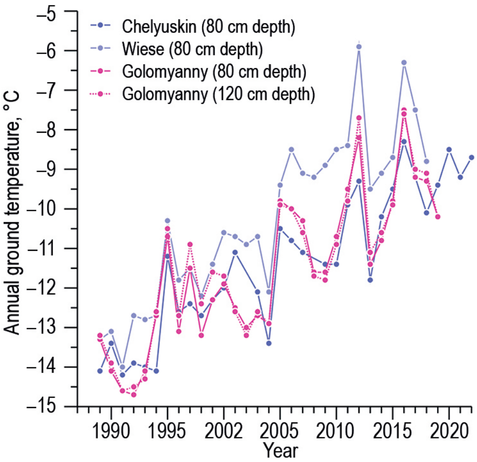

Fig. 4. Change of the Mean Annual Ground Temperature (MAGT) since 1989 on Golomyanny and Wiese islands, and at Cape Chelyuskin

Рис. 4. Изменение среднегодовой температуры грунта с 1989 г. на островах Голомянный и Визе, а также на мысе Челюскин

3°C. In borehole #1 on Wiese Island, starting from the depth of zero-annual temperature amplitudes at 19 m and down to the bottom of the borehole at 25 m, the ground temperature decreases from –10.4 to –10.9 °C (see Fig. 5).

Due to the lack of deep drilling data, an approximation of the thickness of the negative-temperature strata can only be obtained by calculations using the MAGT within the layer of seasonal temperature variation and the assumed average values of the geothermal gradient. If we assume the range of MAGT is –12 to –9 °C and the temperature is linearly rising with a gradient of 1–2 °C per 100 m, the permafrost thickness will amount to 450–1200 m. The actual permafrost thickness is primarily determined by the paleogeographic scenario and changes in the past not only in the MAAT, but also in the glaciation boundaries and sea level.

The permafrost distribution on Severnaya Zemlya continues beneath the glaciers as those are cold-based. According to temperature measurements in boreholes drilled to the base of the Vavilov and Akademii Nauk ice caps, a temperature increase with depth was observed, but the temperature at the glacier bed does not reach values higher than –6 °C [6; 15]. Even in the case of the largest ice caps on Severnaya Zemlya, the combination of mean annual surface temperatures, ice thickness and geothermal gradient do not allow the temperature at the bed to reach positive values. Thus, the glaciers are currently cold-based and do not have subglacial taliks. According to radio-sounding data, the Akademii Nauk ice cap buries several islands and straits, and a significant part of its bed is at absolute elevations below 0 m a. s. l. [6]. If the ice cap's formation occurred during a period when the sea level was not lower than the present day one, we cannot exclude the presence of cryopeg brine lenses near the lower boundary of the glacier.

Closed seasonal taliks are formed underneath the river channels. In summer, permafrost meters installed in the channel of the Mushketova River on Bolshevik Island recorded positive ground temperatures at depths of more than 1.5 meters. In winter, the groundwater in these taliks freezes, squeezes and forms frost blisters at the surface. The 10 m deep borehole #2 (see Fig. 5), drilled in April 2021 on Bolshevik Island in

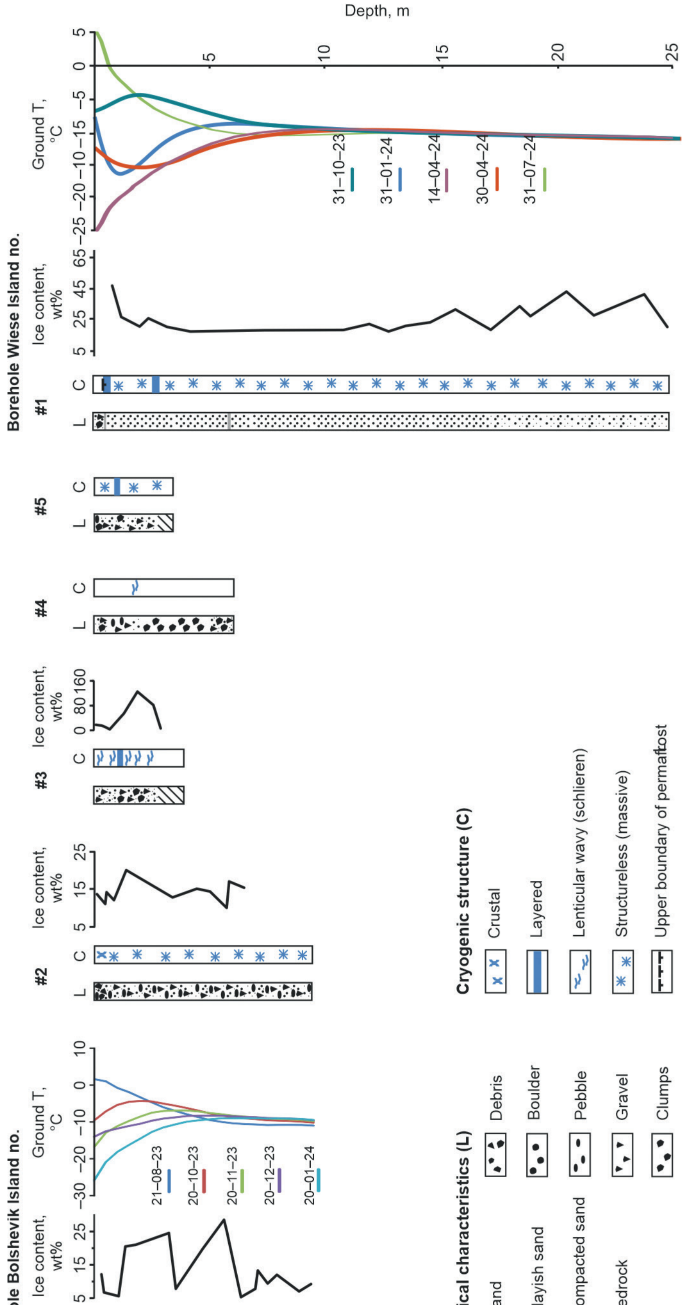

Fig. 5. Cryolithological characteristics, ice content and ground temperatures from permafrost drilling on Bolshevik and Wiese Islands

Рис. 5. Криолитологические характеристики, влажность и температура грунта по данным бурения на островах Большевик и Визе

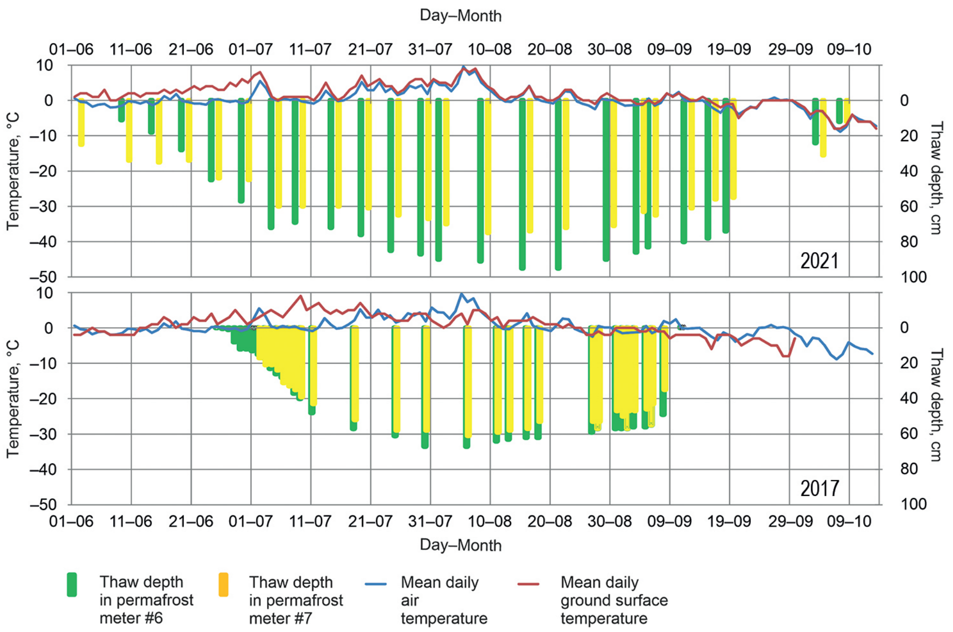

Fig. 6. Seasonal dynamics of the thaw depth according to measurements by permafrost meters in the vicinity of the Cape Baranova Ice Base in (*a*) 2021 and (*b*) 2017

Рис. 6. Сезонная динамика глубины протаивания по данным мерзлотомеров в окрестностях «Ледовой базы Мыс Баранова» в (*a*) 2021 и (*b*) 2017 гг.

the bed of the Novaya River at the base of a frost blister, showed the absence of thawed ground, indicating the seasonal nature of the river talik. Most of the lakes on islands of the Severnaya Zemlya Archipelago are either shallow and freeze to the bottom in winter or are too small to allow the formation of through-taliks. The presence of through-taliks can only be expected below several of the largest lakes and only if they have existed for thousands of years.

According to detailed observations of the seasonal active-layer dynamics using permafrost meters in the area of the Cape Baranova Ice Base station in 2017–2023 (see Fig. 2), thawing starts in late May to early June (Fig. 6).

The ALT reaches its maximum in August, less often in late July or September (Table A.1), at the end of a stable increase of mean daily air temperatures or with a delay of about two weeks relative to this moment. The maximum ALT values varied from 47 to 115 cm depending on the location of the permafrost meter and the year of measurement. No later than late October the ALT completely refreezes. Except for the increase in the maximum ALT in the anomalously warm year of 2020, no clear correlation of the ALT with the MAAT, surface temperature and the sum of positive temperatures for the warm period were observed. The average ALT values measured with a metal probe at a 50 by 50 m site near the Cape Baranova Ice Base station yielded 50 cm on 9 September 2021, 50 cm on 15 August 2022 and 51 cm on 24 August 2023. At Wiese Island, similar measurements at the site on 22 September 2023 showed an average ALT of 45 cm.

Periglacial landforms and permafrost features

Since Quaternary deposits on Severnaya Zemlya are generally poorly developed, the dominant geological process is the cryogenic weathering of pre-Quaternary rocks, transport of weathering products — cryo-eluvium — down the slopes and their sorting. Among slope processes, in addition to solifluction (Fig. 7*a*), the formation of basins during anomalously warm summers plays a significant role, reaching, for example, on October Revolution Island dimensions up to 100 by 200 m [2]. The large number of snowfields leads to an active role of nivation in surface weathering. Patterned ground is common on the archipelago such as stone polygons on the inner plain of October Revolution Island [10]. On watersheds, patterned ground is represented by stone rings, less often polygons, and on the slopes, it turns into various types of sorted stripes [2]. Similar forms of patterned ground are described at the northern end of Bolshevik Island [16], where small-scale polygon frost cracking is widespread in areas with sandy and loamy soils (Fig. 7*b*). On Wiese Island, due to the large aggregations and layers of coarse rock material in the Cretaceous sands, their bulging occurs, as do many stone hillocks and stone placers.

On Severnaya Zemlya ice-wedge polygons can be found in areas with relatively thick Quaternary deposits. On October Revolution Island, they are mainly confined to marine terraces, rarely to river terraces and floodplains [17]. Frost cracks are filled with vertical vein ice, forming ice wedges. On an early-Holocene marine terrace on October Revolution Island, such wedge ice is described from a pit to be about 0.7 m wide [3]. Polygons on this island are tetragonal, with sides 7–20 m long [2]. Similar patterns in the development of ice-wedge polygons are characteristic of Bolshevik Island. On the vast accumulative-erosion plains around the Cape Baranova Ice Base, individual areas with weakly-expressed ice-wedge polygons can be found almost everywhere at absolute elevations between 10 and 60 m a. s. l. Well-expressed polygons are much less common here (see Fig. 7*a*). One of these areas on Bolshevik Island is located close to borehole #1, where a 45 cm thick section of ice wedge has been described in the pit (see section 4.4). The northern part of Komsomolets Island represents one of the most well-developed polygon reliefs on the archipelago.

The entire surface of Wiese Island — except for the gully network — is shaped by tetragonal and pentagonal ice-wedge polygons (Fig. 7*c*). The polygons have typically 5–15 m long sides. Exposed ice wedges are up to 75 cm wide (Fig. 8). As on the islands of Severnaya Zemlya, the polygons on Wiese Island do not have rims characteristic of low-center polygons but represent high-center polygons marked in the relief by shallow depressions reaching up to several decimeters. On the terrace in the island's eastern part, larger polygons of a different generation occur with 15–65 m long sides.

The generally low ALT on Severnaya Zemlya causes unfavorable conditions for frost-heave landforms, which are consequently rare [4]. On the river terraces of October Revolution Island, frost-heave mounds are described as being up to 1.2 m high and up to 10 m in diameter, covered with a network of radially diverging ice-filled cracks [2]. In the riverbeds, small icings formed partly from the meltwater of the seasonally thawed active layer. Figure 7*d* shows such icings reaching a length of about 100 m in the north of Bolshevik Island in the lower reaches of the Basic River. The ice is bluish in colour, in some places it is lifted upwards and cracked.

During the spring field work in 2021, frost blisters were discovered close to the Cape Baranova Ice Base station. They form cones up to 3 m high, having a rounded or elongated

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[6] *Topographic map of USSR 1:200 000.* T-43 IV, V, VI, Polar station Wiese. 1957. (In Russ.).

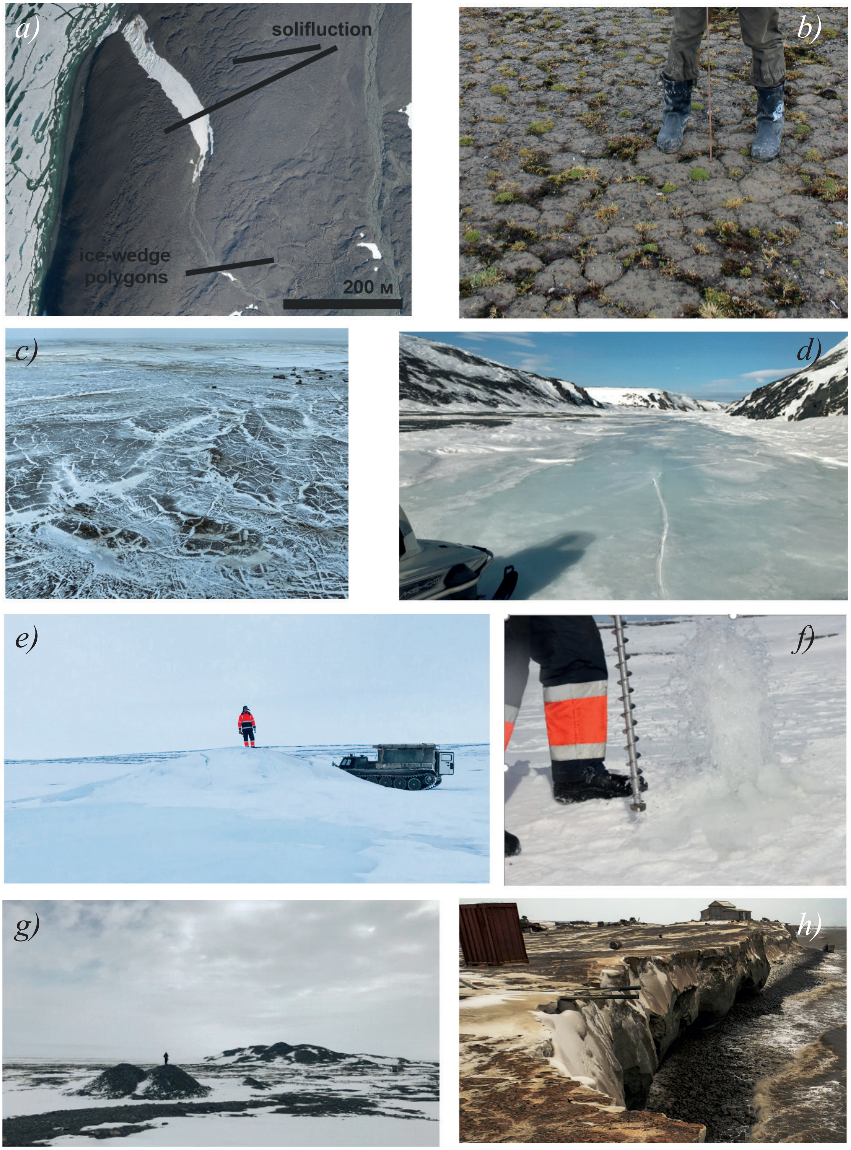

Fig. 7. Periglacial landforms and permafrost features on Bolshevik and Wiese islands: (*a*) solifluction stripes and ice-wedge polygons on Bolshevik Island, (*b*) small-scale polygons on Bolshevik Island, (*c*) ice-wedge polygons on Wiese Island (note the meteorological station in the background), (*d*) icing on Bolshevik Island, (*e*) frost blisters on Bolshevik Island, (*f*) gushed gas-saturated cryopeg brine on Bolshevik Island, (*g*) stone cones on Bolshevik Island, (*h*) thermo-abrasion cliff on Wiese Island

Рис. 7. Криогенные явления и процессы на островах Большевик и Визе: (*a*) солифлюкционные полосы и полигоны повторно-жильных льдов на о. Большевик; (*b*) мелкополигональные образования на о. Большевик; (*c*) полигоны повторно-жильных льдов на о. Визе (на заднем плане — метеорологическая станция); (*d*) наледь на о. Большевик; (*e*) наледный бугор (блистер) на о. Большевик; (*f*) излияние газонасыщенного криопэга из скважины на наледном бугре (блистере) на о. Большевик; (*g*) каменные конусы на о. Большевик; (*h*) термоабразионный клиф на о. Визе crescent shape in plan (Fig. 7*e*). The round cones are dissected by a network of radially diverging cracks, and the elongated ones are dissected by longitudinal cracks. Frost blisters are confined exclusively to riverbeds. Moreover, they gravitate to their estuarine zones but can also be formed more than 10 km away from the estuary, as is the case in the Doubt Valley on the Basic River (Fig. 2*a*). As a rule, frost blisters occur in groups, but free-standing single cones were also found. When drilling in the central part of several large frost blisters, water cavities were recorded, from which gas-saturated cryopeg brine gushed (Fig. 7*f*). The height of the fountain above the top of the cone in the first seconds after opening reached several meters. At the base of the cone in the mouth of the Novaya River, borehole #2 was drilled to a depth of 10 m, a section of which is completely composed of frozen soils without signs of any salinization. The formation of frost blisters on Severnaya Zemlya is due to seasonal comprehensive freezing of river taliks, during which cryogenic metamorphosis and gas concentration occur. Cryopeg brines from frost blisters in the lower reaches of the Novaya River had a chloride-calcium composition and mineralization of up to 70 g L^{-1}. On the Basic River, cryopeg brines from frost blisters have a sulfate magnesium-calcium composition and mineralization of up to 20 g L^{-1}. The growth of frost blisters during freezing of the talik is ensured by two processes: the outflow of pressure water to the surface due to hydraulic fracturing and its freezing in the form of ice, as well as the progressive swelling of ice and its growth from below on the ice-water contact according to the growth model of injection ice and surface heave.

Specific phenomena in cone-shaped piles of coarse clastic material are formed on the periphery of glaciers. The height of the cones can reach tens of meters. Their formation is due to the concentration of clastic material in glacial springs. The cones, which are distant from current glacier boundaries, mark the position of glaciers in the past. Such stone cones are present in the north of Bolshevik Island (Fig. 7*g*). Previously, similar forms were described on Pioneer and October Revolution islands [18].

Severe temperature conditions and weak development of loose deposits limit thermokarst development. On October Revolution Island, shallow thermokarst lakes are located on accumulative marine terraces reaching water depths of up to 1 m [2]. On Bolshevik Island, similar thermokarst lakes are present on the marine terrace on Oleniy Peninsula. On Wiese Island, interpolygonal ponds occur above melting ice wedges, most pronounced in the northern part of the island. The sea shores in the study area are mainly composed of rock, causing only a weak effect of thermo-abrasion. Known areas of intense thermo-abrasion include the southern shore of Malyi Taymyr Island [19], composed of sand-clay deposits, and Wiese Island, composed of sands (Fig. 7*h*). In the latter, thermo-abrasion slows down to some extent due to a large amount of rock aggregations in the sands, which form pebble-boulder beaches. On both islands, frozen blocks with wedge ice erode due to the formation of undercut niches. The modern coastline of Wiese Island, compared to those on the 1957 topographic map[6], shows coastal retreat up to 300 m in places. A coastal retreat of about 150 m is notable at the meteorological stations. Instead, in the eastern part of the island, in the reaches of the lower terrace, sediment aggradation toward the sea takes place, highlighting the modern age of the terrace.

Cryostructures and other permafrost properties

To date, the main sources of information on the cryogenic structure of sediments result from cryolithological descriptions of Quaternary deposits in pits and sweeps on

[6] *Topographic map of USSR 1:200 000.* T-43 IV, V, VI, Polar station Wiese. 1957. (In Russ.).

October Revolution Island [6; 7], complemented by drill cores recently obtained on Bolshevik Island in 2021 and on Wiese Island in 2023.

The marine terraces studied on October Revolution Island are composed of silt, sand and gravel. The sands have massive cryostructure, while the silts show wavy and fine-reticulated cryostructures with ice lenses up to 3 mm thick [2; 3]. Frozen deposits of marine terraces in the north of Bolshevik Island were recovered from borehole #1 drilled at an absolute elevation of 31 m above sea level (a. s. l.) in the lower reaches of the Novaya River, 2 km inland from the shore of Mikoyan Bay (see Fig. 2*a*). The 10 m deep borehole penetrated grey dusty loams with different contents of gravel and pebbles, underlain below 8 m depth by collapsed large fragments of Proterozoic metamorphic rocks (see Fig. 5). A distinctive feature of borehole #1 is the presence of a nearly dry surface soil layer up to 0.5 m thick. At the time of drilling in April 2021, there was no snow cover at the work point. Below the dry soil layer, the loams have a massive cryostructure, with thin subhorizontal ice veins occurring only in certain depth ranges. The ice content of the loams along the borehole section varies from 5 to 25 %, with an average value of 14 %. The terrace surface is shaped by ice-wedge polygons. A 45-cm wide ice wedge (BA-IW1) was uncovered in a pit close to borehole #1 at a depth 75 cm below a layer of gravel with a loamy matrix. The vein ice is opaque, with inclusions of clayey material, with subvertical layering; individual ice veins are several millimeters thick (Fig. 8*a*).

The freezing of the terrace on which borehole #1 is located and the epigenetic formation of the wedge ice occurred after the enclosing sediment had been deposited, i.e. after the yet undated sea-level regression. An earlier palaeogeographic study of this terrace concluded that the marine sediments accumulated during the Last Interglacial in a rapid rise in relative sea level by tens of meters [20].

Epigenetic freezing was also concluded for ice wedge polygons on the marine terrace on October Revolution Island [3]. The terrace is up to 8 m high and composed of Early Holocene loams with inclusions of coarse clastic material. The deep-water depositional environment together with a decrease in the number of ice lenses and ice content down the section, favor of epigenetic freezing.

It cannot be ruled out that part of the marine sediments froze syngenetically below sea level, meaning that deep freezing took place synchronously with ongoing sedimentation. The presence of ice schlieren — thin lenticular layers of segregated ice of various orientations — in the silts of the terrace on October Revolution Island was interpreted as evidence of syngenetic freezing of at least some facies of marine sediments [2]. Further evidence was obtained by drilling borehole #4 from the landfast ice and excavating a pit in the coastal zone in the north of Bolshevik Island in Plashkouta Bay (see Fig. 2*a*). The sea-ice thickness at the drilling point was 1.5 m, the water depth under the ice was 1.5 m. The depth of the borehole #4 from the sea bottom is 6 m (see Fig. 5). The core exposed loams and coarse clastic rocks. From 1.5 m below the sea bottom, ice shards up to several centimeters thick were found in the samples of the disturbed structure, which in natural composition would represent ice schlieren. Due to the presence of large rock fragments in the ground and its temperature close to the freezing point, the natural composition was disturbed during drilling and it was not possible to identify the original cryostructure. Nevertheless, the presence of ice inclusions indicates that there are plastic or solid frozen soils in Plashkouta Bay below the seawater.

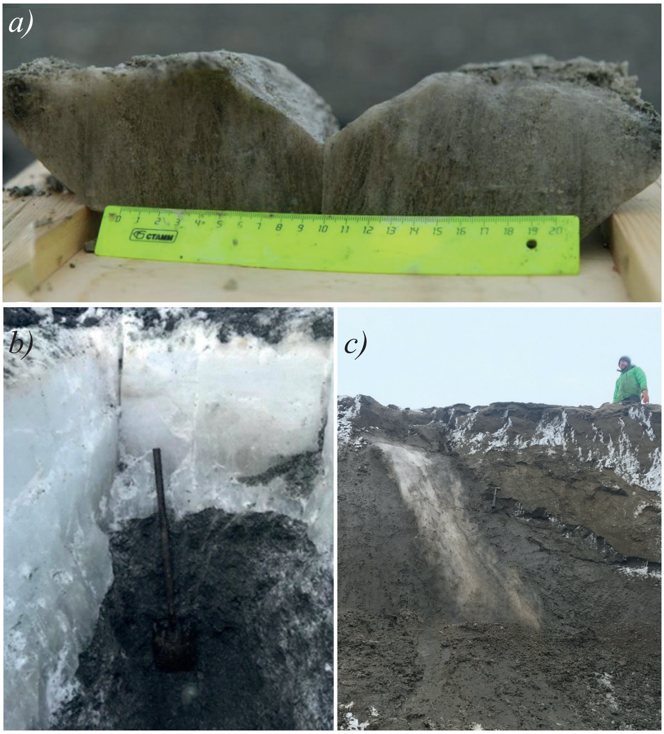

Fig. 8. Ground ice observations and sampling: (*a*) ice wedge BA-IW1 sampled in a pit at 75 cm depth on a marine terrace about 15 km from the Cape Baranova Ice Base on Bolshevik Island; (*b*) pit uncovering the interface between sea ice (1.5 m thick) and frozen pebbles and gravel (at least 1 m thick) at Cape Peschany. Note a shovel for scale, and (*c*) ice wedge Wiese-IW2 in a thermo-abrasional exposure at the southern coast of Wiese Island. Note a person and a geological hammer for scale

Рис. 8. Наблюдения и отбор проб подземных льдов: (*a*) образец повторно-жильного льда BA-IW1, отобранный в шурфе на глубине 75 см в пределах морской террасы примерно в 15 км от «Ледовой базы Мыс Баранова» (о. Большевик); (*b*) шурф, вскрывающий контакт между морским льдом (мощностью 1,5 м) и мерзлыми галечно-гравийными отложениями (мощностью не менее 1 м) на мысе Песчаный, для масштаба указана лопата; (*c*) повторно-жильный лед с точки отбора образца Wiese-IW2 в термоабразионном обнажении на южном побережье о. Визе. Для масштаба в кадре человек и геологический молоток

Solid-frozen ground was also revealed in pits in the coastal zone at Cape Peschany (see Fig. 2*a*; Fig. 8*b*). A one-meter-thick layer of hard frozen gravel with pebble inclusions was uncovered below the 1.5 m thick layer of sea ice. The pit did not go beyond the frozen sediments, but from its bottom, cryopeg brine began to seep into the pit through the frozen gravel and pebble soil.

The alluvial deposits studied on October Revolution Island are composed of gravel and pebble material with sandy and sandy loam aggregates, characterized by lens-like reticulated to layered cryostructures. The thickness of the ice lenses reaches 2 cm, and at a depth of 1.5–2.0 m ice layers up to 6 cm thick are distinguished. Due to the persistence of cryostructures along the section and high ice content, syngenetic freezing is concluded [2]. On Bolshevik Island, alluvial deposits were studied from the section of borehole #2, which was drilled in April 2021 700 m from the shore of Mikoyan Bay directly in the bed of the Novaya River. The 10 m deep borehole revealed a section of frozen clayish sand with varying amounts of gravel and pebbles (see Fig. 5). The cryostructure is massive. The ice content of the sediments ranges from 10 to 20 %, with an average value of 14 %. The difference in the lithological and cryogenic structure of alluvial sediments uncovered by borehole #2 and alluvial sediments studied earlier on October Revolution Island is a consequence of the existence of a relatively wide range of local conditions of sedimentation and freezing in different parts of river valleys. A common feature of alluvial sedimentation on Severnaya Zemlya is significant amounts of coarse-grained particles. In addition, with a complete freezing of all the rivers of the archipelago during most of the year, the alluvial sediments freeze syngenetically.

Boreholes #3 and #5 were drilled near the Cape Baranova Ice Base at an altitude of 10 m above sea level. The bedrock was overlain by a thin cover of marine sediments and reworked into cryo-eluvium (see Fig. 5). Unweathered bedrock is exposed at depths of 2.8 and 3 m. Above the section lie dusty loams with inclusions of crushed stones, pebbles and clasts. The cryostructure of the loams is massive and thin-layered. A distinctive feature in both boreholes is the presence of ice and ice-soil interlayers in the depth range of 1.0–1.2 m. Apparently, the presence of such layered ice belts at the lower boundary of the seasonally unfrozen active layer or slightly below is a characteristic feature of areas with a thin cover of loose sediments, which formed as cryo-eluvium. On October Revolution Island, an ice interlayer with rare inclusions of coarse clastic material with a thickness of 25 cm and an apparent length of 15 m was described from above Devonian sandstones under 70 cm of cryoeluvial loams [2].

A similar picture emerges on Golomyanny Island (the maximum altitude of the island is 26 m a. s. l.), where a widespread presence of ice between the surface layer of dusty loam with inclusions of driftwood and rubble with a thickness of 0.35–0.7 m and the bedrock was noted. The ice contains inclusions of loam and rubble nests. Buried snowfields formed in river valleys are also known on Severnaya Zemlya. In the basin of Changeable Lake [21], located 4 km from the Vavilov Glacier, there are remnants of a lake-alluvial terrace, where ice with a thickness of up to 3 m was described under a 1–2.5 m layer of sand [2].

On Wiese Island, borehole #1 penetrated epigenetically frozen sands (Fig. 2*b*) with massive cryostructure and interlayers of coarser rocky material. The ice content of the sediments ranges from 16 to 31 %, with an average of 21 %. The upper 10 m of the section penetrated by the boreholes is well exposed in thermo-abrasional cliffs. Inspection of the outcrop confirms that the sands are characterized by massive cryostructure. Ice wedges up to 75 cm wide are observed in the outcrop (Fig. 8*c*) and sampled (Wiese-IW2-01). The sample Wiese-IW1-01 obtained from a pit at 45 cm depth (ALT 40 cm) is bubble-rich with elongated bubbles (1 mm in diameter, up to 10 mm long) and contains loamy ground veins in its center.

Wedge-ice and snow stable isotopes

The stable water isotope data from ice wedges on Bolshevik and Wiese islands are the first published in the study region. The sampling location on Bolshevik Island near Cape Baranova on a polygon-patterned marine terrace speaks clearly of the epigenetic formation of wedge ice. The wedge ice was obtained at a depth of 75 cm below the surface exceeding the seasonal thaw depth and no indications of recent cracking could be observed. Mean values and standard deviations for all BA-IW1 samples were –17.7 ± 0.8 ‰ for

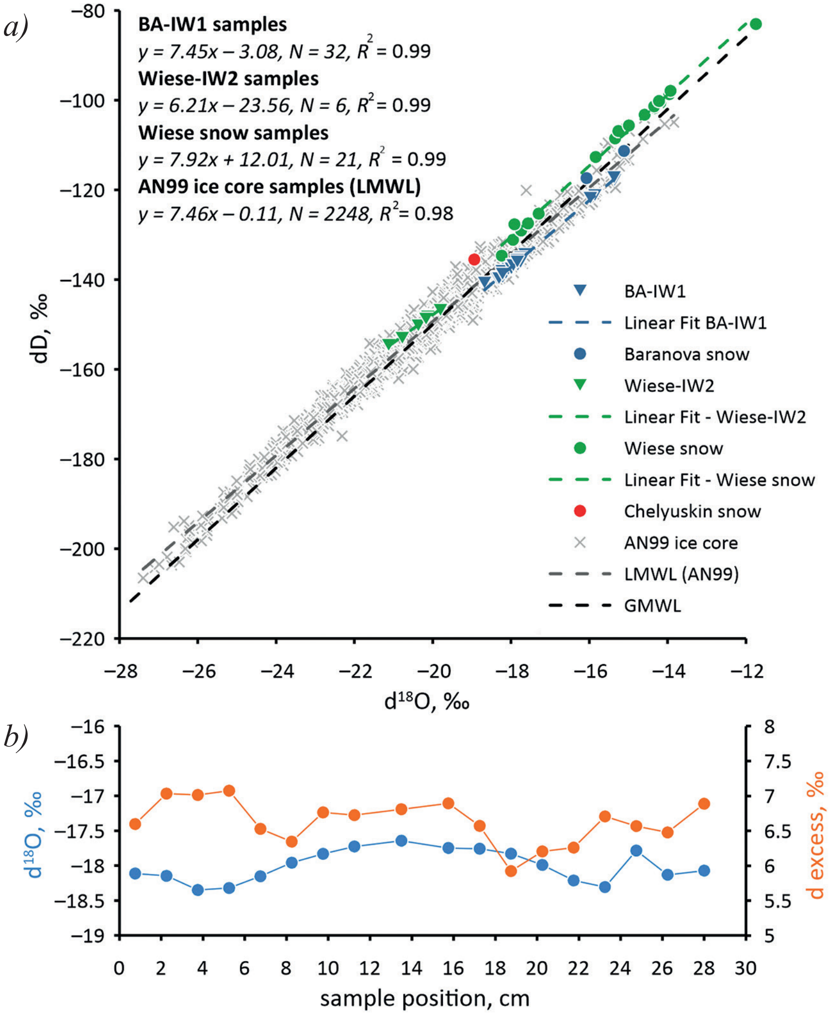

Fig. 9. (*a*) Co-isotope relationship (δ18O, δD) of the ice wedge BA-IW1, ice wedge Wiese-IW2, snow from Cape Baranova, Wiese Island, and Cape Chelyuskin compared to Global Meteoric Water Line (GMWL) [23] and ice-core data from the Akademii Nauk ice cap considered as LMWL [22], (*b*) Profile 1 of the ice wedge BA-IW1 with detailed δ18O and *d* data

Рис. 9. (*a*) Соотношение δ18O и δD для повторно-жильного льда BA-IW1, повторно-жильного льда Wiese-IW2, снега с мыса Баранова, о. Визе и мыса Челюскин в сравнении с Глобальной линией метеорных вод (GMWL) [23] и данными по ледяному керну с ледника Академии Наук, рассматриваемыми в качестве локальной линии метеорных вод (LMWL) [22]. (*b*) Профиль 1 повторно-жильного льда BA-IW1 с детальными данными по δ18O и дейтериевому эксцессу

$\delta^{18}O$, –135.1 ± 6.2 ‰ for δD and 6.6 ± 0.6 ‰ for *d* (Table A.2). The co-isotope relationship of the wedge ice (slope of 7.45 and intercept of –3.08, R^2 = 0.99, n = 32; Fig. 9) is very close to those of ice-core data for Akademii Nauk (AN) ice cap on Komsomolets Island covering the time period 1883–1998 (slope of 7.46 and intercept of –0.11, R^2 = 0.98, n = 2248), which is considered to represent the Local Meteoric Water Line (LMWL)[22].

The isotopic composition of the ice wedge Wiese-IW2 shows a more depleted isotopic composition with –20.4 ± 0.5 ‰ for $\delta^{18}O$, –150.3 ± 3.0 ‰ for δD and 12.9 ± 0.9 ‰ for *d* (Table A.2). The co-isotope relationship of the wedge ice shows a distinctly lower slope of 6.21 with an intercept of –23.56 (R^2 = 0.99, n = 6, see Fig. 9).

Single samples of surface snow from the vicinity of the Cape Baranova Ice Camp station as well as from Cape Chelyuskin and Wiese Island were analyzed. The isotopic composition of these samples shows –16.1 and –15.1 ‰ for $\delta^{18}O$, –117.4 and –111.3 ‰ for δD and 11.2 and 9.6 ‰ for d at Cape Baranova, –18.9 ‰ for $\delta^{18}O$, –135.5 ‰ for δD and 16.0 ‰ for *d* at Cape Chelyuskin, and –11.8 ‰ for $\delta^{18}O$, –83.0 ‰ for δD and 10.9 ‰ for *d* on Wiese Island (Table A.3). Additional snow samples from a snow pit at Wiese Island represent winter precipitation affected by post-depositional processes and due to late summer sampling, likely also by summer precipitation. Mean values and standard deviations are –15.4 ± 1.7 ‰ for $\delta^{18}O$, –109.8 ± 13.8 ‰ for δD and 13.3 ± 1.1 ‰ for *d* (Table A.3). The co-isotope relationship for all the Wiese Island snow samples (slope of 7.92 and intercept of 12.01, R^2 = 0.99, n = 21; see Fig. 9) is closer to the GMWL than to the LMWL.

Discussion

Permafrost conditions, properties and processes

According to direct measurements the MAGT on Severnaya Zemlya and Wiese Island in the layer of annual heat circulation is in the range of –10 to –9 °C. It can be assumed that on Komsomolets Island, due to its high-latitude position, colder permafrost exists with temperatures reaching –12°C. Comparison of MAAT and MAGT trends (see Fig. 3 and Fig. 4) shows that the MAAT are only slightly below the MAGT. One of the main factors explaining the proximity of the values of MAGT and MAAT is the low influence of snow cover and vegetation on the temperature regime of permafrost. The low thickness and high density of snow leads to its low warming capacity. The vegetation is scarce and also does not shift the mean annual ground temperature from the mean annual air temperature.

On Severnaya Zemlya and Wiese Island, the recent increase in MAAT from 0.07 to 0.1 °C per year began in the mid-1970s. In borehole #1 on Wiese Island, a negative temperature gradient is observed below the bottom of the annual heat turnover layer, which indicates an ongoing temperature increase in the upper part of the frozen ground section under the influence of the warming climate.

The ALT remains in a typical range of 45–90 cm. The low thickness of the snow cover and its blowing-out, combined with low winter temperatures and humidity, create vast snowless areas with dry permafrost. The presence of dry permafrost over ice-saturated permafrost is due to free sublimation of ice under low temperature conditions. Similar dry permafrost overlying ice-cemented ground is known from the Dry Valleys of Antarctica [24].

The permafrost conditions of Severnaya Zemlya and Wiese Island are significantly harsher compared to those on Spitsbergen, where the MAGT are in the range of –5.2 to –1.1 °C and the characteristic ALT are 100–200 cm[7]. The Franz Josef Land

[7] Christiansen H., Gilbert G., Demidov N., Guglielmin M., Isaksen K., Osuch M., Boike J. Permafrost thermal snapshot and active-layer thickness in Svalbard 2016–2017 In: Orr E., Hansen G., Lappalainen H. (Eds). *SESS report 2018, The State of Environmental Science in Svalbard — An Annual Report*. Longyearbyen, Svalbard: Svalbard Integrated Arctic Earth Observing System; 2018. P. 26–47. Available at: https://www.sios-svalbard.org/sites/sios-svalbard.org/files/common/SESS_2018_FullReport.pdf (accessed: 01.01.2025).

Archipelago, where, according to RNS BPM data, the MAGT is about –9 °C and the ALT is about 80 cm [5], is closer in its permafrost conditions to Wiese Island and Severnaya Zemlya. At similar latitudes on the islands of the Canadian High Arctic, where no warming influence of the Atlantic Ocean occurs, ground temperatures are significantly lower, reaching about –16.5 °C, while the ALT is about 60 cm, similar to Severnaya Zemlya and Wiese Island [25]. Such a comparable ALT is attributed to the continental climate of the Canadian High Arctic. Despite lower MAAT, summer months are warmer here than on Severnaya Zemlya. In the North-East of Greenland, MAAT are slightly lower than on Severnaya Zemlya, but permafrost temperatures in the region are relatively high, i. e. –8 to –7 °C. Similar ground temperatures and ALT to those on Severnaya Zemlya and Wiese Island are observed in the coastal oases of Antarctica [26]. At the same time, in continental Antarctica, the permafrost conditions are much more severe than on Severnaya Zemlya, while on the Antarctic Peninsula, permafrost temperatures are higher.

On Severnaya Zemlya, the dominant types of cryogenic-geological processes are the cryogenic disintegration of rock deposits, the movement of the weathering products (cryoeluvium) downslope and their sorting to form structural soils. Cryoeluvium is often characterized by ice layers near the active-layer boundary. Ice-wedge polygons with 7–20 m side lengths are present in areas with relatively thick Quaternary sediment strata. They are mainly confined to marine terraces and less frequently to river terraces. The widths of the ice wedges studied are 45–75 cm. The host sediments are characterized by a significant amount of coarse-grained particles, and massive and schlieren cryostructures. The detection of ice-bearing sediments in the nearshore marine area indicates the possibility of freezing marine terraces by both epigenetic and syngenetic processes.

In contrast to Spitsbergen, where warm-based glaciers feed subglacial water whose unloading promotes pingo formation and icings [27; 28], related landforms are missing on Severnaya Zemlya, where the glaciers are cold-based. The dominant cryogenic geological processes and phenomena on Wiese Island, which is composed of epigenetically frozen Lower Cretaceous sands with a massive cryotexture are frost heave, shallow polygon cracking in the seasonally thawed active layer and epigenetic ice-wedge formation. The observed small ice-wedge widths suggest late Holocene formation ages although direct dating is lacking. Except for the northern part of the island, where sedimentation occurs, the island's coastline has retreated several hundred meters in the last 70 years due to thermo-abrasion. The rate of coastal retreat on the island will increase in proportion to the increase in the duration of the ice-free period due to climate warming.

Ice wedge isotopic composition

The mean ice wedge $\delta^{18}O$ values of both Wiese Island (–20.4 ‰) and Cape Baranova (–17.7 ‰) indicate a Holocene origin of the ice wedges studied. They fit very well into the regional pattern of Holocene ice wedges with decreasing $\delta^{18}O$ values from West to East [29; 30]. While Spitsbergen ice wedges with a less depleted $\delta^{18}O$ mean value of –13.9‰ reflect a more maritime winter climate, ice wedge $\delta^{18}O$ values from the Kara Sea coast and the Taymyr Peninsula scatter between –23.1 ‰ and –16.7 ‰, reflecting the colder and less maritime winter climate of the Kara Sea and adjacent land areas.

The differences between Wiese Island (more depleted δ values, higher mean *d* value of 12.9 ‰, lower slope of 6.21) and Cape Baranova, Bolshevik Island (less depleted δ values, lower mean *d* value of 6.6 ‰, higher slope of 7.45) ice wedges may have several causes. As it is unclear when exactly the ice wedges were formed, different climate conditions throughout the Holocene might have played a role. Differences in moisture sources and pathways, potentially related to regional sea-ice cover, might have contributed as well as the incorporation of non-precipitation water sources or snow-cover processes before infiltration of frost cracks and ice-vein formation.

Interestingly, the Baranova ice-wedge isotopic values from Bolshevik Island — representing cold-season precipitation — are more enriched (by about 2 ‰ in $\delta^{18}O$) than those of the AN ice core, which is a year-round archive (mean $\delta^{18}O$ of –20.1±2.0‰ for 1883–1998) [22]. Besides the abovementioned aspects, isotopic enrichment in the snowpack before ice-wedge formation due to e. g. sublimation and/or depth hoar formation [31] may have occurred. However, one has to consider that the ice core was drilled at an altitude of about 750 m and the isotopic composition of the precipitation forming the ice cap underwent (additional) depletion due to the altitude effect compared to the ice-wedge feeding snow at about sea level[8], reported $\delta^{18}O$-altitude gradients between –0.16 ‰ per 100 m on the windward slope and –1.5 ‰ per 100 m on the lee slope of the Vavilov ice cap. This would imply an additional depletion of at least –1.2 ‰ (maximum –11.25 ‰) for the Akademii Nauk ice core site. Using a value of about –0.6‰ per 100 m as reported for Greenland by Dansgaard et al. [32] would yield –4.5 ‰ additional depletion for the Akademii Nauk ice core site, which seems to be a more realistic value for Severnaya Zemlya, considering also the different locations of the Baranova and Akademii Nauk ice cap with respect to the prevailing wind and moisture transport patterns.

Conclusions

Severnaya Zemlya and Wiese Island are characterized by a continuous distribution of frozen strata, which is not interrupted below glaciers. The permafrost in the study region is cold, with typical ground temperatures at the depth of the zero annual amplitude of about –10 to –9 °C and a typical range of active layer thickness of 50–80 cm (in 2021–2024). Colder permafrost with temperatures up to –12 °C can be assumed on Komsomolets Island, due to its high-latitude position. Ground temperatures have been warming at a rate of 0.14 °C per year over, approximately, the last about 30 years, corresponding to mean annual air temperatures increasing at a rate of up to 0.1 °C per year (since the mid-1970s). Further observation of the changes in meteorological and permafrost conditions is conducted by newly-installed permafrost monitoring sites in the RNS BPM framework.

The ground ice content in permafrost deposits on the Severnaya Zemlya Archipelago and Wiese Island is generally low and most often characterized by massive cryostructures. Snowless areas with very dry uppermost (0.5 m deep) frozen deposits exist on Severnaya Zemlya. Noticeable amounts of ground ice are represented by ice layers near the active-layer boundary in cryoeluvium on Severnaya Zemlya, as well as by ice wedges forming polygons on both the Severnaya Zemlya Archipelago and Wiese Island. The isotopic composition of the wedge ice points to Holocene ice-wedge formation and fits into the regional pattern from Spitsbergen to the Taymyr Peninsula. Frost blisters are present in the river valleys and estuaries of Severnaya Zemlya, where seasonal taliks above cryopeg brines refreeze in the wintertime.

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Competing interests. The authors have no conflict of interest to declare.

Funding. Studies on the Severnaya Zemlya Archipelago were undertaken with support by the Russian Science Foundation (grant no. 19-77-10066) and field assistance from the High-Latitude Arctic Expedition (HLAE). Work on Wiese Island was part of the program of development of the Russian National System of Background Permafrost Monitoring (RNS BPM). This research used samples and/or data provided by the Arctic Century Expedition, a joint initiative led by the Swiss Polar Institute (SPI), the Antarctic and Arctic Research Institute (AARI) and GEOMAR Helmholtz Centre for Ocean Research Kiel (GEOMAR) and funded by the Swiss Polar Foundation.

Authors contribution. Conceptualization — ND, YU, SW; Methodology — ND; Data Curation — ND, AR, AG, AYG, AK, NS, SK, KT, TO; Formal Analysis — ND, AR, TO; Visualization — AR, AG, NS, SK, KT, TO, SW; Writing Original Draft — ND, YU, TO, HM, SW.

Конфликт интересов. У авторов исследований нет конфликтов интересов.

Финансирование. Исследования на Северной Земле выполнены за счет средств Российского научного фонда (грант 19-77-10066) и при логистической поддержке Высокоширотной арктической экспедиции (ВАЭ). Работы на о. Визе проводились в рамках создания системы Государственного фонового мониторинга состояния многолетней мерзлоты (ГСМ СММ). В работе использованы образцы и данные Экспедиции Арктический Век, финансировавшейся Шведским полярным фондом и являвшейся совместной инициативой Шведского полярного института (SPI), Арктического и антарктического научно-исследовательского института (ААНИИ) и Центра океанологических исследований Гельмгольца в г. Киль (GEOMAR).

Вклад авторов. Концепция — НД, ЮУ, СВ; Методы — НД, Данные — НД, АР, АГ, АЮГ, АК, НС, СК, КЧ, ТО; Анализ данных — НД, АР, ТО; Визуализация — АР, АГ, НС, СК, КЧ, ТО, СВ; Написание оригинального текста рукописи — НД, ЮУ, ТО, ХМ, СВ.

REFERENCES

1. *Taymyr-Severnaya Zemlya Region*. Sisko R.K.(Ed.). L.: Gidrometeoizdat; 1970. 374 p. (In Russ.).
2. Orlov A.V. Some results of permafrost studies on October Revolution Island. *Proceedings of the AARI*. 1981;367:126–131. (In Russ.).
3. Kostyaev A.G., Boyarskaya T.D., Gluhsanova N.I. New data on early Holocene marine deposits and ice wedges in the western part of October Revolution Island (Severnaya Zemlya Archipelago). *Doklady Akademii nauk SSSR = Proceedings of the USSR Academy of Sciences*. 1981;256:183–187. (In Russ.).
4. Korotkevich E. S. *Polar Deserts*. L.: Gidrometeoizdat; 1972. 420 p. (In Russ.).
5. Demidov N.E., Anisimov O.A., Anisimov M.A., Borisik A.L., Golavskii V.E., Gusakova M.A., Guzeva A.V., Makarov A.S., Morozov A.P., Solovyanova I.Yu., Stepanets A.A., Ugrumov Yu.V., Zaitseva D.K. Conception and first results of the Russian National System of Background Permafrost Monitoring. *Advances in Polar Science.* 2025;36(1):51–60. https://doi.org/ 10.12429/j.advps.2024.0036
6. Bolshiyanov D.Yu., Makeev V.M. *Severnaya Zemlya Archipelago: the glaciation, the history of the environment.* St. Petersburg: Gidrometeoizdat; 1995. 216 p. (In Russ.).
7. Rechnov A. A. Hydrometeorological regime of Bolshevik Island in the second decade of XXI century according to data of standard meteorological and actinometric observations. In: Makshtas A.P., Sokolov V.T. (Eds). *Environmental Research of the High Arctic at the research station «Cape Baranova Ice Base»*. Saint Petersburg: Arctic and Antarctic Research Institute; 2021. P. 10–19. (In Russ.).
8. Savatyugin L.M., Zagorodnov V.S. Glaciological research on Akademii Nauk ice cap. *Materialy Glyatsiologicheskikh Issledovaniy = Data of Glaciological Studies.* 1987;61:228. (In Russ.).
9. Govorukha L.S., Bolshiyanov D.Yu., Zarkhidze V.S., Pinchuk L.Ya., Yunak R.I. Changes of the glacial cover on Severnaya Zemlya in the 20th century. *Materialy Glyatsiologicheskikh Issledovaniy =Data of Glaciological Studies*. 1987;50:155–158. (In Russ.).

10. Wytiahlowsky H., Stokes C.R., Evans D.J.A. Remote sensing of glacier change (1965–2021) and identification of surge-type glaciers on Severnaya Zemlya, Russian High Arctic. *Journal of Glaciology*. 2023;69(278):1764–1784. https://doi.org/10.1017/jog.2023.60
11. Samoylovich Yu.G., Rozhdestvenskaya I.I., Fedorov I.P., Petrunin L.N. New data on stratigraphy of small islands of the Kara sea. *Lithology and paleogeography of Barents and Kara seas: Collection of Scientific Papers*. L.: NIIGA; 1981. P. 66–84. (In Russ.).
12. Demidov N.E. Experience of scientific small-scale drilling of permafrost in Arctic and Antarctic. *Nauchniy Vestnik Yamalo-Nenetskogo Avtonomnogo Okruga = Scientific Bulletin of the Yamal-Nenets Autonomous District*. 2023;121(4):6–20. (In Russ.).
13. Dansgaard W. Stable isotopes in precipitation. *Tellus*. 1964;16(4):436–468. https://doi.org/ 10.3402/tellusa.v16i4.8993
14. Yulin A.V. Sea-ice conditions in the period of thaw of ice cover. In: Ashik I. M. (Ed.) *Seas of the Russian Arctic under modern climate conditions*. St. Petersburg: Arctic and Antarctic Research Institute; 2021. P. 164–177. (In Russ.).
15. Kotlyakov V.M., Arkhipov S.M., Henderson K.A., Nagornov O. Deep drilling of glaciers in Eurasian Arctic as a source of paleoclimatic records. *Quaternary Science Reviews*. 2004;23(11–13): 1371–1390. https://doi.org/10.1016/j.quascirev.2003.12.013
16. Aparin B.F., Aparin V.B., Pfeiffer E.-M. Soils and soil cover of Bolshevik Island, Severnaya Zemlya Archipelago. *Vestnik Sankt-Peterburgskogo Gosudarstvennogo Universiteta = Herald of the Saint Petersburg University*. 2007;3(1):104–116. (In Russ.).
17. Simonov I.M., Yunak R.I. First results of periglacial geosystem studies on October Revolution Island. *Proceedings of the AARI*. 1981;367:151–170. (In Russ.).
18. Dibner V.D., Zagorskaya H.G. Conus-like hills of Arctic tundras. *Priroda = Nature*. 1958;4:90–93. (In Russ.).
19. Romanenko F.A., Baranskaya A.V., Lugovoy N.N., Alyautdinov A.R. Geological and geomorphological observations on Severnaya Zemlya (some preliminary results of the expedition «Open ocean: Arctic archipelagos-2019»). *Relief i chetvertichnie otlozheniya Arktiki, Subarktiki i Severo-Zapada Rossii = Relief and Quaternary deposits of Arctic, Subarctic and North-West of Russia*. 2020;7:168–174. (In Russ.). https://doi.org/10.24411/2687-1092-2020-10726
20. Fedorov G.B., Bolshiyanov D.Yu., Ezhikov I.S., Cherezova A.A., Raschke E.A., Pushina E.V., Ludikova A.V., Poleshuk K.V., Paramzin A.S., Kuksa K.A., Arslanov H.A. Research on Paleogeography in the north-western part of Bolshevik Island. In: Makshtas A.P., Sokolov V.T. (Eds). *Environmental Research of the High Arctic at the research station «Cape Baranova Ice Base»*. St. Petersburg: Arctic and Antarctic Research Institute; 2021. P. 217–239. (In Russ.).
21. Raab A., Melles M., Berger G.W., Hagedorn B., Hubberten H. Non-glacial paleoenvironments and the extent of Weichselian ice sheets on Severnaya Zemlya, Russian High Arctic. *Quaternary Science Reviews*. 2003;22:2267–2283. https://doi.org/10.1016/S0277-3791(03)00139-2
22. Opel T., Fritzsche D., Meyer H., Schütt R., Weiler K., Ruth U., Wilhelms F., Fischer H. 115 year ice-core data from Akademii Nauk ice cap, Severnaya Zemlya: High-resolution record of Eurasian Arctic climate change. *Journal of Glaciology.* 2009;55(189):21–31. https://doi.org/ 10.3189/002214309788609029
23. Craig H. Isotopic variations in meteoric waters. *Science*. 1961;133(3465):1702–1703. https:// dx.doi.org/10.1126/science.133.3465.1702
24. McKay C.P., Mellon M.T., Friedmann E.I. Soil temperature and stability of ice-cemented ground in McMurdo Dry Valleys, Antarctica. *Antarctic Science*. 1998;10(1):31–38. https://doi.org/ 10.1017/S0954102098000054
25. Pollard W., Ward M., Becker M. The Eureka Sound lowlands: an ice-rich permafrost landscape in transition. *GeoQuebec 2015 — The 68th Canadian Geotechnical Conf. and 7th Canadian Permafrost Conf. Proceedings. September 20–23, 2015, Quebec city*. 2015.

26. Vieira G., Bockheim J., Guglielmin M., Balks M., Abramov A.A., Gilichinsky D.A., Boelhouwers J., Cannone N., Ganzert L., Wagner D., Goryachkin S., López-Martínez J., Meiklejohn I., Raffi R., Ramos M., Schaefer C., Simas F., Serrano E., Sletten R. Thermal state of permafrost and active-layer monitoring in the Antarctic: Advances during the international polar year 2007–2009. *Permafrost and Periglacial Processes*. 2010;21:182–197. https://doi.org/ 10.1002/ppp.685
27. Demidov N., Wetterich S., Verkulich S., Ekaykin A., Meyer H., Anisimov M., Schirrmeister L., Demidov V., Hodson A. Geochemical signatures of pingo ice and its origin in Grøndalen, West Spitsbergen. *The Cryosphere.* 2019;13:3155–3169. https://doi.org/10.5194/tc-13-3155-2019
28. Demidov V., Demidov N., Verkulich S., Wetterich S. Distribution of pingos on Svalbard. *Geomorphology*. 2022;412:108326. https://doi.org/10.1016/j.geomorph.2022.108326
29. Streletskaya I.D., Vasiliev A.A., Oblogov G.E., Tokarev I.V. Reconstruction of paleoclimate of Russian Arctic in the Late Pleistocene–Holocene on the basis of isotope study of ice wedges. *Kriosfera Zemli*. 2015;XIX(2):86–94.
30. Porter T.J., Opel T. Recent advances in paleoclimatological studies of Arctic wedge- and pore-ice stable-water isotope records. *Permafrost and Periglacial Processes*. 2020;31:429–441. https://doi.org/10.1002/ppp.2052
31. Opel T., Meyer H., Wetterich S., Laepple T., Dereviagin A., Murton J. Ice wedges as archives of winter palaeoclimate: a review. *Permafrost and Periglacial Processes*. 2018;29:199–209. https://doi.org/10.1002/ppp.1980
32. Dansgaard W., Johnsen S., Clausen H., Gunderstup N. Stable isotope glaciology. *Meddelelser om Grønland*. 1973;197(2):1–53.

Расширенный реферат

Для архипелага Северная Земля и острова Визе характерно сплошное распространение мерзлоты, которое не прерывается под ледниками. В 2021–2024 гг. температура пород на глубине нулевых годовых амплитуд находилась в диапазоне –10…–9 °С, а характерный диапазон мощности сезонно-талого слоя — 50–80 см. Среднегодовая температура грунта оказывается не более чем на 3 °С выше среднегодовой температуры воздуха. Важным фактором, объясняющим близость этих показателей, является относительно низкое влияние снежного покрова и растительности на температурный режим грунтов. На острове Комсомолец, в силу его высокоширотного положения, можно предполагать более низкие температуры мерзлых пород, вплоть до –12 °С. Расчетная мощность криолитозоны в регионе составляет от 450 до 1200 м. В последние 30 лет температура грунтов повышается со скоростью около 0,14 °С в год, что связано с ростом среднегодовой температуры воздуха со скоростью до 0,1 °С в год (с середины 1970-х гг.). Дальнейший мониторинг изменений метеорологических и мерзлотных условий осуществляется на пунктах наблюдений системы Государственного фонового мониторинга состояния многолетней мерзлоты, что создает основу для сравнительного анализа с другими регионами Арктики. Льдистость мерзлых отложений архипелага Северная Земля и острова Визе в целом низкая, для них наиболее типичны массивные криогенные текстуры и в меньшей степени шлировые. На Северной Земле встречаются бесснежные участки, где верхние полметра грунта представлены морозной породой, лишенной льда. Проявления подземных льдов представлены линзами льда у границы сезонно-талого слоя в криоэлювии на Северной Земле, а также повторно-жильными льдами, формирующими полигональные структуры как на архипелаге Северная Земля, так и на

острове Визе. Изотопный состав жильного льда говорит в пользу его голоценового возраста. В речных долинах и эстуариях Северной Земли присутствуют наледные бугры (блистеры), образующиеся в результате зимнего промерзания сезонных подрусловых таликов с криопэгами.

Appendix A. Supplementary data

Table A.1

Maximum active-layer thickness according to measurements by permafrost meters in the vicinity of the Cape Baranova Ice Base and meteorological parameters measured on this station during 2017–2023

Таблица A.1

Максимальная толщина сезонно-талого слоя по данным измерений с помощью мерзлотометров в окрестностях «Ледовой базы Мыс Баранова» и метеорологические параметры, измеренные на этой станции в период 2017–2023 гг.

Permafrost meter no.	Location	2017	2018	2019	2020	2021	2022	2023
		ALT, cm date	ALT, cm date	ALT, cm date	ALT, cm date	ALT, cm date	ALT, cm date	ALT, cm date
Mean air T [°C]		–11.8	–11.6	–12.1	–8.9	–12.4	–11.9	–12.8
Mean soil surface T [°C]		–11.4	–11.1	–11,8	–8.6	–12.0	–11.4	–12.3
Sum of positive temperatures uring the warm period* [°C]		52.2	159.6	133.7	310.1	140.2	121.6	89.7
6	Accumulative-abrasion marine terrace	67 02.08	66 28.08	65 26.08	94 17.09	95 19.08	76 20.08	68 11.08
7	Accumulative-abrasion marine terrace	61 06.08	74 17.08	65 26.08	91 15.08	75 09.08	76 20.08	73 11.08
1	Second floodplain terrace of the right bank of the Mushketova River	51 27.07	59 26.08	59 26.08	75 24.09	73 13.08	61 23.08	61 10.08
2	First floodplain terrace of the right bank of the Mushketova River	57 15.08	69 26.08	70 20.08	78 19.09	92 20.08	71 12.08	71 10.08
4	First floodplain terrace of the left bank of the Mushketova River	47 11.08	63 31.08	65 26.08	91 21.09	88 20.08	78 23.08	74 23.08
5	Second floodplain terrace of the left bank of the Mushketova River	71 15.08	90 14.08	89 26.08	115 28.09	105 16.09	98 23.08	96 23.08

Note. * Warm period — a period characterized by a stable transition of the average daily air temperature above 0 °C

Примечание. * Теплый период — период, характеризующийся стабильным переходом среднесуточной температуры воздуха выше 0 °C.

Table A.2

Stable water isotopes (δ¹⁸O, δD) and deuterium excess values (*d*) of two profiles of the ice wedge BA-IW1 (Bolshevik Island) and one profile of the ice wedge Wiese-IW2 (Wiese Island)

Таблица А.2

Концентрации стабильных изотопов воды (δ¹⁸O, δD) и дейтериевого эксцесса (*d*) в образцах из двух профилей ледяной жилы BA-IW1 (о. Большевик) и одного профиля ледяной жилы Wiese-IW2 (о. Визе)

Sample No.	Sample ID	$\delta^{18}O$, ‰	δD, ‰	*d*, ‰
Ice wedge BA-IW1 profile 1, Bolshevik Island 79°12.211' N, 102°20.305' E				
01	BA-IW1-1-01	–18.11	–138.30	6.60
02	BA-IW1-1-02	–18.15	–138.14	7.03
03	BA-IW1-1-03	–18.35	–139.77	7.01
04	BA-IW1-1-04	–18.32	–139.49	7.07
05	BA-IW1-1-05	–18.15	–138.69	6.53
06	BA-IW1-1-06	–17.96	–137.31	6.35
07	BA-IW1-1-07	–17.83	–135.88	6.76
08	BA-IW1-1-08	–17.72	–135.07	6.72
09	BA-IW1-1-09	–17.64	–134.32	6.81
10	BA-IW1-2-01	–17.75	–135.08	6.89
11	BA-IW1-2-02	–17.76	–135.49	6.57
12	BA-IW1-2-03	–17.83	–136.70	5.92
13	BA-IW1-2-04	–17.99	–137.71	6.20
14	BA-IW1-2-05	–18.21	–139.44	6.26
15	BA-IW1-2-06	–18.31	–139.74	6.71
16	BA-IW1-2-07	–17.78	–135.70	6.57
17	BA-IW1-2-08	–18.13	–138.57	6.48
18	BA-IW1-2-09	–18.07	–137.68	6.89
Ice wedge BA-IW1 profile 2, Bolshevik Island 79°12.211' N, 102°20.305' E				
19	BA-IW1-3-01	–18.23	–138.08	7.72
20	BA-IW1-3-02	–18.67	–140.70	8.70
21	BA-IW1-5-01	–17.98	–137.47	6.39
22	BA-IW1-5-02	–17.99	–137.53	6.37
23	BA-IW1-5-03	–18.21	–138.76	6.95
24	BA-IW1-6-01	–17.81	–135.75	6.73
25	BA-IW1-6-02	–17.94	–136.84	6.70
26	BA-IW1-6-03	–17.84	–135.64	7.08
27	BA-IW1-7-01	–17.76	–136.06	5.99
28	BA-IW1-7-02	–17.84	–136.02	6.68
29	BA-IW1-8-01	–15.36	–117.81	5.03
30	BA-IW1-8-02	–15.37	–117.23	5.71
31	BA-IW1-4-01	–15.86	–121.23	5.63
32	BA-IW1-4-02	–15.97	–121.82	5.97
	n	32	32	32
	Mean	–17.72	–135.13	6.59
	Min	–18.67	–140.70	5.03
	Max	–15.36	–117.23	8.70
	Std	0.83	6.24	0.64

End of the table A.2

Окончание таблицы A.2

Sample No.	Sample ID	δ¹⁸O, ‰	δD, ‰	*d*, ‰
Ice wedge Wiese-IW2, Wiese Island 79°29.332' N, 77°0.83' E				
01	Wiese-IW2-01	–20.37	–150.27	12.65
02	Wiese-IW2-02	–20.12	–148.28	12.71
03	Wiese-IW2-03	–20.17	–148.79	12.58
04	Wiese-IW2-04	–20.78	–153.01	13.19
05	Wiese-IW2-05	–21.12	–154.62	14.36
06	Wiese-IW2-06	–19.80	–146.79	11.63
	n	6	6	6
	Mean	–20.39	–150.29	12.85
	Min	–21.12	–154.62	11.63
	Max	–19.80	–146.79	14.36
	Std	0.48	2.99	0.89

Table A.3

Stable water isotopes ($\delta^{18}O$, δD) and deuterium excess values (*d*) of present-day snow samples from multiple locations

Таблица A.3

Концентрации стабильных изотопов воды ($\delta^{18}O$, δD) и дейтериевого эксцесса (*d*) в отобранных образцах снега

Sample No.	Sample ID	δ¹⁸O, ‰	δD, ‰	*d*, ‰
Snow pit, Wiese Island 79°36.028' N, 76°40.681' E (August 14, 2021)				
01	WI-SP-1-01	–18.24	–134.67	11.22
02	WI-SP-1-02	–17.95	–131.13	12.46
03	WI-SP-1-03	–17.74	–129.06	12.87
04	WI-SP-1-04	–17.56	–127.48	13.04
05	WI-SP-1-05	–17.29	–125.30	13.04
06	WI-SP-1-06	–17.91	–127.68	15.62
07	WI-SP-1-07	–15.84	–112.67	14.03
08	WI-SP-1-08	–15.34	–108.53	14.22
09	WI-SP-1-09	–15.11	–106.47	14.41
10	WI-SP-1-10	–15.26	–106.89	15.17
11	WI-SP-1-11	–14.99	–105.65	14.27
12	WI-SP-1-12	–14.59	–103.25	13.45
13	WI-SP-1-13	–14.31	–101.48	13.03
14	WI-SP-1-14	–14.19	–100.64	12.86
15	WI-SP-1-15	–14.30	–101.77	12.67
16	WI-SP-1-16	–14.33	–101.72	12.94
17	WI-SP-1-17	–14.34	–101.38	13.38
18	WI-SP-1-18	–13.96	–98.66	13.01
19	WI-SP-1-19	–13.93	–97.92	13.49
20	WI-SP-1-20	–14.22	–100.19	13.58
	n	20	20	20
	Mean	–15.58	–111.13	13.44
	Min	–18.24	–134.67	11.22

End of the table A.3

Окончание таблицы А.3

Sample No.	Sample ID	$\delta^{18}O$, ‰	δD, ‰	*d*, ‰
	Max	–13.93	–97.92	15.62
	Std	1.57	12.74	0.98
Snow sample, Wiese Island 79°29.326' N, 77°03.197' E (September 26, 2023)				
01	WI-S-1	–11.75	–83.04	10.93
Snow samples, Bolshevik Island 79°17.155' N, 101°37.939' E (October 8, 2023) 79°16.729' N, 101°39.770' E (October 8, 2023)				
01	B-S-1	–15.11	–111.33	9.58
02	B-S-2	–16.07	–117.37	11.20
Snow sample, Cape Chelyuskin, Taymyr Peninsula 77°42.777' N, 104°17.960' E (October 12, 2023)				
01	MC-S-1	–18.94	–135.53	15.97