Rediscovering the Arctic

10 years of exploring the unique region

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Rediscovering the Arctic

10 years of exploring the unique region

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This publication is a review of scientific and applied research conducted by Rosneft in the Russian Arctic offshore since 2012. Written as a popular science encyclopedia, the book invites readers to learn about modern research methods and discoveries in geology, hydrometeorology and ecology of the Arctic region, to uncover the diversity of ice, rare animal species and millennia-old rocks, to learn about the latest biotechnology and the challenges and dangers of ice navigation. Readers familiar with the subject area will have an opportunity to evaluate the results of the work of fellow scientists and the prospects for further study of the Arctic. Information about scientific projects was provided by participants of Arctic expeditions, scientists of the leading research organizations of the country and the Arctic Research Center corporate institute.

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Content

Foreword

This book is about the Arctic, its science and people. It is about how the conquest of nature was replaced by exploration and acquired special features: a thirst for scientific knowledge, concern for ecology and the safety of people, a readiness to do everything not to disturb the fragile balance of nature.

→ p. 28

The research discussed in this book is focused on the five seas of the Russian Arctic: the Barents Sea, the Kara Sea, the Laptev Sea, the East Siberian Sea and the Chukchi Sea. More precisely, it is focused on their shelf, the part of the seabed bounded on one side by the shoreline and on the other by a fold in the seabed where the depth of the sea increases sharply.

Since obtaining scientific results and exploration of potential oil and gas-bearing areas require comprehensive research, the book covers several disciplines at once: geology, hydrometeorology and ecology. This means that we will talk about the structure of the Earth's crust, the Arctic climate, the properties of ice and its effect on navigation, the rare Arctic animal species and the restoration of natural resources. And of course, about the scientists whose ships are charting the way towards new knowledge.

The research was conducted by Rosneft in cooperation with leading Russian scientific institutions specializing in Arctic research, including the Arctic Research Center, a corporate institute established to support all potential activities of the company within the Arctic region.

This book is the culmination of 10 years of research. It is based on up-to-date results that have been published in scientific journals, patented and awarded prizes. The goal the authors set was to summarize the results of research into a form accessible to the widest possible range of readers. Therefore, at times we have tended to simplify some of the terms and adhere to a somewhat looser rendition of scientific principles. We are grateful to expert scientists for accommodating this approach and helping us to keep the book accurate.

We also hope that the simplification will not only help readers better understand the material, but will also allow the scientists themselves to look at the incredible results that have been achieved.

How to read this book

Any author, or, in our case, a group of authors, wants the reader to read the book from beginning to end. And then come back again and again to reread the best parts.

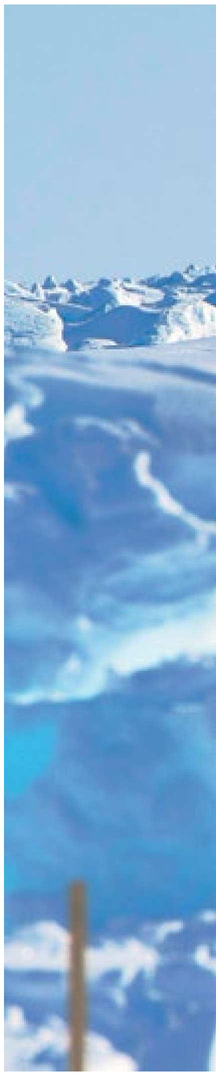
But that's not necessary at all, because you are holding an encyclopedia, an atlas and a journal, and these types of books are rarely read from cover to cover. You are free to choose your own way of reading; we will only tell you how the book is structured.

There are thirteen chapters in this book. The eleven main ones are devoted to scientific projects, and each of them is a self-contained story about the challenge the scientists faced and the ways in which they were able to solve it.

The first two chapters are introductory, but no less valuable. From them, you will learn about the incredible features of the area of the Earth that has been studied by Rosneft over the last 10 years, and before that, for seven centuries by researchers from around the world. You will see what kind of research was conducted and in what order, and how expeditions are generally organized.

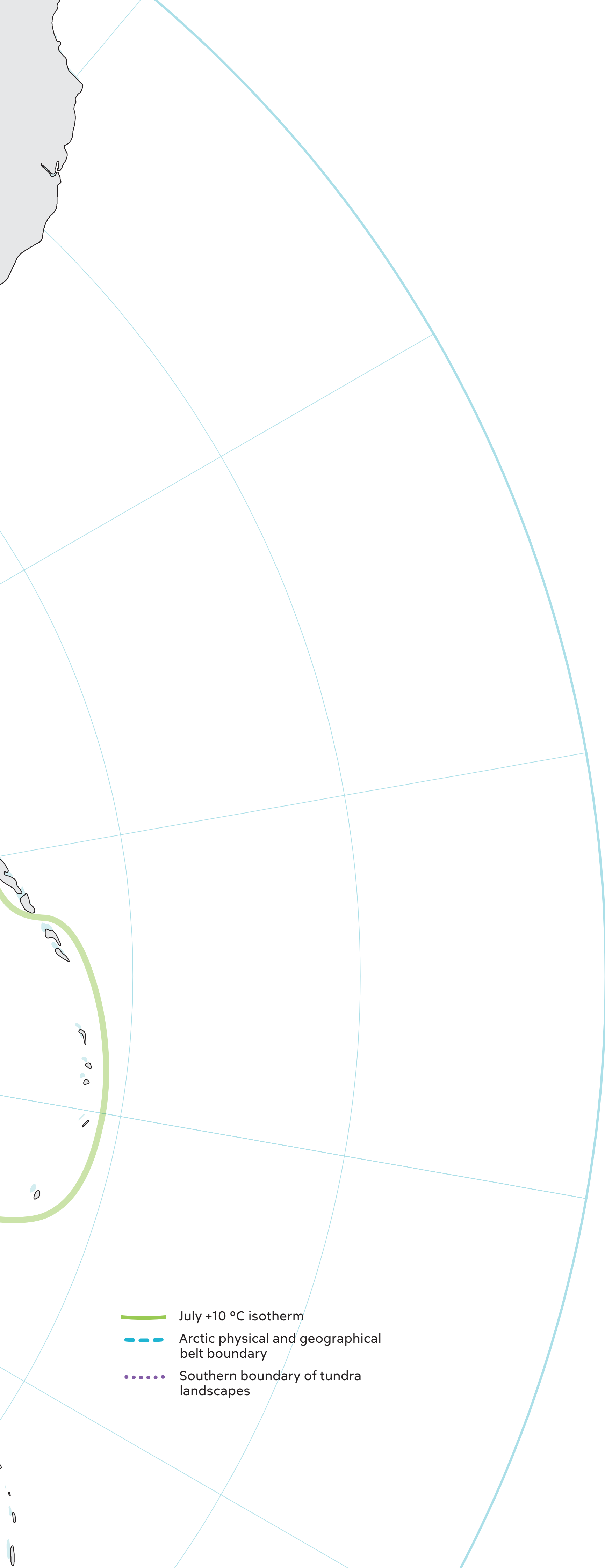
We encourage you to read about what interests you personally. Look through → p. 54 the chronology of research in the introductory chapter and move on to the topic that struck you as the most fascinating. Study the cycle of scientific → p. 37 inquiry and follow its stages in each of the main chapters. As you read any chapter, pay attention to the page number marker and see where it takes you.

Or — there is always that option! — simply read the book from beginning to end.



The Arctic: the Basics


Arctic Circle



What is the Arctic?

The Arctic region is the Earth's northern polar region. It is adjacent to the North Pole and has only a southern boundary, the Arctic Circle. In Russia, the Arctic is often referred to as the Polar Region or the Far North. The Arctic consists of land (mostly tundra) and sea, which is covered by ice for much of the year. Arctic sea ice is a huge reservoir of the purest drinking water. The total area of sea ice is up to 4.72 million km².

→ p. 15

The Arctic is a region with a unique seasonality: for one half of the year it is in winter with the polar night, for the other it is in summer with the polar day. The summer is cold, but the polar day gives enough light for vegetation to grow.

The territory of the Arctic includes parts of the continents of Eurasia and North America, almost all Arctic Ocean with archipelagos and islands (except coastal islands of Norway), as well as adjoining parts of Atlantic and Pacific Oceans.

Water bodies of the Arctic:
- the Arctic Ocean with peripheral seas: the Greenland Sea, Barents Sea, Kara Sea, Laptev Sea, East Siberian Sea, Chukchi Sea, Beaufort Sea, Lincoln Sea, Norwegian Sea;
- inner seas of the Arctic Ocean: the White Sea, Baffin Bay, numerous straights of the Canadian Arctic Archipelago, the northern parts of the Atlantic and Pacific Oceans.

Land areas of the Arctic:
- the Canadian Arctic Archipelago;
- the Svalbard archipelago, Franz Josef Land, Novaya Zemlya, Severnaya Zemlya;
- the New Siberian Islands;
- Wrangel Island;
- northern coasts of Eurasia and North America.

Eight countries — Russia, Norway, Denmark, Sweden, Finland, Iceland, Canada and the United States — have territories within the Arctic borders, but only six of them (Russia, Norway, Denmark, Iceland, Canada and the United States) have territories directly adjacent to the Arctic Ocean.

What is the difference between the Arctic and the Antarctic?

The Arctic is the opposite to the Antarctic geographically, geologically and in terms of human exploration.

→ p. 165

The Arctic is Earth’s northern polar region, an ice-covered ocean surrounded by land. Antarctica is the southern polar region, the ice-covered continent of the Antarctic, surrounded by the Pacific, Atlantic and Indian Oceans. The Arctic is home to polar bears and the Antarctic is home to penguins. About four million people live permanently in the Arctic, while only polar station staff, about 4,000 people in the summer and 1,000 people in the winter, inhabit the Antarctic.

Arctic territories and waters are divided between the Arctic states. Antarctica is used for the benefit of all mankind under the Antarctic Treaty of December 1, 1959. The Treaty provides for freedom of scientific research and encourages international cooperation, prohibits any military activities, nuclear explosions and burial of radioactive materials.

→ p. 16

→ p. 20

What these regions have in common are the polar day and polar night, as well as extremely low temperatures. The similarity in the names of the regions is due to the fact that they both are based on the ancient Greek word *arctos* (ἄρκτος), meaning “bear”, “belonging to the constellation of the Big Dipper”, “northern”.

Arctic boundaries

The area of the Arctic is 27 million km². Almost half of that area, 12 million km², is occupied by the Arctic Ocean. The land border of the Arctic coincides with the southern border of the tundra, but sometimes the Arctic Circle is considered to be the southern border instead, in which case the area of the Arctic is 21 million km². The area of the Russian Arctic is 9.3 million km², of which 6.8 million km² is the sea.

66°33′44″ N

The Arctic Circle is the latitude at which the sun doesn't set during the summer solstice and doesn't rise during the winter solstice.

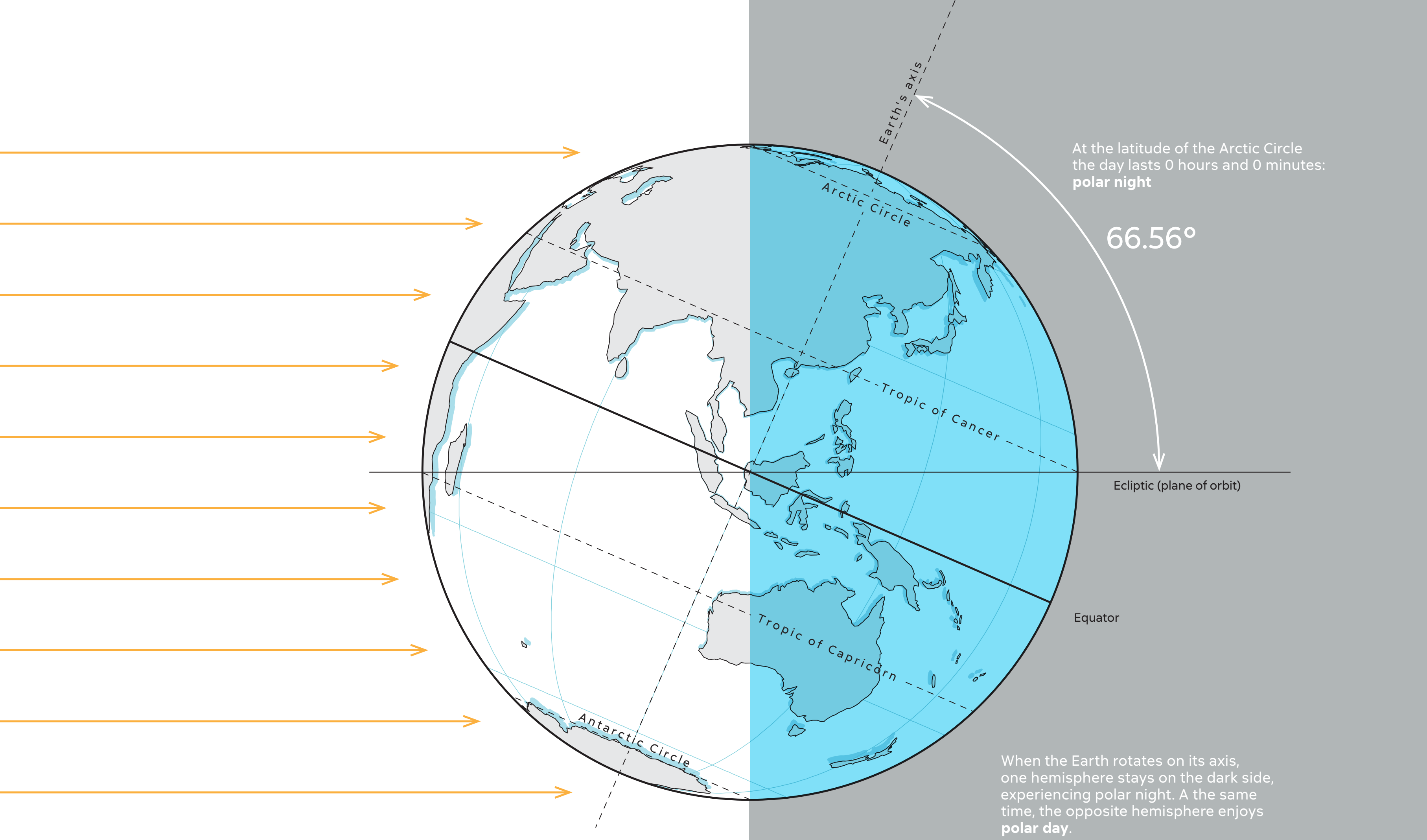
There are several approaches to defining the borders of the Arctic.

→ p. 12

From the climate viewpoint, the southern boundary of the Arctic can be identified by the location of the July +10 °C isotherm that passes to the north of the Arctic Circle and is offset to the south of this geographical boundary only in the area of the White Sea, the Polar Urals, the Kharaulakh Range and on the eastern coast of Russia.

In geobotanical terms, the southern land border of the Arctic coincides with the northern border of the spread of woody vegetation or with the southern border of the tundra, which agrees well with the location of the July +10...+12 °C isotherm.

Taking into account the overall climatic and landscape characteristics, the natural southern boundary of the region is accepted as the conventional line for which the value of annual radiation balance is equal to 62.8 kJ/cm² and average July temperature is +10 °C. Its location is adjusted to reflect the southern boundary of the tundra and the relief. According to this approach, the Russian Arctic includes a part of the Arctic Ocean with its seas and islands, the edge of Eurasia covered by tundra, glacial and desert Arctic landscapes.



Polar day and polar night

The Earth as a space body orbits the Sun every year. This orbital motion causes the seasons to change: spring, summer, autumn and winter. The Earth also revolves around its axis during the day, causing the change of day and night to occur.

The Earth is also tilted: the planet's axis forms an angle of 66.56° with the orbital plane. During another revolution around the Sun, when either the Northern or the Southern hemisphere gets closer to the Sun, two areas can be seen on the Earth, one of which receives constant sunlight, while the other remains in shadow. These two areas are the North and South Poles.

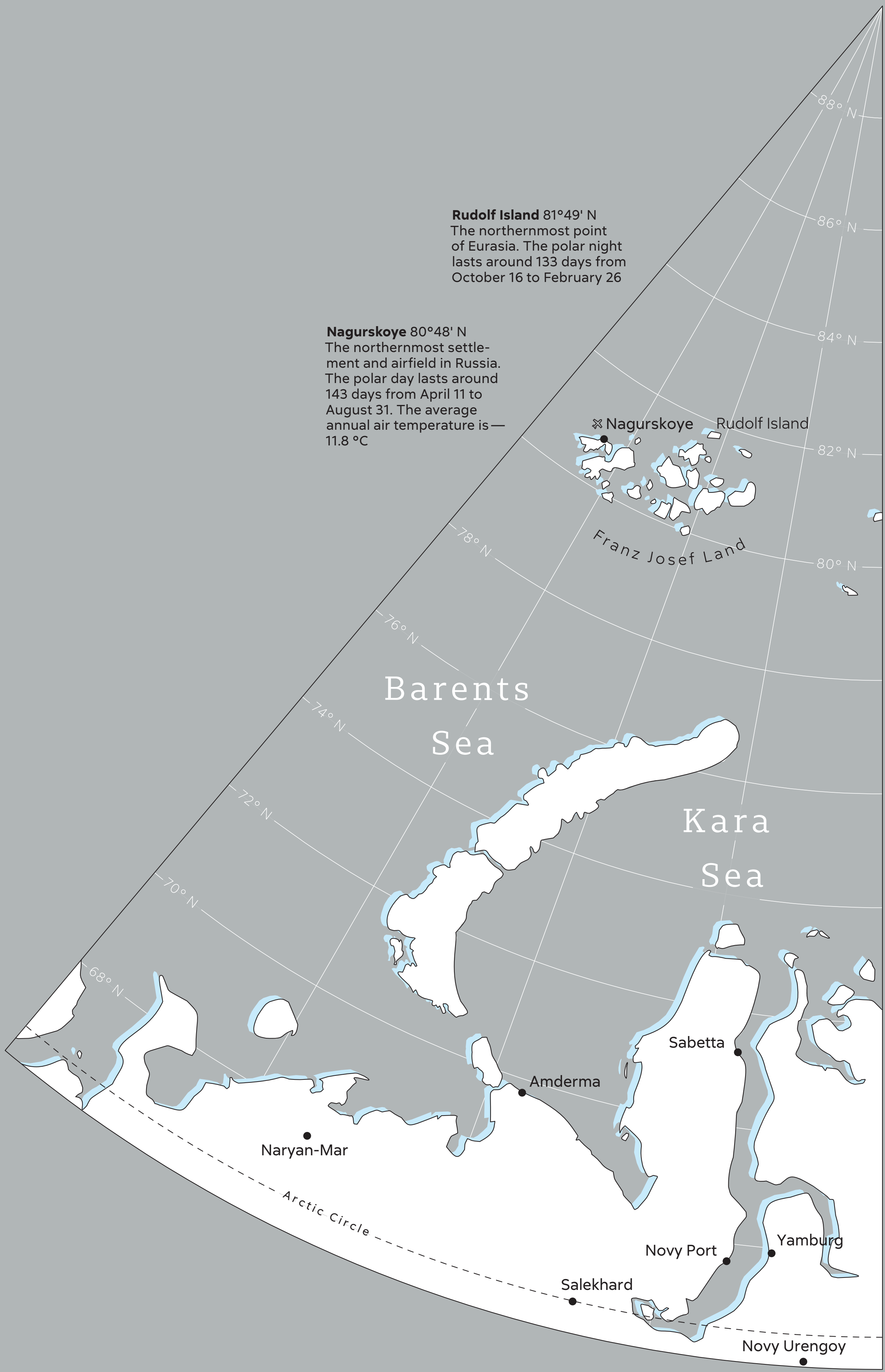
During the polar day, the Sun does not go below the horizon for more than a day, and during the polar night it does not rise over the horizon for more than a day.

The length of polar day and night depends on the latitude. The shortest polar day is observed at the latitude of the Polar Circle. The longest polar day is observed at the poles, lasting more than six months. At the North Pole it continues for about 190 days from March 19 to September 25, and at the South Pole it lasts for 184 days from September 21 to March 23.

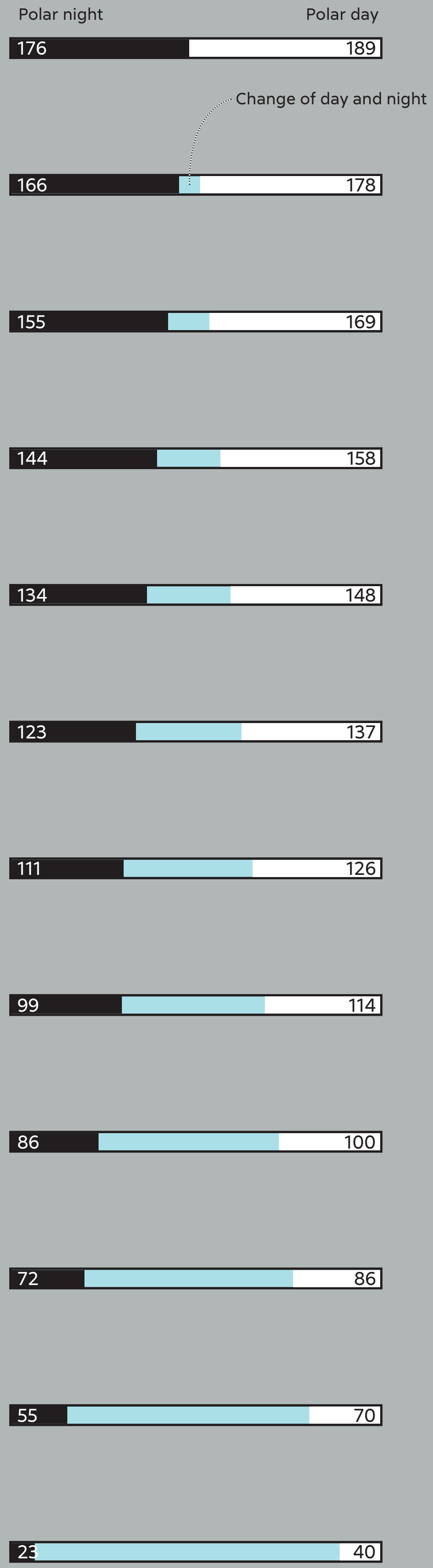
The shortest polar night (two days) is observed at the latitude of the Arctic Circle. The longest polar night is observed at the South Pole, lasting just under six months.

In the Arctic, the polar day comes in the summer. This is favorable for scientific expeditions, as natural illumination allows to continue working on the ship almost around the clock, rotating teams of the expedition's scientific staff. → p. 48

However, it is worth remembering that a long stay in the conditions of a long day or, on the opposite, a polar night, affects the body of an unadapted person due to the imbalance of melatonin or serotonin respectively.



Duration of polar night and polar day at different Arctic latitudes



Northern lights

Also known as the aurora borealis, the northern lights are the glow of the upper layers of the Earth's atmosphere as it interacts with charged particles of the solar wind. It is caused by explosions on the surface of the Sun when solar particles reach the Earth. The Earth's magnetic field directs these particles toward the poles where they cause extensive magnetic storms. Most charged solar wind particles are reflected, but some manage to penetrate the Earth's magnetic field. These particles form a glow by colliding with air molecules in the upper atmosphere (about 100 km above the surface of the Earth). Yellow, green and red colors are caused by oxygen, while blue and purple lights are caused by nitrogen.

→ p. 195 The photo of the northern lights was taken at the White Sea Biological Station, Moscow State University.

Arctic climate

The Arctic climate is harsh but varied. The mildest conditions are found in the western part of the Atlantic sector of the Arctic, in particular over the waters of the Barents Sea. Here, temperature during the coldest month of the winter, February, averages –4...–6 °C. But, despite the relatively warm temperature conditions, this region is characterized by an extremely high frequency of storm cyclones, which means strong winds, sea disturbance and extreme precipitations. The most severe conditions form on the Arctic coast of the Eastern Arctic seas in the winter months as a result of the combination of low temperatures (–30...–35 °C) and frequent storm winds and snowstorms. Climatic conditions of most of the Arctic territories in the winter are identified as severe, and on the Arctic coast of the seas of the Eastern Arctic as extremely severe.

In the summer months the lowest temperatures are registered over the Greenland ice sheet (on average –10...–15 °C) while the highest temperatures are found near the southern border of tundra in Eurasia and North America (on average +10...+15 °C). Above the sea ice masses air temperature fluctuates around 0 °C during the summer.

The Arctic ice cover is formed by sea ice and icebergs. Depending → p. 166
on the season, the ice cover occupies from 45–50 % (September—October) to 75–80 % of the area of the Arctic Ocean. In the winter, only the western and central parts of the Barents Sea are free of ice. From October to November shores of continents, archipelagos and islands are covered with landfast ice. When landfast ice is created as a result of dynamic impacts of drifting ice from the open sea, ridges of hummocks are formed, and if they land on the seabed, they become stamukhas.

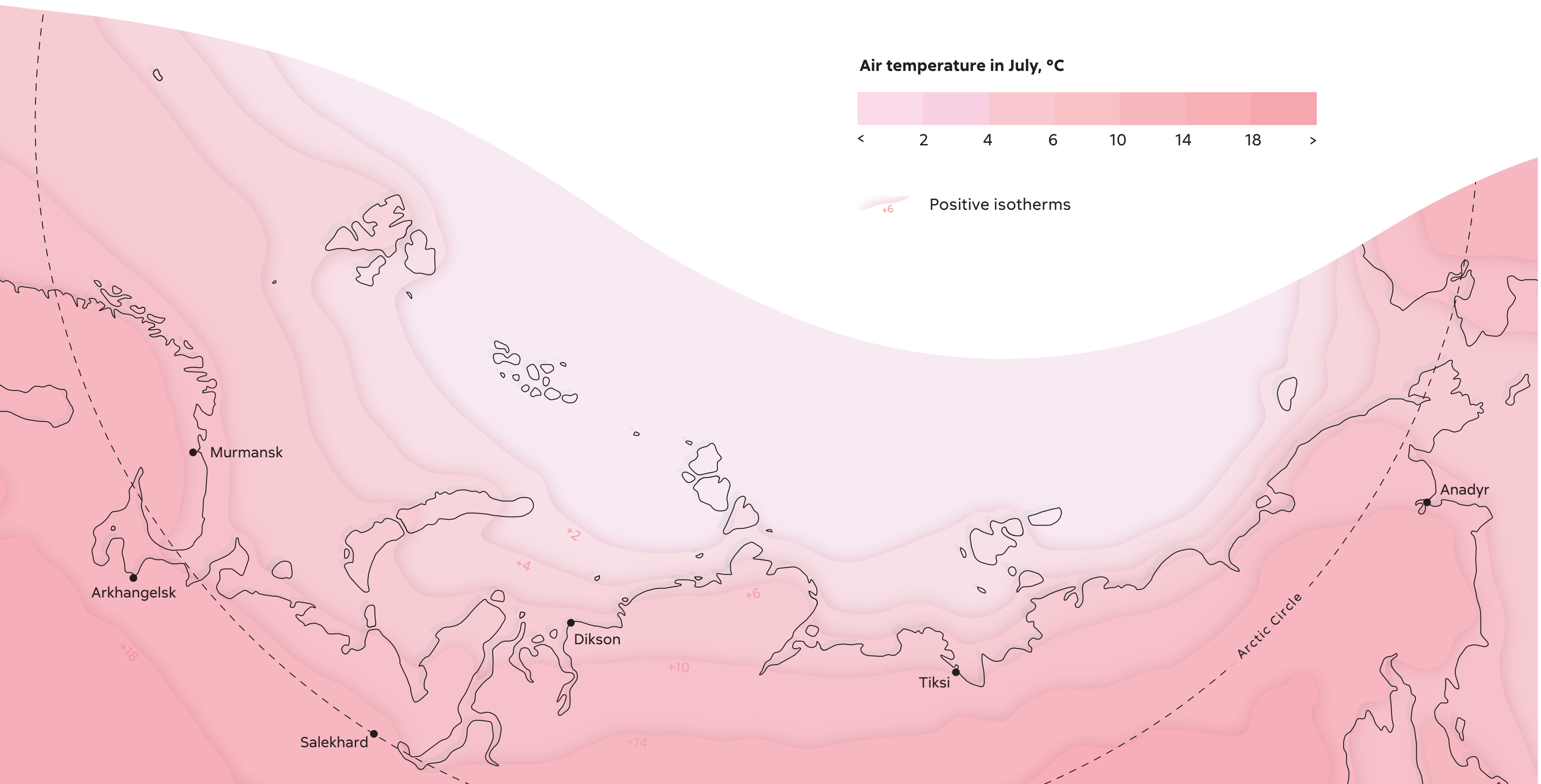
Climate (hydrometeorological and ice) conditions of the Arctic can't be ignored:

— short navigation period, high probability of storms and strong sea waves require careful planning of every activity during an expedition to ensure all of the planned
→ p. 40 research can be completed on time;

— complex ice conditions and insufficient information about them make it necessary to collect as much field data as possible
→ p. 176 and develop methods to ensure ice safety for objects at sea and in the coastal zone;

— lack of a priori data requires hydrometeorologists to collect hydrometeorological information during special expeditionary
→ p. 144 surveys and using observation networks, carrying out complex mathematical calcu-
→ p. 149 lations and modelling of atmospheric and oceanic processes which is a prerequisite for planning of any activities in the Arctic.

Landfast ice is low-mobile sea ice partially frozen to the shore and the seabed in shallow waters.



Sea shores

The land-sea boundary is an extremely dynamic and diverse environment. In the Arctic seas, coastal zone dynamics are characterized by the cumulative effect of the following factors:

→ p. 218

— the geological and geomorphological structure of the coast and the underwater coastal slope;
— the influence of currents;
— the cryolithological condition of the rocks that make up the coast and the coastal seabed;
— the ice phenomena and coast-marine sediment dynamics.

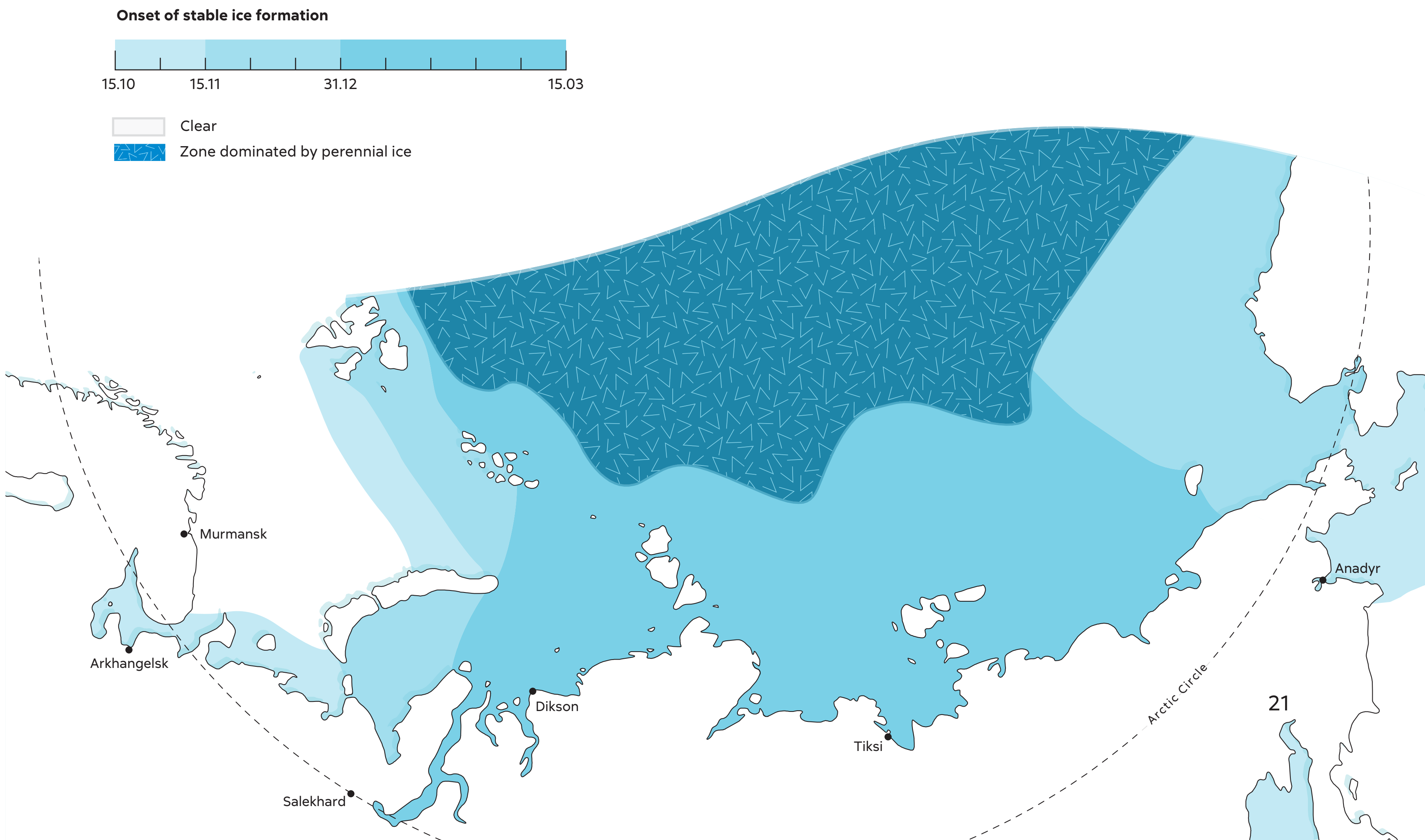
→ p. 224

Among the Arctic coasts there are shores that have been only slightly altered by the sea (fjord and skerry shores), they are typical for the White and Barents Seas. The shores of the Kara Sea are not homogeneous and range from leveled, bay or slightly altered shores to vast deltas formed by large rivers. In the area of the Laptev, East Siberian and Chukchi Seas, shores in some areas are deltaic, sometimes lagoonal, with other types of abrasion and accumulative coasts also being common.

Cryolithology is the study of geological processes and their lithological and geomorphological effect in connection with freezing and thawing of rocks, that is, with ice formation or disappearance of ice in the Earth's crust.

A coast is a zone of interaction of all spheres of nature and, as a consequence, a zone of increased landscape and biological diversity. The coast is also important in economic terms, which makes it necessary to avoid risks associated with economic use of the coastal zone. In order to minimize the risks, it is necessary to know what particular areas of the Arctic seashore require special attention and protection. For this purpose, a methodology of mapping and assessment of environmental sensitivity of the coasts was developed and applied. It is also necessary to develop specific methods of protection of coasts from possible negative influence of anthropogenic factors. To this end, a microbial preparation was developed for cleaning northern water areas from oil pollution, specifically effective in the Arctic conditions.

→ p. 217
→ p. 189



Plant life

Arctic vegetation is of great importance to Earth's biodiversity: the Arctic and Sub-Arctic ecosystems contain over 2,000 species of vascular plants, many of which cannot be found elsewhere.

Plant communities are represented by two types: polar-desert and tundra plants. Dwarf shrubs, grasses, herbs, lichens and mosses all grow in the Arctic. Low summer temperatures result in small plant sizes. There are no trees in the region, but warm areas can serve as home to shrubs of up to two meters in height.

The archipelagos and islands of the Arctic Ocean (Franz Josef Land, Novaya Zemlya, Severnaya Zemlya and the New Siberian Islands) constitute a zone of Arctic desert. There is almost no vegetation, mainly mosses and lichens, seldom grasses that are resistant to low temperatures, such as the polar poppy.

Most part of Greenland, central parts of the Canadian Arctic Archipelago islands, Svalbard and the northern part of Novaya Zemlya are covered by glaciers and are deprived of soil and vegetation.

The majority of the Arctic is occupied by the tundra vegetation zone, stretching along the coast of the Arctic Ocean in Eurasia and North America. Tundras also occupy a significant part of Svalbard and other archipelagos, ice-free coastal areas of Greenland, the northern part of Iceland. The tundra type lacks the tree layer, while low shrubs and bushes play a significant role, and lichens, mosses and perennial grasses are widespread.

Animal life

The Arctic is inhabited by over 20,000 species of animals, plants, microorganisms and fungi, including 450 species of fish, 280 species of birds, 130 species of mammals, four species of reptiles and three species of amphibians. There are about 3,000 species of insects in the Polar region.

The predominance of ichthyofauna among other vertebrate animals can be explained by the fact that one third of the Arctic is covered by water. Due to severe climatic conditions, the fauna of the Arctic seas is relatively poor, but at the same time the number of populations of some species is high, and they can be widely spread. At present, about 5,000 species of marine invertebrates are known, of these, more than 4,000 are seabed dwellers, or *macrobenthos*.

Macrobenthos. This is the name given to invertebrate animals that can crawl on the surface of the seabed, burrow into the ground, cling to rocks and stones, that is, all whose life is connected to the water-bottom interface.

Bottom macrobenthos communities are excellent biological indicators of the sustainability of the ecosystems of which they are a part: they lead sedentary lifestyles and show a cumulative picture of the changes occurring around them. Traditional methods of studying such bottom communities are very time-consuming, which is unacceptable for the short expeditionary season in the Arctic, and do not give an idea of the state and dynamics of the entire community. The company is developing and applying new methods of bottom community mapping that increase the accuracy and speed of such studies. → p. 202

The inhabitants of the water column, or plankton, are less diverse, amounting to less than 400 species. Among the seabed dwellers, the most diverse are arthropods, ringed worms and mollusks. Nevertheless, the biodiversity of high latitudes and seas of the Eastern Arctic is understudied: every year expeditions bring information about new findings. Surprisingly, the least studied is life in the shallowest zone, from the water's edge to the depth of 10–12 meters. Large vessels cannot operate in such depths, and work from the shore or from motorboats is difficult to organize. As a result, the population of the coastal zone of the Kara, Laptev, East Siberian and Chukchi Seas is only known from a very small number of locations where such research was possible.

The Arctic is home to a number of endemic (specific, inhabiting a limited area) animals: musk oxen, wild reindeer, snow sheep, polar bears, Arctic ground squirrels, lemmings, wolverines, ermines and long-tailed ground squirrels. Many species of birds and sea creatures are also endemic. Seals, walruses, cetaceans (baleen whales, narwhals, orcas and beluga whales) inhabit the Arctic seas. During the polar summer, millions of migratory birds nest in the tundra zone of the Arctic. → p. 100 → p. 118

→ p. 98 As part of the Ecology National Project, Rosneft implements projects to study, monitor and protect Arctic animals that are indicators of the state of the region's ecosystems (wild reindeer, polar bears, Atlantic walruses and ivory gulls).

A young polar fox in summer coat. This species is the only member of the canine family which changes its color depending on the season (exhibits seasonal dimorphism)

Arctic zone of Russia

The Arctic zone of the Russian Federation (AZRF) includes the northern coast of the European and Asian parts of the country along the seas of the Arctic Ocean: Barents, Kara, Laptev, East Siberian and Chukchi. This is the longest maritime border of Russia and the area of transport and economic influence of the Northern Sea Route.

The population of the Russian Arctic is 2.5 million people. Most settlements in the AZRF are located on the coast of the Arctic seas or in close proximity to them, as well as in the lower reaches of rivers flowing into the Arctic Ocean. The overwhelming part of the population, up to 89 %, is urban. The Arctic zone is home to Murmansk, the largest city in the world located above the Arctic circle. Its population is almost 300,000 people. The Arctic zone of the Russian Federation includes regions with a high share of rural population, these are places of compact habitation of indigenous people of the Far North. The population of the Arctic zone is relatively young, as it includes mainly people of working age.

According to Presidential Decree No. 296 of May 2, 2014 "On Land Areas of the Arctic Zone of the Russian Federation" with amendments and additions, administrative formations of nine regions were added to the Arctic Zone. In accordance with Federal Law No. 193-FZ "On State Support of Entrepreneurial Activity in the Arctic Zone of the Russian Federation" the free economic zone of the AZRF covers the following territories:

— Murmansk Oblast;

— Nenets Autonomous Okrug;

— Chukotka Autonomous Okrug;

— Yamalo-Nenets Autonomous Okrug;

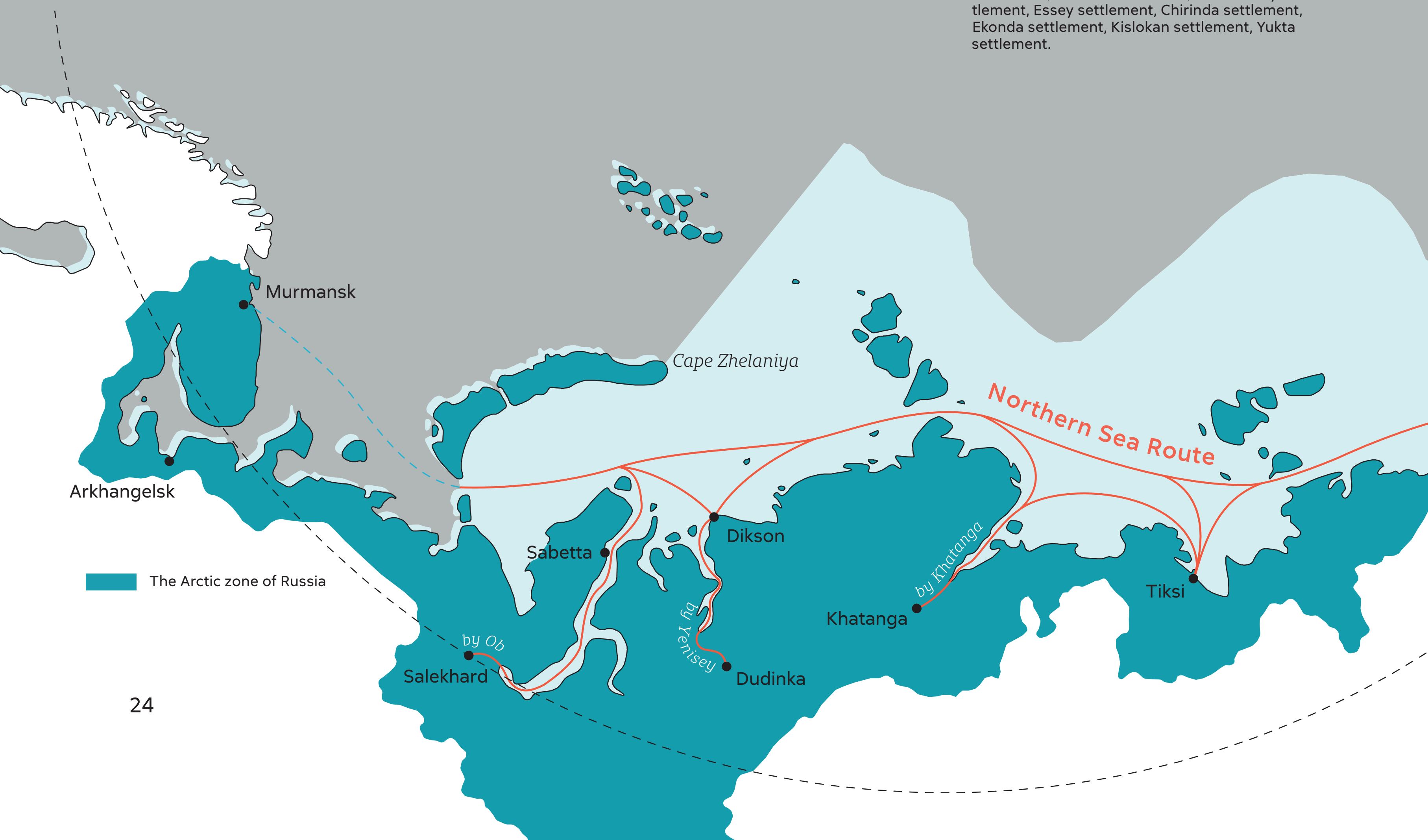
— Komi Republic: urban districts of Vorkuta, Inta, Usinsk and the Ust-Tsilemsky district;

— Republic of Karelia: Belomorsky, Kalevalsky, Kemsky, Kostomukshsky, Loukhsky, Segezhsky districts;

— Republic of Sakha (Yakutia): Abyysky ulus, Allaikhovsky ulus, Anabarsky ulus, Bulunsky ulus, Verkhnekolymsky ulus, Verkhoyansky district, Zhigansky district, Momsky district, Nizhnekolymsky district, Olenyoksky district, Srednekolymsky ulus, Ust-Yansky ulus, Eveno-Bytantaysky national ulus;

— Arkhangelsk Oblast: the cities of Arkhangelsk, Novodvinsk, Severodvinsk; Mezensky, Primorsky, Onezhsky, Leshukonsky, Pinezhsky districts; Novaya Zemlya urban district;

— Krasnoyarsk Krai: Norilsk, Taymyrsky Dolgano-Nenetsky and Turukhansky districts, rural settlements of the Evenki Municipal District: Surinda settlement, Tura settlement, Nidym settlement, Uchami settlement, Tutonchany settlement, Essey settlement, Chirinda settlement, Ekonda settlement, Kislokan settlement, Yukta settlement.



The Northern Sea Route

The Northern Sea Route (NSR) is the shortest route between Europe and the Asia-Pacific region.

The NSR water area is defined as the water space adjacent to the northern coast of the Russian Federation, covering inland sea waters, the territorial sea, the contiguous zone and the exclusive economic zone of the Russian Federation. From the east it is bounded by the 168°58’37” W meridian and the latitude of Cape Dezhnev in the Bering Strait, from the west by the meridian of Cape Zhelaniya of the Novaya Zemlya archipelago, the eastern coastline of the Novaya Zemlya archipelago and the western boundaries of the straits of Matochkin Shar, Kara Gates and Yugorsky Shar.

Although the navigational and administrative services are located in Murmansk, the start of the Northern Sea Route is considered to be at the entrance to the straits of the Kara Sea and the meridian north of Cape Zhelaniya.

The Northern Sea Route serves ports of the Arctic seas and major Siberian rivers with fuel, equipment, timber and minerals transported on the route. The NSR is also used to deliver vital goods to people living in the Far North. The Route runs through the seas of the Arctic Ocean (Kara, Laptev, East Siberian and Chukchi Seas). The length of the route from the Kara Strait to Providence Bay is 5,600 km.

An alternative to the NSR are transport arteries passing through the Suez or Panama canals. The distance from the port of Murmansk (Russia) to the port of Yokohama (Japan) via the Suez Canal is 23,779 km while via the Northern Sea Route it is only 10,686 km. The shorter length of the NSR makes it possible to reduce not only travel time, but also fuel costs, contributing to minimizing the environmental impact of shipping.

The Northern Sea Route

Main ports: Sabetta, Dudinka, Dikson, Khatanga, Tiksi, Pevek

7–15 days
Time to cross

5–13 knots
Travel speed

2–4 months
Navigational period on open water

5,770 nautical miles
Length of route from Murmansk to Yokohama

A Nautical mile is a unit of distance used in sea and air navigation. One nautical mile is equal to 1,852 meters.

34,85 million tons
Cargo traffic volume in 2021

Resources

Despite its severe climate and harsh conditions, the Arctic has long attracted people because of its richness in diverse resources. As easily accessible deposits are exhausted, the interest and need for them increase. That's why the Arctic is now called the storehouse of mankind.

What is the Arctic rich in? First of all, it's energy resources: its depths contain approximately 90 billion barrels of oil, 47.3 trillion m³ of gas and 44 billion barrels of gas condensate, amounting to about 25 % of world's undiscovered hydrocarbon resources. The presence of large deposits makes the region a promising source of oil and gas, whose role in the near future will only increase. Solid mineral resources also deserve special attention. Rare and rare-earth metals, minerals, ores and other raw materials are abundant both on land and on the Arctic Ocean shelf.

In order to better assess the oil and gas potential of the Arctic region, it is necessary to study the regularities of geological structure of sedimentary basins using a variety of methods, as well as to determine priority areas for exploration, all while ensuring the safety of operations.

→ p. 64
→ p. 127

Biological resources are also plentiful: the Arctic seas, mainly the Barents and the Chukchi, are home to many unique animal and fish species (over 150 species of fish, including cod, herring, haddock and flounder which are of primary importance for fisheries).

Such richness makes this harsh region very important for human development and attractive for exploration. It should, however, be treated very carefully, taking into account the existing natural, anthropogenic and environmental risks.

The importance of studying the Arctic

The special features of the Arctic zone are determined by its extreme natural conditions, availability of diverse and significant reserves of mineral and biological resources, small population, remoteness and transport inaccessibility.

At the same time, the Arctic zone plays an important role in preservation of ecological equilibrium. The region regulates the temperature regime
→ p. 178
of the atmosphere thanks to its ice cap which reflects the sun's rays. There are unique natural complexes in the Arctic which are extremely vulnerable to anthropogenic influence. Their degradation may lead to unpredictable consequences on a global scale and negatively affect ecosystems of other latitudes.

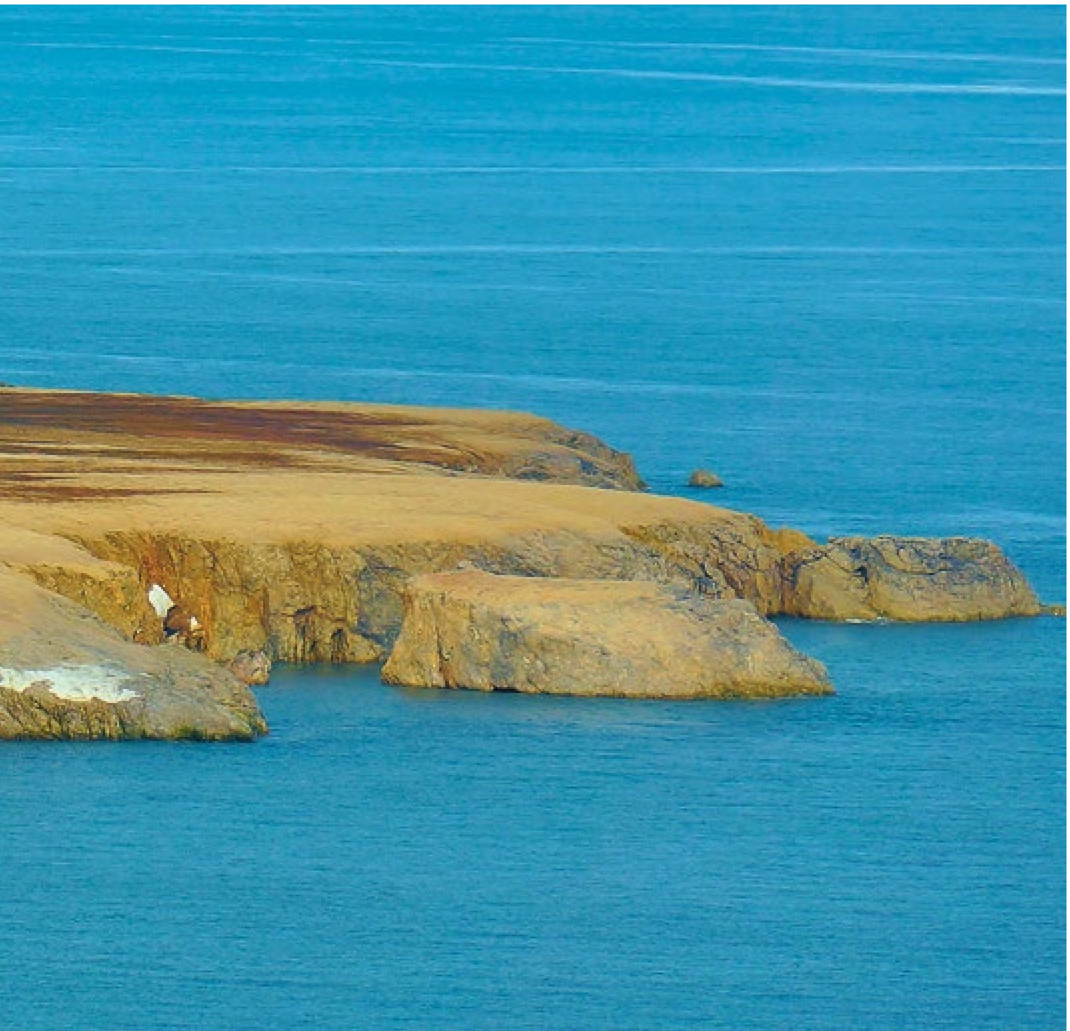
Despite the fact that comprehensive studies of the state of natural components of various Arctic regions have been conducted for over 80 years, spanning from hydrometeorological and geological to biological and ecological research, the state of the environment of the Arctic zone still remains understudied.

Geoportal. To collect, store and process the data accumulated through research, Rosneft has developed an advanced geographic information system, ArcticMonitor, which allows to collect information for analysis and visualization, providing remote access to multiple participants. This enables them to work with spatial data and jointly analyze it with the help of other information services and sources.

Atlases. In addition to the specialized analytical work related to processing of expeditionary and desktop data, it is important to systematize and summarize the accumulated information for further analysis. Many unique results of the ongoing research were obtained for the first time, and their value for science is very high from both the fundamental and applied points of view.

For this purpose, atlases of the seas of the Russian Arctic and the Far East are published. These are scientific publications that help summarize the data and compare it with the results of the latest research, provide comprehensive and relevant information about the exploration of the region and the latest discoveries and publish the results in a clear and easy to understand format.
→ p. 230

The main goal of numerous modern studies and expeditions is not only to learn how to explore the Arctic, but how to do it while ensuring the safety of the unique and vulnerable ecosystem.



Wrangel Island

Greenland
Greenland Sea
Norwegian Sea
Prime meridian
70°N
80°N
40°W
60°W
Amundsen Basin
Nansen Basin
Arctic
Svalbard
Longyearbyen
Medvezhy Island
NORWAY
SWEDEN
FINLAND
Narvik
Tromsø
Kiruna
Hammerfest
20°E
Luleå
Rovaniemi
Oulu
Barents Sea
Franz Josef Land
Svyataya Anna trench
Murmansk
Kandalaksha
Kirovsk
Kem
White Sea
Petrozavodsk
Onega
Lake Onega
Arkhangelsk
Mezen
Kolguyev Island
Novaya Zemlya
Novozemelsky trench
Kara Sea
Severnaya Zemlya
Vilkitsky
Kara Strait
Bely Island
Naryan-Mar
Vaygach Island
Varnek
Amderma
Dikson
Byrranga
40°E
Velsk
Northern Duina
Sabetta
Kotlas
Gyda
Pyasina
Ukhta
Pechora
Vorkuta
Syktyvkar
Pechora
Ural Mountains
Salekhard
Novy Port
Yamburg
Dudinka
Khatanga
Norilsk
Plateau Putorana
Kirov
Tazovsky
Yenisey
Nadym
Glazov
Ob
Solikamsk
Kama
Novy Urengoy
Igarka
Izhevsk
Perm
Serov
Taz
Turukhansk
Neftekamsk
Nizhny Tagil
60°E
60°N
Noyabrsk
Khanty-Mansiysk
80°E

120°W
140°W
160°W
180°
60°N
120°E
140°E
USA
Brooks Range
Barrow
Nome
Point Hope
Wales
Bering Strait
Uelen
Chukchi Sea
Provideniya
Mendeleev Ridge
Lomonosov Ridge
Podvodnikov Basin
Ocean
Wrangel Island
Long Strait
Egvekinot
Anadyr
East Siberian Sea
Pevek
Anadyr
New Siberian Islands
Anzhu Islands
Bilibino
Chersky
Arctic Circle
Laptev Sea
Lyakhovsky Islands
Dmitry Laptev Strait
Strait
Chokurdakh
Srednekolymsk
Kolyma Mountains
Evensk
Mountains
Bolshoy Begichev Island
Indigirka
Kolyma
Lake Taymyr
Tiksi
Ust-Olenyok
Chersky Range
Khatanga
Verkhoyansk
Ust-Nera
Verkhoyansk Range
Oymyakon
Magadan
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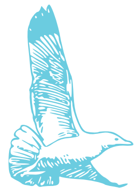
Yakutsk
Vilyuysk



Journey to the Arctic Seas

XIV–XVI

The first detailed geographical descriptions of the Barents Sea coast belong to the Pomors. They started with oral logs describing the “sea route” from the shore of the Onega Bay of the White Sea to Spitsbergen and Novaya Zemlya. Then, having passed through the straits near Novaya Zemlya, the Pomors reached the Kara Sea. Their experience became the foundation for planning of the subsequent expeditions.

Willem Barentsz, a 16th century Dutch explorer, wrote a geographical description of the Barents Sea, discovered the northern part of Novaya Zemlya, described Svalbard, Bear Island and the coast of the Kara Sea.

XVII–XVIII

In the 17th century the Barents and White Seas became well known to seafarers. The Pomors organized regular fishing expeditions to Novaya Zemlya and Svalbard, calling at Norwegian ports, while Arkhangelsk became the center of international trade.

Industrialists and the military explored the lower reaches of the major rivers, the Ob, Yenisey and Lena, and the Arctic shores near them. The lower reaches of the rivers attracted explorers primarily with their permafrost treasure, mammoth ivory. During the Great Northern Expedition, the first detailed description of the coastline of the Kara and Laptev Seas was compiled, with information about the East Siberian Sea down to the Kolyma River added by the end of the 18th century.

The Pomor koch

A wooden vessel used by the Pomors since the beginning of the 14th century for exploring the polar seas. The koch was suitable for sailing or paddling in clear water and in broken ice. Thanks to the ovoid shape of the hull, compressed ice pushed the vessel upwards.

14–15th centuries. Fishing expeditions of Russian Pomors to the Barents and Kara Seas: from the Onega Bay to Svalbard and Novaya Zemlya.

1597. Expedition of Willem Barentsz: Svalbard, the Barents Sea, the passage through the Yugorsky Shar strait and wintering on the shore of the Kara Sea

1633. Expedition of Ilya Perfiliev and Ivan Rebrov from the lower reaches of the Lena River to the Laptev Sea, exploration of the Olenyoksky and Yansky bays.

1498. Anglo-Italian navigator Sebastian Cabot was the first European to attempt the Northwest Passage.

1534. The first of three expeditions led by Jacques Cartier, a French navigator, discovered Chaleur Bay.

1574. The first of three expeditions led by Englishman Martin Frobisher reached Baffin Land.

1585–1587. Expeditions led by John Davis to find the Northwest Passage.

1615–1616. Expedition led by William Buffin advanced as far as Smith Strait.

1619–1620. Unsuccessful expeditions of the Danish explorer Jens Munk.

1631–1632. Expeditions of Thomas James and Luke Foxe.

Research of the Arctic seas

Search for the Northwest passage

Fram ship in March 1894. Wind turbine of the electric generator is clearly visible

1734–1743. The Great Northern Expedition. Description of the Gulf of Ob, the Yenisey Gulf, part of the coast of Yamal. Description of Siberian shores from the east of the Lena River to the lower Kolyma River.

1770. Discovery by Ivan Lyakhov of the southern islands of the New Siberian Islands archipelago between the Laptev Sea and the East Siberian Sea.

1821. Expedition of Fyodor Litke and Pyotr Pakhtusov to the eastern coast of Novaya Zemlya.

1840. Expedition of Alexander von Middendorff along the coast of the Kola Peninsula from the White Sea to North Cape. Gathering a zoological collection for a fundamental study on the fauna of mollusks.

1870. Expedition of Alexander von Middendorff to Novaya Zemlya and the Kola Peninsula, a study of the Nordkapp Current.

1878. Expedition of Adolf Erik Nordenskiöld on the steamship Vega to the Laptev Sea and further, east of the New Siberian Islands. Observations at several oceanographic stations.

1893. Expedition of Fridtjof Nansen on the ship Fram to explore the high latitudes of the Arctic, an attempt to reach the geographic North Pole.

1894–1901. Special hydrographic expedition to study the mouths of the Yenisey and Ob rivers. Observations at 25 stations in the Kara Sea.

1895–1908. Murmansk scientific and fishing expedition. Creation of the Murmansk Biological Station.

1909–1915. Expedition of the Hydrographic Department of the Marine Ministry. First large-scale study of the Kara Sea, hydrological and benthic studies, observations at over 300 stations.

1918–1919. Expedition of Sergei Averintsev to study the fisheries of the Arctic Ocean.

1921. First voyages of the Floating Marine Scientific Institute.

1926–1927. Expedition of the Yakutsk Commission of the Academy of Sciences of the USSR to the southern part of the Laptev Sea.

1932. Expedition led by Otto Schmidt, head of the Arctic and Antarctic Research Institute, on the vessel Alexander Sibiryakov traversed the Northern Sea Route for the first time in a single season.

1977. The most powerful at the time nuclear-powered icebreaker Arctica reached the North Pole for the first time in history, traversing 1,200 miles of perennial ice.

1987. Expedition of the Sibir icebreaker to the North Pole to evacuate the drifting polar station SP-27 and deploy the new station SP-29.

2012. Start of Rosneft scientific research in the Arctic.

1741–1762. A series of expeditions commissioned by the Hudson's Bay Company during which explorers determined that the Northwest Passage through the continent at low latitudes does not exist.

1776–1779. James Cook's third round-the-world voyage, the main purpose of which was the discovery of the Northwest Passage.

1816–1817. Russian round-the-world expedition led by Otto von Kotzebue.

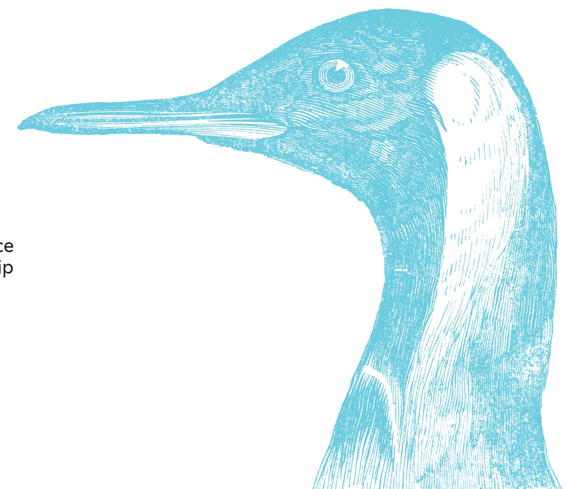
1818. Two polar expeditions by the British Admiralty, one of which reached a record latitude of 80°30'.

1819–1822. Two expeditions led by Briton William Parry who complied a description of the shores of the Baffin Sea.

1845–1848. Perishing of the British expedition led by John Franklin.

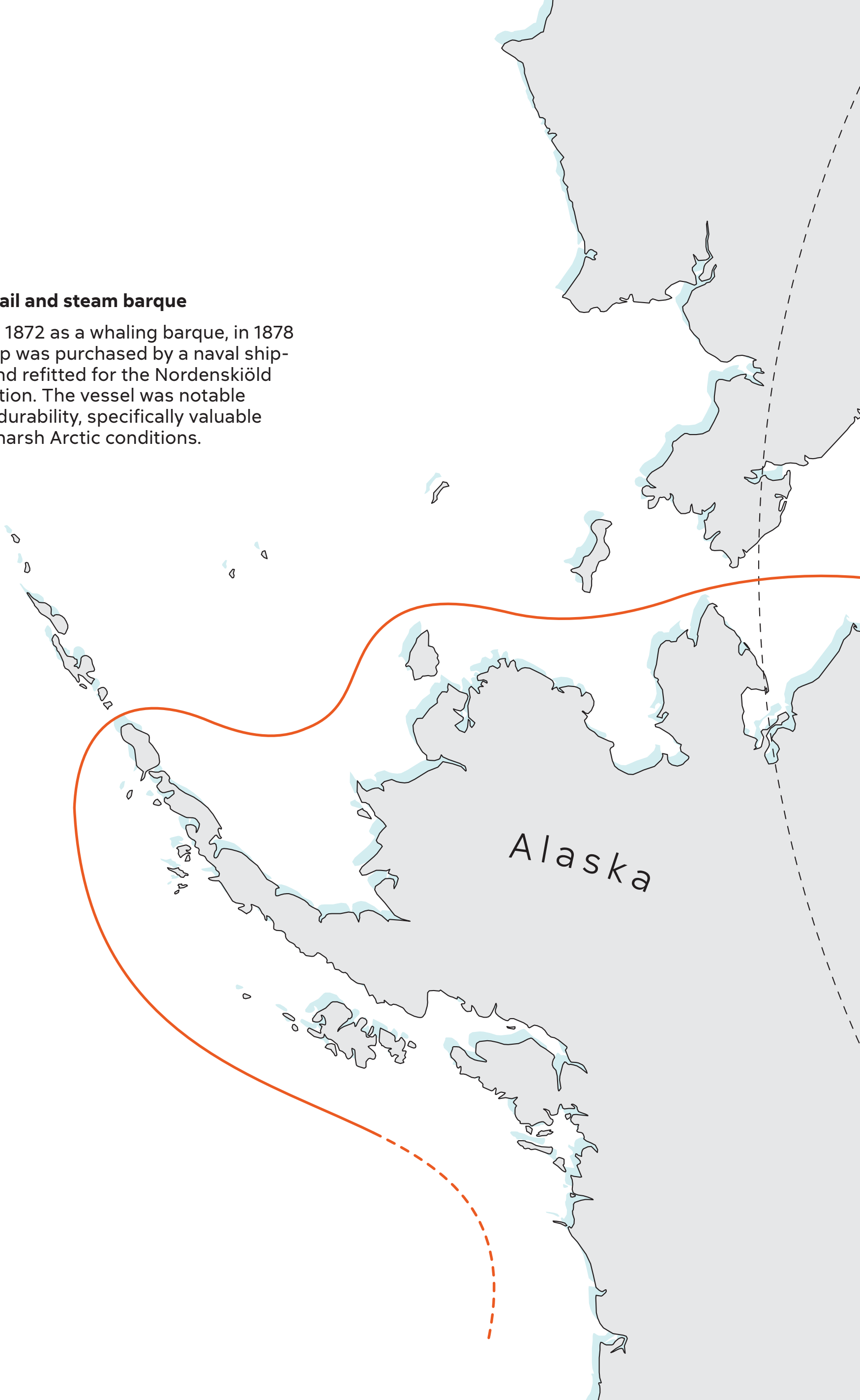
1850–1853. Robert John McClure navigated the Northwest Passage, but traveled part of the way over ice and returned to England on the ship of another expedition.

1903–1906. First traversal of the Northwest Passage entirely by water by Roald Amundsen.



Vega sail and steam barque

Built in 1872 as a whaling barque, in 1878 the ship was purchased by a naval shipyard and refitted for the Nordenskiöld expedition. The vessel was notable for its durability, specifically valuable in the harsh Arctic conditions.



XIX

Expeditions were becoming more specialized. Zoological collections were gathered in the Barents Sea and the influence of currents was studied. The study of fauna became an essential component of Arctic expeditions, in particular of the Special Hydrographic Expedition to study the estuaries of the Yenisey and Ob rivers.

The Nordenskiöld expedition on the steamship Vega established several oceanographic stations in the Laptev Sea and conducted the first trawls and dredges. Nansen’s expedition conducted the famous Fram drift from Kotelny Island, when the expedition vessel was purposefully frozen in pack ice for the purpose of conducting systematic comprehensive research of the Arctic Ocean basin. This was the first polar expedition of the 19th century in which not a single life was lost.

XX

The Arctic research program grew bigger, scientific institutes were created, including the Murmansk Biological Station, the Floating Marine Research Institute and the Murmansk Marine Biological Institute of the Academy of Sciences of the USSR. Specimens that were collected in the Kara Sea became the foundation of the Arctic animal collection in the Zoological Institute of the Russian Academy of Sciences.

Starting with the 1920s, the intensity of research increased manyfold. Almost all expeditions conducted comprehensive research, including hydrology, studies of phyto- and zooplankton and benthos at each station. Technical equipment of expeditions was improving, voyages to the Arctic were done on steam-powered icebreakers Malygin, Vaigach, Taymyr, Alexander Sibiryakov and the specially equipped research vessel Persei. The second half of the 20th century saw the appearance of nuclear-powered icebreakers capable of reaching the Geographic North Pole.

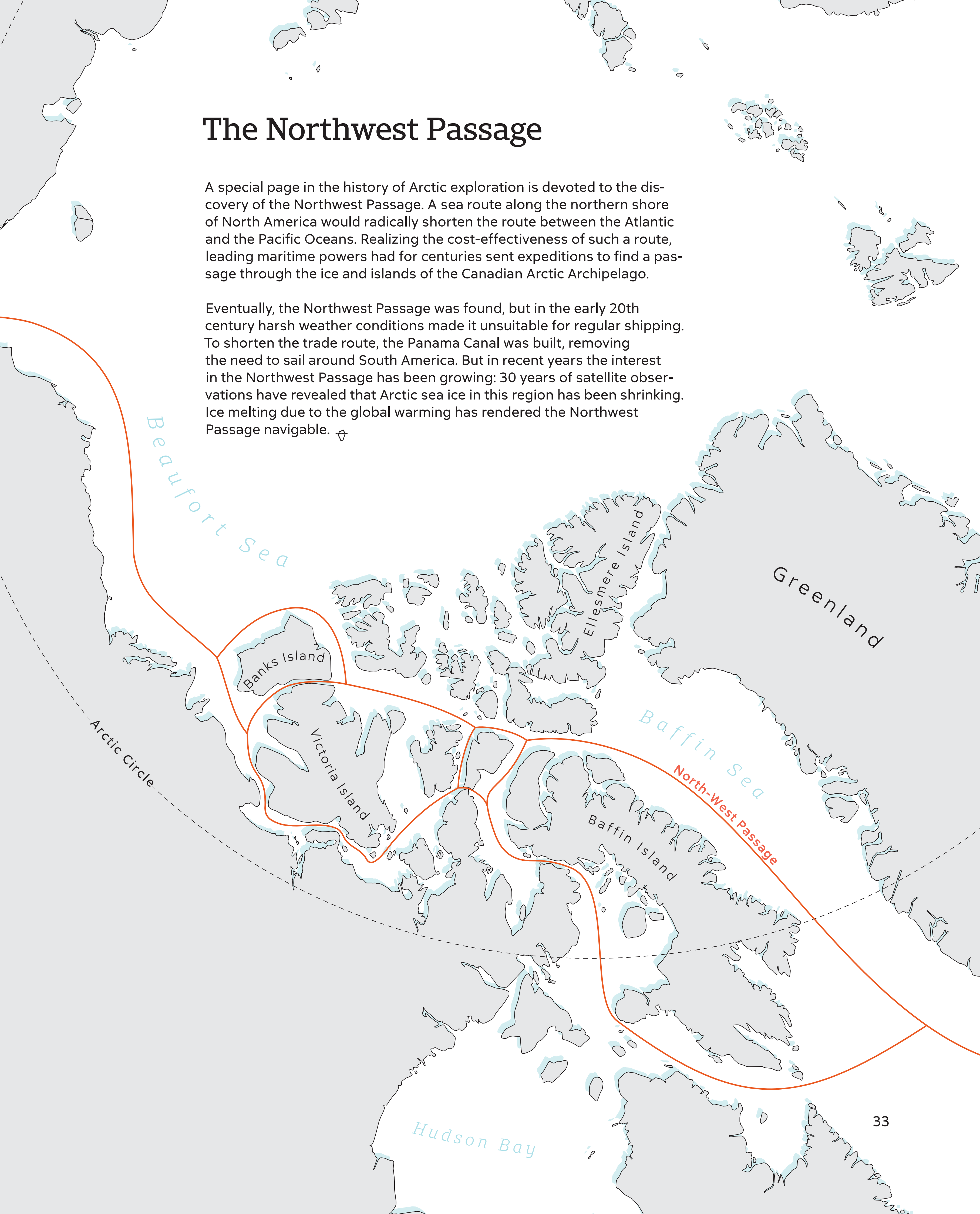
Vaigach steam-powered icebreaker

Launched in 1909, it was the first Russian vessel to sail the Northern Sea Route from Vladivostok to Arkhangelsk. It participated in the discovery of the Severnaya Zemlya archipelago, the last significant geographical discovery on the planet.

The Northwest Passage

A special page in the history of Arctic exploration is devoted to the discovery of the Northwest Passage. A sea route along the northern shore of North America would radically shorten the route between the Atlantic and the Pacific Oceans. Realizing the cost-effectiveness of such a route, leading maritime powers had for centuries sent expeditions to find a passage through the ice and islands of the Canadian Arctic Archipelago.

Eventually, the Northwest Passage was found, but in the early 20th century harsh weather conditions made it unsuitable for regular shipping. To shorten the trade route, the Panama Canal was built, removing the need to sail around South America. But in recent years the interest in the Northwest Passage has been growing: 30 years of satellite observations have revealed that Arctic sea ice in this region has been shrinking. Ice melting due to the global warming has rendered the Northwest Passage navigable.



How to Study the Arctic

The work to understand the world

We're used to science being shrouded in a veil of complexity and incomprehension. This is partly true: in order to draw the correct scientific conclusions, you have to develop specific skills and apply a whole range of data processing techniques. In the case of natural sciences such as geography, geology and biology — which is what this book is about — a number of approaches are used along with mathematical and statistical methods.

If you think about it, however, science is quite comparable to other fields: manufacturing, development of IT services and even art. Sure, you need to know and be able to do many things, but it's just a job, only it serves the purpose of giving us a clearer picture of the world we live in.

In this chapter we formalize the process of gaining scientific knowledge → p. 40 and also answer the questions of why explorers set off to the Arctic seas in the first place, and what they have to do upon their return. Behind every expedition is a tremendous amount of important work, even though it might look like a normal office process: people work at computers, have meetings, read articles and study reports. Through all that, scientific knowledge emerges: reasoned and correct conclusions about the Arctic.

Cycle of scientific knowledge

Research work in the field of natural sciences follows a hypothetical-deductive model, which means that scientific knowledge is presented as a system of deductively linked hypotheses which are gradually justified by inference and verification of verifiable patterns. Six steps lead to scientific knowledge.

Setting a scientific goal → Analyzing archives and formulating a hypothesis → Setting scientific objectives and tasks of an expedition → Data collection, expedition → Processing and analysis of data → Conclusions and scientific results

Scientists work through all the steps sequentially. The challenge is to find a gap in knowledge and a way to close it, which means building a process of gathering and analyzing data that would be correct from the standpoint of the scientific method. The steps are always the same, but within each step every task is solved in a different way.

The **Scientific method** is a system of values and principles that guide the scientific community. The method includes ways of research and adjustments to new and previously acquired knowledge. The method is objective: its assertions are not taken on faith and rule out subjective interpretation.

A **Scientific hypothesis** is a "reasonable assumption" whose veracity the scientific community has not yet recognized. It is based on preliminary knowledge and observation.

Modelling is a study of real natural phenomena using abstract graphic and mathematical models.

An **Experiment** is a tool to test a hypothesis. It is a method of inquiry in which natural phenomena are investigated under controlled conditions.

Scientific observation is a specially organized observation that allows to arrive at an answer to a previously posed question.

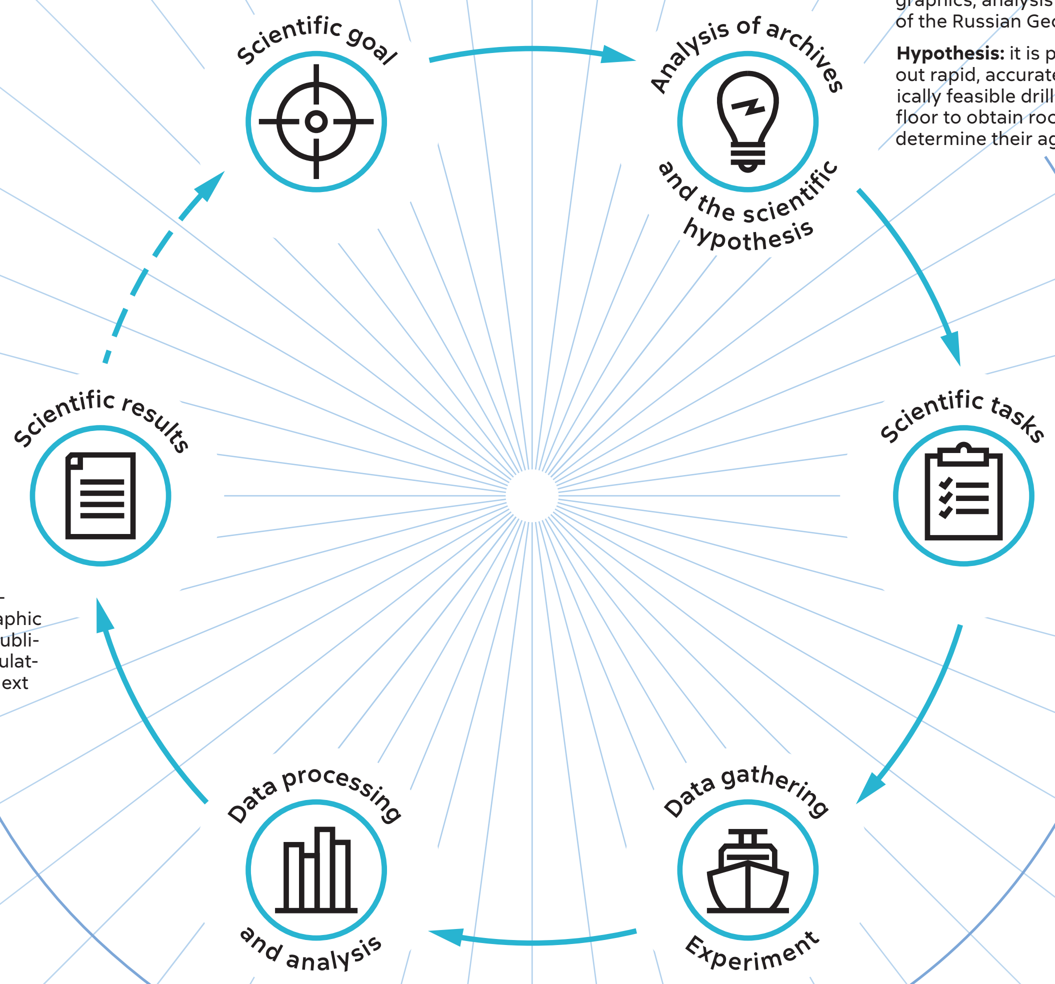
Measurement is a process of obtaining information about quantitative attributes of studied objects, organisms or events.

Cycle of scientific knowledge using the example of the Creating a Geological Model of the Arctic project

Determitaion of the age of the formations in the study area of the seafloor and their sequence of occurrence.

Search and selection of scientific articles and reports on seismographics, analysis of the materials of the Russian Geological Fund.

Hypothesis: it is possible to carry out rapid, accurate and economically feasible drilling of the seafloor to obtain rock cores and determine their age.



What actions are necessary for drilling to be effective: choosing the optimal location and number of drilling points; determining borehole parameters: depth, number of samples. A program of field and office tasks is created.

Expedition: voyage to the point of study, drilling and extraction of rock cores.

Desk part of the expedition: processing numerical data, decoding field diaries, laboratory analysis of core samples.

Refinement of the geological model, stratigraphic mapping of the area. Publication of results. Formulating questions for the next research cycle.

Stages of scientific knowledge

Setting a scientific goal

In the broadest sense, the mission of science is to produce and systematize knowledge about the world. But of course, at the level of individual scientific projects goals are set more specifically and are conventionally divided into several types:
1. Describing a phenomenon.
2. Identifying a pattern.
3. Explaining a pattern.
4. Predicting a behavior or development of a phenomenon.

Usually these goals do not work separately. The are linked in chains and follow one another: to explain a pattern, it is necessary to describe a phenomenon to a sufficient degree, and then relying on the formulated explanation it is possible to predict how the phenomenon will behave in the future.

In the case of Arctic research, the first thing scientists focus on is description, that is, gathering data about the objects of study. Observations of marine fauna, descriptions of coastal types and climate dynamics of the Arctic territories are good examples of many years of systematic data collection.

Explanation of patterns occurs at a stage when the amount of accumulated data allows to draw reliable conclusions. For example, using collected samples scientists determine which species of microbes are able to consume hydrocarbons efficiently in the Arctic seas.

Predicting variations in the behavior of a phenomenon could mean, for example, building predictions from big data using mathematical modelling. The scientific goal comes down to hypotheses that need testing and specific scientific objectives. → p. 147

Analysis of archives and formulating a hypothesis

Even in the Arctic, which is not well studied, a scientific goal is never set "from scratch". It is always preceded by other scientific goals that have been or are in the process of being attained. And where there are goals, there are results.

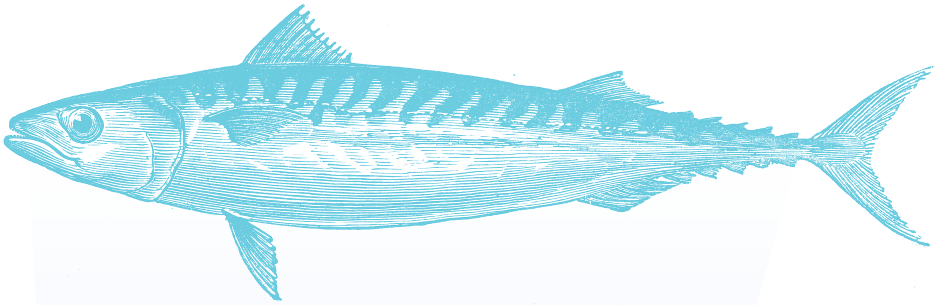
The first way to get closer to achieving a goal is to find information about what has already been done. To do this, scientists go through archives of prior research and publications in scientific funds, including expedition → p. 71 data, maps, conclusions — everything. This foundation in the form of goals and materials of previous research allows to formulate a scientific hypothesis.

Setting scientific goals and objectives of an expedition

The formulated scientific goal is fleshed out into specific tasks. Scientists decide how to collect data over large areas with a certain accuracy. For example, measuring meteorological data once every three hours will ensure quite high accuracy. If some type of data is not available in the archives or was not collected regularly, in some cases it becomes clear that an expedition is needed.

A scientific project moves from beginning to end, progressing through stages of scientific knowledge in sequence, involving different specialists at different stages. Sometimes a project can take several years, and an expedition or a series of expeditions my be just one of its stages.

Setting a scientific goal — **Analysis of archives and formulating a hypothesis** — **Setting scientific goals and objectives of an expedition**



Data collection, expedition

The types of scientific data needed depend on what exactly we study and whether we deal with social or natural sciences.

For social sciences, qualitative data can include results of processing a series of interviews, while quantitative data can be obtained from surveys. This isn't easy either: you have to choose the right respondents and ask questions aimed at solving the scientific problem at hand. Still, such data can often be obtained from the Internet, in archives and libraries, or at least without leaving the city.

With natural sciences things are quite different. Often there is simply no data, even in archives, and the only way to get actual numbers is to organize an expedition, take measurements or install equipment for continuous monitoring. We still know so little about the Arctic that any research results from the region become a valuable contribution to global knowledge.

Data processing and analysis

Sometimes an expedition accomplishes all tasks and even slightly exceeds the plan, other times some of the data cannot be collected for objective reasons. But in any case, all information needs to be processed and prepared for analysis.

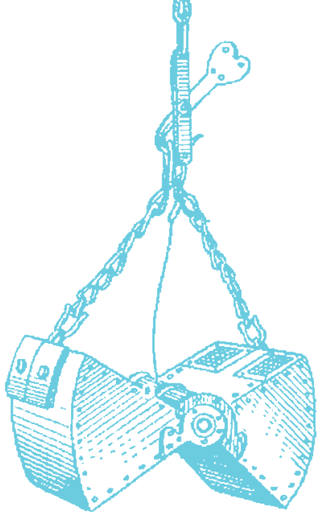
Data can be digital and physical. For example, core samples obtained during drilling need to be described, rock layers identified and isotopic analysis performed. Photographic, video and digital materials need to be transferred to laboratory computers and prepared for modelling. Audio recordings of field diaries that specialists record during the work need to be decoded.

The field data is compared to the original hypotheses and scientific goals. Open-ended questions are answered, hypotheses are confirmed or disproved and numerical data is summarized in mathematical models.

Conclusions and scientific results

At the end of the cycle, scientists have a complete picture of the given area of study. Not all data can be shared (because it constitutes a trade secret, for example), but science is a global and collective endeavor, so much of it ends up being published. Scientific results are part of the body of fundamental information about how local ecosystems and the planet as a whole are structured; in particular, Rosneft has a whole series of ecological atlases. → p. 230

Along with results come new questions that will form the basis for further research and restart the cycle. Scientists rely on new publications, check and compare findings with other regions and landscapes. New scientific knowledge, new hypotheses and new unexplored areas emerge. But scientists are more than happy with this state of things.



Arctic expedition

Goals and objectives of expeditions

The times of great expeditions have gradually passed. The last great geographical discovery, the Severnaya Zemlya archipelago, was made at the beginning of the 20th century. With time, human interests narrowed and now science deals with tasks more specific than discovering a new island.

Yet any expedition, large or not, requires preparation. The purpose of the earliest stage of preparation is to determine the goals of the research and the results that need to be obtained. It's done not in the field or on the ship. It's done in companies and research institutes when scientists set goals, examine archives and prioritize objects of research.

In addition to the purely scientific research which has no short-term practical application, there is also the so-called industrial research. It is carried out by companies and corporations to monitor environmental and metocean conditions and study a region for the purpose of planning their commercial activities. This also happens in the offshore of the Russian Arctic.

Industrial research is no less important than fundamental studies. It helps carefully control the situation during operations and plan subsequent work as safely as possible for the region's biota. The goals of the scientific expedition are divided into groups: ecology, hydrometeorology and geology.

Expedition program

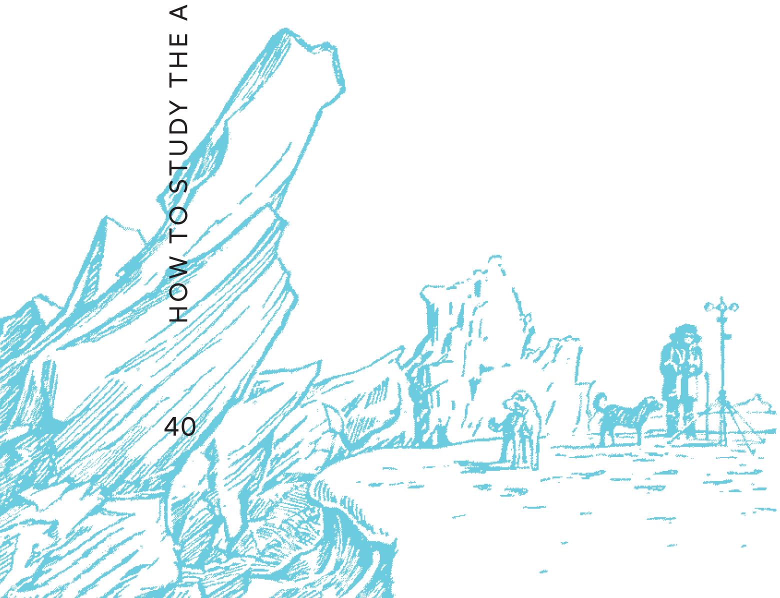
Scientists gradually start to form a program of the expedition, which happens at the desk planning stage. No single specialist can cover all areas of the expedition, so the program is written jointly by a large group of people, with everyone responsible for their own part. The scientists are in charge of the research component, the technical team is responsible of the operation of the fleet and technical preparation. The more remote the selected area is, the more challenging their work will be. Accountants keep track of the finances, and so on.

An expedition is practically a living creature, which requires a lot of attention from very different angles.

Safety of people and nature

In the past, people set out unprepared to the ends of the earth, relying on their ingenuity, skill and strength. Nowadays, it's not enough to set a goal, move towards it and even get results. We have to do it as safely as possible, both for people and for nature. History knows examples of ships that poured oil or blubber overboard while fighting storms, or cases when abandoned ships for centuries have been decaying on the shores of the Arctic. Since the mid-20th century, a number of international conventions and environmental safety regulations have been written, especially relevant for the states bordering the Arctic seas. The Arctic's ecosystem is extremely fragile and can easily be disturbed.

No port captain would let an unprepared or unreliable vessel out to sea. The work to prepare for sailing is conducted almost year round. A vessel returning from a voyage is sent out for routine repairs. During the off-season, the vessel is constantly improved and all systems are checked. And even if something fails, a backup system will be triggered, since all critical components are redundant.



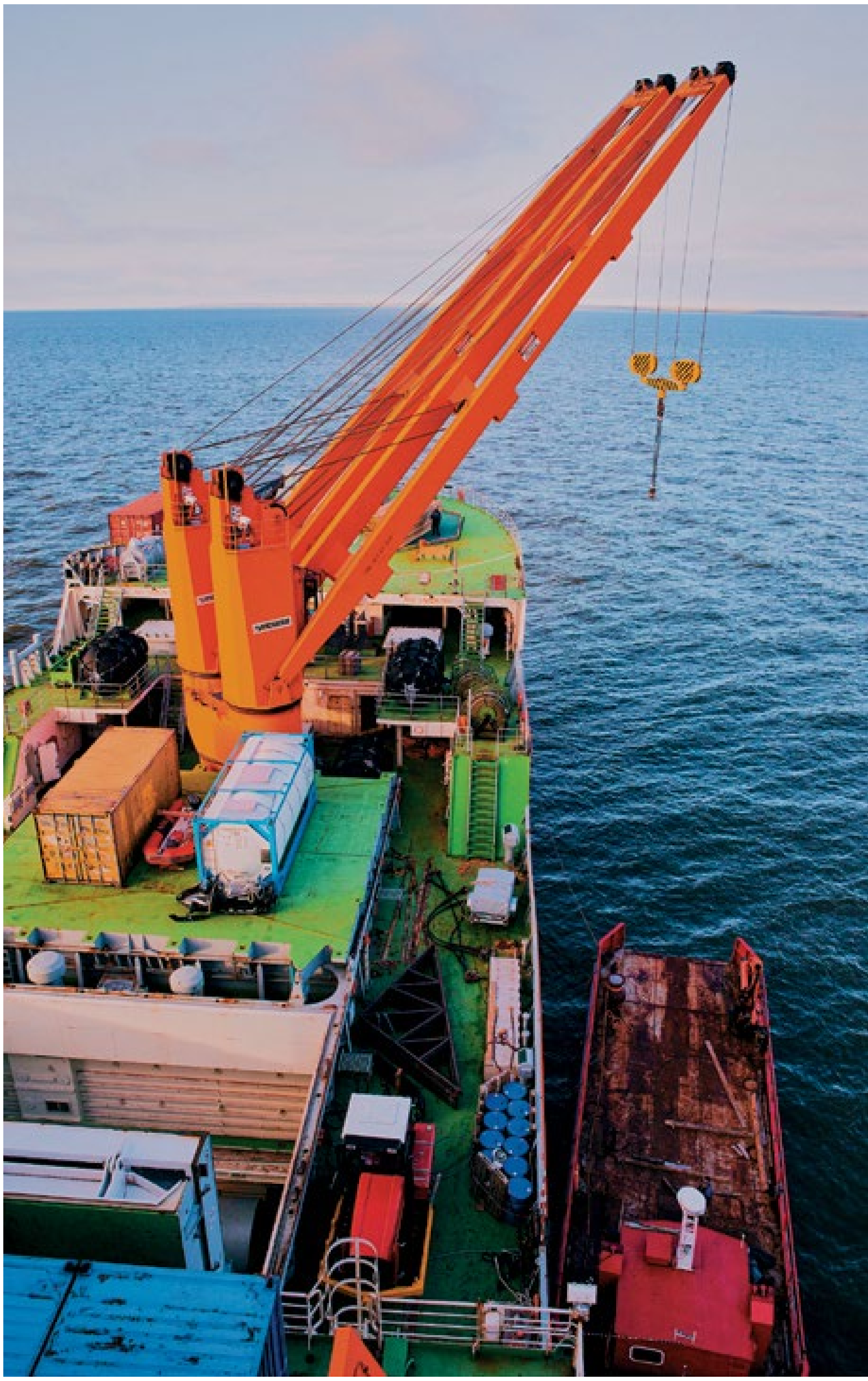
Assembling the crew

As the vessel is being prepared, people undergo training. A person working on an expedition ship must have a number of skills and specialties. A marine scientist is not just a scientist, he or she is also a sailor, a carpenter, a mechanic and a rigger. Some of these specialties are taught in special training centers. Without proper training, no scientist can go on an expedition.

The same applies to the health of the crew and expedition personnel. It's easy to deal with a toothache while you're in a city, but on board a ship it may become a life-saving operation. That's why crew members and scientists undergo serious examination. Not as rigorous as astronauts of course, but still: people preparing to spend three to four months in remote areas far from hospitals should be as healthy as possible.

There is another important issue related to isolation during the voyage. People on the ship need to be as psychologically compatible as possible. Crew members leave their families and familiar environments to live in difficult conditions virtually as a new family. It may be temporary, but for a while instead of seeing thousands of people on city streets, they will see the same forty faces every day. Psychological resilience becomes of utmost importance. You can be a world class scientist, but if you have a difficult personality and do not fit in well with the team, things are likely going to be difficult for you and most importantly you will slow down the work of others.

That's why positions of responsibility are often filled not by the most experienced specialists, but by those whom others will follow unconditionally, those who are called leaders. Such a person must be able to lead others, to prevent discord in the crew, which has been known to affect even the best expeditions. If an expedition is well prepared technically, but poorly organized psychologically, it will fail, or at least experience serious difficulties.



Cranes and winches on the ship are placed in working areas, near bilges, boat decks and the helipad: in all areas where lowering and lifting operations and manipulations with heavy equipment take place

Expedition composition

Two teams work together on the ship during the expedition: the ship's crew and the scientific team. The ship's crew consists of the captain, assistant captains, the boatswain, sailors, the cook and stewards — everyone who keeps the ship running and on the route.

The composition of the scientific team depends on the goals of the expedition and can include ecologists, geologists, chemists and climatologists — all the people who directly perform scientific work.

Everyone who lives on the ship follows a set routine, and the control of the process is in the hands of the leaders of both teams.

The two captains

The role of the expedition leader, the head of the expedition on board the vessel, should be highlighted. He coordinates between the numerous services on shore, the technical support service, the ship's crew and other scientists who will advise him in the course of the voyage.

In fact, there are two chiefs on every ship: the expedition leader who is in charge of scientific activities and related work, and the ship's captain.

According to all maritime conventions and laws of the sea, the ship's captain is solely responsible for everything that happens on the ship. It's important to establish communication with the captain and his subordinate crew from the first day on the ship. If the expedition leader and the ship's captain have a disagreement, the success of the voyage is going to be jeopardized.

One can't say that either of these two people is more important than the other. All members of the expedition team and all members of the crew are equally important. Everyone is doing their job. The job of the captain is to keep people alive and ensure that the ship is operated safely. The job of the expedition leader is to execute the scientific program.

A perfect example are expedition vessels of the Academy of Sciences of the Russian Federation. Scientists who have been at sea for a long time have marine knowledge equal to that of an average ship officer. And ship officers know scientific research, its importance and the order of operations at the level of an average scientific technician. And this is very good. The intertwining skills allow all members of the expedition to treat each other not as consumers, customers or contractors, but as human beings, which maximizes the return for everyone involved.

The start of the expedition

Once everything has been planned, written down, approved, financed and coordinated and the equipment has been assembled and delivered to the port, one of the hardest and yet most enjoyable stages begins: the happy rush of preparing for departure. Bunker trucks approach the vessels, trucks full of food arrive, equipment is serviced and installed. The expedition is preparing to leave.

The day of departure is always a day of celebration. That's how it is seen by scientists and even hardened members of the crew. It's the beginning of a big job, a big project. People are not yet tired, they are fresh and realize that their time has come: in spite of all difficulties ahead, this moment is exactly why they all came together.

After the departure, routine but important work begins: the scientific team continues to prepare the equipment, hold meetings and refine their goals and tactical plans.

Work on the ship is divided into shifts. The ship's crew uses the classic watch: four hours of work followed by eight hours of rest, while the scientists' watches often last twelve hours. The night watch is considered harder, although this is more noticeable in regions where, unlike the Arctic, the sun sets over the horizon. The shift life makes certain adjustments to the daily routine which every crew member must find a way to get used to. They become a part of the mechanism where they have no right to break the established rules.

One shouldn't think though that an expedition is nothing but a series of hardships, deprivation and facing adversity. In fact, on every ship there are simple human pleasures. Despite the acute lack of sleep, people still gather to watch movies and play board games when they are not on watch. Birthdays and holidays are never ignored or forgotten. Alcohol is prohibited of course, but a cake and congratulations from colleagues on someone's birthday are perfectly normal.

Maritime traditions have not gone away either, although of course they have changed. People on the ship unite and support each other, sharing joys and hardships. And every holiday is a special event, full of sincere feelings that can sometimes be forgotten on the land.

Scientific research vessel

A vessel can be constructed specifically for research purposes, in which case the "research" designation will be assigned to it when it is built. Otherwise, vessels of other types such as fishing boats, tugs, and military ships can be converted and adapted for research purposes. Usually, a research vessel is a vessel that has the necessary tools to perform various scientific tasks. First of all, they include lifting devices, laboratory facilities and auxiliary equipment: boats, cranes, a helipad, a set of hydrographic and geophysical instruments. → p. 182

The main difficulty in converting other types of ships into research vessels is related to installing winches, crane beams and hydraulic cranes on structures not intended for that purpose. Yet lifting equipment is critical: a properly equipped ship makes it easier for the crew to do their job and expands research capabilities of the vessel.

Remotely operated underwater vehicle (ROV)

The remotely operated underwater vehicle is used for remote inspection of underwater objects and the seabed: its topography, bottom biotopes, animals and man-made objects. It can be equipped with manipulators, cameras, a sonar and small geophysical instruments. The typical diving depth is around 1,000 meters, or around 200–300 meters in the Arctic seas, which allows it to be used for any jobs.

Quadcopter

Drones with cameras are used for geodetic aerial photography, coastal relief surveys and observations of mammals, such as counting walruses. Another application is ice observations. The drone drops buoys on ice that allow to monitor ice field drift.

Hydraulic crane

The crane is used for loading equipment from the berth to the ship, moving cargo on deck, lowering and lifting it out of the water. It rotates 360° and makes the work of the crew much easier.

Power plant

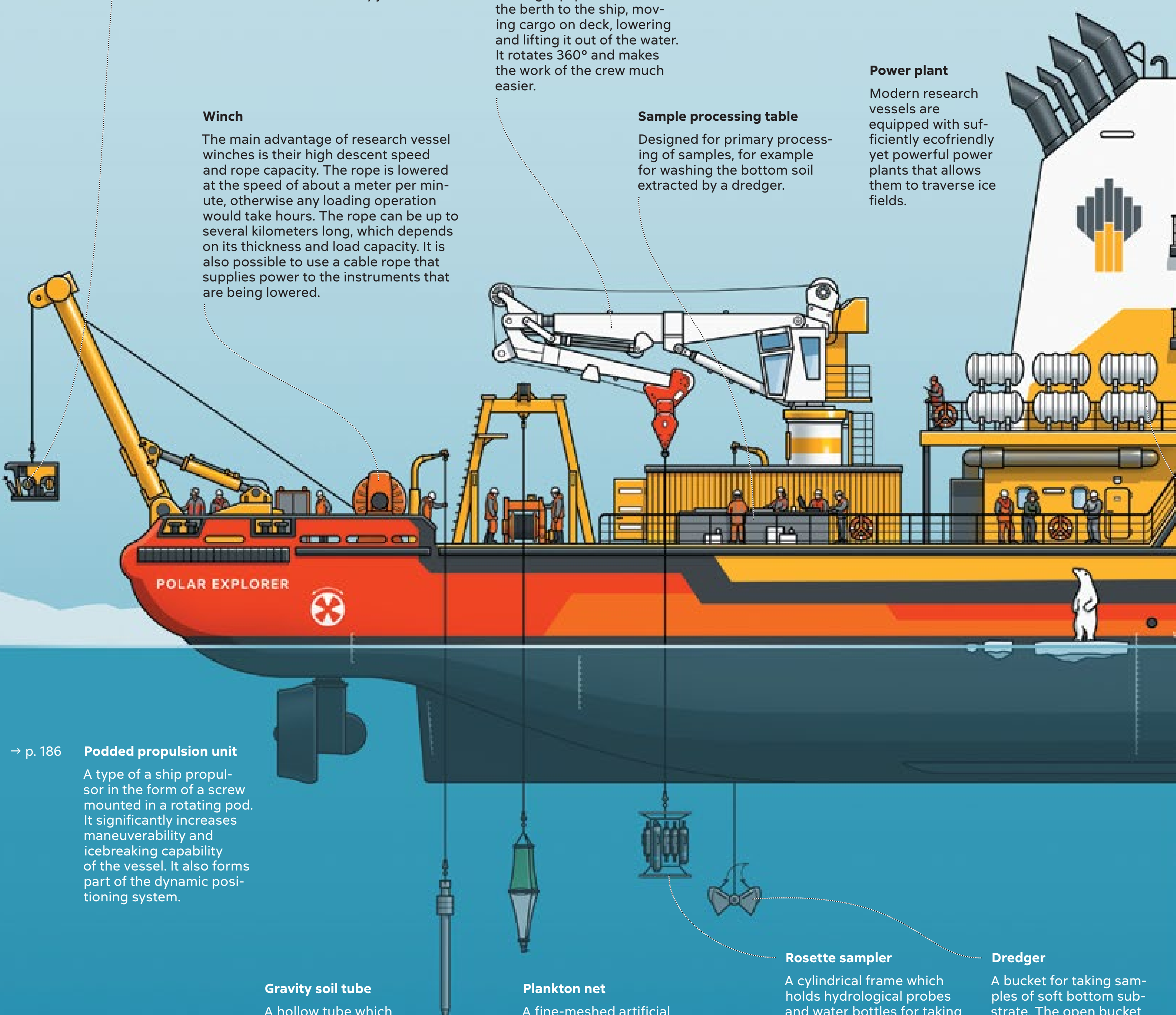
Modern research vessels are equipped with sufficiently ecofriendly yet powerful power plants that allows them to traverse ice fields.

Winch

The main advantage of research vessel winches is their high descent speed and rope capacity. The rope is lowered at the speed of about a meter per minute, otherwise any loading operation would take hours. The rope can be up to several kilometers long, which depends on its thickness and load capacity. It is also possible to use a cable rope that supplies power to the instruments that are being lowered.

Sample processing table

Designed for primary processing of samples, for example for washing the bottom soil extracted by a dredger.



→ p. 186 **Podded propulsion unit**

A type of a ship propulsor in the form of a screw mounted in a rotating pod. It significantly increases maneuverability and icebreaking capability of the vessel. It also forms part of the dynamic positioning system.

Gravity soil tube

A hollow tube which under its own weight or with the help of a vibration motor is pushed into the rock strata at the bottom of the sea and then extracted after the bottom opening is closed. It allows to study the structure of bottom rocks layer by layer.

Plankton net

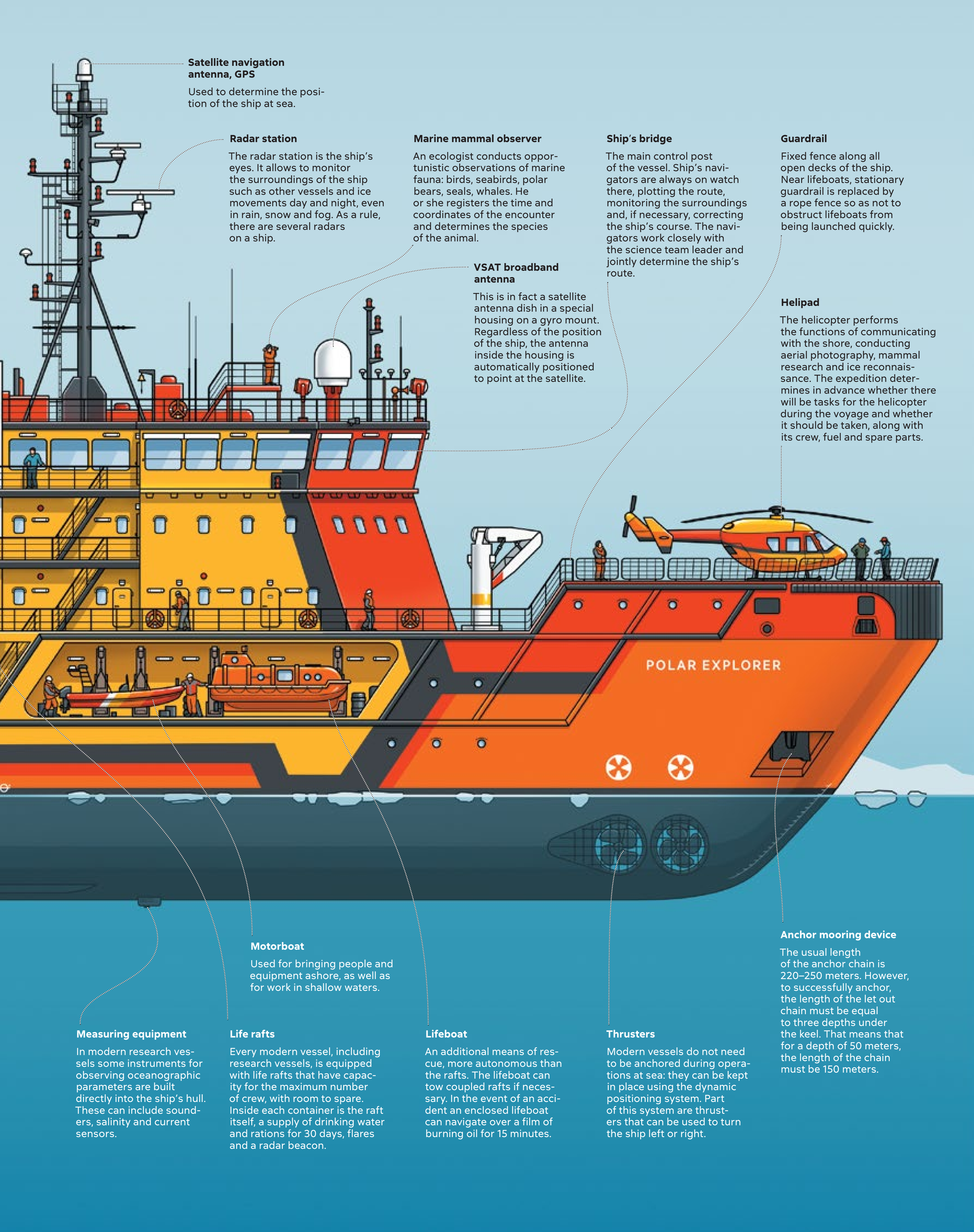
A fine-meshed artificial fiber net for plankton fishing. The mesh size is chosen based on which organisms need to be studied. Scientists can collect plankton at a certain depth or gather samples from an entire water column from the bottom to the surface in a single net.

Rosette sampler

A cylindrical frame which holds hydrological probes and water bottles for taking water samples from a certain depth. In fact, these are bottles with an automatic plug: during one dive of the sampler, scientists can take water samples from several different depths.

Dredger

A bucket for taking samples of soft bottom substrate. The open bucket is lowered by its own weight to the bottom where it is closed. Scientists retrieve the bucket and begin the cycle of examining the microorganisms in the sample.



Satellite navigation antenna, GPS
Used to determine the position of the ship at sea.
Radar station
The radar station is the ship's eyes. It allows to monitor the surroundings of the ship such as other vessels and ice movements day and night, even in rain, snow and fog. As a rule, there are several radars on a ship.
Marine mammal observer
An ecologist conducts opportunistic observations of marine fauna: birds, seabirds, polar bears, seals, whales. He or she registers the time and coordinates of the encounter and determines the species of the animal.
Ship's bridge
The main control post of the vessel. Ship's navigators are always on watch there, plotting the route, monitoring the surroundings and, if necessary, correcting the ship's course. The navigators work closely with the science team leader and jointly determine the ship's route.
Guardrail
Fixed fence along all open decks of the ship. Near lifeboats, stationary guardrail is replaced by a rope fence so as not to obstruct lifeboats from being launched quickly.
VSAT broadband antenna
This is in fact a satellite antenna dish in a special housing on a gyro mount. Regardless of the position of the ship, the antenna inside the housing is automatically positioned to point at the satellite.
Helipad
The helicopter performs the functions of communicating with the shore, conducting aerial photography, mammal research and ice reconnaissance. The expedition determines in advance whether there will be tasks for the helicopter during the voyage and whether it should be taken, along with its crew, fuel and spare parts.
POLAR EXPLORER
Motorboat
Used for bringing people and equipment ashore, as well as for work in shallow waters.
Anchor mooring device
The usual length of the anchor chain is 220–250 meters. However, to successfully anchor, the length of the let out chain must be equal to three depths under the keel. That means that for a depth of 50 meters, the length of the chain must be 150 meters.
Measuring equipment
In modern research vessels some instruments for observing oceanographic parameters are built directly into the ship's hull. These can include sounders, salinity and current sensors.
Life rafts
Every modern vessel, including research vessels, is equipped with life rafts that have capacity for the maximum number of crew, with room to spare. Inside each container is the raft itself, a supply of drinking water and rations for 30 days, flares and a radar beacon.
Lifeboat
An additional means of rescue, more autonomous than the rafts. The lifeboat can tow coupled rafts if necessary. In the event of an accident an enclosed lifeboat can navigate over a film of burning oil for 15 minutes.
Thrusters
Modern vessels do not need to be anchored during operations at sea: they can be kept in place using the dynamic positioning system. Part of this system are thrusters that can be used to turn the ship left or right.

Crew members wearing PPE

Shore services

One might think that while the expedition is at sea, the work of on-shore technical services stops. In fact, they continue to support the vessel: they receive reports, determine whether additional provisions or fuel is needed. They arrange extra trips to the port or deliver what's needed directly to the research area. The shore services are also ready to come to help at a moment's notice in case of an emergency, including coordinating with rescue centers and participating in rescue operations as much as possible.

Shore services are on duty 24 hours a day, and this work is no less important than the work on the vessel itself. Most of it is invisible to an outsider, but those who have been at sea for a long time have great respect for their colleagues on the shore. Shore services often employ older seafarers, retired captains, navigators and mechanics.

Daily schedule

At last, the ship arrives to the survey area and the research program begins. Ecologists lower the dredgers and plankton nets, marine mammal observers launch their boats and search for walruses, bears and large marine biota, while operators of submersible vehicles pore over their screens and control panels.

When work is under way on the vessel, there are usually regular 10-minute meetings to adjust the work plan depending on the expedition objectives. Safety meetings before each shift are also mandatory.

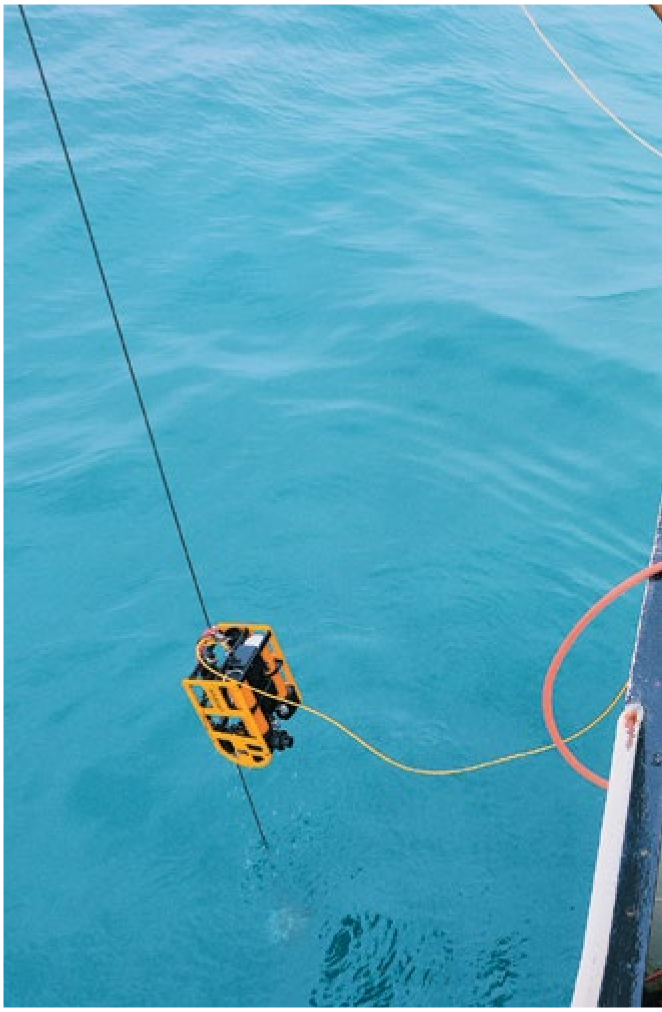
At the research site, the work never stops, even at night. Every day is valuable: at any moment a storm may come and the program will have to be reduced or timelines will have to be shortened. At the same time, all teams try to help each other as much as they can.

It's almost a Strugatsky day when Monday begins on Saturday and work prevails even over such basic instincts as eating and sleeping. People can stay awake for 2–3 days, not out of necessity, but because they are driven by passion, they want to learn something new and get the most out of it. But of course such schedule is not the norm, and the captain and the expedition leader are vigilant about it. A person on deck who didn't get proper sleep is just as dangerous as someone who is sick or drunk.

A safe expedition

Safety continues to come first. No one walks under cranes and lifting machinery without wearing a hardhat, and no one goes out to open decks without a life jacket. The "check yourself, check your buddy" rule works the same way as, for example, in diving, when after checking your gear you check your partner's equipment.

Likewise, all equipment is tested before each work shift. Any injury or malfunction is feared, and with reason: in the Arctic any emergency is complicated by weather and isolation. Initial measures to repair equipment and treat people are thought out, but a serious accident would require returning to port, and that means the end of the expedition.



Health and safety and personal protective equipment

Work in any specific circumstances requires following certain rules which ensure the safety of the process for all participants. A welder needs a special mask, a skier needs wrist and knee protection and an astronaut needs a spacesuit.

Occupational safety while working on a ship is not a formality: everyone needs to be extremely attentive, properly equipped and diligent about following instructions. Each member of the scientific crew undergoes compulsory training and knows what rules must be followed and what personal protective equipment (PPE) must be worn.

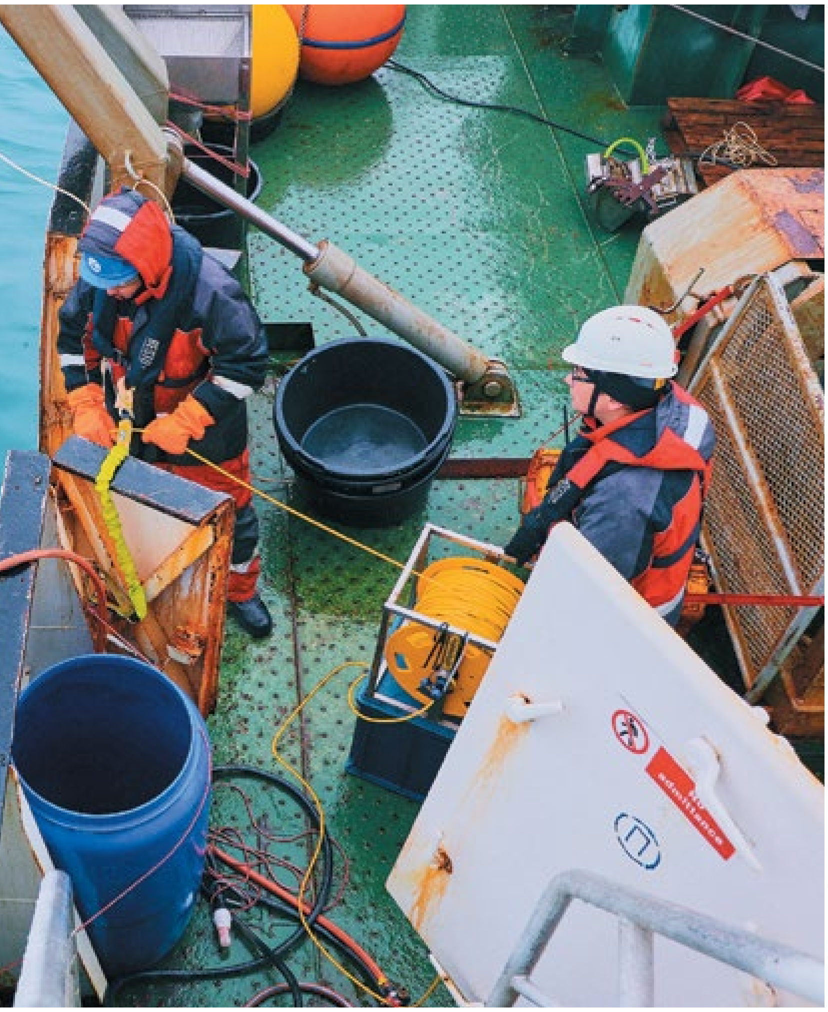
What is PPE

The acronym combines a group of items that are necessary for ensuring safety at work. A set of PPE is selected based on the role, and depends on the type of work and the climate.

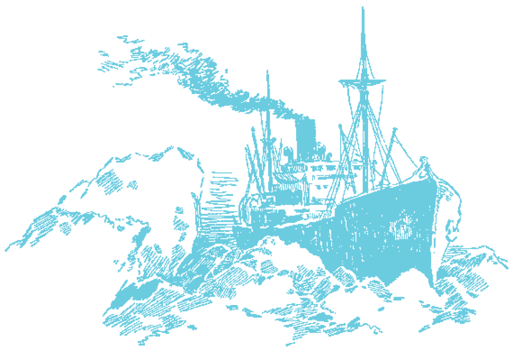
There is a reason protective equipment is called personal. Each employee has his or her own personal set of equipment and protective items: clothes, shoes, hardhat, gloves, goggles... They are issued for a certain period of time, for example a hardhat lasts five years, while seasonal clothing is issued for a year.

All employees take care of their PPE, check its integrity and send it to the dry cleaner's when needed — there is one on the ship! If something is out of order, an employee can always ask for a replacement. There is some spare stock, but it is not endless, so everybody tries to handle their PPE with care.

In addition to personal items, there is other equipment such as respirators, life jackets and harnesses that is used collectively. There is no special term for them and they are also called PPE.



Members of the scientific crew lower an ROV overboard. They are fully equipped with PPE and are secured to the deck



What PPE protects from during an Arctic expedition

The territories where Arctic expeditions take place belong to a special climate zone. Work here requires the highest class of protection in clothing, and the first task of PPE is to protect people from hypothermia, frostbite and the general effects of frost, rain, snow and wind.

→ p. 20

The second type of threat is what is called "general industrial contamination". The textbook "falling bricks", rotating cranes or dropped nails should not lead to injuries. Which is why it's important to wear a hardhat and thick shoes.

And finally, some specific issues:
— the risk of falling overboard into icy water when working on an open deck;
— skin and eye protection when working with chemicals in the laboratory.

PPE types and features

For all members of the expedition. This type includes clothing for different weather and types of work, footwear, as well as simple protective and supporting items: hardhats, gloves, splash goggles, flashlights. Clothing and footwear are divided into seasonal kits with their own specifics. For example, the winter set includes a flashlight for working in polar night conditions. And in any case, clothing must be bright so people can see each other from a distance.

For specific jobs. Specific safety attributes are developed for each type of activity: safety belts and life jackets for working on the open deck and by the board, safety harnesses for working at heights, coats and respirators for laboratory work. Some PPE for specific jobs is included in the personal kit, other types are shared by the crew and passed from watch to watch.

Workwear should not only be certified, which means made from special materials, but also comfortable. There is a place for taste here: some people like overalls while others prefer combining bib pants with a jacket.

Shoes can also be specialized, equipped with non-slip soles and metal toe pads. Shoes with open heels are forbidden on the ship: even slippers must have a heel, otherwise they're not safe. That's why everyone prefers light rubberized slippers.

Gloves must protect hands not only from the cold, but also from friction: when working with cables, palms and fingers must remain shielded without compromising their grip and mobility. That's why gloves are made of a durable membrane material that withstands friction.

Maximum protection from moisture if provided by a suit called Rokon Buksa. This is the generalized name for "fisherman's clothing", a rubberized suit which won't let you get wet even if you are being hosed down.

Scientific personnel wearing Rokon Buksa suits

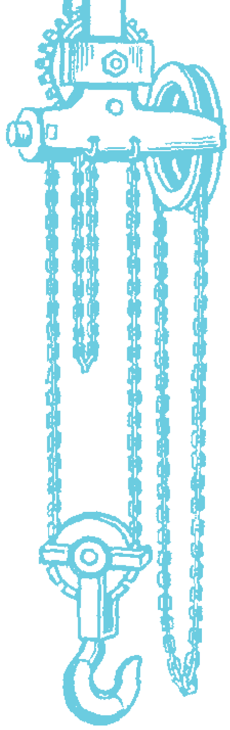
A researcher working in a laboratory onboard a ship

PPE in occupational safety

PPE will protect a person in case of an emergency. Naturally, the crew does everything possible to make sure the expedition goes smoothly and nothing out of the ordinary happens, but that is impossible to guarantee. The risk is always there, so the crew is prepared not only to prevent problems and injuries, but also to deal with them.

Non-passenger vessels with less than 50 crew members do not have a dedicated doctor, but several members of the crew do have extensive medical training.

Every person about to board an expedition vessel receives a Shipboard Damage Control Manual certificate. The document confirms that everyone is aware of the crew's responsibility to ensure survival of the ship, i. e. the vessel's ability to maintain and restore its navigational qualities and ensure the safety of the people on board. So the expedition team is ready to handle most threats on the high seas.



Systematizing data

The work on the ship is very intense, and to an uninvolved observer it may look like chaos. But this is not the case: work programs and assignments are carefully prepared, and each person knows exactly what to do and in what order. All samples are being taken, labeled and packed in a strict order. The results are checked by team and expedition leaders. Videos and aerial photos are stored in multiple copies. Everything is double checked, because without order in systematization, storage, packaging and transporting of data it would be very hard to get a sensible result.

Field diaries are diligently kept, containing dates and times of collected samples, nuances that happened during sampling or bottom surveys. The diaries must be sent together with the samples and the data to help people who will be processing them. A field diary answers many questions that arise when examining samples.

The way home

When the research program is completed, samples are collected and data is gathered, the vessel begins its voyage back to the port. During this time, the scientific personnel clean, pack and store equipment, while the shore services prepare for the ship's arrival: they will have to unload the equipment, refuel the vessel and dispose of garbage and waste. And also start preparing the vessel for a new voyage: the Arctic season is short and 2–3 days after entering the port, the ship is ready to go back to sea with a new expedition.

Scientists try to use the navigation period from July to October as efficiently as possible. When the sea is frozen, only icebreakers and heavy ships can operate. As a rule, almost as soon as the vessel arrives, it is serviced by trucks, cranes, and all samples and equipment that were packed during the voyage home are immediately unloaded and sent for storage or processing.

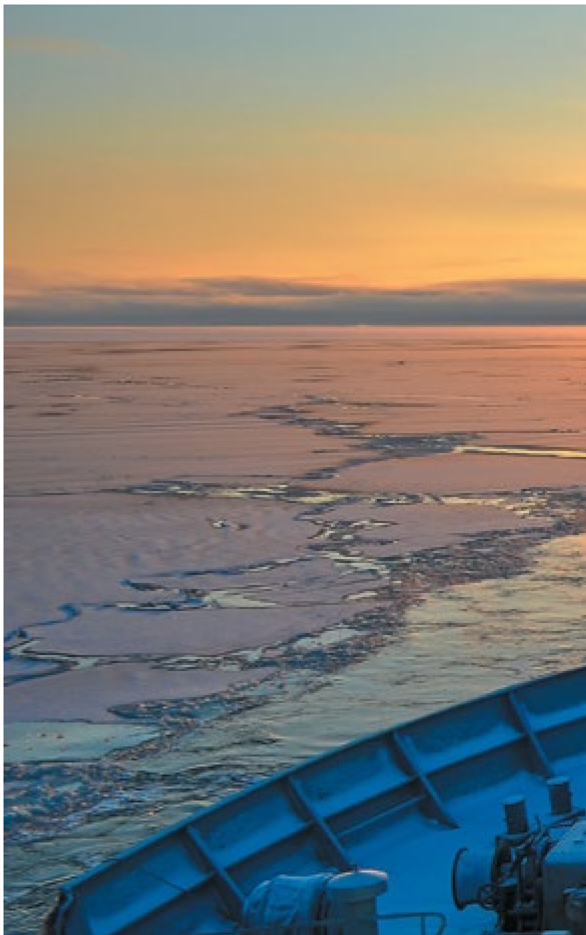
Desk research

The field part of the expedition is only half the battle, although probably the most interesting one. The samples and unprocessed data alone are not going to benefit the mankind. They also need to be analyzed. This is where the next stage of work — desk research — begins, which will result in a publication of a scientific article or obtaining production data for subsequent research.

This work takes no less time than the expedition, sometimes even more. Samples and survey data obtained during the expedition can be processed throughout the entire winter. But the desk stage is the stage at which scientific discoveries are made.

When the results are processed and scientific reports are written, the time comes for conferences, public discussions of expedition results and plans for future years: the wheel of scientific knowledge has taken a turn and has come back to its starting point. Scientists are again thinking about what can be studied, which areas of the sea they still haven't visited and where they will travel the next time.

Informal meetings follow the formal ones: during the voyage team members get used to each other so much, they start missing each other's company and want to meet again as soon as possible. People who met on the ship become good friends on land as well.



An icebreaker escorting a caravan of ships in late fall

Scientific exploration of the Arctic

→ p. 62
→ p. 37

The Arctic as a scientific object is studied by scientists in a variety of disciplines, including geologists, hydrometeorologists, ecologists. They follow the cycle of scientific knowledge, incorporating relevant scientific methods to overcome data deficit. Geologists study the structure of the seafloor and its underlying structures, hydrometeorologists focus on the climate, while ecologists accompany all activities with observations and studies of ecosystems.

Setting of scientific goals and objectives and the analysis of data usually take place within individual research projects, but the collection of data, in our case expedition data, often takes place collaboratively, to share the complexity and cost of organizing an expedition.

Over the 10 years of scientific research, more than 30 expeditions have been conducted. See the chronology of these studies on the next page.

Rosneft research over 10 years

Area of research: geology, hydrometeorology, ecology

2010 **2011** **2012** **2013**

10.2010

License for subsoil use in the Arctic seas

Rosneft acquired four licenses for subsoil use in the Pechora Sea (Yuzhno-Russky block) and the Kara Sea (Vostochno-Prinovozemelsky-1, -2 and -3 blocks). The company began to analyze the results of previous studies, develop a strategy for geological exploration and prepare the first exploration and appraisal studies in the new areas.

10.2011

Arctic Research Center

Rosneft established the Arctic Research Center which performs the full cycle of scientific and design work related to exploration of offshore fields.

08.2012

Seismic research in the Pechora and Kara Seas

The company began MOGT-2D seismic surveys [p. 64] in the Kara Sea and MOGT-3D in the Pechora Sea and at the Universitetskaya structure within the Vostochno-Prinovozemelsky-1 block in the Kara Sea. By 2022, the unprecedented amount of MOGT-2D surveying was done in the entire Arctic offshore, covering over 144,000 km, completing ahead of schedule and considerably exceeding the expected volume of work under the licensing obligations. The top-priority structures totaling 28,700 km² were covered by MOGT-3D surveys.

Study of rock outcrops on islands

Geological expeditions to the Arctic are resumed. In the Western Arctic, field work was carried out on the Severnaya Zemlya and Franz Josef Land archipelagos. In the Eastern Arctic, work was completed in the west of Chukotka, on Wrangel Island, the Laptev Sea coast near the mouth of the Lena River, on New Siberia Island, Eastern Taymyr and the Anabar-Khatanga saddle. Overall, 14 geological expeditions commissioned by Rosneft have been carried out in the Arctic since 2012. The obtained rock samples [p. 129] made it possible to better understand the geological structure of the subsoil in the region and plan the geological exploration strategy.

Engineering and geological surveys in the Kara Sea

Within the Universitetskaya priority structure, engineering and geological surveys were carried out for deployment and safe operation of the floating drilling rig at the well construction site. Conclusions were made about the engineering, geological, natural, technogenic, metocean, oceanographic and hydrological conditions of work. Engineering and geological surveys were carried out at 19 sites for deep drilling.

07–08.2012

Metocean observation network. Kara-Summer 2012

Vessels Fridtjof Nansen and Mikhail Somov departed from the ports of Murmansk and Arkhangelsk for the first Arctic expedition [p. 74] to collect data on metocean and ice conditions of the Kara Sea.
As a result, an automatic observation network for metocean parameters was deployed, consisting of submerged autonomous buoy stations (SABS) and automatic weather stations (AWS).

04.2013

Kara-Winter 2013

The first research expedition [p. 76] on the nuclear icebreaker Yamal with a Ka-32 helicopter on board. Mobilization in the port of Murmansk. In the Kara Sea, ice stations were installed on hummocks and icebergs frozen into ice fields. Maintenance of island metocean stations was conducted using the helicopter.

08.2013

Kara-Summer 2013

Expedition [p. 77] to maintain the network of SABS and AWS stations in the Kara Sea.

Aerial survey of the Kara Sea shores

The first aerial survey of the shores [p. 226] of the south-western part of the Kara Sea aimed at creating a detailed coastline map and assessing its environmental sensitivity.

2014

2015

09.2014

Start of exploratory drilling units in the Kara Sea

Russian President Putin launched the drilling p. 127 of the country's northernmost Arctic well Universitetskaya-1. The drilling was performed in a record-breaking month and a half with absolute compliance with all technological and environmental requirements.

Discovery of a unique field

The unique Pobeda oil and gas field was discovered, containing total recoverable reserves of about 130 million tons of oil and 396 billion m^3 of gas.

08–10.2014

Metocean observation network in the Eastern Arctic

The first Arctic voyage of Roshydromet's flagship, vessel Akademik Tryoshnikov. The vessel, equipped with a Ka-32 helicopter, left the port of Arkhangelsk to carry out work in the Barents, Kara, Laptev, East Siberian and Chukchi Seas. In the course of the work, the automatic network of submerged autonomous buoy stations was extended to the Eastern Arctic. For the first time, the company carried out helicopter-based radar surveying of glaciers and icebergs p. 172 (the Novaya Zemlya and Severnaya Zemlya archipelagos).

04–05.2014

Kara-Winter 2014

An ice research expedition p. 78 to the Kara and Laptev Seas on the nuclear icebreaker Yamal with a Ka-32 helicopter on board, mobilization in the port of Murmansk. The geography of work in the Laptev Sea was expanded.

01.2014

Metocean database

A database of metocean conditions p. 146 at Rosneft's license areas was started.

Marine mammal research program

The program of priority research of marine mammals p. 98 in the Russian Arctic offshore was developed.

Methodology of collaring a female polar bear

The first collar was fitted p. 102 on a female polar bear on August 31 on Zhokhov Island (the Chukchi Sea). The work was carried out as part of the comprehensive expedition Kara-Summer 2014.

Aerial survey of the Kara Sea shores

The geographical coverage of the aerial survey of the shores p. 220 of the Kara Sea was expanded. The coast of the Taymyr Peninsula, Baydaratskaya Guba p. 220 and the southeast coast of the Novaya Zemlya archipelago were also studied.

The first regional geological model of the Western Arctic

Structural and sedimentation models were built, regional development history was reconstructed, a model of hydrocarbon system formation was created, oil and gas geological zoning was conducted, resources and geological risks were assessed. Prospective subjects for further field exploration were selected. The modelling allowed to reconstruct the history p. 138 of development of the basins in geological time, determine the parameters of oil and gas content, carry out a complete analysis of the development and formation of hydrocarbon systems, significantly reduce the degree of geological uncertainty and refine the strategy of exploration.

09–10.2015

Chukotka-Summer 2015

The expedition p. 84 started from the port of Pevek on the ship Mikhail Somov. Deployment of the observation network for metocean parameters was completed with the installation of automatic weather stations and automatic broadband seismic stations on Wrangel Island. Maintenance of existing stations was also successfully carried out.

01.09.2015

Study of the largest Arctic glaciers and forecast of iceberg production

Conducted research of the conditions of iceberg production of glaciers p. 172 on Novaya Zemlya, Franz Josef Land and Severnaya Zemlya which account for 70 % of total iceberg discharge of all glaciers in the Russian Arctic. Forecast of iceberg formation for the next 50 years was completed. In 2017, the paper "Development of an Ice Management System for the Conditions of the Kara Sea" became the winner of the first prize of an International Competition of Scientific, Technical and Innovative Solutions Aimed at the Development and Exploration of the Arctic and the Continental Shelf.

04–06.2015

Kara-Winter 2015

An ice research expedition p. 82 in the Kara and Laptev Sea on the nuclear icebreaker equipped with a Ka-32 helicopter. A network of automatic broadband seismic stations on the islands of the Laptev Sea was established.

Hummocks database

One of the most extensive databases of hummocks p. 176 in the world was created, containing around 200 hummocks and stamukhas. A unified classification for Arctic hummocks based on the shape of their underwater part was developed and implemented.

Atlas of metocean and ice conditions of the Arctic seas published

As a result of summarizing the data from the expeditions of 2012–2014, the Atlas p. 230 of Metocean and Ice Conditions of the Seas of the Russian Arctic was published, becoming the first summary of meteorological, hydrological and ice conditions of the Russian Arctic published since 1970.

Species diversity analysis: a list of bioindicators

The program for conservation of biological diversity at Rosneft's license areas was developed. An analysis of species diversity in the company's license areas was performed and a list of indicator species p. 98 of sustainable state of marine ecosystems was prepared.

08.2015

Walrus research on the islands of the Pechora Sea

As part of the geological exploration work in the Pechora Sea, additional walrus research p. 112 was conducted on the islands of Nenetsky State Nature Reserve. The research was conducted before, during and after the seismic surveys to estimate their influence on rookeries of animals.

Methodology for trapping and satellite monitoring of reindeer

The first 10 reindeer were fitted with collars p. 119 of the Argos satellite monitoring system with built-in GPS receivers. Methods of trapping wild reindeer in their wintering grounds were developed. Unique data on routes, lengths and timing of deer migration was collected and summarized.

2016 **2017** **2018** 2019 →

07.2016

Patent for the new methodology of geophysical research

The new approach allows to combine different geophysical technologies in a single vessel pass, optimize preparation of objects for deep drilling, assess geological and technical features of areas at the early stages of exploration. The methodology was developed jointly with scientists from Moscow State University and tested during a two-year program of regional engineering and geological work in the Laptev Sea.

09–10.2016

Iceberg towing experiments

The icebreaker Kapitan Dranitsyn departed from the port of Murmansk to carry out comprehensive experiments on iceberg towing p. 175 (Iceberg-Summer 2016). In the course of the experiments, current and wind profiles, as well as the dynamics of towing force, were recorded. World's first towing of icebergs in the presence of ice in the water area was carried out, as well as several towings of icebergs weighing over one million tons. Technical solutions for towing characteristic icebergs of the Barents and Kara Seas showed a high level of efficiency and operational safety. In 2019, the paper "Determining Characteristics of Ice Formations in the Seas of the Russian Arctic and Practical Implementation of Technological Solutions to Reduce the Risks of Their Negative Impact on Offshore Oil and Gas Facilities in the Development of the Continental Shelf" was awarded the State Prize of the Government of the Russian Federation in the field of science and technology.

08–09.2016

Year-round temporary field camp Khastyr

The vessel Akademik Tryoshnikov departed from the port of Arkhangelsk for the deployment of the year-round temporary field camp Khastyr p. 180 in the area of Kosisty Cape of the Khatanga Bay. Maintenance of the network of submerged autonomous buoy stations and automatic weather stations and helicopter radar sounding of glaciers were also performed.

Year-round study of physical and mechanical properties of sea ice

Four experimental sites for year-round research of the evolution of physical and mechanical properties of sea ice were organized. The tests were conducted in the areas of the Khastyr River, Cape Baranov, Nogliki settlement, city of Okha, Melkovodnaya Bay. In 2020, the results of the research were published under the title "Development of Methods and Technologies to Ensure the Reliability of Offshore Hydraulic Structures in the Development of the Arctic and the Pacific Shelf", which was later awarded the State Prize of the Government of the Russian Federation in the field of science and technology for young scientists.

Analysis of species diversity: list of bioindicators

Based on the list of bioindicator species approved by the Ministry of Natural Resources and Environment of the Russian Federation, analysis of planktonic and benthos organisms p. 202 was added to the list of programs of industrial environmental control and monitoring.

08.2016

Survey of the rookery of the Laptev subspecies of the walrus

On August 28, 2016 one of the most remote and hard to reach rookeries of the Laptev subspecies of the walrus p. 107 on Bennett Island in the East Siberian Sea was studied. Skin and subcutaneous fat samples were taken for molecular genetic analysis. Satellite transmitters were fitted on three animals and photo recorders were installed at the rookery. Shore work was accompanied by shipboard benthos sampling to assess the food supply of the animals.

Methodology of recording marine mammals

A methodology for recording marine mammals concurrent with other shipboard observations p. 69 was developed in cooperation with the Marine Mammal Council. The methodology also describes measures to minimize the impact on marine mammals made during exploration operations in the Arctic offshore.

08.2016

Ecological atlas of the Kara Sea

The ecological atlas p. 230 of the Kara Sea was signed into print. This extensive review of current knowledge of the Kara Sea ecosystems is based on the analysis of archive data and materials collected by Rosneft, including the aerial survey of the shores of the Kara Sea conducted in 2013 and 2014.

Database of environmental data of the Kara Sea

The ecological atlas of the Kara Sea database was developed and registered. It contains information on physical, geographic, socio-economic, archaeological and ecological parameters of the water area and the coastal zone of the Kara Sea. The atlas also includes data on the biodiversity of the Kara Sea and maps of environmental sensitivity of its shores.

09.09.2017

Ice Monitoring System (IMS)

The development of the main elements of the IMS p. 174, a key factor in the safe performance of maritime operations in the Arctic seas, was completed. Iceberg formation zones were studied and their maximum possible sizes were determined. Satellite images and aerial survey data were used to examine the size and shape of forming icebergs and the direction of their drift. Large-scale studies of interaction of the icebreaker hull with hummock ridges were carried out.

10.2017

Study of bottom communities

A methodology for mapping the distribution of bottom communities p. 210 using geophysical data was developed at the White Sea Biological Station of Moscow State University. Application of this technique in October 2016 allowed to study the distribution of bottom communities in the northern part of Rosneft's largest license area in the Arctic offshore.

11.2018

Methodology of geocryological mapping of the Arctic seas

Maps of geocryological zoning of the Kara Sea and the Laptev Sea were created with the help of the new methodology.

Digital archive of parameters

Data accumulated over five years of expeditions was gathered into a single database and prepared for modelling the fields of main parameters of the metocean regime.

Technological form of microbial preparation

A technological form of microbial preparation p. 194 for cleaning water areas of the northern seas from hydrocarbon pollution was developed. The preparation is in the form of hydrophobic-coated granules that contain microbial cells in a dormant state and nutrients necessary for them to begin active growth.

Area of research: geology, hydrometeorology, ecology

← 2018

2019

11.2019

Results of the analysis of expedition data of morphometry and internal structure of the Laptev Seas stamukhas

The scientific article “Morphometric Parameters of the Laptev Sea Stamukhas” was awarded the Best Scientific Article 2019 prize of the International Society of Offshore and Polar Engineers (*ISOPE*).

12.2019

Agreement on preserving biological diversity

Rosneft and the Ministry of Natural Resources and Environment of the Russian Federation signed an agreement on cooperation within the Ecology National Project. The agreement is aimed at cooperation in the field of biodiversity conservation. In particular, Rosneft will implement a corporate program to study, conserve and monitor key bioindicator species of Arctic ecosystems: polar bears, Atlantic walruses, wild reindeer and ivory gulls.

Modernization of the building of the Laboratory of Flow-through Marine Systems

With the support of Rosneft, modernization of the Laboratory of Flow-through Marine Systems at the Nikolai Pertsov White Sea Biological Station of Moscow State University on the shore of the Kandalaksha Bay of the White Sea was started.

Microbial preparation testing

The biological preparation for cleaning the northern seas from hydrocarbon pollution was successfully tested [p. 197] in the Laboratory of Flow-through Marine Systems at the White Sea Biological Station.

2020

The northernmost drilling in the history of Russian Arctic offshore exploration

A series of shallow (up to 90 meters) wells was drilled in the North Kara Basin, a difficult to access and one of the least studied parts of the Arctic waters. Over 300 meters of core samples were taken from 10 wells with a total depth of over 500 meters, serving as a direct source of geological information [p. 128] necessary to determine the age, composition and conditions of rock formations.

Two new fields in the Kara Sea

Two unique fields [p. 138] named after Marshal Zhukov and Marshal Rokossovsky with total reserves of over 1.3 trillion m³ of gas and 50 million tons of condensate were discovered. The discoveries confirmed the high hydrocarbon potential of the new oil and gas bearing areas of the Kara Sea.

07–08.2020

Ivory gull surveys

Under the agreement with the Ministry of Natural Resources and Environment of the Russian Federation, research of ivory gull [p. 114] populations on the islands of the Kara Sea was conducted. The main study site was Vize Island in the northern part of the Kara Sea. For the first time, the white blood cell formula of the bird was described and comprehensive studies were carried out to assess its level of stress and other health parameters.

2021

2021

Accelerated drilling techniques

A successful project to drill shallow wells made it possible to transfer the acquired experience to other poorly explored sedimentary basins. In the Laptev Sea, the *Piggyback* combined drilling technology was used for the first time, accelerating the drilling process and increasing the depth of boreholes to 221 meters. Fiber-optic VSP technology was used as well, making it possible to conduct surveys in uncased boreholes. A total of six shallow wells were drilled in the Laptev Sea with the total depth of over 800 meters and the total core recovery of over 400 meters.

2021

Mathematical modelling of iceberg towing

Physical (in an experimental wave pool and in a wind tunnel) and mathematical modelling of the ice towing process was conducted. A simulator and special software were developed to simulate iceberg towing under various operating conditions.

Crew algorithm for iceberg towing

Methods and algorithms of actions of a tugboat crew during iceberg towing [p. 175], were developed, along with scientific and methodological recommendations on organizing iceberg protection of offshore oil and gas production facilities.

08.2021

Second study of the Atlantic subspecies of the walrus

During the research on the Franz Josef Land archipelago, the most numerous rookery of walruses [p. 112] of the Atlantic subspecies on Eva-Liv Island numbering over 2,000 animals was described.

Sonar survey of the underwater part of an iceberg in Zhuravlev Bay in the Kara Sea

Regional Research

Regional research areas

To work in the Arctic conditions, the company needs to rely not only on time-tested methods, but also on new technologies, materials and a vast amount of up-to-date knowledge of the region. The Arctic requires highly effective planning and accounting for the fragility of the unique ecosystem and narrow weather windows.

The main task of Rosneft's scientific program is to ensure that economic activities in the offshore are safe for man and nature. This systematic work is carried out in conjunction with the country's leading scientific and design organizations. Since 2012, the company has launched a comprehensive long-term scientific program in the fields of geology, hydrometeorology and ecology.

The number of outstanding tasks and gaps in modern knowledge of the Arctic is so great that regional research is needed first and foremost. We are talking about obtaining top-level overview information about the state of the environment throughout the Russian Arctic, from geological data to the knowledge about the distribution of the most vulnerable members of marine fauna.

Regional research is needed in all three areas mentioned above. But the goals are different.

Geological research is needed for prospecting and exploration, from discovering general patterns in the sedimentary basin structure to forecasting oil and gas content and selecting the most promising zones and areas for more detailed investigation.

→ p. 72

Metocean research is required to collect data that would supplement the coverage of the national metocean observation network in key areas of the company's operations. Since 2012, Rosneft has been conducting a series of expeditions to deploy and maintain infrastructure for observation of metocean and ice conditions.

Environmental research is intended to obtain data on the state of ecosystems before the start of active operations in the region. In the first stages, shipboard observations are important, providing researchers with information on the distribution of seabirds and mammals. While there are major limitations to the method — data only can be gathered along the route of the vessel — winter observations of marine fauna provide unique details on the distribution of animals during ice seasons.

Regional studies in each of the three areas become the foundation, the starting point for subsequent detailed research.

Regional geological exploration

In order to discover a new hydrocarbon field, or to refine the structure of an already known one, it is necessary to have a fairly clear idea of the general geological structure of the region.

→ p. 138

Identifying areas with promising prospecting targets requires collecting all possible data about the region, that is why this stage of geological exploration is called *regional*: it covers most of the offshore of the Russian Arctic seas. In 2012–2019 a unique program was implemented by the company to organize and conduct 14 Arctic expeditions to the islands and coastal land areas which are key to understanding offshore geology.

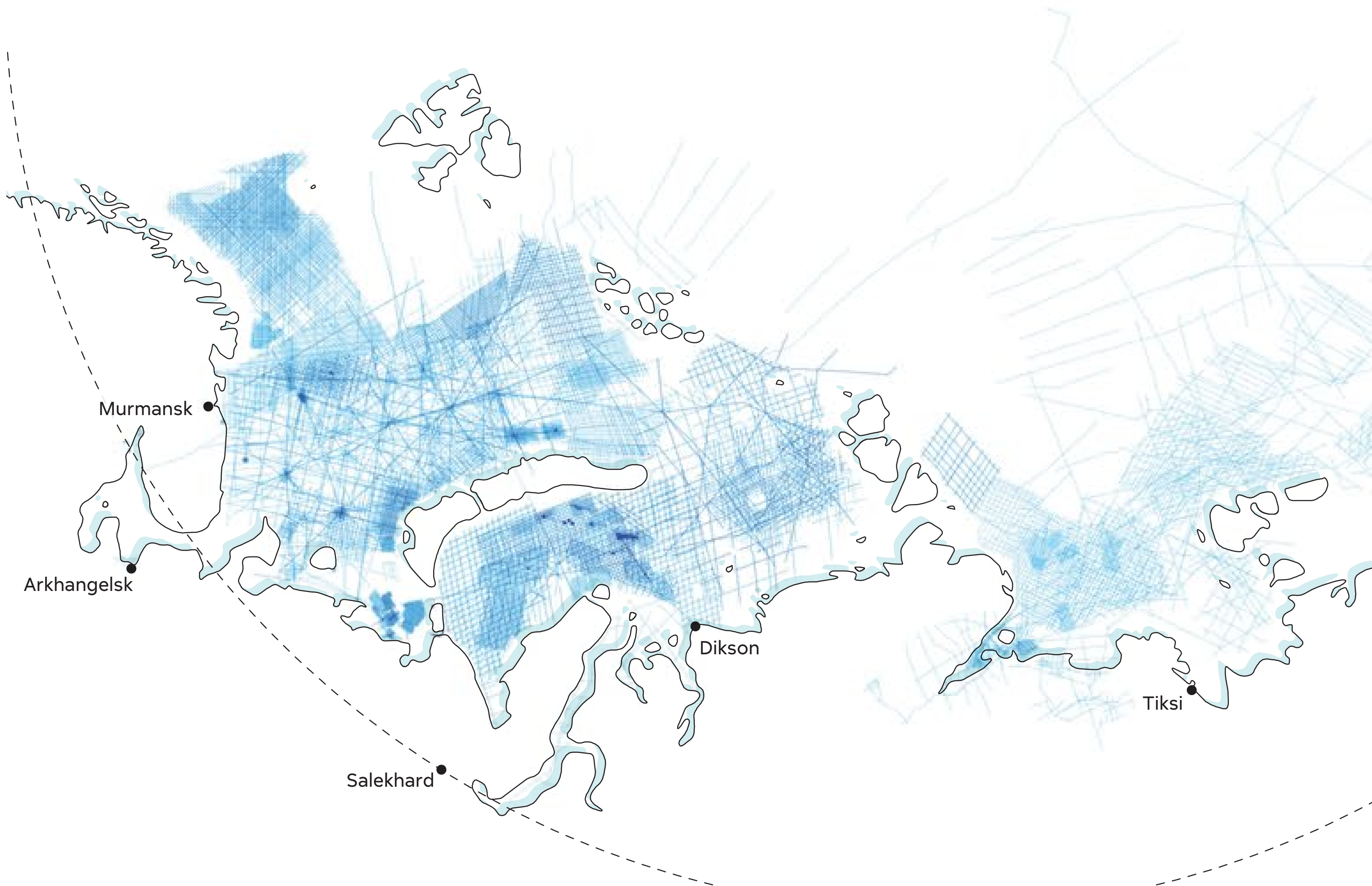
A **Sedimentary basin** is a part of the Earth's crust where prolonged sagging creates space for sediment accumulation. While deposits are underground, they are subjected to increasing pressure and heat. The processes of compaction and lithification begin, turning them into sedimentary rocks.

An **Oil and gas bearing basin** is a part of a sedimentary basin where the processes of generation, migration, accumulation and conservation of hydrocarbons (oil and gas) take place.

Goals of the regional stage of geological exploration

1. Study basic patterns of geological structure of understudied sedimentary basins.
2. Assess possible oil and gas content of the region, identifying the most promising zones and areas.
3. Determine priority areas for exploration.

Coverage of Russia's Arctic seas by 2D seismic surveys



Seismic exploration technique

Rosneft is focused on regional exploration which includes a large amount of geophysical work, primarily seismic surveys.

The method is based on the fact that there are differences in densities and velocities of elastic waves in different rocks. An elastic seismic wave is sent into the subsurface, which propagates at different velocities through different materials. The wave reflects from → p. 129 the boundaries of geological layers and comes back with modified properties to be recorded by a receiver. Scientists obtain information about the velocity of the elastic waves and the timing of their registration in each of the layers, which allows them to estimate the geological structure of the cross section. The result is a two- or three-dimensional image of rock layers that make up the subsurface of the Earth.

Seismic surveys require expensive equipment, and offshore seismic equipment must meet special environmental protection requirements. Rosneft has been carrying out 2D and 3D seismic surveys at the company's Arctic offshore license areas since 2012.

In the Western Arctic (in the Barents, Pechora and Kara Seas), the total length of seismic profiles performed by Rosneft is 70,353 km. In the Eastern Arctic, despite the fact that the Laptev, East Siberian and Chukchi Seas are traditionally regarded as less explored, the total length of 2D seismic survey profiles is slightly longer at 73,663 km.

Over

75 %

of all Rosneft's geophysical surveys carried out in the Arctic offshore are seismic surveys

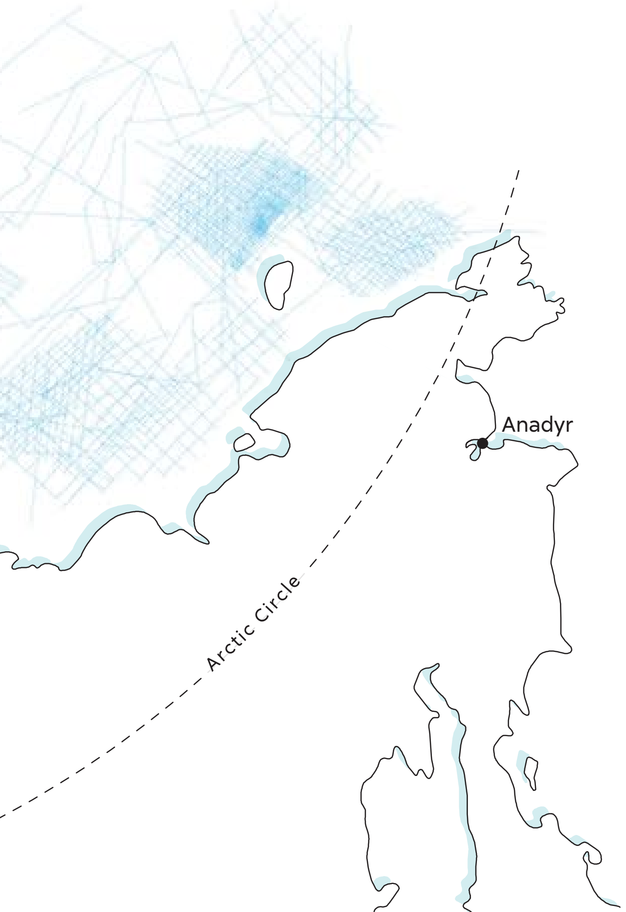
The concept of seismic surveying

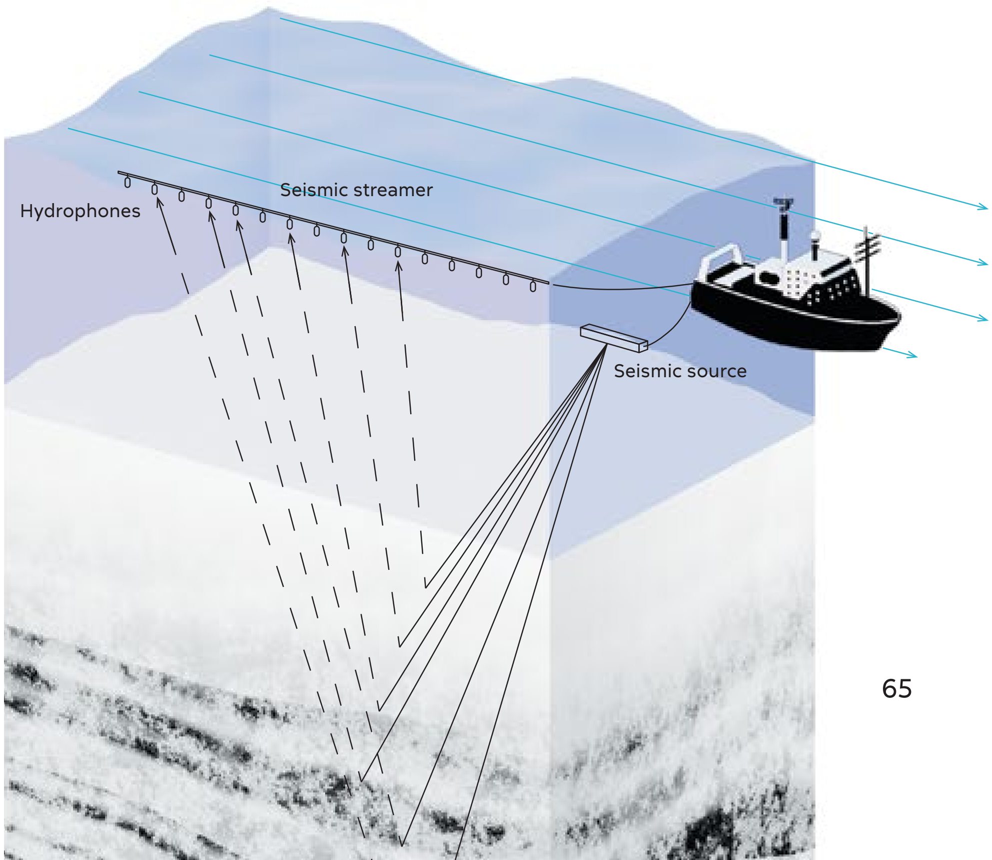
Seismic data is registered automatically when a ship with a seismic survey station is on the move. A seismic source (an air gun) produces elastic oscillations with a period of several seconds. These oscillations are captured by hydrophones on floating seismic streamers and are recorded on magnetic or digital media.

During digital processing the recorded data is used to create time and depth sections which are then interpreted to get an understanding of the main features of the geological structure → p. 130 of the study area.

The positioning of seismic streamers depends on the dimension of the seismic survey. In 2D exploration, the streamers are arranged in a straight line, while in 3D exploration they form a block of parallel lines.

A **Seismic streamer** is a cable with near-neutral buoyancy which is used to connect together hydrophones, seismic signal receivers.





Hydrometeorology

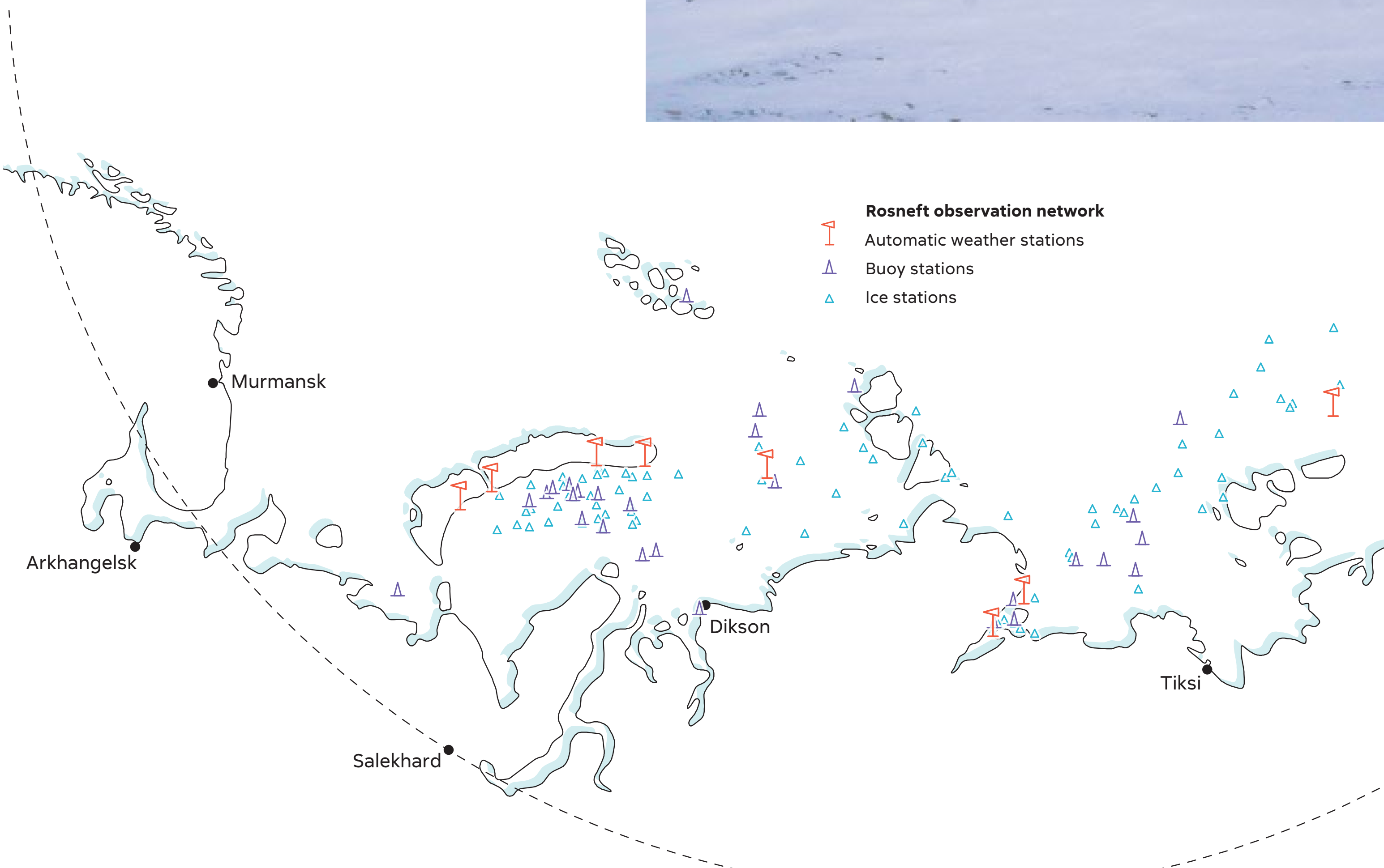
Exploration of promising territories should be conducted carefully and thoughtfully. Traditional technologies may be ineffective under extreme climatic conditions and proven equipment may not be suitable.

In order to adapt the existing solutions and develop new ones, reliable data on the conditions of their use is needed, including operating temperatures, sea current speeds, ice thickness and strength and others. Natural and climatic data is collected with the help of metocean surveys.

→ p. 72

Rosneft has deployed an extensive observation network of automatic meteorological and submerged autonomous buoy stations in the seas of the Russian Arctic. Its main purpose is to obtain metocean and oceanological data. The information is also of particular interest for climate research, since part of meteorological data is obtained from hard to access and previously unexplored areas of the Arctic, the "weather kitchen" of the Earth.

→ p. 142



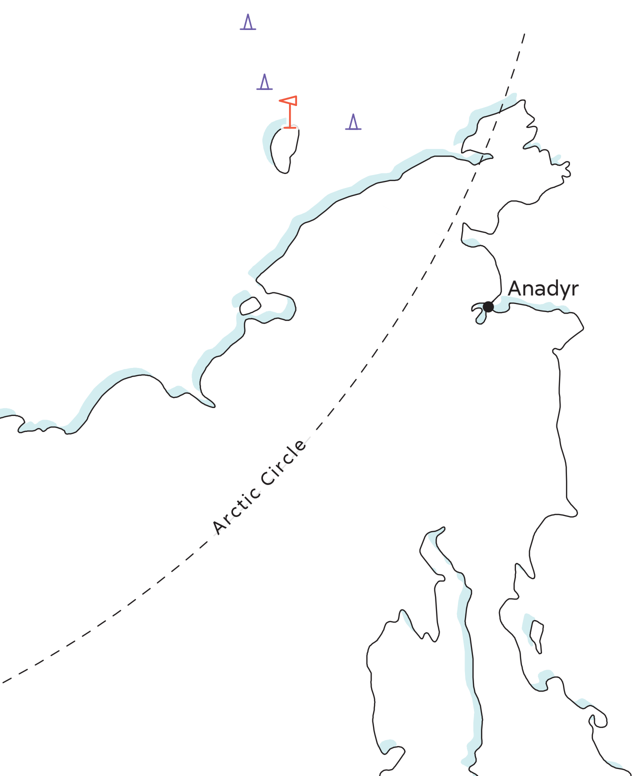
Automatic weather stations

Automatic weather stations (AWS) collect and transmit climatic data:
— air temperature and humidity;
— wind speed and directions;
— atmospheric pressure;
— solar activity;
— snow cover.

The deployed AWS are certified for the Arctic climate. Observations are transmitted via a satellite communication system as short messages and are continuously recorded in the device memory.

With the help of data obtained from the stations it is possible to:
— determine statistical characteristics and identify hazardous events;
— fine-tune mathematical models;
— provide information in real time to support operations.

Automatic weather station, Northern Island, Novaya Zemlya archipelago



Submerged autonomous buoy stations

Submerged autonomous buoy stations (SABS) record wave and sea level, currents by horizons, draft, ice drift direction and speed. The SABS are installed for up to a year at the depth of roughly 60 meters.

They make it possible to:
— determine statistical characteristics and identify hazardous events;
— fine-tune mathematical models.

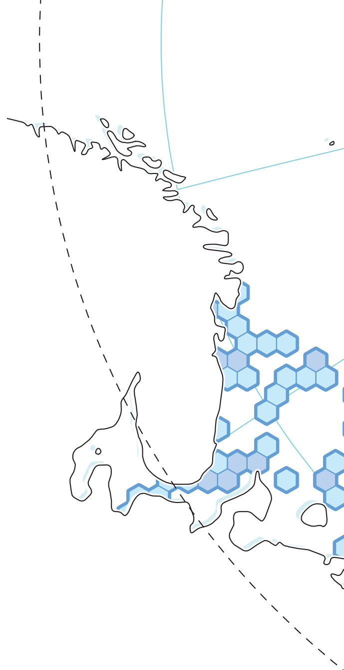
Another option for SABS installation is near-bottom. This kind of equipment attracts seabed dwellers whose eggs and colonies can be recovered when the stations are raised. There were also cases of more active impact on the stations: in the south of the Kara Sea a station was displaced by the keel of a large iceberg during a storm. Large marine mammals were also supposedly interested in the station.

SABS deployment in the Kara Sea

Automatic broadband seismic stations

The automatic broadband seismic stations (ABSS) were used to create a catalog of earthquakes which identified new earthquake centers in the Laptev Sea and the Khatanga Bay and compared them with the map of faults created using seismic survey data. Seismic velocity anomalies at the depths of 30–60 km were determined using tomography methods and compared to tectonic structures of the Laptev Sea.

Due to the fact that ABSS can record not only earthquakes, but also coastal ice breakup and anthropogenic noise, they are installed far way from any infrastructure and from the ocean coastline. To protect the ABSS and their battery packs from prying bears, stations are housed in large vandal-proof containers.



Shipboard marine fauna observations

When data about a region is scarce, scientists take advantage of every opportunity to obtain it. Information on marine fauna, bird and mammal sightings can be collected opportunistically, that is, directly from the ship while sailing. There is nothing dismissive about the use of the word "opportunistically" here. Such ship observations are an important part of complex Arctic expeditions, and for zoologists they provide a chance to fill the gaps in their knowledge of marine mammals in the Russian Arctic.

Complex expeditions are an excellent opportunity to collect additional material along the way. For example, scientists may find themselves in a hard to reach water area during the winter. The material collected along the ship's route not only makes it possible to update already known data on the distribution of marine mammal species, but also to add to it, which is especially important for the understudied central part of Russia's Arctic seas basin.

→ p. 78

The job of the observer

Offshore industrial activities, including seismic surveys, create underwater noise that affects cetaceans and pinnipeds, their ability to communicate and navigate. The job of the observers is not only to record encounters with fauna, they are also responsible for measures to protect them. They need to make sure that there are no vulnerable animals in the area of work, or at least to ensure that noise sources are turned on gradually, giving animals time to adapt or leave the area. The observer team is usually made up of three theriologists who work in shifts. They carry out observations throughout the daylight hours, which for high-latitude expeditions in the summer season means working round the clock. Observations are made from the highest platform on the vessel, most often from the wings of the bridge, and in bad weather, from inside the bridge.

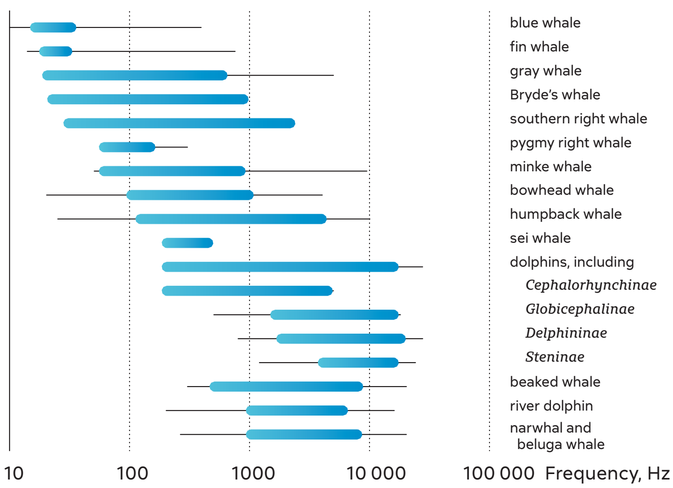
Tools and data

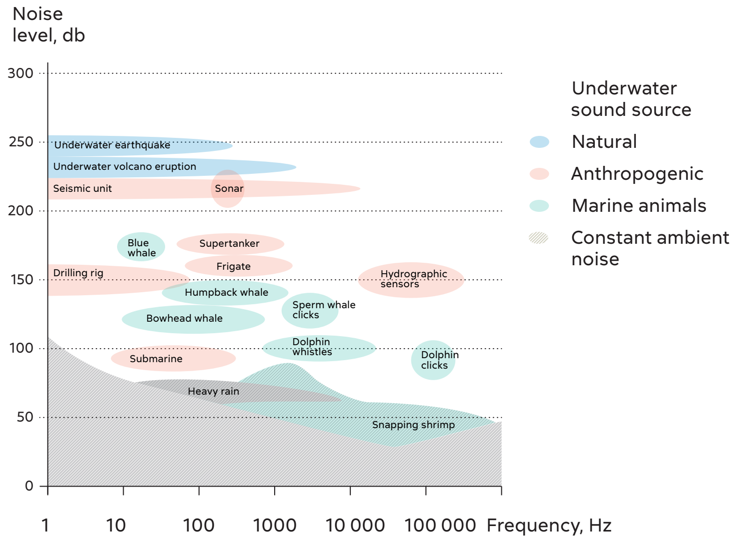
The observer watches over the area through a set of binoculars or with the naked eye. He or she records the species of animals and their numbers, their behavior, as well as the presence of cubs in the group. If possible, sex and age of animals is also determined.

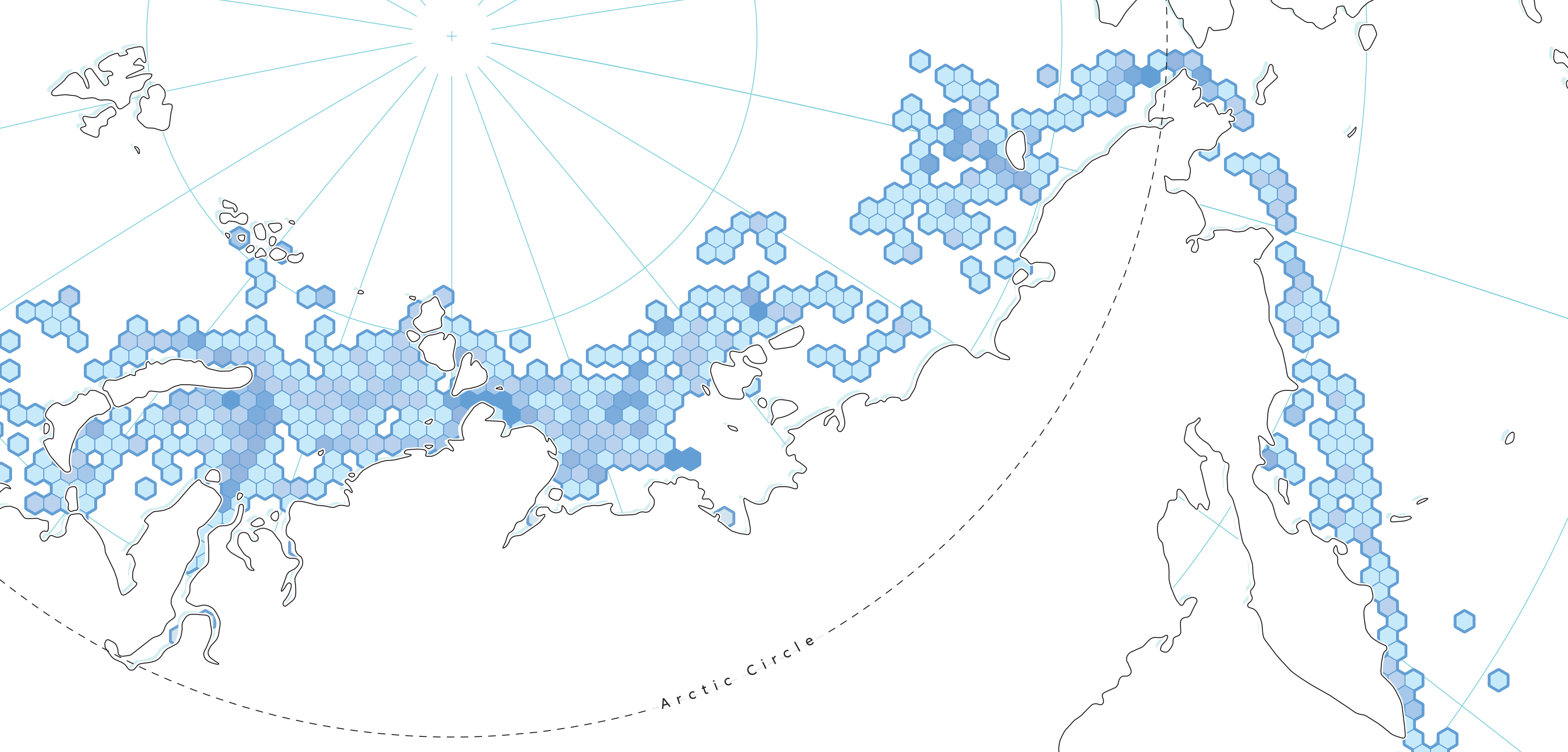
The distance to the animals is measured using range scales, reticle binoculars, shipboard radars, lidars and laser rangefinders. Coordinates of encounters are registered with a portable GPS receiver and geolocation equipment available onboard the vessel.

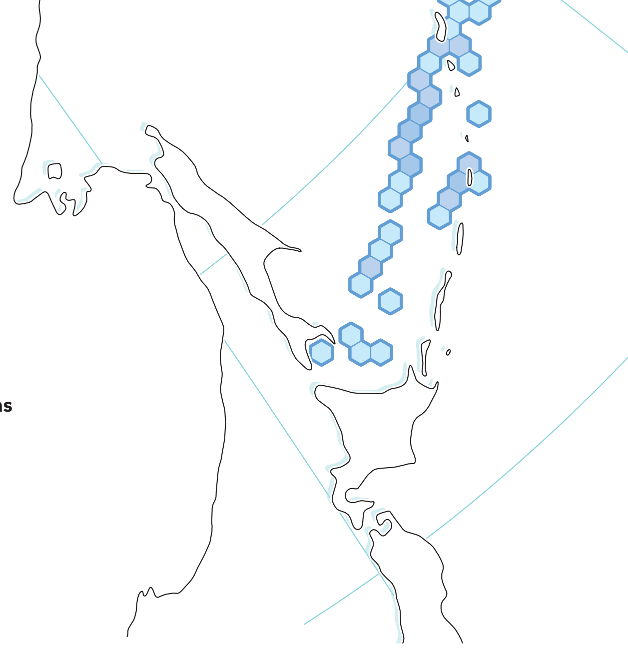
In addition to information about animals, special forms are used to record vessel course and speed, visibility, surface conditions and sea depth at the point of encounter, as well as ice cohesion and sea disturbance. This data is needed to assess the abiotic characteristics of the encounter area.

Voice and whistle ranges of cetaceans









Observation methodology

The company organized the first observations of marine mammals during geological and geophysical activities in 2012, followed by opportunistic shipboard observations during scientific expeditions in 2014.

At that time there were no unified recommendations for ship observations and data collections. There were standardized methods created for the waters of the Gulf of Mexico, the continental shelf of Great Britain, Canada and New Zealand, but it was impossible to use them without adaptation, as they did not take into account the specifics of the Arctic seas of Russia. Due to the difference in experience and scientific approach, researchers collected data in different formats, which made it difficult to process and compare it.

All observations that are being conducted today strictly follow the methodology developed in 2015 by Rosneft's Arctic Research Center in collaboration with the Marine Mammal Council of Russia. The methodology takes into account the specifics of working in the Arctic seas of Russia, standardizes methods of primary data collection, the format and parameters of encounter registration.

The recommendations include extensive reference material:
— assistance in identifying species of encountered animals;
— guidelines for collecting supplemental data: observation conditions, sea surface pollution;
— instructions on conducting observations safely, as well as handling and storage of collected data.

Results over 9 years

12 seasons

3 ice seasons, 9 ice-free seasons
Total span of expeditions with observations

2,022 days

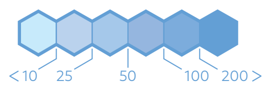
of uninterrupted observations in the seas of the Russian Arctic and the Far East

5,987

encounters with marine mammals and polar bears

14,812

animals encountered



Collecting Metocean Data

Expeditions: collecting metocean data

A number of Arctic expeditions are partly or sometimes completely devoted to collecting information about climate, ice conditions and the state of the region's hydrosphere. Metocean data is needed to address applied and long-term tasks: to ensure the safety of exploratory drilling units and the next expedition, to establish parameters of design solutions that will make possible construction and operation of stationary facilities and ensure safe logistics.

Metocean objects of research

It is impossible to explore and develop the Arctic without knowing the state of the climate system: air temperature, water salinity, currents and ice conditions.

Absolutely accurate data is unlikely to be available, but knowledge of thresholds and general patterns → p. 25 is essential for navigation of the northern seas and designing structures. This information is obtained through direct data collection during expeditions and later used to create a more accurate picture of metocean conditions of the region.

The research comes down to collecting data on objects of the hydrosphere, cryosphere and atmosphere. Such objects include:

— seawater: temperature, salinity, character of currents in the summer and winter;
— sea ice: thickness and strength (during winter);
— atmosphere: temperature, speed, direction;
— icebergs: size and shape, drift trajectory, possibilities for towing;
— glaciers: current velocity, power and size of the "tongue" coming out into the water area for forecasting iceberg discharge;
— hummocks and stamukhas: size, shape and strength properties.

Deployment of a submerged autonomous buoy station (SABS), Chukotka-Summer 2015

Expedition goals and research methods

Data collection requires installation of instruments appropriate to the needs of study of different objects, and the subsequent maintenance of the instruments to ensure data series are obtained in a reliable and uninterrupted manner.

→ p. 146

Data collection methods and techniques	Data
SEA ICE	
Ice stations, ice field studies, thermal drilling	Physical and mechanical properties of level ice and ice formations
SEAWATER	
Submerged autonomous buoy stations (SABS)	Speed and direction of currents by horizons, sea level, water temperature, wave parameters, speed and direction of the drift of ice and sediment ice formations
CTD profilings	Vertical distribution of water salinity, temperature and density
ATMOSPHERE	
Automatic weather stations (AWS)	Air temperature and humidity, atmospheric pressure, wind speed and direction
HUMMOCKS AND STAMUKHAS	
Tacheometric surveying	Above-water dimensions
Thermal drilling	Internal structure
Sonar surveying	Underwater dimensions of hummocks and keel contours
ICEBERGS	
Deployment of GPS-equipped buoys	Movement parameters
Sonar surveying	Shape and dimensions of the underwater part
ICE FIELDS	
Deployment of radio buoys on ice fields and ice formations	Drift parameters
GLACIERS	
Thickness surveying	Estimation of possible iceberg sizes and ice consumption for their production
Aerial photography	Current above-water dimensions

Organization of metocean expeditions

In order to observe the studied objects in all necessary states, expeditions were conducted in the summer and winter. The names of the expeditions are thus formed by combining the name of the region with the season, meaning Kara-Summer is a summer expedition to the Kara Sea.

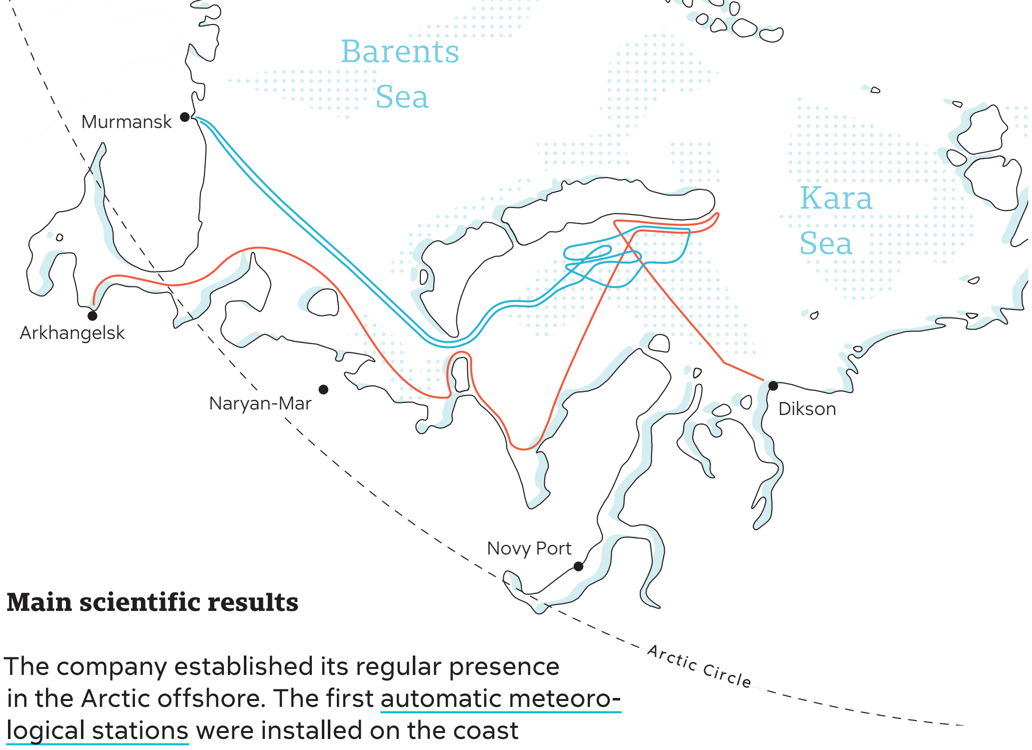
Considering a variety of research activities during the expedition, all of the following were involved:
— research vessels;
— scientific expedition vessels with on-deck helicopters;
— nuclear and diesel-electric icebreakers;
— unmanned aerial vehicles;
— temporary field bases equipped with helicopters.

→ p. 180

The use of ships and helicopters made it possible to study metocean conditions over a large water area, while the observation infrastructure and the field camp provided researchers with year-round data on the parameters and properties of sea ice at a static measurement point.

The analysis and summarizing of the data obtained over 3–5 years made it possible to explore the spatial and temporal variability of conditions in different water areas, both in deep waters where there are promising prospecting sites, and in the coastal zone, which is important for ensuring safe logistics.

Expedition Summer 2012

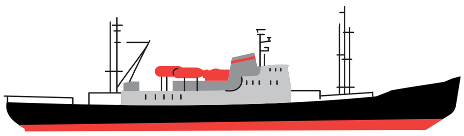


54 days

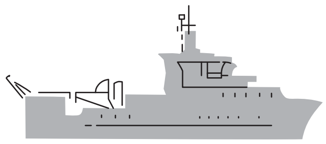
Kara-Summer

July 29 — August 17, 2012
July 26 — August 30, 2012

Work carried out in the southwestern part of the Kara Sea.



Scientific expedition vessel Mikhail Somov



Research vessel Fridtjof Nansen

Key expedition objectives

— Install automatic weather stations on the coast of Severny Island, Novaya Zemlya archipelago;

— monitor metocean and ice conditions, drift parameters of icebergs and their fragments;

— asses the size, shape and movement of ice cover, sea level fluctuations and currents.

Main scientific results

The company established its regular presence in the Arctic offshore. The first automatic meteorological stations were installed on the coast of the Novaya Zemlya archipelago and islands of the Kara Sea.

→ p. 67

Strong winds blowing from the mountainous coast of Novaya Zemlya towards the sea were studied. Extreme values of wind speed and gusts were recorded, which should be taken into account when conducting operations in the area. On the night of August 9–10, 2012 wind speed reached 26 m/s with strongest gusts reaching 55 m/s (approximately 200 km/h). Storm develops over 3–4 hours and is difficult to predict, which is why it poses a significant danger to offshore and helicopter operations near the coast of Novaya Zemlya.

2 deployments of automatic weather stations

6 redeployments of buoy stations

4 deployments of drifting buoys on icebergs

82 oceanographic soundings

Drifting iceberg fragments in the Kara Sea

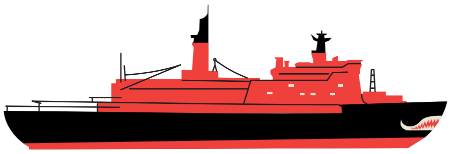
Expedition | Winter | 2013

Kara-Winter

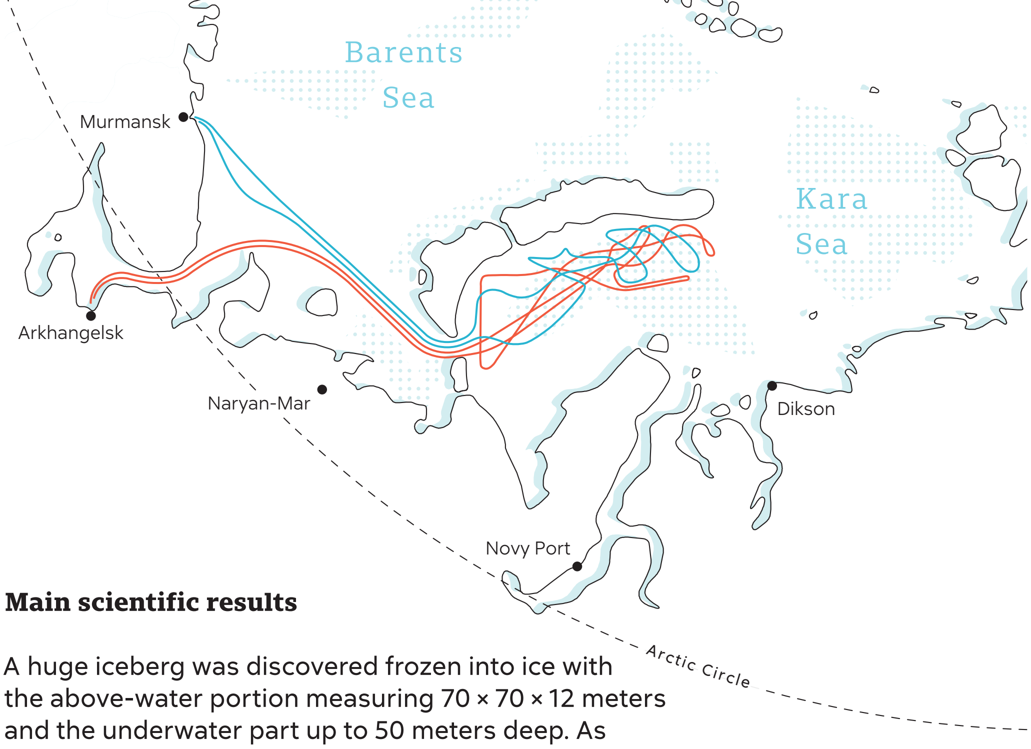
29 days

April 30 — May 28, 2013

Work carried out in the southwestern part of the Kara Sea.



Yamal nuclear icebreaker



22 ice stations

22 ice fields studied

35 hummock ridges studied

1,290 thermal drilling boreholes

Results

Thickness surveying of level ice	358 measurements
Ice temperature	28 cores
Ice salinity and density	22 cores
Ice texture	23 cores
Ice plate bending test	16 cores
Ice compression test, parallel samples	297 cores
Local strength test	662 tests
Consoles tested	8 consoles
Oceanographic sounding	23 stations
Current measurements at ice stations	23 stations
Ice gouging studies	8 surveys
Underwater keel surveying	22 surveys

Key expedition objectives

— Conduct satellite monitoring of icebergs and giant ice fields and measurement of drift parameters;

— determine sizes, shapes, and relief of icebergs, hummocks and smooth ice;

— determine physical properties and strength of smooth and deformed ice.

Main scientific results

A huge iceberg was discovered frozen into ice with the above-water portion measuring 70 × 70 × 12 meters and the underwater part up to 50 meters deep. As the iceberg freezes into the ice, a belt of hummocks is formed around it. This leads to a manyfold increase in ice formation mass and requires a special approach to the design of gravity platforms for year-round hydrocarbon production. The ice in the Kara Sea is dynamic, with ice drift rates reaching 2 km/h, which leads to the formation of ice hummocks. The hummock belt near Novaya Zemlya is a significant obstacle for exploration of deep water structures of the Kara Sea. The maximum keel depth of the studied hummocks was 26 meters which exceeds keel depths of Sakhalin offshore hummocks (up to 23.2 meters).

→ p. 167

Protecting antennas from bears

It was discovered that the automatic metocean station equipment installed on Severny Island of the Novaya Zemlya archipelago is of particular interest to polar bears: the antennas of the meteorological stations were broken. To protect them, a special structure safe for bears was installed.

Preparation of ice cores for studying their physical and mechanical properties

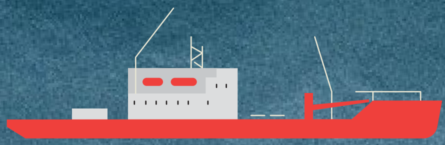
Expedition Summer 2013

35 days

Kara-Summer

July 12 — August 16, 2013

Work carried out in the southwestern part of the Kara Sea.



Scientific expedition vessel Akademik Fedorov

Key expedition objectives

— Install an automatic metocean station on the eastern coast of the Novaya Zemlya archipelago;

— conduct a detailed hydrological surveying of the water area and CTD sounding;

— collect data on iceberg dynamics, update the catalog of icebergs of the southwestern part of the Kara Sea.

3 deployments and inspections of automatic weather stations

6 redeployments of buoy stations

20 deployments of drifting buoys on icebergs

86 oceanographic soundings

Main scientific results

A complex of metocean measurements was conducted. Submerged autonomous buoy stations (SABS) were redeployed for another year of service in the area of Ragozinskaya, Nansen, Universitetskaya, Vikulovskaya, Tatarinovskaya and Matusevich geological structures. Two SABS were deployed for measuring sea currents, sea level and sea wave parameters for the duration of the expedition and lifted at its end. Materials on morphometry and dynamics of icebergs were collected; the catalog of icebergs of the Kara Sea was updated.

→ p. 67

700 kilometers of glaciers

Thanks to the unique Russian software and hardware systems, radar scanning and aerial photography of over 700 km of glaciers on the archipelagos of Novaya Zemlya, Severnaya Zemlya, De Long Islands, as well as of around 1,000 large icebergs was conducted. Thus, 90 % of the glaciers of the Russian Arctic were studied.

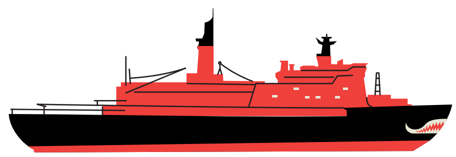
Expedition Winter 2014

61 days

Kara-Winter

April 8 — June 8, 2014

Work carried out in the Kara, Laptev and East Siberian Seas.



Yamal nuclear icebreaker

35 ice stations

35 ice fields studied

49 hummock ridges studied

1,836 thermal drilling boreholes

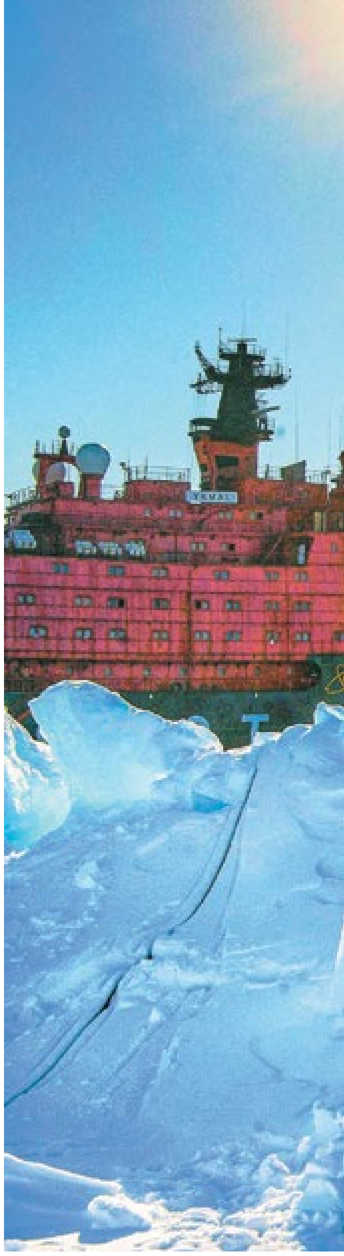
36 current measurements at ice stations

50 underwater keel surveys

35 oceanographic soundings

Main scientific results

— A complex of ice and metocean measurements at 35 stations was conducted, automatic buoys were installed on ice fields and icebergs to determine their drift;
— aerial photography of icebergs and hummock ridges was carried out from a helicopter and an unmanned aerial vehicle;
— underwater surveys of iceberg and hummock keels were conducted, 3D models of ice formations were created.



Results

Studied icebergs or stamukhas	4 icebergs
Thickness surveying of level ice	990 measurements
Ice temperature	56 cores
Ice salinity and density	44 cores
Ice texture	34 cores
Ice plate bending test	24 cores
Ice compression test, parallel samples	360 cores
Local strength test	935 tests
Consoles tested	27 consoles
Ice gouging studies	22 surveys

Key expedition objectives

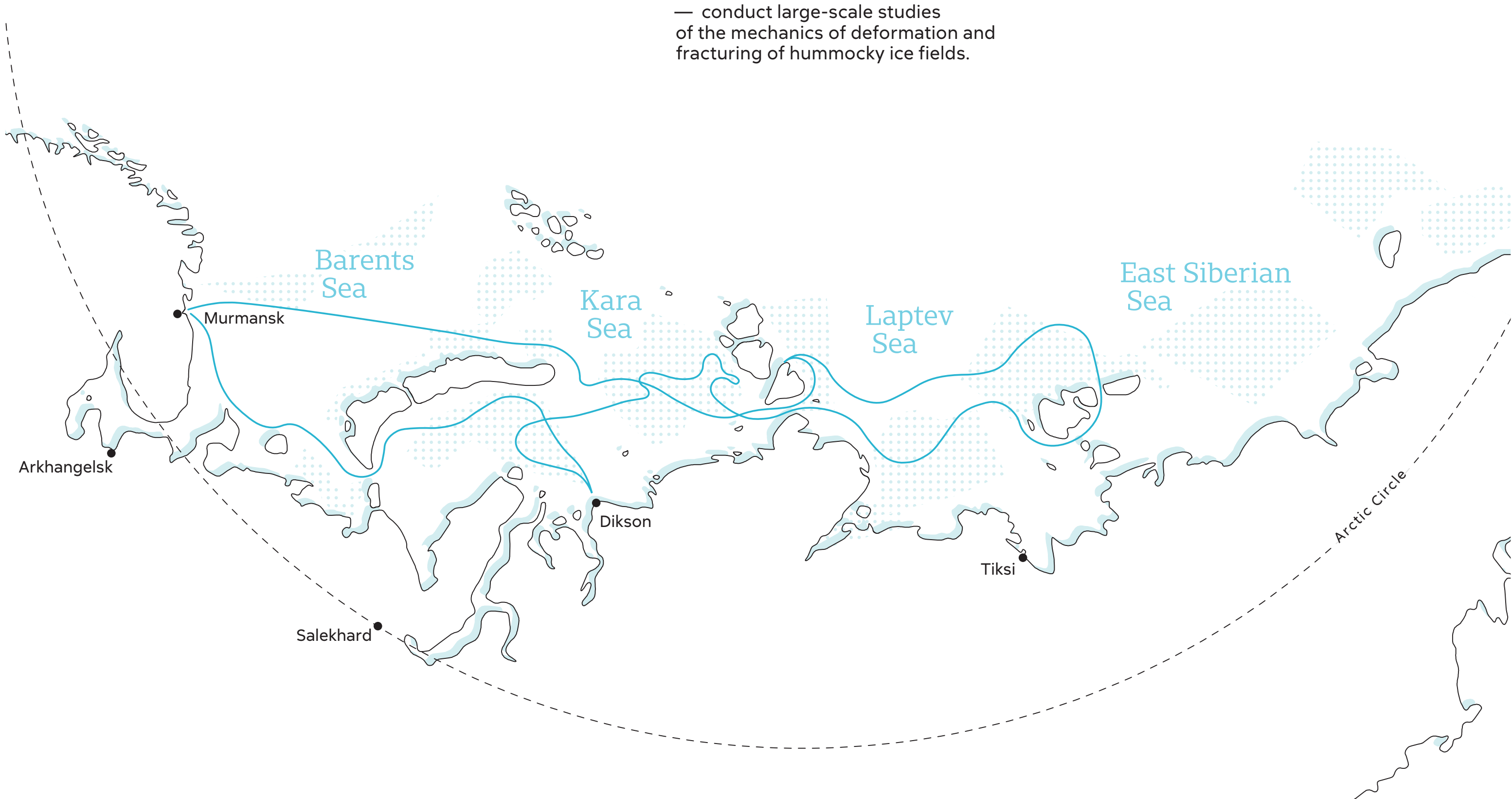
— Conduct satellite radar monitoring of icebergs and stamukhas in the operation area;

— determine characteristics of gouges in bottom soil;

— measure iceberg and ice field drift, study the dynamic processes in the "sea ice — iceberg" system;

— measure the thermohaline structure of waters and subglacial currents;

— conduct large-scale studies of the mechanics of deformation and fracturing of hummocky ice fields.



Studying the internal structure of a hummock

Thermal drilling of smooth sea ice

Drifting iceberg fragment in the Kara Sea

Deployment of a submerged autonomous buoy station

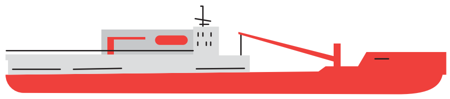
Expedition | Summer | 2014

55
days

Kara-Summer

July 30 — September 22, 2014

Work carried out in the Kara, Laptev, East Siberian and Chukchi Seas.



Scientific expedition vessel Akademik Tryoshnikov

3 deployments and inspections of automatic weather stations

16 redeployments of buoy stations

62 deployments of drifting buoys on icebergs

177 oceanographic soundings

673 km of radar glacier surveys

Key expedition objectives

— Gather data about thermohaline conditions in the study area;

— evaluate iceberg parameters using aerial photography;

— conduct radar and aerial photography of frontal parts of glaciers at the Novaya Zemlya and Severnaya Zemlya archipelagos;

— search for submarine discharge zones of hydrocarbons migrating from oil deposits.

Main scientific results

It was determined that the Moschny and Nansen glaciers are the most productive in terms of icebergs on the eastern coast of Novaya Zemlya. The glaciers are covered with a network of cracks, which leads to the formation of small icebergs, most of which remain aground near the glaciers and are destroyed. Typical linear size of icebergs in the southwestern part of the Kara Sea is 40–60 meters. Individual icebergs or iceberg fragments reach prospective structures of the East Prinovozemelsky field license areas. In August 2012, one of the icebergs was drifting in the area of the Universitetskaya structure for about two weeks.

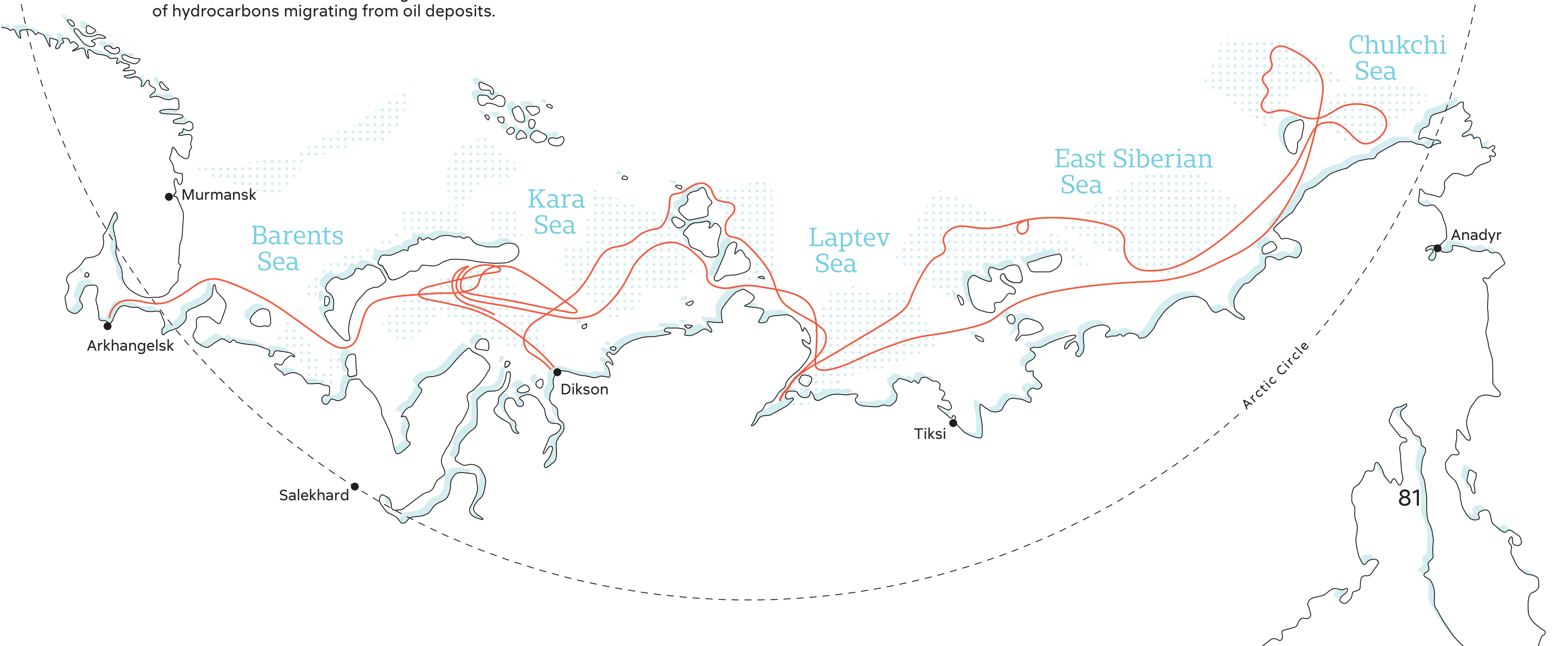
→ p. 172

Trenches left by bottom ice gouging up to 0.5 meters deep were found at the Universitetskaya and Ragozinskaya structures. In contrast to the Pechora Sea and the Sea of Okhotsk, the ice gouging is caused by icebergs rather than hummocks, which leads to trenches appearing at greater sea depths. The maximum depth of the sea at which gouging was detected is 60 meters.

→ p. 157

Keeping an eye on the climate

An observation network of seven island meteorological stations and 16 submerged autonomous buoy stations was deployed. A unique archive of observations of hydrological parameters in the waters of the Russian Arctic seas was compiled, making it possible to assess seasonal and inter-annual variability of parameters.



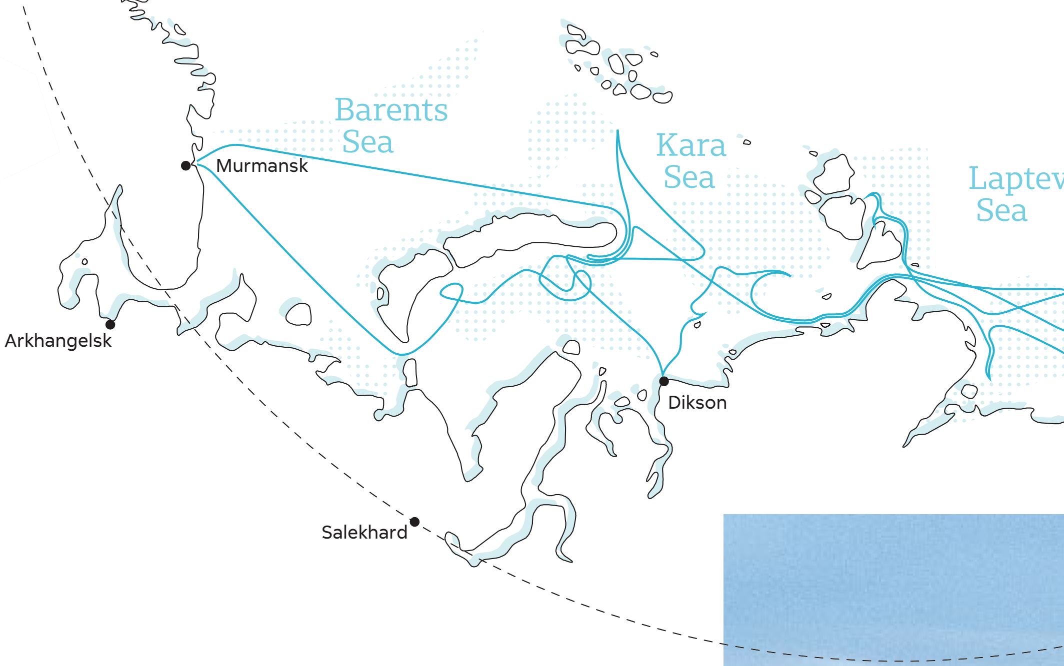
Expedition · Winter · 2015

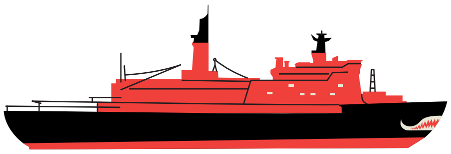
68 days

Kara-Winter

April 8 — June 15, 2015

Work carried out in the Barents, Kara, Laptev and East Siberian Seas.





Yamal nuclear icebreaker

34 ice stations

33 ice fields studied

35 hummock ridges studied

31 oceanographic soundings

66 underwater keel surveys

30 current measurements at ice stations

1,768 thermal drilling boreholes

Results

Studied icebergs or stamukhas	5 icebergs
Thickness surveying of level ice	741 measurements
Ice temperature	73 cores
Ice salinity and density	68 cores
Ice texture	74 cores
Ice plate bending test	69 cores
Ice compression test, parallel samples	189 cores
Local strength test	1825 tests
Consoles tested	25 consoles
Ice gouging studies	21 surveys

→ p. 178

Key expedition objectives

— Determine the parameters of level ice, hummocky formations, icebergs, ridges of hummocks and stamukhas, determine the strength of smooth and deformed ice;

— measure the thermohaline structure of waters and subglacial currents;

— conduct radar and aerial photography of the frontal parts of the glaciers of the Franz Josef, Novaya Zemlya, Severnaya Zemlya archipelagos and De Long Islands;

— carry out large-scale studies of the mechanics of deformation and fracturing of hummocky ice fields.

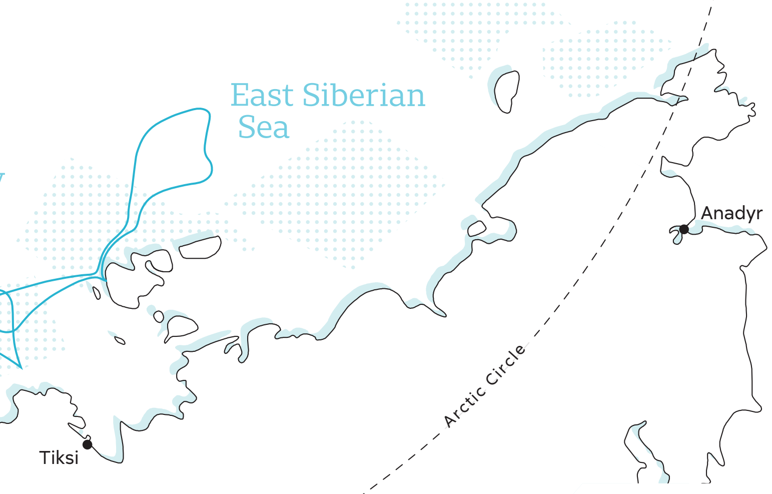
Main scientific results

A complex of meteorological, oceanographic, ice, glaciological and biological observations was carried out. Specialists performed over 2,000 measurements of physical and mechanical properties of ice at 35 ice stations to calculate the load on engineering structures that are being designed. Additionally, over 100 autonomous sensors were installed on icebergs and ice fields to measure drift parameters and trace their coordinates. Frontal parts of glaciers were studied using radar and aerial photography. Unmanned aerial vehicles were also used to study the ice cover, allowing to determine the distribution of hummock ridges and their geometric dimensions. Remotely operated underwater vehicles and sonars were used to study the structure of the seabed, hummock keels and icebergs.

Hummock catalog

One of the most extensive databases of hummocks in the world was created, containing around 200 hummocks and stamukhas. A unified classification for Arctic hummocks based on the shape of their underwater part was developed and implemented.

Glacier of the Novaya Zemlya archipelago


East Siberian
Sea
Anadyr
Arctic Circle
Tiksi

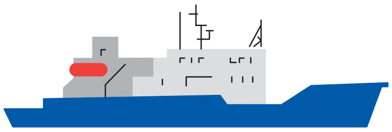
Expedition Summer 2015

Kara-Summer

26 days

August 22—September 17, 2015

Work carried out in the Kara, Laptev and East Siberian Seas.

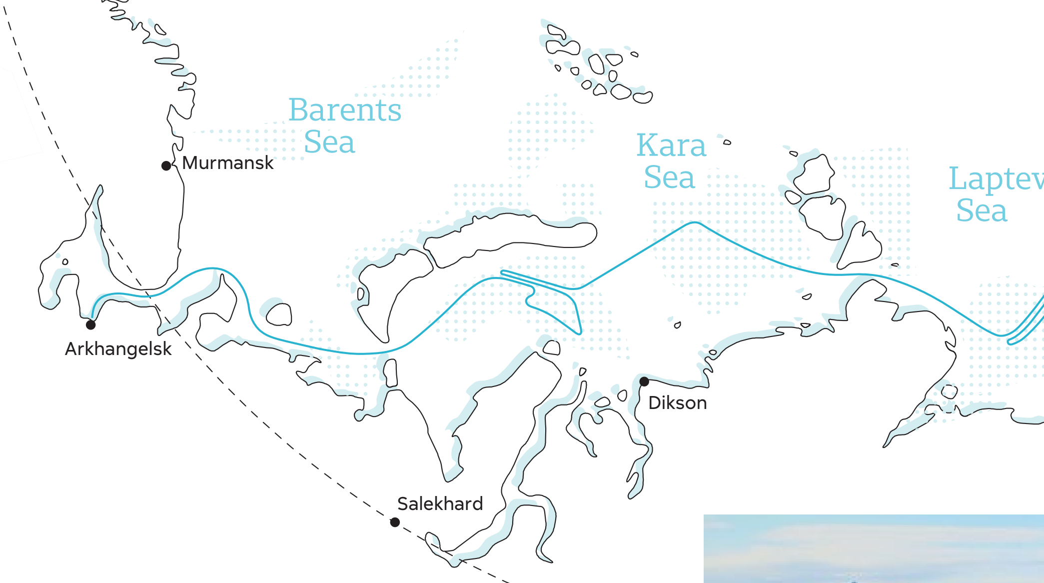


Research vessel Viktor Buynitskiy

6 inspections of automatic weather stations

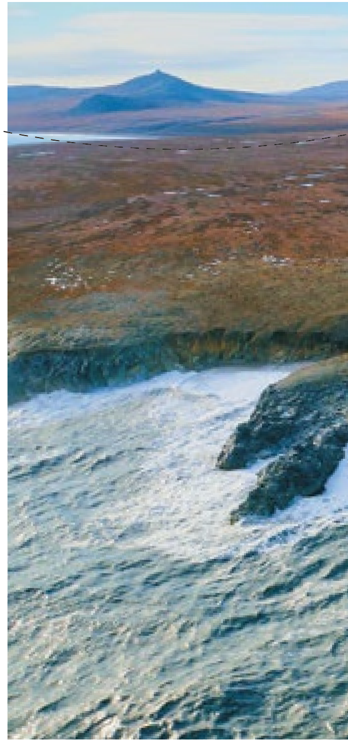
11 redeployments of buoy stations

407 km of radar glacier surveys



Where icebergs are born

Glaciers on the Novaya Zemlya, Franz Josef Land and Severnaya Zemlya archipelagos produce 70 % of icebergs of all glaciers in the Russian Arctic. A forecast of iceberg formation for the next 50 years was created.

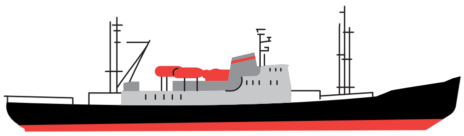


Chukotka-Summer

14 days

September 21—October 4, 2015

Work carried out in the Chukchi Sea. This was the tenth research expedition organized by Rosneft.



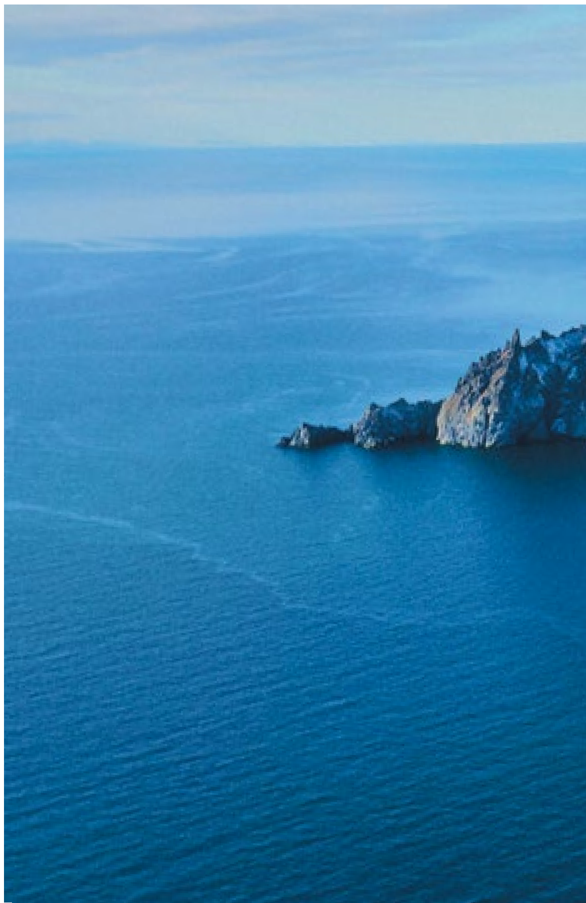
Scientific expedition vessel Mikhail Somov

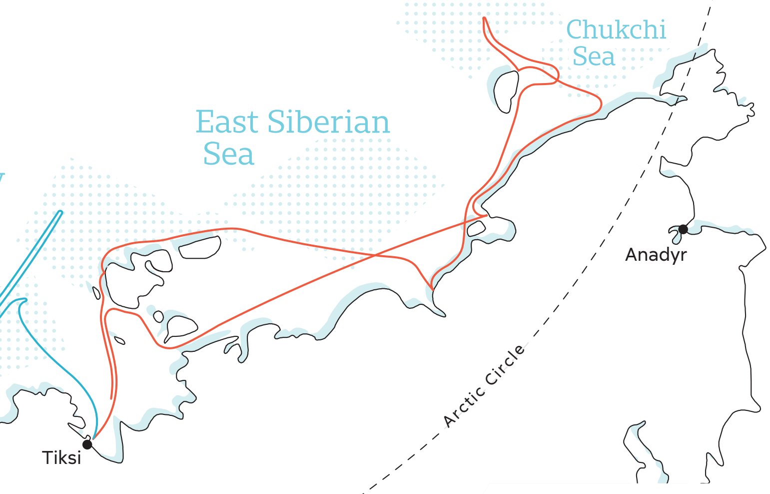
1 deployment of automatic weather stations

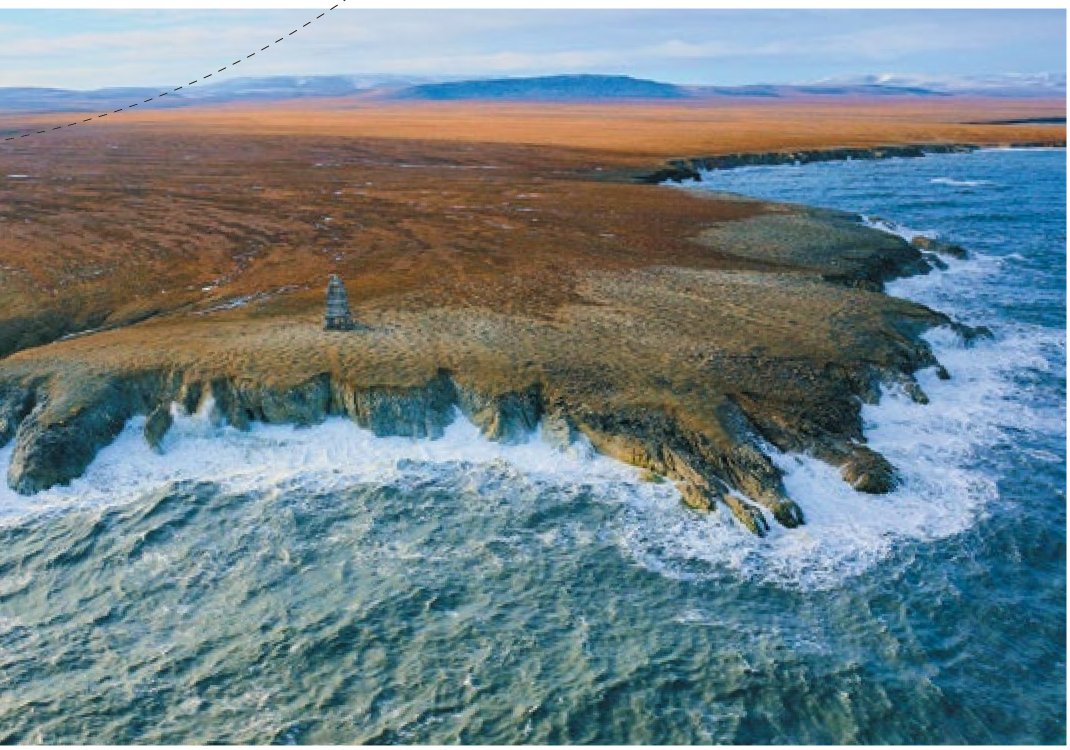
3 redeployments of buoy stations

Main scientific results

Herald Island in the Chukchi Sea, located 70 km east of Wrangel Island and previously inaccessible to researchers, was studied. Automatic weather stations were deployed. A previously unknown walrus rookery was discovered.







Lighthouse on the coast of Wrangel Island

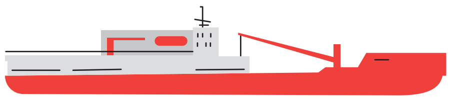
Expedition · Summer · 2016

Kara-Summer

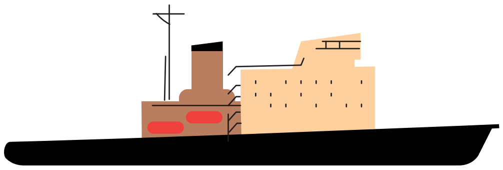
90 days

August 2 — October 9, 2016
September 10 — October 10, 2016

Work carried out in the Barents, Kara, Laptev and East Siberian Seas.



Scientific expedition vessel Akademik Tryoshnikov

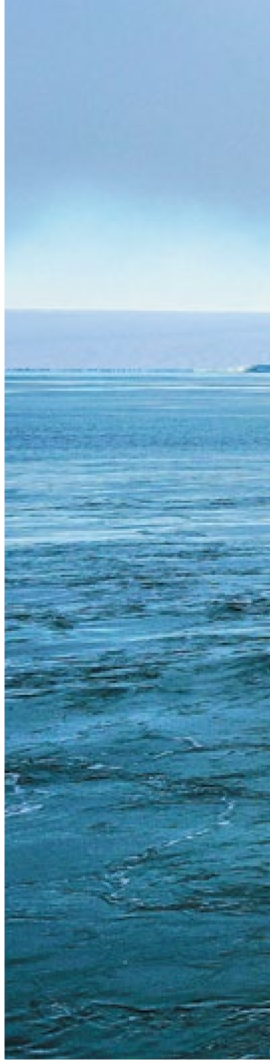


Diesel-electric icebreaker Kapitan Dranitsyn

Main scientific results

For the first time in Russia, a unique technology to change the drift trajectory of icebergs by an external force was tested. Specialists have successfully towed an iceberg weighing over one million tons, which was not only the first such accomplishment in the Russian Arctic, but also a significant event in world practice. → p. 175

— World's first towing of icebergs in the presence of ice in the water area was carried out, as well as several towings of icebergs weighing over one million tons;
— technical solutions for towing icebergs in the Barents and Kara Seas were tested;
— several subglacial geographic objects were discovered, including future islands of the Kara and Laptev Seas.



6 deployments and inspections of automatic weather stations

11 redeployments of buoy stations

24 deployments of drifting buoys on icebergs

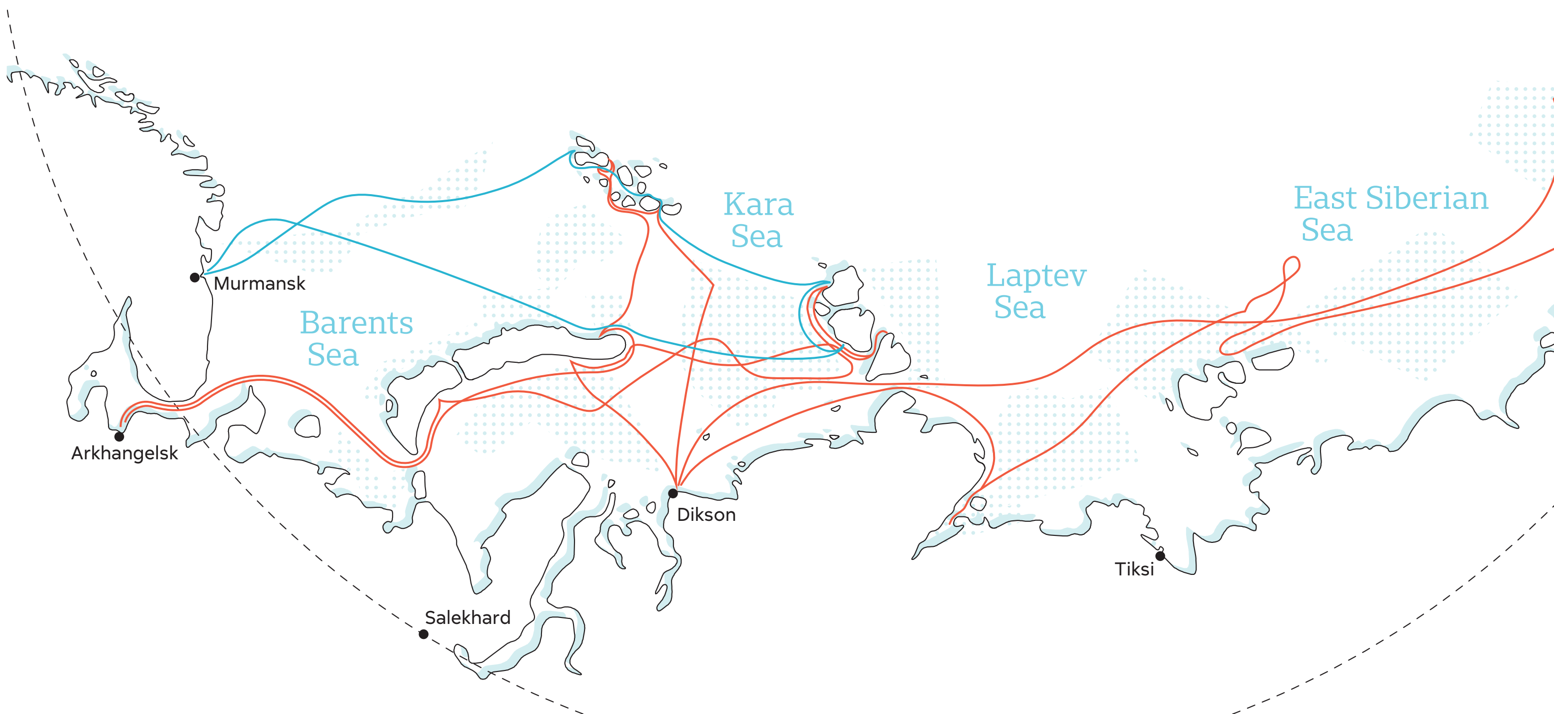
46 oceanographic soundings

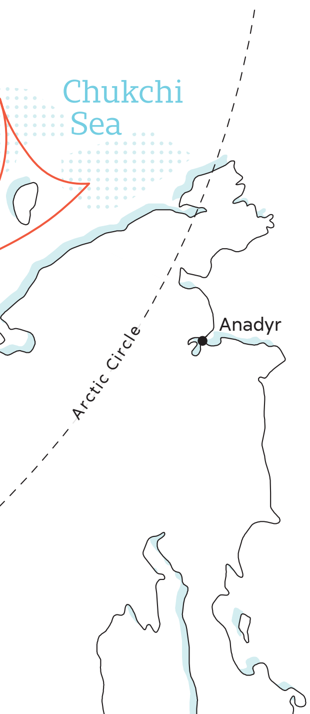
18 iceberg towings

622 km of radar glacier surveys

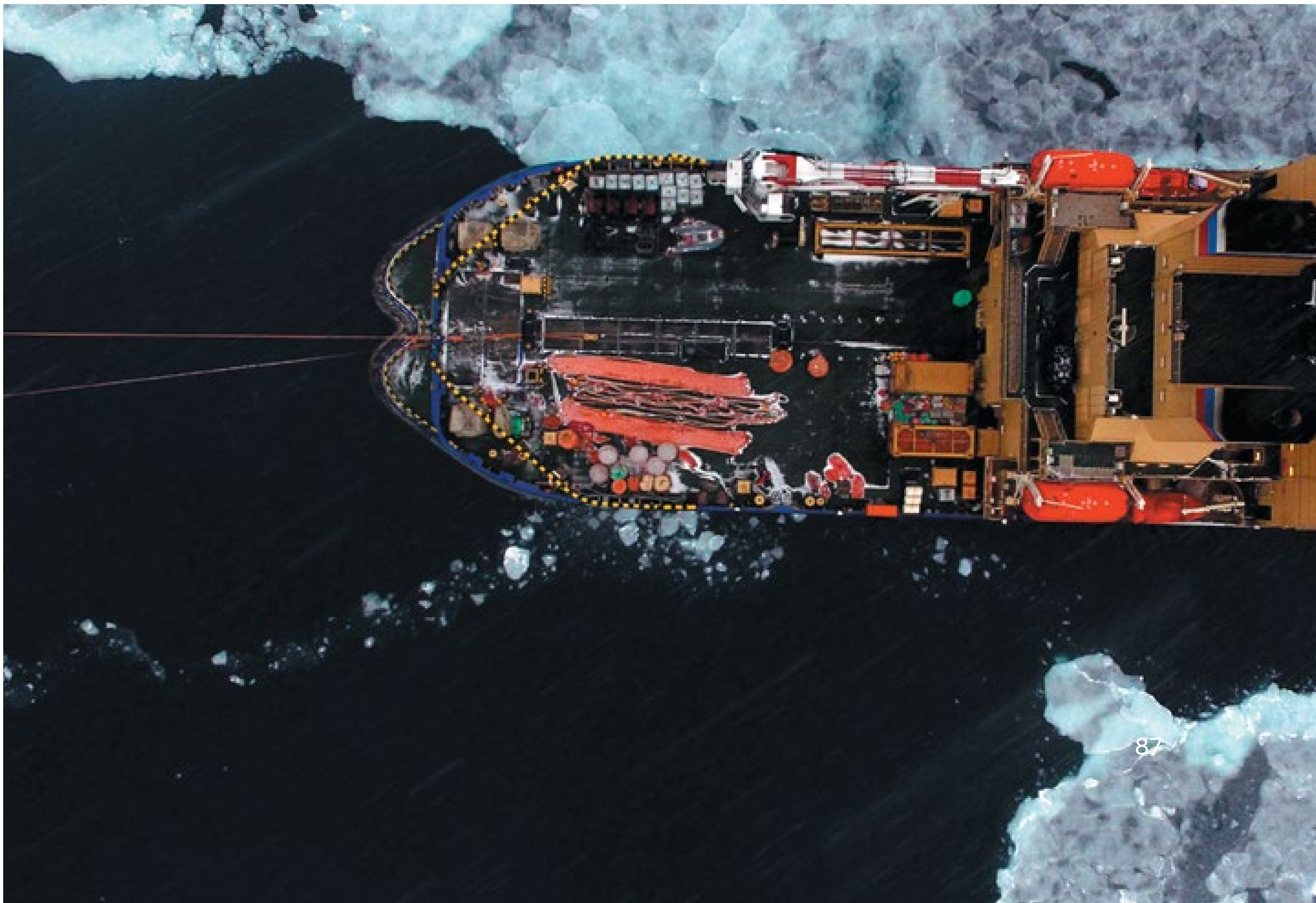
→ p. 91

Overall, in 2016 and 2017 a total of 36 experiments on towing icebergs of various shapes and sizes in a wide range of weather conditions were conducted. Icebergs were towed using icebreakers, changing the direction of travel 90 and 180 degrees relative to their original drift trajectory. Experiments on towing icebergs under conditions of initial ice formation and polar night were also carried out. The experience gained will make it possible to protect marine infrastructure facilities from icebergs when conducting economic activity in the Arctic offshore. In addition to changing the trajectory of icebergs, scientists studied them in detail. Above-water and underwater surfaces of icebergs were surveyed, buoys were installed to determine their drift and rotation parameters and 3D models of icebergs were built.

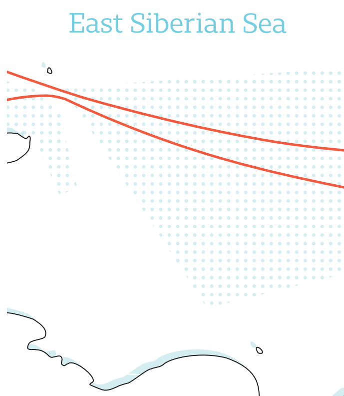




Iceberg towing, view from above



Study of the thermohaline structure, descending a rosette sampler with a bathometer

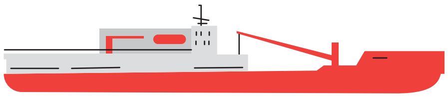


Expedition Summer 2016

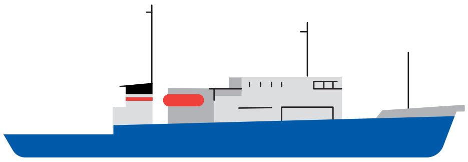
Chukotka-Summer

July 15 — August 1, 2016
September 1 — 9, 2016

Work carried out in the Chukchi Sea.



Scientific expedition vessel Akademik Tryoshnikov



Research vessel Professor Multanovskiy

1 inspection of automatic weather stations

2 redeployments of buoy stations

177 oceanographic soundings

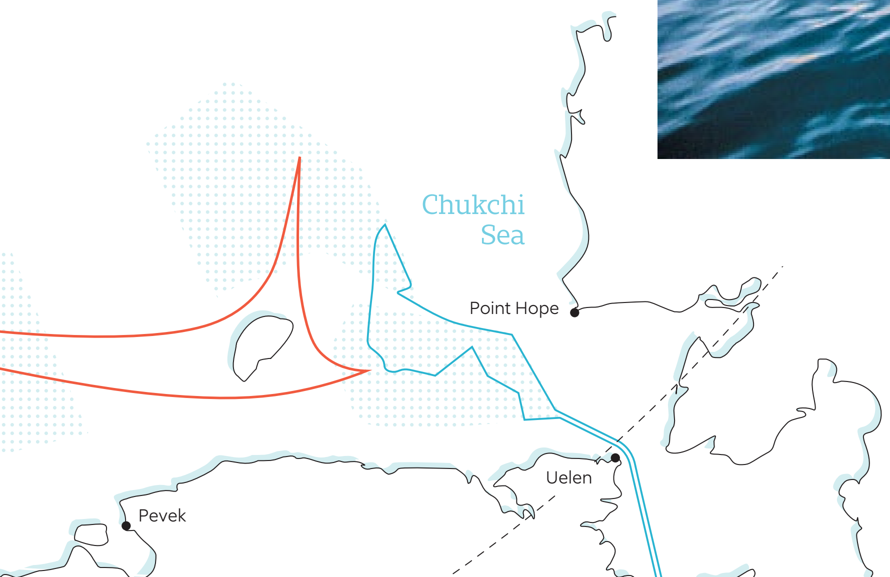
Key expedition objectives

— Study the thermohaline structure of the waters, lift and redeploy two instruments assessing the characteristics of ice cover, sea level fluctuations and currents;

— conduct preventive maintenance of automatic meteorological and seismic stations installed on Wrangel Island.

Main scientific results

Data on summer metocean and ice conditions in the Chukchi Sea was collected. This is necessary to assess the impact of environmental parameters during the development of the company's license areas. Maintenance and redeployment of submerged autonomous buoy stations in the area was carried out, allowing to analyze the annual variability of ice cover, sea level fluctuations, waves and currents in the Chukchi Sea license areas. An automatic weather station was installed on Wrangel Island in the Chukchi Sea as part of the program to restore the meteorological observation system in the Arctic which has been underway since 2012. A seismic station was installed as part of a stationary system of seismic activity monitoring.



Expedition · Winter · 2017

Khatanga-Winter

64 days

March 13—May 15, 2017

Work carried out in the Laptev Sea.

40 ice stations

40 ice fields studied

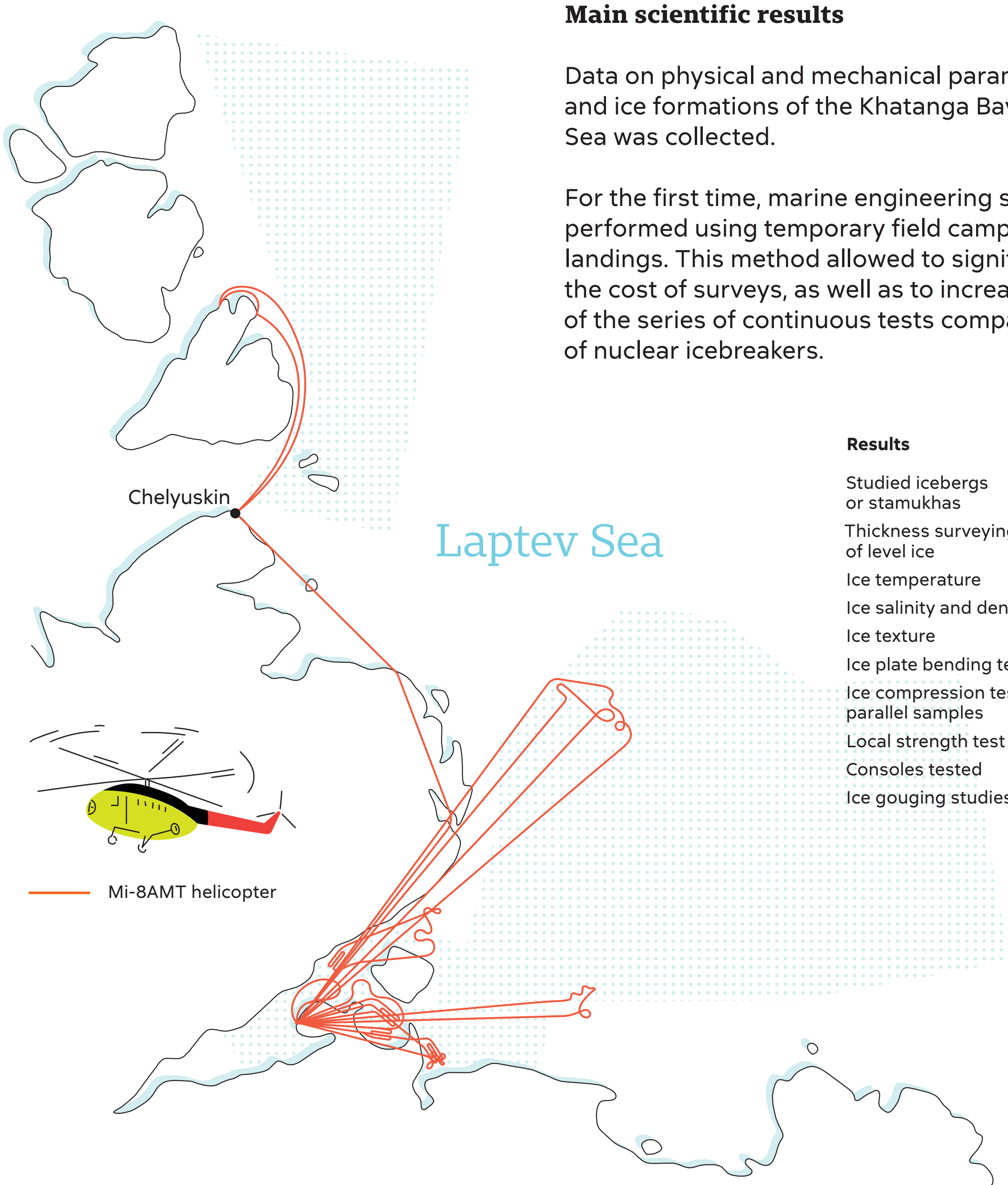
24 hummock ridges studied

1,803 thermal drilling boreholes

80 underwater keel surveys

40 current measurements at ice stations

43 oceanographic soundings



Main scientific results

Data on physical and mechanical parameters of sea ice and ice formations of the Khatanga Bay of the Laptev Sea was collected.

For the first time, marine engineering surveys were performed using temporary field camps and helicopter landings. This method allowed to significantly reduce the cost of surveys, as well as to increase the duration of the series of continuous tests compared to the use of nuclear icebreakers.

Results

Studied icebergs or stamukhas	17 icebergs
Thickness surveying of level ice	1,059 measurements
Ice temperature	80 cores
Ice salinity and density	80 cores
Ice texture	80 cores
Ice plate bending test	80 cores
Ice compression test, parallel samples	160 cores
Local strength test	1,011 tests
Consoles tested	42 consoles
Ice gouging studies	40 surveys

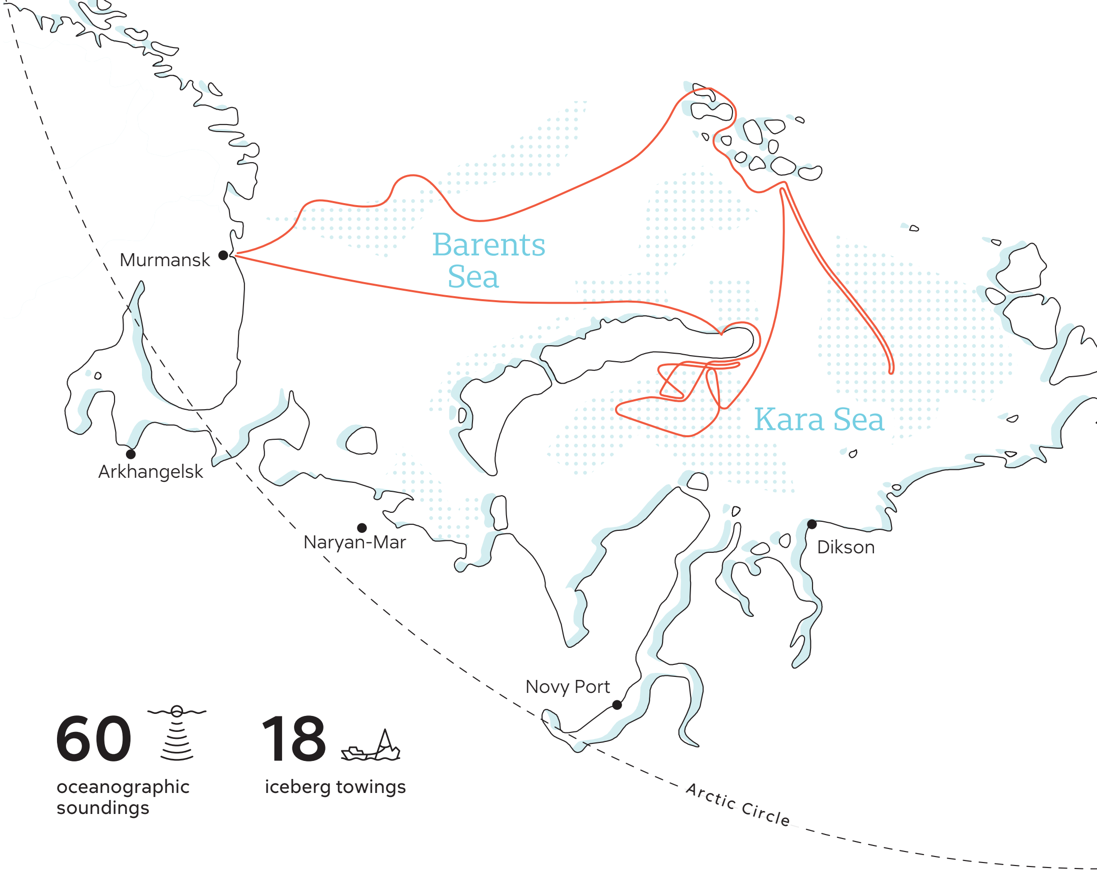
Expedition Summer 2017

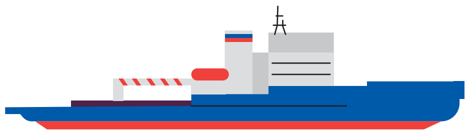
Kara-Summer

40 days

September 9 — October 19, 2017

Work carried out in the Kara Sea.





Diesel-electric icebreaker Novorossiysk

3 inspections of automatic weather stations

6 redeployments of buoy stations

40 deployments of drifting buoys on icebergs

60 oceanographic soundings

18 iceberg towings

Key expedition objectives

— Conduct a series of experiments on physical interaction of the ship with icebergs, including during towing;

— carry out comprehensive tests of iceberg detection equipment, organization of a shore-based operations center to support expedition activities;

— perform maintenance of automatic weather stations on the eastern coast of the Novaya Zemlya archipelago and on Uyedineniya Island;

— conduct observations of the thermohaline structure of waters, lift and redeploy two instruments assessing the characteristics of ice cover, sea level fluctuations and currents;

— determine iceberg drift parameters using a shipboard radar and deploy autonomous buoys on them.

Main scientific results

Experiments were conducted on towing icebergs in the Barents and Kara Seas, the results of which were used for numerical and physical modelling of the towing process. → p. 175

Specialists of the center developed the main elements of the ice condition monitoring system (ICMS): iceberg formation zones were studied using radar and their maximum possible sizes were determined, satellite images and aerial survey data were used to examine the size and shape of forming icebergs and the direction of their drift. Large-scale studies of interaction of the icebreaker hull with ridges of hummocks were carried out.

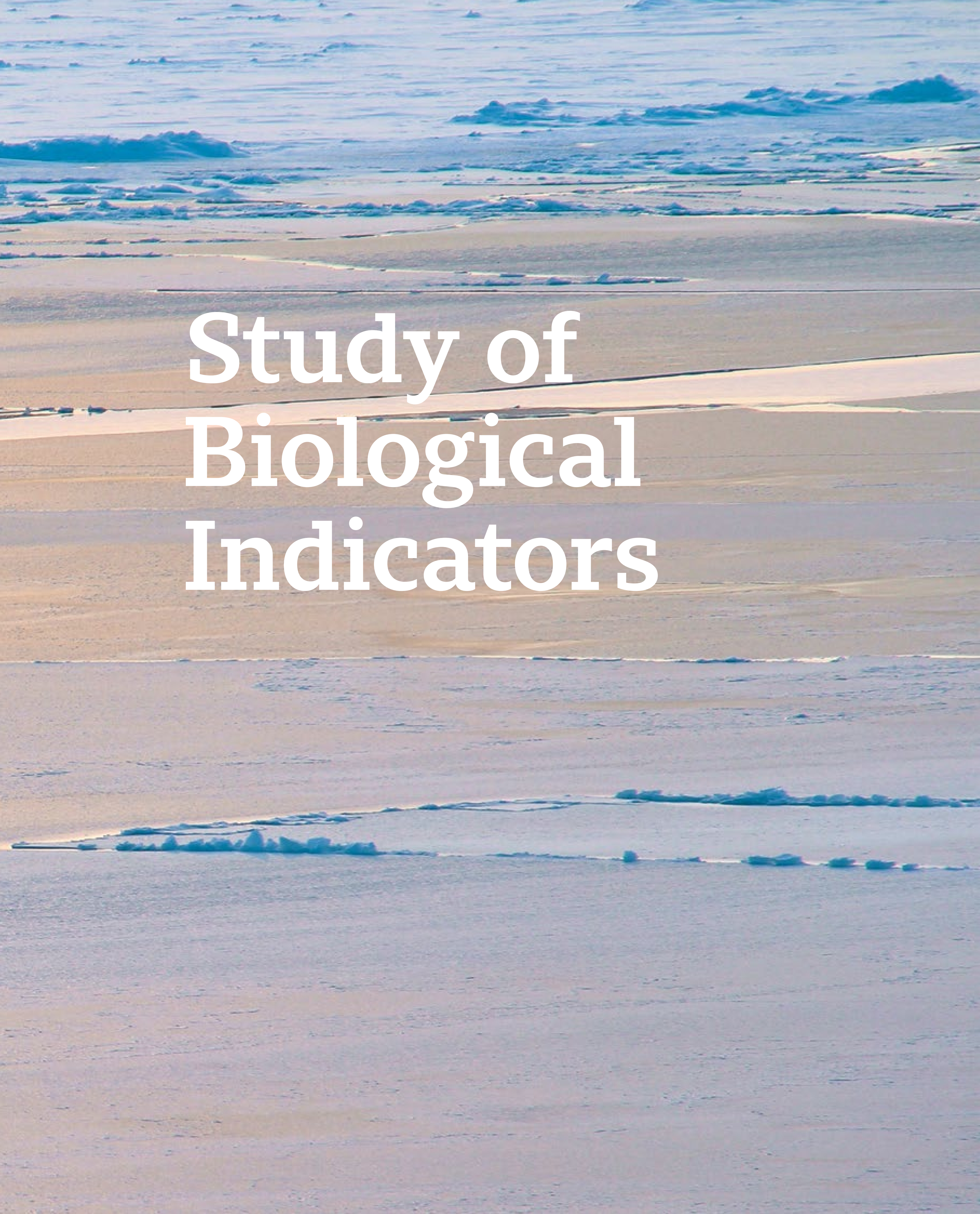
Deployment of drifting buoys

Iceberg fragments in the Inostrantsev Bay

A drifting iceberg in the northern part of the Kara Sea

Glacier tongue. Blocks of ice that break off from its edge become icebergs

Study of Biological Indicators



Biological indication

The concept of “biological indication” (bioindication) means assessing environmental parameters by the state of living organisms. Species composition and characteristic species of a region can sometimes be used to draw more accurate conclusions about the environment than performing direct measurements of individual indicators. For example, the species composition of plankton can be used to determine temperature and salinity characteristics of the water mass and identify the structure of currents.

Groups of organisms serve as indicators of various variables and provide information in different spatial and temporal scales: short-lived organisms react to rapid changes in the environment, while the long-lived ones reflect changes accumulated over long periods of time.

In a narrow sense, bioindication is understood as a method of assessing changes in the environment resulting from human impact, including pollution and changes in the habitat of species. It is in this sense that bioindication is used as an additional tool for monitoring the state of the environment on land, in freshwater and marine ecosystems. This approach has only recently begun to be used in the sea. The most important limitation is the degree of knowledge about marine flora and fauna.

In order to use certain species as biological indicators, it is important to not only thoroughly study their distribution and population size, but also to understand the biology of species. The purpose of Rosneft’s species research work is to revise current knowledge about these species for use in environmental monitoring.

Total amount of work performed since 2014:

19
field seasons spent in hard to reach and poorly studied regions of the Russian Arctic

36 months
total duration of field research activities

55,000 km
total length of all routes

500 hours
duration of aerial observation

150
camera traps installed in animal habitats

300,000
photographs from camera traps processed

400
animals inspected in detail

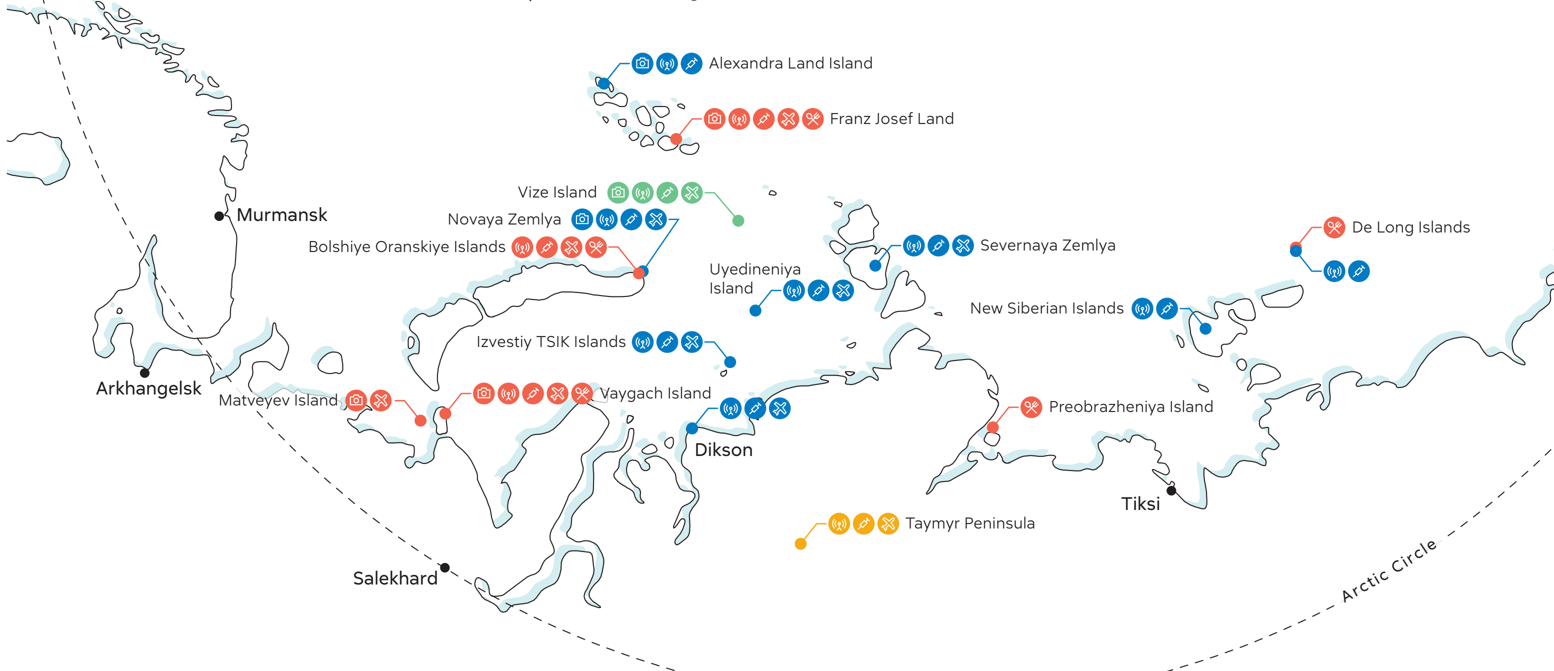
140
animals fitted with satellite transmitters

1,500
biological samples taken and analyzed in the laboratory

Studies completed as part of researching biological indicators

- Atlantic and Laptev subspecies of the walrus
- ivory gull
- wild reindeer
- polar bear

- Installation of photo recorders
- Installation of satellite transmitters
- Biological sampling for laboratory research
- Food supply studies
- Aerial counting



Investigated bioindicator species

Polar bear

The polar bear is at the top of the trophic network of Arctic marine ecosystems. Thanks to such a position, these biological indicators allow to obtain an integral assessment of the state of the ecosystem. Polar bear occurrence depends on ice conditions and distribution of main food items, especially seals. The state of the polar bear population is assessed by the number of species and its annual increase, migrations and spatial structure of the population.

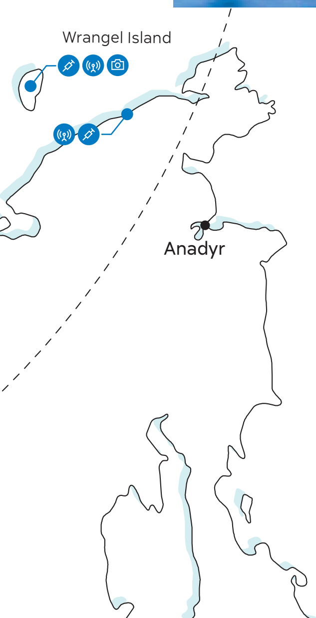
Walrus

For the Arctic seas of Russia the walrus is one of the best indicator species among marine mammals: it is widespread, migrationally active, significant in number and is available in the study area throughout the year. Due to its lifestyle and diet, the walrus, just like the polar bear, integrally reflects the state of other components of the marine biota.

Ivory gull

The ivory gull is an Arctic endemic whose habitat is closely associated with sea ice, as it inhabits the high-altitude areas of the Arctic. Like the walrus and the polar bear, the ivory gull is a high order predator (feeds on invertebrates, small fish, found carrion) and tends to accumulate pollutants from the environment in its body.

An **endemic** is a species of animal or plant that inhabits a relatively small geographic area. Endemics are often listed in Red Books as rare or endangered species.



Wild reindeer

The reindeer is one of the most important Arctic species, its role for both Arctic ecosystems and the life of indigenous peoples of the North cannot be overestimated. There are two ecological types of reindeer, the tundra and forest reindeer, which are well adapted to their respective habitats. Rosneft's research focuses on the tundra wild reindeer.

Polar bear

Ursus maritimus

This is the largest living terrestrial predator. The body length of males reaches 280 cm, the height at the withers can be up to 160 cm and the weight up to 600 kg. The polar bear is listed in the IUCN Red List of Threatened Species and the Red Book of Russia. It is the only terrestrial mammal with its main habitat in the drifting ices of the Arctic. Scientists identify 19 local populations of polar bears.

Russia became the first country to develop a National Strategy and Action Plan for Polar Bear Conservation (2010).

The main problem

Despite the high level of interest from the scientists, the problem of insufficient research of both individual polar bear populations and the species as a whole still remains. For this reason, the main focus of Rosneft's research is to fill the gaps in current knowledge about the state of polar bear populations.

Prior to the work organized by Rosneft, large-scale expedition studies of bears in the Russian Arctic were conducted in the late 1980s and early 1990s. In the 2000s, with the exception of individual projects, collection of information about bears was mostly occasional in nature.

How to study

Quantitative and qualitative shipboard and shore-based studies, aerial surveys to estimate the total number of species and numbers of different sex and age groups, studies of spatial distribution of animals. This data is necessary, among other things, to correctly interpret other monitoring surveys.

Biopsy collection and laboratory research. Tissue contamination analysis, immunological and microbiological tests to detect pathogenic conditions.

Tracking the movement of animals with satellite transmitters.

→ p. 81

Kara-Summer 2014 expedition

→ p. 102

Five bears were immobilized to conduct a full range of studies.

Two females were fitted with satellite transmitters.

Collected for laboratory research:

— seven skin biopsy samples;

— 67 hair samples;

— 17 feces samples;

— 14 samples of polar bear bone carcasses.

73 encounters with 115 individuals were recorded.

Kara-Winter 2015 expedition → p. 82

13 bears were immobilized to conduct a full range of studies.

Four females were fitted with satellite transmitters.

104 samples collected for laboratory research, including:

— three biopsy samples taken with an injector;

— 13 biopsy samples taken from immobilized bears.

59 encounters with 79 individuals were recorded.

Chukotka-Summer 2015 expedition → p. 84

Four bears were immobilized to conduct a full range of studies.

Four bears were fitted with satellite transmitters, including:

— one female bear was fitted with a satellite collar;

— three bears were fitted with satellite transmitters using a new method of attachment to the animal body, which for the first time allowed tagging a male.

197 encounters with 330 individuals were recorded.

115 biological samples were collected for laboratory research, including 14 skin biopsies.

58 camera traps were set up (55 on Wrangel Island, three on Herald Island).

Kara-Summer 2016 expedition → p. 86

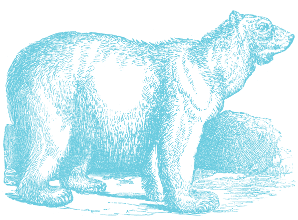
10 bears were immobilized to conduct a full range of studies.

10 bears of varying sex and age were fitted with satellite transmitters which was made possible by the use of the new method of attachment to the animal body.

40 biological samples were collected for laboratory research.

15 camera traps were set up.

95 encounters with 129 individuals were recorded.



Rosneft began a full-scale program to study the polar predator from the very start of its research projects in the Arctic offshore. During the first expedition activities starting in 2012, marine mammal observers collected data on polar bear encounters. The first expedition to include a dedicated polar bear research team was Kara-Summer 2014. This expedition perfected a methodology of combining shipboard observations, noninvasive collection of biological methods and invasive methods, such as immobilizing polar bears or remote sampling of skin biopsies, fitting animals with satellite transmitters and subsequent comprehensive analysis of information at the processing stage. The goal was to obtain the fullest possible set of data on the animals. The first polar bear collar was fitted during the expedition to Zhokhov Island in the East Siberian Sea.

→ p. 81
→ p. 69

Summer expedition to Cape Zhelaniya, Novaya Zemlya archipelago

Six bears were immobilized to conduct a full range of studies (three males and three females).

All three females were 1.5-year old cubs which provided completely new data on the sex and age composition of polar bears inhabiting the northern tip of Novaya Zemlya during the summer. Of the six solitary bears captured during the expedition, only one male was an adult. None of the bears were tagged.

30 biological samples were collected for laboratory research.

A total of 47 polar bears were registered.

Spring expedition to Alexandra Land, Franz Josef Land archipelago

For the first time in company's research activities, work was carried out in the period when females left maternity dens. The latest UAVs equipped with photo and thermal cameras were used to locate and study the dens. Unique data on emergence of females from the dens and feeding of their young was gathered.

Three females were fitted with collars with satellite transmitters.

72 biological samples were collected for laboratory research.

Nine encounters with polar bears were recorded (15 individuals, including three females with cubs).

Location of four maternity dens was discovered.

Summer expedition to Cape Zhelaniya, Novaya Zemlya archipelago

Six bears were immobilized to conduct a full range of studies (three males and three females).

Two females were fitted with collars with satellite transmitters.

41 biological samples were collected for laboratory research.

A total of 29 polar bears were registered.

2019 2020 2021

Field studies

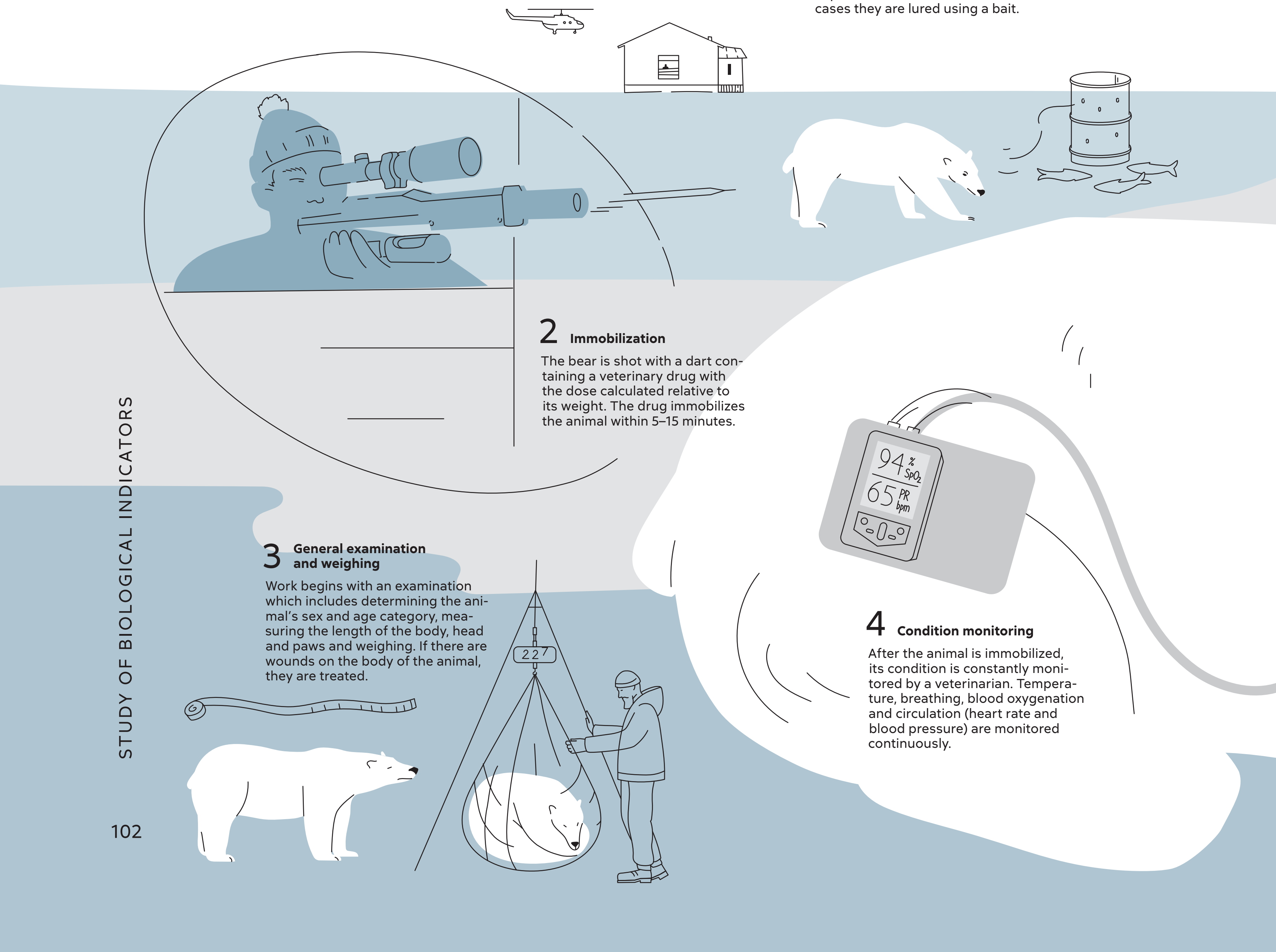
In order to obtain detailed information about the largest terrestrial predator in the wild, it is necessary to temporarily immobilize it with safe veterinary drugs that induce muscular relaxation and anesthesia. On average, the animal is immobilized for less than an hour, during which time scientists conduct a general examination, take biological samples, tag the animal and fit it with a collar with a satellite transmitter.

Satellite tagging. The method of tracking the movements of animals using satellite technology is widespread in the world practice of ecological research. The first tagging of a polar bear with a satellite transmitter in Russia took place on Wrangel Island in the Chukchi Sea in 1990. Using this technique, it is possible to get information about the speed, distance traveled and the area of animal's movement almost in real time.

During the comprehensive expeditions of 2014-2016, polar bears were immobilized from a helicopter, while during the 2021 winter work on Alexandra Land they were immobilized from snowmobiles on land or on landfast ice in bays. During the summer expeditions of 2020 and 2021 animals were captured using bait.

1 Tracking and luring

Polar bears are tracked by helicopter or land vehicles. In some cases they are lured using a bait.



2 Immobilization

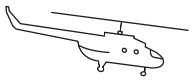
The bear is shot with a dart containing a veterinary drug with the dose calculated relative to its weight. The drug immobilizes the animal within 5–15 minutes.

3 General examination and weighing

Work begins with an examination which includes determining the animal's sex and age category, measuring the length of the body, head and paws and weighing. If there are wounds on the body of the animal, they are treated.

4 Condition monitoring

After the animal is immobilized, its condition is constantly monitored by a veterinarian. Temperature, breathing, blood oxygenation and circulation (heart rate and blood pressure) are monitored continuously.



Most often, scientists use *Argos* satellite tags mounted on collars. Such collars can only be fitted on female polar bears: adult males have a neck that is wider than their head, preventing the collar from staying in place, while young bears are still growing and the collar will press against their neck.

To expand the capabilities of the method, Rosneft designed and in 2016 patented a special clip for attaching the satellite tag to the animal's body coat. It made it possible to attach the tags regardless of the sex and age of the individual without the risk of injury or other negative consequences. Elimination of the collar significantly reduced the weight of the transmitter. A coat clip fitted on August 29, 2016 allowed to receive the first track from a male bear on Zhokhov Island (an island in the De Long Islands group in the East Siberian Sea).

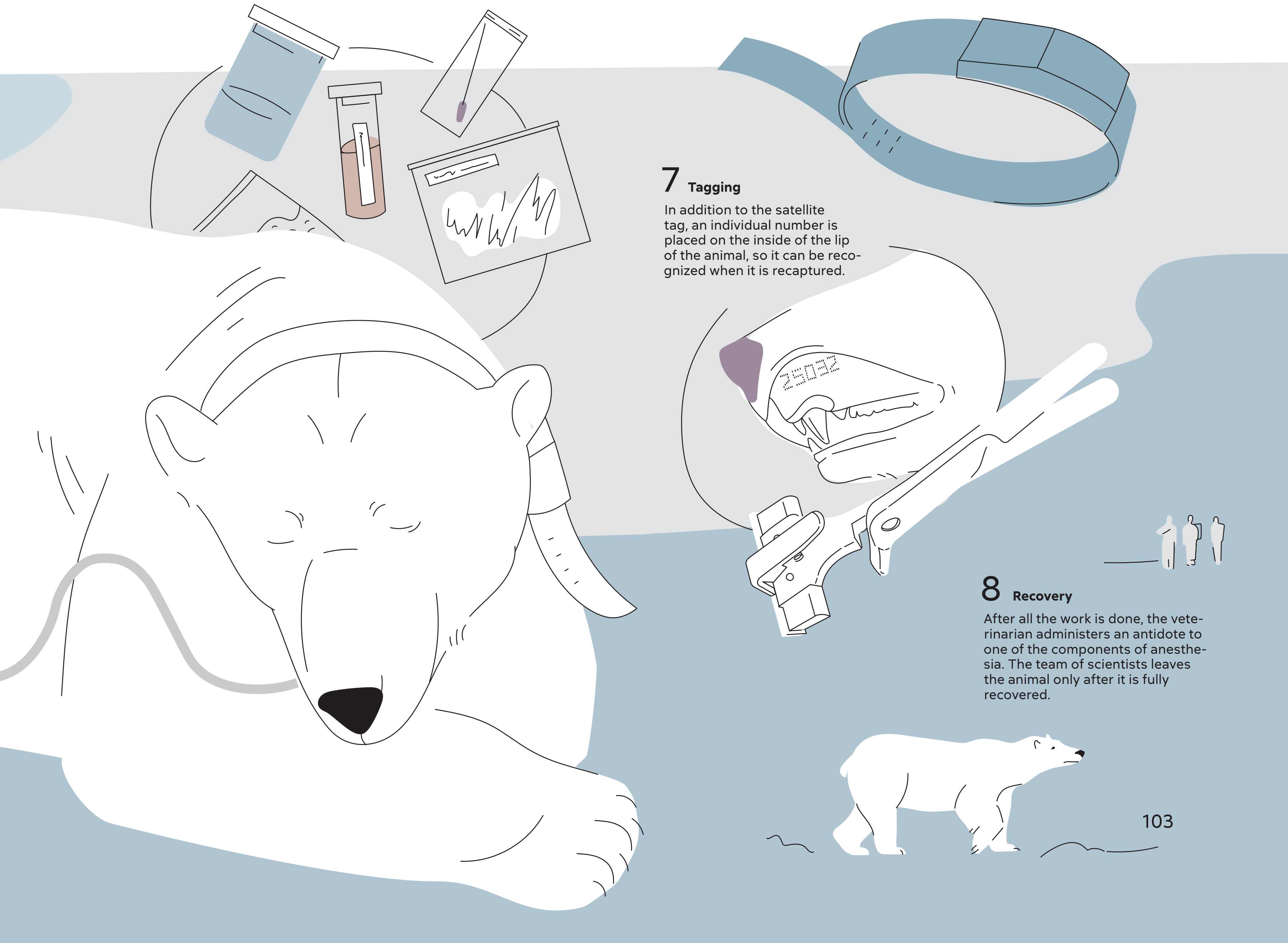
5 **Sampling**

Blood samples and mucous membrane swabs, skin biopsies with subcutaneous fat and hair samples are taken from the bear. The samples are properly stored and transported so they can be processed in the laboratory after the end of the expedition.

→ p. 104

6 **Collar fitting**

Females are fitted with a collar containing a satellite tag. The collar causes no discomfort to the bear and its lock is designed to break over time from exposure to seawater.



7 **Tagging**

In addition to the satellite tag, an individual number is placed on the inside of the lip of the animal, so it can be recognized when it is recaptured.

8 **Recovery**

After all the work is done, the veterinarian administers an antidote to one of the components of anesthesia. The team of scientists leaves the animal only after it is fully recovered.

Laboratory analysis of biological samples

Studies on the levels and composition of contaminants. Biological samples of blood, hair and subcutaneous fat of polar bears are analyzed for the content of heavy metals and persistent organic pollutants. Once in the environment, persistent organic pollutants are accumulated through food chains in animal's tissues and can be passed on to bear cubs with their mother's milk. This data provides the basis for toxicological monitoring of Arctic marine ecosystems, of which the polar bear is an indicator.

Hematological and immunological studies. Blood tests allow to characterize the state of innate immunity of the animal, assess the level of parasitic load and how the contaminants accumulated in the body affect the functionality of the cells of the immune system. Inflammatory processes are detected and the performance of the immune system is evaluated. The accumulated information on blood parameters determines the limits of the norm which are further used to assess the health of the examined individuals.

Molecular genetic studies. The molecular genetic analysis of the DNA isolated from blood, feces and hair samples of polar bears, as well as from bones and teeth of fallen animals allows to draw conclusions about genetic structure and diversity in populations. Higher diversity indicates a healthy state of the population.

Microbiological studies. In physiologically normal state, the polar bear organism contains hundreds of species of microorganisms. However, under the influence of stress, starvation, toxic pollution and chronic diseases, some of them may exhibit pathogenic properties, causing illnesses. Microbiological studies of polar bears in natural populations are conducted to assess the health of individuals, detect pathogens of infectious diseases, as well as to determine the origin of isolated microflora and to identify and describe microorganisms which act as markers of animal health status.

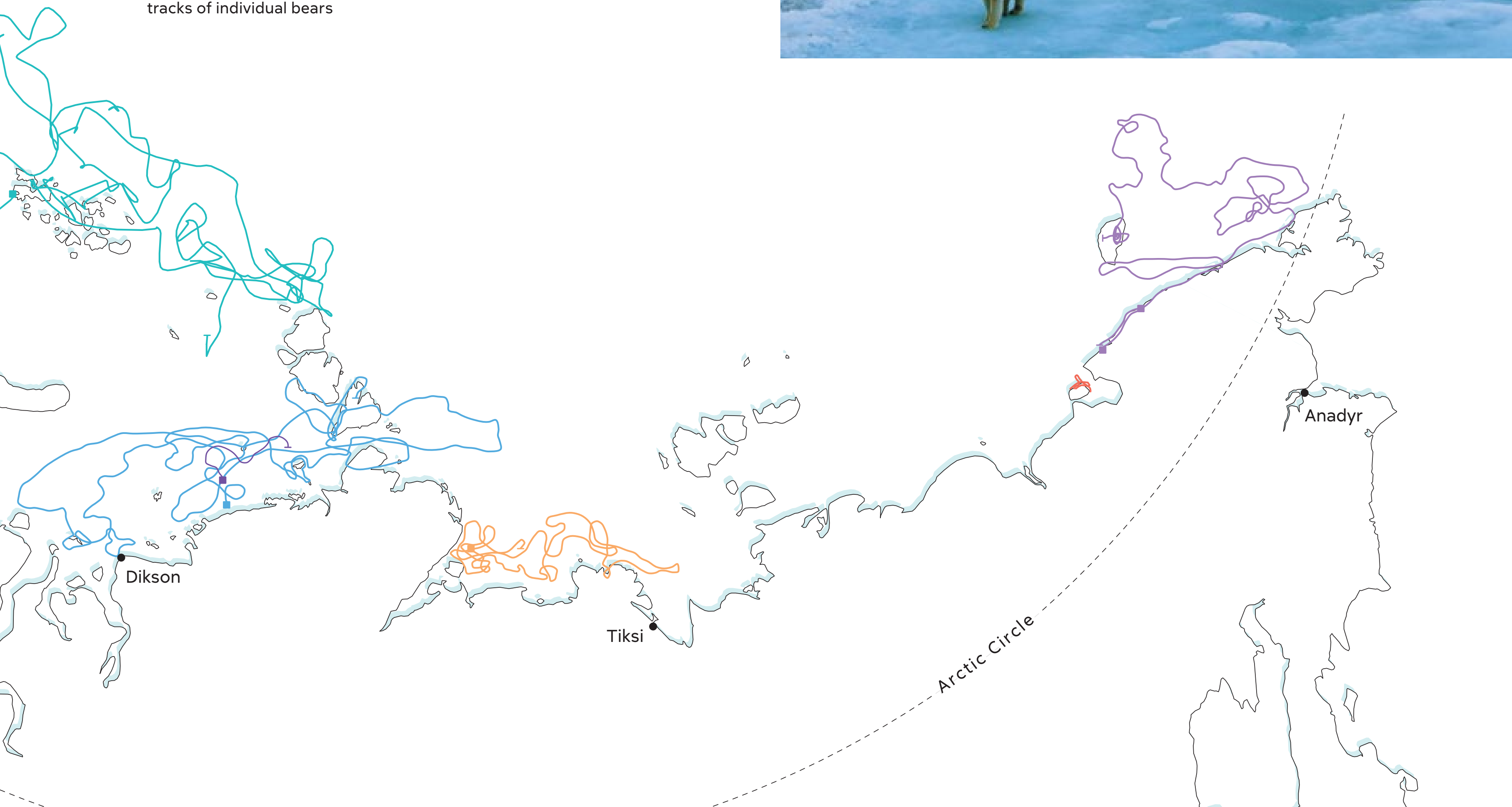
Global warming has forced polar bears to move from their natural habitats at the edge of ice to land and look for food close to human dwellings. Unusual food alters the microbiota of the gut.

Satellite telemetry results

A total of 21 bears were fitted with satellite transmitters during Rosneft's surveys. The total duration of observations is over 3,000 days. The obtained information makes it possible to study how bears act in different types of habitats and how this depends on ice conditions, to interpret the results of molecular genetic studies, identify key habitats such as maternity denning areas of pregnant bears, as well as areas of interest for predators in terms of food availability. Satellite telemetry made it possible to remotely locate polar bear dens in areas that are difficult to access for field research, to track monthly activity and the total surface area of territories used by the animals.

Routes of polar bears marked by satellite transmitters in 2015-2021.

Different colors on the map show tracks of individual bears



Walrus

Odobenus rosmarus

The walrus is the largest pinniped in the Northern Hemisphere. Males reach up to 3.5 meters in length and 900 kg in weight; females are smaller, up to 2.4 meters in length and 800 kg in weight. Their large body is covered with a thick skin with wrinkles and folds. Tusks are present in both males and females. The species is listed in the Red Book of Russia and the IUCN Red List of Threatened Species. In the summer and fall walruses congregate on coastal rookeries, while in the winter and spring they live on the ice where females bear their young. There are three subspecies of the walrus living in the Arctic waters: the Atlantic walrus, the Pacific walrus and the Laptev walrus whose existence is questioned by some researchers.

In Russia, hunting of the Atlantic walrus has been banned since 1956. Despite its impressive size, it is one of the most vulnerable inhabitants of the Russian Arctic.

The main problem

As in the case of the polar bear, the main problem of the walrus as a biological indicator is insufficient knowledge of the species and its individual populations. Part of the population inhabits hard to reach areas, which is why large scale surveys have not been conducted for over 10 years, and for some populations since the Soviet times.

The main indicator values are:
— general population characteristics: estimated total number of animals and rookeries, sex and age composition, analysis of migrations and spatial structure;
— individual characteristics of animals and their groups: stress and disease levels, contamination of animal tissues.

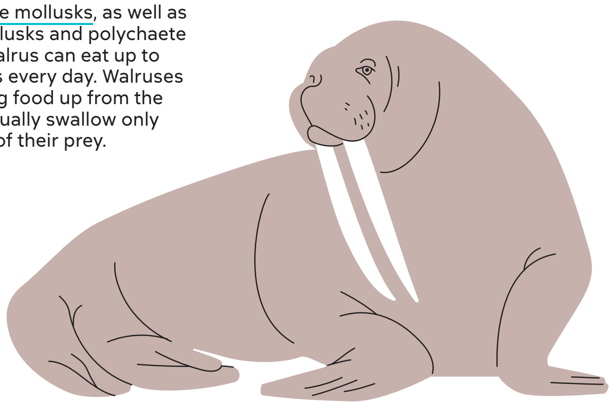
In order to interpret this data, food supply of the walrus is studied. Closing these gaps in knowledge about the current state of the species is the goal of Rosneft’s work in 2020-2022.

900 kg
weight

3.5 meters
length

→ p. 203

Walrus nutrition is based on bottom-dwelling bivalve mollusks, as well as gastropod mollusks and polychaete worms. One walrus can eat up to 6,000 mollusks every day. Walruses feed by sucking food up from the bottom and usually swallow only the soft parts of their prey.



How to study

Rosneft conducted its first walrus studies in 2015 on the islands of Nenetsky State Nature Reserve during geological exploration activities in the Pechora Sea. The research was conducted jointly with the Reserve's personnel: local rookeries and feeding areas were identified, impact of production operations on animals was assessed. Animal counts were recorded as part of comprehensive expeditions. In 2016, studies of the Laptev subspecies of the walrus were conducted on Bennett Island.

The recent studies of the Atlantic walrus population are the most extensive of all conducted by Rosneft. The work includes quantitative and qualitative shipboard and coast-based surveys, aerial counting in rookeries using UAVs, long-term monitoring of rookeries using camera traps, collection of biopsy samples for comprehensive laboratory analysis and the study of spatial distribution using satellite tags.

→ p. 81

Kara-Summer 2014 expedition

During the special polar bear studies, a new walrus rookery was discovered in the hard to reach and poorly explored area on Bennett Island in the De Long Islands archipelago.

Over 700 animals were registered.

Four biological samples were taken for genetic studies.

Bennett Island is located on the boundary of the Laptev and Pacific subspecies of the walrus which have different conservation status. The Pacific subspecies is commercial, while the Laptev one is listed in the Red Book of Russia. In this regard, it appears important to conduct genetic studies of the obtained samples in order to determine which subspecies the animals belong to.

Research on Matveev Island, Nenetsky Reserve

An assessment of the species composition and numbers both in the rookery and the coastal area of the island was carried out.

The total length of aerial observations with full coverage along the coastal strips of the islands of the reserve amounted to 2,400 km.

13 camera traps were set up.

Maximum number of registered animals in October was over 500.

Using satellite observation data, a permanent walrus migration route between Vaygach Island and Matveev Island was located.

→ p. 86

Kara-Summer 2016 expedition

Walrus surveys were conducted at four shoreline rookery formation sites: Preobrazheniya Island, Bennett Island, Geddes Island and Oransky Islands.

Six walrus rookeries were discovered. Five adult walruses were fitted with satellite transmitters.

23 biopsy samples of walrus skin and subcutaneous fat were collected for molecular genetic analysis, 11 biological samples were collected noninvasively for toxicological studies. For the first time, scientists managed to take biological samples from walruses on Preobrazheniya Island where one of the largest rookeries is located.

Six camera traps were set up, including at one of the most remote and hard to access coastal rookeries on Bennett Island.

Benthos fauna surveys were conducted at 29 stations in shallow water areas and at 23 stations in areas where rookeries were found in order to study potential walrus food sources (bottom communities). A total of 187 samples were collected for laboratory research.

2014 2015 2016 2017

Research on Vaygach Island and Matveev Island

Species composition and numbers in the rookery and in coastal waters were evaluated.

10 camera traps were set up.

Five adult walruses were fitted with satellite transmitters.

Maximum number of animals registered using UAV surveys was 323 individuals.

Over 40 biological samples were collected, including 20 skin biopsy samples of the Atlantic walrus.

19 stations were surveyed in order to study potential walrus food sources (bottom communities).

Three rookeries were discovered, at one of which scientists evaluated the dynamics of its use by animals and estimated animal disturbance level over two months.

Research on the Franz Josef Land archipelago

For the first time, comprehensive surveys of the Franz Josef Land islands were conducted with detailed mapping of already known walrus rookeries, as well as descriptions of new animal locations.

40 islands were studied.

18 rookeries were discovered and studied, including one previously undescribed.

A total of over 3,000 walruses were registered. More than 100 biopsy samples were collected from all large groups of animals.

10 satellite tags were fitted on animals of different sex and age groups. Tags were fitted on the most northern, as well as the most populous and well-known rookeries.

10 camera traps were set up to collect information on seasonal use of territories.

42 stations were investigated in rookery areas in order to study potential walrus food sources (bottom communities). A total of 115 samples were collected for laboratory research, remotely operated underwater vehicle surveys were carried out at 17 stations.

Second expedition to the Franz Josef Land archipelago

The largest rookery of the Atlantic walrus, 2,004 individuals, was discovered on Eva-Liv Island.

34 islands were studied.

16 rookeries were discovered and studied, two more were identified during the processing of satellite imagery and tag data.

A total of over 7,300 walruses were registered. 115 biopsy samples were collected from all large groups of animals.

16 satellite tags were fitted on animals of different sex and age groups, including six tags with sensors that collect data on temperature, depth and duration of diving which will allow to describe walrus feeding (duration and depth of feeding dives) and rest behavior for the first time in the region.

Five camera traps were set up.

28 stations were investigated in rookery areas in order to study potential walrus food sources (bottom communities). A total of 84 samples were collected for laboratory research, remotely operated underwater vehicle surveys were carried out at 11 stations.

2019 2020 2021 2022

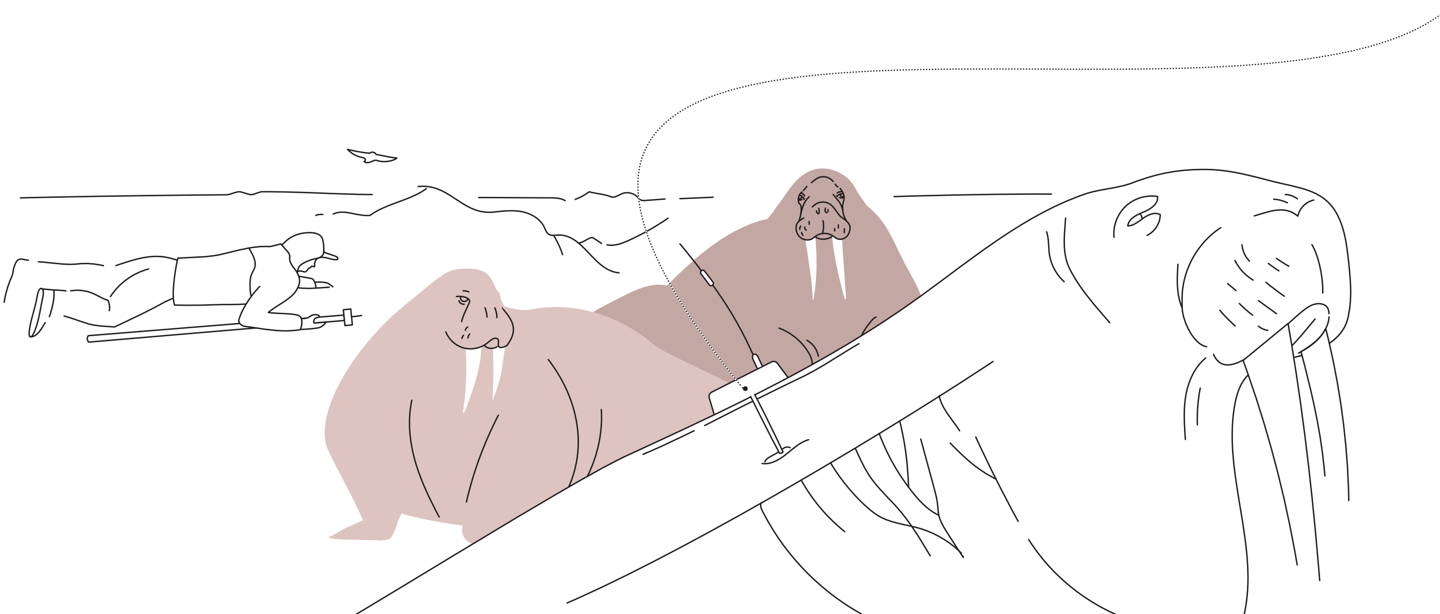
Field research

The islands of the Franz Josef Land archipelago — the territory of Russian Arctic National Park almost entirely untouched by humans — were chosen as the area to study the Atlantic subspecies of the walrus that will make it easier to obtain the most valuable information about the biology of the species. Walruses live in this area year-round as an isolated group. In 2020, research in cooperation with A. N. Severtsov Institute of Ecology and Evolution of the Russian Academy of Sciences was conducted on 40 islands. In 2021, a repeat expedition to the archipelago yielded unique results about the size of this group of walruses.

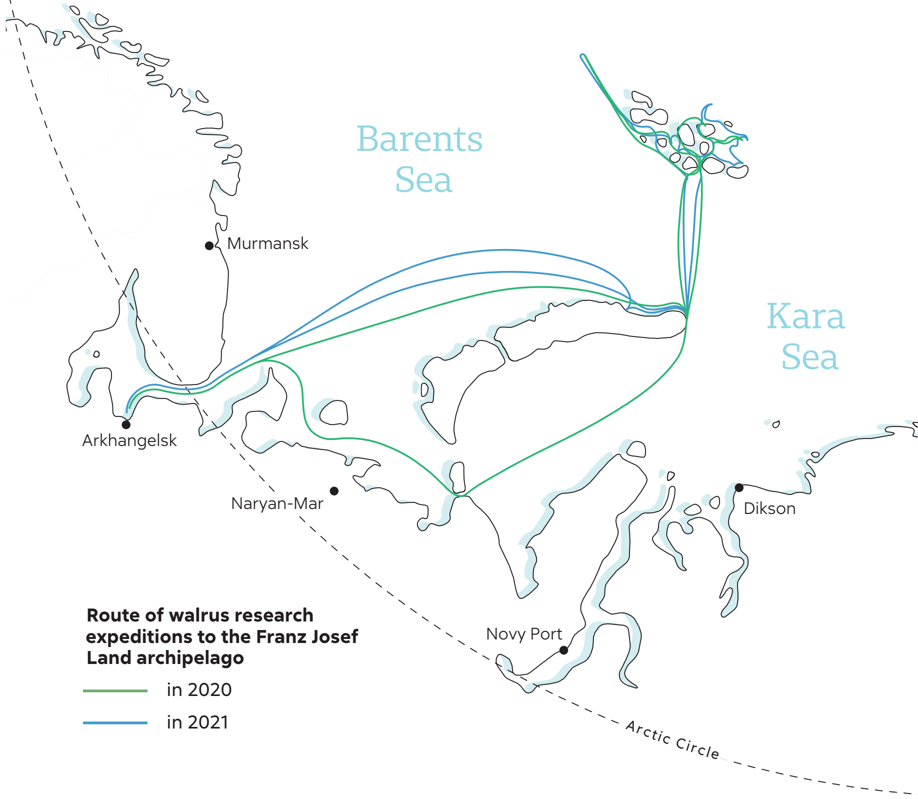
Primary work activities were carried out at the rookeries. First of all, animals were counted, this helped establish the attachment of animals to certain habitats, identify the dynamics of their activity, the nature and factors that determine seasonal changes in their numbers. Work included:
- remote collection of skin and subcutaneous fat biopsy samples;
- tagging with satellite transmitters;
- collection of noninvasive material and registration of traces of walrus activity.

Walrus tagging and why you need to crawl to approach a walrus. Satellite tags fitted on walruses provide information on distribution, local and seasonal migrations and usage patterns of different habitats. The data is also used to interpret the results of laboratory tests for pollution and genetic research.

In contrast to polar bears which are medically immobilized to be fitted with a collar, walruses are treated differently. Sleep physiology of pinnipeds is still insufficiently studied and carrying out such manipulations in the field requires extreme caution. The process of tagging a walrus takes about an hour on average. Most of this time the theriologist spends crawling up to the animal with a pole that has a satellite transmitter attached to it through a special socket. You need to move very slowly and to crawl: walruses do not perceive objects lower than themselves as a threat.



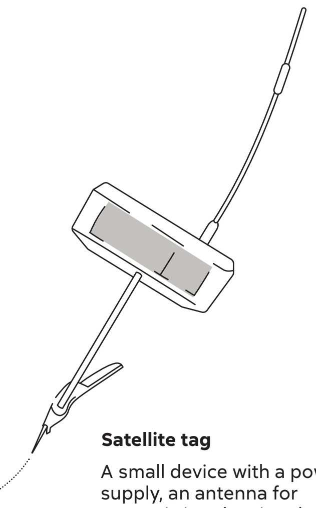
The walrus is a herd animal that develops close relationships within groups of 2–5 to 100 or more individuals that are formed in both wintering and feeding grounds. At rookeries, the animals are positioned so that females and young walruses are located at the center of the group with large males at the edges, standing guard and warning their mates of nearby danger with roars.



Over two field seasons researchers fitted 26 satellite transmitters. Part of them were used to collect data on temperature, depth and duration of diving which will allow to describe walrus feeding (duration and depth of feeding dives) and rest behavior for the first time in the region. Using the data obtained from tags installed in 2020, the migration activity of walruses and spatial use of the water area of Franz Josef Land were studied, new rookeries and feeding areas were discovered.

In parallel with the work at the rookeries, scientists researched food sources of the walruses in the area. The walrus is a highly specialized species of pinnipeds, and as it has already been mentioned, it primarily feeds on bottom-dwelling invertebrates, mainly bivalve mollusks which walruses catch at the depths of 30–80 meters. In 2020–2021, quantitative material from 70 benthic stations at depths of 11 to 176 meters was processed. The sampling stations were divided into two groups: monitoring stations (located near walrus rookeries) and search stations, located in potential walrus feeding areas based on satellite telemetry data of 2020.

→ p. 207



Satellite tag

A small device with a power supply, an antenna for transmitting the signal and a small harpoon that is attached to the body of the animal using a pole or a crossbow. Walrus skin can be up to 4 cm thick with a layer of fat underneath that can reach 15 cm, so this method is painless and does not cause the animal any considerable inconvenience.

Algorithm of operations at a rookery

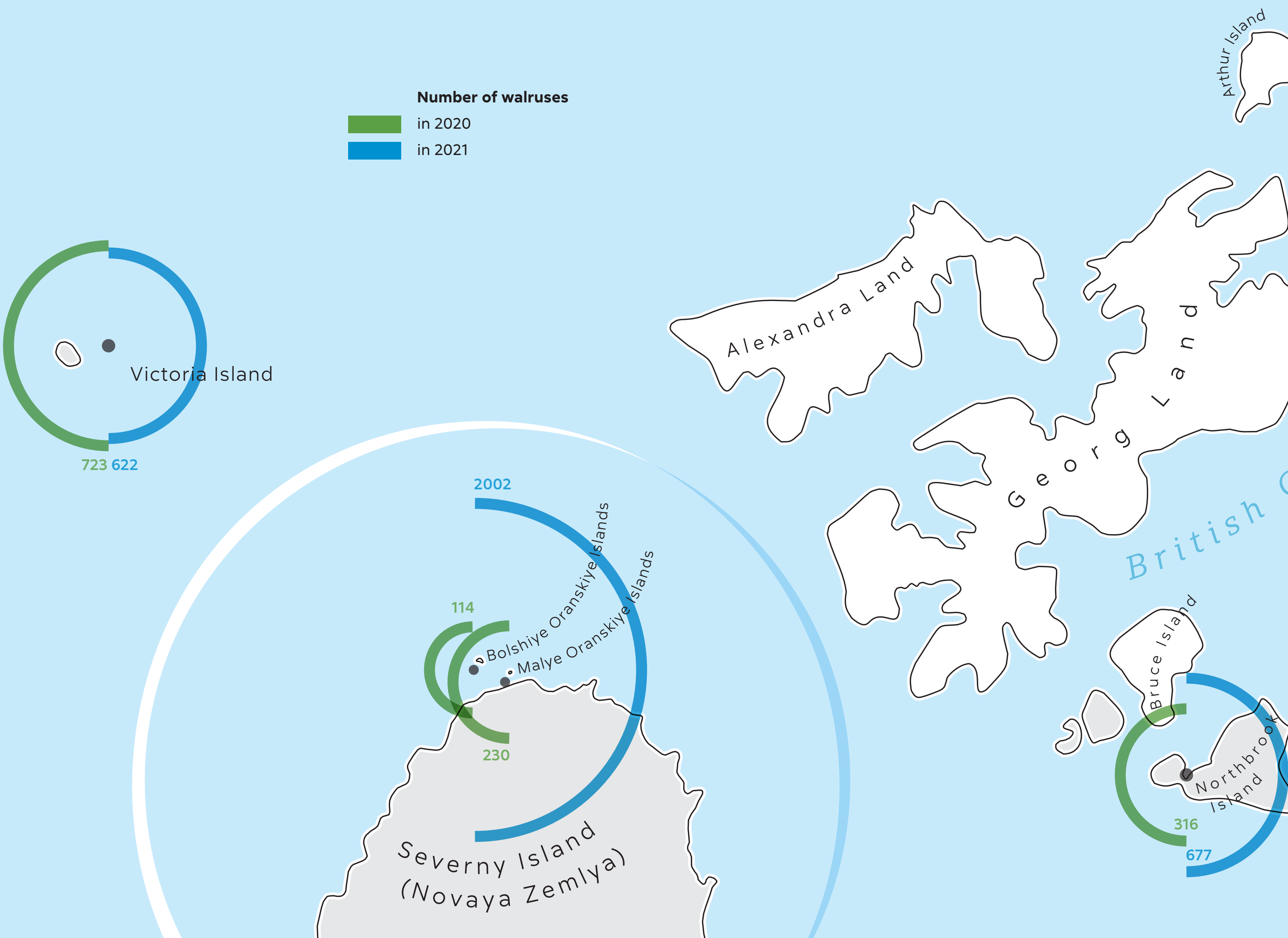
1. Inspection of the rookery using a UAV prior to landing: planning the work and checking its safety, including searching for polar bears, aerial counting of the number of walruses.
2. Disembarking from the vessel away and windward from the rookery so as not to disturb the animals prematurely.
3. Fitting satellite transmitters. This is the most important stage since if the animals are disturbed, they will move out of the rookery and into the water, and there may not be another chance for tagging.
4. Biopsy sample collection. Samples are taking remotely, using a crossbow. At the end of the crossbow bolt is a hollow cylinder that pierces the walrus skin and takes a small piece of it with a layer of subcutaneous fat. In case the animals do get disturbed, this operation can still be performed even if the walruses move into the water.
5. When operations involving walruses are finished, scientists set up camera traps and take non-invasive samples from dead animals, if there are any, and from traces of vital activity.

Results of the research on the Franz Josef Land archipelago

The work on the islands of the Franz Josef Land archipelago constituted the first large-scale research of walruses with detailed mapping of known rookeries and description of new ones. Three previously undescribed rookeries were discovered along with the largest (over 2,000 individuals) concentration of the Atlantic walrus subspecies on the archipelago on Eva-Liv Island.

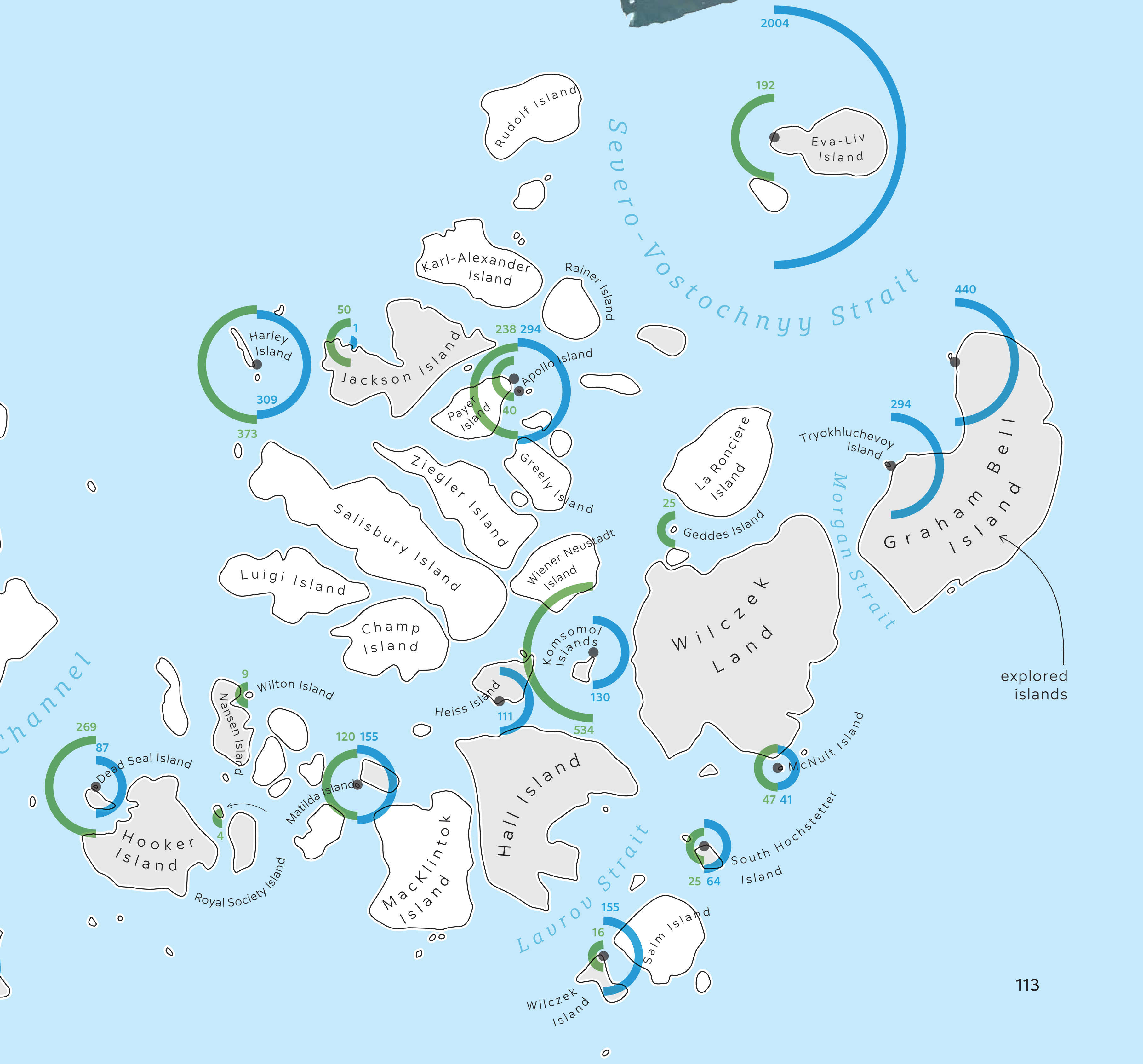
For the first time, a single full-scale census of walruses on the archipelago was conducted using unmanned aerial vehicles (over 7,000 individuals). A total of 43 islands were studied over two field seasons.

Toxicological tests of 73 walruses showed lower levels of pollutants in the bodies of animals compared to other territories. This is probably due to the conservation status of the area located in Russian Arctic National Park, as well as the absence of active vessel traffic compared to, for example, the Pechora Sea. In addition, the indicators may have been influenced by the difference in sample size and sample structure: the available open sources contain the results of studies of males, whereas the project collected samples from animals of different sex and age, which are more representative.



Russia has the largest walrus rookery. More than 100,000 walruses of the Pacific subspecies congregate at Cape Serdtse-Kamen during their autumn migration from the Chukchi Sea to the Bering Sea.

During the Rosneft expedition of 2021, the largest rookery of the Atlantic subspecies of the walrus was discovered: 2,004 animals on Eva-Liv Island (Franz Josef Land archipelago). It looks like this →



Ivory gull

Pagophila eburnea

The ivory gull is a species of small subpolar carnivorous birds. Adult birds have all-white plumage and black legs, and males do not differ from females. It is a rare and protected species, the smallest and endemic species of Arctic seabirds with a limited breeding range. The ivory gull is included into the Red Book of the Russian Federation and the Red List of the International Union for Conservation of Nature. Most of its world population nests on the territory of Russia spanning from Svalbard eastward to the Laptev Sea.

The global population of the species is very approximately estimated to be 58,000–78,000, but this may be an overestimate. Around 70–80 % of the global population nests in Russia. In a favorable year, the number of colonies (for example, on Domashniy and Vize Islands in the Kara Sea) reaches 2,000. Overall, there is a general decrease in the number of birds, which may be due to climatic changes: the territories of the Arctic are getting warmer and the area of sea ice decreases every year.

The main problem

The gull lives unevenly within its habitat and nests in hard to reach places, which makes it impossible to collect accurate information about its numbers, territorial links and population structure.

Targeted studies of the ivory gull populations of the last 10 years have been focused mainly on the foreign Arctic, and the only large-scale census was conducted in 2006. Satellite observation data in recent years indicates changes in abundance and distribution of the species, yet there is no sufficient information on diet, trophic relationships, concentration of pollutants in tissues and their impact on the bird’s organism.

Ivory gulls on Vize Island

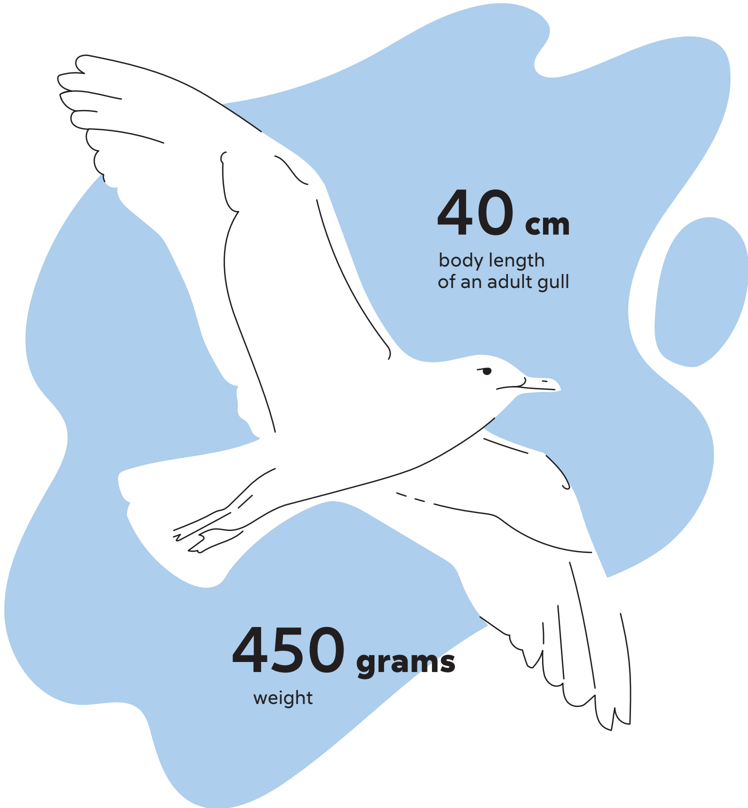
How to study

The only way to get the missing data on the species' biology is through focused work on nesting colonies when researchers count adult and juvenile birds and the number of eggs, capture birds to collect samples and fit transmitters to track their movement.

In 2020 Rosneft, together with the Arctic and Antarctic Research Institute, began studies on Vize Island in the northern Kara Sea. The summer season of 2020 was characterized by extremely unfavorable breeding conditions for ivory gulls. This manifested itself in late nesting dates and low breeding success. Scientists examined ivory gull colonies in the northeastern part of the Kara Sea. For the first time in the last 25 years, complete failure to breed was detected simultaneously in three largest ivory gull colonies in the core of their natural habitat. In nine studied colonies the total number of gulls attempting to nest in 2020 was the lowest in the entire available series of observations and amounted to approximately 350–400 pairs, compared to the most successful years when 3,000–4,000 pairs were able to nest.

In the course of the two months of work on Vize Island, the expedition team performed:

— visual inspection of colonies, installation of camera traps and route surveys to assess nest conditions and count the number of ivory gulls and other birds;
— catching birds for biological sampling and fitting GPS trackers.



52 days of stationary observations on Vize Island:

Six camera traps were set up in ivory gull colonies.

50 ivory gulls were examined.

Seven adult gulls were fitted with *Milsar* GPS trackers.

More than 260 biological samples were collected for laboratory research.

19,000 photographs and 4,000 video clips from camera traps were processed.

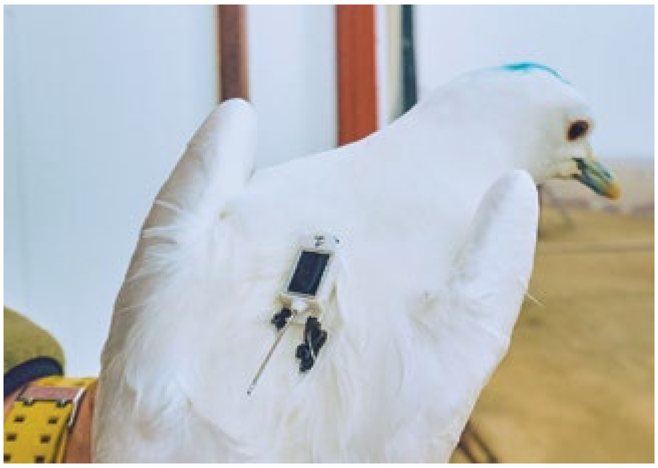
Samples and parameters

Feathers. Determination of stable isotopes: the content of ^{13}C and ^{15}N is determined. This data provides information about the diet of the bird during the molt period (when the feathers are growing) and the level of the stress hormone corticosterone.

Food samples. Many birds regurgitate food when they are caught and manipulated, often it is a food lump intended for the nestlings. Birds may also drop food scraps near nests where scientists can look for them. These samples are used to identify bird food objects. Small Arctic cod fragments were found in all samples. In addition to the ivory gull, this analysis was also performed for the kittiwake, another species of the gull family.

Venous blood. Used to determine stable isotopes, contaminants and conduct parasitological and hematological analyses.

In addition to these activities, all captured birds are thoroughly examined: measurements are taken, birds are inspected for ectoparasites (mites, lice) and ringed for identification during recapture.



A tracker on the back of an ivory gull

Movement tracking

Biotelemetry is used to determine feeding areas and food search radius during the nesting period. Adult birds were captured at the beginning of the season and fitted with GPS trackers in the form of small "backpacks".

Scientists used two types of trackers:

— *Milsar NanoTag-14* which records GPS coordinates every five minutes and transmits them to a base station set up at an elevated location near the colony;

— *PinPoint* trackers that capture GPS coordinates and record them into the device's internal memory. The built-in memory capacity is 1,700 locations, so birds have to be recaptured every 5–6 days to download the data.

Unlike the satellite tags that are fitted on bears and walruses, bird trackers weigh only 12 grams, which is approximately 2.5 % of the bird's weight, and are powered by a solar battery, rather than built-in battery packs.

A total of seven individuals were equipped with trackers in 2020. Six of them were tracked for a short period of 1–4 days, one gull returned after a long absence, bringing data on its movements over 19 days.

The maximum flying radius in this period varied from 2.4 to 22.4 km and was limited to the spread of landfast ice near the eastern part of Vize Island. In other words, gulls did not leave the vicinity of Vize Island and were feeding in the limited area of ice habitats of residual landfast ice. The area of potential feeding habitats was 300–450 km² at that time, but judging by the tagging data, less than half of it was used.

Track of a gull on the map

Field research and results

Ivory gulls in the Russian part of their habitat were fitted with GPS trackers for the first time, resulting in the first highly accurate data on their movements.

For the first time in the Russian Arctic, studies of trophic relationships of the ivory gull were carried out using comprehensive methods with the use of stable isotope analysis and the study of seasonal dynamics of the trophic niche. For the first time, complex studies of peripheral blood cells in ivory gulls were carried out to assess stress level.

A collection of biological samples (feathers and blood) most representative of the Russian part of the ivory gull population was gathered to estimate trophic relationships and health parameters of the population (stress level).

The white blood cell formula for the white gull was described for the first time in this study. It can be used as a starting point for monitoring the leukocyte stress index of ivory gulls, taking into account that the baseline data was obtained during the unfavorable nesting season.

Unique data on the biology of ivory gulls during an unfavorable season was obtained, which will help improve the monitoring methodology and interpret the data of molecular genetic studies.

Wild reindeer

Rangifer tarandus

The reindeer is one of the most important Arctic species, an integral part of the Arctic ecosystem and a key component of food security of the indigenous population of the northern territories. In relation to humans, wild and domestic reindeer are distinguished. There are two subspecies of the wild reindeer in Krasnoyarsk Krai: the Siberian tundra reindeer (*Rangifer tarandus sibiricus*) and the Siberian forest reindeer (*Rangifer tarandus valentinae*). Despite the keen interest in the reindeer, a number of issues relating to its ecology still remain poorly studied.

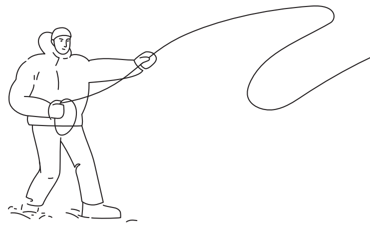
Rosneft, together with Siberian Federal University, has been studying the state of the wild reindeer population in Krasnoyarsk Krai since 2014. The work was started with grant support of Vostsibneftegaz, a subsidiary of Rosneft. The main focus of the research lies in estimating the number and studying migrations of the Taymyr-Evenki population of the species, which also inhabits the territory of Krasnoyarsk Krai.

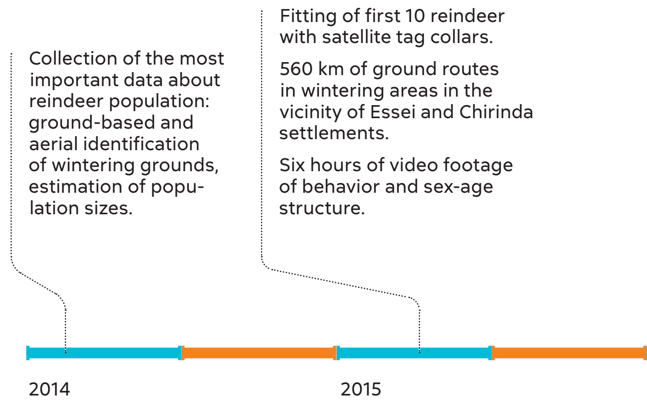
Extended expeditions to study wild reindeer are being conducted. The expeditions start at the beginning of June, and the last participants return in October-November. Main methods of research include:
— recording the number of reindeer from the air (using manned and unmanned aerial vehicles);
— counting the number of reindeer and conducting visual observations at key sections of migration routes (from the coast during river crossings);
— biotelemetric research and biological sampling.

Today, scientists possess a database of 87 tagged individuals. Since the studies of wild reindeer began in 2014, scientists have been recording increasing changes in the behavior of animals. The length of reindeer stay in traditional calving areas in the summer pastures of Taymyr today averages only 63 days, which is three times less than in the 1960s. According to satellite tag data, reindeer, having barely reached the northern end of the Byrranga Mountains, turn around and proceed in the opposite direction. In the last decades, herds have been leaving the tundra as early as mid-August. With an average speed of 13–14 km a day, the reindeer would return back to Evenkia forests for the winter by August.

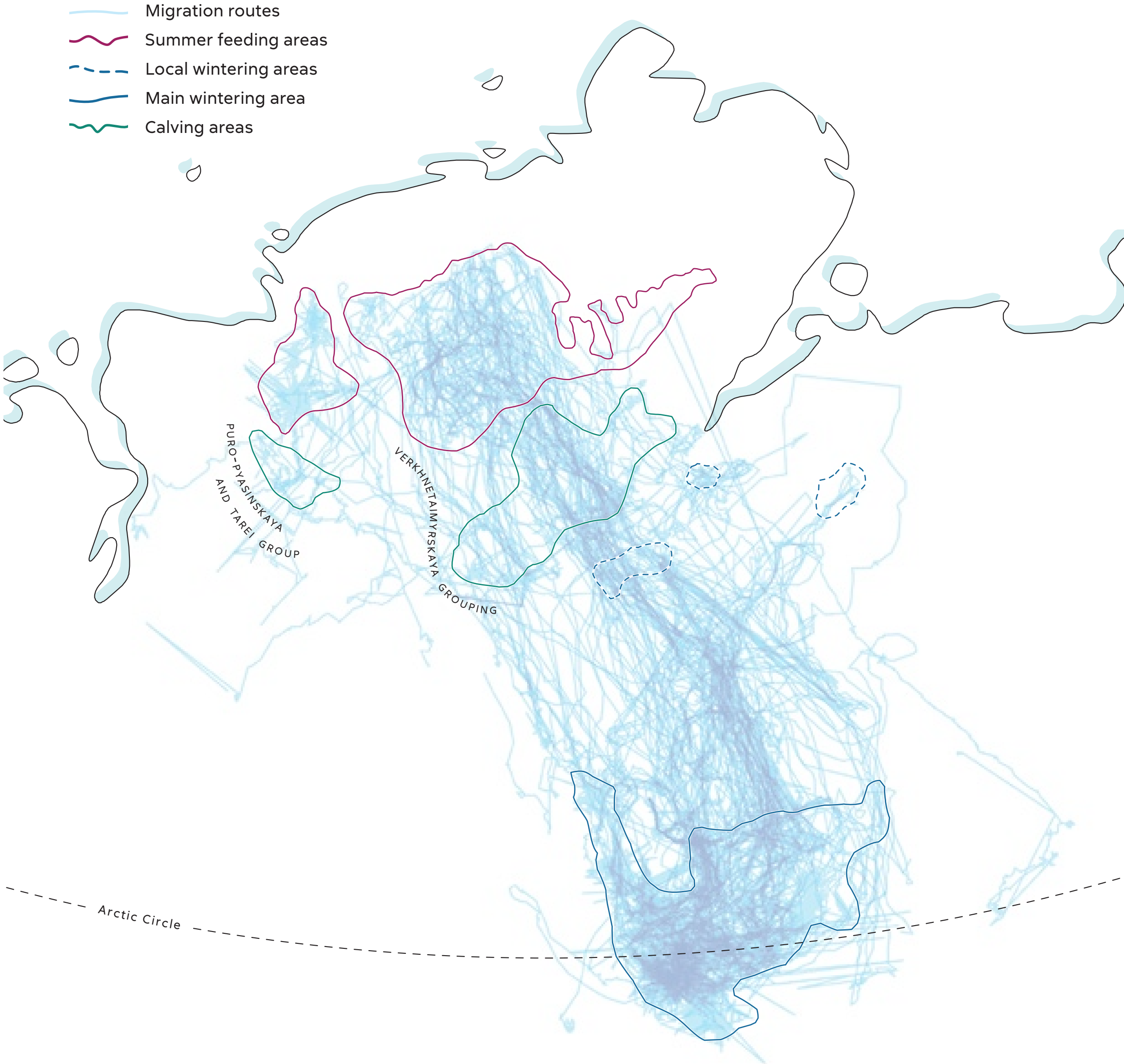
Scientists note not only the abnormal decrease in the time reindeer stay on Taymyr from 7–8 months to 63 days, but also a decrease in the length of their travel, from 1,100 km to 700 km over the years of observations.

The habitat area of the Taymyr-Evenki wild reindeer population stretches from Cape Chelyuskin and the northern spurs of the Byrranga Mountains to the northern taiga of Evenkia. In the west, the boundary is at 79° E and in the east it is at 112° E. The total area is over 1.5 million km^2. For most of the year the animals are on the move, traveling up to 6,500 km annually.





Routes of wild reindeer fitted with satellite transmitters in 2015–2021



Collar fitting

Scientists use collars with *Argos*/GPS satellite beacons to study wild reindeer migration. To fit the collars, the reindeer are captured at water crossings, on trails and in wintering areas. Usually, local residents take part in the trapping which, thanks to their experience and knowledge of animal behavior, considerably simplifies the search for suitable locations and minimizes the negative impact on reindeer.

In winter, reindeer are caught by roping. However, the most common method is catching them at river crossings during the migration period. After carefully approaching a reindeer in a motorboat, the animal is held with a rope loop, injected with a veterinary drug (immobilized), and then transported to dry land. While the animal is asleep, the collar is attached and samples and measurements are taken. After approximately 40 minutes the animal is able to stand back up on its own.

Testing of domestically produced radio transmitters in low temperatures and collars in extreme conditions.

Maximum duration of continuous signal reception: 444 days.

Seven reindeer were fitted with transmitters.

Maximum duration of continuous signal reception from satellite transmitters with new battery packs: 570 days.

35 hours of video footage of behavior and sex-age structure.

45 hours of visual and instrumental observations.

For the first time it was proven and documented that the autumn reindeer migration begins and ends sooner than in the previous century.

The long stay (up to 9 months) of reindeer in the forests of Evenkia and the southward shift of rutting areas was discovered.

It was proposed to use the name Taymyr-Evenki, rather than Taymyr, for the population of tundra reindeer.

Spring expedition to study reindeer in one of the key sections of the migration route in the Maymecha River basin.

540 km of registered routes.

140 hours of aerial surveys.

693 hours of visual and instrumental observations.

356 hours of video footage of behavior and sex-age structure.

The most comprehensive monitoring of wild reindeer in the project history was conducted:

1,470 hours of daily stationary observations of reindeer migration

6,000 km of registered routes

28 hours of aerial surveys

Nine reindeer were tagged with satellite transmitters

50 samples were collected for laboratory research.

2016 2017 2018 2019 2020

Systematic study of biological indicators

Biological indication is an extremely useful tool for scientists: using indirect indicators (the state of certain species), it is possible to draw conclusions about the state of the ecosystem as a whole. The main problem that prevents this method from being widely used to assess the condition of marine ecosystems is the lack of knowledge about the biology of species.

In its studies over the last 10 years, Rosneft has been filling the gap in the data on the state of animal populations: the ways they use their territory, their migrations, accumulation of pollutants in their tissues and their genetic diversity.

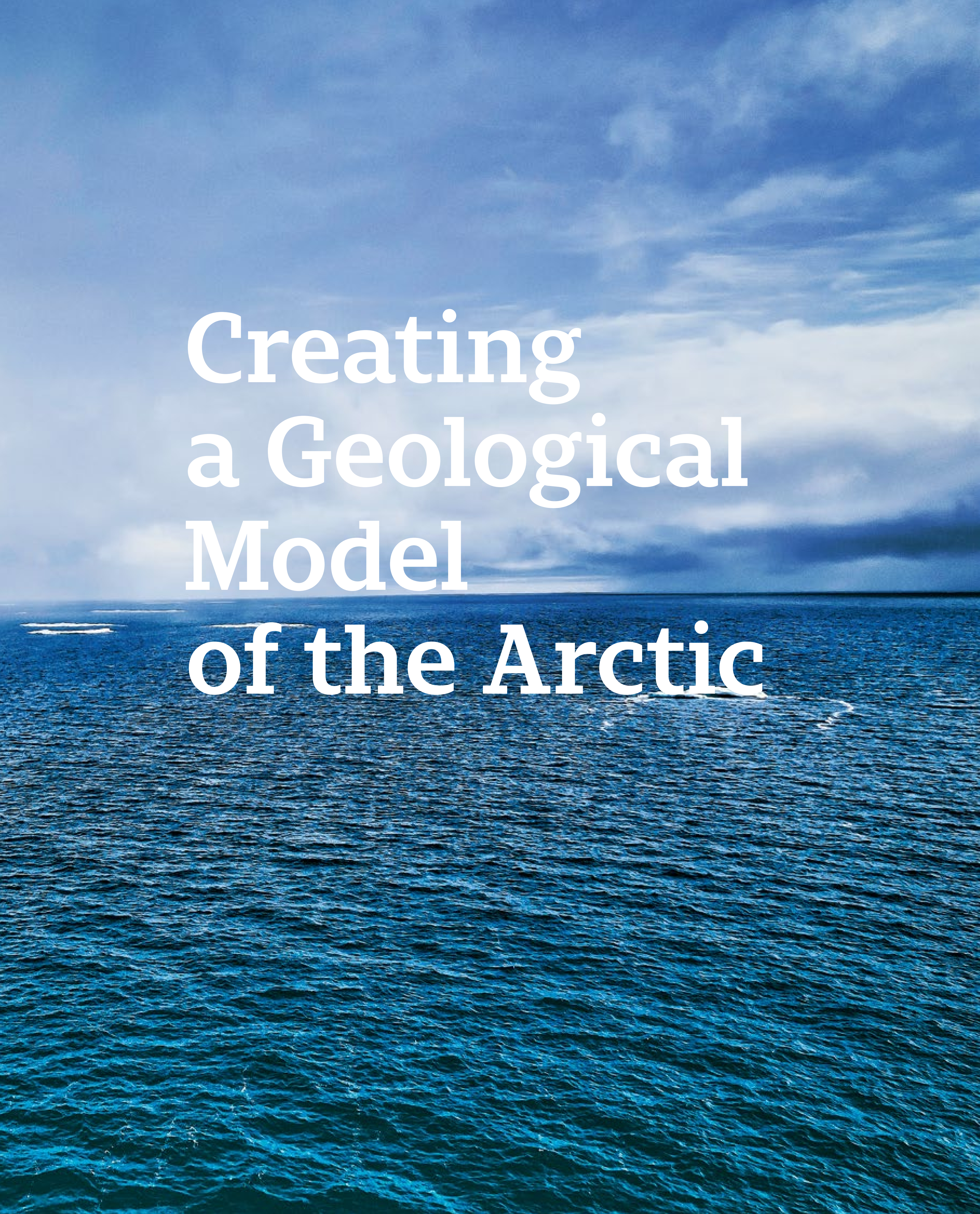
This work not only provided relevant data for the development of monitoring programs of these species as biological indicators and measures for their conservation. The results of expeditions yielded valuable scientific data on the change of reindeer migration routes, the microbiome of polar bears, the state of population of rare species of Arctic seabirds in a year of unsuccessful reproduction, the current number of Atlantic walruses on the Franz Josef Land archipelago.

The degree of understanding of various taxonomic groups varies greatly. While the biology of marine mammals, birds and some fish species has been studied in relative detail, for many groups of invertebrates or algae there exist only general notions about their preference for temperature, salinity and other parameters.

Intensive research in the seas of the Russian Arctic in recent years, including the studies organized by Rosneft, has expanded and improved the knowledge of the biology of many species. New findings are changing the understanding of species distribution in the Arctic seas, and a growing body of data needs periodic revision. In 2020, Rosneft published an atlas of biological indicator species which contains information about the biology of species proposed by the Ministry of Natural Resources and Environment of the Russian Federation for use as environmental indicators.

→ p. 230

Creating a Geological Model of the Arctic



Exploration of the Earth's crust

There is no place for major geographic discoveries on Earth anymore: the surface of the planet has been completely photographed by satellites and mapped. However, the related field of geology still has potential. Geology studies the structure of the Earth's crust and the world ocean presents rich opportunities for research in this regard. Today, less than half of the ocean has been explored in detail with geological and geophysical methods. Even topographical maps of the Moon and Mars are more detailed than those of the ocean floor, yet oceans cover 70 % of the globe.

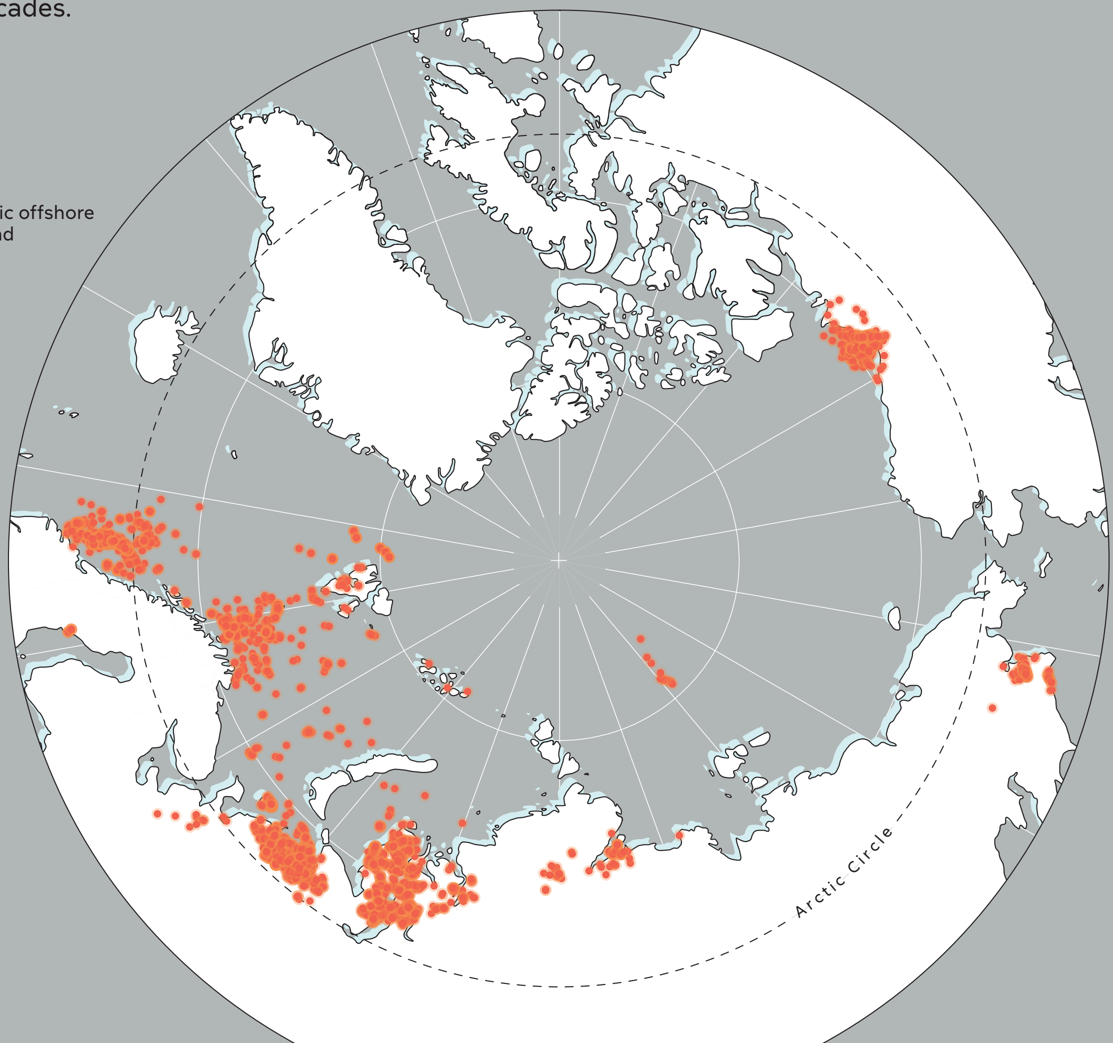
In August 1968, a ship carrying offshore drilling equipment sailed into the Gulf of Mexico. It was the first expedition of the deep-water drilling project that began the process of systematic exploration of the Earth's crust in water areas. Since then, a dense network of wells has covered all of the Earth's water areas. All but one — the Arctic. There are 13 major sedimentary basins, but only half of them have been studied by deep drilling. The polar region at the tip of the northern hemisphere is covered by ice for most of the year, so getting to the surface of the sea floor, much less drilling deep into it, is not easy. Active exploration of Arctic waters coincides with the beginning of the search for oil and gas deposits. For example, numerous wells have been drilled on the shelves of the USA, Canada, Norway and Greenland in recent decades.

→ p. 64

In the Russian Arctic, geological and geophysical research used to be concentrated mainly in the Barents Sea and the southern part of the Kara Sea. But in 2014 Rosneft began to gradually move eastward, carrying out extensive geological exploration activities in the Eastern Arctic. In 2020, unique expedition work was organized in the north of the Kara Sea, during which first stratigraphic wells in the region were drilled. In 2021, Rosneft's stratigraphic drilling program was successfully continued in the Laptev Sea, and in the future the company is planning to drill wells in the Chukchi and East Siberian Seas. The reasons for moving eastward are clear: until recently, there were no wells in these Arctic seas whose total area is four times that of France. And without core samples and evidence of the deep structure of the subsoil, it is impossible to confidently determine the age and composition of the sedimentary basins of the Arctic region.

→ p. 15

Wells in the Arctic offshore and adjacent land



Offshore drilling

Exploratory drilling units

The search for hydrocarbons in the subsoil begins with geological and geophysical surveys (first of all, seismic surveys), which are necessary for subsequent exploration drilling. The goal of drilling is to conduct an initial assessment of the presence of oil and gas in the target layers (geological horizons) and to determine the properties of the host rock. Offshore drilling is carried out from drilling platforms and requires considerable effort. Exploration and appraisal wells are relatively deep, penetrating the rock strata for 2–4 km or more.

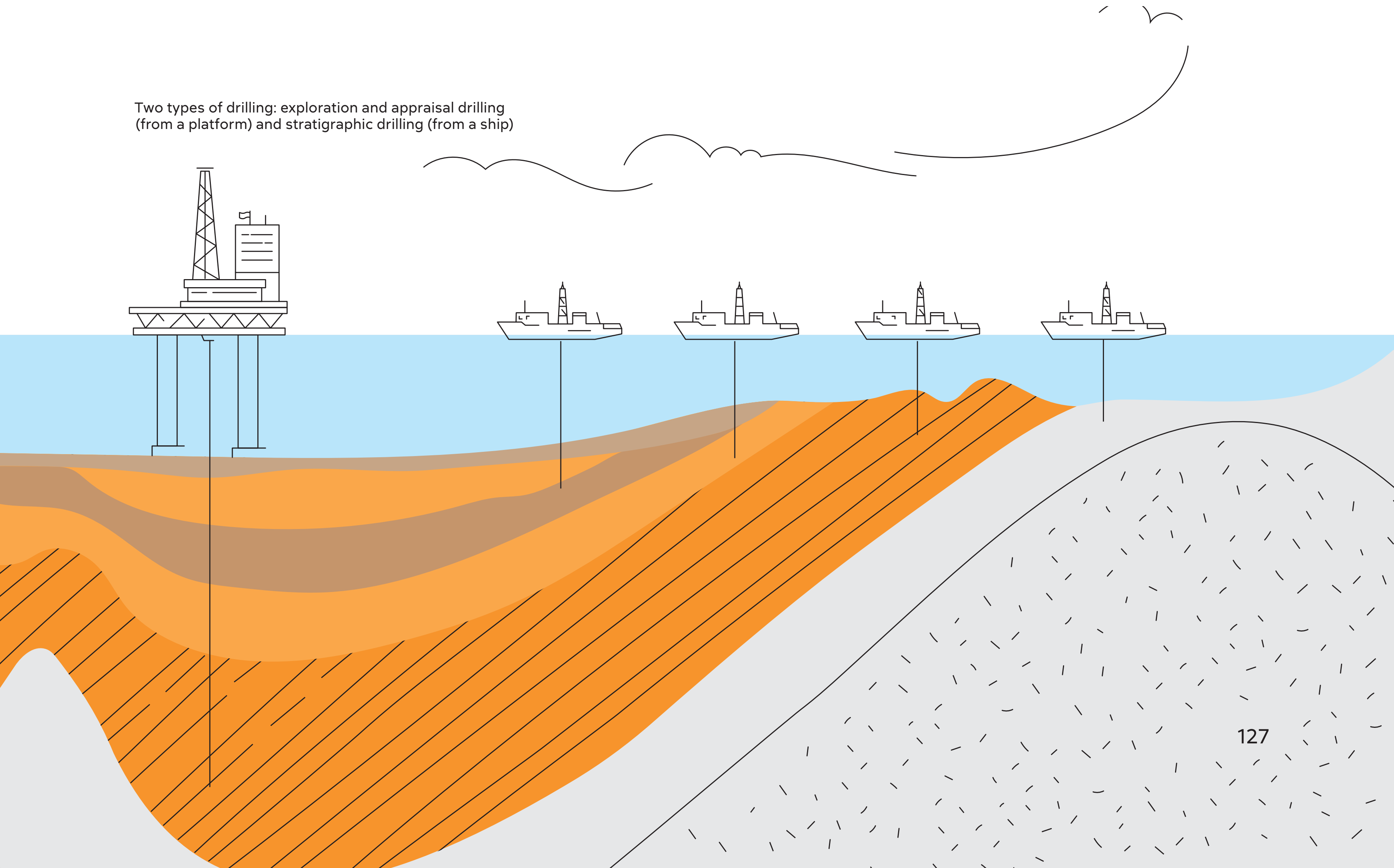
If signs of oil and gas are found during prospective drilling, it is possible to say a field was discovered. But before progressing from the analysis of geological and geophysical information to drilling prospecting and exploration wells which will localize deposits and allow to estimate the volume of hydrocarbons in the depths of such inaccessible regions as the Eastern Arctic, the stage of stratigraphic drilling is necessary.

Stratigraphic drilling

The nature of the method lies in the term “stratigraphy”, which means determining the age of geological layers. Instead of uncovering oil and gas deposits, the purpose of stratigraphic drilling is to ascertain the regional geological structure of the water area. The goal is to obtain cores from geological horizons by drilling shallow wells, information from which can then be extrapolated to the entire sedimentary basin of the region. → p. 37

The location of stratigraphic wells is chosen based on seismic data and is focused on the most favorable areas for accessing the target geological horizons. → p. 65

Two types of drilling: exploration and appraisal drilling (from a platform) and stratigraphic drilling (from a ship)



Geological model

When studying marine sedimentary basins, geologists and geophysicists build a digital model, a two- and three-dimensional visualization of the earth's structure. It reflects the age, depth and geometry of the layers, predicts the composition of their constituent rocks and details the history of the region's development.

The geological model shows:

— whether the geological layers of the Earth's crust were stretched or compressed, and whether they were disturbed by faults in the study area;
— where and how much sediment has been accumulated and what is its composition;
— whether sedimentary rock complexes came to the surface in the geological past.

From the constructed model, scientists learn where the Earth's crust is of the continental or oceanic type, what geological processes have taken place here over many tens or hundreds of millions of years, and where promising areas for mineral exploration can be identified.

Arctic geological models are based on marine geophysical surveys and analyses of rock samples from the adjacent land. But for a model to be credible, it is necessary to link cross sections and diagrams resulting from interpretation of geophysical data with actual rock samples. This is where stratigraphic drilling helps. Tens of meters of core samples obtained from boreholes allow to conduct a detailed laboratory analysis, correlate them with interpreted geophysical data and understand how the basin evolved over geological time.

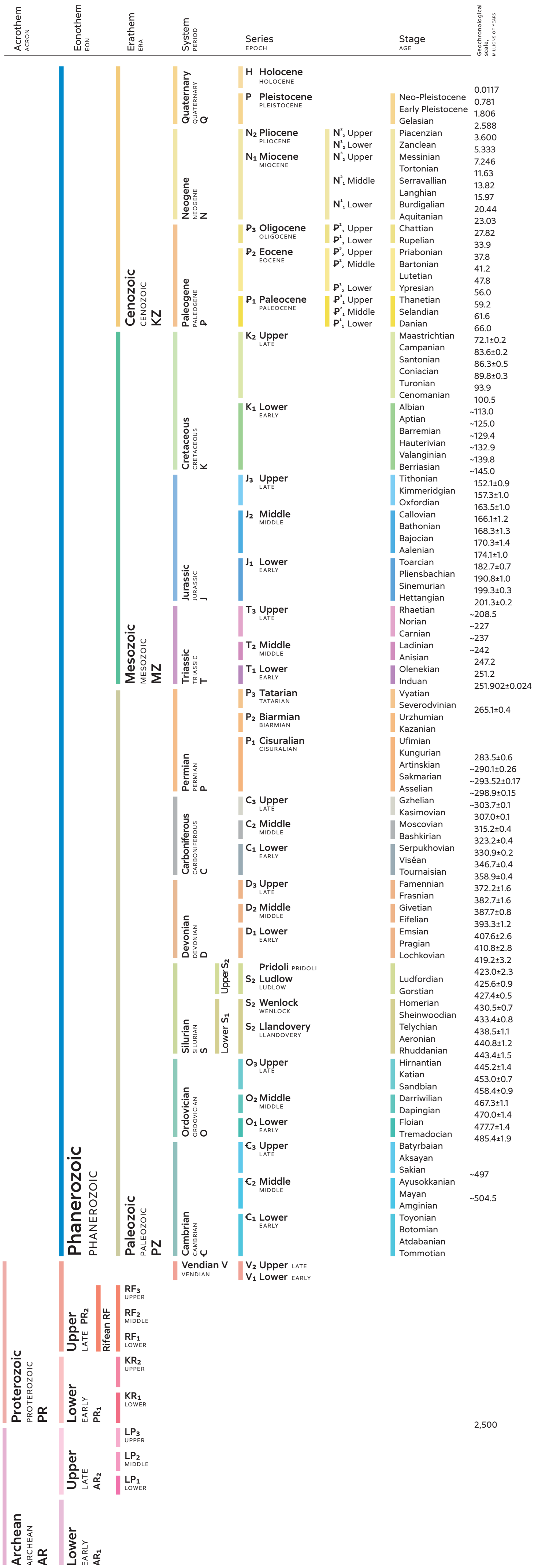
Core sample from the subsurface

Prior to drilling

Before a well can be drilled, the geometry of the geological strata beneath the seafloor must be mapped. → p. 65 Researchers start with a seismic survey, an "ultrasound" of the Earth's crust. It only requires two elements: a seismic source and a seismic streamer. The first emits elastic vibrations into the Earth's crust, the second records their propagation.

The role of the seismic source in marine surveys is usually played by an air gun that shoots compressed air into the water. The geological environment is heterogeneous, so the velocity of the elastic waves will depend on the physical properties of the rocks. The result is a velocity cross section, a "layered cake" where each layer is a geological horizon with its own set of physical properties.

Seismic surveying reveals the geometry and elastic properties of the layers, however these black and white or colored cross sections don't help find out their age. The work "in the field" is done parallel to seismic surveys. Geologists are taken to the islands on ships and helicopters where they chip away samples of rocks from natural rock outcrops. By comparing the relationship of layers with different physical properties on land and at sea, assumptions can be made about their correlation. Samples are taken to laboratories where their composition and age are studied. Finally, scientists can compare the two types of data.



Geochronological scale

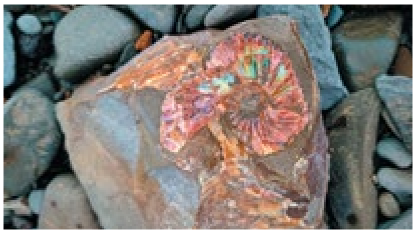
The geological history of the Earth is usually illustrated with a geochronological scale. The scale looks like a calendar that consists of intervals lasting millions or even billions of years. Colors on it show eras and periods at the boundaries of which the most important geological events in Earth's history took place. The lower down the scale, the farther an event is from the present.

Each interval of geological time has its own unique biota. For example, four billion years ago the Earth was inhabited by simple life forms, prenuclear organisms or prokaryotes. Conditions were constantly changing, and through the process of biological evolution, Earth became inhabited by ancient arthropods, fish, underwater and terrestrial plants, dinosaurs, birds, mammals and many other creatures. Geologists and paleontologists continue to search for new data to find the keys to understanding the complex and fascinating history of life on our planet.

How geologists search for the truth

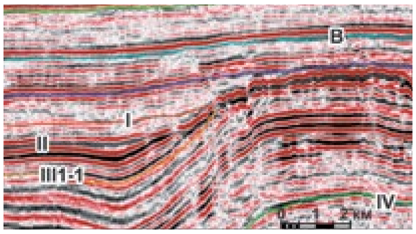
Imagine: there are facts that geologists see with their own eyes: natural outcrops on islands and on the landward rim of the Arctic seas. There are rock samples from these outcrops that are used for scientific research. And there is also a monochrome or color seismic picture. In the process of offshore exploration, legitimate questions arise. What intervals in the offshore seismic cross sections do the onshore rock samples belong to? How can they be reliably compared and how can the age of the horizons identified by seismic data be determined, so we can paint them in colors corresponding to the main periods and epochs of the geological time scale?

The North Kara sedimentary basin has been studied by several scientific groups at different times, and each of them put forward a different version of progression of geological events. One group concluded that the basin was formed in the Precambrian (Riphean) time, the other claimed it happened in the Paleozoic (Ordovician period). There was also no agreement on the dating of the upper part of the sedimentary cover: the Devonian, Permian and Triassic periods were all suggested here. The difference between proposed ages of the same boundary in different models can be up to several hundred million years. Although experts have the same material on hand, there is no consensus: geologists have different answers based on their experience and vision and can propose a dozen geological models, just as it happened in the case of the North Kara sedimentary basin. Currently, only stratigraphic drilling can resolve these uncertainties and reduce the number of models to one that is truly comprehensive.



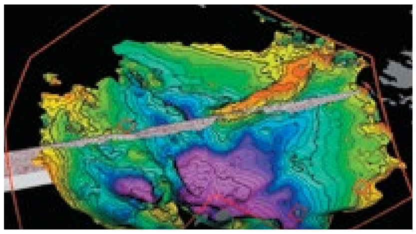
Field expeditions on adjacent land

For decades, Arctic researchers have been conducting field expeditions to study the natural rock outcrops of the North Kara Basin on the adjacent land of the Severnaya Zemlya and Novaya Zemlya archipelagos and the Taymyr Peninsula. Thanks to this research, an understanding of the diversity of age, lithology and properties of the rocks that make up the subsoil of the adjacent territories became possible. Scientists began to better understand the tectonic history of the region, as well as how rock complexes underwent changes during various geological processes.



Seismic data

Seismic surveys are one of the main methods of exploring the Earth's crust, they are the beginning of a detailed study of a sedimentary basin. Figuratively speaking, it is an "ultrasound of the Earth", which allows us to look many kilometers deep into the crust. Seismic waves pass through seawater and rocks, reflect back from geological boundaries and are picked up at or near the sea surface. Geologists take seismic images and mark out important geological boundaries.



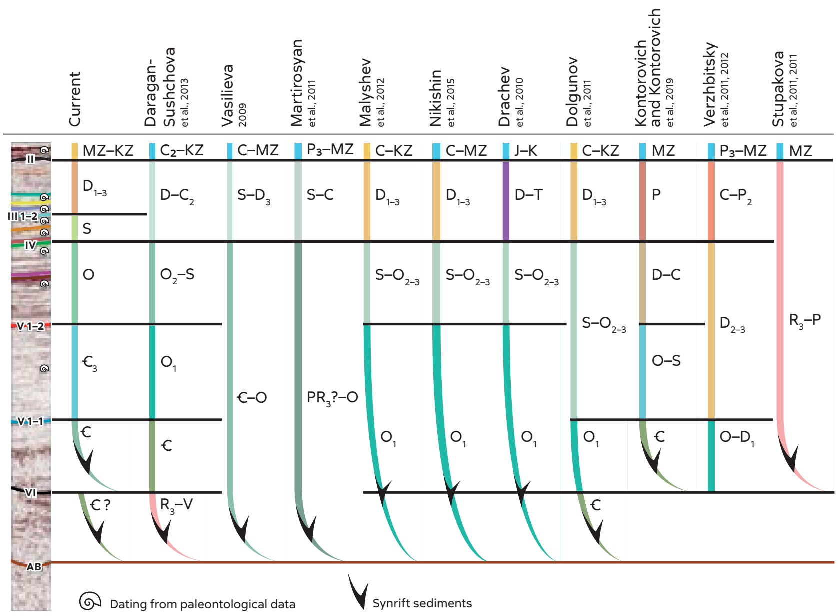
Creating a geological model

Rocks collected during expedition, seismic data and other geophysical studies in the Kara Sea have long been the basis for substantiating the geological structure of the North Kara sedimentary basin. They were used to create its geological model using specialized software. But the notions about the age and composition of the rocks derived from such data are often contradictory and allow different interpretation. This can cause errors both in oil and gas prospecting and in fundamental research.

Models of stratigraphic referencing of the sedimentary cover based on previously published data and the current one based on the results of drilling shallow wells

The time of formation of the northern Kara Sea basin lies at the bottom of the geochronological scale, colored in turquoise-brown colors

Malyshev N. A., Verzhbitsky V. E., Skaryatin M. V., Balagurov M. D., Ilyushin D. V., Kolyubakin A. A., Gubareva O. A., Gatovsky Yu. A., Lukashev R. V., Stupakova A. V., Suslova A. A., Obmetko V. V., Komissarov D. K. (2022). Stratigraphic Drilling in the North Kara Sea: First Project Experience and Preliminary Results. Geology and Geophysics



Selecting a drilling location

Locations for stratigraphic drilling are chosen based on the results of a comprehensive analysis of geophysical survey data. However, this is where the "detailed ultrasound" of high-frequency seismic surveys from specialized vessels comes into play. It helps look closely at the structure of the strata under the seabed and find areas that will be directly traversed by the drilling string.

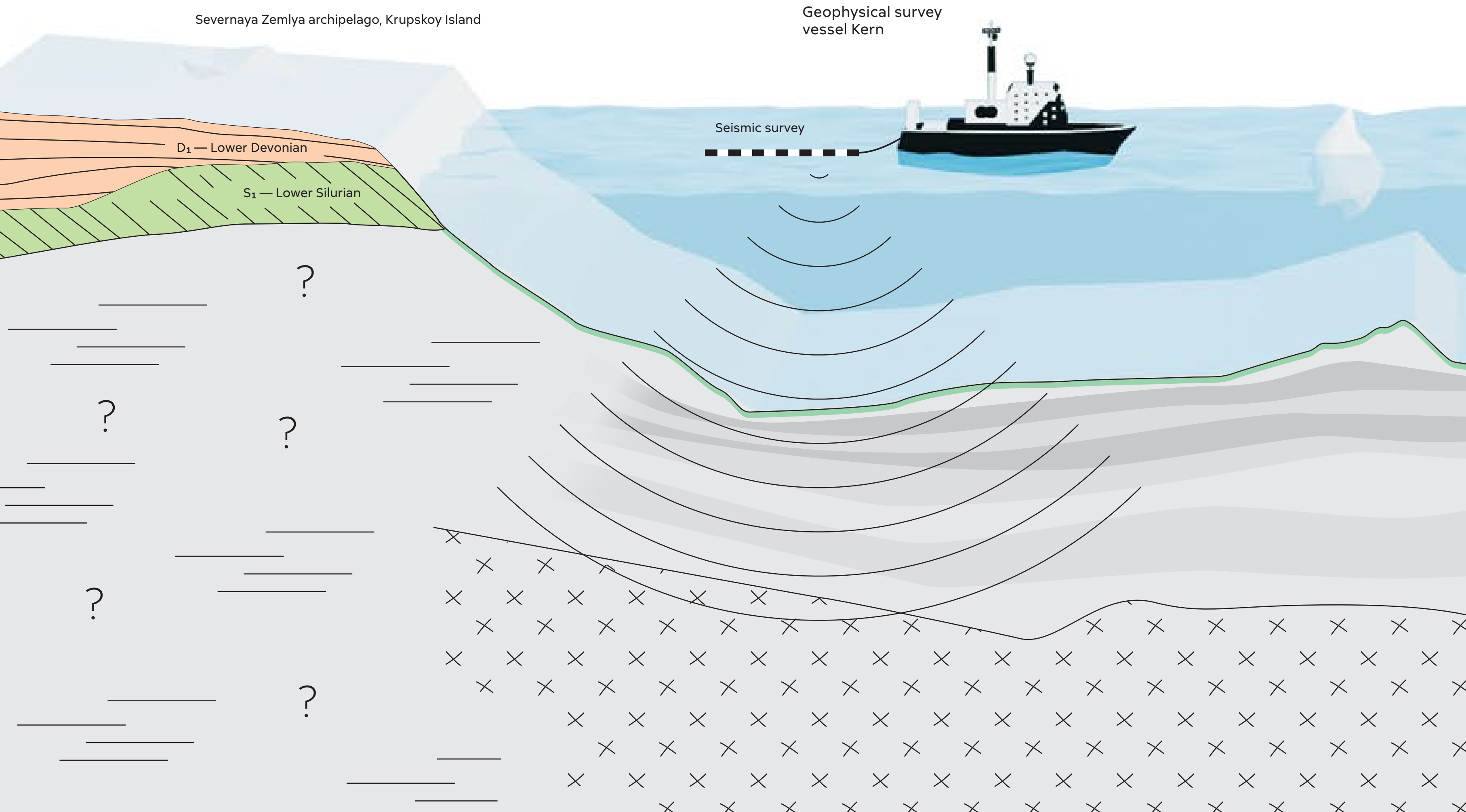
→ p. 44

In 2021, the geophysics vessel Kern worked in the Laptev Sea to the north of New Siberia Island, preparing future well sites for the drilling ship Bavenit and transmitting the necessary data interactively.

Geologists look for places where layers reach the seabed or are cut by a near-surface unconformity. Such a fortunate situation occurred in the northern part of the Kara Sea. Here, a Pleistocene glacier cut the sediments on the seafloor, so ancient layers emerged directly onto the surface of the seabed. In basins with a thick sedimentary mantle, such as the Laptev Sea, geologists are searching for basement uplifts where many layers of different age are gathered in the first hundreds of meters. When selecting stratigraphic drilling locations, the goal is to cover the widest time interval possible, from the youngest to the oldest rocks. But there is no minimum number of layers to be drilled into, since the age of the basins varies greatly in the Arctic.

→ p. 154

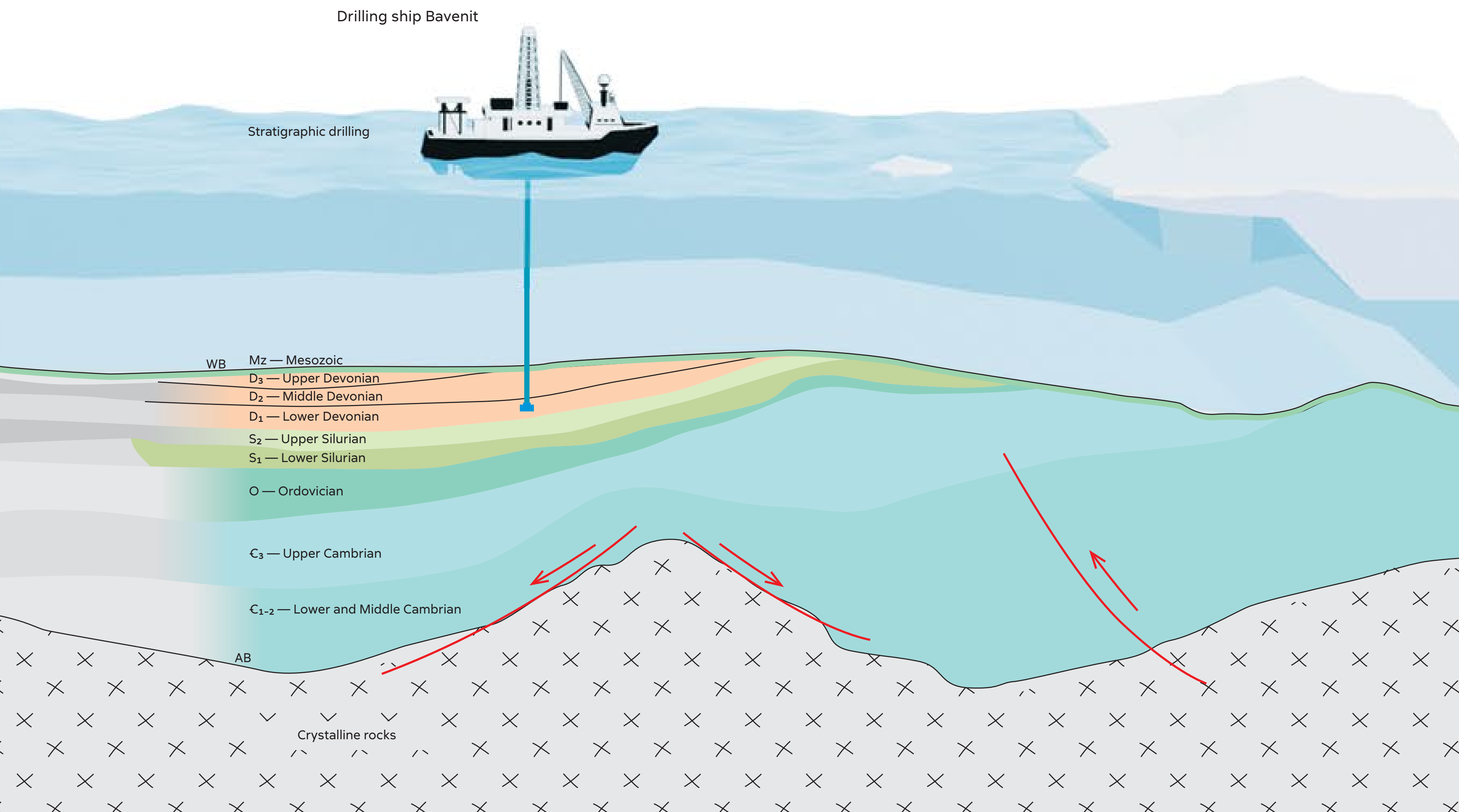
Drilling rig on the vessel Bavenit



Drilling

When drilling points have been selected, the expedition's tasks are clear: drill the wells, obtain core samples and deliver this evidence of subsurface structure to the mainland. But drilling in the Arctic zone is a long and technologically complicated process which is regularly and seriously affected by weather.

The mobilization stage, when the ship first prepares to leave and is loaded with equipment before proceeding to the area of work, lasts from a couple of days to several weeks. During the passage, icebergs and ice fields can block its path. When the work begins, it is severely complicated by storms and icy conditions. Gales can toss one side of the ship relative to the other by several meters. Under these conditions, only perfectly synchronized actions of the ship's crew will allow the task to be accomplished successfully. For example, during the stratigraphic drilling expedition in the Kara Sea, the storm hindered the work for at least 9 days out of 48, and in the Laptev Sea for 10 days out of 52.



Core extraction

Express analysis of stratigraphic well core aboard Bavenit

Core packaging

Initial core analysis

At the end of the expedition, researchers have hundreds of meters of core with a minimum diameter of 70 mm. Cores obtained in the North Kara sedimentary basin are unique: no wells had been drilled here prior to the 2020 expedition.

The primary question about the geological age of rocks is answered by studying the remains of ancient organisms inside the samples. Examination of the cores reveals different kinds of remains of ancient fish and bivalves: they lived in a narrow time interval, so they are highly accurate in indicating which period of the geochronological scale the rocks can be attributed to. And if marine sediments are interbedded with continental sediments, then plant spores and pollen can be used instead of fish: they are carried far by the wind and they preserve well in fossilized state.

After determining the age of the rocks, geologists begin to match the age references found in the cores with the reflective horizons in the seismic cross sections. Then, they correlate the material from the wells to rock samples from adjacent islands and the landward rim of the areas. The age determined from the cores is extrapolated to the entire territory of the sedimentary basin, and the seismic cross sections take on a stratigraphic color. The researchers now have a complete picture before their eyes, a reliable geological model of the region.

→ p. 129

Rosgeologiya's team promptly described and photographed all drilled cores right on board Bavenit and immediately transmitted the data via satellite communication to Rosneft's project team which updated the geological model of the basin in real time. The descriptions and photographs sent from the ship allowed to obtain the first data about the faunal finds in the core, remains of ancient armored fish and bivalve mollusk shells. All cores were then hermetically sealed, since some rocks with a predominance of clay cement are prone to drying and cracking in atmospheric conditions.

Similar work is being done in the Laptev Sea. Researchers have already obtained the age of the upper meters of well cores. It was found to be Pleistocene, dating back to the epoch that began 2.58 million years ago and that lasted until 11,700 years ago. Further laboratory research and stratigraphic correlation of the data will help determine the true age of rocks in the poorly explored East Arctic region.

A faunal find in a core on Bavenit: remains of a mollusk shell

Studies of stone material samples in the laboratory of Innopraktika

Cores in the laboratory

Rock samples from the North Kara basin were sent to Innopraktika and the Geology Department of Lomonosov Moscow State University.

Already during the initial description of the samples, scientists noted the diversity of their lithological composition and textural and structural features. Both carbonate (dolomite and dolomitized limestone) and terrigenous rocks (sandstone, siltstone and argillite) were uncovered. In general, lithological and sedimentological observations confirm the understanding of predominantly shallow-water marine sedimentation conditions throughout most of the history of the North Kara basin that were previously put forward by researchers.

The most important type of laboratory research is biostratigraphy which determines the age of rocks. In the course of laboratory work, faunal remains were found and characterized in well cross sections, including ancient fish of different shapes and sizes, remains of other extinct animals, as well as palynomorphs — spores, pollen and shell fragments of ancient plant organisms.

Mesozoic sediments were identified in the upper parts of the well cross sections. This dating is confirmed by the presence of bivalves, belemnites and spores. Scientists determined the species of bivalves and belemnites which made it possible to establish a more accurate geological age of the rocks.

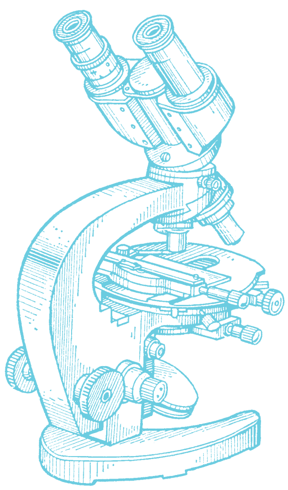
As for the Paleozoic part of the sedimentary cover, faunal remains and acritarchs — ancient microscopic remains of unicellular organisms, a variety of palynomorphs — were discovered. Well SSD 31 which was drilled into the sandstones of the Upper Paleozoic complex, revealed remains of placoderms, which existed in the Silurian and Devonian periods. A representative of their genus, identified in the course of the study, was extensive in the Middle and Late Devonian, and the heyday of this group occurred in an even narrower interval of geological time. According to palynological data, the sediments date to the Frasnian age of the Late Devonian period.

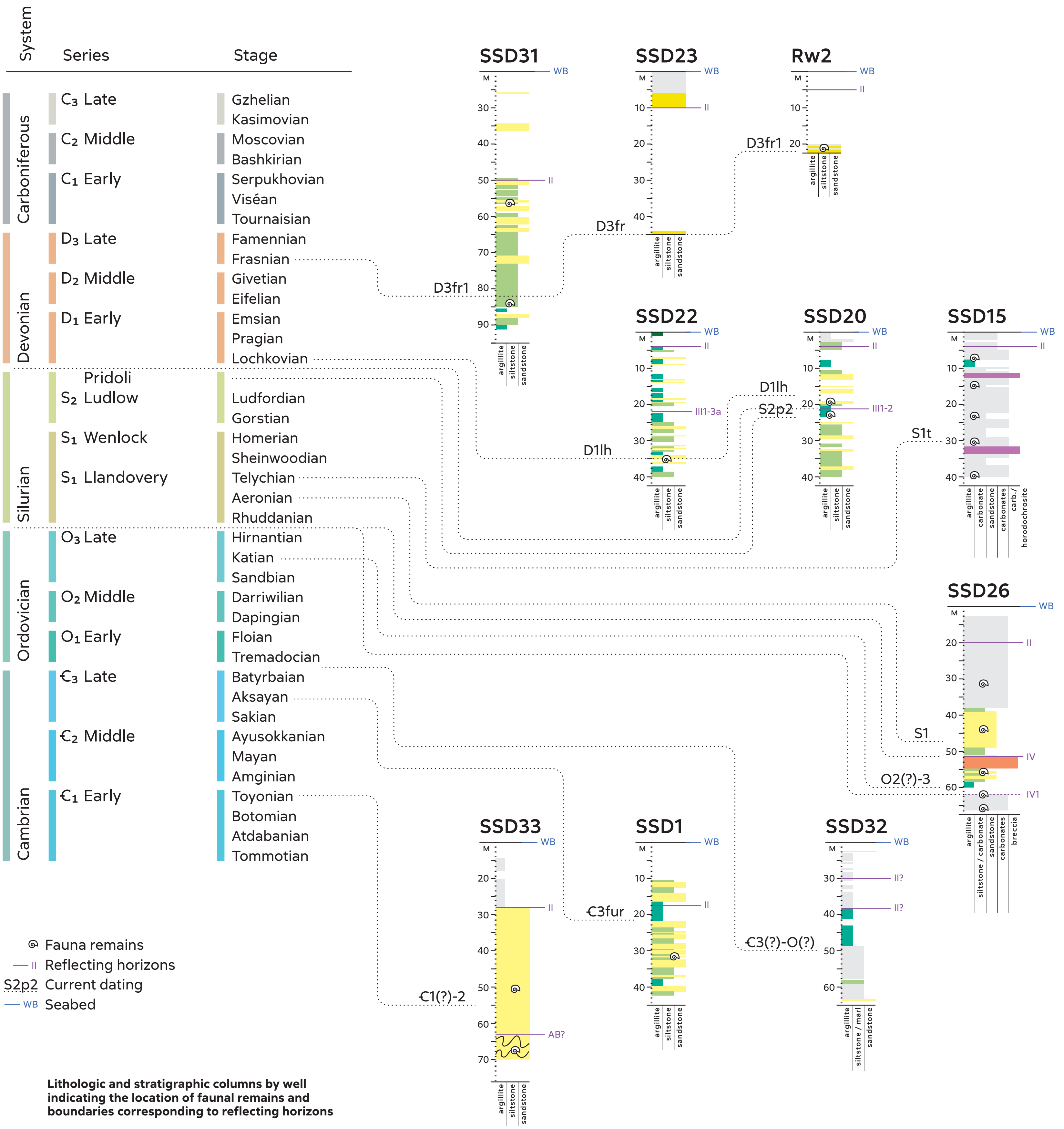
Fragments of a bone spike of another ancient fish and a shell print of an ostracod — a shell crustacean characteristic of Early Devonian time — were found in the siltstones in the cross section of well SSD 22. In the neighboring borehole SSD 20, the underlying complex contained imprints of fish bone plates, and shell fragments dating to the Silurian — Early Devonian period.

Wells SSD 15 and SSD 26, which penetrated the same complex located even lower in the basin, contained carbonate sediments. These are dolomites and dolomitized limestones with Silurian conodonts (tooth-like remains of ancient chordates) and fragments of colonial corals that existed from the early Silurian to the early Devonian periods. In addition, well SSD 26 revealed an even more ancient rock complex. The carbonate sediments of this complex contain fragments of colonial tabulate corals, widespread in the Silurian — Early Devonian period, as well as Ordovician — Early Silurian conodonts. → p. 129

The terrigenous cross sections of wells SSD 1 and SSD 32 which uncovered even older sediments, contained complexes of acritarchs, which suggests the Cambrian age of the uncovered rocks.

The completed complex of biostratigraphic studies unambiguously determined the dating of primary sedimentary complexes of the North Kara basin and eliminated a lot of uncertainties in the history of its geological development. The studies also yielded data on the quality of reservoir rocks, fluid seals and the degree of maturity of oil and gas bearing rocks.





Lithologic and stratigraphic columns by well indicating the location of faunal remains and boundaries corresponding to reflecting horizons

Malyshev N. A., Verzhbitsky V. E., Skaryatin M. V., Balagurov M. D., Ilyushin D. V., Kolyubakin A. A., Gubareva O. A., Gatovsky Yu. A., Lukashev R. V., Stupakova A. V., Suslova A. A., Obmetko V. V., Komissarov D. K. (2022). Stratigraphic Drilling in the North Kara Sea: First Project Experience and Preliminary Results. Geology and Geophysics

Current geological model

Stratigraphic drilling in the North Kara sedimentary basin was preceded by studies performed by Rosneft and other organizations. A geological model of the region was built using 52,000 km of MOGT-2D seismic profiles and other geological and geophysical data, including 70,000 km of airborne gravity and magnetic survey data and two geological expeditions organized by Rosneft in 2013 and 2019 to the Severnaya Zemlya archipelago.

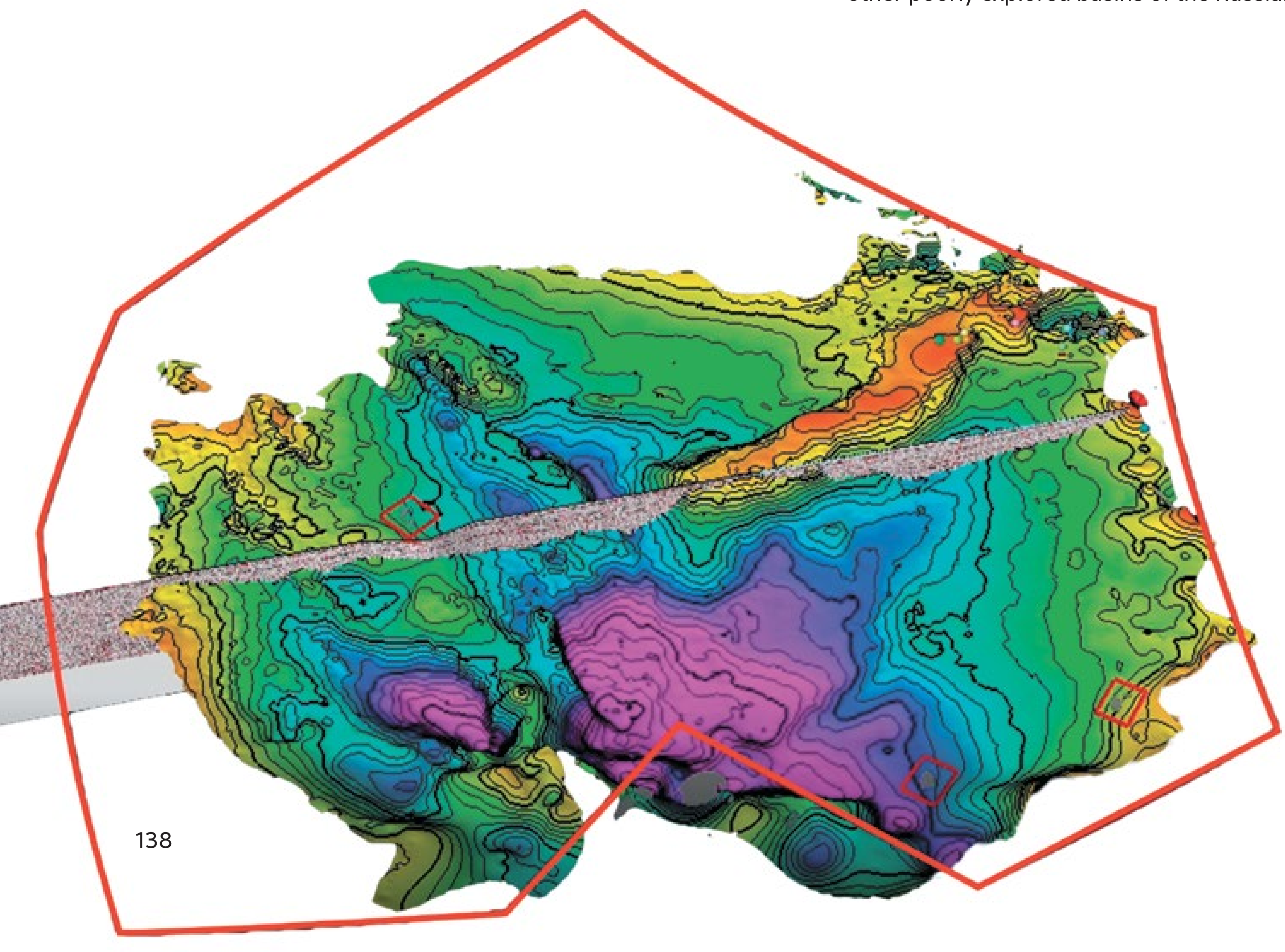
The drilling helped to significantly refine the geological model: scientists obtained crucial information about the age and composition of rocks, their ability to generate, conduct and retain oil and gas.

The new data on the age and composition of sedimentary rocks is closely related to solving fundamental problems for the entire Arctic region. The data makes it possible to more accurately and unambiguously identify key geological boundaries in the sedimentary cover of the offshore of the North Kara basin, reconstruct the history of sedimentation in the region, the movement of lithospheric plates and climate changes in the Paleozoic and Mesozoic eras.

The most important applied significance of determining the age and composition of the rocks is in building three-dimensional digital models that reflect the configuration of rock layers in the basin, their composition and the history of formation of oil and gas deposits.

The results of studies of fossil organisms in well cores confirmed the Paleozoic model of the main part of the sedimentary cross section of the North Kara basin; datings starting from the Late Cambrian were obtained. In general, there is a tendency for the ages of some rock complexes to increase compared to the model adopted before the drilling.

Stratigraphic drilling significantly reduces geological risks when searching for hydrocarbons by providing unique direct information on age, composition and properties of prospective sedimentary complexes of the basin. The technique is recommended for use in other poorly explored basins of the Russian Arctic shelf.



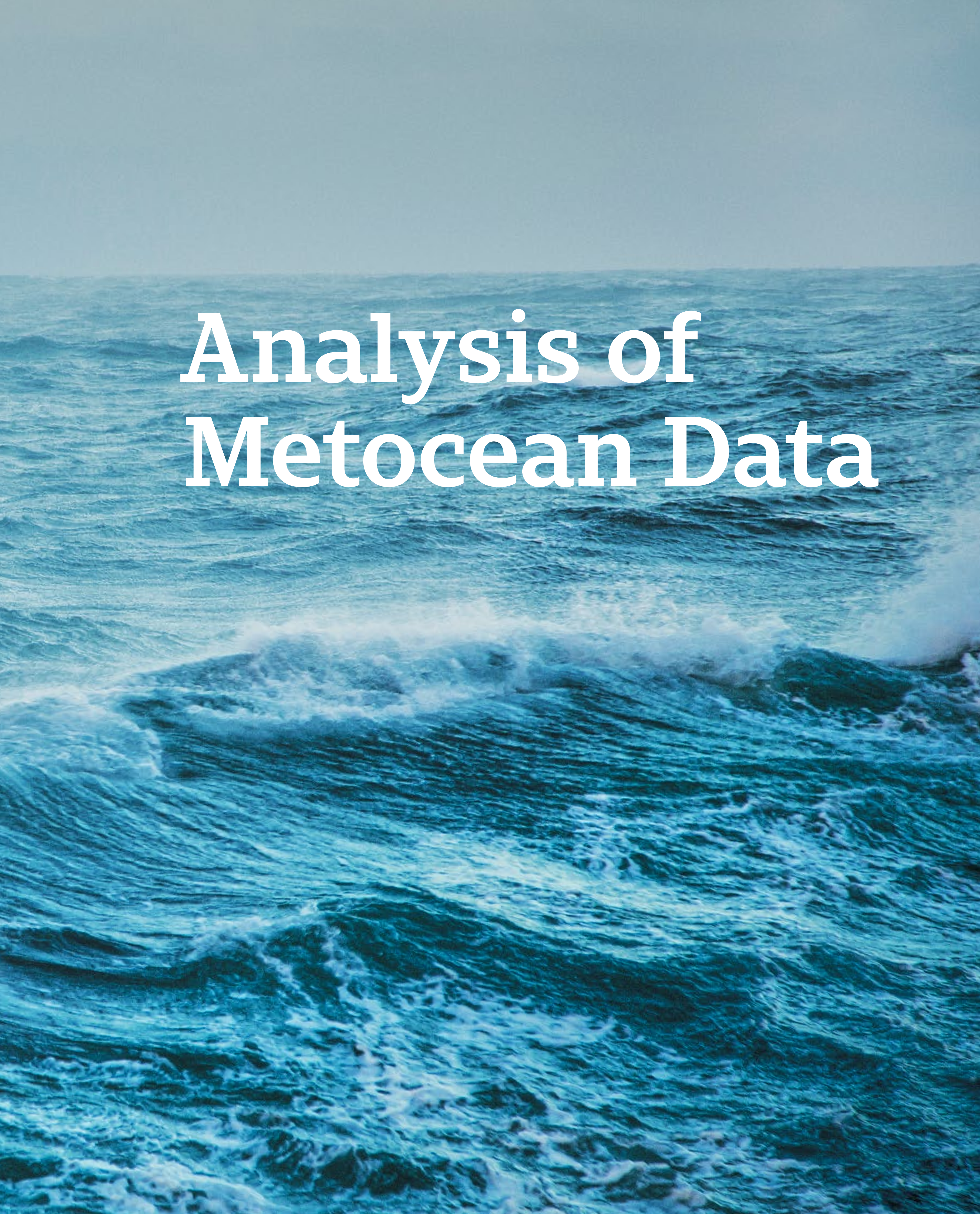
The comprehensive drilling program implemented by Rosneft in the Kara Sea has confirmed the high potential of the new oil and gas province comparable to the Gulf of Mexico, the Arctic shelf of Alaska and Canada and the largest provinces of the Middle East.

The project started in 2012 with 2D and 3D seismic work. In the course of further work (exploration drilling) at the Vostochno-Prinovozemelsky-1 license block, one of the world's largest fields, Pobeda, was discovered in 2014. Tests confirmed the high quality of the Kara oil: it is ultra-light, exceeding the benchmark *Brent*, *Siberian Light* and *WTI* grades by key indicators (density and sulfur content).

In 2020, unique gas fields named after Marshal Zhukov and Marshal Rokossovsky were discovered in the Vostochno-Prinovozemelsky-1 and Vostochno-Prinovozemelsky-2 blocks.

The total recoverable reserves of Rosneft's three discoveries amount to more than 1.7 trillion m^3 of gas and 180 million tons of oil and gas condensate. A total of more than 30 prospective structures were discovered in the three Vostochno-Prinovozemelsky license blocks of the Kara Sea.

Analysis of Metocean Data



From observations at points to spatial data

The study of any region implies the most detailed and systematic study of its climate. This is doubly important for the Arctic: snow cover, glaciers and sea ice play a significant role in the dynamics of the Earth's climate system.

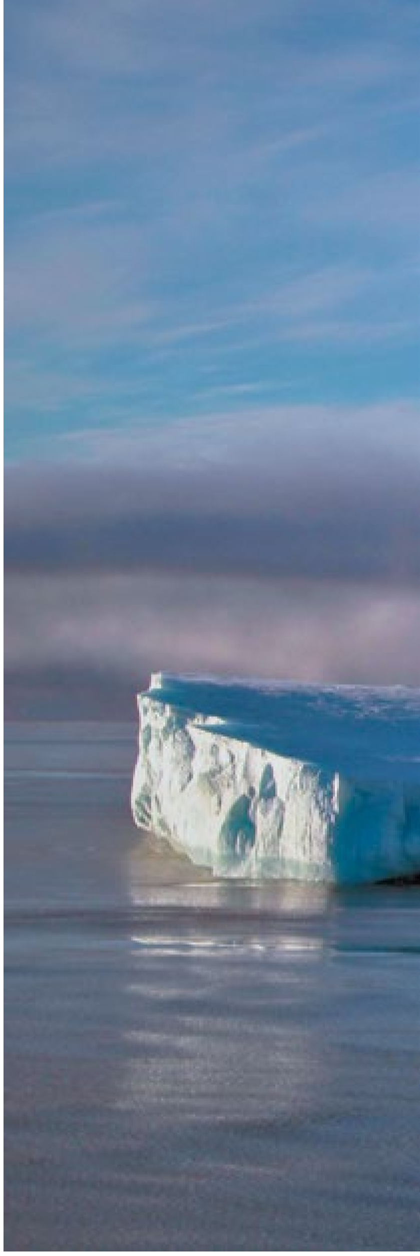
Global warming, for example, primarily manifests in the changes in temperature in the high latitudes of the Northern Hemisphere: from 1880 to 2015, global surface temperature in the Arctic increased by 2.5 °C which is almost three times more than on average throughout the planet.

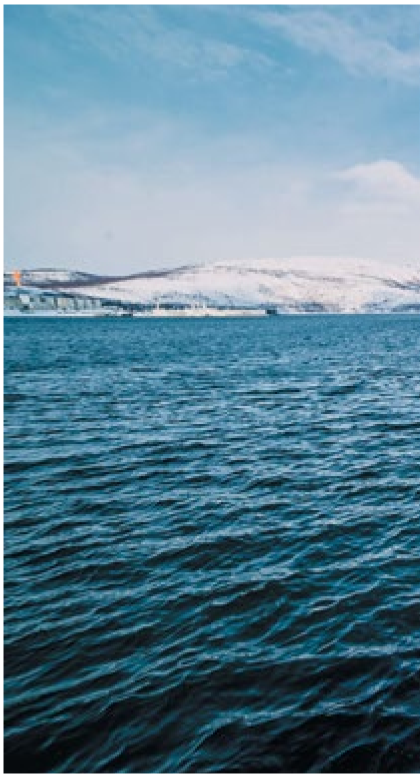
The Strategy for Developing the Russian Arctic Zone and Ensuring National Security until 2035 was elaborated and approved.

The Arctic is a home to people, there are large enterprises, ports and offshore projects, shipping along the Northern Sea Route is developing. Knowledge about the dynamics of metocean processes is necessary for the safety of industrial operations and the comfort of people.

→ p. 72

Reliable metocean data allows to:
— determine the characteristics of meteorological and hydrological conditions in water areas: sea current speed and direction, wave height, sea level, tidal range, ice thickness, water temperature and salinity, wind speed and direction, etc.;
— evaluate the characteristics of extreme events: tsunamis, storms, maximum wave heights, wind speeds during storms, ice thickness and ice drift rates;
— better understand the period and frequency of their occurrence;
— study scenarios of their development;
— evaluate possible risks for marine and offshore exploration operations related to extreme events or consequences of climate change;
— develop risk prevention measures.



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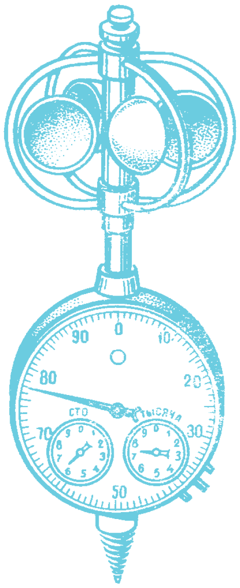


Point observations

Observations are a necessary and the most reliable tool of any research. Numerous observations of metocean parameters have been carried out on Arctic expeditions over the years: data on meteorology, oceanology, physics and dynamics of ice and sea biology was collected in ice-free areas in summer and from drifting ice stations in winter.

→ p. 54

→ p. 72

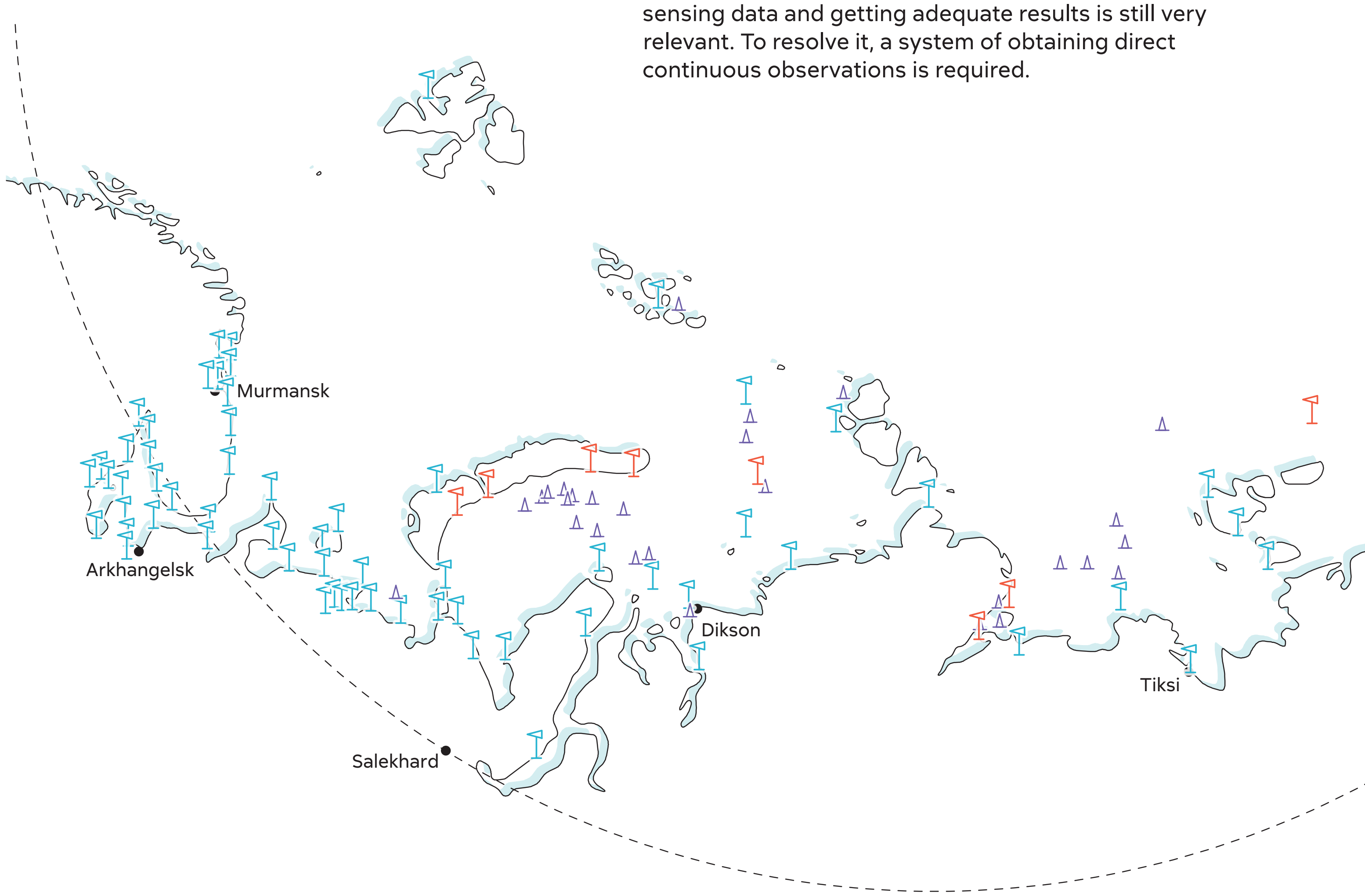
Their main drawback is that point data is scattered and represents, in fact, single measurements. Moreover, the amount of available information decreases as one moves eastward: the Barents and White Seas are much better studied than the Laptev, East Siberian and Chukchi Seas.

But even these isolated measurements, such as consistent data from hydrological profiling on century-old cross sections, make it possible to assess changes in climatic conditions in specific areas of the Arctic. The materials of airborne ice surveys of the 1960s–1980s are truly invaluable, as well as the data of satellite imaging that has been collected since the 1990s to assess the distribution of various types of ice.

But the issue of automatic processing of remote sensing data and getting adequate results is still very relevant. To resolve it, a system of obtaining direct continuous observations is required.

Network of metocean stations in the Russian Arctic

- Roshydromet stations
- Rosneft automatic weather stations
- Rosneft submerged autonomous buoy stations



Steps to systematization

Russia has a network of coastal and island metocean stations managed by the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). The duration of continuous observations at some stations can reach dozens of years. Unfortunately, there are few such stations in the Arctic region, and they record only a limited set of parameters.

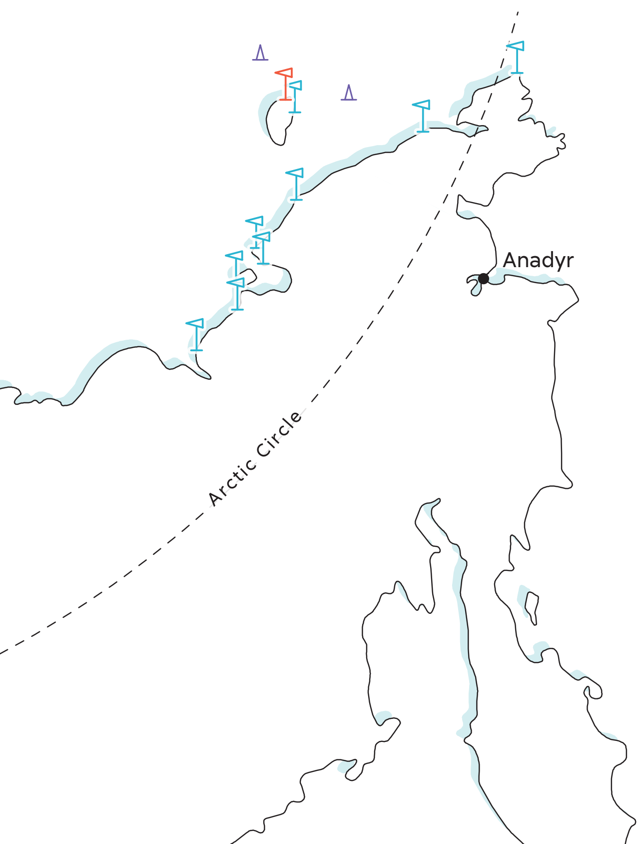
At all stations, a standard set of meteorological observations is carried out eight times a day, measuring atmospheric pressure, air temperature and humidity, wind speed and direction, amount of precipitation and atmospheric phenomena.

Observations of hydrological parameters are carried out at a considerably smaller number of stations. Usually, these are visual observations of surface waves and ice conditions, less often they include daily measurements of sea level and water temperature in the surface layer.

→ p. 28

In the seas of the Eastern Arctic such observations are not taken at all. If sea level is measured, for example, in the Barents and Kara Seas, it is usually recorded four times a day; hourly observations are exceptionally rare. They are carried out in large ports, often with the support of production companies. Roshydromet does not conduct instrumental observations of surface wave parameters or measure speed and direction of currents.

An automatic weather station fenced with bear protection mesh



Since Roshydromet's observation network stations are located primarily on the mainland coast, the available data does not reflect conditions in the open sea. There are no systematic observations of metocean parameters in the open parts of the Arctic seas that for most of the year are covered with ice.

Therefore, in 2012 Rosneft began conducting comprehensive studies of metocean conditions in the seas of the Russian Arctic. The research included comprehensive expedition work, as well as a large amount of data processing and mathematical modelling.

Metocean operational design criteria characterize normal or usual conditions under which the facility will function.

The **Extreme** ones describe the conditions in which the structure should survive without losing its functional qualities.

Data collection

→ p. 72

The main purpose of expedition work is to collect information on the parameters of the metocean conditions. In order to obtain continuous year-round data, observation infrastructure was deployed (SABS, AWS, the Khastyr base), seasonal points observations (seasonal SABS, ice ranges) and individual measurements (hydrological sounding, registration of drift trajectories of ice formations) were taken. Properties of level and deformed ice were studied and its drift velocities were observed in winter conditions. After each expedition, the collected data was summarized which allowed to accumulate a large amount of systematized data on the parameters of the metocean regime of the Russian Arctic. Up to 3–6 years of regular observations have been collected at several locations.

The main task of data processing is to obtain statistical characteristics and define limits of variability of parameters. That means to understand what are the average (normal) values, what are the minima and the maxima and what events affect the change in the parameters.

→ p. 54

When observations span several years, it is possible to assess intra- or inter-annual variability. Today, in the era of global climate change, it is especially noticeable.

→ p. 66

For example, observations reported by automatic buoy stations clearly show a positive trend in water temperatures and variability in wave characteristics.

Previously, by the end of October the Kara Sea was covered with ice and wind waves did not develop, whereas today ice may form in mid or even late December, and maximum wave heights are recorded in October or even in late November.

But regardless of how substantial the archive is, it still contains only observations taken at individual points. And scientists need to know the distribution of metocean characteristics over a certain water area — the field of metocean data.

→ p. 27

Moreover, according to current regulatory documents, reliable design characteristics of the metocean regime can only be determined using data spanning 30 years or more. It is even recommended to use data over 50 years, and no one possesses such observations for the Arctic.

Summary of data obtained in key areas

Parameter	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Ice field stations	0	22	35	33	0	40	21	47	22	0	220
Hummock stations	0	35	49	35	0	24	0	0	2	0	145
Studies of icebergs in ice cover and stamukhas	0	2	4	5	0	17	0	0	3	0	31
Thermal drilling wells	0	1290	1836	1768	0	1803	0	0	50	0	6747
Measurements of ice physical properties	0	50	100	141	0	160	63	141	66	0	721
Measurements of ice strength properties	0	983	1346	2108	0	1293	141	297	147	0	6315
CTD profilings	82	119	212	31	46	103	21	47	22	0	683
Deployment of drifting buoys	4	50	125	100	24	116	0	0	0	0	419
Automatic weather stations	2	3	6	7	8	8	6	6	3	1	50
Automatic buoy stations	6	6	16	14	14	14	10	11	5	4	100
Automatic seismic stations	0	0	0	6	6	6	0	0	0	0	18
Radar surveys of glaciers	0	0	673	407	622	0	0	0	0	0	1702
Iceberg towing experiments	0	0	0	0	18	18	0	0	0	0	36

Reanalysis

Modern meteorology and oceanology are math. If the duration of observations is insufficient, series of values of metocean parameters can be obtained from mathematical modelling. Moreover, modelling is the only way to obtain spatial metocean data. The mathematical model of meteorological, hydrological and ice processes is a system of equations representing the evolution of natural processes and their mutual influence.

Naturally, a model cannot reproduce a natural process in its entirety, but depending on the degree of abstraction, it represents its individual aspects with greater or lesser accuracy. Mathematical modelling is both a tool and the pinnacle of all research. Formalizing a process implies learning its nature and establishing cause-and-effect relations both within the process and with the factors that affect it.

The only way to assess the quality of modelling is to compare its results with observational data.

It is not always possible to make a comprehensive comparison, since observation data is available only for a few points in the area, and the observation period may not include certain events. However, good agreement between calculated and observed values in several points allows us to believe that the processes are reproduced adequately in other parts of the region as well.

In 2016–2018, the Arctic Research Center and ITMO University carried out a project to create a *reanalysis*, a digital archive of metocean parameter fields for the period from 1966 to 2017 in the Arctic Ocean and the Russian Arctic seas. A specialized storage facility for fast access to the data was also developed.

Mathematical modelling was carried out using a set of coupled hydrodynamic models, which reproduced the main metocean characteristics of the Arctic basin. *WRF* model was used for modelling meteorological processes, *NEMO* model was used for water mass circulation, *LIM 3* was used for ice characteristics and *WaveWatch III* was employed for modelling sea waves. The results of calculations were adjusted by applying ensemble methods and assimilating retrospective observational data. To verify the results, observation data from metocean stations of the region, as well as oceanographic data from submerged autonomous buoy stations (SABS) and automatic weather stations (AWS) in the Kara, Laptev and Chukchi Seas was used.

WRF (Weather Research and Forecasting) is a mesoscale numerical atmospheric modelling system which is widely used both in scientific research and in operational weather forecasting.

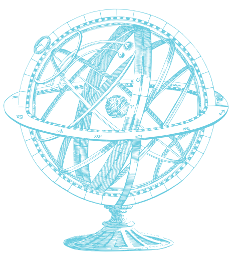
NEMO (Nucleus for European Modelling of the Ocean) is a platform designed for modelling the ocean and its interaction with other components of the Earth's climate system over a broad space-time range. NEMO is used for modelling on regional and global scales, both at a preset atmospheric influence and in conjunction with an atmospheric model. The platform includes components for modelling ocean hydro- and thermodynamics and ice sheet dynamics and thermodynamics.

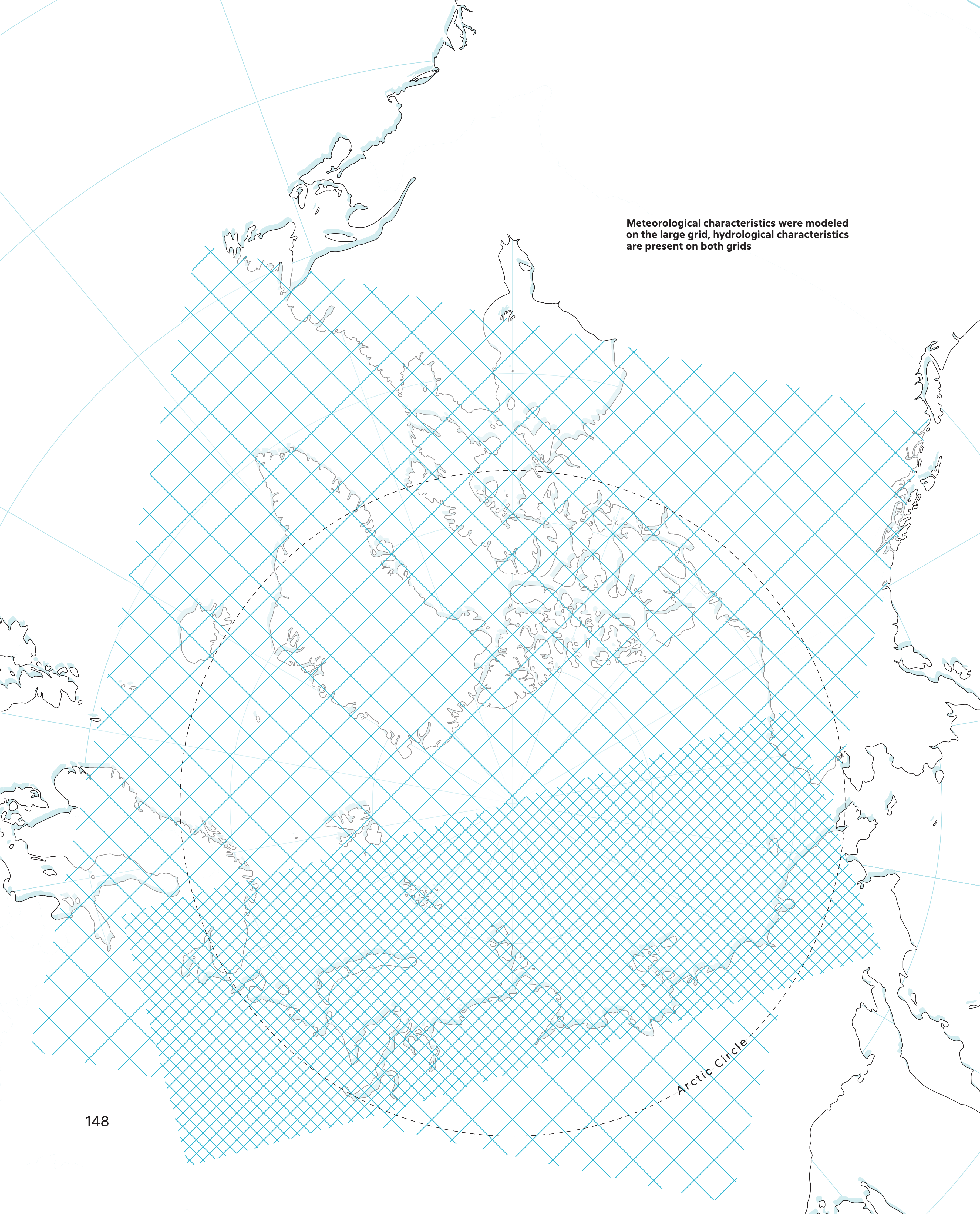
WaveWatch is a nonlinear nonstationary numerical hydrodynamic model for calculation of wave parameters. The model takes ice cover into account. It was tested on different natural objects and is successfully used for diagnostic and forecasting calculations in the world ocean and in local water areas.

Reanalysis is the reconstruction of spatial and temporal fields of metorological and oceanographical parameters on a grid based on mathematical models and observational data.

The **Result of Reanalysis** is an archive of fields of metocean parameters for a long period, represented on a grid.

The first archives developed in accordance with this methodology were created at the end of the previous century and contained fields of meteorological parameters. In recent years, many archives have appeared that contain fields of oceanographic elements (surface wave parameters, current velocities and directions at horizons, temperature and salinity at horizons, characteristics of ice cover). However, the quality of archives of oceanographic parameters (marine reanalyses) is very difficult to assess, since there are very few field observations of the basic elements of sea dynamics.




Meteorological characteristics were modeled on the large grid, hydrological characteristics are present on both grids
Arctic Circle

Reanalysis characteristics

Calculations using mathematical models

The calculations were performed at two scales. The main 14 × 14 km grid covers the Arctic Ocean. The fine 5 × 5 km grid covers the Russian Arctic seas.

The modelling period is from 1966 to 2017. The time step is one hour.

Meteorological parameters and wind waves were modeled on the main grid, while hydrological parameters are present on both grids.

The archive contains fields of the following meteorological parameters:
— atmospheric pressure;
— air temperature two meters above the surface;
— wind speed and direction 10 meters above the surface;
— precipitation amounts.

The archive contains fields of the following hydrological parameters:
— height, period and direction of wind waves;
— sea level;
— velocity and direction of currents by horizons;
— water temperature and salinity by horizons;
— ice concentration and thickness.

One of the main advantages of reanalysis is the possibility to obtain retrospective data for the main metocean parameters that is continuous in time and space. The fields of such an archive make it possible to investigate the formation and development of individual events and scenarios of changing conditions in the whole sea area, which allows to plan activities, assess their feasibility, etc.

This makes it possible to use it not only for obtaining statistical assessments of parameters and their distribution in the water area, but also for further calculations: drift of icebergs, sediment transport, propagation of various pollutants and testing the efficiency of methods of their collection.

Quality of the calculations

When it comes to the results of mathematical modelling, special attention should be paid to the quality of reproduction of natural conditions in the region.

The models were tuned based on observation data collected from SABS and AWS deployed in the Kara, Laptev and Chukchi Seas in 2012–2017.

For tuning meteorological models, observation data from meteorological stations throughout the Arctic was used. For tuning hydrodynamic models, available observation data was used, mainly level data, and of course observation data collected during expeditions in 2012–2017.

Scientific data for industrial tasks

Such extensive archives make it possible to obtain characteristics of metocean conditions for a very large water area, study their variability in space and construct maps. This provides important information for resolving many practical issues in establishing navigation along the Northern Sea Route, planning maritime operations, studying and developing the Arctic seas.

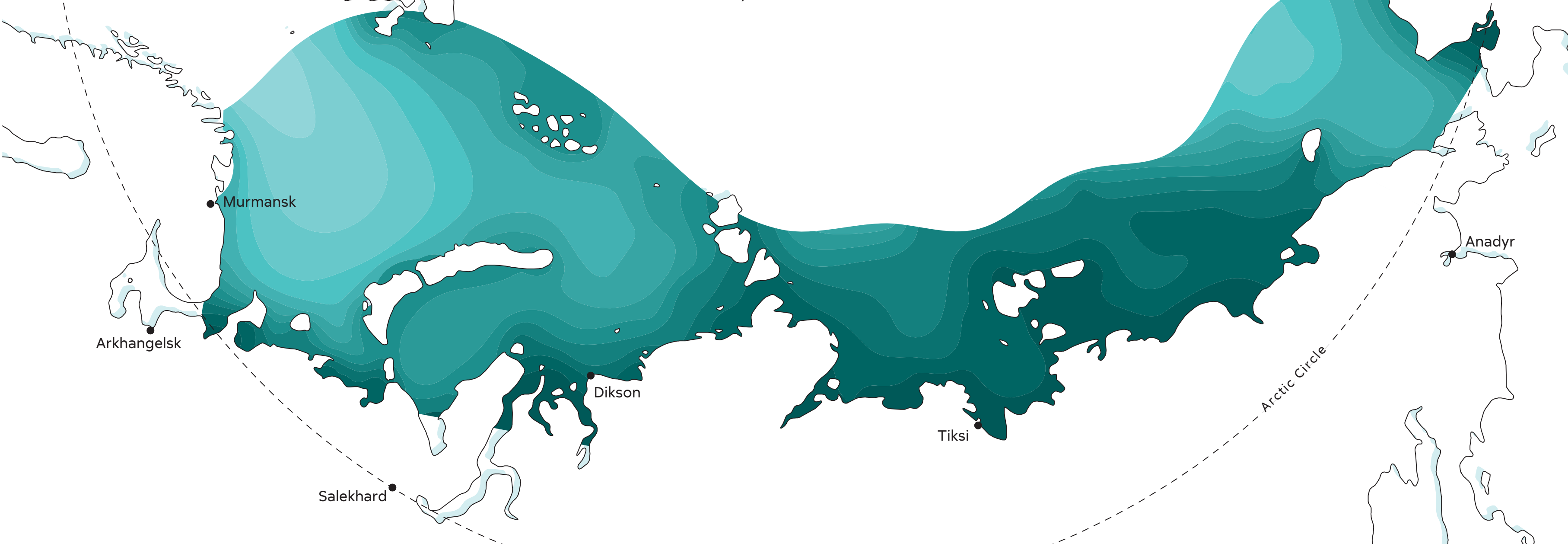
One of the key requests when planning maritime operations is determining the duration of allowable operating conditions, the period of time when safe execution of maritime operations is possible. Usually, limiting factors are the presence of ice and the combination of wind speed and wave height.

Frequency of occurrence of allowable operating conditions,%

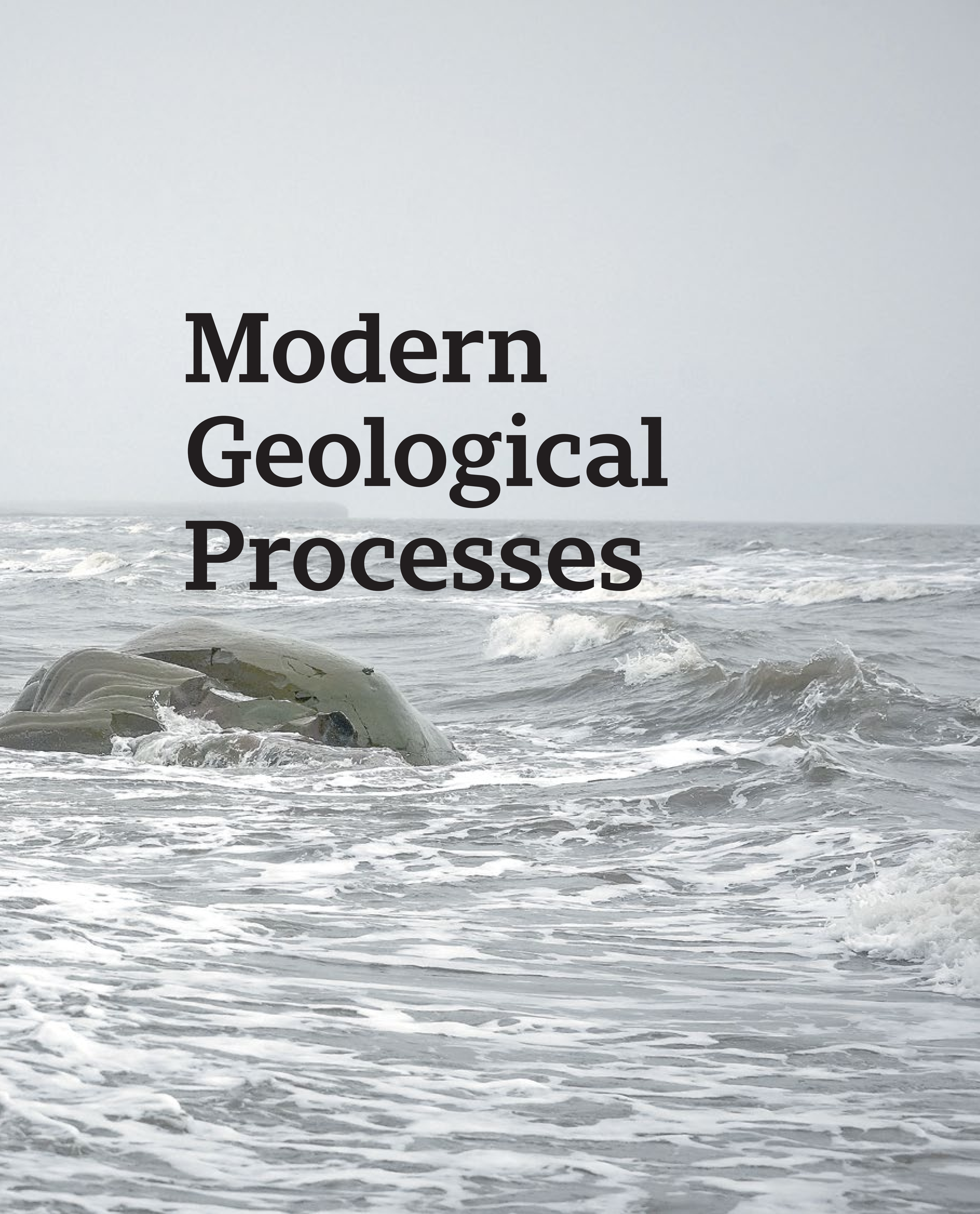
40 45 50 55 60 65 70 75 80 85 90 95

On average, conditions with wave heights up to 2.5 meters and wind speeds up to 17 m/s are considered to be allowable. When conducting complex operations involving transportation or movement of heavy and tall structures, limitations on allowable conditions can be much stricter: wave heights up to 1 meter and wind speeds up to 10–12 m/s.

The time during which operating conditions in the Arctic seas are considered to be allowable was calculated for October. It can be seen that in October in the southwestern and central parts of the Barents Sea allowable operating conditions are 40 %, whereas in the Laptev Sea they reach 90 %.



Modern Geological Processes



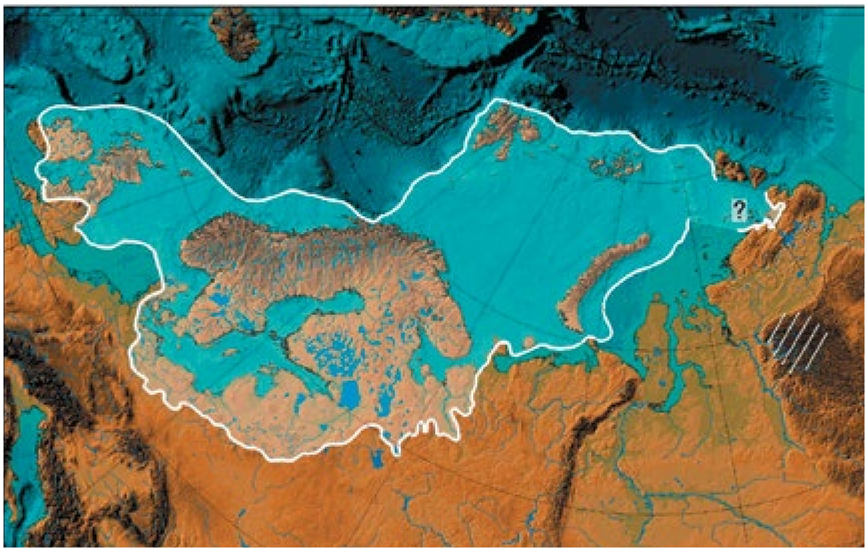
Geological history of the Arctic

Exploring hard to reach areas of the Arctic, let alone building and maintaining engineering structures, is risky because of the harsh climate. But in addition to weather conditions, there are risks that await explorers deep in the Arctic soil.

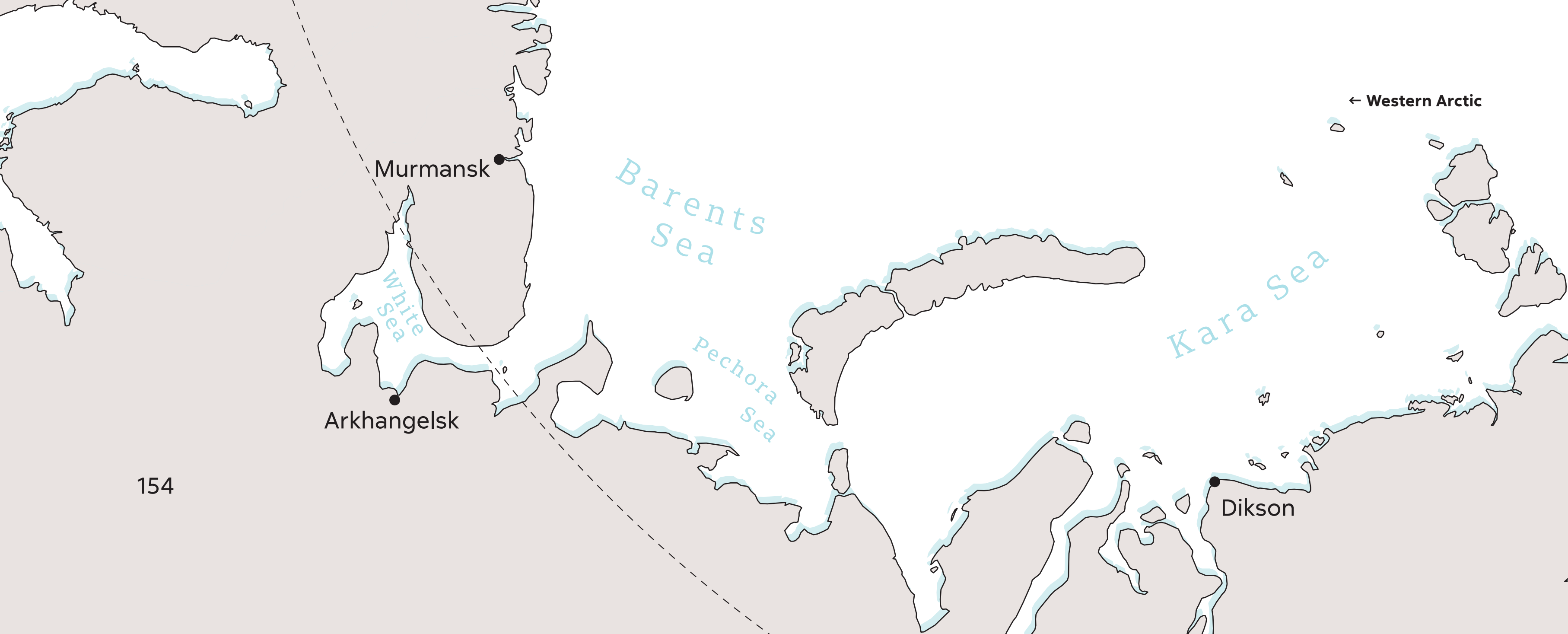
To understand the nature of dangerous geological processes and their causes, we first need to look back 18,000–25,000 years. Or, as scientists say, look into the recent geological past. The natural environment in the Arctic at that time was radically different from what it is today. Mammoths roamed on the future seabed of the Eastern Arctic, while the western part of the shelf from the North Sea to the Kara Sea was covered by solid ice several kilometers high.

Glaciations of the Western Arctic

Complex geological events took place in the western part of the region. Glacier advance was accompanied by erosion and deformation of soils underneath them, including formation of trough valleys, ice gouging and glacial dislocations. As glaciers retreated (melted down), moraine ridges, eskers, subglacial flow channels and outwash plains were formed.



Reconstruction of the maximum extent of the last glacier in the Western Arctic (*Svendsen et al.*, 2004)

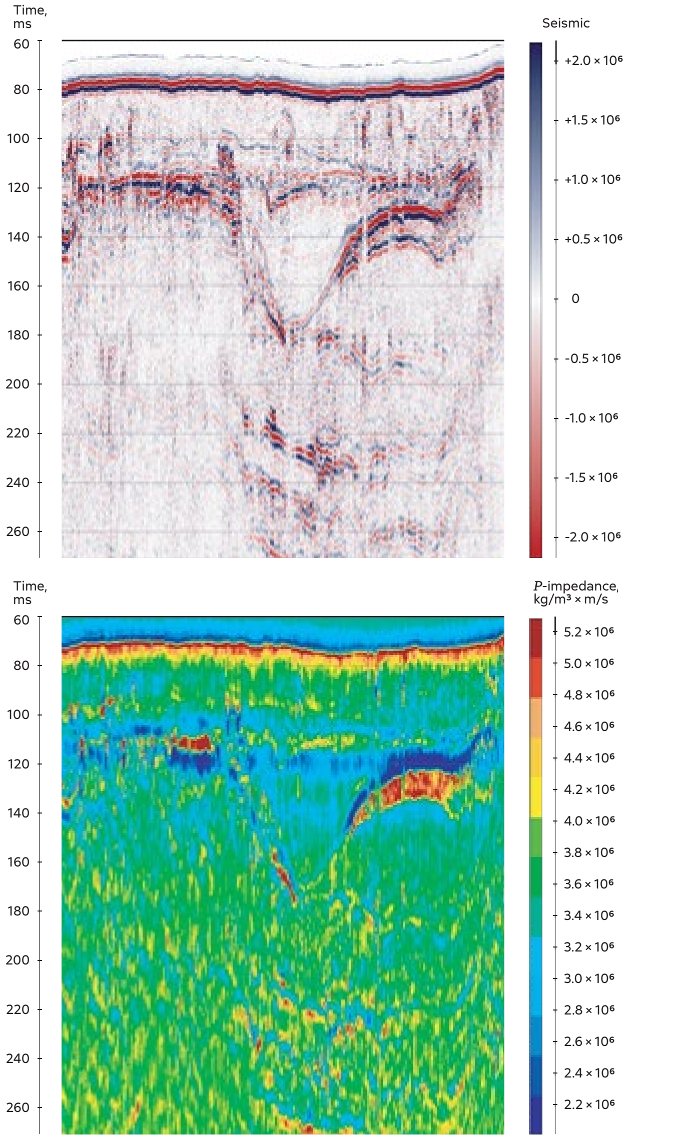


Cryolithozone of the Eastern Arctic

In areas where the land was not covered by the ice cap, the ground froze hundreds of meters deep at temperatures as low as −80 °C, forming a continuous layer of permafrost. Cracks and pores were filled with ice and became virtually impermeable to hydrocarbons, leading to gas accumulation within them and lower, below the permafrost layer. In addition, low ground temperatures created conditions for the formation of gas hydrates — crystalline compounds of water and natural gas. One volume of gas hydrates produces 160 volumes of gas, so the thawing of gas hydrates during construction and drilling can lead to a major gas release and ground subsidence.

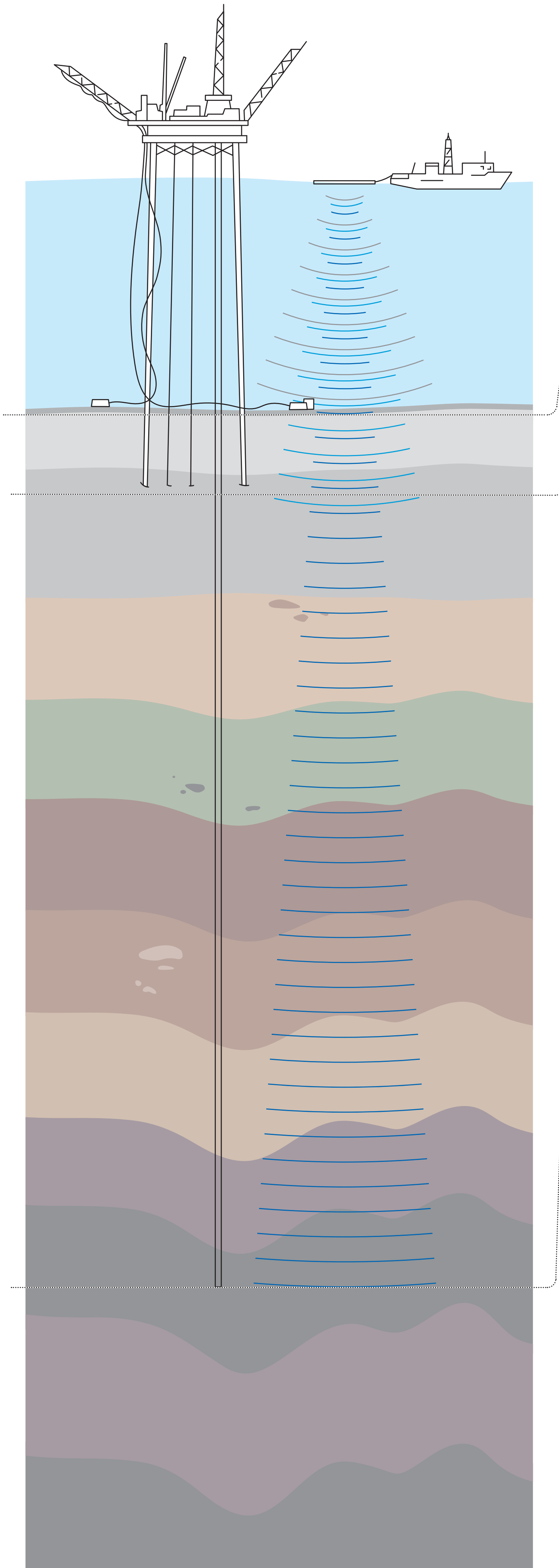
Thawing (degradation) of permafrost rocks complicates the structure of the upper part of the section to a depth of up to a kilometer. Soils are deformed, large amounts of water are released and post-cryogenic gas is formed. The gas seeps into the water and the atmosphere.

In the vast areas of the Eastern Arctic flooded by the sea during melting of glaciers (post-glacial transgression) relict relief elements typical of the polar land — thermokarst depressions, polygonal surface forms and pingos — have been preserved.



Permafrost lens on the board of a paleovalley in the Laptev Sea. Characteristic features of permafrost: high amplitude reflections (on the seismic cross-section, above), high (red color) values of impedance (on the acoustic impedance cross-section, below).

Eastern Arctic →



Geological processes that must be considered

The list of geological features of the offshore is extensive, including landforms themselves and the processes that form them.

The top 10 meters are important for light technical structures, pipelines and anchors. Here, it is necessary to consider the peculiarities associated with seabed irregularities and processes.

The top 100 meters need to be studied when constructing capital structures such as drilling platforms.

The top 1,000 meters are important for drilling deep wells. Here, the main risks are gas saturation, faults and permafrost.

The list of major geological features includes:

— local bottom irregularities: glacial landforms, coastal longshore ramparts, accumulative uplands, megaripples, sand ridges, pockmarks, ledges, drainage channels and troughs;

— heterogeneity of ground strata: bedrock outcrops, boulders and boulder fields, inversion of soils;

— modern gravitational processes: landslides, rockslides;

— fractures and modern geodynamic processes: earthquakes;

— increased gas saturation;

— vertical fluid migration: movement of water and gas through the section;

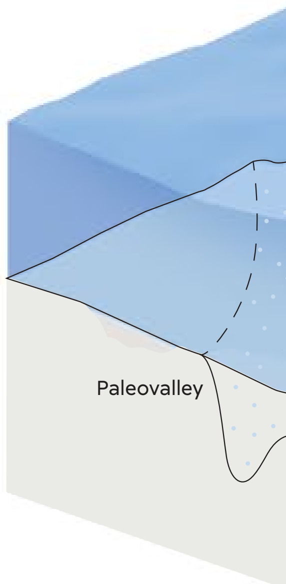
— abnormally high formation pressure: fluid pressure in rock pores;

— gas hydrates: crystals of water and gas;

— lithodynamic processes: transport, erosion and accumulation of bottom sediments;

— permafrost soils and post-cryogenic transformations of the soil massif;

— paleovalleys and paleochannels.



Local bottom irregularities

If a glacier faces the open sea, massive blocks of ice — icebergs — break away from it as it melts. These ice formations scratch the seabed with their keels, leaving deep gouges. The danger to structures on the bottom, especially to underwater pipelines, is obvious. But it should be kept in mind that gouges at depths of over 100 meters could have been formed in the distant past, in the early stages of the post-glacial transgression, when the sea level was lower. For example, in the Barents Sea such traces remain from ancient times and are now taken into account by engineers as seabed irregularities. That is, the concern is not about the danger of the underwater part of an iceberg going over the bottom, but about the stability of structures, weakening of anchor holding power and development of landslides on the slopes of the gouges.

Paleovalleys

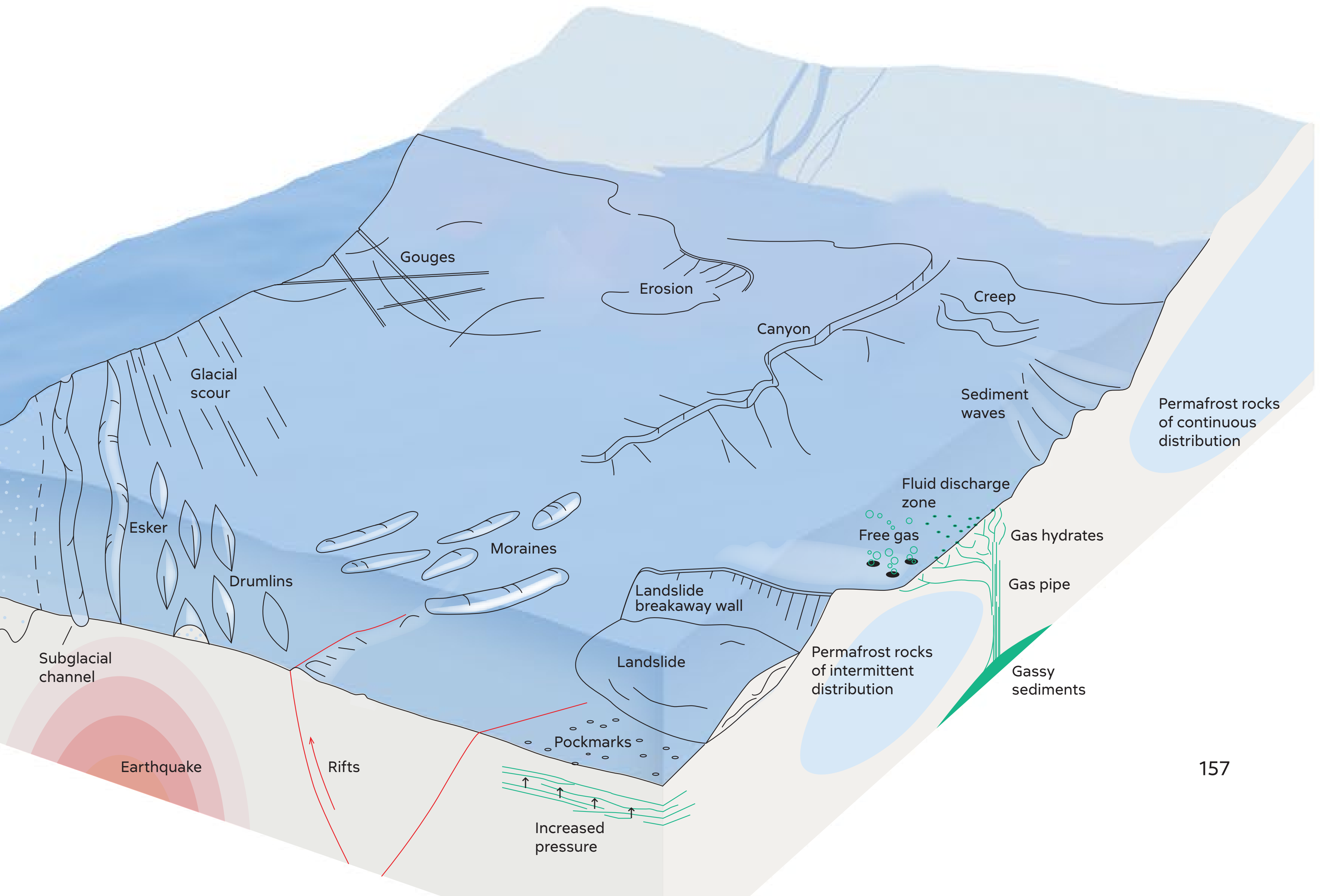
Paleovalleys are preserved ancient valleys that were carved by water and then filled with sediment. Today, these forms from the geological past are preserved in the sedimentary strata. Buried valleys can be found using seismic methods. Paleovalley areas are avoided for several reasons. The valleys can be filled with materials of lesser strength, which means that engineering structures and drilling platforms will not settle down evenly. The bottoms of ancient incisions may contain coarse clastic deposits such as pebbles and gravel. A layer with coarse debris is likely going to be difficult to penetrate when drilling. Often, seismic records indicate the presence of gas in the valleys which also introduces complications.

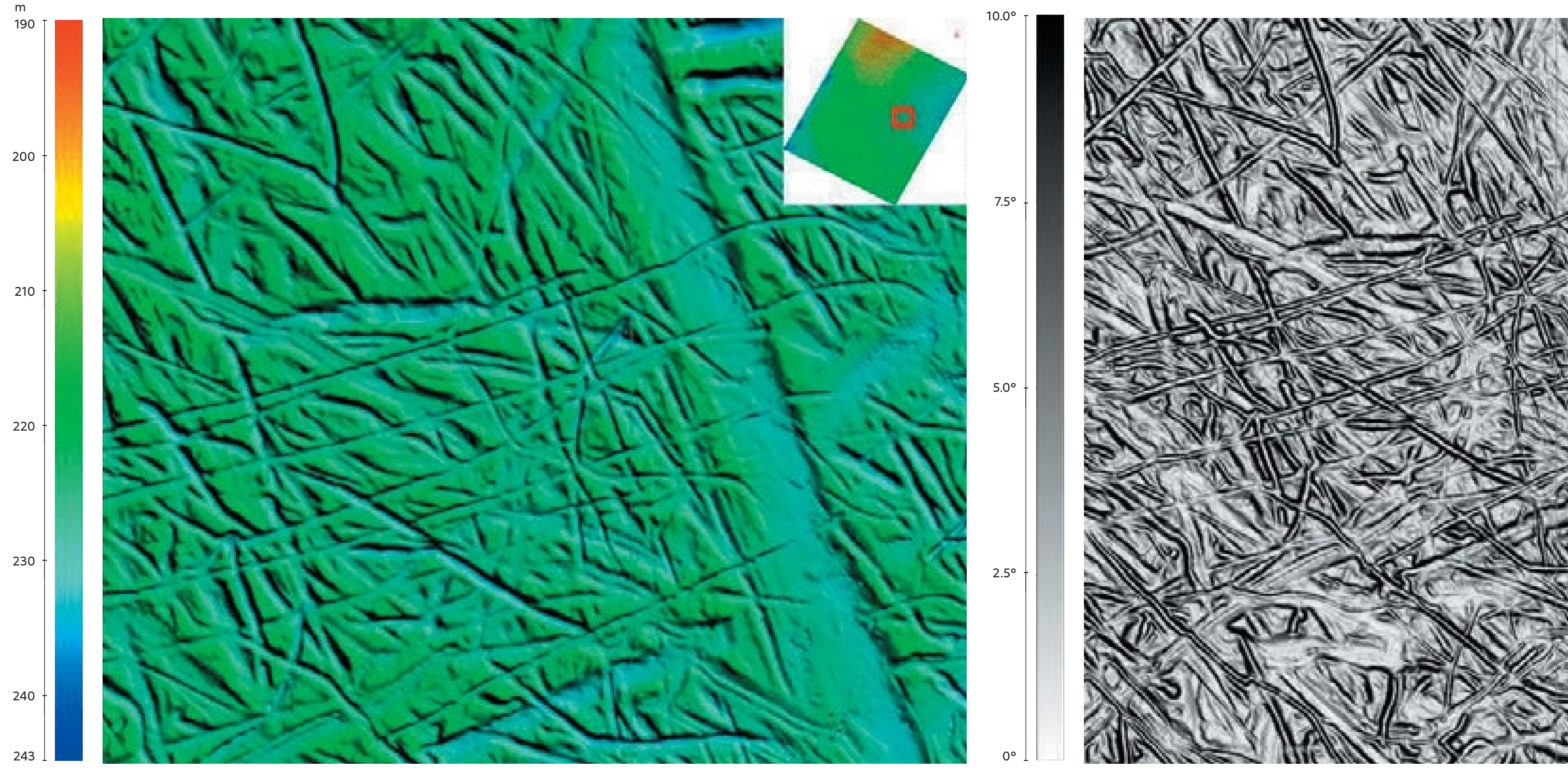
Gas-saturated soils

Deposits may contain gas in free and dissolved forms. Gas accumulations may appear due to transformation of local organic matter or through seepage from underlying productive strata through faults and weakened zones. In areas where gas seeps to the surface, the bottom may be covered with pockmarks, craters up to several hundred meters in diameter and up to tens of meters in depth. Leaks can lead to a drop in reservoir pressure. The ground subsides, disturbing the stability of structures located on it.

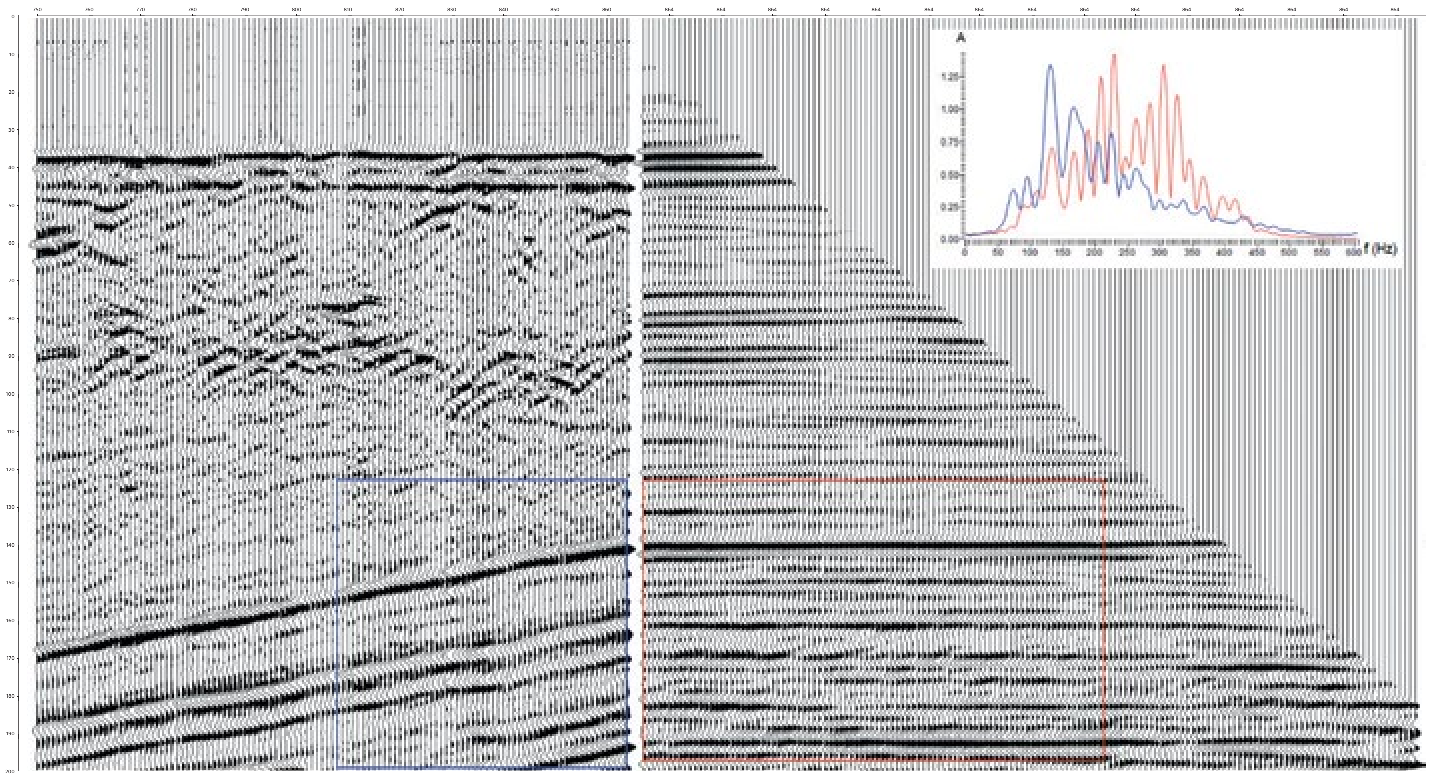
Permafrost rocks

It is not easy to identify permafrost. On the shallow Arctic shelf permafrost is not evenly distributed, and the rocks themselves are not homogeneous. They can be plastic-frozen or solid-frozen, and all this leads to the complexity of seismic imaging. Qualitative analysis which relies on drilling shallow wells comes to the rescue. In addition, the velocity of elastic waves increases in permafrost rocks, which can be measured by multichannel seismic observations. Also, the top of frozen soils is usually highly indented, which can appear on seismic data as an abrupt lateral termination of boundaries and a shift to a chaotic record.

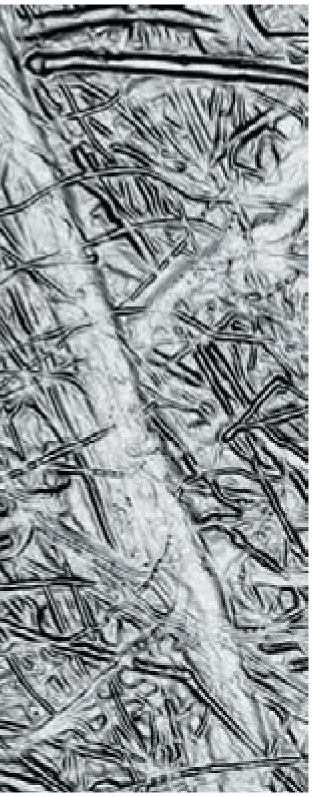




Hydroacoustic research. Fragment of the map of the digital model of the Barents Sea bottom based on hydroacoustic survey data. The map shows ice gouges left by icebergs. The average gouge width varies from 10 to 60 meters and depth from 2 to 15 meters.



Geophysical research. Results of a high-resolution seismic survey (left) and vertical seismic profiling (VSP, right). A unique solution for thermal, seismic and acoustic observations in shallow offshore wells is the use of fiber-optic systems for distributed acoustic observations. They identify not only the structure, but also the properties of sediments, intervals of frozen ground and the true depth of reflecting horizons.



How to study the structure of a cross section

Methods and technologies for studying geological hazards are typical for engineering and geological surveys in the offshore, but are more detailed. Complex methods of mathematical processing and data interpretation are used. Repeated observations are made, allowing to receive data on the dynamics of processes and their development in space.

Types of research

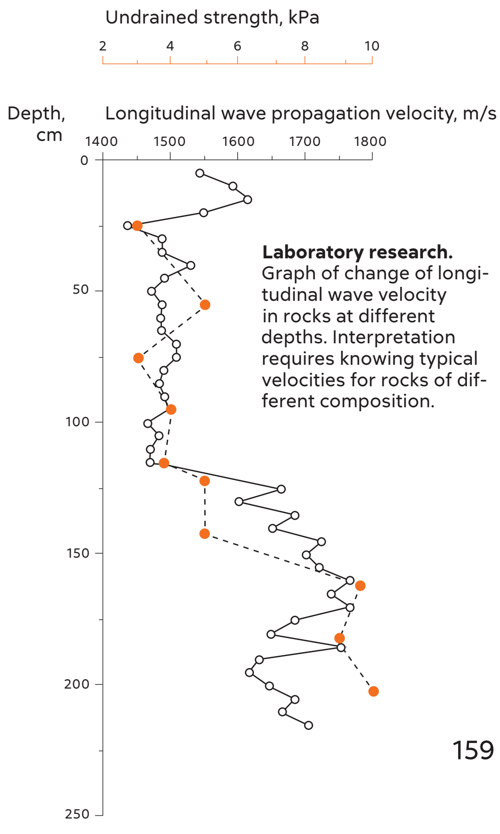
Hydroacoustic. Multibeam echo sounder survey of the seabed, side-scan sonar and acoustic profiling.

Geophysical. High and ultra-high resolution seismic surveys, electrical surveying and marine magnetometry.

Geotechnical. Bottom drilling to a depth of 50–100 meters, static sounding with pore overpressure measurement. Borehole soil sampling at a depth of 5–10 meters with water hammer, gravity and piston tubes. Bottom soil sampling with bucket and box samplers.

Laboratory. Sample analysis, processing and interpretation of materials.

Geotechnical studies. Core extraction from a coring tube



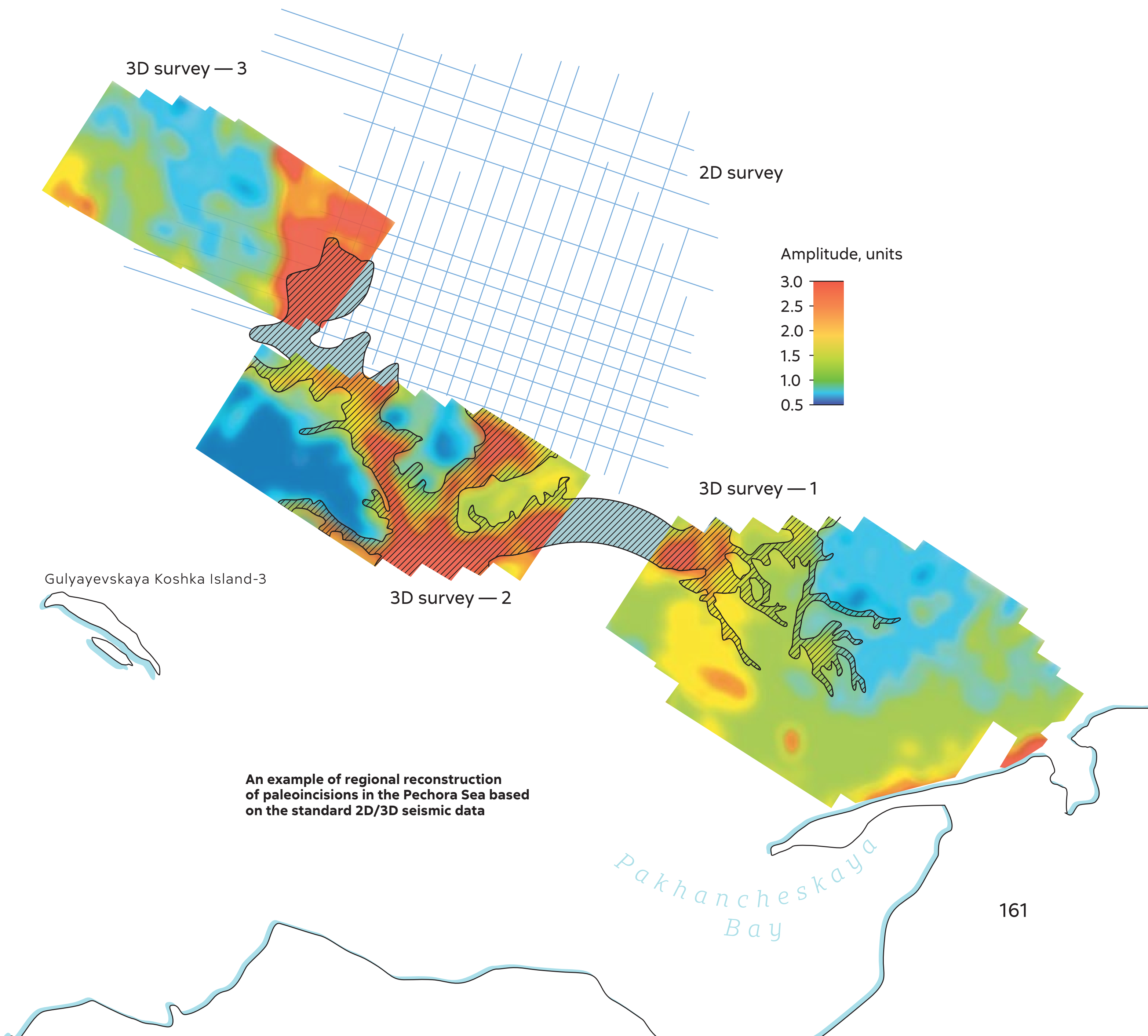
Laboratory research. Graph of change of longitudinal wave velocity in rocks at different depths. Interpretation requires knowing typical velocities for rocks of different composition.

Research potential

The Arctic offshore remains the most understudied and difficult to explore region. Therefore, each expedition brings back unique information about geological structure, hazardous processes and phenomena, engineering and geological conditions and applicability of technologies.

With an unprecedented amount of data and half a million kilometers of highly informative geophysical surveys, Rosneft together with Innopraktika is reconstructing the geological history of the Barents Sea — Kara region, moving from disparate factual data on paleogeography and glacier movement to identifying regional patterns. Equipped with this information, engineers are able to minimize technological risks when developing the offshore.

In 2008, the company introduced specialized processing of standard 2D/3D seismic data proposed by Lomonosov Moscow State University. Ten years later, this technology was further developed in the offshore of the Pechora Sea and applied to processing and interpretation of all seismic data with the goal of identifying hazardous processes and building a generalized model of engineering and geological conditions, covering over 25,000 km².



An example of regional reconstruction of paleoincisions in the Pechora Sea based on the standard 2D/3D seismic data

Monitoring Ice Conditions

Summer and winter ice hazards

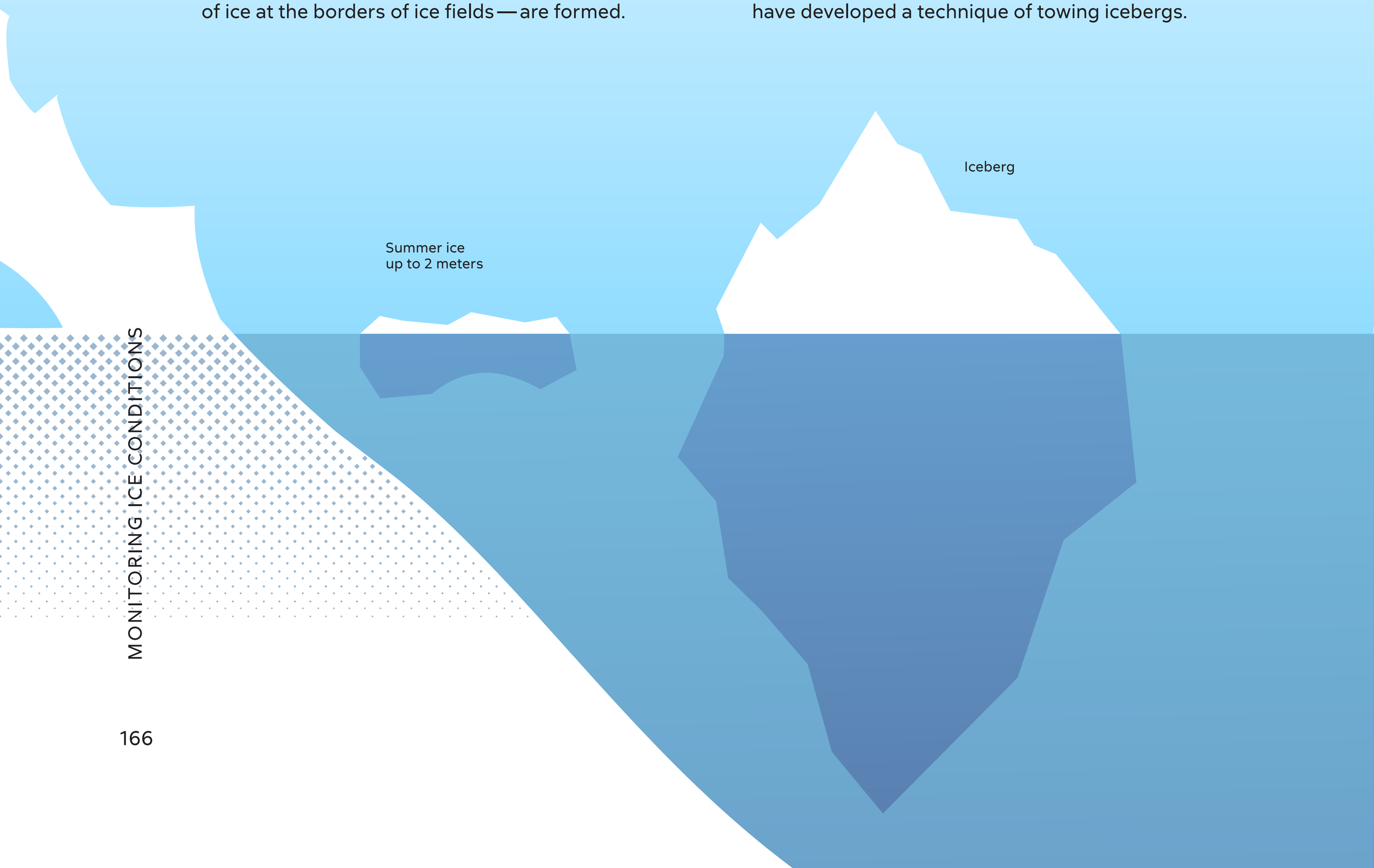
Ice in the Arctic is both beautiful and dangerous. It can jam a ship, damage infrastructure facilities, disrupt a weather buoy station, interfere with navigation along the Northern Sea Route → p. 25 and research work throughout the Arctic seas. Therefore, properties of ice and ice formations need to be studied not only for the development of cargo navigation, but also for safe scientific exploration of the region.

In the Arctic seas, ice is present all year round, but its types differ depending on the season.

In the winter, the surface of the ocean is almost completely frozen over and covered with a layer of ice more than a meter thick. However, the ice cover is not static, it looks like a mosaic of separate ice fields. Under the influence of temperature, winds and currents, the ice fields move, their edges get compressed and high pressure areas appear. This is how hummocks — piles of ice at the borders of ice fields — are formed.

In the summer the ice cover thaws and cracks, and part of the surface becomes free. One can say that the Arctic Ocean becomes similar to other oceans, except for floating icebergs and thin ice fields.

When working in the offshore in the summer, an iceberg is the most dangerous ice formation. There is a high probability that a collision with an iceberg will damage stationary structures, so such encounters should be avoided as much as possible, and to this end, scientists have developed a technique of towing icebergs.

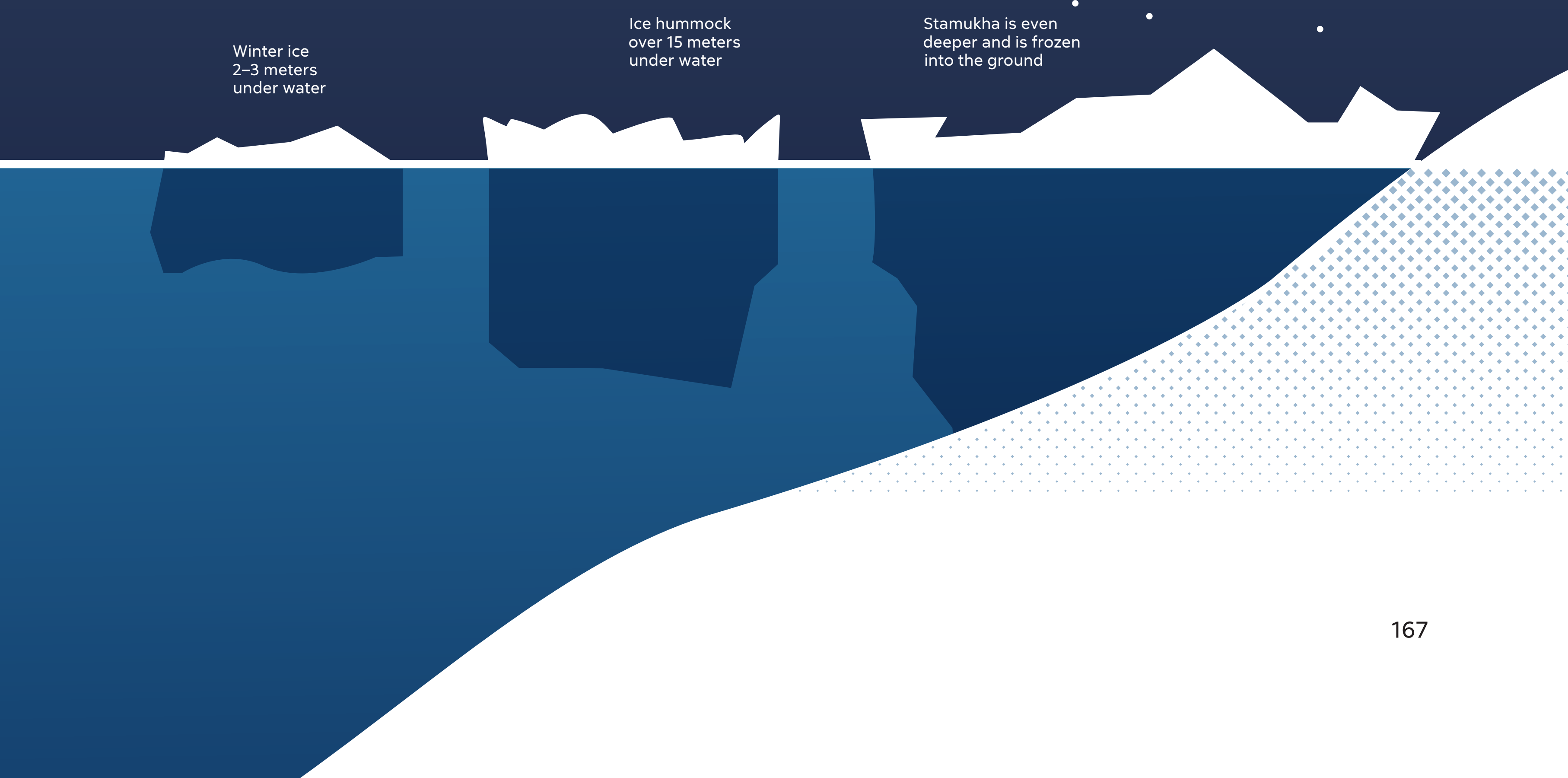


In the winter, it is impossible to avoid contact between structures and ice formations, just as it is impossible to prevent drifting of ice fields and hummocks. Therefore, it is important to determine physical and mechanical properties of ice, its possible distribution areas, as well as parameters of hummocks, so that potential loads on structures can be calculated in advance.

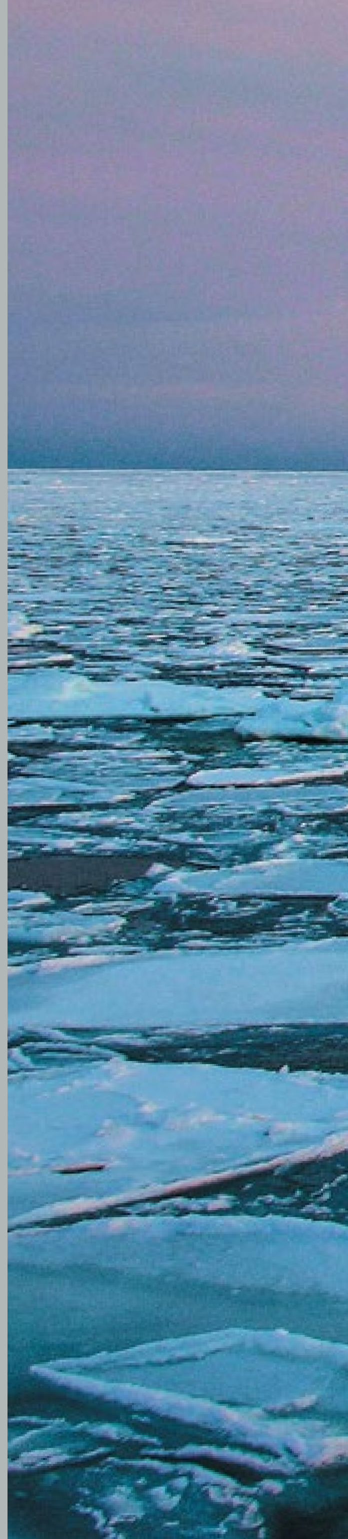
An **Iceberg** is a massive free-floating piece of ice that protrudes above see level for over five meters, usually after being broken off from an ice shelf.

A **Hummock** is a hilly pile of broken ice which is formed when ice is crushed at the borders of ice fields.

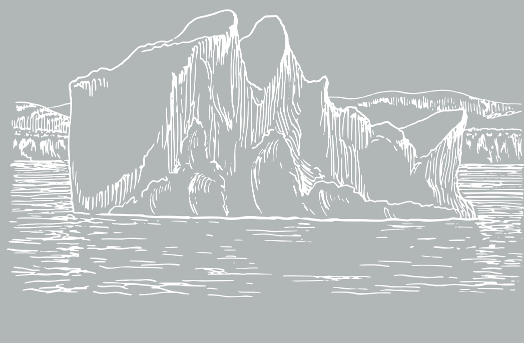
A **Stamukha** is a hummocky formation that has run aground.



Pancake ice forming in the process of fall ice formation



An iceberg in the southwestern part of the Laptev Sea



Iceberg safety

The glaciers that cover the polar archipelagos begin to move more actively in the summer, pieces of them break off and begin to drift freely in the water. Such fragments are called icebergs.

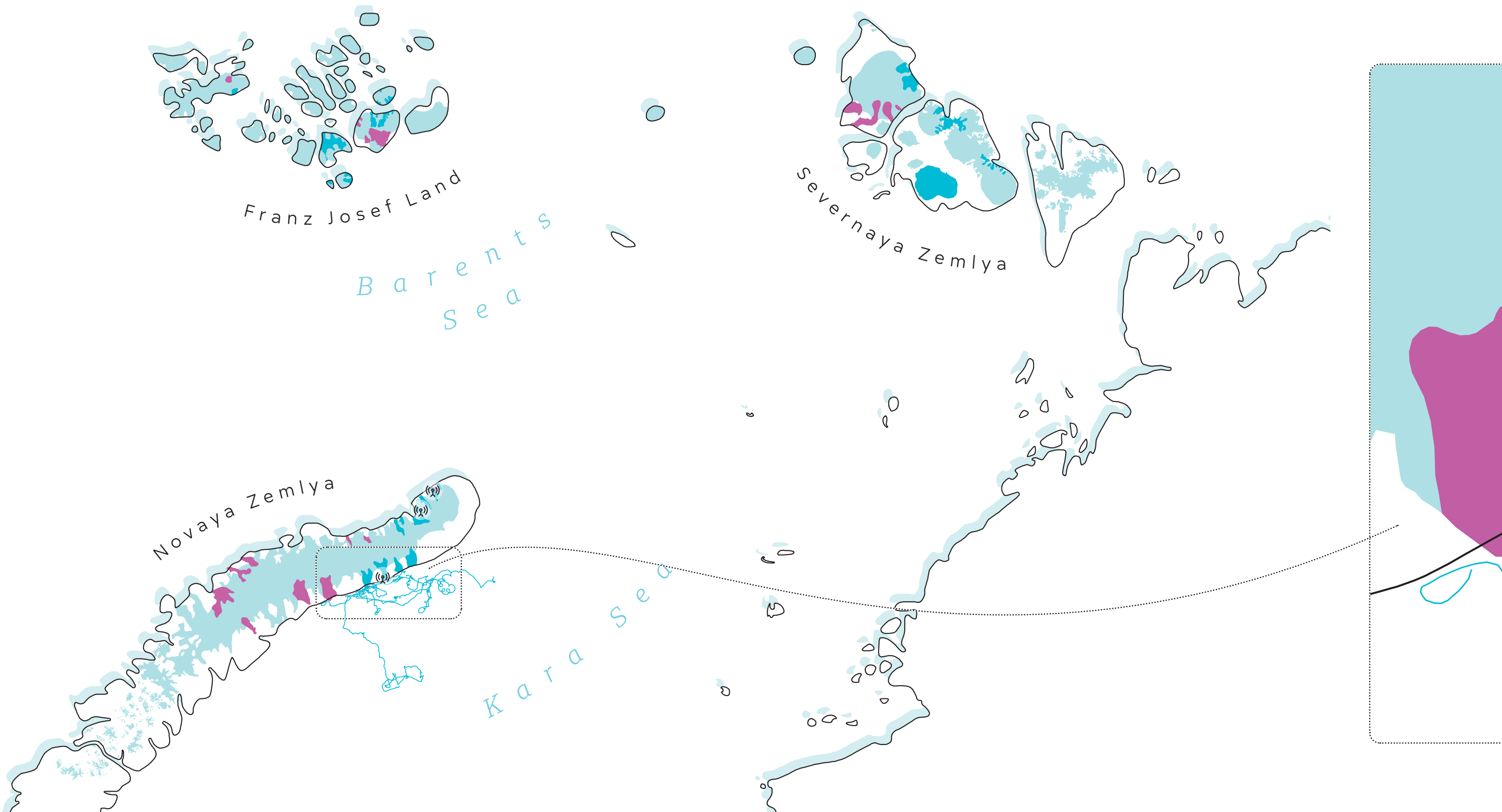
The broken off ice takes a variety of forms. It can be debris, table-shaped blocks, pyramids and entire small islands. It is almost impossible to visually estimate the size of an iceberg, as only the tip, one tenth of an iceberg, can be seen, and the bulk of it is hidden underwater.

Svalbard Island is the "record holder" in iceberg production. Its outlet ice tongues supply 5 km^3 of ice into Arctic waters each year. The glaciers of Franz Josef Land and Novaya Zemlya make substantial contribution as well, producing 1.5 km^3 of ice each into the Barents and Kara Seas. The glaciers of the Severnaya Zemlya archipelago produce icebergs both into the Kara Sea and the Laptev Sea. Although the highest concentration of icebergs is observed near their formation areas, they can drift over considerable distances.

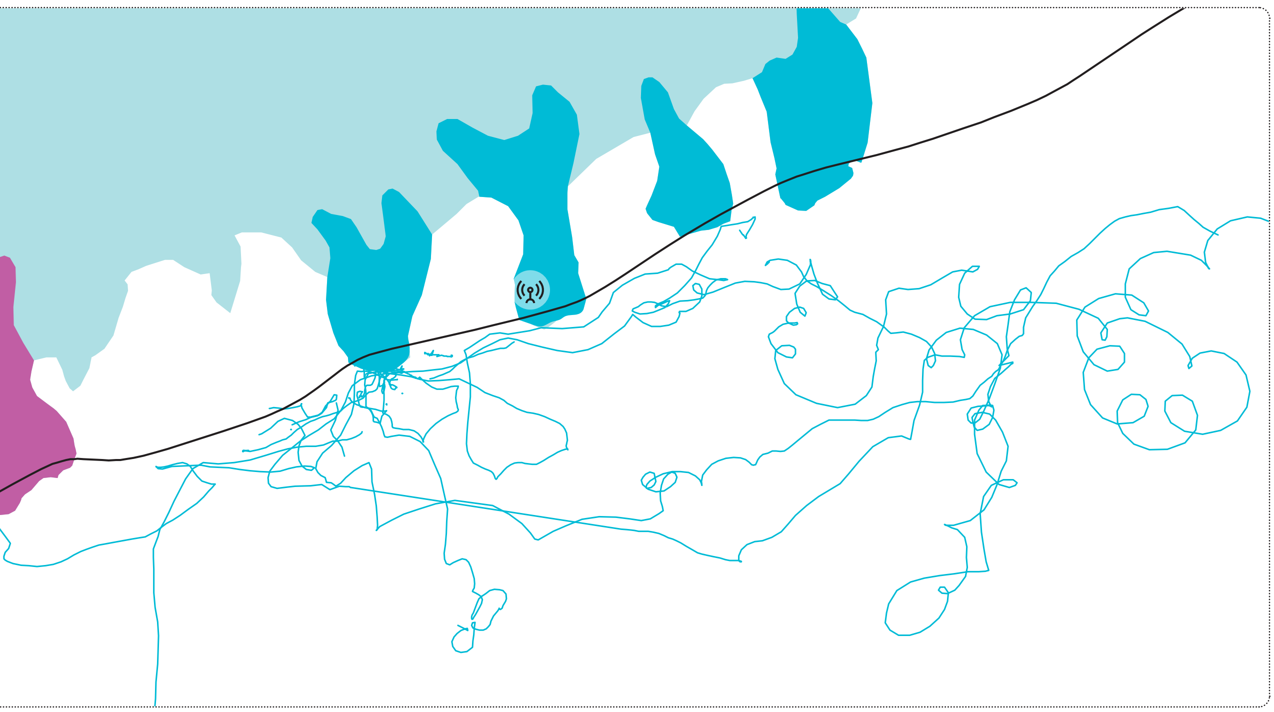
Many discovered hydrocarbon fields and promising geological structures are located in close proximity to iceberg formation centers. For example, for the Kara Sea the average drift time of an iceberg formed near Novaya Zemlya to an exploration drilling platform is about three days. Such drift speed makes it fundamentally important to obtain the most complete and up-to-date information about the condition of iceberg producing glaciers.

An iceberg protection system has been developed to ensure safe exploration and potential development of the fields. It takes into account the conditions of iceberg formation and spreading and contains solutions for iceberg detection and changing their drift trajectories.

A drifting iceberg



MONITORING ICE CONDITIONS



Map of iceberg-producing glaciers in the Russian Arctic

Argos radio beacon
Iceberg trajectory
Studied with a GP radar
Planned for study

Searching for drifting threats

Glacier monitoring

The study of icebergs is preceded by constant monitoring and study of glaciers, in particular their thickness and flow velocity. Despite its overall mass and size, a glacier moves — it flows. A glacier that protrudes into the sea with one of its edges is called an outlet glacier.

Information about outlet glaciers is necessary for estimating the probability and constructing a scenario of encountering an iceberg: based on the data, it is possible to build a model of glacier movement and "illuminate" zones of iceberg formation.

Glacier thickness. An airborne radar survey is carried out to measure the thickness of glaciers. A helicopter with a suspended radar moves over the glacier at a speed of 100 km/h. Flight routes are chosen either along or across the glacier front in order to gather the most complete information about ice thickness over the entire area. The results of the thickness survey are combined with a digital terrain model. Maps of the subglacial relief, ice thickness and the location of hydrostatic surfacing zones of the glacier sections are then created.

Glacier velocity. In sections of the glacier that are the most interesting, scientists choose locations with the highest theoretical flow velocities to install autonomous buoys. Each buoy is equipped with a GPS receiver and a satellite data collection system transmitter. The buoys move together with the ice and make it possible to accurately measure the distance covered by the glacier. The beacon battery lasts for more than a year, so they serve as a reliable source of information on seasonal changes in glacier velocity.

It is also possible to monitor the displacement of the glacier surface remotely. To achieve that, a number of satellite images taken at different times are compared: during processing, a fragment of interest is highlighted and its position is traced through the entire set of images.

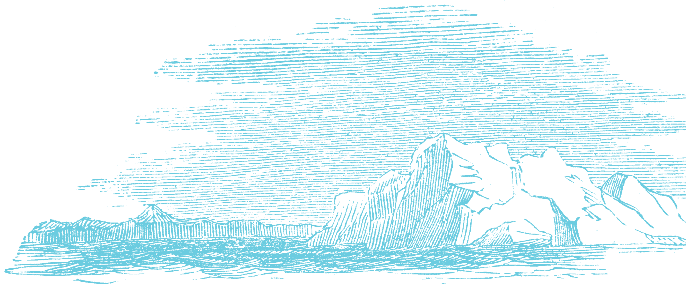
Glaciers have different thickness and speed of movement. They influence the size of icebergs that have drifted away from the glacier. And the location of the glacier and the direction of wind and currents determine in which direction the iceberg will drift.

Wandering ice

Having determined the supposed birthplaces of icebergs, researchers concentrate on studying the ice formations themselves, their location and size. The search for icebergs is done either by direct observation from the ship, when an observer sees and iceberg and maps it, or with the help of the ship's radar equipment. The maximum detection range depends, on the one hand, on the design of the ship, which determines how high above the surface the observer with a set of binoculars is located. On the other hand, it depends on the size and shape of the iceberg itself. For example, a ship's radar can detect a table-shaped iceberg at a distance of up to 27 km, but a pyramid-shaped or an inclined one only up to 12 km.

→ p. 84

Data from satellites is actively used in planning operations. As in glacier monitoring, radar images allow to see the ice fragment of interest even in overcast conditions. And when weather conditions are favorable, researchers work with high-resolution images in the visible spectrum.



The process of iceberg destruction. A significant contribution to the degradation process of a drifting iceberg is made by crumbling of its surface

Iceberg profile

Morphometric parameters of an iceberg are determined in two stages. A multibeam echo sounder is required to photograph the underwater "basement", while aerial photography is used to capture the above-water part. Aerial photography is conducted from a helicopter at a low altitude or from an unmanned aerial vehicle.

After processing survey materials, a three-dimensional model is created. It can be used to calculate the volume of the above-water part and the weight of the iceberg.

Such surveys help carry out a comprehensive study of icebergs and give not only qualitative but also quantitative characteristics of drifting icebergs, determine their types and dimensions and the fraction of fragments, as well as work out the most important issues of offshore structure operations: direction of iceberg drift, speed distribution and average movement per day.

Methods of studying icebergs:

- ship-based observations;
- satellite monitoring and aerial photography;
- deployment of GPS buoys on icebergs;
- echo sounding of the underwater part;
- building 3D models.

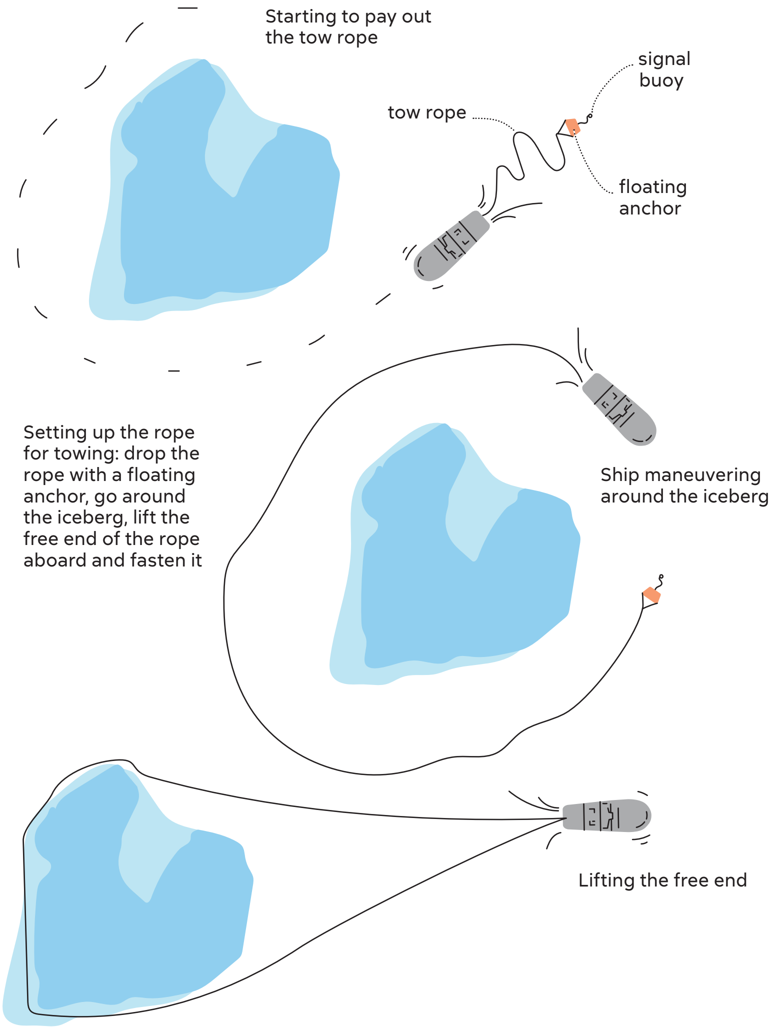
A three-dimensional model of an iceberg

Iceberg towing

When monitoring is set up, scientists can see the direction and speed of an iceberg from its formation to the beginning of its drift. If an iceberg starts to threaten navigation or offshore activities, a decision can be made to change its drift course to clear the water area.

→ p. 86

Prior to the research of 2016–2017, Russian science had no proven technology for physically manipulating icebergs. Experiments and subsequent refinement of the technology of “iceberg pulling” were performed off the coast of the Novaya Zemlya, Severnaya Zemlya and Franz Josef Land archipelagos. Icebergs were towed in different weather conditions, the design of the towing system was developed and the sequence of actions of the towing vessel crew was described.



During field work

Tow method	Number of experiments
With a floating rope	29
With an ice net	6
Exposing the iceberg to a directed water jet from the ship’s firefighting unit	1
Circulation of the ship around the iceberg	1

Towing an iceberg in October, view from the stern of the ship

Technological results of towings

Maximum weight of towed iceberg	1,200,000 tons
Minimum weight of towed iceberg	3,000 tons
Maximum daily movement distance	50 miles
Maximum towing speed	3,2 knots
Maximum towing force	1040 kN (around 100 tons)

Several towings were done in ice up to 20 cm thick

Ice safety

In the winter, researchers shift their attention from studying icebergs to the properties of sea ice. Ice fields that span over many kilometers are heterogeneous: in some places they expand and crack, in others they shrink and begin to crush each other, creating ridges of ice debris, or hummocks. In these places, the ice thickens significantly, its mass and pressure greatly exceed the average values for ice fields.

→ p. 76

A separate type of an ice hummock is called a stamukha. It is a grounded hummock that cuts into the bottom and freezes to the ground, but when the water area clears, it floats up and begins to drift like an iceberg. Unlike icebergs, hummocks and stamukhas cannot be moved, one can only learn to build structures that can withstand the pressure of such ice.

Deeper into the hummock

Methods of studying hummocks and stamukhas:

— aerial photography;

— tacheometric survey;

— thermal drilling;

— study of physical and mechanical properties of ice.

It is only possible to design structures that are sufficiently strong and safe if one has a detailed understanding of forces exerted by ice. Protective structure engineers must know the basic morphometric parameters of ice ridges and stamukhas for a particular area: their ridge length, sail height and width, keel depth and width, total thickness, porosity and the thickness of the consolidated layer.

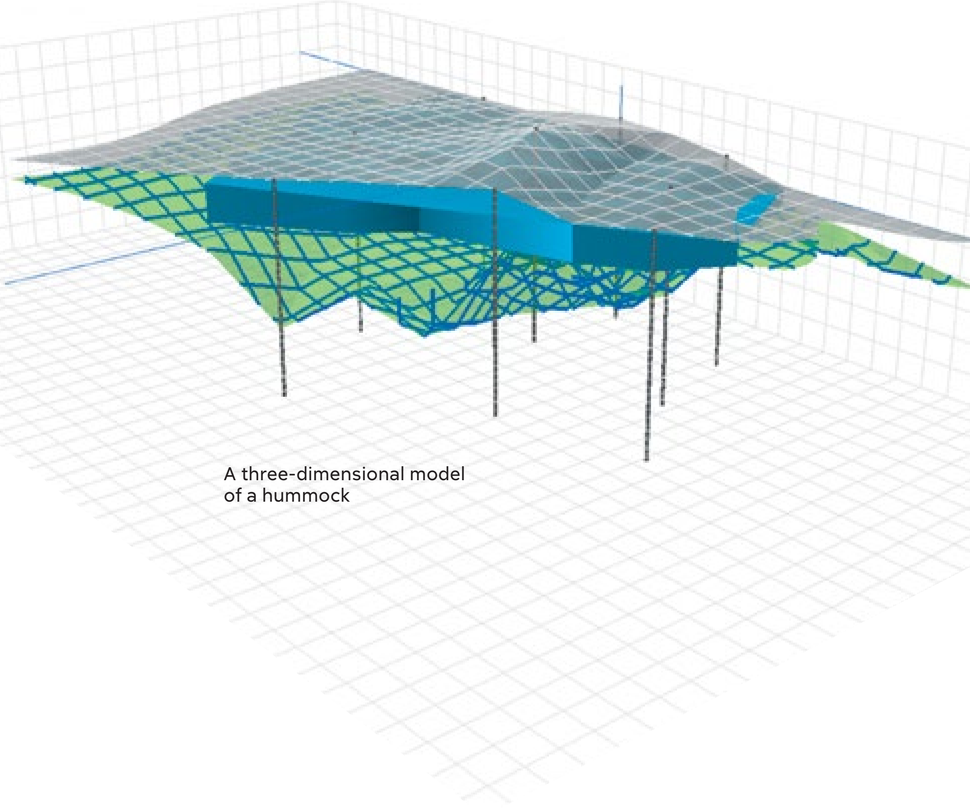
A relatively large ice formation is selected in the desired area. Two to five profiles, depending on the size of the hummock or the stamukha, are laid perpendicular to the ridge 15–20 meters apart.

Preparing for thermal drilling of a hummock

Thermal drilling points are marked along the profile. During the processing of thermal drilling data, the size of the above-water and underwater parts of the ice formation, boundaries of voids and ice of different densities in the borehole are determined.

Simultaneously with thermal drilling, tacheometric and sonar surveys of the above-water and underwater parts respectively are conducted. With the help of specialized software, the results of these surveys help construct 3D models of hummocks/stamukhas, as well as to determine the volumes of ice formations.

→ p. 167



A three-dimensional model of a hummock

Such research helps determine:
— size distribution laws of ice formations;
— internal structure of ice formations (porosity, consolidated layer);
— correlations between physical (temperature, salinity) and mechanical (strength) properties of deformed ice.

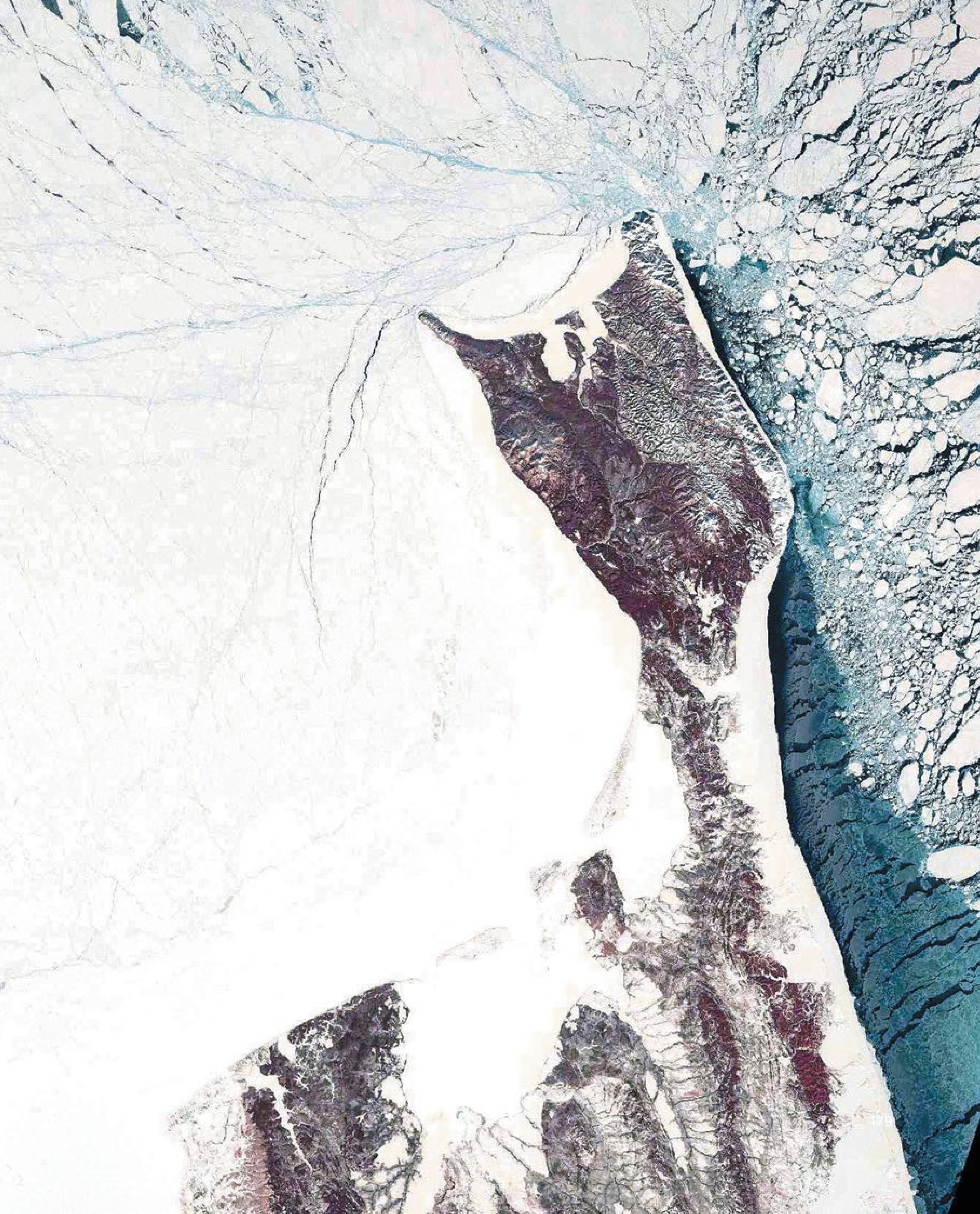
Based on the results of the analysis, principles for unified classification combining hummocks and stamukhas were proposed. A correlation of the main indicator of their strength with winter temperature conditions has been uncovered, and drift characteristics of all ice formations have been determined. Based on the obtained data, technical specifications were developed which drive requirements for engineering structures in the Arctic offshore.

Many faces of ice

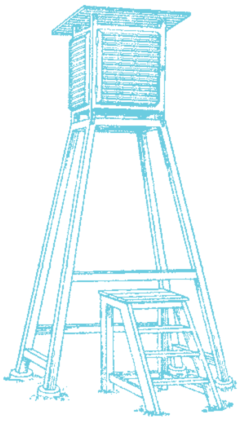
Ice is a fascinating substance. Not only water is the only substance in which the solid phase is less dense than the liquid phase, making ice float rather than sink, ice also acquires new properties at high pressure. This is why glaciers “flow”, developing viscoplastic properties under their own weight. The characteristics of ice during the formation of hummocks and stamukhas are described by complex mathematical laws without studying which it is impossible to design safe, year-round functioning hydrotechnical structures in the offshore.

For 10 years the properties of smooth and deformed ice have been studied in expeditions and laboratories. Season after season, at different sites but using the same methodology scientists have been obtaining complete, reliable and comparable data. Their analysis allows to understand the nature of physical, chemical and strength properties of ice and to model and predict their changes.

The results of these studies help not only design structures for operating in Arctic conditions, but also assess climatic changes affecting the region.



Khastyr field camp



The most comprehensive data on the properties of ice was obtained at the Khastyr camp. It was founded in August 2016 on the coast of the Khatanga Bay of the Laptev Sea. Before it was built, all winter ice research activities were performed from nuclear icebreakers. Although valuable, such studies have the disadvantage of being expensive and lacking long-term observations. The field camp successfully solved the issue of cost optimization, but most importantly allowed to conduct observations year-round. They are extremely valuable: scientists can study ice from the beginning of landfast ice formation in September–October until the moment of complete clearing of the water area in May–June. A number of observations include data on smooth and deformed ice, hummocky formations and stamukhas.

→ p. 176

During the period of active research in 2016–2018, at least seven people were working at Khastyr at the same time. The living conditions were spartan, but comfortable enough for an Arctic base. The base consists of several buildings: staff cabins, a mess, galley, generator building and the weather station, the meteorologist's cabin and, of course, the ice research laboratory. Food and fuel are stocked for a year of autonomous operation, but the supplies are usually replenished more frequently during shift changes and scheduled equipment deliveries.

Industrial safety and environmental protection requirements are observed, there is appropriate rescue equipment and a helipad in case of an emergency. This shows the advantageous geographical location of the base: on the one hand, it allows studying the ice during its entire life cycle, on the other hand it is located within the flight radius of a helicopter from the nearest settlement, Khatanga.

Zvezda shipbuilding complex

The Arctic needs special ships

Arctic routes mean long and hard journeys through the northern seas, through bad weather and ice. They also mean various tasks — transport, economic and scientific — that require ensuring the crew's welfare and safety for months at a time.

→ p. 44 These tasks require suitable vessels. Not just suitable, but specialized ones, vessels with sufficient load-carrying capacity, icebreaking capability, lifting and navigation equipment. Such ships are not just rare or expensive, they may not exist at all, which means they need to be built.

Building such vessels requires huge shops and the appropriate infrastructure. There are about 150 state and private shipyards in Russia, but only one of them specializes in large-capacity vessels suitable for the challenging Arctic tasks: the Zvezda shipbuilding complex based in the town of Bolshoy Kamen in Primorsky Krai, 120 km from Vladivostok.

The company builds truly enormous vessels, among them:
- **the nuclear icebreaker Rossiya**, the lead ship of the Leader project, the world's largest nuclear icebreaker which will be able to provide waterways for large-capacity vessels in four meter thick ice;
- **ARC 7 class gas tankers** capable of overcoming ice up to two meters thick, withstanding Force 12 storms and sailing autonomously for up to 80 days. They run on liquefied gas and are highly environmentally safe.

Multipurpose supply vessel Katerina Velikaya

How Zvezda is structured

Zvezda is a young shipyard, it was officially launched on September 1, 2016. Within six years, all key functions of the complex were put into operation, including shops for fabrication, painting and fitting of sections and blocks with maritime systems and other equipment, an open heavy dock slipway with several lanes for ship construction, a transfer floating dock for launching ships into the water. At the end of 2021, one of the largest dry docks in the world was put into operation.

Zvezda is a high-tech facility. For the first time in Russia, the shipyard has introduced large-block shipbuilding technologies. It means that different parts of the ship are built separately, then combined into sections, sections are combined into blocks, blocks are used to form large blocks which are then joined together with millimeter accuracy. This approach makes it possible, for example, to build a ship's superstructure without waiting for the hull to be completed. This production principle not only saves an enormous amount of time, but also ensures that each block is assembled independently, because the blocks arrive in the assembly shop already fitted with piping and all necessary shipboard equipment.

Today, about 5,000 people work at the shipyard and new vacancies are posted every day. Retraining and social support programs are available for employees, and entire housing districts are being built for them.

A multipurpose supply vessel on the slipway

Main shipyard facilities and equipment

Hull fabrication unit. This is where metal cutting, machining and welding takes place that is required to manufacture vessel parts and sections up to 300 tons in weight and 23 × 13 × 12 meters in size.

Paint shops for cleaning, painting and drying of hull structures. The shops are designed for sections of up to 23 × 27 × 10 meters in size and up to 400 tons in weight.

Block assembly shop where large ship blocks with preinstalled equipment weighing up to 2,700 tons and up to 46 × 23 × 20 meters in size and assembled together.

Open heavy dock slipway. 485 × 230 meters in size, it has three technological lines for assembling vessels from sections and blocks. It is equipped with a powerful crane fleet consisting of seven cranes with lifting capacities from 100 to 1,200 tons, including the unique Goliath crane with lifting height of 98 meters, crossbeam length of 230 meters and lifting capacity of 1,200 tons. A rail-mounted ship transportation system is used to move hull blocks and vessels, consisting of 216 powered and non-powered hydraulic bogies with a lifting capacity of 250 tons each. The total lifting capacity of the system allows transporting vessels up to 40,000 tons.

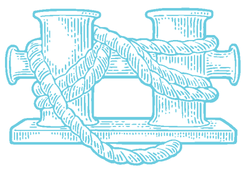
Dry dock. Measuring 485 × 114 meters and 14 meters deep, it is one of world's largest hydrotechnical structures. It allows the construction of vessels with a displacement of up to 350,000 tons. The dry dock is equipped with an inner technological gate that allows to work on several vessels simultaneously, as well as a floating bulkhead 114 meters long and 13.5 meters high. The second Goliath crane with a lifting capacity of 1,200 tons is mounted on the side of the dry dock. Its height is 120 meters and width is 189 meters. The dock is also equipped with four tower cranes with a lifting capacity of 60 tons each.

Crane equipment. There are 40 pieces of crane equipment installed at the shipyard, including two Goliath gantry cranes with lifting capacity of 1,200 tons each.

Transfer floating dock. The dock has a lifting capacity of 40,000 tons and is intended for launching large ships up to 300 meters in length and over 50 meters in width with a launching weight of up to 40,000 tons and deadweight tonnage of up to 350,000 tons.

Slipway

The slipway is a complex hydraulic engineering structure covering an area of 12 hectares. The transferring berth of the slipway is the most robust in the country, allowing to transfer vessels and other heavy cargo weighing up to 40,000 tons from the slipway to the transfer floating dock.



Ships for Rosneft

The mission of Zvezda shipbuilding complex is to build heavy-tonnage ships predominantly of ice class, as well as elements of offshore platforms, special vessels and other types of marine equipment. The order portfolio of Zvezda includes more than 60 vessels.

Rosneft is one of the shipyard's major customers; contracts for the construction of 28 ships have already been signed:
— four multipurpose supply vessels of reinforced ice class;
— 12 Aframax tankers;
— 10 Arctic *ARC 7* class shuttle tankers with a deadweight tonnage of 120,000 tons;
— one Arctic shuttle tanker with a deadweight tonnage of 69,000 tons;
— one drilling vessel.

Deadweight tonnage is the difference between gross and empty displacement of a ship, i. e. the weight of payload, fuel, liquids, drinking water, crew, luggage and provisions.

Two of the Aframax tankers have already been handed over to Rosneft. One of them, Vladimir Monomakh, was the first vessel delivered by Zvezda shipyard. Other key vessels are under active construction. The multipurpose reinforced ice class supply vessel Katerina Velikaya has already been launched.

Aframax tankers are oil tankers designed for an unrestricted area of operation. The ship's main and auxiliary power units can run on both conventional fuel and the environmentally friendly liquefied natural gas, which complies with new regulations for limiting emissions of sulfur oxides and greenhouse gases in the northern seas.

Multipurpose supply vessel Katerina Velikaya

Podded propulsion units
Azimuth thrusters

→ p. 25 When traversing Arctic routes, vessels have to navigate ice fields and bridges, quickly change operating modes and maneuver in narrow passages between the ice. Modern vessels are able to cope with these tasks quite easily thanks to azimuth thrusters.

How it worked before

The traditional ship control design consists of a diesel engine, from which a propeller shaft runs to the propeller. As shipping developed, ships got bigger and longer, and engines became more powerful and heavy. Due to their weight, engines had to be placed in the center of the hull, so the size of the propeller shaft also grew and could reach up to 30 meters in length and up to a meter in diameter. This led to two major problems:

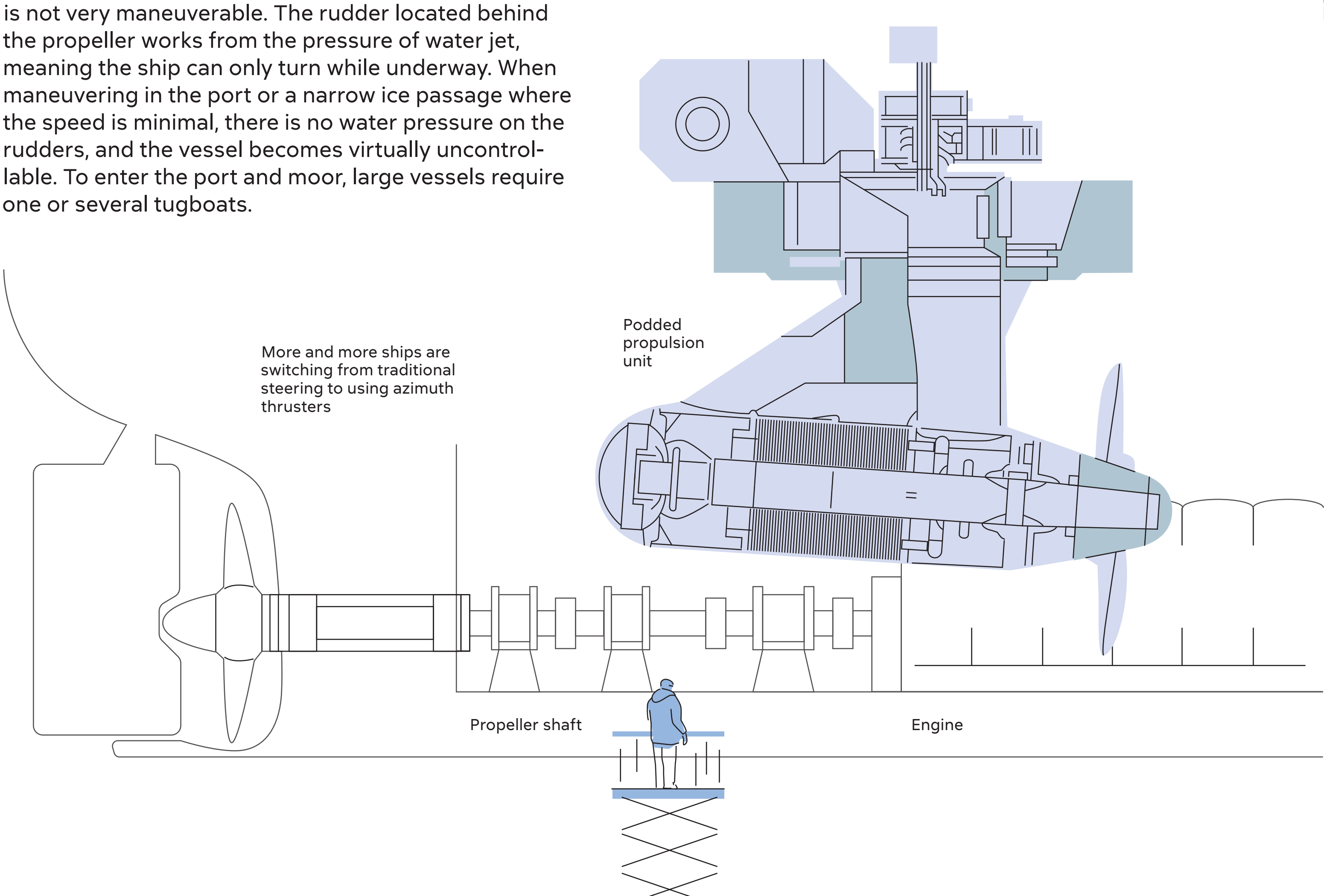
— the propeller shaft passed through several compartments, necessitating a complicated mechanism of keeping them sealed;
— when moving through ice, the ice exerted a strong and unevenly distributed load on the hull: the entire huge structure with the propeller shaft was subjected to shocks and vibrations.

In addition to that, with this propeller design the vessel is not very maneuverable. The rudder located behind the propeller works from the pressure of water jet, meaning the ship can only turn while underway. When maneuvering in the port or a narrow ice passage where the speed is minimal, there is no water pressure on the rudders, and the vessel becomes virtually uncontrollable. To enter the port and moor, large vessels require one or several tugboats.

From propeller shaft to electric propulsion

These problems have been resolved in several stages, the first being the change from mechanical transfer of power to the propeller to electrical. The diesel engine still works as before, but is no longer turning the propeller shaft directly. Instead, it produces energy for a compact and less inert electric motor.

This approach has two advantages. The use of an electric engine allows to avoid relying on the long propeller shaft, because the engine is now located closer to the stern and the propellers. But more importantly, the electric drive allows to change operating modes and responds to loads much faster. This is crucial when moving through ice when propeller speed and torque need to be changed in a fraction of a second.



The first azimuth thruster was installed on a ship in 1990. In Russia thrusters of this type are produced at the new shipbuilding complex Zvezda

Operation of the Northern Sea Route in terms of hydrocarbons delivery only became possible thanks to the azimuth thruster. Tankers can navigate through the ice without icebreaker support, enter ports and moor without tugboats, resulting in enormous savings in time and technical capacities.

Turn of the screw

At the next stage of development, the screw and the engine came even closer together. The propeller was mounted on a short shaft. The shaft, together with the engine, was placed in a watertight pod under the ship's hull where the entire structure could rotate 360°. And this is how an azimuth thruster was born.

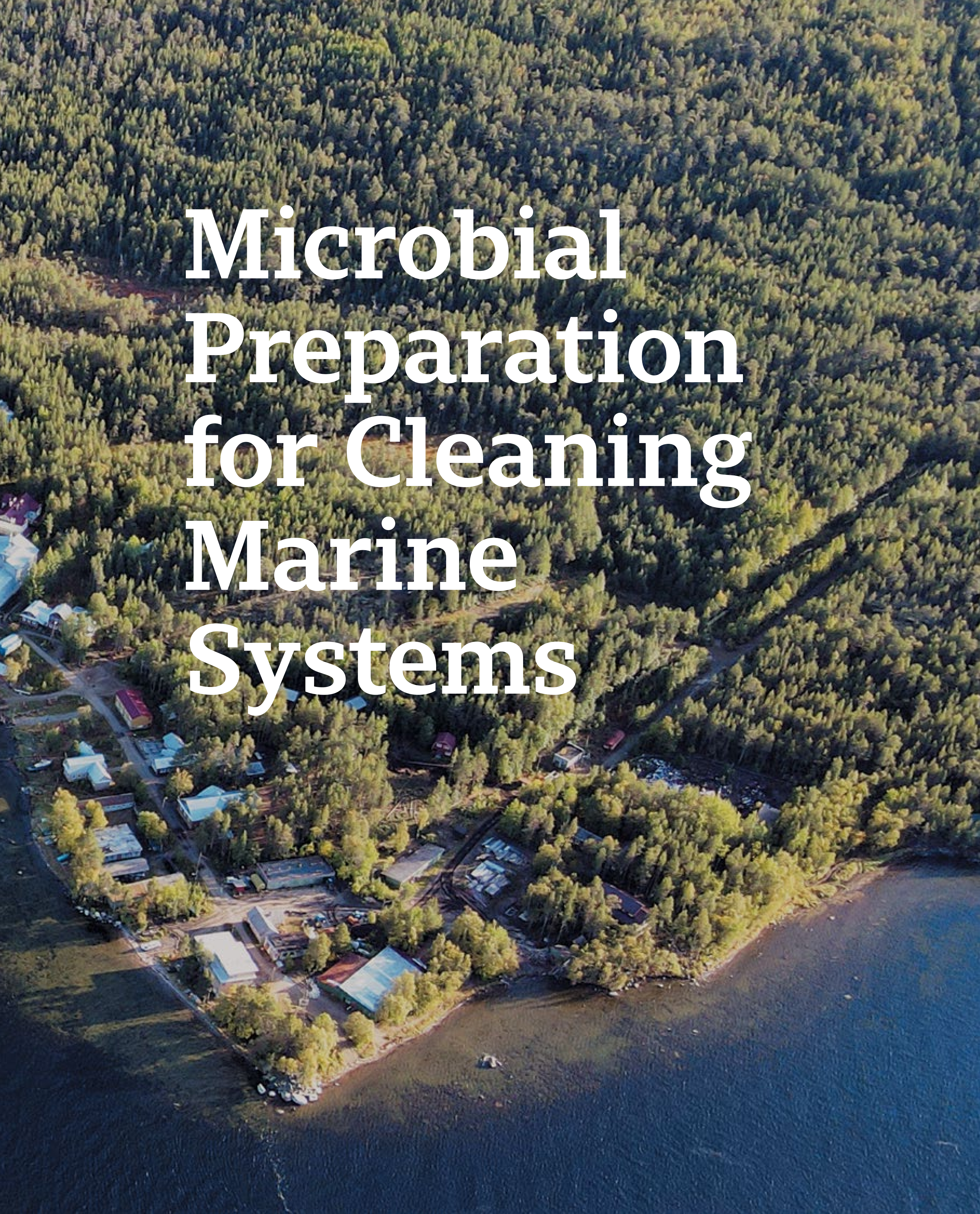
The podded propulsion unit completely solves the maneuverability problem. It becomes an active rudder: the ship can move in any direction and turn at the slowest possible speed. When you add the dynamic positioning system, which allows the vessel to remain stationary without any input from the navigator by automatically engaging and steering the screw, the azimuth thruster becomes a truly invaluable tool. Even ships much larger than research vessels can now enter ports, maneuver and moor independently.

Icebreaking capability

Captains of icebreakers with a traditional propeller arrangement noticed that when a vessel moves out of heavy ice in reverse, its icebreaking capability increases: screws start milling through the ice, helping the vessel advance.

In the case of the azimuth thruster, this effect is used to the maximum. Sharp-edged screws are made for Arctic vessels which are more efficient at cutting through the ice, thus allowing the ship to overcome ice bridges that it would not have been able to go through head-on. This effect is more pronounced in large tonnage ships, but it is also present for research vessels.

Microbial Preparation for Cleaning Marine Systems



Risks of marine pollution

Oil enters the marine environment in a variety of ways: with poorly treated sewage from land and ships, through leaks during production and transportation, as well as naturally, by seepage from the oil-bearing layer.

Once in the water, oil negatively affects all marine life. Animals, birds and fish can become poisoned and die of asphyxiation or starvation. Oil film interferes with photosynthesis, disrupting food chains. Organisms living in the coastal zone, both on the surface of water and on the bottom, suffer the worst.

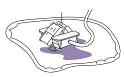
Biotechnology in pollution purification

The choice of treatment method and technology depends on the nature of contamination. Types of pollution can be divided into two large groups: accidental and chronic. According to statistics, the share of accidental spills is quite low. Much greater “contribution” is made by chronic, local pollution during operation of marine transport.

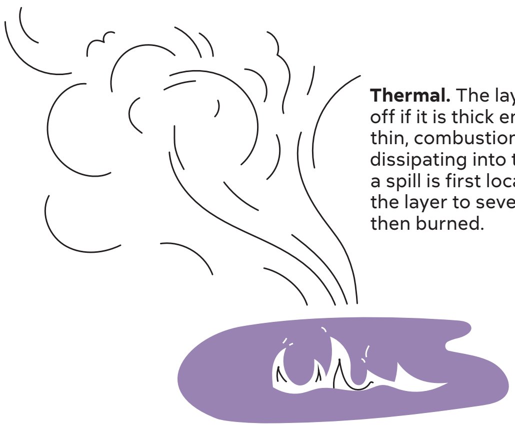
Mechanical, thermal and chemical methods of purification are suitable first of all for elimination of accidental spills, that is when both the area of the spill and the oil film thickness are considerable, and when main consequences need to be quickly dealt with.

When complete cleanup is required, preparations developed by microbiologists using strains of hydrocarbon-oxidizing microbes are used. These biopreparations are used for small chronic pollution, during the last stages of spill cleanup and in cases of difficult terrain, such as in wetlands or in areas with rugged coastlines. But how did it happen that scientists decided to use microbes in the first place?

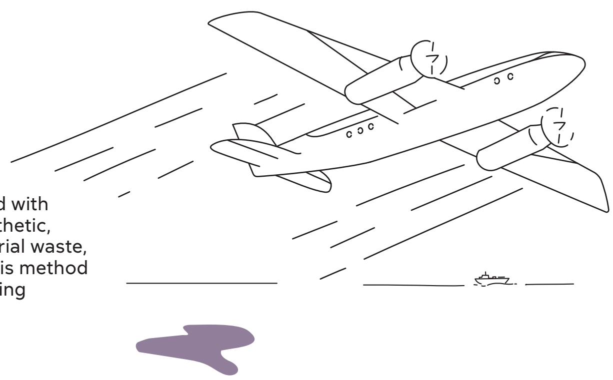
Mechanical. Oil is collected from the surface manually or with machines. The oil slick is contained with floating barriers, booms, and pumped out with special pumps.

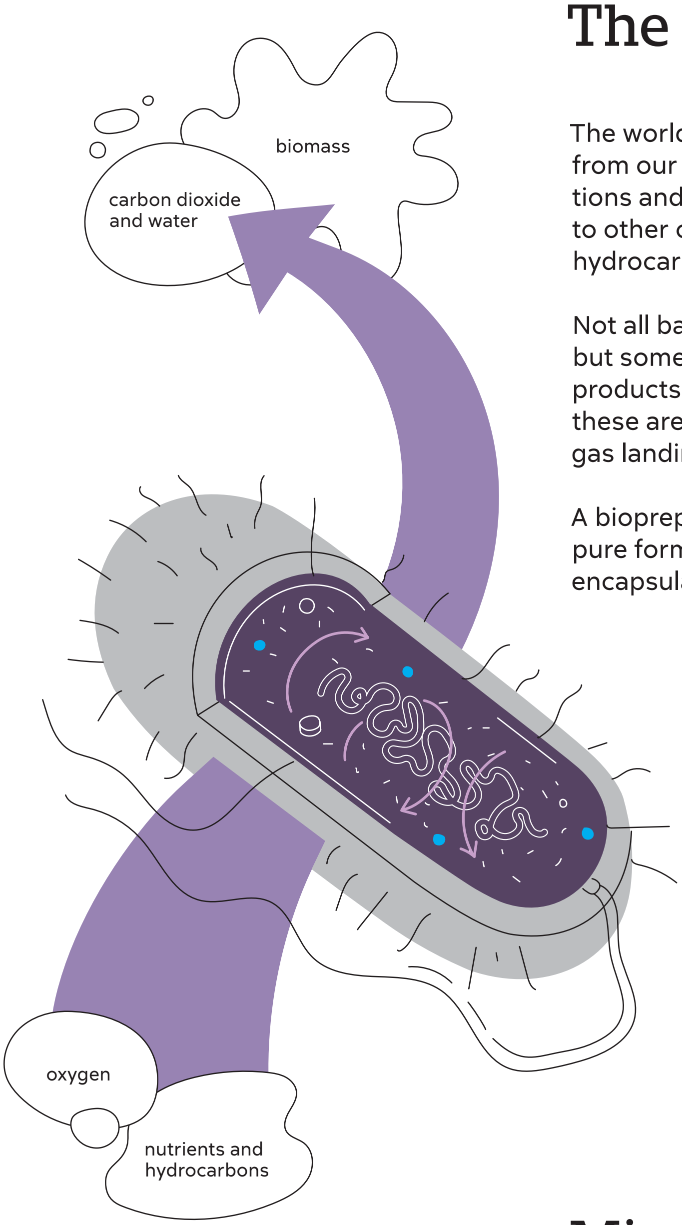


Thermal. The layer of oil can be burnt off if it is thick enough. If the film is thin, combustion stops due to the heat dissipating into the water. Therefore, a spill is first localized by thickening the layer to several centimeters, and then burned.



Chemical. The oil is cleaned with various sorbents: coal, synthetic, organic materials or industrial waste, e. g. from woodworking. This method is only suitable for eliminating the floating layer of oil.





The basis of the biopreparation

The world of microbes is diverse and very different from our own. Bacteria almost never live in ideal conditions and rely on substances that have little or no value to other organisms for nutrition. A perfect example is hydrocarbon-oxidizing microbes.

Not all bacteria are able to break down hydrocarbons, but some species have adapted to use petroleum products as their primary energy source. Most often these are the bacteria that initially inhabited oil and gas landing sites.

A biopreparation, however, is not microbes in their pure form, but a mixture of microbes and nutrients encapsulated in a technological form.

Environmental biotechnology

Biotechnology as a whole focuses on harnessing the beneficial and sometimes unexpected properties of living systems for the benefit of humans. Environmental biotechnology is centered on the utilization of contaminants, and one such application is biopreparations for the disposal of oil pollution.

The idea of a biopreparation is not new

The idea of using microorganism-based products to decontaminate oil pollution dates back to the middle of the previous century, and since then dozens of such preparations have appeared on the market. However, they were all designed for warm climates, since the higher the temperature, the higher the speed of chemical reactions.

Microbes in the Arctic

Humans are actively developing the Arctic: ports and oil terminals are being built, cargo flow and the number of ships passing through the Northern Sea Route is only increasing. But the more rapid the growth of economic activity, the greater the risk of damage to marine and coastal ecosystems.

−4...+8 °C — water temperature in the Arctic seas at which the preparation will be used.

The task of researchers is to develop a technology that would be effective in the unique conditions of the Arctic. The biological method of purification has suitable properties, but there is a serious limitation: low temperatures. It means that we need to use microorganisms that are not afraid of the cold.

Microbes suitable for the preparation

Microbial strains for the biopreparation that will be used in the Arctic must have several important properties. They have to be adapted to low temperatures and be isolated mainly where the preparation is going to be used (native strains). They must be able to withstand drying and granulation, i. e. conversion to a technological form, and be capable of long storage in the dried state. And of course, proven efficiency of hydrocarbon utilization is of utmost importance.

Expedition for the strains

Nature has microbes for all occasions, and the problem is more in their diversity rather than scarcity. At the first stage, the task of the researchers is to find suitable strains of microorganisms and select the most active ones. The search for strains starts with an expedition.

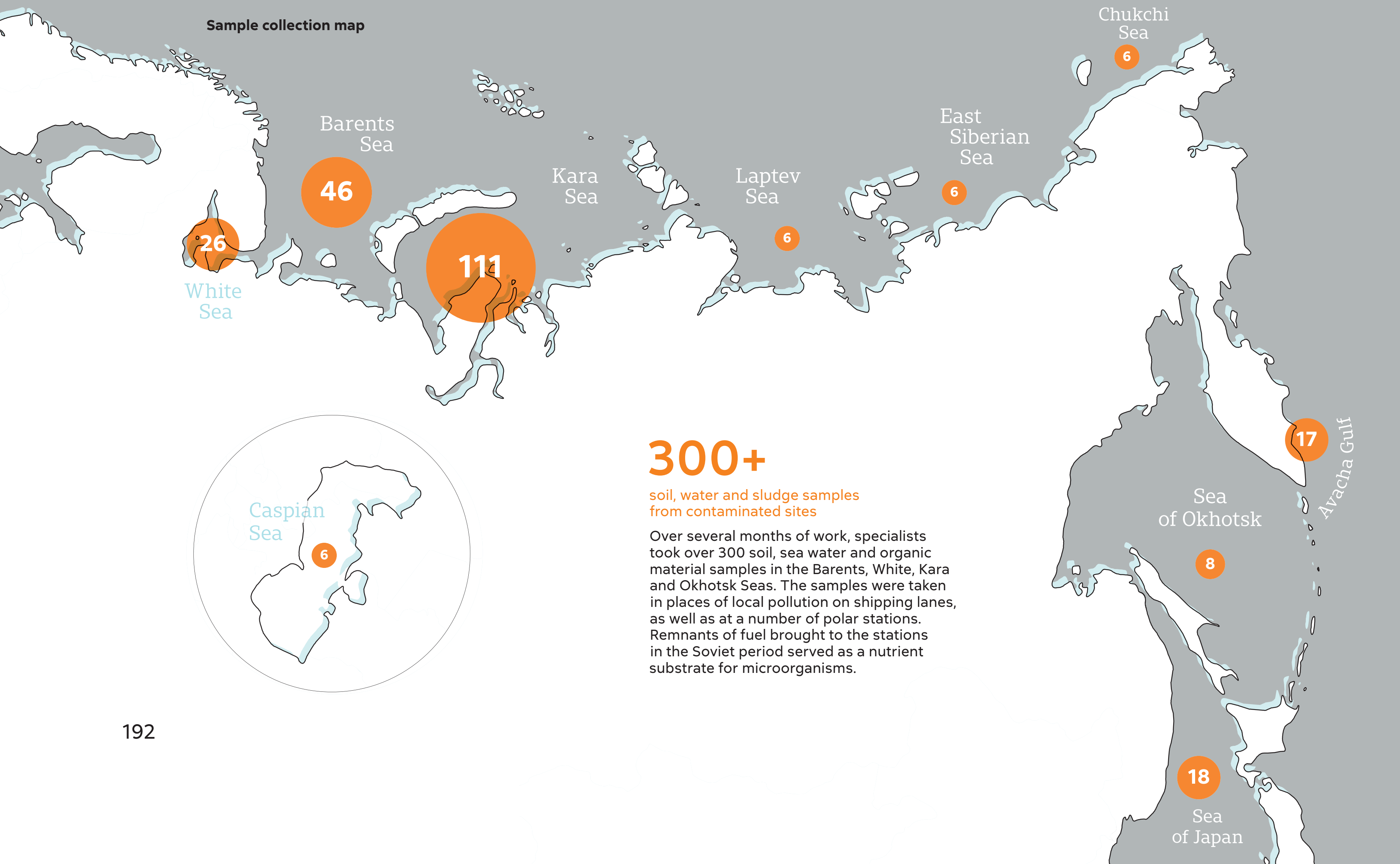
In 2014, a research team from Rosneft's Arctic Research Center, Innopraktika and the Department of Biology of Lomonosov Moscow State University went on the first Arctic expeditions to search for suitable microorganisms. The chance of finding the most active strains was higher in the Arctic, since native microorganisms are already well adapted to low temperatures.

→ p. 81

Algorithm of developing a biopreparation

Find suitable strains → Select the most promising species of microorganisms → Determine the composition of the future preparation → Give the preparation a technological form → Scale up production → Conduct laboratory trials → Test it in real sea conditions

Sample collection map



300+

soil, water and sludge samples from contaminated sites

Over several months of work, specialists took over 300 soil, sea water and organic material samples in the Barents, White, Kara and Okhotsk Seas. The samples were taken in places of local pollution on shipping lanes, as well as at a number of polar stations. Remnants of fuel brought to the stations in the Soviet period served as a nutrient substrate for microorganisms.

Selection of strains in the laboratory

224 samples

1. Cultivation

After the samples have been transferred to the laboratory, the microorganisms meeting the specified requirements are isolated from them. The conditions for strain growth — a selective growth medium with high salinity and a single source of energy in the form of hydrocarbons — are created in flasks. The cultivation cycle of cold-loving (psychrophilic) organisms is long, with each experiment taking from 10 to 60 days. Scientists also had to modify laboratory equipment to maintain low and negative temperatures.

66 active microorganisms

2. Pure culture isolation

Microbiologists perform inoculation of samples into Petri dishes so that the microorganisms grow in separate colonies within the same Petri dish. This helps separate the community into separate pure cultures. At least five passages are required to ensure the purity of the isolated culture. Due to the low cultivation temperature, each inoculation can take up to a week. The activity of specific strains can then be determined.

3. Rapid assessment of efficiency

Before a detailed evaluation, specialists perform an additional step of visual assessment of activity of the selected strains. An oil-soaked paper filter is placed on top of a Petri dish with a microorganism culture and the “brightening” of the filter allows to make initial conclusions about its effectiveness. This seemingly simple step takes up to three days, in contrast to a full-fledged work of at least 10 days.

38 strains

4. Identification

Identification allows to determine the species identity of selected microorganisms. Bacterial DNA is isolated and sequenced, which means nucleotide sequences of certain sections of the DNA are read. Usually, reading 1,500 nucleotides is sufficient to determine the species. Microorganisms of the genera *Psychrobacter*, *Arthrobacter*, *Pseudoalteromonas*, *Leucobacter* and *Rhodococcus* were isolated from the samples, a total of over 60 species which are characterized by effective utilization of hydrocarbons.

29 strains

5. Evaluation of hydrocarbon losses

The activity of each microorganism and its food preferences are determined. The method of gas-liquid chromatography allows to conduct a detailed analysis of how effectively the selected microorganisms cope with oil utilization. It turns out that in laboratory conditions some strains are able to utilize up to 80 % of oil products within 30 days.

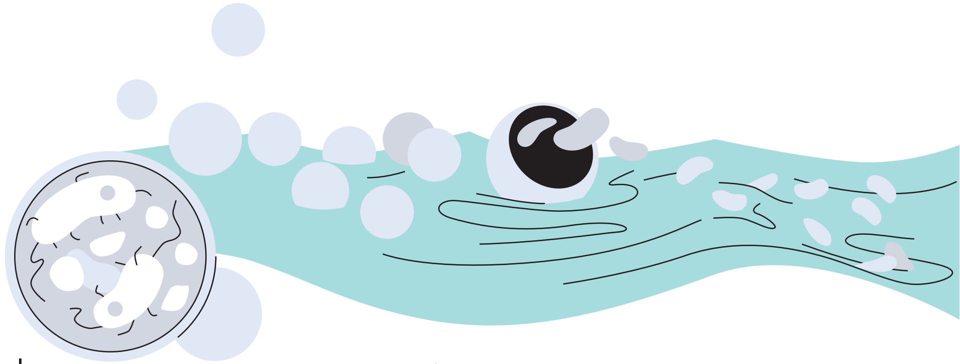
6. Creating a collection

In order to secure the rights to the discovered microorganisms, it is not enough to just isolate and store the necessary strains in the laboratory. Obtaining a patent requires transferring the strains to a specialized collection, such as the All-Russian Collection of Industrial Microorganisms. In such centers, the microorganisms are additionally tested to make sure they belong to the indicated species and are then preserved for dozens of years.

How to store a collection of microorganisms

For long-term storage, the biomass of microorganisms is most often dried by spray drying or freeze-drying. In the laboratory, strains are also stored frozen in a low-temperature refrigerator at −80 °C which provides the easiest way to recover them for experimental work.

Technological form of the preparation



However effective, the microorganisms selected by scientists are not yet a biopreparation. They only become one after they have been given a technological form, a state in which they can be transported and stored for a long time and used where they are needed. It is not always possible to deliver the product to the point of contamination, for example to an inaccessible part of the coastline in stormy conditions. This means the ingredients will need to spend a long time in the water before they can come into contact with hydrocarbon contaminants.

The concept of a biopreparation implies obtaining a granular form covered by a thin hydrophobic shell. The granule contains dried microbial cells and nutrients necessary to initiate their active growth.

The hydrophobic shell covering the granule is soluble in petroleum hydrocarbons and is weakly soluble in water.

The granules are buoyant. When they enter seawater, they spread over the surface, and the shell gets dissolved on contact with oil. The cells of the microorganisms are activated and the nutrients in the granule stimulate their growth and multiplication.

Activation takes place only in the contaminated area, this ensures the most efficient use of the product.

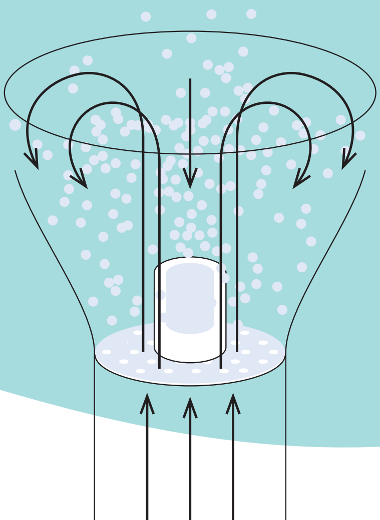
Algorithm of developing a technological form

Test premixes → Dry and granulate the biomass → Create a hydrophobic shell → Refine the production technology → Conduct trials in laboratory and real conditions

Testing premixes

Premixes are nutritional supplements necessary to stimulate microbial growth during the first stage of microorganism activation when the hydrophobic shell begins to dissolve. A combination of soybean and wheat flour is used as a premix. These substances turned out to be convenient to use not only as nutrition, but also as a carrier: the microorganisms successfully survived the drying process on such a matrix.

The process of forming granules and applying coating



Biomass drying and granulation

The mixture of premix and microbial biomass is granulated by spraying in a fluidized bed. A special unit uses nozzles to atomize the liquid containing the solids. The water wets the solids and evaporates, while granules are formed around the particles layer by layer. The average granule size is between 0.75 mm and 2 mm — such granules ensure optimal survival of microbial cells and maintain positive buoyancy in seawater. The granulated product is stable during long-term storage and is easy to pack and transport.

Aquarium system trials

Simulation of oil pollution in a real sea environment is impossible from the ecological point of view. One of the options for testing was to use flow-through aquarium systems at the White Sea Biological Station. The continuous inflow of fresh sea water into the aquariums allowed to fully simulate marine environment conditions. Such systems are traditionally used for marine invertebrates research, but they turned out to be convenient for microbiological work as well.

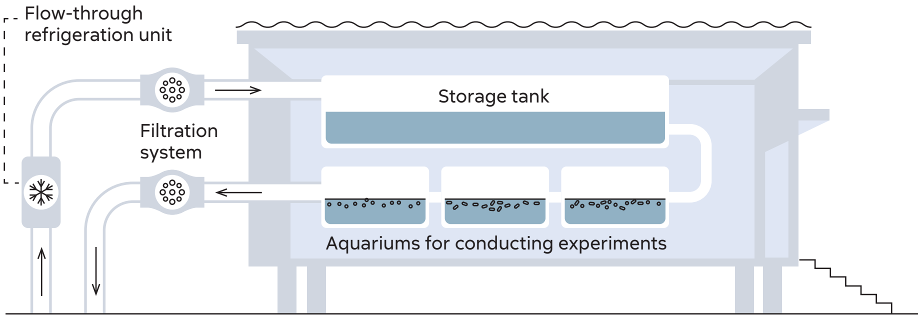
During the test, researchers have discarded a number of strains that were effective in laboratory conditions but performed much worse in real seawater conditions.

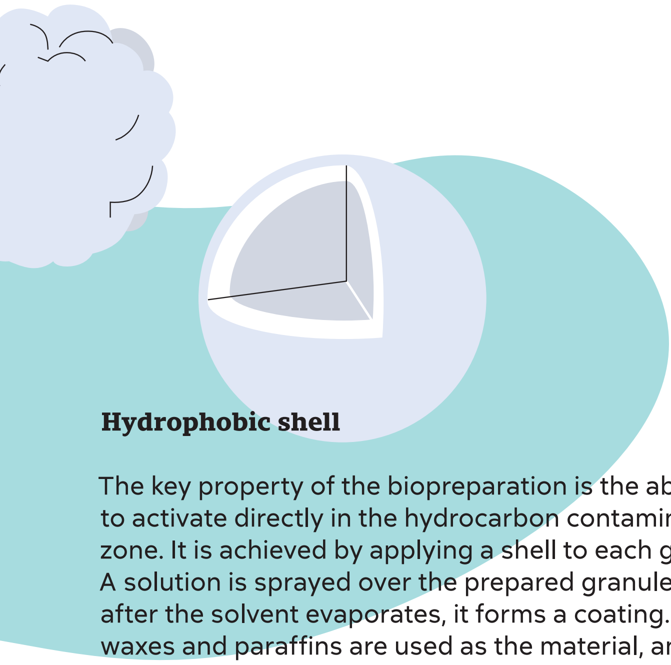
Initially, more than 80 strains and their combinations were selected. After the aquarium tests, 29 remained. The experiments also showed that the lower operating temperature threshold can be lowered from +4 °C to – 2.5 °C, at which point ice begins to form in seawater. Even in the presence of ice, certain strains showed a total loss of oil products of up to 62 % within 60 days. There were 15 such strains out of 29.

The new aquarium systems building at the White Sea Biological Station, Moscow State University

In the process of developing the microbial preparation, scientists found that the aquarium system not only helps to successfully eliminate the most ineffective strains, but also allows to conduct more in-depth research, including quantitative evaluation of oil product loss in ice conditions.

The flow-through aquarium system at the biological station was modernized and turned into a testing ground for year-round microbial preparation testing. The final tests of the technological form of the preparation are carried out here, including efficiency studies, evaluation of preparation consumption and simulation of its distribution under various weather conditions.





Hydrophobic shell

The key property of the biopreparation is the ability to activate directly in the hydrocarbon contamination zone. It is achieved by applying a shell to each granule. A solution is sprayed over the prepared granules, and after the solvent evaporates, it forms a coating. Organic waxes and paraffins are used as the material, and components that are completely consumed by the microorganisms are selected.

In order to conclusively prove the efficiency of the product, one has to leave the laboratory walls. It is essential to test the activity of the microorganisms under conditions that are as close to real life as possible.

Nikolai Pertsov White Sea Biological Station

The Nikolai Pertsov White Sea Biological Station of the Department of Biology of Moscow State University was founded in 1938 at the initiative of Lev Zenkevich who at that time headed the Chair of Zoology of Invertebrates. The university was required to produce specialists well acquainted with methods of working at sea, with marine flora and fauna, and a permanent station was necessary for that purpose. The Kandalaksha Bay of the White Sea turned out to be a good place for such a facility.

The biological station is located on the territory of Polyarny Krug Nature Reserve, which means all practical courses and scientific research at the station take place in untouched northern nature. The station is an isolated village of about 50 buildings.

Great credit for the creation of the station in its present form goes to Nikolai Pertsov, who served as its director from 1951 to 1987. Today, the biological station bears his name.

66°34′ N, 33°08′ E

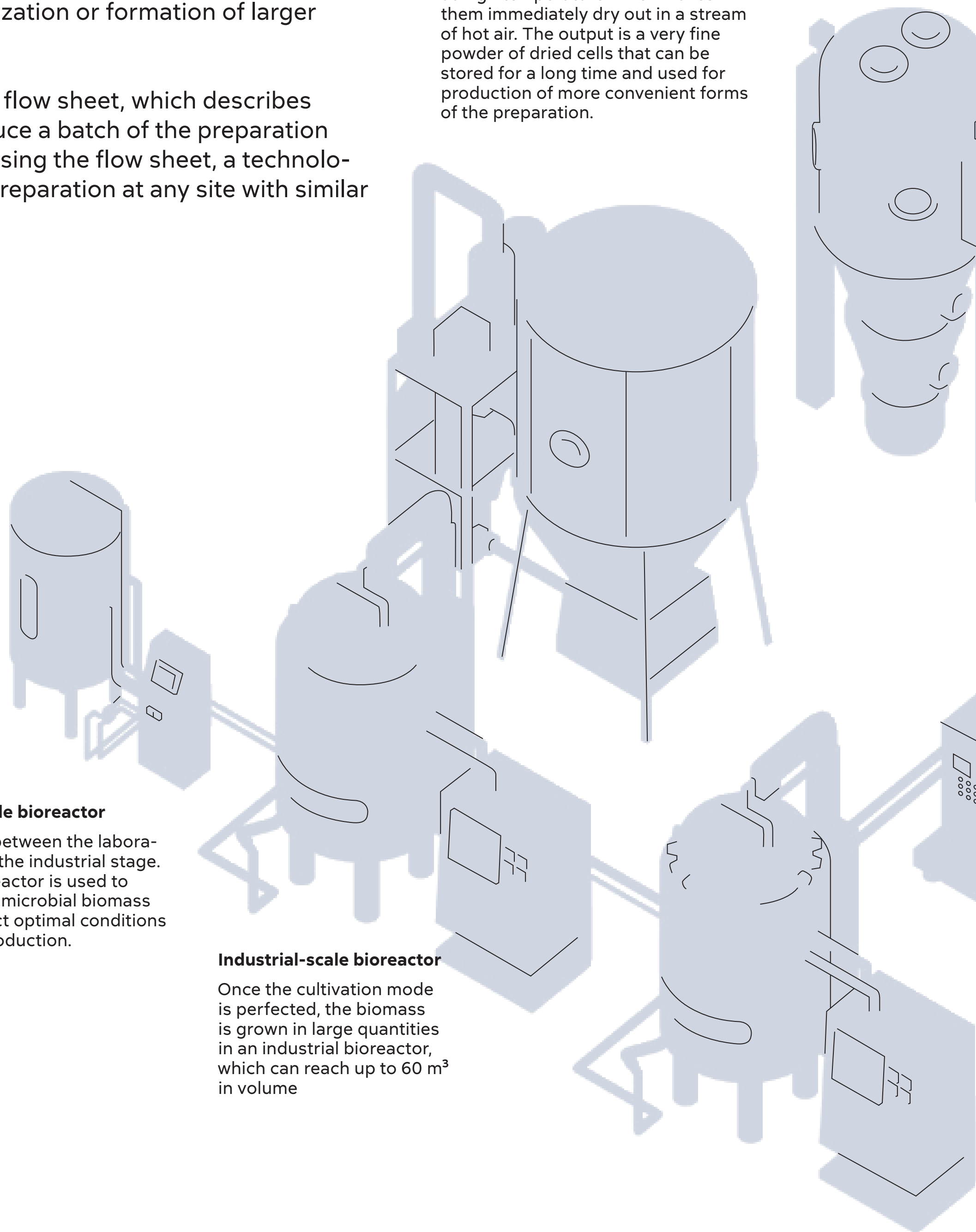
geographic coordinates of the station

Technology development

A limited amount of the preparation, 1–2 kg, can be obtained in laboratory conditions. To produce it in industrial quantities, it is necessary to work out all the processes in large volume and consider several nuances.

1. In large volumes of nutrient, microbes grow different than they do on Petri dishes: the growth rate and dynamics of nutrient consumption change. Technologists consistently grow bacteria in volumes from 10 liters to several cubic meters in order to prepare the production schedule — the most optimal parameters for large volumes.
2. The biomass concentration stage is added, since it is extremely inconvenient to work with liquids in large volumes, something that is not a problem in the laboratory.
3. With large-scale drying and granulation operations, process parameters such as drying temperature, particle size, granule size and shell thickness may differ. The component composition of the preparation may also change: for example, substances may be added to lower the stickiness of granules during fluidization or formation of larger granules.

As a result, researchers obtain a process flow sheet, which describes what equipment to use and how to produce a batch of the preparation that meets the specified requirements. Using the flow sheet, a technologist can organize the production of the preparation at any site with similar equipment and microorganism strains.



Spray dryer

In this machine the liquid biomass is dispersed into very small droplets at high temperature which makes them immediately dry out in a stream of hot air. The output is a very fine powder of dried cells that can be stored for a long time and used for production of more convenient forms of the preparation.

Technological complex for biopreparation production

Pilot-scale bioreactor

The link between the laboratory and the industrial stage. The bioreactor is used to grow the microbial biomass and select optimal conditions for its production.

Industrial-scale bioreactor

Once the cultivation mode is perfected, the biomass is grown in large quantities in an industrial bioreactor, which can reach up to 60 m³ in volume

Microbial preparation trial results

As a result of the research, it was possible to move from fundamental science to practical implementation of the project:

— develop a technological form of the preparation that provides targeted delivery of components to the contaminated area;

— develop a process chain that makes it possible to obtain the preparation in industrial quantities;

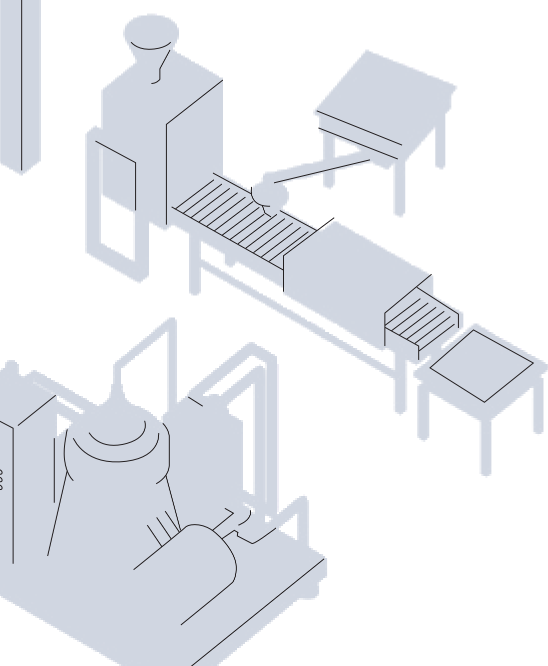
— ensure the microbial strains are safe for humans and warm-blooded animals: all of the selected strains are nonpathogenic and hypoallergenic, which means they can be used in making the preparation.

The flow-through aquarium systems block was renovated for preparation testing. All final forms of the preparation will be further tested to confirm their effectiveness in Arctic conditions. In addition, further research on the ecosystems of the northern seas can be conducted in the aquarium block, making additional contributions to fundamental and applied science.

Fluidized bed

The purpose of this machine is to produce a granular form of the product. The dry biomass is mixed with the nutrient premix in an ascending air flow and forms granules through wetting. The process is called fluidized bed granulation: the particles are in constant motion, suspended in the airflow, and their mixing process resembles boiling of a liquid.

Once the granules have been formed, the coating material is applied in the same apparatus as the solution directly onto the moving granules. This way, they can be coated with a thin and even layer.



Packaging line

The final stage is product packaging. It is important to preserve the obtained preparation so that the cells of the microorganisms retain their vitality as long as possible and the preparation maintains its effectiveness.

Separation system

In order to work comfortably with the biomass, it is necessary to reduce its volume without sacrificing the cells, i. e. to concentrate it. Different technologies can be used to reduce the volume several times, such as continuous flow centrifugation, vacuum evaporation or membrane concentration.

224
samples from four Arctic seas

66
active microorganisms isolated in pure cultures

38
strains identified

29
strains analyzed in detail with analytical methods

of them
14 can utilize hydrocarbons at +4 °C
15 at −2.5 °C

3
forms of the biopreparation are planned to be registered for use in different temperature ranges: up to +4 °C, up to 1 °C ±0.5, up to −2 °C ±0.5 in the presence of ice conditions

Clean Arctic

Active exploration of the Arctic began in the first decades of the twentieth century, and much work was done in the Soviet period. Numerous traces of economic activity have been left there since the period of the “conquest of nature”, including spills of fuel and lubricants which were brought in large quantities for the operation of scientific and meteorological bases and military facilities.

In the recent years, a responsible attitude towards natural resources has become one of the priorities in exploration of the region: the fragile northern ecosystems require utmost care. An important aspect of researchers’ work is not only developing responsible approaches to studying the Arctic, but also minimizing the environmental damage accumulated over the years.

Soil samples were taken on Alexandra Land

Start of the project

In order to assess the extent of pollution created during the exploration of the Arctic in the Soviet era, Clean Arctic, a comprehensive joint project by Rosneft and Russian Arctic National Park, was created. The project was launched in 2019 with the mandate to restore the ecosystem of Russia’s northernmost territories and the Franz Josef Land archipelago which is part of the national park. The project continues the work done in 2012–2017 on remediation of accumulated environmental damage on the islands of the Franz Josef Land and Novaya Zemlya archipelagos within the boundaries of the national park.

The tasks include:
— determining the boundaries of areas of accumulated environmental damage;
— analysis of the dynamics of fuel and lubricant content in soil;
— assessment of the impact of historical heritage on the ecosystems of the islands of the specially protected area.

Scientists’ recommendations should help determine the amount of work required to eliminate pollution and remediate Arctic soils.

2019

During the first stage, specialists of the Institute of Geography of the Russian Academy of Sciences and researchers of Russian Arctic National Park conducted research work on Alexandra Land island. It is located in the Franz Josef Land archipelago, in the Northern cluster of the national park. The island has been extensively cleaned from accumulated garbage, however the soil has not been remediated. Scientists have found that Arctic frozen soils are capable of natural bioremediation thanks to microorganisms that utilize oil products and other pollutants.

Russian Arctic National Park

The park is the northernmost and one of the largest specially protected natural areas of Russia. The area of the national park is 8.8 million hectares. The park is located on two polar archipelagos in Arkhangelsk Oblast: the northern part of Novaya Zemlya and Franz Josef Land. There are no permanent residents on the park’s territory, however it is home to seven species of animals listed in the Red Book, including the polar bear, Atlantic walrus, narwhal and bowhead whale.

2020

Scientists obtained new data during the expedition to Heiss Island in the Franz Josef Land archipelago. They found oil products that turned out to be “preserved” in the frozen rocks: with the onset of the polar summer they melt and enter the waters of the Barents Sea. Special drilling equipment was manufactured at Institute of Physics of the Earth of the Russian Academy of Sciences which was used to take core samples to determine the depth of penetration of pollution.

Scientists of the Clean Arctic project have determined the mechanism of migration of oil products: during seasonal thawing of soil, oil products are transported along with melting water by surface runoff, reaching the sea water area in small concentrations due to dilution with water. In summer, temporary watercourses turn into chains of isolated water reservoirs, along the banks and at the bottom of which oil products are deposited from surface films. Year by year, these reservoirs move closer to the shoreline and reach the Arctic Ocean.

Using quadcopters, aerial observations of changes in the ecological condition of contaminated areas were conducted on Heiss Island. They allow to compare the current state of polluted areas with the data of the aerial survey performed in the same place three years ago. This will help trace changes in Arctic landscapes after the “big Arctic cleanup”. Laboratory studies of the samples allow to determine the content of petroleum products and the species composition of microbial communities in the soils of Heiss Island. Desk work is carried out both in the national park itself and in the laboratories of Institute of Geography of the Russian Academy of Sciences, Dokuchaev Soil Science Institute of the Russian Academy of Sciences, Winogradsky Institute of Microbiology of the Russian Academy of Sciences and the Department of Geology of Lomonosov Moscow State University.

2021

Rosneft and Russian Arctic National Park have launched the third and final stage of the project to study the impact of economic activities on Arctic ecosystems. During the expedition, specialists took soil samples on Alexandra Land and Heiss islands to analyze the dynamics and nature of changes taking place in the Arctic ecosystems. According to the results of monitoring, it is already possible to draw conclusions about the ability of Arctic ecosystems to self-purify. Based on the results of the research, a comprehensive plan will be created that will lay out the methods, composition and scope of work necessary to eliminate secondary contamination and conduct remediation of Arctic soils in the archipelago.

“Hardening” microorganisms

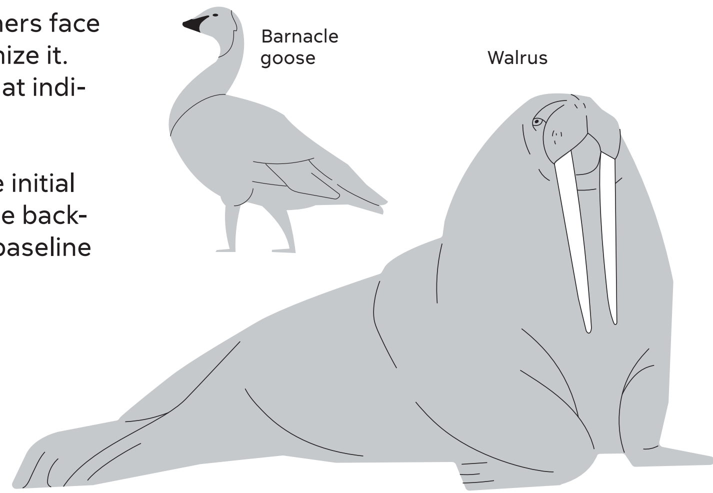
When oil products get into the soil, they not only reduce the number of microorganisms, but also change the ratio of different groups within the microbial community. In contaminated soils, those species that are able to utilize the substances gain an advantage. At the same time, such restructuring may increase the intensity of bioremediation: bacteria in contaminated soils actively consume oil products, using them as a nutritious substrate and destroying them as a result.

Marine Habitat Mapping

The most sensitive bioindicators live on the bottom

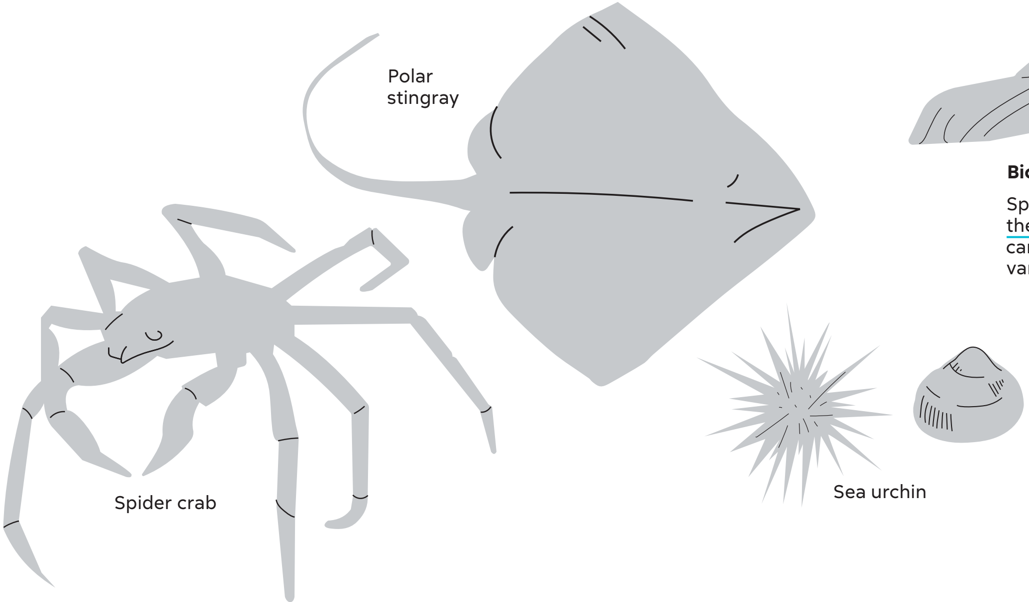
All human activities affect the ecosystem. The challenge researchers face is learning how to measure this impact and finding ways to minimize it. One way to control ecosystem processes is to monitor species that indicate the state of the environment.

First, scientists conduct a baseline survey, that is, they assess the initial state of the ecosystem, and then continue regular monitoring. The background survey is a mandatory and prolonged stage of research: baseline data is gathered over 3–4 years prior to the start of work.



Bioindicators

Species and groups of species that reflect the ecological condition of a region. These can be birds, land and marine mammals, various fishes and invertebrate animals. → p. 98



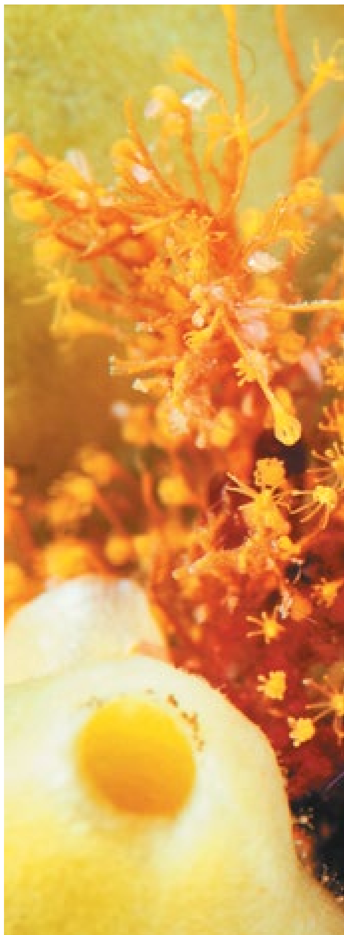
Over
3,800
total species diversity of Arctic marine benthic communities

90 %
of invertebrate species of the Arctic are representatives of the bottom fauna

Marine research, drilling and seismic surveys primarily affect the soil and the organisms that live in it and form bottom communities.

Bottom communities have a fairly long lifecycle and they respond to stressors on the time scale that we need: during operations, the soil is dug, silt moves, disturbed rocks settle out and the “affected” zone is formed.

Due to their small size and fairly slow movement, bottom organisms are easy to study. It is much more convenient than, for example, immobilizing polar bears and monitoring changes in hormones in their blood. → p. 102



The polychaete *Serpula uschakovi* lives in a rigid calcareous tube. Only a corolla of tentacles is located outside which the polychaete uses for breathing and feeding.

Bottom communities

Communities of organisms living on the bottom of the sea or in its upper layers. They are an important element of the Arctic trophic network, playing the role of a food base for other animals and acting as a seawater filtration mechanism.

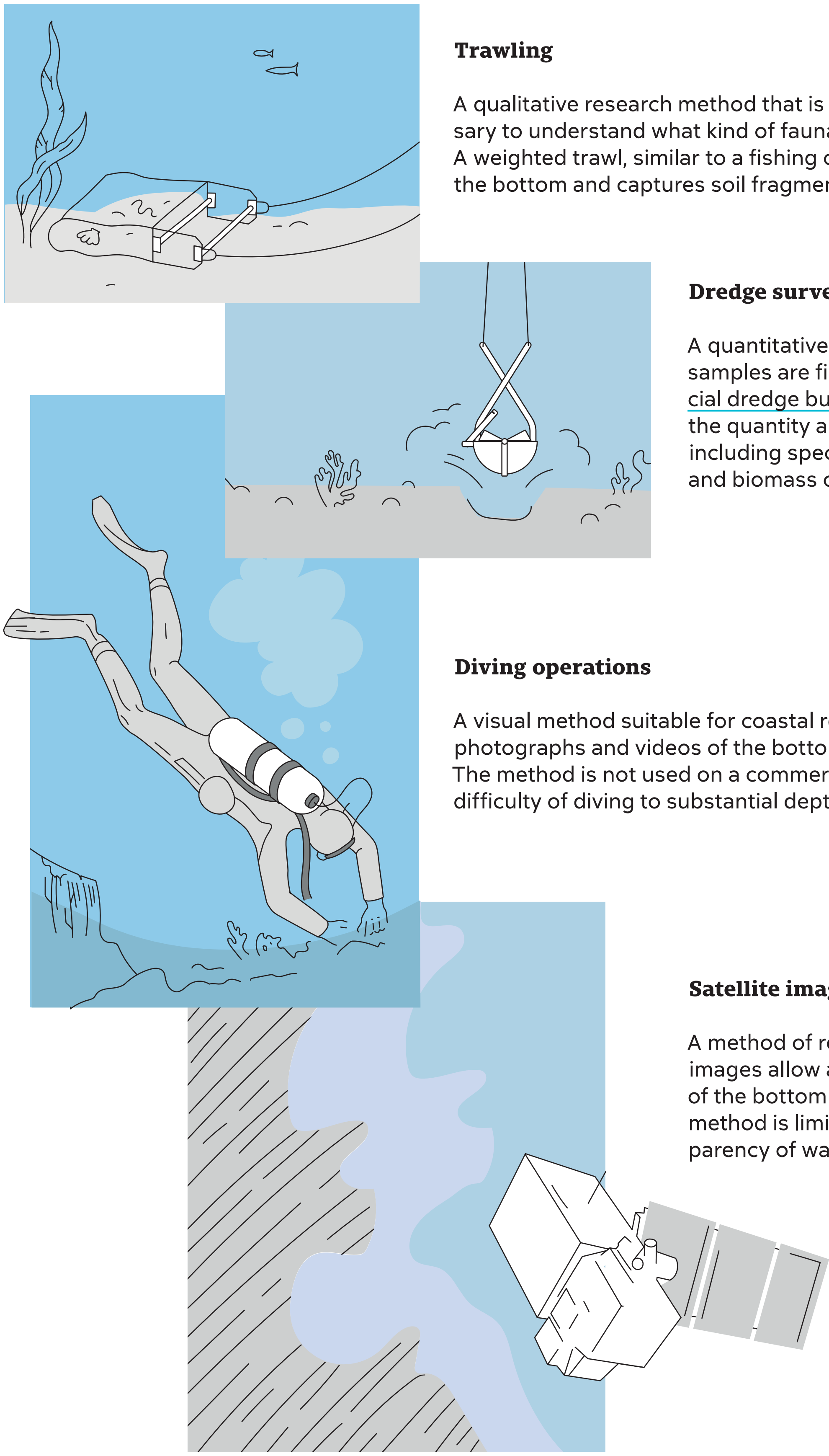
As a rule, they consist of dozens of invertebrate species belonging to different groups, including crustaceans, mollusks, polychaetes and echinoderms.

The richest in species diversity in the Russian Arctic is the Barents Sea, but it's important to understand that the number of described species depends on how well the area is studied.

The sea spider *Nymphon grossipes* has nothing to do with terrestrial spiders. It is an understudied and fairly small group of marine arthropods. They are found on different types of substrates, often on rocks and their fouling, due to which they are rarely caught by the dredger.

The gastropod mollusk *Corypehlla verrucosa* feeds on hydroid polyps and can use their stinging cells for its own protection. It is a typical species of the Arctic seas.

Bottom community research methods



Trawling

A qualitative research method that is used when it is necessary to understand what kind of fauna inhabits a region. A weighted trawl, similar to a fishing one, is dragged along the bottom and captures soil fragments.

Dredge survey

A quantitative method in which soil samples are first extracted with a special dredge bucket and then studied for the quantity and quality of organisms, including species diversity, abundance and biomass of individual species.

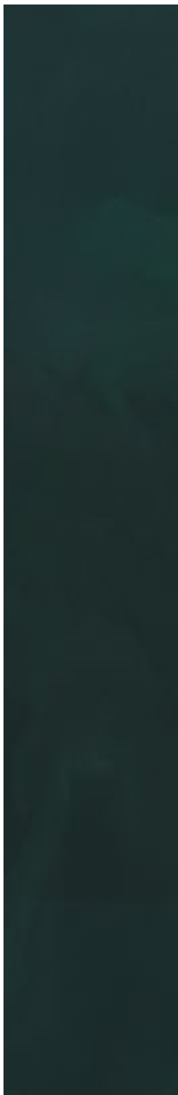
→ p. 207

Diving operations

A visual method suitable for coastal research. A diver takes photographs and videos of the bottom or takes samples. The method is not used on a commercial scale due to the difficulty of diving to substantial depths.

Satellite imaging

A method of remote research. Satellite images allow a sufficiently detailed view of the bottom topography, however the method is limited by the depth and transparency of water at the survey site.



Natural color image taken by *Sentinel-2/MSI* imaging system on March 5, 2021. Western Rum Cay Island (Bahamas). Modified Copernicus Sentinel data 2021/Sentinel Hub, www.sentinel-hub.com, Sinergise Ltd.

Natural color image taken by *Sentinel-2/MSI* imaging system on July 2, 2020. Litke and Ngonyartso Islands, Baydaratskaya Guba in the Kara Sea.
Modified Copernicus Sentinel data 2021/Sentinel Hub, www.sentinel-hub.com, Sinergise Ltd.

Preparing for research

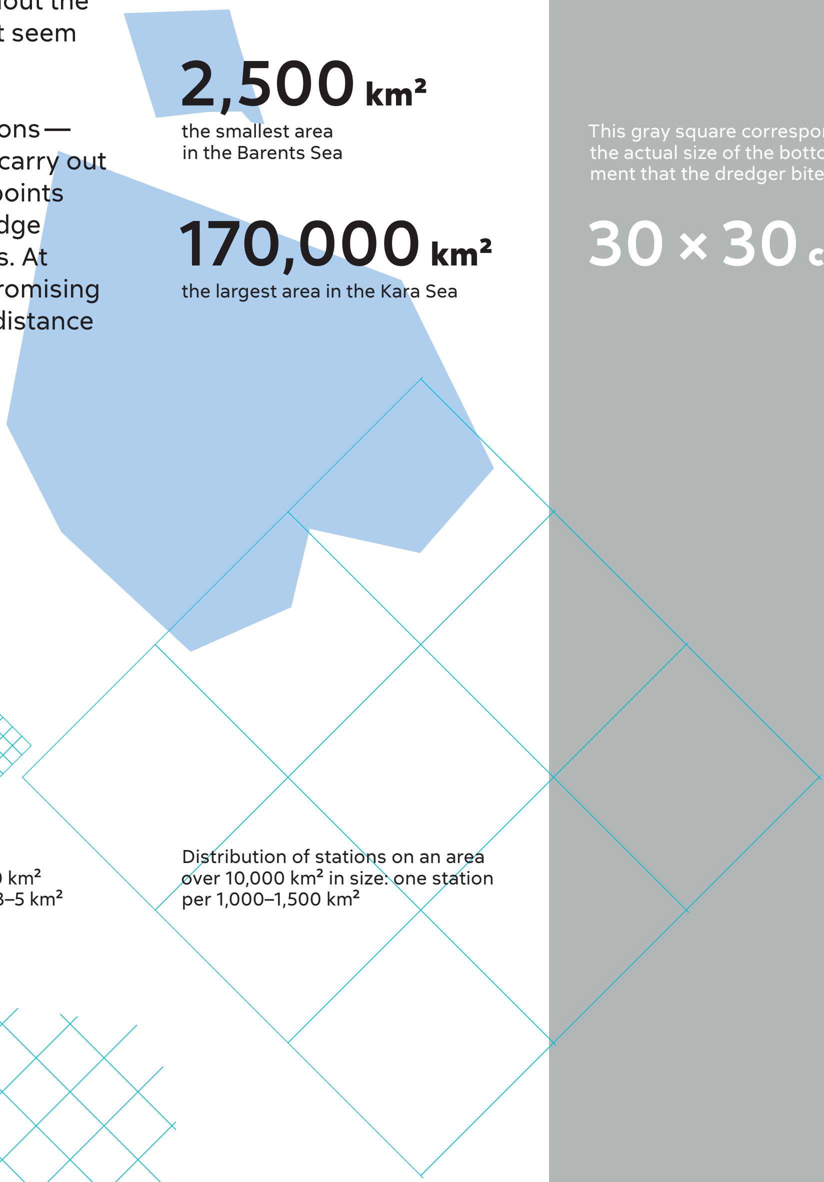
The traditional way to study bottom communities is a dredge survey. This method can be called historical, because the principle hasn't changed over the years: you need to capture a fragment of the bottom, lift it and study it.

Algorithm of conducting a dredge survey

Identify background survey locations → Collect samples with a dredge → Transfer samples to the laboratory → Rinse and examine the composition of organisms → Record the data and map it

The background survey is conducted throughout the entire area, but especially in those places that seem promising for research.

The license area is marked with a grid of stations — geographic coordinates where scientists will carry out background surveying and sampling. These points are determined based on the general knowledge of the water area, its topography and currents. At first, the station grid is sparse, but as more promising areas are found, the scale increases and the distance between stations shrinks.



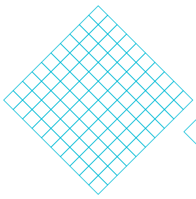
This gray square corresponds to the actual size of the bottom fragment that the dredger bites out

30 × 30 cm

Survey frequency

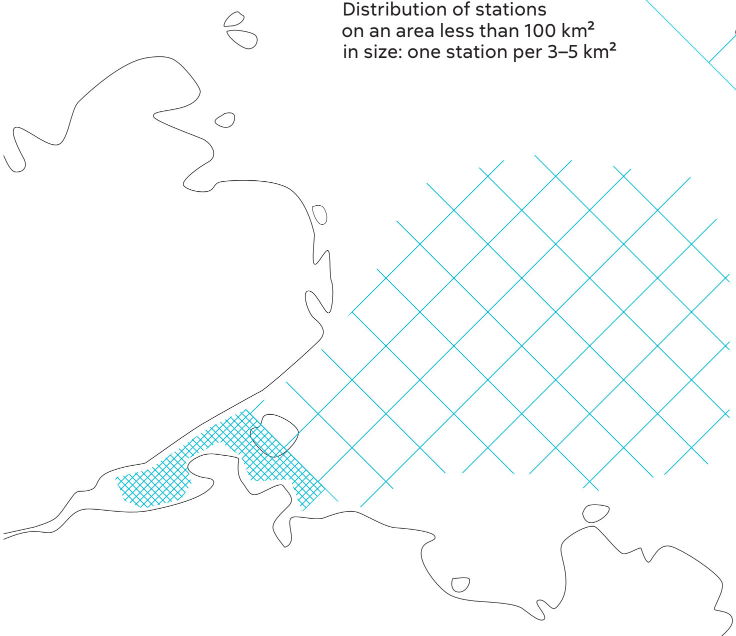
Each station needs to be studied frequently, at least once a year

Sea	Number of stations
Barents (including the Pechora Sea)	234
Kara	123
Laptev	58
East-Siberian	64
Chukchi	12



Distribution of stations on an area less than 100 km² in size: one station per 3–5 km²

Distribution of stations on an area over 10,000 km² in size: one station per 1,000–1,500 km²



Dredge surveying: pros, cons and pitfalls

To conduct sampling, a research vessel reaches the station and biologists lower a dredge, a bucket that bites out a fragment of the bottom of a defined surface area, such as 0.1 m². The sample is then lifted onto the deck and transferred to the laboratory for examination.

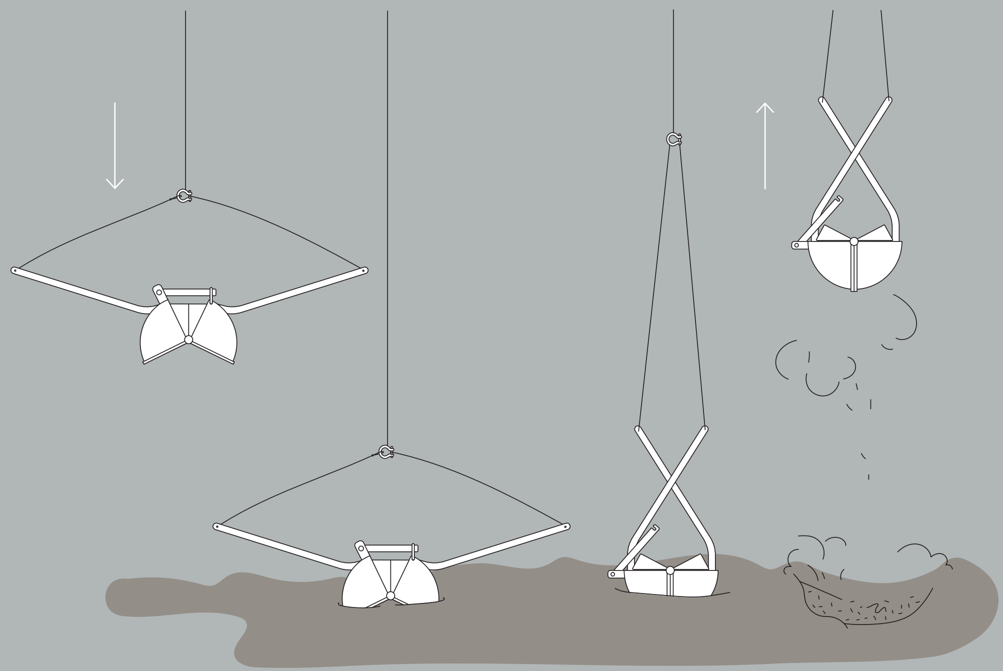
When studying repeat samples, biodiversity is compared with the results of the baseline survey in terms of average biomass, abundance of species and predominance of certain species over others.

Comparison result	Conclusion
Average sample biomass and species composition do not change significantly	Impact on the ecosystem is within limits
Sample is dominated by species characteristic of water bodies with high organic content. The biomass has increased significantly while species diversity has decreased	Possible dumping of organic waste
Species diversity has sharply decreased (from 50 to three species), only the most resistant species remain	Significant disturbances in the ecosystem

The dredge survey faces several problems. It can only be done on soft and relatively flat soils. The dredge will not be able to extract a sample from a rocky bottom or from a reef. If the dredge comes up empty three times, researchers say that a sample cannot be taken at that location.

In addition, bottom communities are arranged unevenly. Biologists lower the dredge 1–5 times at each station, but this may still not be enough. To significantly increase the accuracy of the method, 25–30 samples are needed, and this significantly increases both the time spent at a station and the duration of laboratory studies.

The challenge for researchers is to improve the quality of the survey, that is, to increase its accuracy and speed up the study. Is it possible to turn point surveys into area surveys? Yes, it is.



Bottom communities include large organisms as well. If you look at the bottom and see a dozen sea stars, even if there is only one per square meter, it would be obvious that starfish live in this location. But the likelihood of a starfish ending up in the bucket of a dredger is almost zero. This causes underestimation of the number of large and rare organisms.

How long does the survey take?

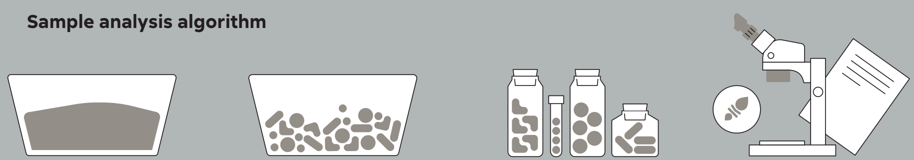
The timeline of dredge surveying is a sum of three parts:

— vessel movements between stations. No longer than a day;

— surveying at a station. About three hours at depths of up to 30 meters and with no more than five dives of the dredger;

— laboratory research. The most laborious part of work: 3–4 days per sample.

Sample analysis algorithm



1. Initially, an unwashed sample looks like a large handful of sand or silt.
2. It is washed through a sieve, leaving only the organisms themselves. They are preserved in formalin or alcohol.
3. The selected animals are divided into groups and handed over to biologists.
4. Biologists estimate the number and biomass of organisms in the sample, if possible, identifying all animals down to the species level.

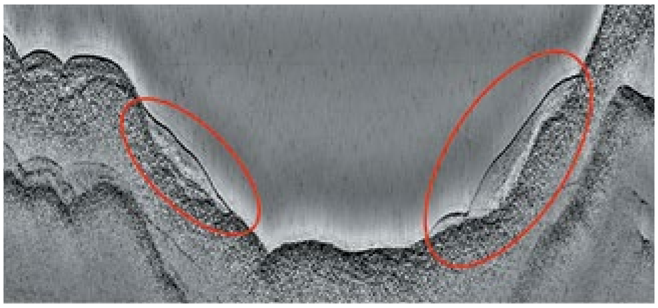
From point to area data

Biological research is point-based. Extrapolating data from, for example, a dredge survey, is only possible over a small area. And the accuracy of this extrapolation is not going to be great.

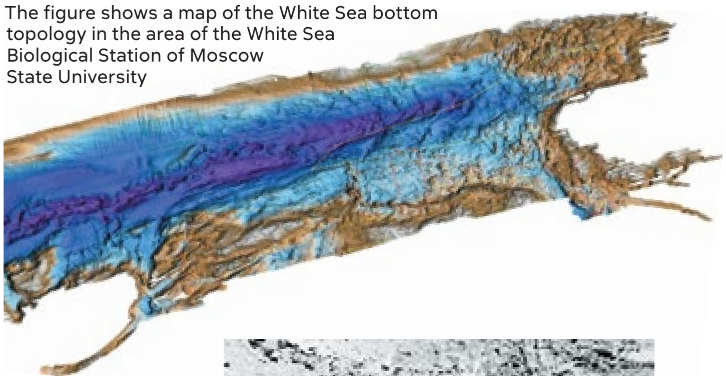
To increase survey accuracy, it is necessary to plan it correctly, which means getting reliable data on the state of the bottom. And to achieve that, area surveys are required.

The satellite imaging method mentioned above works only at shallow depths and in clear water. To get data on the state of the bottom at depths, results of geophysical surveys are required.

This is how a high-frequency profiler sees the bottom. Landslide bodies are marked in red



This is how a multibeam echo sounder sees the bottom. The figure shows a map of the White Sea bottom topology in the area of the White Sea Biological Station of Moscow State University



This is how a side-scan sonar sees the bottom. The illustration shows a fragment of the profile with prominent objects — boulders on the bottom

Area survey tools

All three area survey methods, essentially, rely on echo sounding. The principle of its operation relies on sending sound waves through the water. When the pulse reaches the bottom, objects on the bottom or vegetation, it bounces back to the surface. The sonar measures the time it took for the sound wave to reach the object and come back and calculates the depth. It also measures the strength of the return pulse: the stronger the pulse, the more solid the object that reflected it is.

Bottom profiler

Thanks to its low emission frequencies and significant power, the bottom profiler's acoustic signal is able to penetrate deep into the bottom ground to obtain a picture of the vertical structure of bottom sediments. The bottom profiler allows to get information about dozens of centimeters of sediment on the bottom surface. Sometimes, scientists use high and ultra-high resolution seismic surveys instead of a bottom profiler to map bottom communities. This methods yields results comparable to the profiler data.

→ p. 65

Multibeam echo sounder

The multibeam echo sounder performs area-based surveys and produces a highly accurate map of bottom topography. Unlike the single-beam echo sounder, the device transmits a fan-shaped acoustic pulse towards the bottom and records the reflected signal.

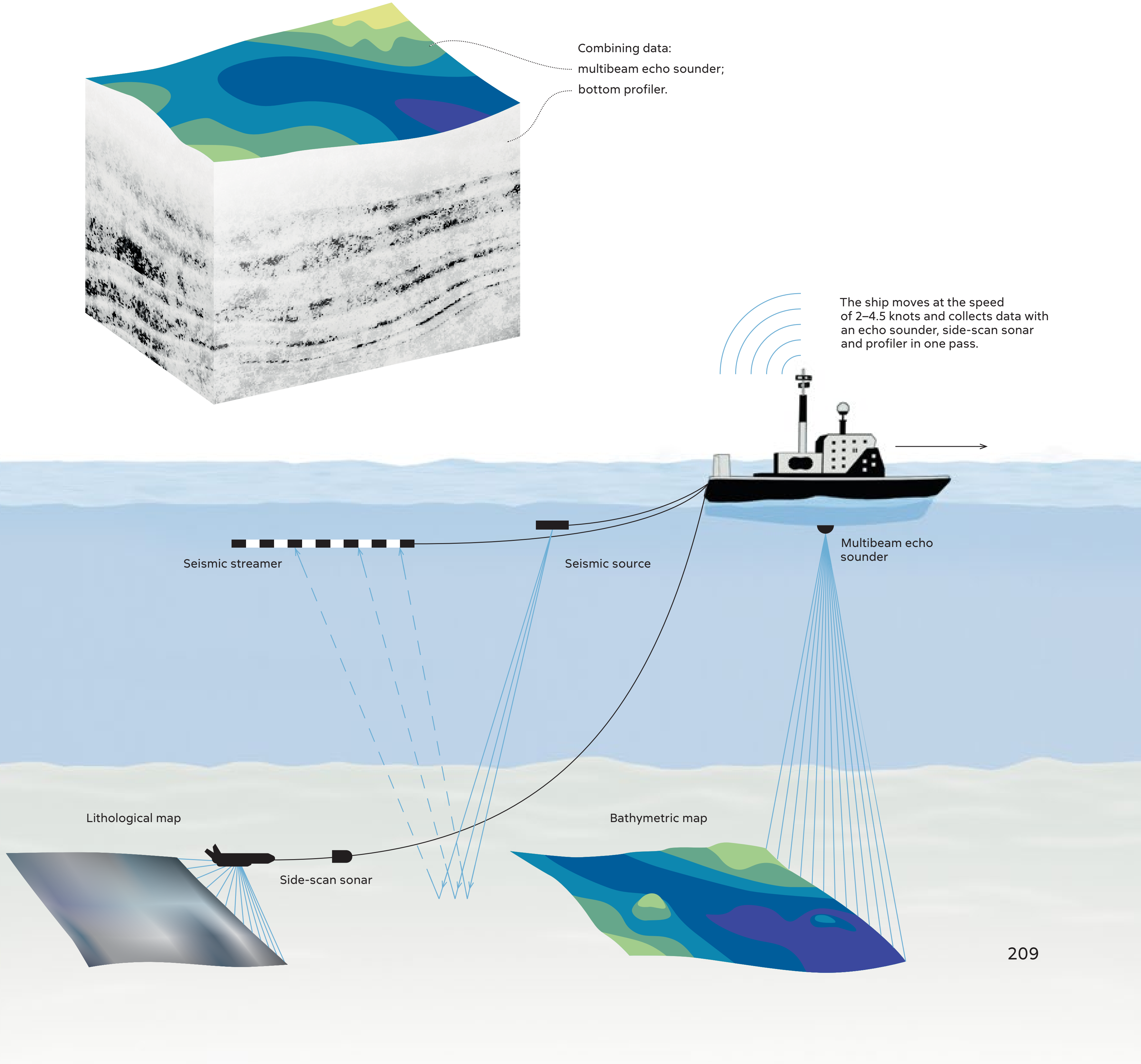
Side-scan sonar

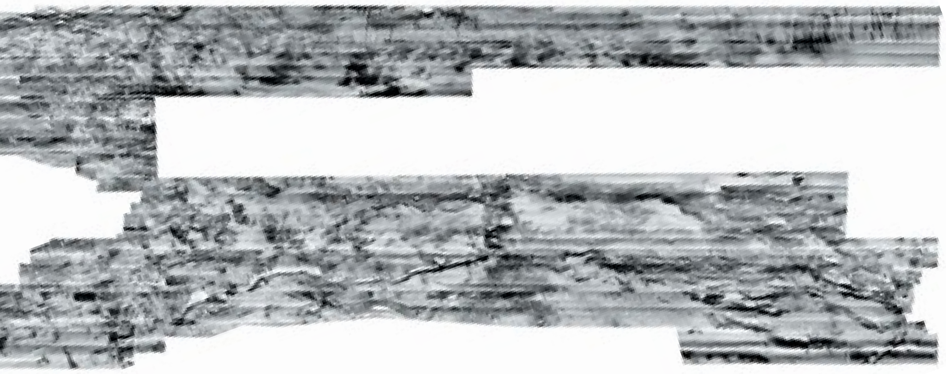
The side-scan sonar allows to get reliable information about the granulometric composition of bottom sediments. Originally developed for locating sunken objects, it is now used in engineering surveys, relief studies, searching for archaeological sites and in environmental monitoring.

Collecting geophysical data

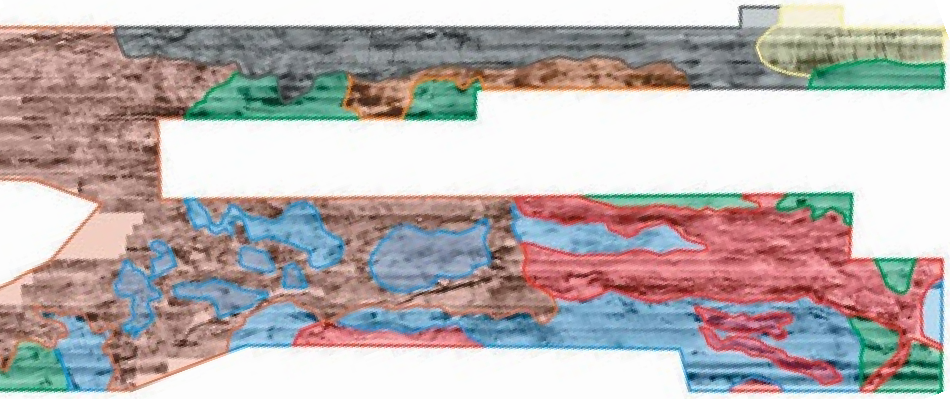
Algorithm of application of complex methods

Traverse the bottom with an echo sounder, sonar and profiler → Collect data on depth, topology, soil composition and currents → Select optimal points for biological research → Carry out research → Combine geophysical and biological results according to criteria → Extrapolate research results over a large water area





Side-scan sonar mosaic with homogeneous areas of different soil types highlighted



Use of side-scan sonars to map bottom communities

Based on the following principles:

— there is a fairly close relationship between sediment type and bottom population composition;

— boundaries between sediments of different types can be reliably determined on sonograms;

— the reflected acoustic signal characterizes not only the sediment type, but also the composition of bottom communities: different species of living organisms and the results of their activity significantly influence the microrelief of the bottom surface, changing its acoustic characteristics.

Why make maps

Many bottom habitats are critically important, including to rare and endangered species. A number of habitats can also be vulnerable on their own, for example sponge reefs or cold-water reefs, which are very slow to regenerate.

Also, many underwater biotopes are important as feeding grounds for fish and walruses. The Arctic seas (with the exception of the Barents Sea) remain relatively understudied, and many of the critical habitats in these seas are still undiscovered. Integrated underwater landscape mapping can help identify vulnerable habitats. The use of integrated biotope maps will allow correct planning of economic activities to minimize or eliminate damage to particularly sensitive habitats.

To analyze, interpret and map the distribution of bottom communities, scientists use biological, geological and geophysical characteristics.

Geological and geophysical characteristics

— soil reflectivity (silt has low reflectivity, while gravel, pebbles and boulders have high reflectivity);
— sediment homogeneity (dispersion): poorly sorted sediments, i. e. those with equal proportions of different grain size fractions, have high dispersion values;
— soil sorting: predominance of finely-dispersed particles, such as siltstone and pelite or coarse-clastic material;
— monotypicality of the soil (the measure of predominance of the dominant fraction) and other characteristics.

Biological characteristics:

— biomass and abundance of dominant species;
— results of bottom community classification.

Species diversity of animals inhabiting hard substrates is much higher than that of bottom populations of soft substrates. But the inhabitants of rocky substrates are rarely caught in a dredger sample. In order to obtain reliable information on bottom communities confined to boulders, rock scatterings and reefs, it is necessary to apply a comprehensive approach that includes not only sampling, but also geophysical and visual observation methods

Testing the methodology at the White Sea Biological Station

In 2016, Rosneft developed a methodology for mapping bottom communities using a combination of methods. It included traditional dredging benthic surveys, geophysical observations using a side-scan sonar, multibeam echo sounder and profiler, as well as visual observations from a remotely operated underwater vehicle which is lowered from a vessel, controlled by an operator and transmits an image of the seabed in real time.

Studies for the development of the methodology were conducted at the test site located in the Velikaya Salma Strait in the White Sea near the White Sea Biological Station of Lomonosov Moscow State University. The water area around the biological station is one of the most studied areas beyond the Arctic Circle.

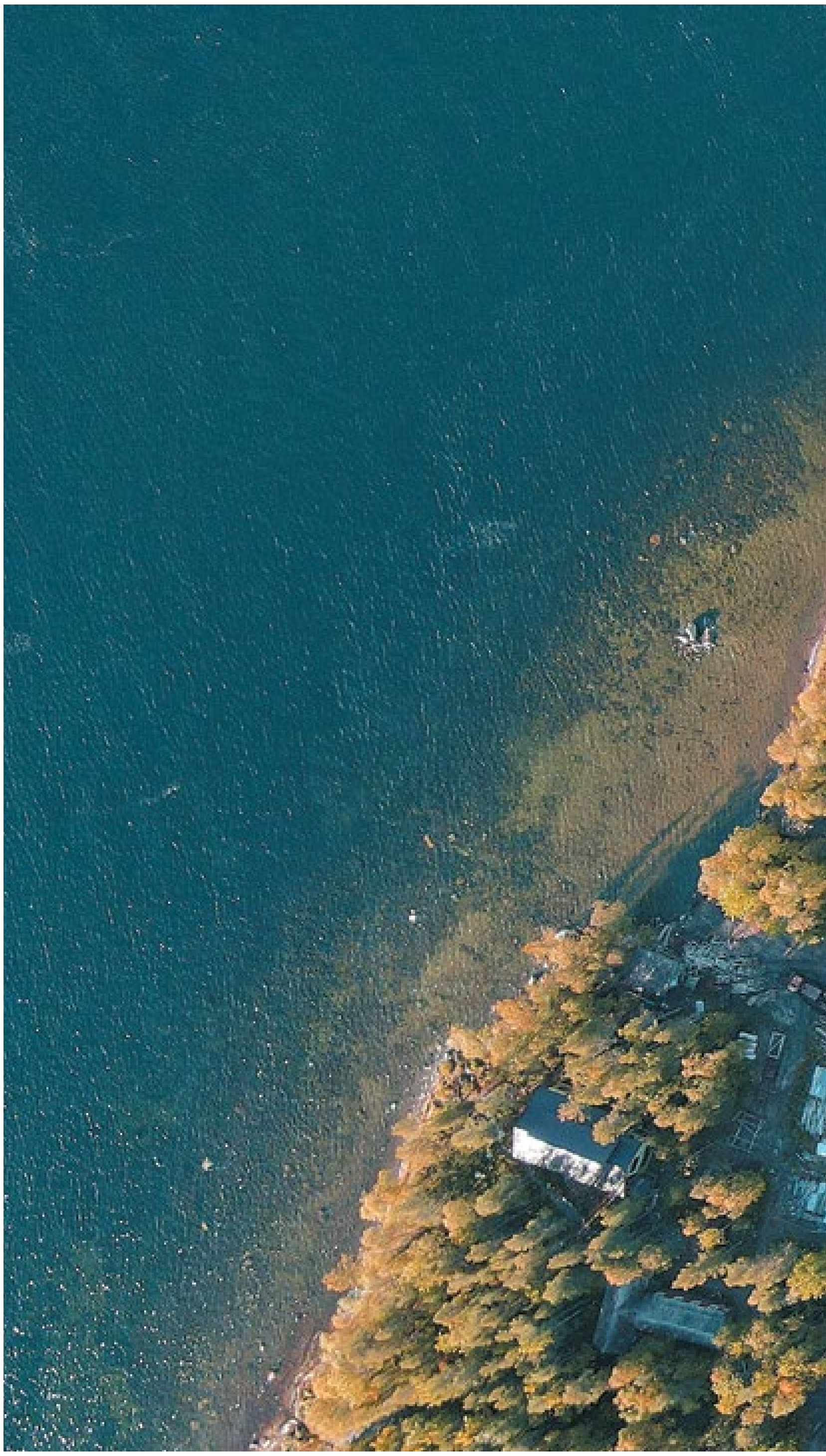
→ p. 195

The data obtained at benthic research stations was extrapolated to the bottom areas for which lithological characteristics and underwater topography obtained with a side-scan sonar and multibeam echo sounder are well known.

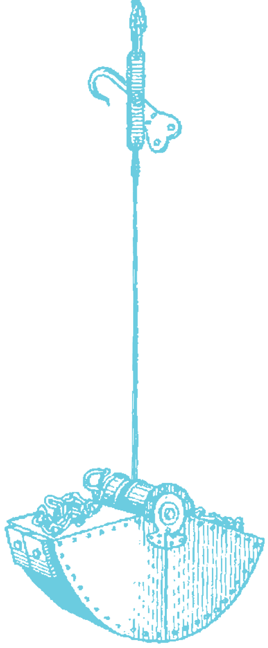
Complex analysis of side-scan sonar and multibeam echo sounder data allowed to identify areas of the bottom that are homogeneous in topography and sediments. The ROV data allowed to visually interpret and further characterize the obtained samples and supplement the description with information on the quantitative characteristics of benthos.

The combination of all three methods (side-scan sonar, multibeam echo sounder and unmanned vehicle observations) allows to not only plan a station grid in a rational and cost-effective way, but also to more completely characterize the fauna of bottom communities and effectively map highly mosaic bottom communities.

Remote acoustic methods were used, as recommended, prior to direct sampling, as acoustic differentiation of soils and identification of underwater mesorelief structures make it possible to select the most appropriate points for verification of remote data and detect areas where conditions are different from homogeneous.



White Sea Biological Station of Moscow State University, aerial photo



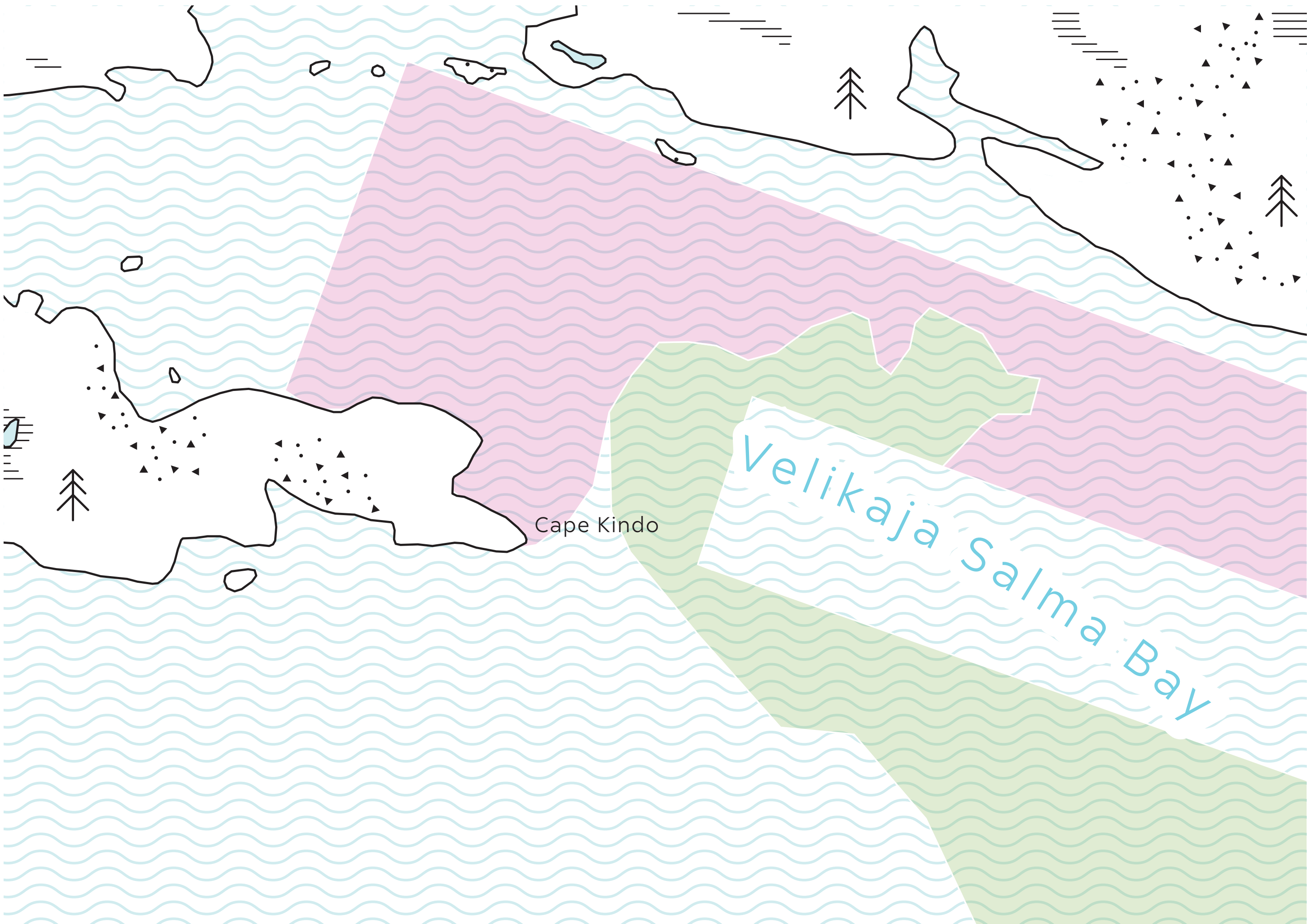
Progress of mapping results

This fragment of a map highlights two complexes of bottom communities. Data for the map was collected in 1953–1960 by qualitative (trawl) and quantitative (dredge) methods. → p. 204 Scientists noted the “extreme unreliability” of the dredge survey results in areas with strong currents and hard soils. Divers were involved in describing fauna of such areas in 1960.

The map was published in the paper “Bottom Fauna of Velikaya Salma and Adjacent Areas of the Kandalaksha Bay of the White Sea” by V. Brotskaya, N. Zhdanova and N. Semenova.

Map of distribution of bottom communities based on the results of the 1963 dredge survey

Astarte elliptica — Galathowenia oculata
Epifauna communities

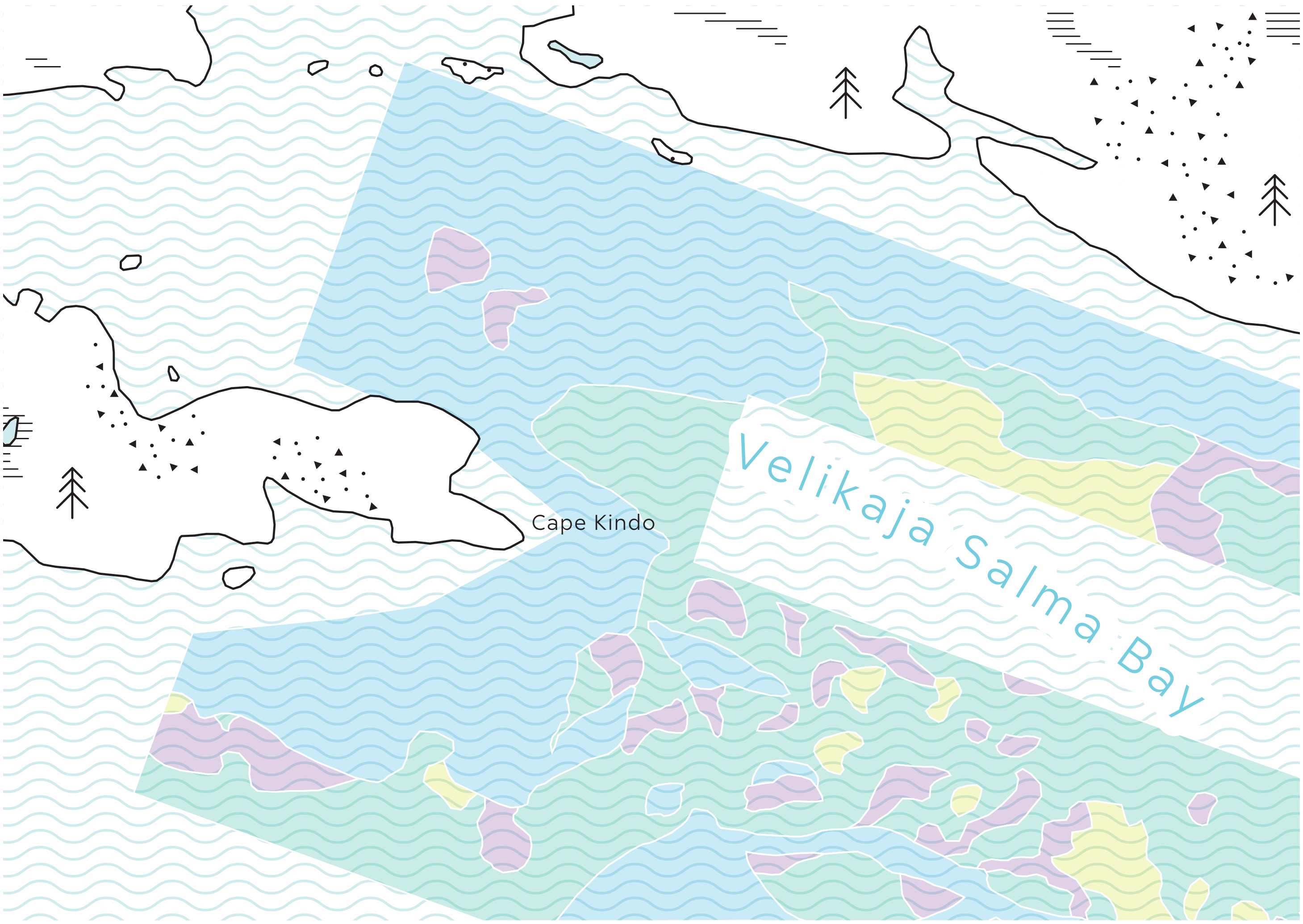


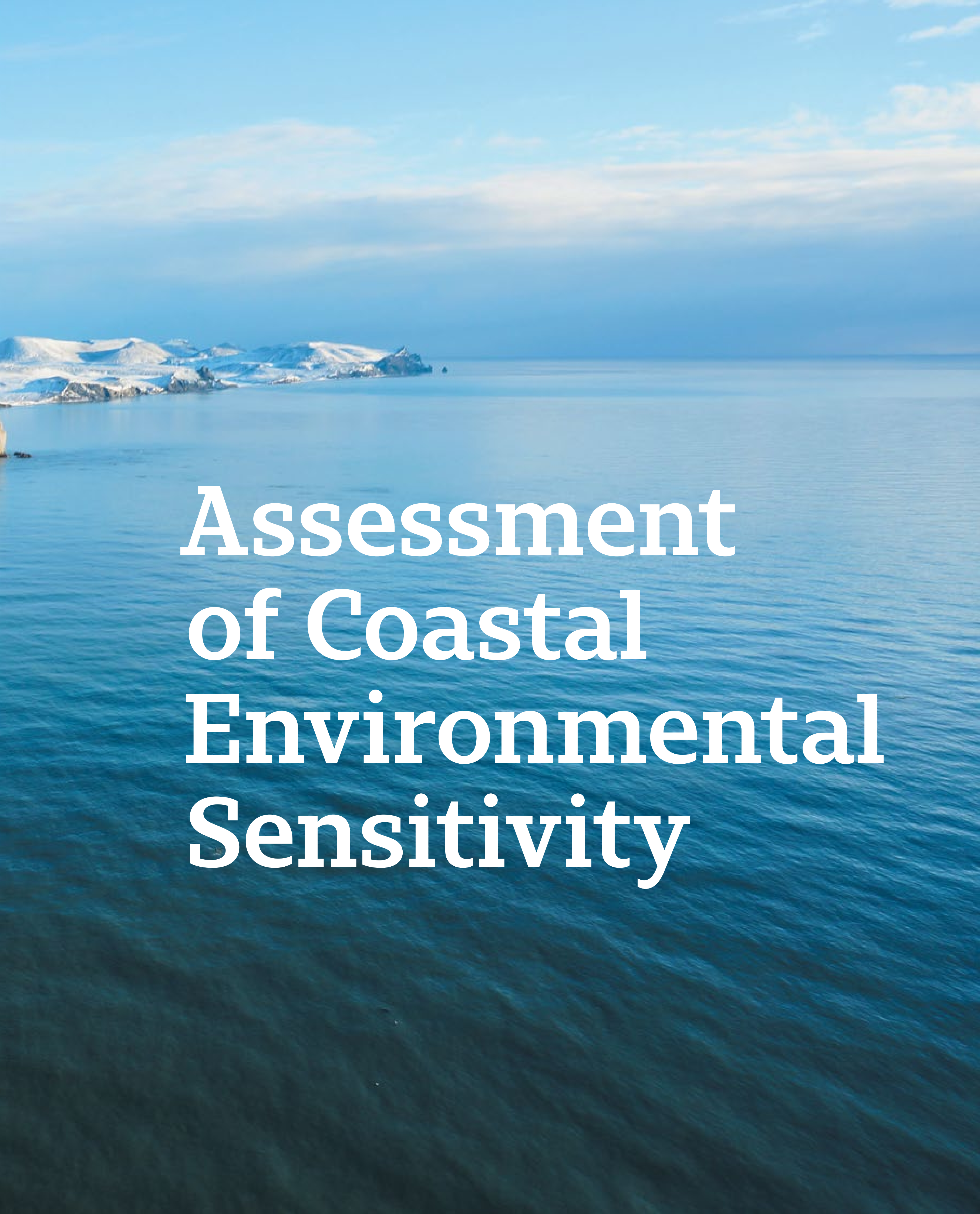
In 2016, a map predicting the distribution of bottom communities at the White Sea test site was created as a result of the development of the mapping methodology relying on data from traditional biological studies and remote geophysical data.

Four types of communities were identified in the studied area. Data from the survey conducted half a century ago using traditional methods was used for comparison. The new methodology allowed to reliably identify boundaries of communities on the map, including those belonging to rocky soils.

Map of distribution of bottom communities based on the results of the 2016 complex survey

- *Galathowenia oculata — Chaetozone setosa*
- *Macoma calcarea — Scoloplos acutus*
- Rocky soils with fauna represented by fouling organisms
- *Galathowenia oculata — Chaetozone setosa* communities assumed to be transitioning into the *Portlandia arctica* community





Assessment of Coastal Environmental Sensitivity

Assessment of coastal environmental sensitivity

What is environmental sensitivity?

Environmental sensitivity is the degree of vulnerability of seashores to the effects of human activities. In 1978, American scientists proposed the *Environmental Sensitivity Index* (ESI) which used field studies to identify 10 levels of environmental sensitivity and 25 types of coastlines, from tundra and Arctic to mangroves.

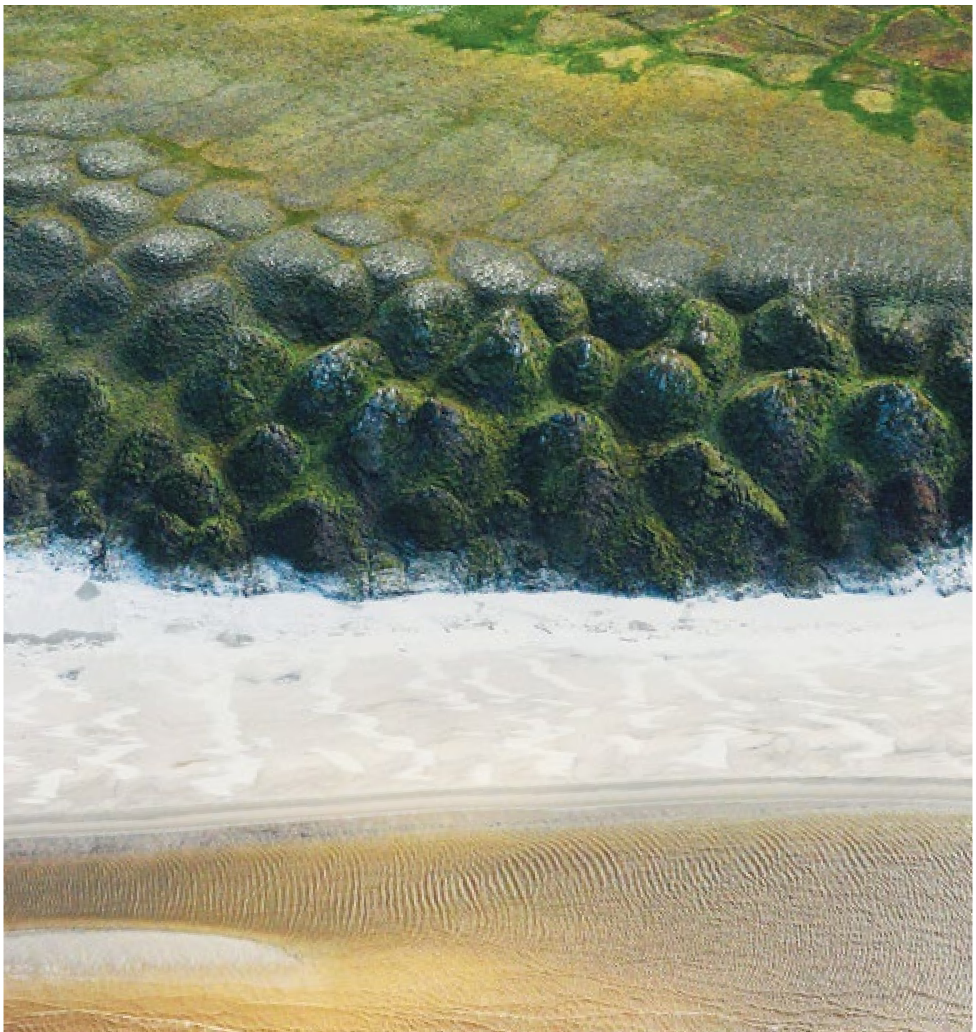
Coasts are heterogeneous: there are rocks, shoals, shallow marshy areas. Each type of coastline reacts differently to human presence and economic activity.

No matter what kind of expedition or project researchers prepare, it always begins and ends on the shore. In addition to the fact that the shore is the boundary between two biotopes that acts as a barrier to any pollution, the coastal zone has a great diversity of animal and bird species. That's why shorelines are studied just as detailed as the water area.

It is important to know which areas require priority attention, where to place materials and equipment and how to distribute efforts in case of unforeseen situations. To plan for all this, a coastal environmental sensitivity map is needed.

Zveroboy Island, Pyasina Bay, western coast of the Taymyr Peninsula

Yadareyakha River mouth area, western shore of the Yavay Peninsula, Gyda Peninsula



Environmental sensitivity map

Creating a map requires up-to-date information about the state of the coastal zone and its geomorphological characteristics. The source for such data can be satellite and aerial photography, field surveys and accumulated results of research in the region.

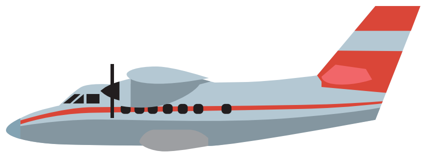
The more extensive economic and scientific activities are planned in the sea, the more detailed the map has to be. In the process of Arctic exploration, Rosneft has been preparing environmental sensitivity maps for the Barents, Kara and Laptev seas.

In 2013–2014, the most detailed maps at a scale of 1 : 200,000 were made for the Kara Sea. Satellite images, materials from field surveys on the coasts of the Yamal and Yugorsky Peninsulas and literature data were all used. However, the main mapping tool was aerial survey.

Geomorphology is the scientific study of the relief — irregularities on the Earth's surface — its appearance, origin, history of development, modern processes within it and patterns of its distribution.

The northern shore of Pestsovy Island, Plavnikovye Islands, western coast of the Taymyr Peninsula

Airborne laboratory



L-410 Nord laboratory aircraft is used for conducting research in challenging conditions of the Arctic region

Flight range: 1,800 km

Flight time: 6 hours

Flight altitude: 100–4,000 m

Speed: 230–300 km/h

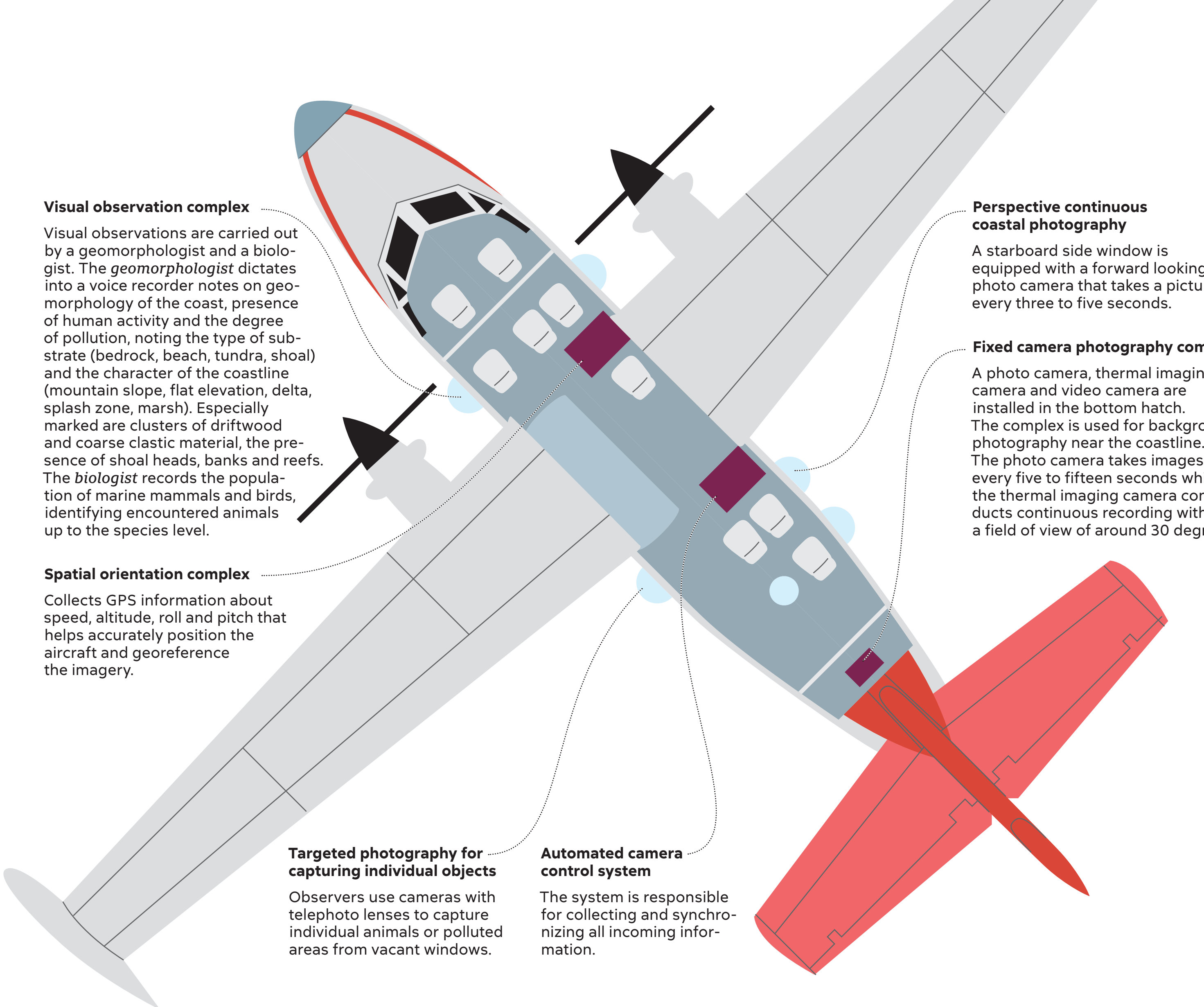
Onboard observers: 5

The L-410 Nord aircraft was chosen for conducting aerial surveys as it is suitable for working in the challenging conditions of the Arctic region. Especially important for the success of the survey are the long flight range, ability to install all necessary equipment and enough seats from which scientists can carry out handheld photography.

Algorithm of conducting an aerial survey

Choose a suitable airplane → Install surveying equipment → Create a flight plan → Fly the route and collect data → Desktop analysis: data processing and mapping

Moving at the speed of 230–300 km/h, the airplane travels along the coastline while photography is being carried out both by automatic cameras and manually by onboard observers through special convex windows. Six data gathering systems are operating throughout the flight.



According to the data from September 23 to October 4, 2014

In the air

9 flights

48 hours total flight time

12,945 km total flight distance

5,170 km in research mode

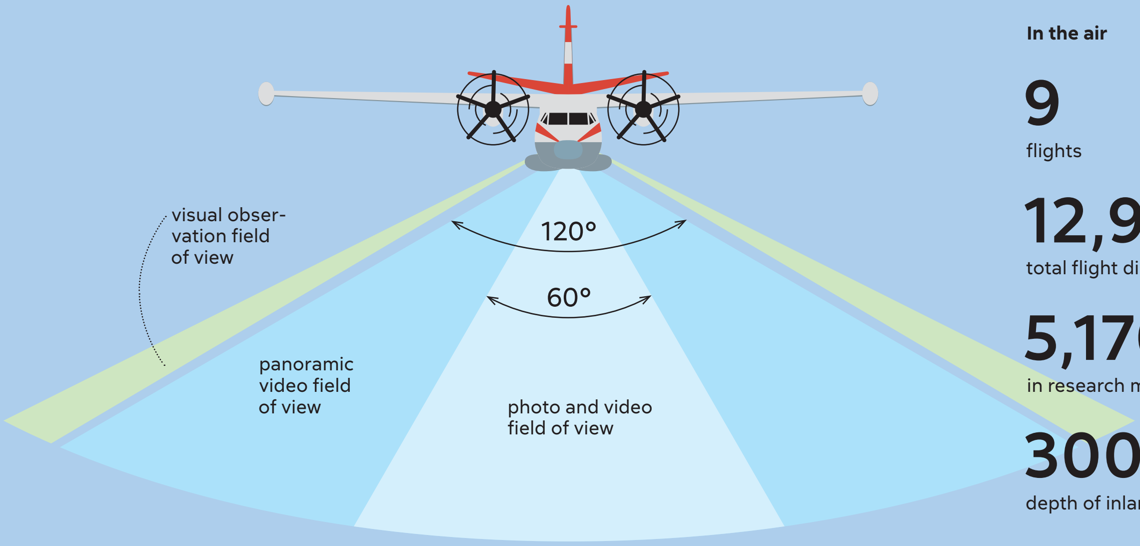
300 meters depth of inland description

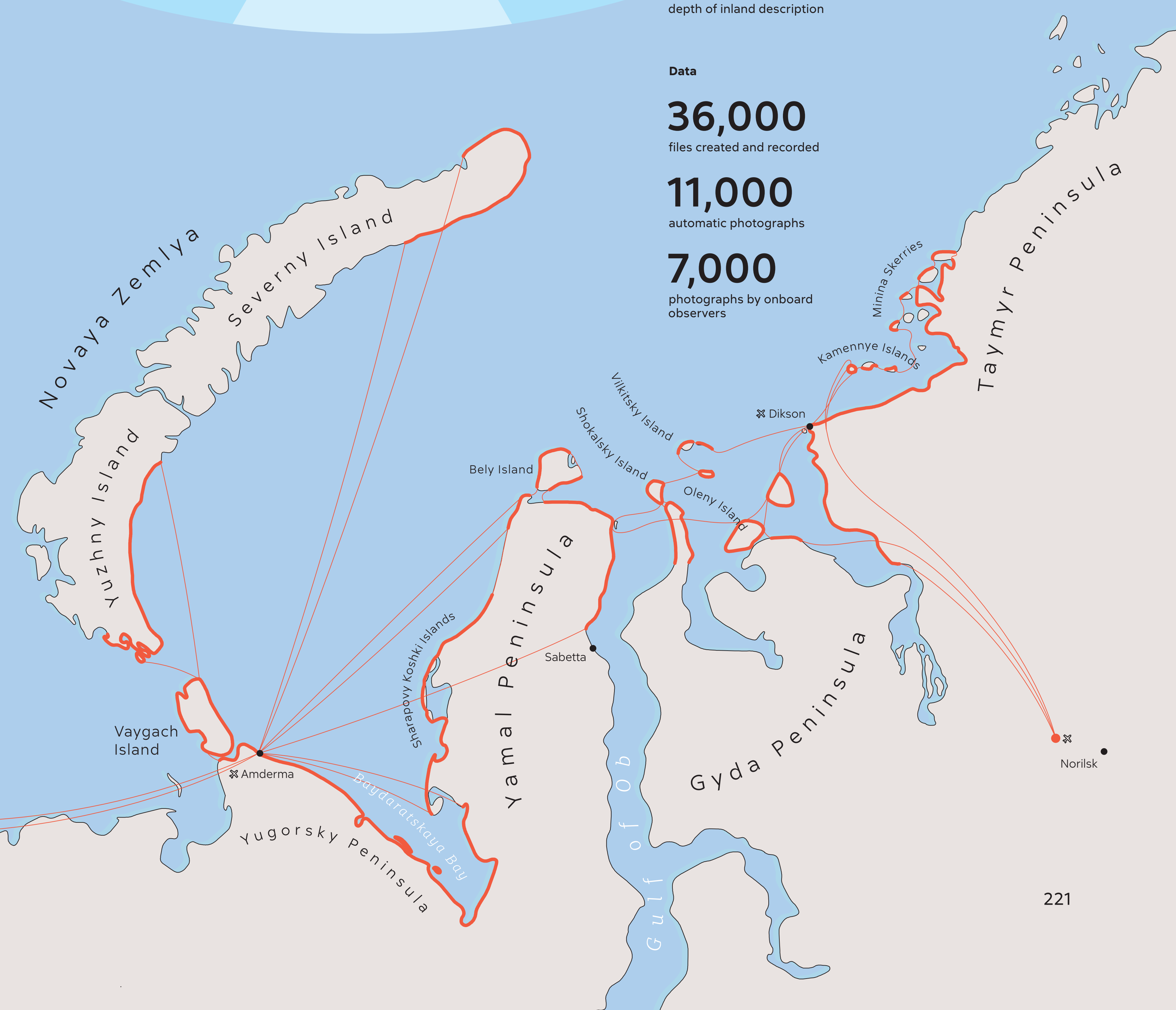
Data

36,000 files created and recorded

11,000 automatic photographs

7,000 photographs by onboard observers



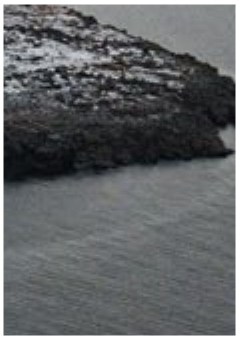


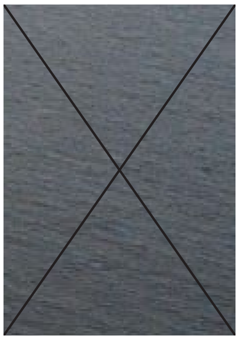
Aerial survey results of the Kara Sea in 2014

In order to obtain the raw data for the environmental sensitivity maps, the collected materials had to be analyzed. It was also necessary to process navigation data and create survey routes, decode images and audio recordings, describe the distribution of animals, pollution and other events along the flight route.

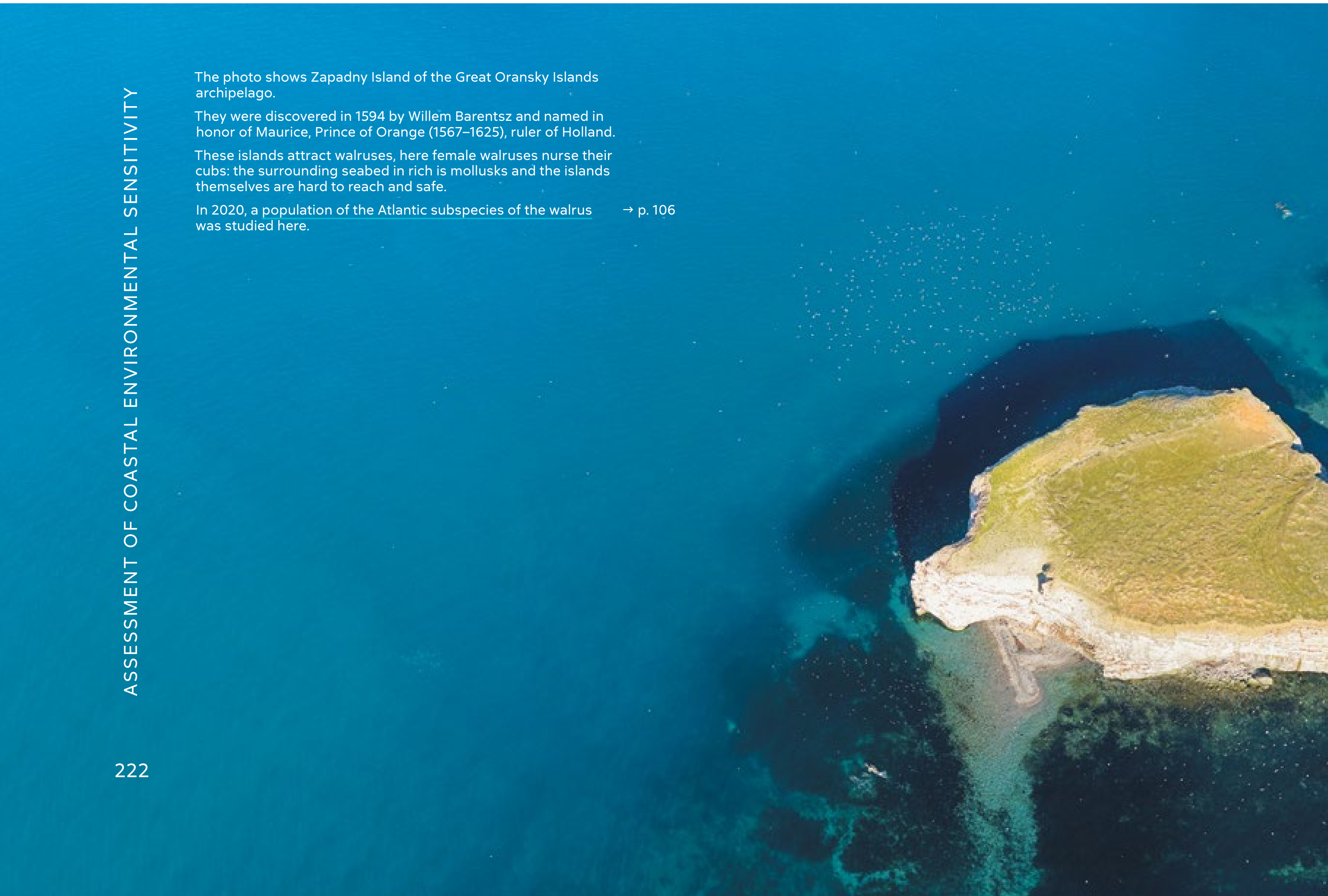
Photo selection criteria

The main source of information for creating maps are photos and videos. Researchers processed over 60,000 images from 2013 and 2014 using three criteria.





1. **Representativeness.** The photos must be representative of the coast. Photos that show only the water surface were eliminated.

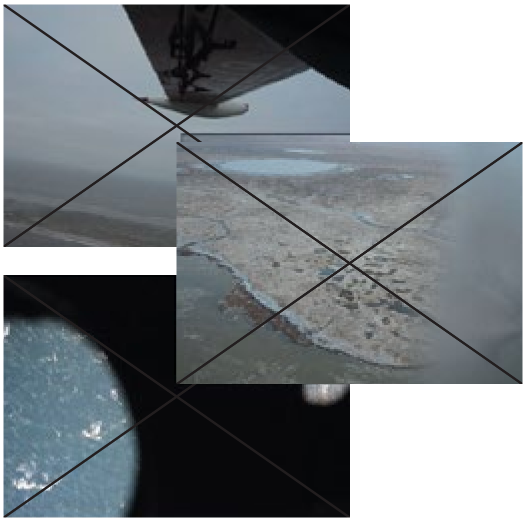


The photo shows Zapadny Island of the Great Oransky Islands archipelago.

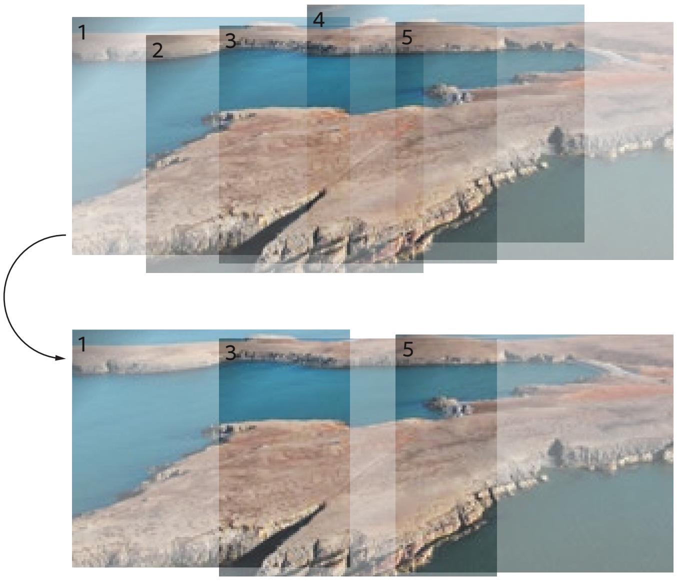
They were discovered in 1594 by Willem Barentsz and named in honor of Maurice, Prince of Orange (1567–1625), ruler of Holland.

These islands attract walruses, here female walruses nurse their cubs: the surrounding seabed in rich is mollusks and the islands themselves are hard to reach and safe.

In 2020, a population of the Atlantic subspecies of the walrus was studied here. → p. 106



2. **Quality.** Blurry, out-of-focus photos or photos with incorrect white balance were eliminated, as well as those where high cloud cover makes it difficult to see the relief.



3. **Sufficiency.** Photos shouldn’t repeat each other. Airplane maneuvers, terrain features and high frequency of photography lead to overlapping photographs. Series of photos were processed manually and duplicate images were eliminated.

Shore types of the Kara Sea

According to the international ESI system, coast classification takes into account coast exposition, the nature of the rock that makes up the coast, the hydrodynamic influence of waves and tides. For the Kara Sea, scientists used a specially adapted approach that takes into account the geocryological processes specific to the region, such as the presence and depth of permafrost.

Environmental Sensitivity Index system

ESI index and color code	Shore type	Тип берега
1A	Exposed rocky shore	Открытый скалистый берег
1B	Exposed, solid man-made structures	Открытый берег с прочными техногенными сооружениями
1C	Exposed rocky cliffs with boulder talus base	Открытые скалистые обрывы с валунно-глыбовой отмосткой
2A	Exposed wave-cut platforms in bedrock, mud or clay	Открытые волноприбойные платформы (бенчи), выработанные в коренных породах, глинистых и илистых отложениях
2B	Exposed scarps and steep slopes in clay	Открытые уступы и крутые склоны в глинистых отложениях
3A	Fine- to medium-grained sand beaches	Пляжи, сложенные мелко- и среднезернистым песком
3B	Scarps and steep slopes in sand	Уступы и крутые склоны в песчаных отложениях
4	Coarse grained sand beaches	Пляжи, сложенные крупнозернистым песком
5	Mixed sand and gravel beaches	Пляжи, сложенные смешанными песчано-гравийными отложениями
6A	Gravel beaches (granules and pebbles)	Галечные пляжи (гравий и галька)
6B	Riprap structures and gravel beaches (cobbles and boulders)	Искусственные каменные наброски и галечные пляжи (глыбы и валуны)
7	Exposed tidal flats (large sandy area often covered at high tide)	Открытые приливные отмели (большие песчаные площади, часто затопляемые при высоких приливах)
8A	Sheltered scarps in bedrock, mud or clay and sheltered rocky shore	Защищенные уступы в коренных породах, глинистых и илистых отложениях и защищенные скалистые берега
8B	Sheltered solid man-made structures (permeable)	Защищенные прочные техногенные сооружения (проницаемые)
8C	Sheltered riprap	Защищенные искусственные каменные наброски
8D	Sheltered rocky rubble shores	Защищенные скалистые крупнообломочные берега
8E	Peat shorelines	Торфяные берега
9A	Sheltered tidal flats	Защищенные приливные отмели
9B	Vegetated low banks	Покрытые растительностью банки
9C	Hypersaline tidal flats	Гипергалинные приливные отмели
10A	Salt and brackish water marshes	Соленые и опресненные марши
10B	Freshwater marshes	Пресноводные марши
10C	Swamp	Болота
10D	Mangroves	Мангровые заросли
10E	Inundated low-lying tundra	Пойменные (затапливаемые) низинные тундры

Steep rocky ledges of the Piritovy Peninsula, Yuzhny Island, Novaya Zemlya archipelago

Abrasion ledge with a boulder and clay scarp in the area of Cape Perovsky, Yuzhny Island, Novaya Zemlya archipelago

Abrasion platform developed in bedrock, Great Oransky Islands archipelago

At the first stage of creating maps, morphodynamic zoning of the coasts is performed. The coastal zone is divided into sections, then each section is assigned an environmental sensitivity index according to the ESI system and taking into account the interaction of oil with various types of sediments that weaken the coastline.

A total of 12 types of shores were identified that were named by adapting the names from the international system to the regional conditions. Indices in the table are given in order of increasing sensitivity, from 1 to 10.

Leveled shore with a beach and tidal draining on the west coast of the Yamal Peninsula

Abrasion shore with a gravel beach in the Zapadnoe Golomno Bay, Bereg Petra Chichagova

Thermal denudation shore, eastern shore of the Yavay Peninsula

Abrasion and thermal denudation shore with a retreating ledge in sandy sediments, eastern shore of the Yugorsky Peninsula

Low thermal denudation shore, Vilkitsky Island

Sheltered shallow shore with extensive drainages, eastern shore of Shokalsky Island

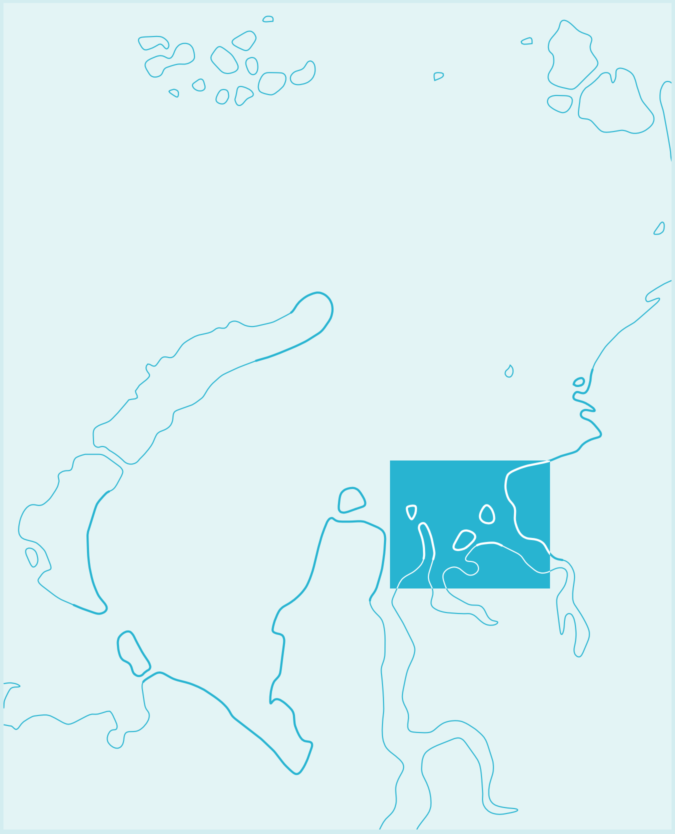
Accumulative shore with a beach on the western shore of Bolshoy Island, Arctic Institute Islands

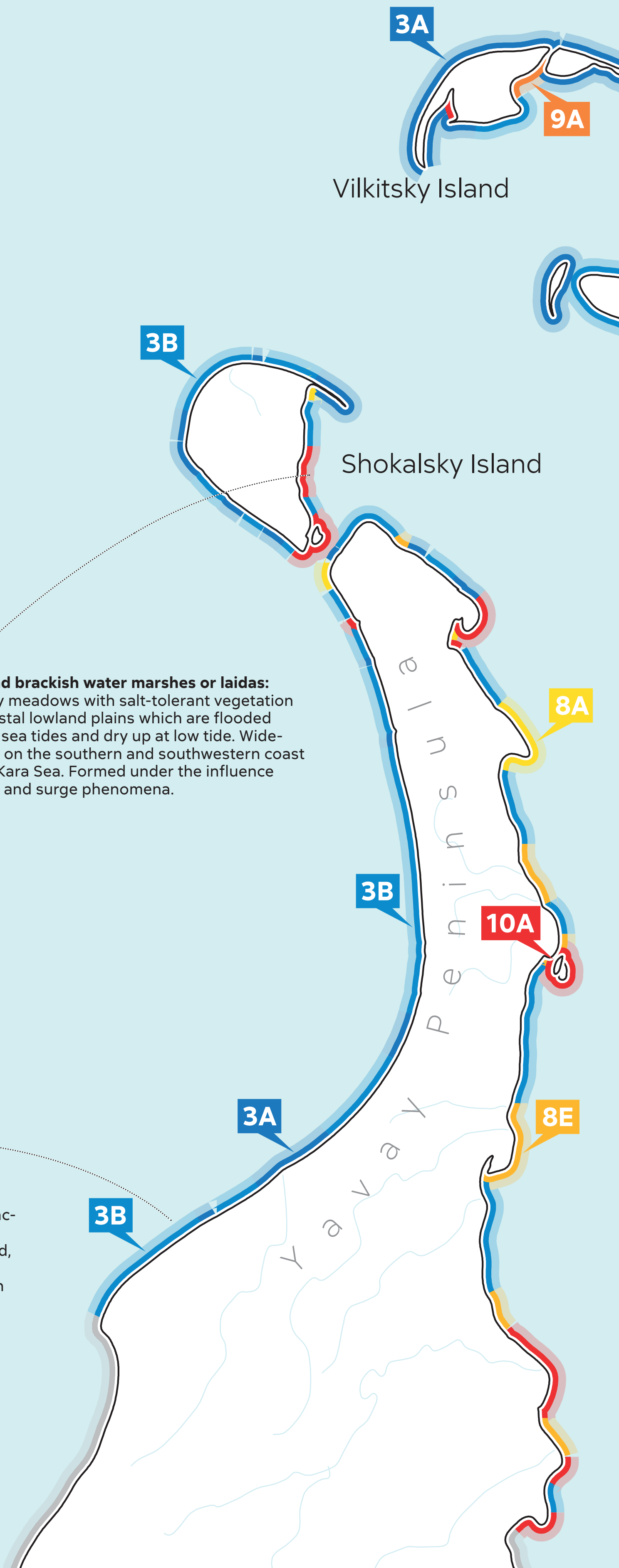
Abrasion and thermal denudation scarp near Cape Kuznetsovsky, eastern shore of the Yenisey Gulf

Laida surface on a shallow shore, Preobrazheniya Bay, Yamal Peninsula

Environmental sensitivity map

As a result, environmental sensitivity maps were created for the southwestern part of the Kara Sea based on direct visual observations.





10A

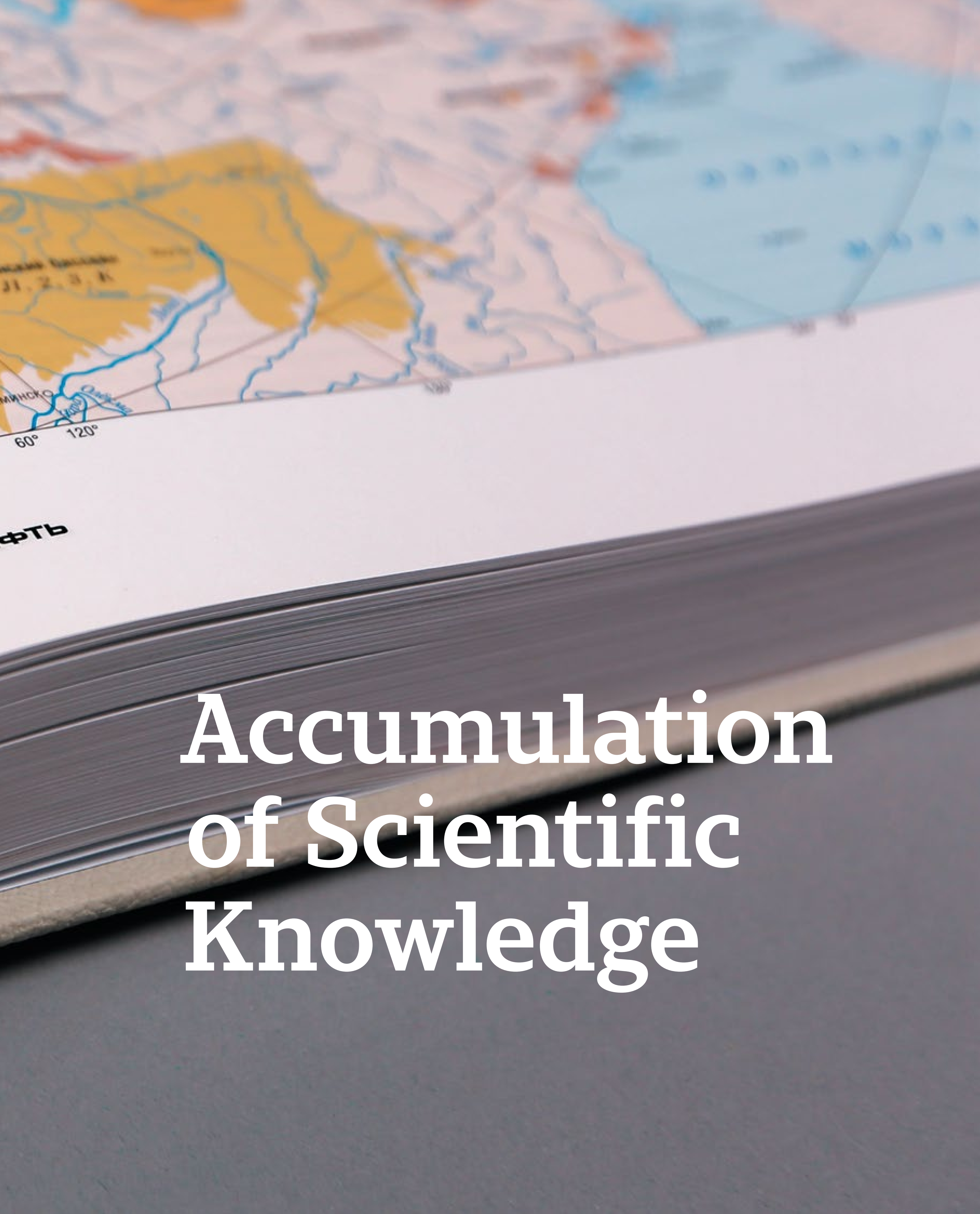
Salt and brackish water marshes or laidas: marshy meadows with salt-tolerant vegetation on coastal lowland plains which are flooded during sea tides and dry up at low tide. Widespread on the southern and southwestern coast of the Kara Sea. Formed under the influence of tidal and surge phenomena.

3B

The southern and southwestern parts of the Kara Sea are characterized by **scarps and steep slopes in sandy sediments**. They are formed when permafrost, from which the coast is composed, is destroyed. Destruction occurs when it is thawed and eroded by waves. The average speed of destruction and retreat of such shores is from 0.5 to 2–4 meters per year.


Kara Sea
Dikson Island
Dikson
Bereg Petra Chichagova
Taymyr Peninsula
1C
6A
1A
1A
Exposed rocky shores are characterized by a sharp underwater slope and the absence of a beach, so that waves act directly on the shore scarp, doing most of the work of chipping away boulders and destroying the scarp further.
Neupokoev Island
Sibiryakov Island
3B
8A
8A
8D
5
Mixed sand and gravel beaches can be formed on abrasion and accumulative landforms, i. e. their sediments can be taken from an eroding cliff or be brought in by the wave and tidal phenomena.
3B
3A
Oleny Island
3A
3B
Yenisei Gulf
5
3B
Oleny Island
Yuratski Bay
Mamonta Peninsula
Gydan Bay
8D
Sheltered rocky rubble shores develop under conditions of low wave exposure. Because of this, the clastic material remains unsorted and extremely heterogeneous in its composition.


Нижняя Тунгуска
Тура
Учами
Подкаменная Тунгуска
Чуня
Таймура
Вилюйское
вдхр.
Чона
Мирный
100°
110°



Accumulation of Scientific Knowledge

Atlases

Contrary to the popular opinion, an atlas is not simply a collection of maps and descriptions of animals or plants or their mechanical combination into one album. It is a systematic, programmatic collection of materials, designed as a coherent product.

Scientists use atlases as overview reference material that gathers information about various characteristics of one object. For example, to compile the section on macrozoobenthos of the Barents Sea, 226 sources were used, including atlases published from 1804 to 2020.

→ p. 37

For Rosneft, the creation of atlases is a contribution to accumulation and systematization of scientific knowledge and a way to open up access to the results of the company's ecological research.

Interconnection of projects

→ p. 222

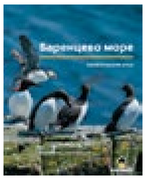
In 2014, Rosneft carried out a project to map the Kara Sea coastal zone and determine environmental sensitivity of its coasts. Desktop analysis of materials was not limited to the results of aerial surveys of the coasts. Researchers brought in data on hydrometeorology, hydrochemistry, composition of sediments, descriptions of flora and fauna of the Kara Sea from microalgae and land plants to fishes and marine mammals. It turned out that the amount analytical work done was so great, that it closed major gaps in systematized data on the current state of the Arctic seas. That's when the idea to create a series of ecological atlases was born.

The first ecological atlas of Rosneft was published in 2016 and was devoted to the Kara Sea. It is based on the data on the state of marine ecosystems obtained from scientific publications and monographs, as well as Rosneft's own data acquired from aerial surveys, comprehensive scientific expeditions and environmental studies in licensed areas.

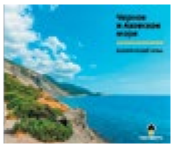
The next year after the publication of the ecological atlas of the Kara Sea, similar work was done for the Laptev Sea. The second atlas followed the same principles of structuring material as the first publication. By this time, plans emerged to prepare atlases for all seas of the Russian Arctic which fall into the area of the company's research interests.

Structure of the 2016–2017 atlases

1. History of the water area research.
2. Physical, geographic and oceanographic characteristics of the sea.
3. Description of the biological diversity of flora and fauna.
4. Anthropogenic load on water areas and coastal zones.
5. Estimation of environmental sensitivity of the coasts.



Ecological atlas. Barents Sea



Ecological atlas. Black and Azov Seas

Biological indicators of the state of Arctic marine ecosystems

Not only sea atlases

→ p. 68

Since 2014, Rosneft has been observing sea birds and mammals around the clock during comprehensive scientific expeditions and geological exploration activities. By 2016, more than 900 days worth of observations have been accumulated, 10,000 marine mammals have been registered, and a significant amount of data on the polar bear and walrus population in the seas of the Russian Arctic has been collected.

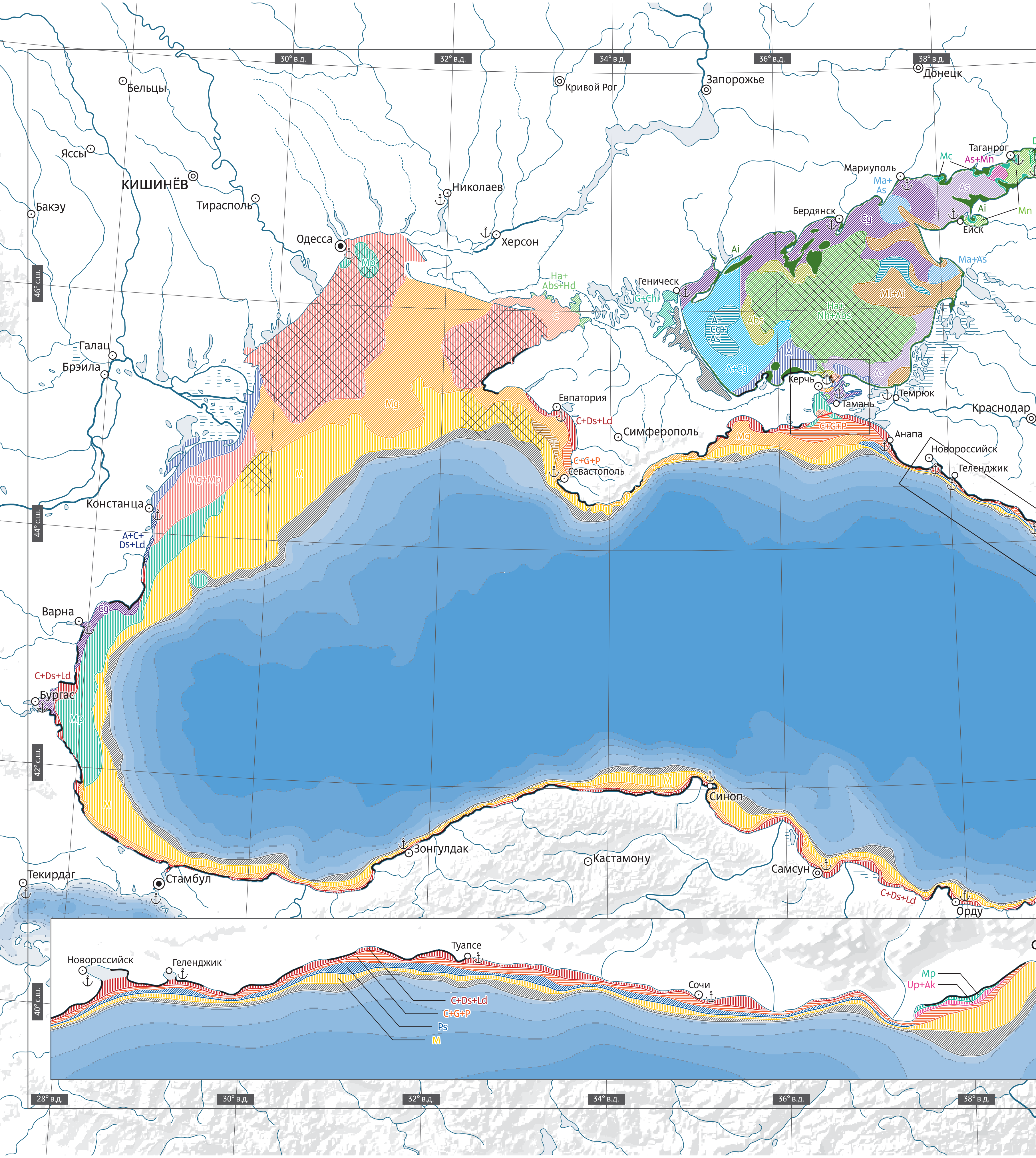
Accumulation of data opens up the possibility and requirement for its systematization, so in 2017 Rosneft prepared and published the atlas “Marine Mammals of the Russian Arctic and the Far East”. This publication is structured fundamentally differently from ecological atlases of the seas. It is a catalog of marine mammal species which can be found in the Arctic and the Far Eastern seas of Russia. Each species is discussed in a separate essay that describes appearance of the animal, gives modern data on population structure, migrations and abundance, current conservation status and a map of distribution. The species information is preceded by a description of the Arctic and Far Eastern seas as habitats for these animals. Much attention is paid to biological illustrations which not only accompany the text but also explain the identifying features of the species.

As new information was accumulated, the series of publications continued in 2020 with an atlas of biological indicators. The next publication devoted to fauna is an atlas of sea birds of the Russian Arctic.

→ p. 72

Based on the results of metocean expeditions, in 2015, the Arctic Research Center published an atlas of metocean and ice conditions of the Russian Arctic. It contains a summary of archive materials and expedition research conducted in 2012–2014.

In 2019, the atlas “Russian Arctic. Space, Time, Resources” was published in cooperation with Innopraktika. The publication is the result of many years of work by over 140 authors, cartographers and illustrators. The centerpiece of the book is the description of the natural environment and resources of the Arctic, although it also covers the history, culture, ethnography, economy, social sphere, infrastructure and development opportunities of the polar regions.



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Евпатория
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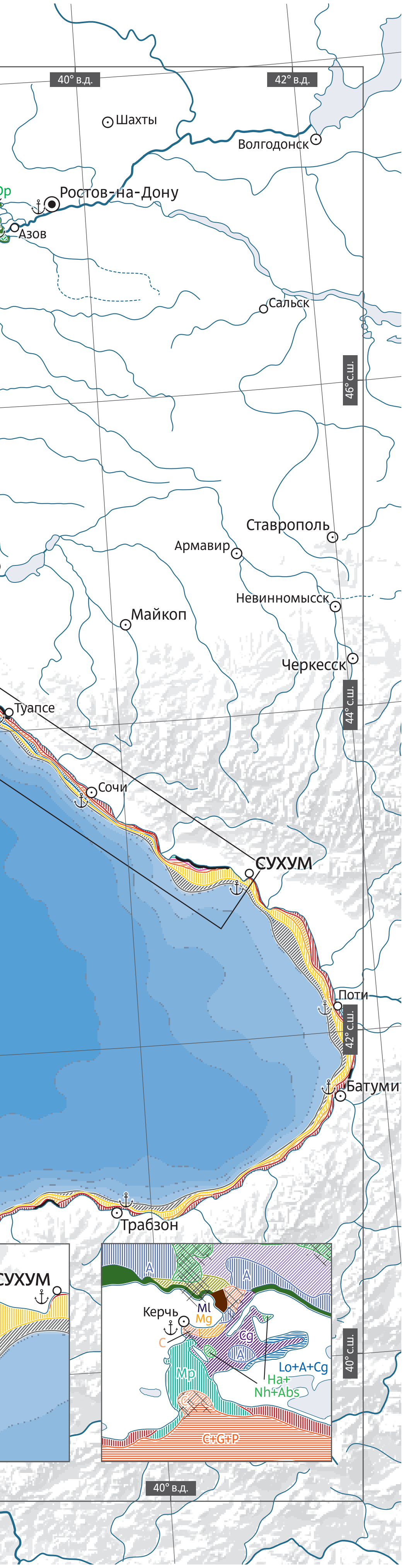


Map of bottom communities distribution from the ecological atlas of the Black and Azov Seas (2019)

Not only the Arctic

In 2019, the geography of publications was expanded. Rosneft published an ecological atlas of the Black and Azov Seas, and the series changed its name from “Atlases of the Russian Arctic Seas” to “Ecological Atlases of the Russian Seas”. The new atlas is in many ways unique in the series, and not only because of its geographical coverage. A team of over fifty scientists, cartographers and publishing specialists worked on the book. It also contains one of the most complex maps in the entire series, the map of the bottom communities of the Black Sea.

→ p. 203

Bottom communities of the Black Sea

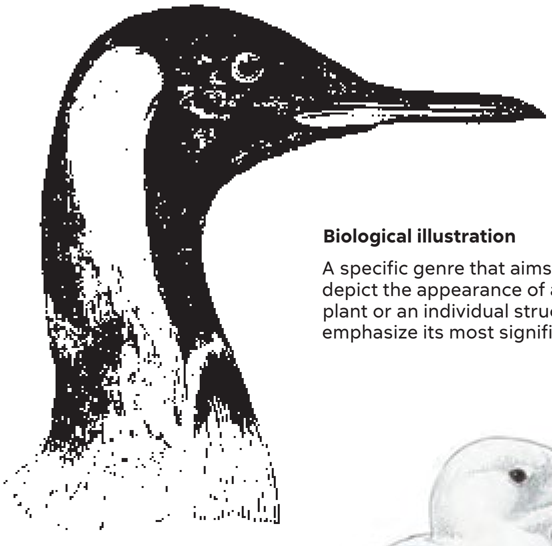
Because of the sharply outlined basin and a layer of water with increased content of poisonous hydrogen sulfide that starts at the depth of 50 meters, only a narrow part of the Black Sea coastline on the Caucasian coast is inhabited by bottom communities. On the map, this strip ends up being only a few millimeters wide, yet it has to clearly show the boundaries of individual communities.

Environmental sensitivity without aerial surveys

The final chapter of each of the ecological atlases of the seas contains a description of the coasts and environmental sensitivity maps. Earlier we mentioned that aerial survey data that produced a large amount of photos and videos was used for the Kara Sea atlas. For subsequent atlases, no such materials on coastal typification existed, yet it was still possible to construct the maps.

→ p. 222
→ p. 230

In the case of the well-studied coasts of the Black and Azov seas, numerous photographs of the coastline and unmanned aerial vehicle images were used. For the less accessible Laptev and Barents seas, cartographic, satellite and archive data was used, as well as photo and video materials from scientific and tourist expeditions of different years.

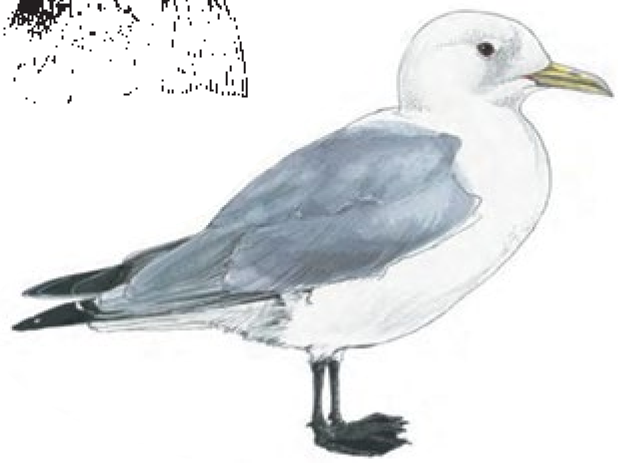


Modern biological illustration

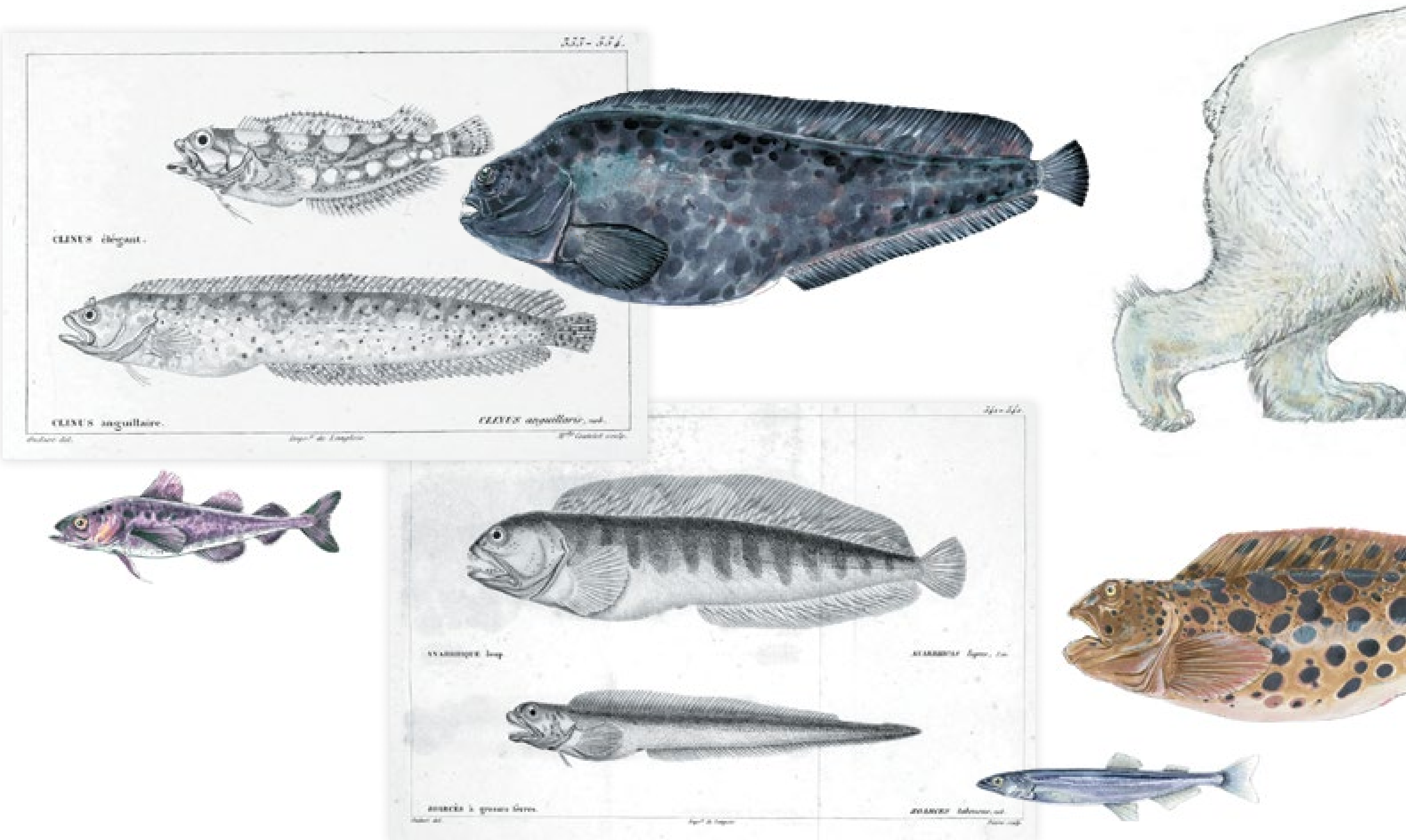
For publications on flora and fauna, biological illustrations have historically been the only way to visualize the material. One of the first known illustrated manuscripts containing biological drawings is the work of the ancient Greek physician, pharmacologist and naturalist Dioscorides "On Medicinal Products". The most famous of the "reprints" of the manuscript is the 6th-century "Vienna Dioscorides" which contains more than 400 illustrations of plants and animals that were used for practical species identification.

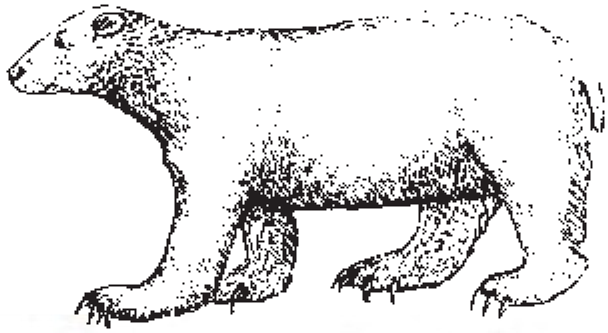
Biological illustration

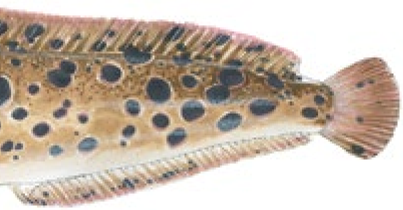
A specific genre that aims to not only depict the appearance of an animal, plant or an individual structure, but to emphasize its most significant details.



Traditional biological illustrations are done with ink and watercolor. The drawings are meticulously elaborated and the artist may work on each one for weeks or sometimes months. When preparing illustrations for Rosneft's ecological atlases, modern tools and materials have been used, including liners, alcohol markers for color, white ink for shades and highlights. The result is bright, memorable illustrations that combine an innovative approach with the traditions of scientific drawing.







Paper cartography in the digital world

Printed atlas cartography is a traditional means of collecting and systematizing data. However, nowadays most maps that scientists use for applied research are digital. Compared to paper atlases, digital sources have the advantage of mobility, yet they also have their limitations: using geographic information systems and digital maps requires knowledge and skill.

An atlas is much more democratic in this respect, which makes it suitable for a wider readership. All materials in Rosneft's atlases are supplemented with descriptions and intuitive visualization tools and are prepared using the most up-to-date digital maps at the time of publication.

The books have not only a scientific function, but also a reference and an educational one. They are useful to students and specialists interested in the study and practical use of the natural resources of Russia's seas. Scientists use them for scientific research. Decision makers rely on them for making management decisions on the sustainable use of natural resources and conservation of the region's wildlife.

Conclusion

Over the 10 years in the Arctic, Rosneft has managed to combine fundamental scientific research with applied offshore development projects. Ten years may not be a long time for science, but it makes the achievements that have been made all the more valuable:

— studying the geological structure of the Western and Eastern Arctic;
— collecting data on key bioindicator species;
— conducting multi-year and year-round metocean and ice studies;
— using mathematical modeling to reconstruct the parameters of metocean conditions in the Arctic seas over the last 50 years;
— creating area maps of the offshore of the Arctic seas to ensure drilling safety;
— developing a microbial preparation for cleaning marine systems and creating a technological form for its effective delivery;
— building maps of environmental sensitivity of sea shores.

And this list is far from exhaustive.

This information will not only become the foundation for further Arctic research, but will also greatly accelerate the development of economic infrastructure.

In addition to being used within the company, the findings will also be published in scientific articles and atlases. This means they will serve the purpose of accumulating global knowledge, in accordance with the modern, open approach to science.

It would be hard to mention everyone who helped create this book. In addition to the authors, the book was prepared with the help of leaders and experts of Innopraktika, the Geography, Geology and Biology Departments of Lomonosov Moscow State University, Rosgeologiya, Far Eastern Federal University, Siberian Federal University, the Arctic and Antarctic Research Institute, the Severtsov Institute of Ecology and Evolution of the Russian Academy of Sciences, the Shirshov Institute of Oceanology, the Lomonosov Moscow State University Marine Research Center, Zvezda, heads and employees of departments of Rosneft and its subsidiaries (Arctic Research Center, RN-Shelf-Arktika, RN-Exploration, Vostsibneftegaz, Sapphire Applied Engineering and Training Center and others), as well as experts in various research fields.

We thank all those who answered the author's questions, read and commented on drafts of the chapters, shared photographic and illustration materials, participated in and led Arctic research projects. We thank Art. Lebedev Studio for the way this book looks and for the new level of expression that the story of scientific projects has gained.

Thank you for your contributions. We consider every one of you a co-author of this book!

Scientific publication
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10 years of exploring the unique region

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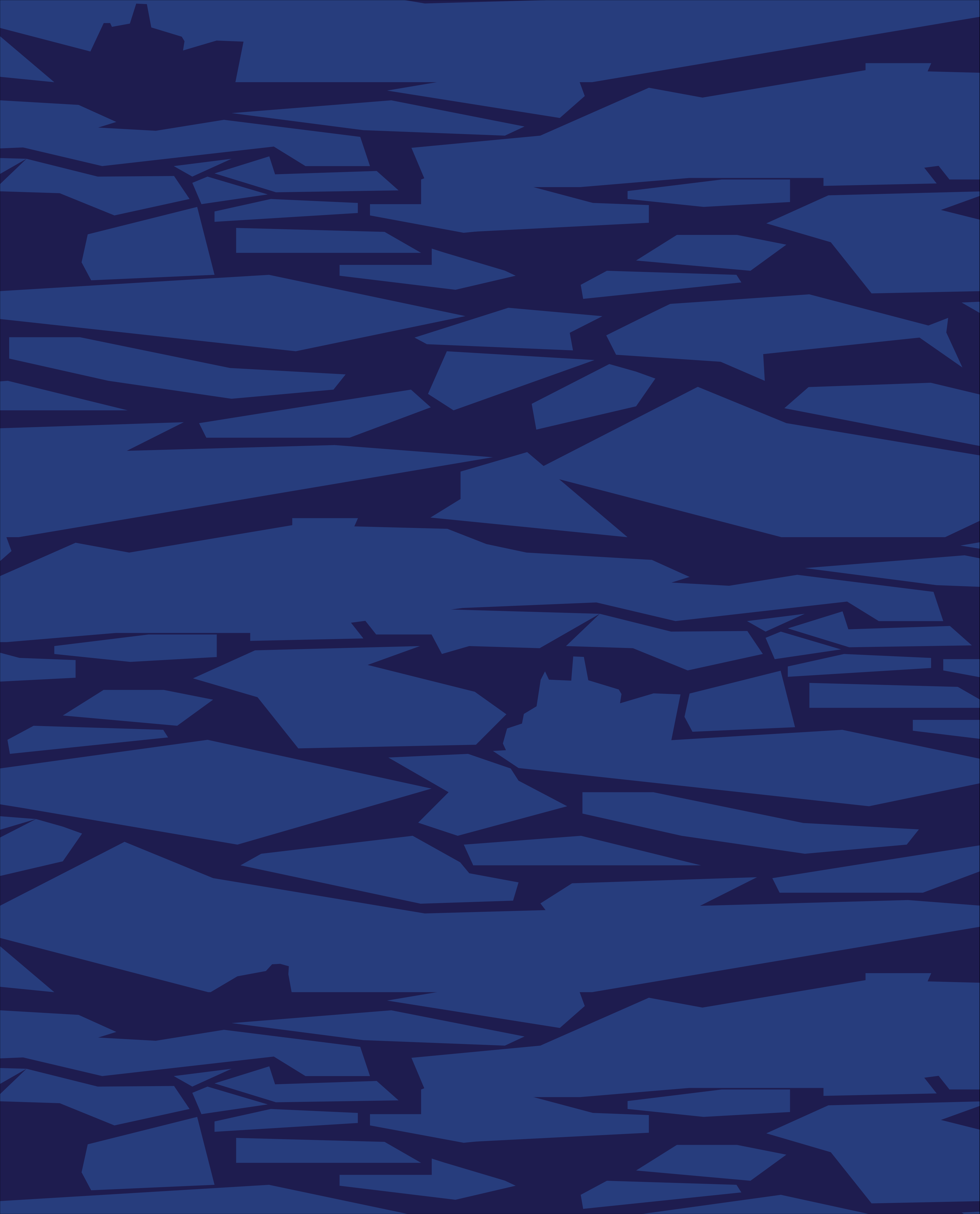


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