

FROM ARCTIDA to the present-day ARCTIC

*The Arctic Ocean
through the eyes of a geologist*

*“The Northern ocean, by the way, is a spacious field
where Russian glory can grow, combined
with an unprecedented benefit...”*

Mikhail V. Lomonosov

With an area of about 15 million km², the Arctic Ocean is the smallest and the youngest of the Earth's oceans. Its main specificity is that most of the ocean floor is occupied by a continental shelf (over 45%) and offshore continental margins. An increasing interest in the Arctic Ocean is primarily accounted for by geopolitical issues and challenges of managing mineral resources on the Arctic shelf, as well as by environment related problems, climate changes, and permafrost degradation.

Solving these problems largely relies on our knowledge of the geological structure of the Arctic Ocean basement, including the structural features of the Arctic sedimentary basins with respect to their oil and gas potential. Geological knowledge also provides substantial insights into the correlation between continental margins, including submerged shelves, and different structures largely characterized by terrain features of the Earth's crust but lying at a considerable distance from the mainland, which appears vital in solving the problem of establishing the outer limits of Russia's and other Arctic states' sectors of the continental shelf



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THREE THOUSAND KILOMETERS ACCROSS TAIMYR PENINSULA

*“There are cherished places in endmost lands of the earth...”
(from a poem by Lana Grig)*

The author of this article is familiar with the Arctic firsthand. While a student, back in 1974, he made his first trip to the Chelyuskin peninsula during his summer practice work and learned his lessons in the geology of the Arctic Region from the geological routes on the shores of the Kara and Laptev Seas, under the supervision of I.D. and A.L. Zabiaka, both having a Cand.Sci. degree in geology and mineralogy and a wealth of practical experience. Many interesting facts about the geology of the Arctic he learned from the lectures of the famous polar geologist, professor L.V. Makhlaev. And then he, in his own words, was lucky enough to be engaged for four decades in the geological research and studies of a sparsely populated part of our planet with an extremely harsh climate. The field practice of a graduate student made the beginning of almost yearly Arctic expeditions, in which he took part first as a young professional, and later in the capacity of a Candidate and Doctor of Sciences. Valery Vernikovskii prepared his Cand.Sci. thesis under the supervision of a renowned geologist N.L. Dobretsov. It was dedicated to the role of metamorphism in ore-grade gold mineralization of the northeast Taimyr, while his Dr.Sci. research focused on the geodynamic evolution of Taimyr and its relationship with other ancient blocks in the Arctic. The works have attracted attention of many outstanding

scientists, true experts in the Arctic geology: V. E. Khain, N. A. Bogdanov, L. P. Zonenshain, and L. M. Natapov, which resulted, eventually, in the joint development and publication of geological and tectonic maps of the Arctic region and scientific articles. The part of life spent together with his colleagues in the tents next to glaciers have cumulatively added up to several years, and records on their walking routes across the Taimyr Peninsula alone exceeded three thousand kilometers! In those years, vehicles used to be simple, not very fast, but reliable. Geologists had all-terrain vehicles to navigate through the Taimyr tundra, and inflatable boats to they used to float along the rivers and across the lakes.

The onset of the era of helicopters commenced only in the late 1990s; it first became popular with the international expeditions with the participation of several dozen researchers from different countries. In recent years, apart from the helicopters, Arctic geologists have been using not only but ice-breakers and even submarines! Today, they have at their disposal completely different technical capabilities, fundamentally new methods and technologies for data analyses. And only the Arctic as it is - an unforgettable land of contrasts - has remained the same ...

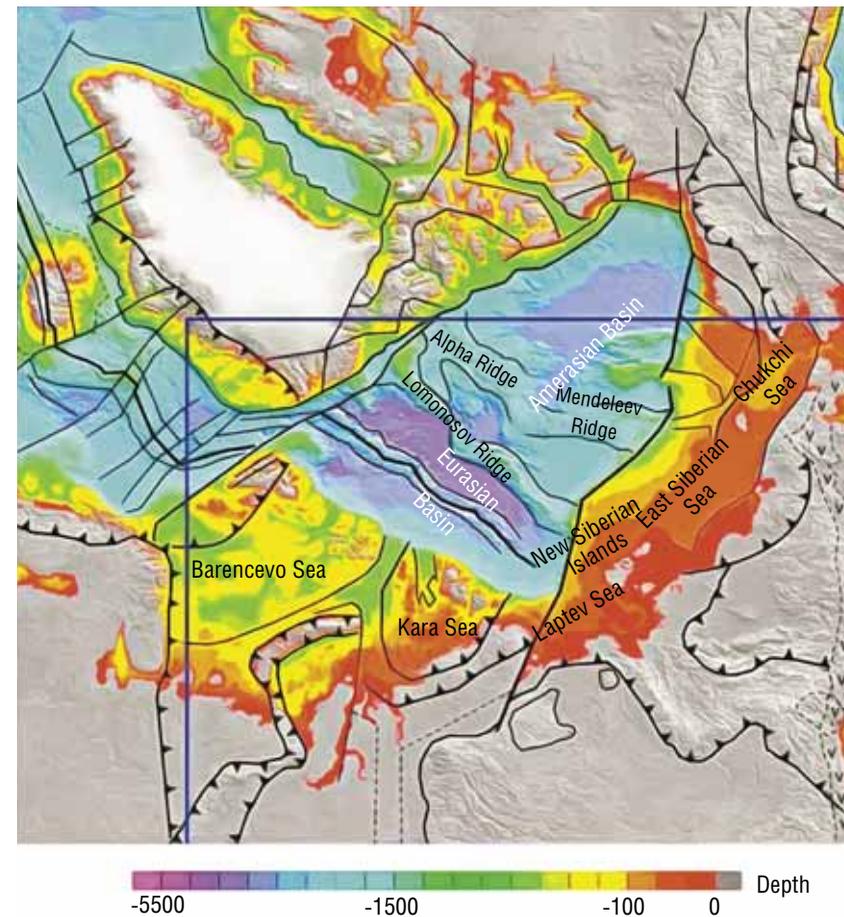
ATVs (first GAZ-47, and then the GAZ-71) would help the geologists to navigate through the Taimyr tundra.
From the author's archive



Valery Vernikovskii in a field camp on the Leningradskaya River. Taimyr, 1981

The geology of the Arctic region and its “cold heart,” the Arctic Ocean, has long appealed to Russian scientists. The increased geological knowledge and geophysical data accumulated over the past decades, along with the application of innovative analytic techniques, has resulted in the generation of new geological and tectonic maps, geodynamic models, paleo-tectonic reconstructions, providing novel insights into the geological history and tectonic evolution of this region.

The Novosibirsk center for paleomagnetic studies with cryogenic



magnetometer has greatly facilitated works on paleotectonic reconstructions and geodynamic models. The scientists can now determine the direction of the ancient natural remanent magnetization (NRM) of rocks, their paleomagnetic poles position and, given that the age of rock is known, identify the positional relationship of the continents and individual terranes (fairly large crustal blocks bounded by faults).

In particular, paleomagnetic data collected during the field studies on the Severnaya Zemlya archipelago provided novel evidence consistent with the tectonic and geodynamic reconstructions, those built earlier relying on structural and geochronological data (Vernikovskii, 1996), and revealed the kinematics (motion) of the Kara microcontinent

and its collision with the Siberian paleocontinent (Metelkin *et al.*, 2005).

Today, it has been ascertained that the Arctic Ocean continues to change in size, which is related to both the configuration of the surrounding paleocontinents and its geographical position on the globe. In this context, in the Silurian-Devonian (430-400 million years ago), the configuration of the ocean space between Baltica (East European Platform), Laurentia (North American Craton) and Siberia in many ways resembled the present-day delineation of the Arctic Ocean, the only difference being its location on the equator! Now it becomes apparent why Early Silurian thermophilic corals, known to have formed 430 million years ago, were found on Koteln Island (the New

The Arctic Ocean is the youngest, the smallest (about 15 million km²) in size, and the shallowest ocean on the Earth. Most of its seafloor is the shelf (over 50%) and continental margin.

Here and below the maps are adapted from IBCAO (International Bathymetric Chart of the Arctic Ocean) Version 2.23 (<http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/>)

Siberian Islands, 76° N) in the habitat conditions similar to those presently characteristic of the Australian Great Barrier Reef!

In search of Arctida

The existence of the ancient Precambrian continent, often called Arctida, has been inferred by many researchers studying geological structures in the Arctic (Zonenshain, Natapov 1987). The paleocontinent breakup resulted from rifting processes, while its individual plates and terranes either became subsequently overlain by the sediments transported from the continental margins and ocean, or were accreted to the fold belts along the ocean's periphery (on the Taimyr Peninsula, in Chukotka, Alaska, etc.). It stands to reason that the Kara microcontinent is but one of the fragments of the paleocontinent.

In order to develop more detailed kinematic models and paleotectonic reconstructions, it is required to utilize the wealth of paleomagnetic database for the entire Arctic region. In recent years, the researchers from the A.A.Trofimuk Institute of Petroleum Geology and Geophysics (IPGG) SB RAS (Novosibirsk)



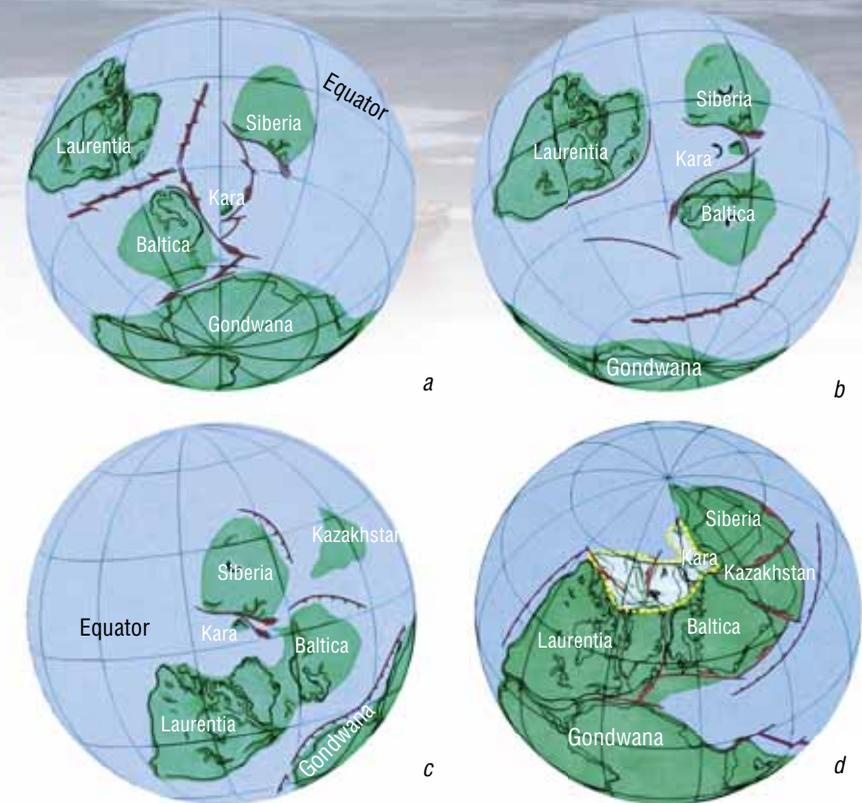


The route plan of the diesel-electric ship *Mikhail Somov* (Expedition 2011) with stopping points for geological research and targeted sampling



The paleomagnetic data obtained during expeditions on the Severnaya Zemlya archipelago supported the paleogeographic reconstruction of the Kara microcontinent motion in relation to other paleocontinents in the Paleozoic:

- (a) Cambrian Ordovician (510–480 Myr ago);
- (b) Late Ordovician (465–440 Myr ago);
- (c) Silurian-Devonian (430–400 Myr ago);
- (d) Permian (280–260 Myr ago)



and Novosibirsk State University (NSU) have been able to obtain new paleomagnetic and geochronological data on the igneous and sedimentary rocks of the Severnaya Zemlya and Novaya Zemlya archipelagos, Franz Josef Land, De Long archipelago, New Siberian Islands, and Taimyr Peninsula and contiguous areas.

These data were collected, in particular, during the unique international expeditions organized in 2011 and 2013 by the A. P. Karpinsky All-Russian Geological Research Institute, VSEGEI (St. Petersburg), with the use of the diesel-electric ship *Mikhail Somov* with an Mi-8 helicopter onboard. The integrated geological and geophysical studies were successfully carried out on the New Siberian Islands, including the De Long archipelago.

The new paleomagnetic data obtained for this region by a team from the IPGG SB RAS laboratory for geodynamics and paleomagnetism suggest that the rocks composing the area have been developing on the uniform Precambrian basement within

Unique finds on the Kotelny Island (New Siberian Islands): early Silurian corals existent there about 400 Myr ago, are the paleontological evidence of the continents drift in the geological history of the Earth (right)

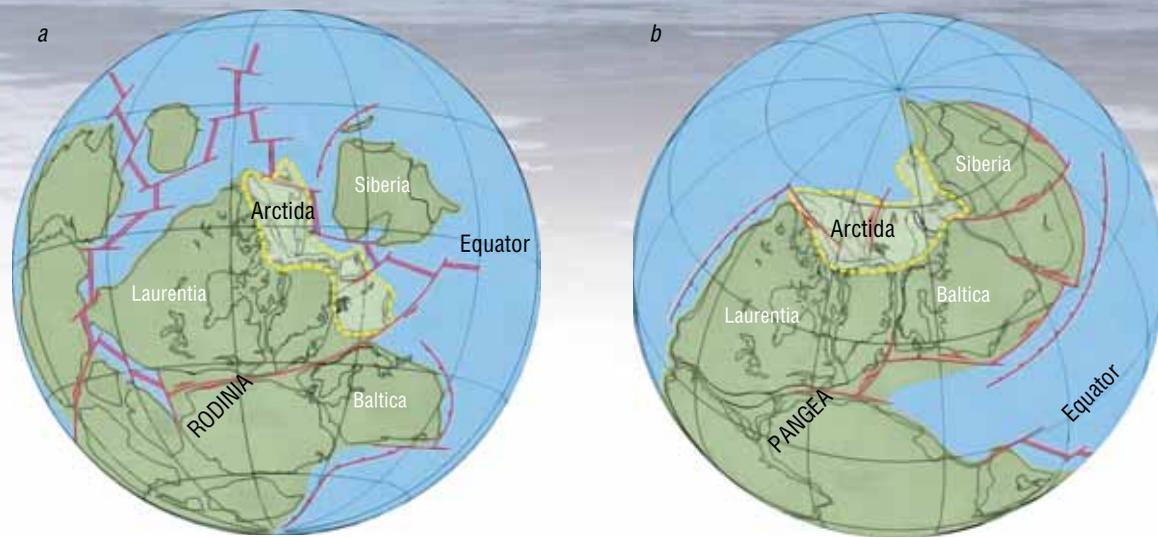
the bounds of the New Siberian terrane since, at least, the early Ordovician (early Paleozoic) (Vernikovskiy *et al.*, 2013).

Using these data in combination with the key paleo-poles data for the circum Arctic Ocean margins made up by Laurentia (North America), Baltica (Eastern Europe) and Siberia has allowed for plate tectonic reconstructions that represent a record of positions of the

continents and terranes amalgamated into the Arctida paleocontinent in the late Precambrian–late Paleozoic time period between 950–250 million years.

The illustration represents only two of the 14 reconstructions that match the configuration of the Arctida blocks existent 950 and 250 million years ago. During the time period spanning from Rodinia to Pangea supercontinents, Arctida is known to have changed its





Over the time period of 700 Myr Arctida, originally accreted to Rodinia supercontinent (950 Myr ago; a) and then to the supercontinent Pangea (250 Myr ago; b), changed its configuration and latitudes, but retained its position between Laurentia, Baltica, and Siberia paleocontinents.

Adapted from: (Metelkin et al., 2015)

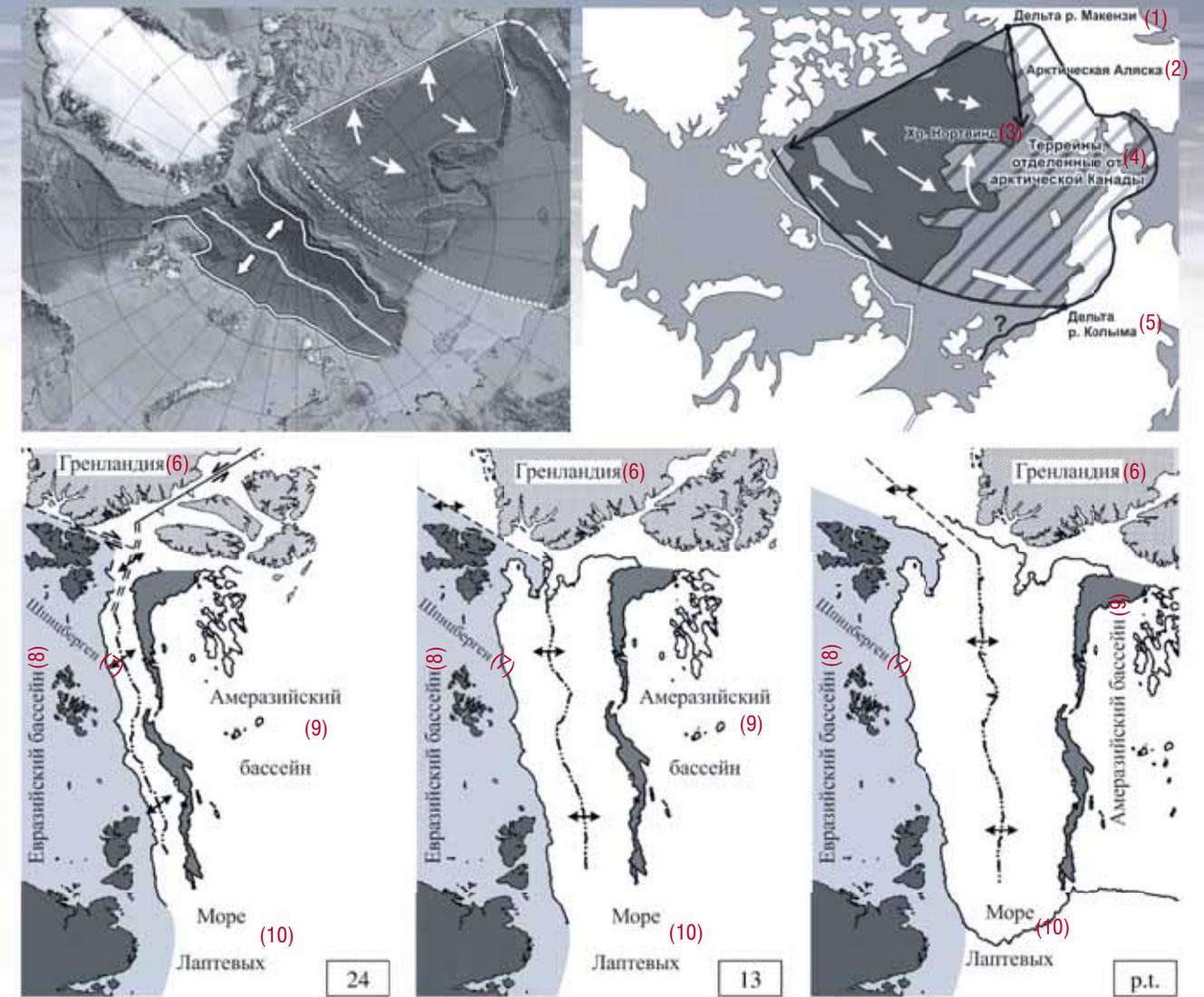
The expedition participants studying the section and samples from the Bennett island (De Long archipelago).
Photo by the author

configuration, and its latitudes shifted from the equatorial to the near-polar domain, though the landmass placement between Laurentia, Baltica and Siberia persisted.

Thus, the completion of the major processes of the Arctic continental accretion proved coeval with the formation of Arctida II and supercontinent Pangea 250 million years ago, which was followed by the Jurassic-Cretaceous rifting. This stage is particularly associated with the onset of the formation of present-day Eurasian continental margin.

The process was triggered by the Chukchi-North Alaskan microplate breakup from the North American Craton, which led to the formation of the Canada Basin in the Arctic Ocean 140–120 million years ago, then followed by the closure of the South Anyui paleocean, and, subsequently, by the fold-and-thrust belts developing in the direction from the New Siberian Islands through Chukotka and as far as the Brooks Range mountains in Alaska.

Concurrently, the seafloor spreading ceased in the Canada Basin and the spreading centers began their motion from the Atlantic to the Arctic Ocean. The process was accompanied, first, by some blocks rifting off the Alpha–Mendeleev rise and then, 55–54 million years ago, by the continental blocks of the



Map Legend: 1 – Mackenzie River Delta; 2 – Arctic Alaska; 3 – Northwind Ridge; 4 – terranes separated from Arctic Canada; 5 – Kolyma River Delta; 6 – Greenland; 7 – Svalbard; 8 – Eurasian Basin; 9 – Amerasian Basin; 10 – Laptev Sea

Lomonosov Ridge, from the Barents-Kara continental margin due to the changing spreading zone and opening of the Eurasian Basin.

The incremented shelf to add value

The continental origin of the Lomonosov Ridge has hardly stirred any disputes lately, as there is lots of evidence supporting this assumption, including data obtained from drilling the area by American geologists in 2004, while with regards to the Mendeleev Ridge opinions still differ.

As is known, in December 2001, Russia made an official submission into the UN Commission on the Limits of the Continental Shelf, with a proposal to extend the Russian continental shelf area from the baseline of the Exclusive Economic Zone beyond 200 nautical miles (nmi), comprising most of the Lomonosov Ridge, Podvodnikov Basin, Mendeleev rise and, partly, the Makarov basin.

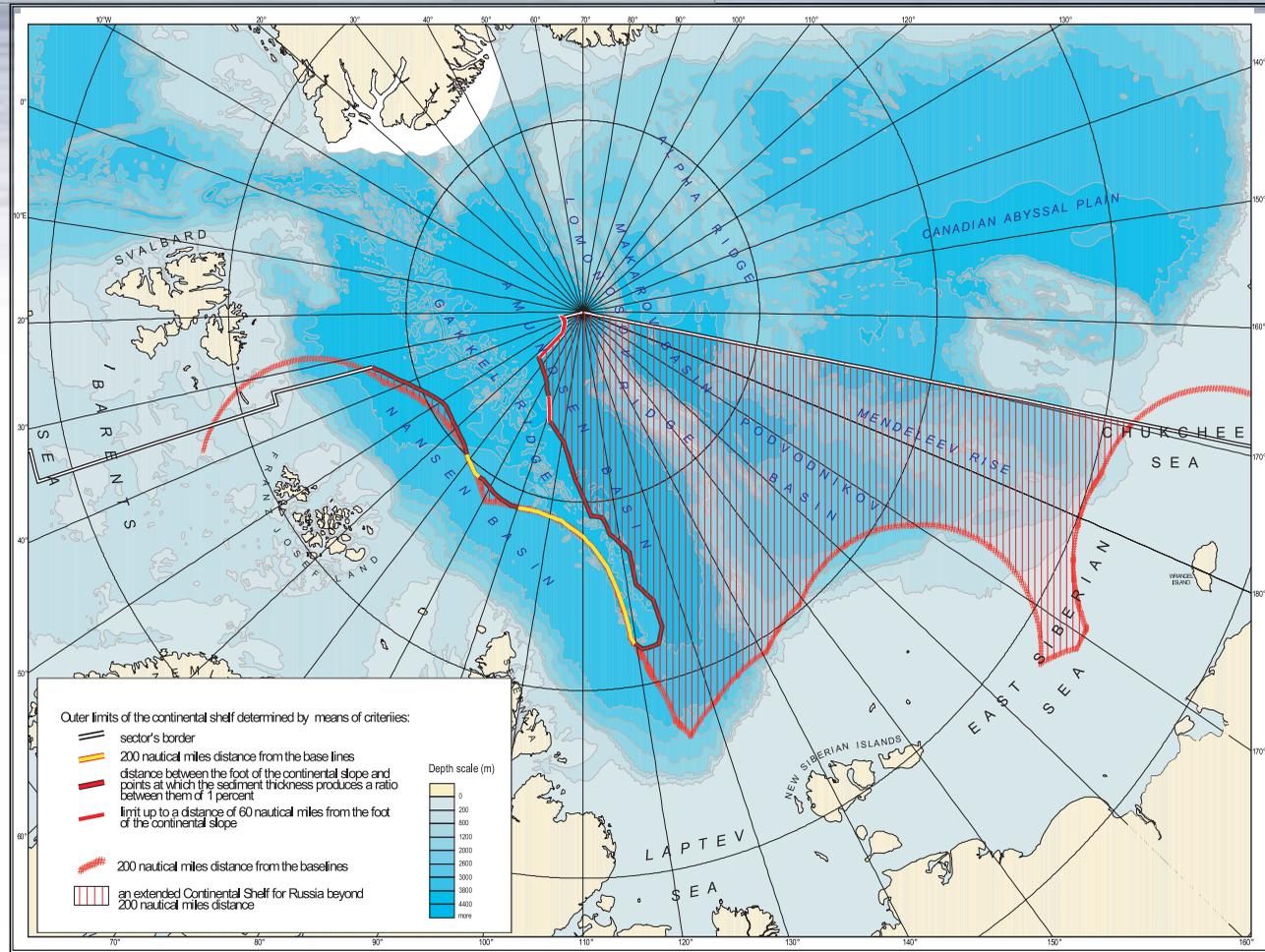
The restrictive criterion of 350 nautical miles from the baseline, contained in paragraph 5, Art. 76 of the UN Convention on the Law of the Sea 1982 was not applied therewith, though. This was done on the basis

Models of the opening of the Amerasian (Canada) (140–120 Myr ago) and the Eurasian (55–0 Myr ago) basins in the Arctic. Adapted from: (Grantz et al., 1998; Glebovskii et al., 2006)

of para. 6 of the same article, which states that the 350 nautical miles limit does not apply to submarine elevations that are natural components of the continental margin, such as plateaux, rises, caps, banks and spurs (Continental shelf limits, 2000).

However, the UN Commission rejected Russia's claim, with the statement predicated on the assumption





This is how the bathymetric map shows the area of Russia's extended continental shelf in the Arctic, including the Lomonosov and Mendeleev Ridges

that the Mendeleev Rise is a volcanic structure sitting on the ocean crust of plume nature, while the Lomonosov Ridge being a separate ridge was subject to the distance limit of 350 nautical miles, and thus, narrowing the potential area of the legitimate Russian shelf area in the Arctic to the lowermost limit.

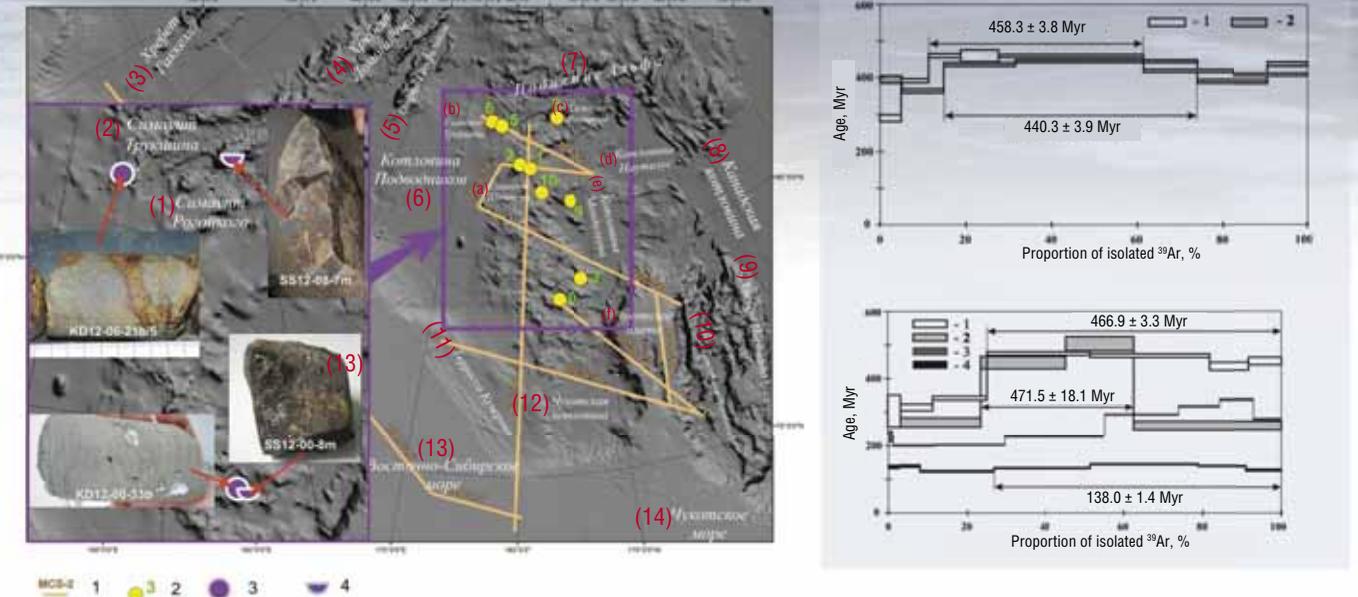
In order to study in detail the geological structure of the Mendeleev Ridge and the surrounding crustal blocks, Rosnedra oil company and its affiliate organizations (VSEGEI, VNIIOkeangeologia, Sevmorgeo *et al.*), conducted a high-latitude expedition using the research vessels and icebreakers, with the participation of research groups from RAS Institute and foreign scientists. So, the *Arctic-2012* expedition with the with support of the *Kapitan Dranitsin* icebreaker and research submarine, was primarily aimed at examining and sampling the seafloor of the Mendeleev rise.

GBU-2/4000L drill rig was used for sampling the bedrock in the northern and southern parts of the Mendeleev rise,

where three boreholes were drilled, and the research submarine was equipped with a manipulator mounted on its bottom. The sampling sites were located in areas close to escarpments with the previously targeted outcrops of acoustic basement, relying on the video and seismic survey data.

The four of many other thus collected specimens of dolerite and basalt were used for petrographic descriptions and mineralogical analyses, as well as for further isotope studies, conducted to determine the age of rocks with the argon-argon method at the Sobolev Institute of Geology and Mineralogy (IGM SB RAS) analytical center, Novosibirsk. The isotope studies have revealed in the spectra of all samples of minerals the presence of an ancient component, to all appearances related to the time of rocks' formation, dating approximately 472–467 million years, which is close to the Lower-Middle Ordovician boundary (Vernikovskiy *et al.*, 2014).

Along with the ancient component, younger age indicators were established in the spectra of a number of samples, which is accounted for by a huge amount of flood basalts during the plume events at the Paleozoic-Mesozoic boundary and in the Mesozoic. This allows us to ascertain that the age of basalt and dolerites collected from the



Map Legend: 1 – Rogotsky Seamount; 2 – Trukshin Seamount; 3 – Gakkel Ridge; 4 – Lomonosov Ridge; 5 – Geofizikov Island; 6 – Podvodnikov Basin; 7 – Alpha Ridge; 8 – Canadian Basin; 9 – Northwind Ridge; 10 – Northwind Basin; 11 – Kuchеров Terrace; 12 – Chukchi Basin; 13 – East Siberian Sea; 14 – Chukchi Sea.
Right Inset: a – Shamshur Seamount; b – Trukshin Seamount; c – Rogotsky Seamount; d – Nautilus Basin; e – Mendeleev Basin; f – Chukchi Cap

Geological sampling sites on the seafloor of Mendeleev Rise during the Arctic-2012 expedition (August 10–October 6, 2012) and ⁴⁰Ar/³⁹Ar age-spectra

Mendeleev Ridge slopes dates to the Early Paleozoic. This inference underpinned by the materials from the seismic survey expedition *Arctic-2012*, complemented by new geological and geophysical data for the New Siberian Islands, imply that the Precambrian basement of the continental block of the Mendeleev Rise to all appearances is similar to the continental block comprising the New Siberian Islands and De Long archipelago.

Moreover, it has become apparent that the Lomonosov and Alpha-Mendeleev ridges, including the Makarov and Podvodnikov basins between them, constitute a natural “bridge” built up of continental crust, connecting North American and Asian continents. These data will positively provide a weighty contribution to the substantiation of our country's claim for an extension within the Russian Arctic sector's area as far as the North Pole, owing to which Russia may be able to have an increment of an area over one million square kilometers to its Arctic shelf.

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