A Good Journal for Inquisitive People

SCIENCE First Hand

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MAYBE-BAG AND LET IT BE

LIVE SILICON OF LAKE BAIKAL

THE FISH OF LAKE BAIKAL AGAINST ATHEROSCLEROSIS

PHYSICIST AND BIOLOGIST: HIGH ENERGY PAIR

I EXIST!

2.
2016
popular science journal

SCIENCE First Hand

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Academician M. A. Grachev: "I call crisis the "riddle" of the century because no such trouble has occurred on Baikal, at least not in the last 100 years of scientific observations

The olfactory neurons of the yellowish Baikal sculpin can modify during the spawning season: olfactory cells become secretory and begin to evolve molecules into the ambient environment

Professor Andrey Seryi: "NSU alumni "accelerator mafia" has an immence influence on the world science"

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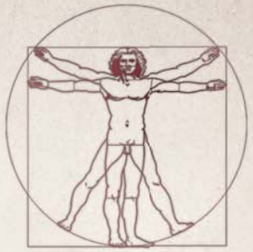

"The natural desire
of good men is knowledge"

Leonardo da Vinci

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Dear Friends,

Twelve years ago, we dedicated an issue of this journal to Baikal – the deepest and most ancient fresh lake of the planet featuring the greatest biodiversity among freshwater lakes. Over half of Baikal animals and up to 10% plants are endemics, that is, do not occur anywhere else in the world.

Our journal published materials about the bacteria capable of destroying hydrocarbons at very low temperatures, which can be of interest for the developers of biotechnologies to control oil contamination (Invisible guards of Baikal by Olga N. Pavlova); communities of ice "jungles" inhabiting the pores and canals of melting ice (Ice as the keeper of life by Nina A. Bondarenko, Lyubov A. Obolkina and Oleg A. Timoshkin); "methane preserves" – gas hydrates first lifted from the bottom of the freshwater lake in 1997; the unique chronicle of sediments, many kilometers long, that can be read with the help of diatom algae, and about many other phenomena of Baikal.

In 2011, SCIENCE First Hand was the first official Russian mass medium to break the news of a troubling event: the disease and death of Baikal's endemic filtering sponges that keep the lake water clean (What has happened to Lake Baikal Sponges? by Aleksei E. Bormotov.

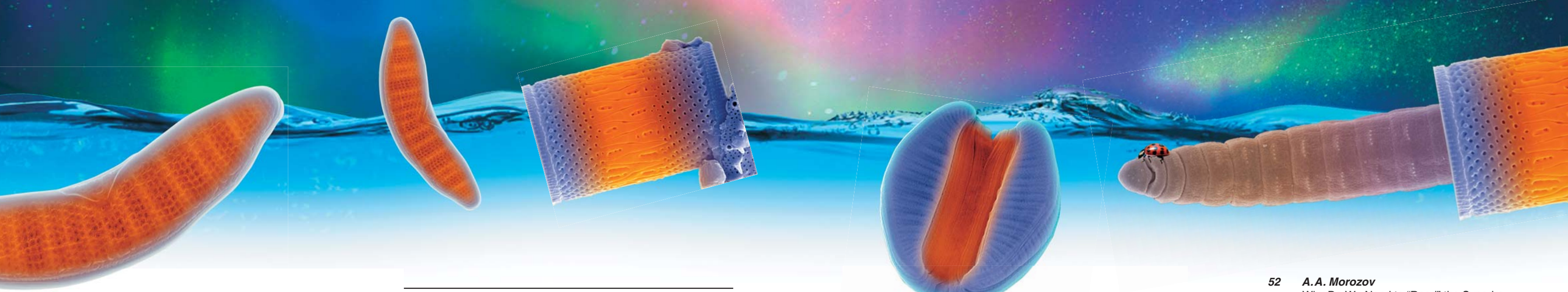
The latest expeditions conducted by the Irkutsk-based Limnological Institute SB RAS have found that the negative phenomena span the 1,800-kilometer perimeter of the lake shallow water. Thousands tons of putrefying spirogyra cover the lakeshore, and Baikal's underwater landscapes have changed beyond recognition because of the dead sponge "forests" and a thick layer of slime spreading over the offshore bottom.

In an attempt to explain these fast changes, researchers have put forward a lot of hypotheses. Some of them refer to the previous stages of warming resulting in similar changes or to more disastrous global warming and thinning of the ozone layer. There are some more exotic events like the return to Baikal of huge flocks of cormorants or emergence of a new spirogyra species. And yet the most likely cause, according to the specialists of the Limnological Institute, is the excessive income of biogenic elements (nitrogen and phosphorus) together with inadequately treated industrial and especially household effluents. This seemingly simple answer generates a lot of new questions. Why do the contaminated shallow waters not exchange with the main sea of Baikal? What is the connection between the crisis events that happen virtually simultaneously? What mechanisms are at the heart of the stability of the lake ecosystem, and what does the near future have in store for us? There are no answers to these questions so far.

In the new issue of the journal, young scientists of the Limnological Institute SB RAS, together with their leaders Academician M.A. Grachev and Doctor of Biology E. V. Lishovai, share with us their insight into the remarkable dwellers of Baikal, which continue doing their everyday work, invisible yet necessary for the lake. You will find out about the crownwork on the "teeth" of epischura, a tiny crustacean that is one of the main filter-feeding organisms of the lake and basal feed for the Baikal cisco; the role of Baikal fish in controlling arteriosclerosis and age-dependent mental deficiency; and mapping the entire genome of the diatomic algae Synedra acus.

Despite many problems, Baikal lives on, and limnologists continue with their research of the mechanisms underlying the functioning of this complex system, where infinitely small reasons can generate infinitely great consequences.

Academician Nikolay L. Dobretsov,
Editor-in-Chief



Seismic tomography studies of **SUPER VOLCANO** Toba on Sumatra showed that the **DEEP WATER MIGRATION** was the main trigger for the Largest **ERUPTIONS** in the Earth`s history. **P. 6**

If we put the **EGGS** laid by the yellowish Baikal sculpin to an aquarium with a **MALE** ready to breed, his body begin to vibrate and evolve **REPRODUCTIVE PRODUCTS** even though the male does not see the object of his adoration – he reacts to the **SMELL**. **P. 24**

The **“SILICON NANOTECHNOLOGIES”** of diatomic microalgae can become the basis of **REVOLUTIONARY** biotechnological production. **P. 42**

To crack the **“HOUSE”** built of **SILICONE** dioxide, where diatomic algae hide, the tiny **BAIKAL CRUSTACEAN** epischura has grown silicon crownwork. **P. 56**

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Major SUPERERUPTIONS in the Earth's History Were Caused by Deep WATER Migration

Ivan Yu. KOULAKOV, Dr. Sci. (Geo.-Min.), Trofimuk Institute of Geology and Geophysics SB RAS (Novosibirsk). He is the author and coauthor of 70 research papers

Siberian scientists, in collaboration with colleagues from France and Saudi Arabia, used a comprehensive geophysical study of the deep structure beneath the Toba Caldera on Sumatra to simulate the processes leading to the recurrent supereruptions. The results of this study have been published in the prestigious journal Nature Communications

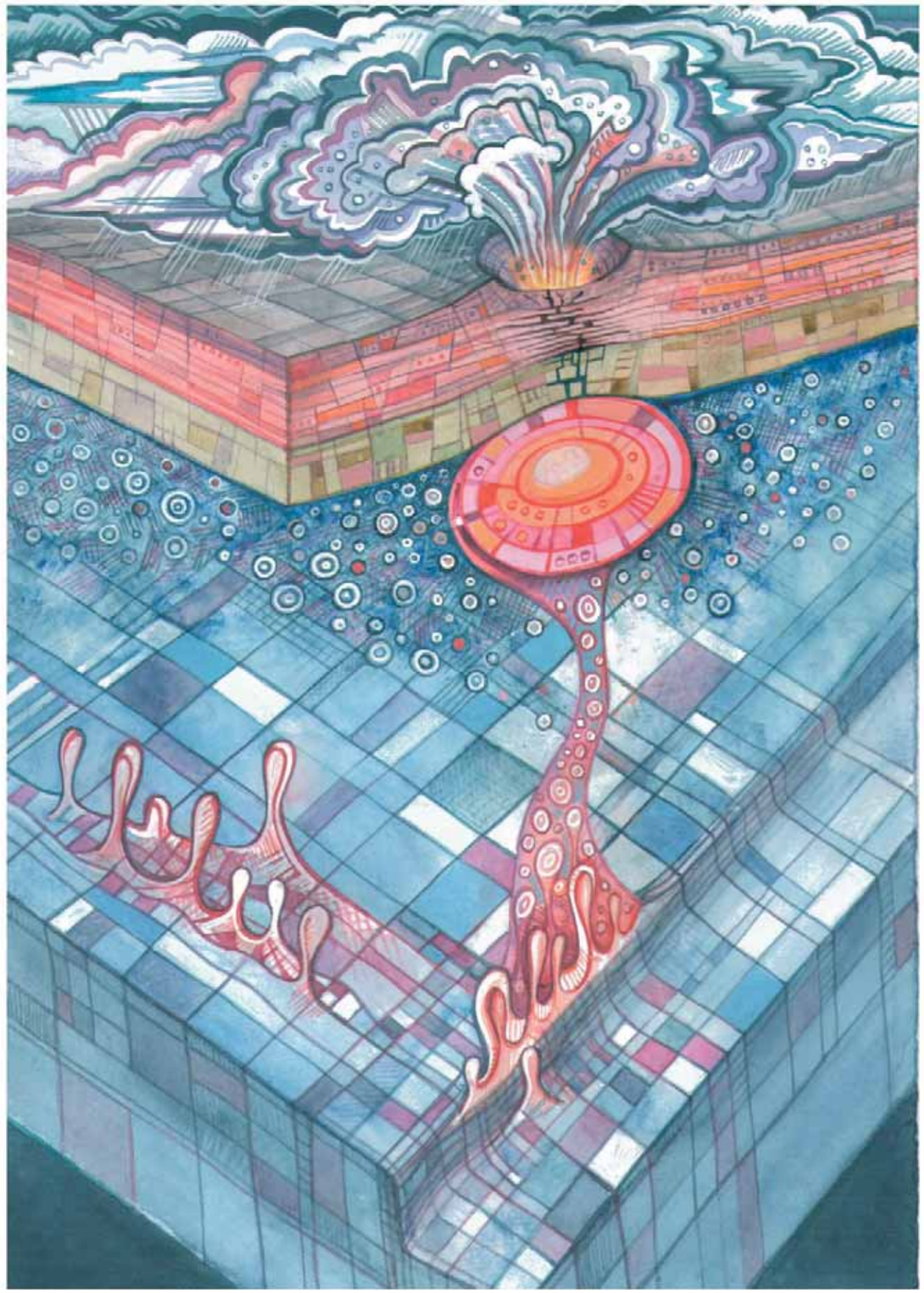
The supereruption is an explosive eruption ejecting, in a single event, over 1000 cubic kilometers of material in the dense rock equivalent. Over the past million years, there have been three supervolcanoes on the Earth, which were active: Yellowstone in North America, Taupo in New Zealand and Toba in Sumatra. The Toba supereruption ~74,000 years ago, which ejected over 2,800 km^3 of material, is considered to be the largest terrestrial volcanic eruption over the past several millions of years. The volcanic event created a huge caldera filled with an 80-km lake, which is the largest terrestrial volcanic lake. Amazingly, this is a site of several catastrophic eruptions, at least three in the last million years.

The human civilization has never encountered a supereruption. The largest eruption recorded by man had a volume of about 150 km^3 and occurred at Tambora Volcano in Indonesia in 1815. This disaster led to a substantial climate cooling throughout the northern hemisphere and to tens of thousands of victims due to famine and epidemics. However, the scale of this event is incompatible to the consequences of supereruptions. Since supervolcanoes are a potential hazard to the mankind, we should be very careful about studying the processes in these volcanoes and monitoring all the anomalies in their activity.

The main cause of the supereruptions is the accumulation of water in the Earth's interior, which makes water, however paradoxical it may sound, the most explosive substance on the Earth. Beneath the Toba Caldera, large amounts of water are transported into the mantle via the Investigator Fracture Zone (IFZ), a major transform zone in the Indian Ocean plate. This zone, which clearly stands out on the map of the seabed, separates two parts of the plate with different ages and is a weakened part of the lithosphere, which facilitates the penetration of seawater to the crust. In the subduction zone, the oceanic Indian plate sinks into the mantle beneath Sumatra and pulls there the water-saturated IFZ. At a depth of about 150 km, directly beneath the Toba Caldera, this water is ejected from the subducting lithospheric plate.

Then, the water begins to migrate upward through the mantle wedge, altering the mantle rocks to make them more fusible and less dense. The ascent of the rocks leads to the formation of a huge under-crust reservoir of partially

Key Words: supervolcanoes, Toba, Sumatra, Indonesia, seismic model, tectonics, subduction, volcanism, caldera, crust structure, magma chambers, supereruptions



Main cause of supereruptions is the accumulation of water in the Earth's interior, which makes water, however paradoxical it may sound, the most explosive substance on the Earth.
Drawing by Ivan Koulakov, watercolor on paper

molten mantle material with a high content of fluids. In the tomographic model, this chamber is traced as an anomaly with reduced seismic velocities with a size of about 50,000 km^3. In a projection onto the caldera's surface, the shape of this anomaly coincides almost perfectly with the uplift of the Earth's surface around the caldera to a altitude of more than one kilometer.

Although the mantle rocks are overheated, they remain heavier than the crustal rocks. Therefore, they cannot rise further through the crust. But water is a different story. When it passes through the mantle wedge, its temperature can reach 1300 degrees, but it remains liquid due to high pressure. It can safely continue to migrate upward through the crust, being a very effective means of heat transfer. The numerous earthquakes recorded in the lower crust beneath Toba are likely to be a reflection of this process. The migration of hot water causes the heating and melting of rocks in the upper crust, which in turn leads to the formation of another magma chamber at depths between 7 and 15 km. The structure of this chamber was discussed in detail in another article by the same authors (Jaxybulatov *et al.*, 2014), which was previously published in *Science*.

The partially molten material in the upper-crust chamber is saturated with water, which is still in a liquid state. Upon reaching a certain threshold value, a part of the water can vaporize due to decompression or high temperatures. This will largely increase the pressure, possibly leading to new cracks in the crust, along which a new portion of boiling water will flow. Eventually, this avalanche process can cause a voluminous explosion.

This mechanism explains the recurrence of supereruptions and their strength. Indeed, making a "time bomb" requires the accumulation of a critical amount of water, which must come from the mantle. Thus, there will be supereruptions at Toba as long as the IFZ continues to subduct beneath Sumatra and brings abnormal amounts of water to the mantle. However, given that the last eruption at Toba Volcano was only 76,000 years ago and the intervals between supereruptions are hundreds of thousands of years, the mankind is unlikely to face the threat of a catastrophic eruption of this volcano in the near historical future.

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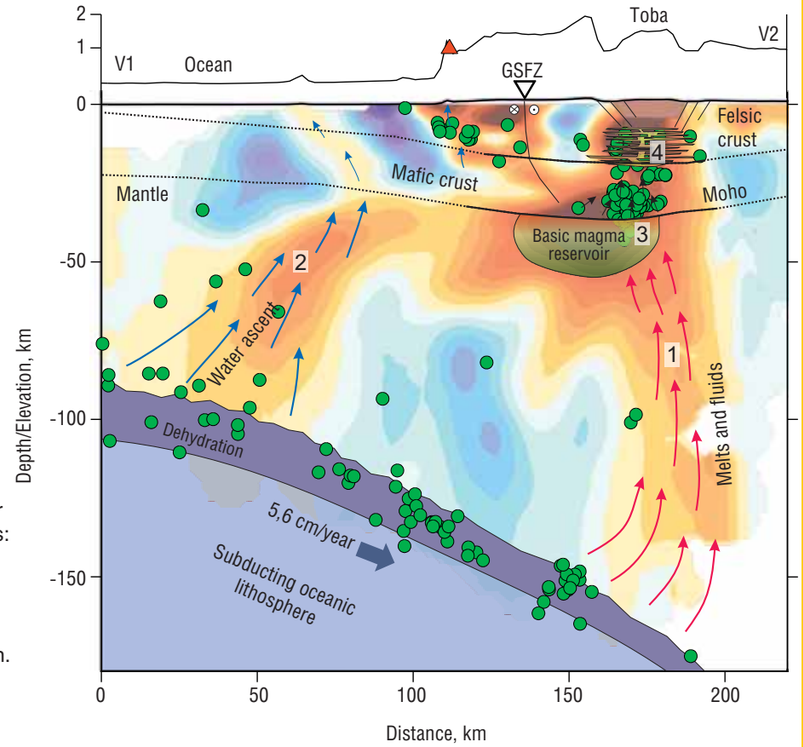

Tomographic model in the vertical section and its interpretation. S-wave velocity anomalies are shown in the background. Red areas: lower velocities (a lot of water and/or high temperature); blue areas: higher velocities (cold solid rocks). Green dots depict the earthquakes. Arrows indicate the path of ascending water and melts. *Above*: topography along the section. GSFZ: transection with the Great Sumatran Fault Zone

Schematic representation showing the role of the Investigator Ridge in the initiation of the Toba supervolcanism. Red dotted lines: the Investigator Fault Zone with a tear of the slab, which facilitates the ascent of water from the lithosphere. Tomographic section beneath the Toba Caldera

The eruption of Toba Supervolcano in north-central Sumatra, Indonesia, created Lake Toba, the largest volcanic lake on the Earth (*left*)
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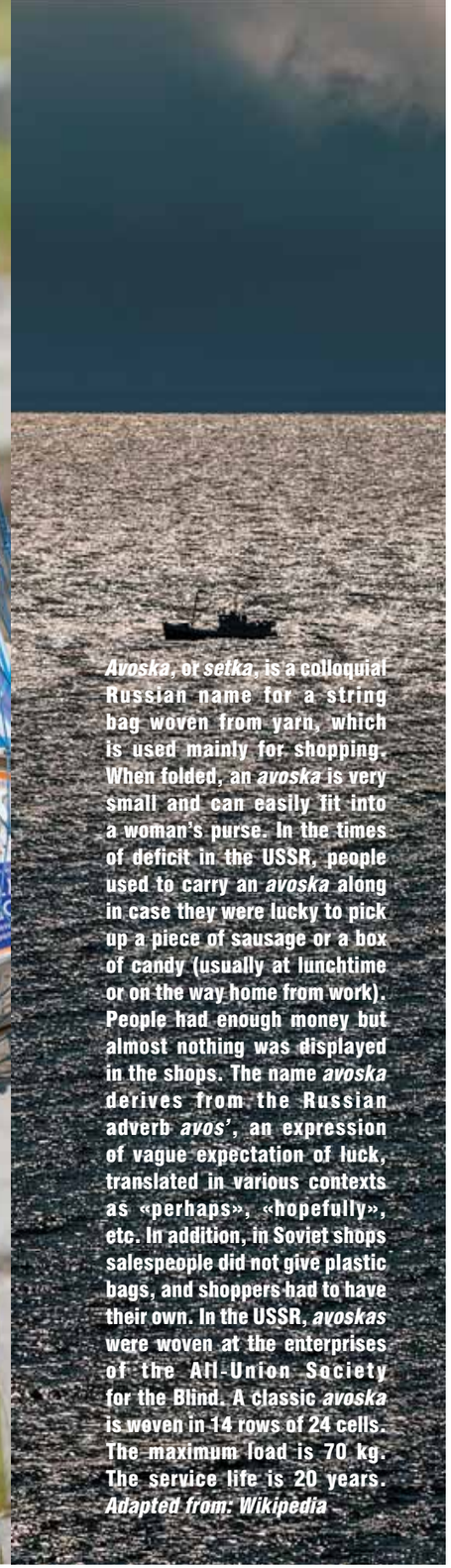
Maybe-Bag and Let It Be

Ecological Crisis in Lake Baikal: A Mystery of the Century

M. A. GRACHEV

Photo by V. Korotkoruchko



Avoska, **or** ***setka,*** **is a colloquial Russian name for a string bag woven from yarn, which is used mainly for shopping. When folded, an** ***avoska*** **is very small and can easily fit into a woman's purse. In the times of deficit in the USSR, people used to carry an** ***avoska*** **along in case they were lucky to pick up a piece of sausage or a box of candy (usually at lunchtime or on the way home from work). People had enough money but almost nothing was displayed in the shops. The name** ***avoska*** **derives from the Russian adverb** ***avos',*** **an expression of vague expectation of luck, translated in various contexts as «perhaps», «hopefully», etc. In addition, in Soviet shops salespeople did not give plastic bags, and shoppers had to have their own. In the USSR,** ***avoskas*** **were woven at the enterprises of the All-Union Society for the Blind. A classic** ***avoska*** **is woven in 14 rows of 24 cells. The maximum load is 70 kg. The service life is 20 years.**
Adapted from: Wikipedia

Prologue

TV shows a nightmarish picture: three gigantic mountains of plastic waste, mostly used bottles and bags, have piled up in the oceans. Plastic decomposes very slowly and produces tiniest scales; these scales are swallowed by fish and other inhabitants of the Ocean, who then die in terrible agony.
Neither foreigners nor young Russians can now remember themselves go shopping with an avoska, or maybe-bag, a string bag that was popular in the Soviet times.
An obvious solution: let's prohibit plastic bags and bottles worldwide. Let's give everyone a string maybe-bag and replace plastic bottles with glass ones, and, maybe, there will be no plastic mountains in the ocean. This may look fine and feasible, however... It is not that simple. The production of plastic creates millions of jobs and generates enormous profits. As long as consumer society holds sway, there will be plastic in the ocean, fish will suffer and shrimps will die...

Mikhail A. GRACHEV, Full Member of the Russian Academy of Sciences, Doctor of Chemistry, Director of the Limnological Institute SB RAS (Irkustsk, Russia) from 1987 to 2015. Research interests: bioorganic chemistry, paleoclimate, and analytical chemistry. Contributed to drafting the Law on the Protection of Lake Baikal. The USSR State Prize (1985) and Karpinsky Prize (1998) awardee.
Author and coauthor of 153 scientific publications

SCIENCE FIRST HAND http://scfh.ru/en/papers/ecological-crisis-in-lake-baikal-a-mystery-of-the-century/ September • 2016 • N 2 (44)

Ecological crisis in Lake Baikal

The ecological crisis in Lake Baikal, which began in 2011, has been vastly discussed in scientific literature by my colleagues and other scientists, as well as in the media; we can hear about it on the radio and television. We are constantly reminded about the crisis by nongovernmental organizations, such as the environmental movement led by Anzhelika Tissen (Severobaikalsk). The cause of the crisis is unclear. It is a large-scale phenomenon affecting the entire coastal zone of Lake Baikal all around the perimeter 1,800 km in length. Cows and horses do not drink the water; people cannot drink the water even after boiling. Swimmers slip down when they enter the lake. *National Geographic* calls the Baikal substance green slime, which covers the bottom. Previously, divers could see objects at a distance of 20—30 m, but now the visibility can at times be down to 2 m. This is the current state of the UNESCO World Heritage Site...

Here I will only briefly list the facts:

- Rampant proliferation of the filamentous green alga Spirogyra, an uncommon species in Lake Baikal, thousands and thousands of tons.
- Extinction of almost all of Baikal sponges, which belong to several endemic species.
- Disappearance of the August herd of Baikal sculpins, which is one of the food resources for the Baikal omul.
- Excessive growth of cyanobacteria on diseased and dead sponges and on the bottom; the formation of thick slippery algal—bacterial mats.
- Emergence of cyanobacteria that produce saxitoxin, a deadly nerve poison.

All these processes occur in the coastal zone with a width of about 100—200 m and a depth of 25—50 m; at this depth there is still sunlight, which is essential for the development of Spirogyra.

The pelagic (deep) zone of Lake Baikal has not been affected yet; there are no changes in the water chemistry, phytoplankton, the abundance of the Baikal omul, or the life conditions of the Baikal seal. These are facts, not just my opinion.

Over the past four years, we have organized 50 expeditions on board of four research vessels and several more expeditions on ice. We have made laboratory analyses and calculations; this work involved at least fifty our researchers and ten foreign scientists as well as Russian dedicated specialists. Our divers made 200 extreme dives to depths as great as 50 m. We acknowledge the very helpful support of the Federal Agency for Scientific Organizations (FASO Russia), which paid for the fuel, purchased spare parts for foreign instruments, and allowed us to make amendments to the government assignments.

The "fortress walls" of Ust'-Anga. *Photo by V. Korotkoruchko*

Anzhelika Tissen, leader
of the nongovernmental organization
For the Pure North Baikal (*Severobaikalsk*)

Anzhelika V. Tissen, born in 1971, graduated from Irkutsk Agricultural Institute with a major in the biology of game species, worked as a psychologist for the military enlistment office, as a software engineer for Buryatenergo, and as an entrepreneur. Currently, she is the head of the nongovernmental organization *For the Pure North Baikal* (Severobaikalsk). In 2011, it was she who discovered the mass washouts of dead Spirogyra on the northwest coast of North Baikal and secured a visit of the federal environmental inspector E. A. Ivanov. The inspector made sure that Tissen was right and asked our institute to help investigate the situation.

Since 2011, Tissen has been approaching all levels of government, seeking their support to save Lake Baikal, and not without success. She has recently met with Vyacheslav Nagovitsyn, the head of the Republic of Buryatia. A wise man, he told her: "You should not worry about that; time will pass, and so will the crisis.

Lake Baikal: the tide line. *Photo by V. Korotkoruchko*

Near Baikal there is a small lake, Kotokel, which also was in an environmental crisis a few years ago. Scientists expressed great concern; they could not figure out the exact cause, and we did almost nothing. Now Lake Kotokel is clean again, everything is alright."

It is true that scientists do not know the cause of the Baikal crisis; finding this cause is an affair of honor for science

Vyacheslav Nagovitsyn, head of the Republic of Buryatia
© Government of the Republic of Buryatia

Lake Baikal is a complex system; not a very complex, but a complex one. This is a mathematical term rather than just a saying.

According to the English physicist Isaac Newton (1643—1727), if we knew the coordinates and momenta of every particle in the universe, then we could describe its past and predict the future. The old man was, however, wrong: we cannot do that, but not because we do not have the instruments, observers, or super sophisticated computers, but for fundamental philosophical reasons. All real-life systems in our world are complex and are never in equilibrium, and it is fundamentally impossible to predict their behavior.

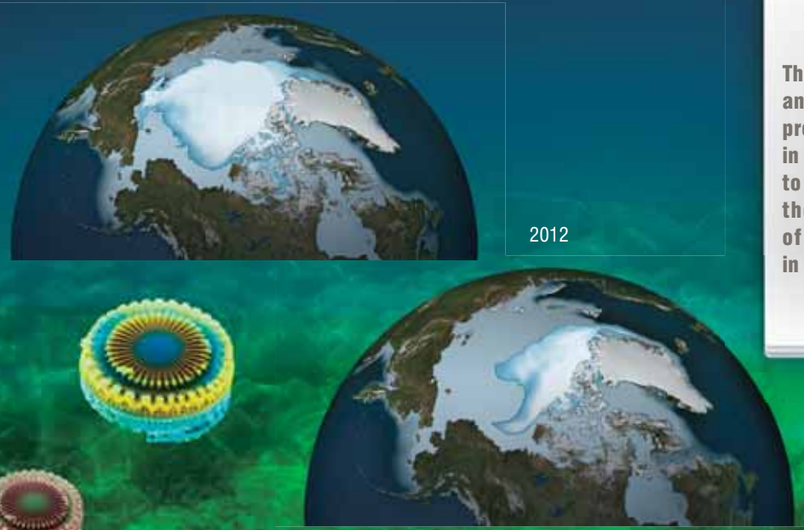
However, scientists produce hypotheses—this is their job. Here I give a list of hypotheses about the possible causes of the Lake Baikal disaster (see the table).

Scientific and Non-Scientific Hypotheses Guesses and speculations

Coastal eutrophication

Eutrophication is an excess of food. It is obvious that there is eutrophication in the coastal zone. However, how does it get there and why has there been no rapid growth of *Spirogyra* for hundreds of years since the times of Archpriest Avvakum in 1662.* This is a mystery of the century. A very likely source of nutrients is rampantly developing tourism

Global warming



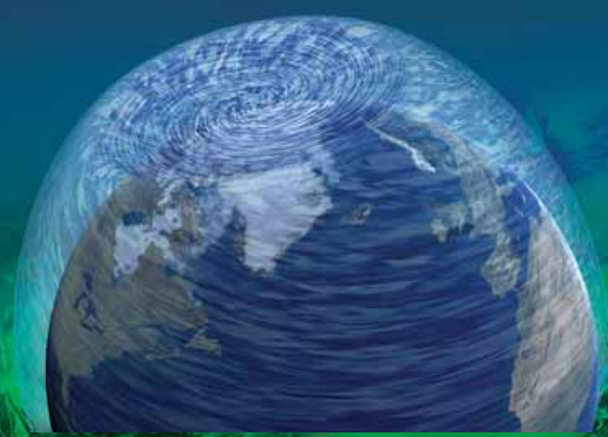
The connection between the crisis and global warming has not been proved; there were warm years in the past, but they did not lead to Spirogyra crises. Moreover, the peak in the development of Spirogyra in Baikal occurs in October rather than in summer

Scientific and Non-Scientific Hypotheses Guesses and speculations

Invasion of a new Spirogyra species (there are about 400 species of Spirogyra worldwide). This genus is ubiquitons

The hypothesis is now under investigation

Thinning of the ozone layer in the troposphere over Siberia



Science fiction

Scientific and Non-Scientific Hypotheses Guesses and speculations

Uncontrolled proliferation of the Baikal seal

There is no scientific proof of the increase in the seal population. However, a seal eats 4 kg of fish every day, and its nutrient-rich feces reach the coastal waters. The total number of the Baikal seal is about 100,000; that of indigenous people on the shore, about 120,000

Return to Baikal of huge flocks of cormorants, which discharge their excrements into the coastal waters

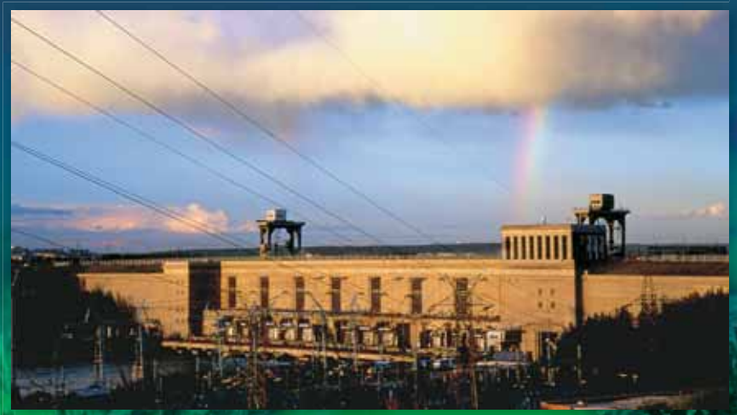
The connection has not been studied yet

Scientific and Non-Scientific Hypotheses Guesses and speculations

Destruction of the gas hydrate layer at the bottom of Baikal and a dramatic increase in the concentration of methane, which has killed the sponges

Sponges do not care about methane; it is a proven fact

Decrease in the level of Lake Baikal due to the actions of “bad guys” in the energy industry



Energy companies are not “bad guys”. There were similar decreases in the level of Lake Baikal in the past, but they never led to crises

Panorama of the middle basin of Lake Baikal from a coastal cliff. *Photo by V. Korotkoruchko*

** One of the first delighted accounts of Lake Baikal was left by the Russian Archpriest Avvakum. On his way back from the exile in Dauria in the summer of 1662, the rebellious priest had to cross Baikal from east to west. This is what he wrote about the lake:*

"...During the crossing the wind fell, and we had to use our oars. In that place the lake is not very wide, only eighty to one hundred versts or so. When we reached the other shore, a storm began to blow up, and we could scarcely land because of the waves. From the shore rose steep hills and sheer cliffs. I have dragged myself twenty thousand versts and more, but never have I seen such high mountains. And their summits are crowned with halls and turrets, pillars and gates, and walls and courts, all made by the hand of God. In those hills grow garlic and onion, the bulbs larger than those of Romanov onions, and very sweet. And there is also hemp, sown by God's hand, and in the courts, beautiful grass and sweet-smelling flowers. There are wild fowl in great number–geese and swans floating on the lake like snow. And there are also fish: sturgeon and salmontrout, sterlet and omul and white-fish, and many other kinds. This is a fresh-water lake, but great seals and sea-hares live in it. I never saw the like in the great ocean, when I lived on the Mezen River. And the fish is abundant; the sturgeon and salmon-trout are so fleshy, one cannot fry them in a skillet, it would be nothing but fat. And all this has been created by Christ for man, that he should find pleasure in it and praise God."

The Life of Archpriest Avvakum by Himself, in: The Way of a Pilgrim and Other Classics of Russian Spirituality, ed. by G.P. Fedotov, Dover, New York, 2003, P. 160—161

Mystery of the century

I call this crisis a mystery of the century, because at least for the last 100 years of scientific research Lake Baikal has never suffered such a disaster. And before that, in the days of the Russian Archpriest Avvakum, Spirogyra seems dared not to have make such a mischief. Where does the mystery lie? The people living on the shores of Lake Baikal dump into the water about 50 tons of inorganic phosphorus per year. The total amount of inorganic phosphorus in the lake is 308,000 tons, i.e. greater by a factor of 6,000. Moreover, a large part of the phosphorus flows away with the waters of the Angara River. A negligible annual addition—a 1/6,000 fraction—could not have caused and has not caused the eutrophication of the entire lake. Imagine that you have ordered a pot of peas, but the chef made a mistake and put one extra pea. Will it affect your weight?

However, the addition of a pea of nutrients into the coastal waters of Lake Baikal could indeed cause the eutrophication of the coastal zone if the latter were separated from the open deep waters with a waterproof wall: the volume of the coastal zone is only five cubic kilometers whereas that of the entire lake is 23,000 cubic kilometers.

But there is no wall. Why does the water of the coastal zone not mix with that of the open lake? This is a very complex problem of fluid dynamics. Routine imitation models are useless; we need physical models that can only be designed by high-level physicists and mathematicians rather than by computer scientists. These mathematicians and physicists will also need experimental settings such as rotating vessels with water. A physical model of Lake Baikal will not appear tomorrow.

Moreover, we will have to explain not only the bloom of Spirogyra but the extinction of sponges and the well-being of poisonous cyanobacteria.

The mass mortality of marine sponges is observed worldwide—in the Gulf of Mexico, in the Caribbean Sea, in the North Atlantic, in the Mediterranean Sea, and on the Great Barrier Reef. However, this is the first time we have reported the mass mortality of freshwater sponges. The world's leading biologists are searching for the cause of the mass mortality of marine sponges, blaming unknown microbes, global warming, poisons of human origin, increased supply of nutrients, etc. There have been studies since the mid-twentieth century, but so far they have led to no success, and it remains unknown why the sponges are dying.

Lake Baikal is a much simpler ecosystem than the Ocean, and our researchers could do a lot in three years if they were adequately financed. Many scientists from Russia and from abroad now study the sponge disease in Lake Baikal; probably, we will succeed, but we have very limited financial resources. We cannot work without chemicals and consumables, without repairing the instruments, without outsourcing, without reagent kits, etc. Unfortunately, there is no dedicated fund to solve emergent environmental disasters in Russia, and the regular financing is not sufficient. Of course, we reported about the crisis to the scientific community and policy makers as early as in 2011, but no special money came.

In 2012, the government adopted the Federal Targeted Program "On the Protection of Lake Baikal and on the Social and Economic Development of the Baikal Natural Territory" with a budget of 57 billion rubles (about $1 billion), but, unfortunately, according to the existing rules, this money cannot be spent on financing fundamental science, although we need only 0.4 % of this amount to try and understand what is happening. Without a better understanding of the nature of the disaster, one cannot be sure that the proposed measures will give a real result.

There are 29 wastewater treatment plants on the shores of Lake Baikal; however, only two are functioning, and even those two do not meet the existing very strict requirements adopted for Lake Baikal. The lake needs not the common facilities with biological treatment, but special treatment plants which can remove nitrogen and phosphorus. A common facility with biological treatment of sewage produced by a settlement on the shores of Lake Baikal will cost 400 million rubles (about $6 million). A special treatment plant for the removal of nitrogen and phosphorus would cost twice as much. However, the entire west coast of the lake lacks not only treatment plants but also sewage collection systems, without which treatment plants are useless.

Two decades ago one could hope that Lake Baikal would cope with the human waste by itself. On the road leading from the city of Irkutsk to the settlement of Listvyanka, the nearest place for Baikal tourism 70 km off Irkutsk, there were a few dozen cars that went back and forth; herds of cows were wandering about, and the cars made way for them. According to the traffic police data, three thousand cars came to Listvyanka on one day in 2015, with an average of four people in a car. There are no sewage collection systems in most parts of Listvyanka, let alone sewage treatment plants; the wastewater from homes and hotels gets into the lake, one way or another, under the ground.

The construction of wastewater treatment plants and sewage collection systems on the shores of Lake Baikal will require much time and money.

However, let's imagine for a moment that scientists are wrong; they made a mistake, and the beautiful facilities will fail to stop the crisis. The money for the phosphorus removal system will be spent in vain. However, a wastewater treatment plant must be built; this is the existing law. Policy-makers often have to issue decisions

without having enough information; this is their work. But, of course, it would be better if information were at hand.

Now it is necessary to develop and test various systems to remove phosphorus from wastewater, build pilot wastewater treatment plants and, ideally, to prove that these efforts can stop and reverse the environmental crisis in Lake Baikal, and this is an affair of honor for us scientists.

We all know that a cheapskate pays twice. I am positive that the pilot plants will be built and tested. Today the attitude towards this issue has changed dramatically.

Black swan

The crisis in Lake Baikal is totally unexpected, and it is unlikely that it could have been predicted. Let me remind you that Baikal is a complex system.

There is a famous American philosopher, mathematician, economist and successful stock gambler, Nassim Nicholas Taleb. He was born in Lebanon in 1960. He calls the famous Harvard Business School a Soviet–Harvard institution, whose main task is to predict share prices and the welfare of the state. As he jokes, this school has a department of ornithology where birds are kept in cages and professors teach the birds to fly. They wave their arms, lift their legs, lower their noses... Three months later the cages are opened and the birds are released. Wow! The birds have learned to fly and they fly away. Glory to the professors! An excellent school!

Taleb introduced the concept of a black swan. Russian economists appear to have heard of it. The black swan is a very rare event of a large amplitude, which is fundamentally impossible to predict, even if one has unlimited computing power. The typical Soviet–Harvard methods cannot be used to gamble on the stock market, to forecast the climate, or to predict oil prices and currency exchange rates. Neither can they be used to predict the results of our research, because Lake Baikal is a complex system in which infinitely small causes can sometimes lead to enormous consequences. Taleb's secret was that he was always ready to meet a black swan.

We do hope for success. The money will come—our may-be bag is at hand. And let it be.

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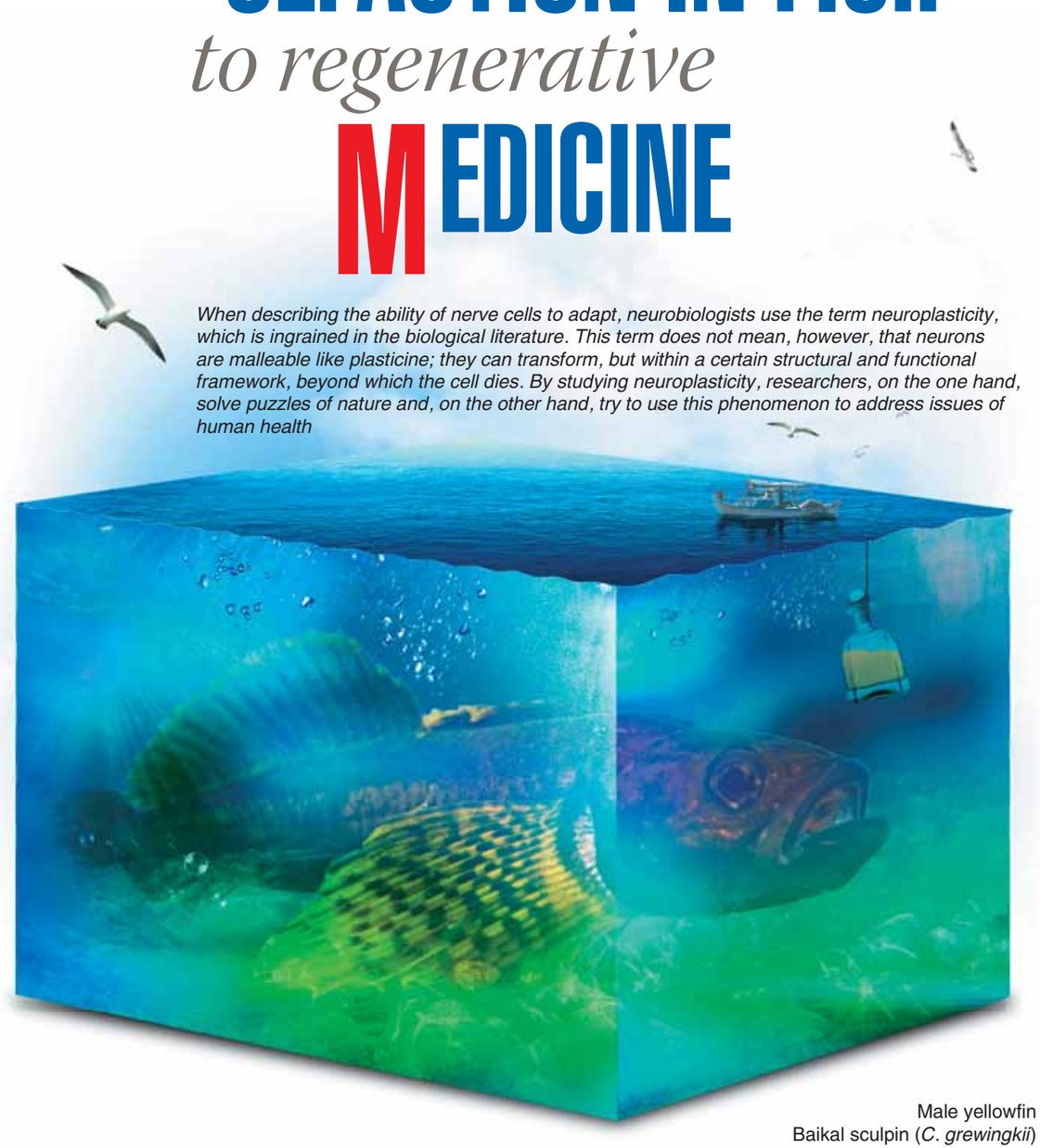
Key words: Lake Baikal, East Siberia, coast eutrophication, Spirogyra

This publication uses the photos:
p. 16 – by V. Korotkoruchko; NASA/Goddard Scientific Visualization Studio; p. 17, by S. Ihnken; p. 18 – Ministry of Natural Resources and Environment, Russia, Government Report "On the State of Lake Baikal and the Measures for Its Protection in 2014"; by V. Glupov, O. Khlystov, V. Korotkoruchko, and E. Volkova; p. 22 – Black swan, Cygnus atratus. Centiennal Park, Sydney, Australia, August 9, 2008. Photo: https://www.flickr.com

I.V. KLIMENKOV

From OLFACTION IN FISH *to regenerative* MEDICINE

When describing the ability of nerve cells to adapt, neurobiologists use the term neuroplasticity, which is ingrained in the biological literature. This term does not mean, however, that neurons are malleable like plasticine; they can transform, but within a certain structural and functional framework, beyond which the cell dies. By studying neuroplasticity, researchers, on the one hand, solve puzzles of nature and, on the other hand, try to use this phenomenon to address issues of human health



Male yellowfin Baikal sculpin (*C. grewingkii*) in a spawning dress

Key words: olfaction, odor, chemoreceptors, receptor proteins, dendrite, neurosecretion, dendritic neurosecretion, yellowfin Baikal sculpin, fish, Baikal

Olfaction is the most ancient sense organ. We perceive smells with the help of chemoreceptor cells, which are sensitive to chemical substances. These cells are bipolar neurons, and, like many neurons, they have one axon, a long projection going to the brain, and one dendrite, a short projection. The dendrite of the chemoreceptor cell extends into the external environment with its sensors, or cilia (flagella), whose membranes contain membrane-bound receptor proteins.

In many animals, chemoreceptor cells have developed throughout the evolution a highest degree of specialization; in fact, they reached the physical limit of the discrimination capacity of the olfactory system and are able to unerringly identify individual molecules and send information to the brain. Especially important are the chemical signals that determine the eating, defensive, and reproductive behavior. Moreover, a recent discovery shows that olfaction is used to evaluate more subtle biological characteristics such as social status, physiological condition, and other personalized data about individuals of one's own or other species.

How do these nerve cells acquire such a high specialization in the course of individual development? What are the resources underlying the reliability of their work? These questions are important not only for the study of the complex behavior of animals but also for some issues of human health, such as combating Alzheimer's disease and transplantation issues.

Yellowfin Baikal sculpin: sexual behavior based on smell

The neuroplasticity phenomenon involves both functional cell changes and structural ones, which can be seen under an electron microscope. To identify clear morphological, i. e. ultrastructural, criteria for high or low sensitivity of receptor cells, scientists need a good model. Such a model was found in the chemocommunicative behavior of the yellowfin Baikal sculpin (Cottocomephorus grewingkii).

It turned out that when the spawning season comes, the males of these fish acquire a very high sensitivity to the female sex pheromone. In the female's ovary, mature eggs are stored in the ovarian fluid, which keeps them, for a relatively long time, ready for fertilization. The ovarian fluid is rich in biologically active compounds called pheromones, i. e. substances that cause certain neuroendocrine and behavioral responses in an animal of the same species as the individual that secretes them.

The pheromones not only attract the male yellowfin sculpin to the female but also synchronize (with the female!) the maturation of his sexual products. More detailed studies have shown that one of the key components of the female pheromone—17-dihydroxyprogesterone steroid—is effective at a very low concentration of 10^{-11}–10^{-13} M.

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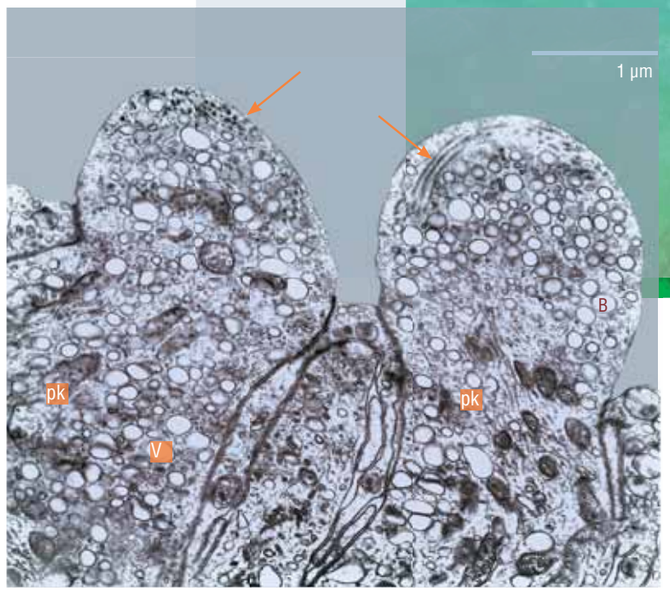
Based on the materials of joint research with Cand. Sci. (Bio.) N. P. Sudakov (Irkutsk Scientific Center of Surgery and Traumatology; Irkutsk Scientific Center, Siberian Branch, Russian Academy of Sciences; Irkutsk State University), A. V. Kurylev (Irkutsk State University), Cand. Sci. (Bio.) M. V. Pastukhov (Vinogradov Institute of Geochemistry, Siberian Branch, Russian Academy of Sciences, Irkutsk), and Dr. Sci. (Bio.), Prof. N. P. Kositsyn (Institute of Higher Nervous Activity and Neurophysiology, Russian Academy of Sciences, Moscow).

In fish, in contrast to humans, olfactory cells are localized in a special flower-like organ, i. e. an olfactory rosette consisting of 5—6 separate petals. *The photo* shows the olfactory rosette of the yellowfin Baikal sculpin (*C. grewingkii*);
a – general view, *b* – enlarged fragment of the epithelium with tops of a flagellar-type receptor cell (pk).
Electron microscopy



Receptor cells (pk) of the yellowfin sculpin during the spawning period, in the dendritic neurosecretion phase. Cilia (indicated by arrows) are localized inside the dendrites. One can see numerous vesicles (V), which are transported to the top of the cell where they embed themselves into the membrane, releasing their contents into the olfactory mucus

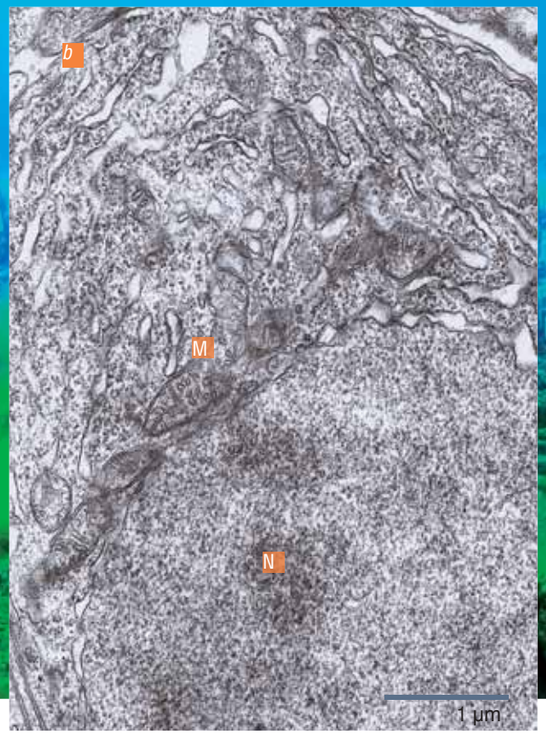
The corresponding experiment looks very impressive: if you take the roe from one female, put it into one hundred milliliters of water and then add one drop of the solution to an aquarium with a male ready for spawning, then, even without seeing the object of his adoration, he will immediately begin to demonstrate sexual behavior. Driven by the smell, the male rolls over and his body begins to vibrate, excreting sexual products "in vain." Females also respond to the pheromones which males release into water with urine.

That is, a very small portion of biologically significant molecules can radically change the behavior of the fish. Notably, in the spawning period, sculpins have pronounced sexual dimorphism. The male's head becomes carbon-black, and his fins become lemon-yellow: this color helps attract a female and withstand the tough competition for her. In this respect, females are less attractive: like most fish species, they almost do not change their color during spawning; i. e. the male does not attach particular importance to the color of the sexual partner. However, the chemical signals produced by the ready-to-spawn female are of paramount importance.

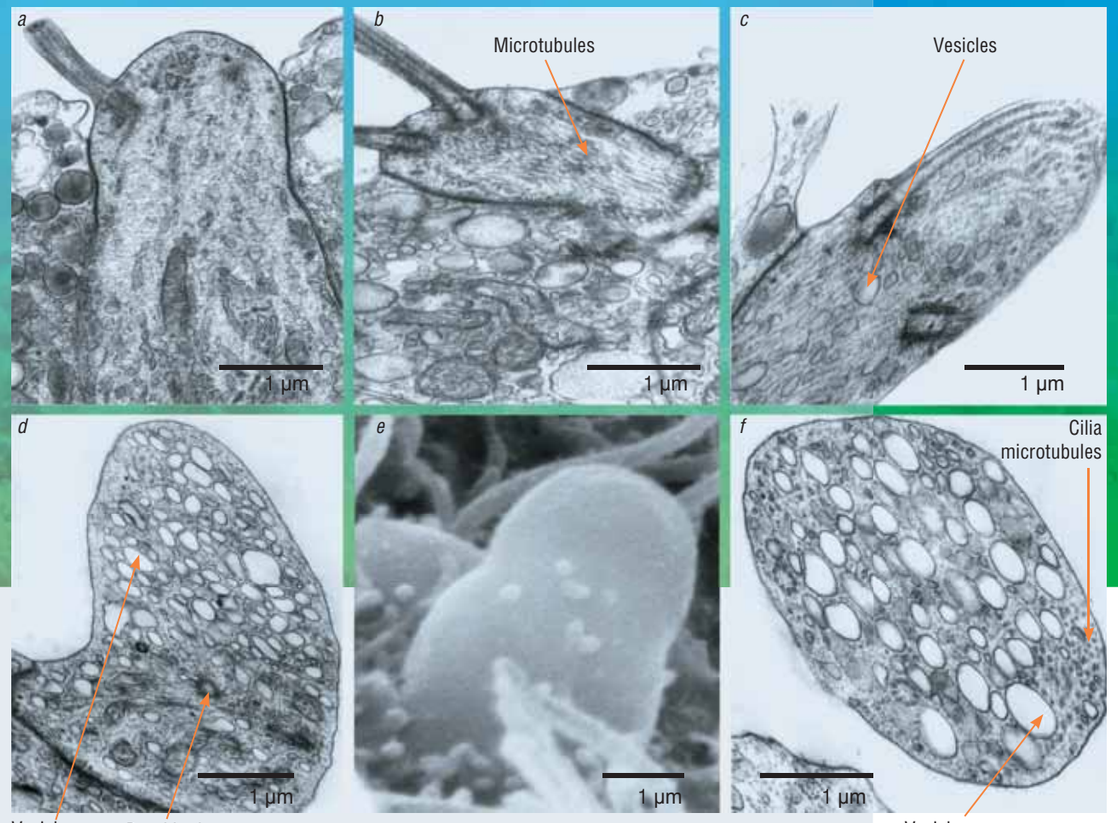
Thus, during the spawning season, the olfactory cells of male yellowfin sculpins somehow switch from the perception of food signals, which are typical of the inter-spawn period, to pheromonal ones, without which these fish cannot propagate themselves.

From olfactory to secretory

When the chemoreceptor cells of yellowfin sculpins become sensitive to pheromones, they begin to show ultrastructural signs of increased metabolism. There is an increase in nuclear cytoplasmic interactions:



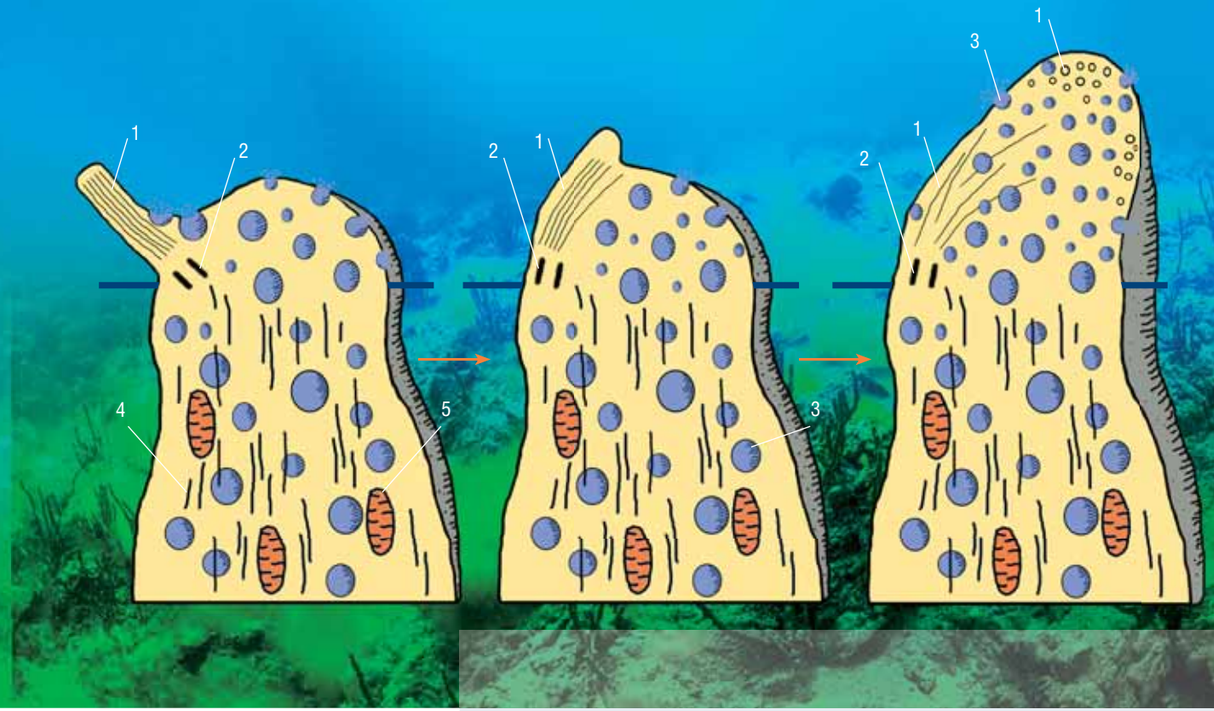
In comparison with (*a*) the inter-spawn period, (*b*) in the reproductive phase, the olfactory neurons of the yellowfin sculpin show the activation ofxnuclear-cytoplasmic interactions. The nucleolus (N), where ribosomes are synthesized, is close to the nuclear membrane, which acquires a higher pore density; mitochondria (M) adhere to the nuclear membrane



the nucleolus becomes active; the nuclear membrane shows an increased density of pores; near which the mitochondrial "power plants" concentrate. Consequently, in the cytoplasm there is an increase in ribosomes, i. e. "molecular machines" for protein synthesis. The chemoreceptor cell dendrites are observed to have clearly structured microtubules, which are elements of the cytoskeleton, i. e. the transport system of the neuron. This is important since adaptive changes in the cells must affect the need in the corresponding enzyme systems which are urgently delivered through the microtubules from the cell body to the receptive area. Thus, we found morphological parameters that accompany the adaptation of the olfactory cells to the perception of very low concentrations of chemical agents.

We must admit that these structural changes are not fundamentally different from those in the other neurons of the central nervous system, when they are at work. These changes are commonly referred to as reactive properties of the neuron, which, given an optimal functional load, exhibits structural signs of stress, i. e. adaptation to the stimulus.

Ultrastructural reorganizations at the tops of receptor cells in yellowfin sculpins in different phases of their life cycle and reproductive behavior:
a – inter-spawn period; the cell functions as an ordinary chemoreceptor cell perceiving food signals;
b – spawning; the cell is tuned to the perception of pheromones; an ordered system of microtubules is developed;
c – cilium is immersed into the dendrite;
d – top of the cell in the dendritic neurosecretion phase. The basal body, i. e. the structure from which the cilium extends; here it is covered with a large number of secretory vesicles;
e – this is how the top of the cell without flagella looks like;
f – disaggregation of the microtubules immersed inside the cell during its dying after an active secretory process.
Electron microscopy



Schematic illustration of successive stages in the restructuring of the chemoreceptor cell top in yellowfin Baikal sculpins when it is switched to dendritic neurosecretion: *1* – cilia microtubules; *2* – basal bodies; *3* – secretory vesicles; *4* – dendrite microtubules; *5* - mitochondria

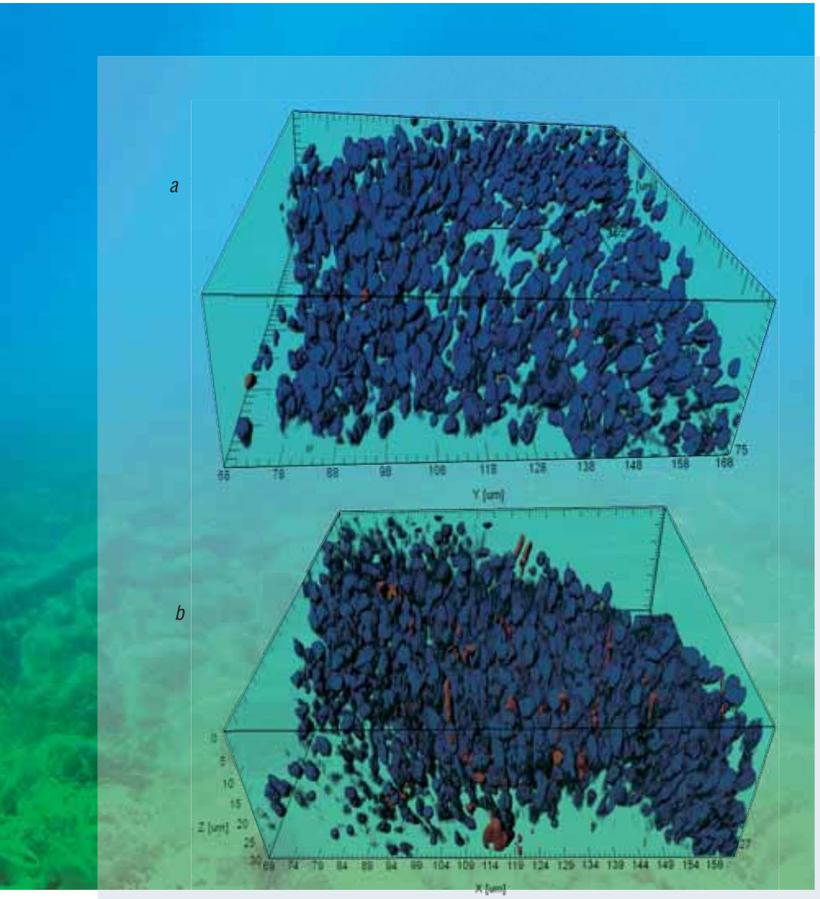
However, the other changes are not typical of sensitive cells. When male sculpins switch to parental behavior, i. e. protecting the roe, some receptor cells reveal, against the background of enhanced protein synthesis, the activation of the Golgi apparatus, i. e. a system of intracellular membrane structures in which various substances mature and accumulate to be later transported to their destination. The cells clearly show a directed transport of secretory vesicles to the top of the cell where they are embedded into the membrane, releasing their contents into the olfactory mucus.

During the transformation, the chemoreceptor cells lose their surface receptor apparatus, i. e. sensitive cilia. Their cytoskeleton is immersed into the top of the dendrite, and the cell appears to lose the chemoreception ability. That is, the cells cease to be olfactory... now they are secretory!

This does not fit into the traditional understanding of the functional purpose of olfactory neurons. From the earliest works (Schultze *et al.*,

SIMILAR TO IMMUNE CELLS

Interestingly, the dynamics of changes in chemoreceptor cells under the influence of an odorant stimulus are very similar to in the B lymphocytes those of the immune system during their response to an immune stimulus. This is not at all surprising since both the immune and olfactory systems work on the same task associated with the decoding of foreign molecules, i. e. antigens.
The evidence of immune principles in the functioning of olfactory cells comes from some of the important properties of the latter. Like lymphocytes, olfactory cells are monospecific and have a great diversity (polymorphism) of the genes that encode odorant-binding receptors (Buck and Axel, 1991). On top of this, there are two important facts which have been obtained quite recently. Analysis of the human genome revealed that promoters (the place where the RNA synthesis begins), which controll the expression of olfactory receptor genes and of the major histocompatibility complex proteins, also have a very high point polymorphism (Ignatieva *et al.*, 2014).
In addition, there is another unexpected circumstance in support of the still little-understood evolutionary parallelism of the olfactory and immune systems: last year, German scientists discovered olfactory and taste receptors in the membranes of immune cells (Malki *et al.*, 2015)



In comparison with (*a*) the pre-spawn period, the respiratory activity of mitochondria in yellowfin Baikal sculpins is substantially enhanced (*b*) during reproduction.
Coloring on the nuclear material (*DAPI*, *blue*) and mitochondria (MitoTracker® Orange); 3D-reconstruction; confocal microscopy

1856) to the present day, it has been generally believed that the top of the chemoreceptor cell is always specialized only in chemoreception. Furthermore, it is well known that neurosecretion in any nerve cell, with some exceptions, goes through the axon, which transmits information to another cell, not through the dendrite.

It is true that some authors described elements of morphological change that appear to suggest the reorganization of the olfactory cells into the dendritic neurosecretion mode. The key elements of these reorganizations—bubbles with a light content in different quantities—were seen in the dendrites and receptor cell tops in many animals and even in humans. However, these studies revealed no substantial increase in the secretory function of the Golgi apparatus, which would be accompanied by substantial restructuring of the cell top. Therefore, unfortunately, the bubbles found in the olfactory cells have so far attracted little attention.

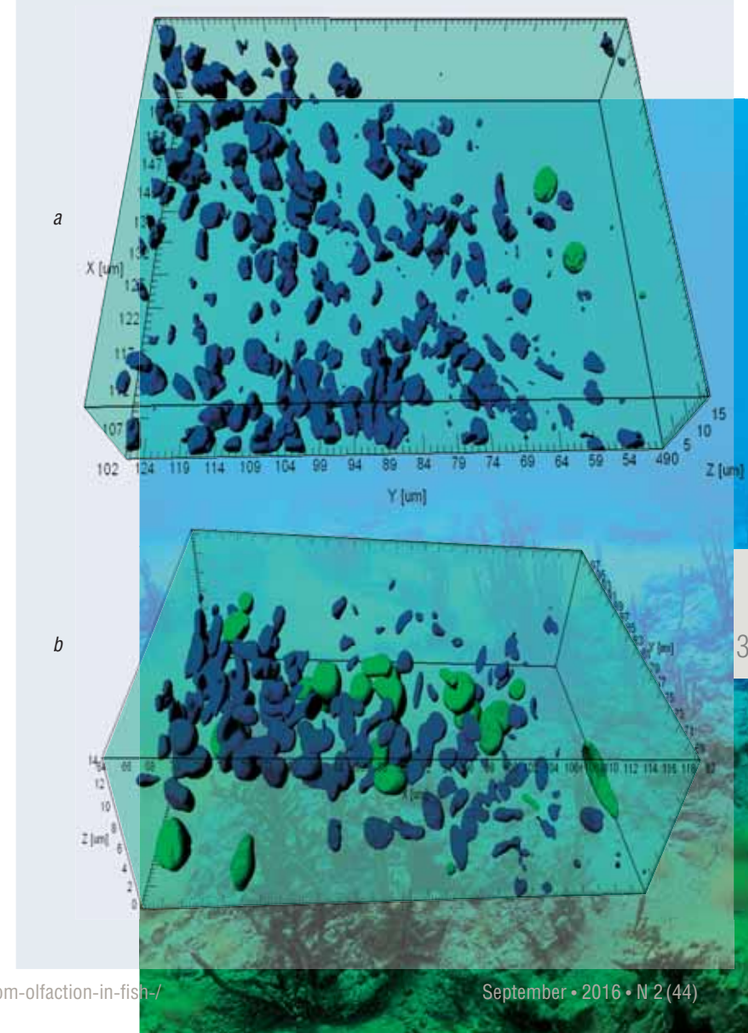
Beyond spawn season

Dendritic neurosecretion occurs in fish not only in the spawning period. One can see similar ultrastructural reorganizations of olfactory cells if a fish is subjected to a prolonged odor impact with nontoxic water-soluble substances; we used a mixture of amino acids and peptides.

We assumed that the stimulated chemoreceptor neurons begin to produce not a membrane-bound, but a water-soluble form of proteins (Klimenkov *et al.*, 2015), which bind the odorant molecules directly in the olfactory mucus, providing an adaptive loss of smell: if a fish has long been exposed to an odor, it stops feeling the smell.

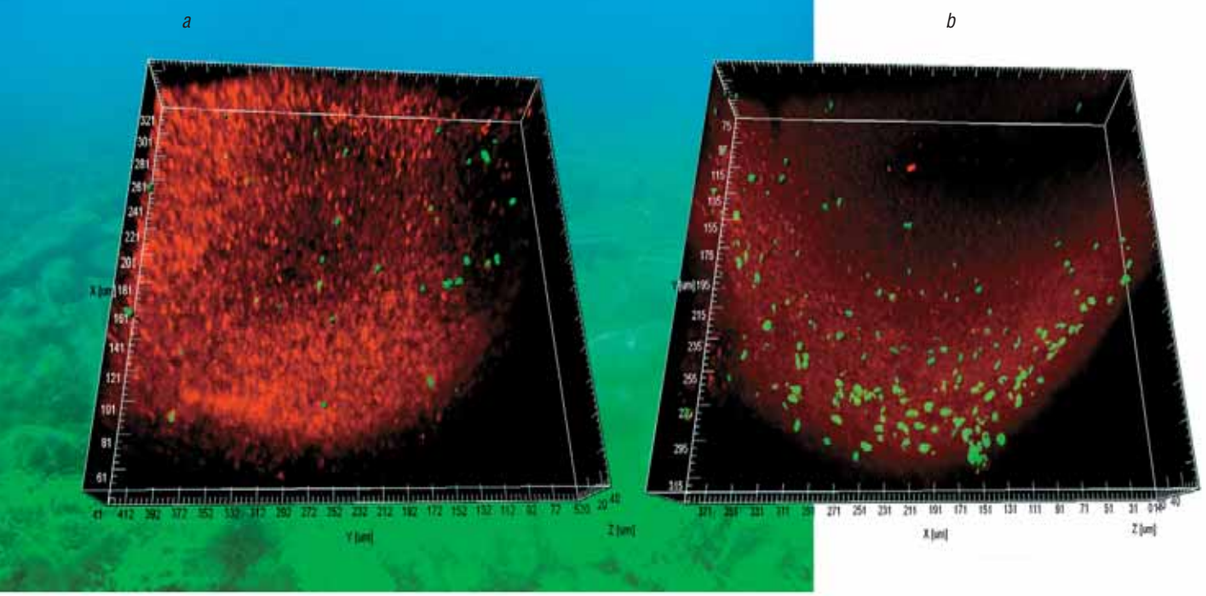
Although this is a fascinating hypothesis, it remains unclear whether the cells can switch from the synthesis of a membrane-bound form of receptor proteins to that of a secreted form while maintaining their specificity, because it is still unknown how to collect the water-soluble form of the receptors. It is possible that, during dendritic neurosecretion, neurons may switch to the synthesis of some other proteins or short neuropeptides. Such an interpretation gives rise to the "oligogene" hypothesis of the encoding of receptor proteins, according to which olfactory cells can express, at different stages in their development, not one but several genes that encode the odorant receptors (Mombaerts, 2004).

Baikal sculpin of the species *Procottus major*, Taliev, 1949



In comparison with (*a*) the control conditions, there is enhancement of programmed cell death in the olfactory epithelium of the pearl gourami (*T. leeri*) (*b*) after a prolonged chemical stimulation with a heterogeneous mixture of amino acids and peptides.
Click-iT® TUNEL; the nuclei of dead cells are colored with *Alexa Fluor* (*green*); those of viable cells, with *Hoechst* (*blue*); confocal microscopy; 3D-reconstruction

It should be noted that olfactory cells with dendritic neurosecretion are morphologically similar to hypothalamic neurosecretory cells, whose "job" is to synthesize and release substances of different chemical nature, which take part in information processing and ensure neuroplasticity. Currently, researchers admit that, along with amino acids and monoamines, these substances include neuropeptides secreted by both the axons and dendrites of nerve cells (Leng and Ludwig, 2008). Neuropeptides may act not only in the synapse. Their half-life is rather long; they diffuse into the extracellular space and can affect more distant targets (Son *et al.*, 2013). Therefore, in addition to the quick-acting neurotransmitters, neuropeptides



Individual folds of the olfactory epithelium in stone sculpins (*Paracottus knerii*) (*a*) under the control conditions and (*b*) after a prolonged exposure to a heterogeneous mixture of peptides and amino acids. Selective coloring of the nuclei of mitotically active cells with *FITC* anti-bromodeoxyuridine antibodies (*green*). Nondividing cell nuclei are colored with 7-aminoactinomycin (*red*); confocal microscopy; 3D-reconstruction

are considered as a major means of chemical communication in the brain. Thus, the dendritic neurosecretion phenomenon, which is observed in some types of central nervous system cells, is perhaps not an extraordinary property of olfactory neurons either.

Compensatory neurogenesis and medicine

It was found in experiments that, during a prolonged exposure to an odor, some olfactory cells undergo neurodegenerative changes and die. This is preceded by damage to the mitochondria in these cells and increased formation of free radicals, which is observed during the development of many pathological processes. We have to make a paradoxical conclusion: even completely harmless odorous substances, when taken in excess amounts, affect the cell as a stress factor.

We hypothesized that in such conditions, there should be compensatory neurogenesis processes in the sensitive epithelium. Indeed, the intensity of proliferative activity in the experimental fish was higher by a factor of 2.6 than in the control group. That is, the formation of new cells in animals' sensor apparatus can be activated not only after the transection of the olfactory nerve and mechanical or acute toxic impacts, as we believed, but also during an enhanced odor stimulation and the subsequent degenerative changes.

This phenomenon is very important from a practical point of view. Now there is a great concern about the sources of undifferentiated neural cells which could be cultivated and used as a biological "glue" to treat traumatic lesions of the nervous system. The most important requirement for such a "glue" is its genetic compatibility with the cells of the individual who needs the treatment. Addressing this problem encounters many challenges, including ethical issues. Baikal sculpins could provide exciting material not only for understanding their biology and mechanisms of adaptation to the chemical factors of the environment but also for using this knowledge to address some issues of regenerative medicine. The olfactory epithelium is the only available source of autologous undifferentiated neural cells which can be used for transplantation in the treatment of the nervous system diseases (Viktorov, 2006).

There is a theory to support this idea: the structural and functional properties of the olfactory epithelium are not different in fish and in humans, and it is necessary to conduct studies on mammals. The epithelium should be treated with an odorant in a water-soluble, not volatile form, whereby the solution is injected into the nasal cavity. In this case, neurons should be better activated, which would lead to their more intense degradation, with subsequent compensatory activation of the stem cell division and formation of a pool of undifferentiated neural cells which have potential applications in medicine. From a practical point of view, taking such a biopsy is quite simple.

Another aspect is that the olfactory system is involved in the development of a number of socially significant neurodegenerative diseases such as Alzheimer's, Parkinson's, etc. It is known that dementia (impairment of the higher functions of the brain), which is usually due to aging, is accompanied by a decrease in the quantity of chemosensitive cells and an olfactory dysfunction. If we find out how to noninvasively stimulate neurogenesis at the level of the peripheral olfactory analyzer, the lost cells could at least be partly replenished. We should not exclude the possibility of the positive effect of the increased influx of odors on the central structures of the brain with which olfactory cells are associated. We can even suggest that this phenomenon lies at the core of the therapeutic effects of aromatherapy, which was born many centuries ago in the East.

In conclusion I would like to quote our colleague, a prominent expert in neurobiology, Professor N.S. Kositsyn (Institute of Higher Nervous Activity and Neurophysiology, Moscow), who said: "In these studies, Lake Baikal is more than a unique endemic-rich lake, it is a methodological approach that gives us natural models to investigate complex issues of medicine as well as biology."

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Male bighead sculpin
(*Batrachocottus baicalensis* Dybowski, 1874)

N.P. SUDAKOV, I.V. KLIMENKOV, M.V. PASTUKHOV

THE FISH OF LAKE BAIKAL against Atherosclerosis

On a New Experimental Object for Medicine

Cholesterol metabolism imbalance leads to atherosclerosis and is a factor causing myocardial infarctions and strokes. Atherosclerosis and the triggered cardiovascular diseases are major contributors to population mortality in Russia and in other industrially developed countries. To design efficient methods for making early diagnoses and then treating this disease, it is necessary to acquire thorough knowledge about the mechanisms of its development. Amazingly enough, some fish of Lake Baikal can help in solving this problem

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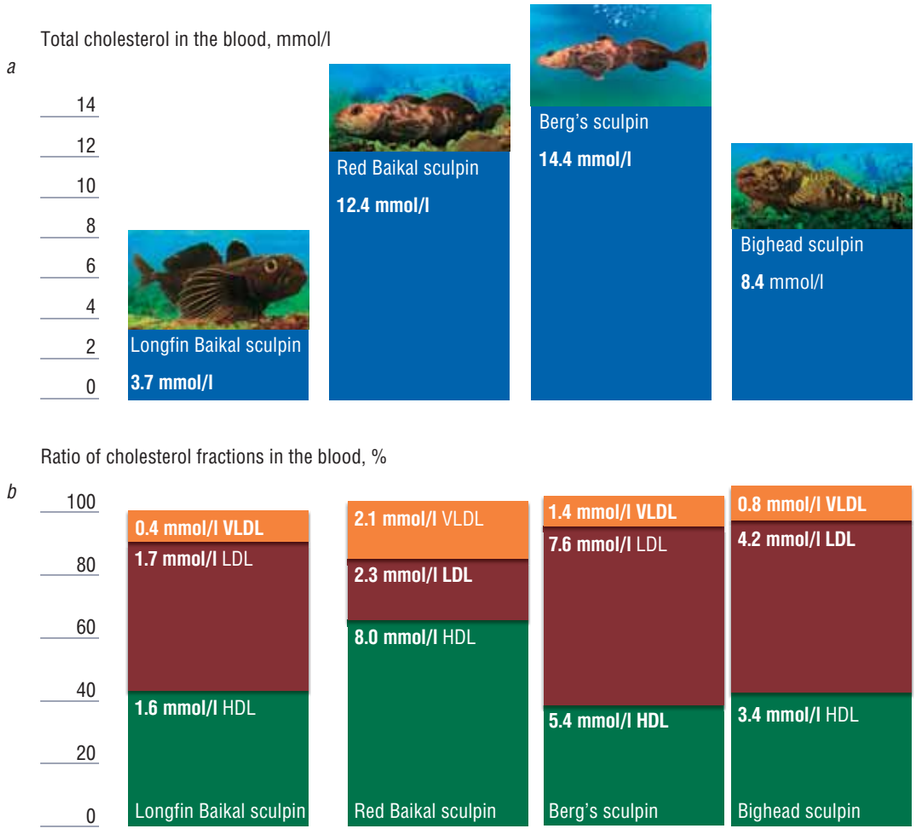
Key words: cholesterol, lipoproteins, Baikal, fish, Cottoidei, animal models, atherosclerosis, atherogenic lipoproteins



Differences in the cholesterol concentrations and (*a*) its atherogenic and antiatherogenic fractions (*b*) in the blood of Lake Baikal sculpins

Cholesterol and other fats travel in the bloodstream as *lipoproteins*. These particles have a rather intricate structure composed of a "drop" of fat and specialized proteins that help the drops to interact with the cells of a body. Lipoproteins either partially exchange their lipids with cells or are just captured by cells.

Bad and Good Cholesterol

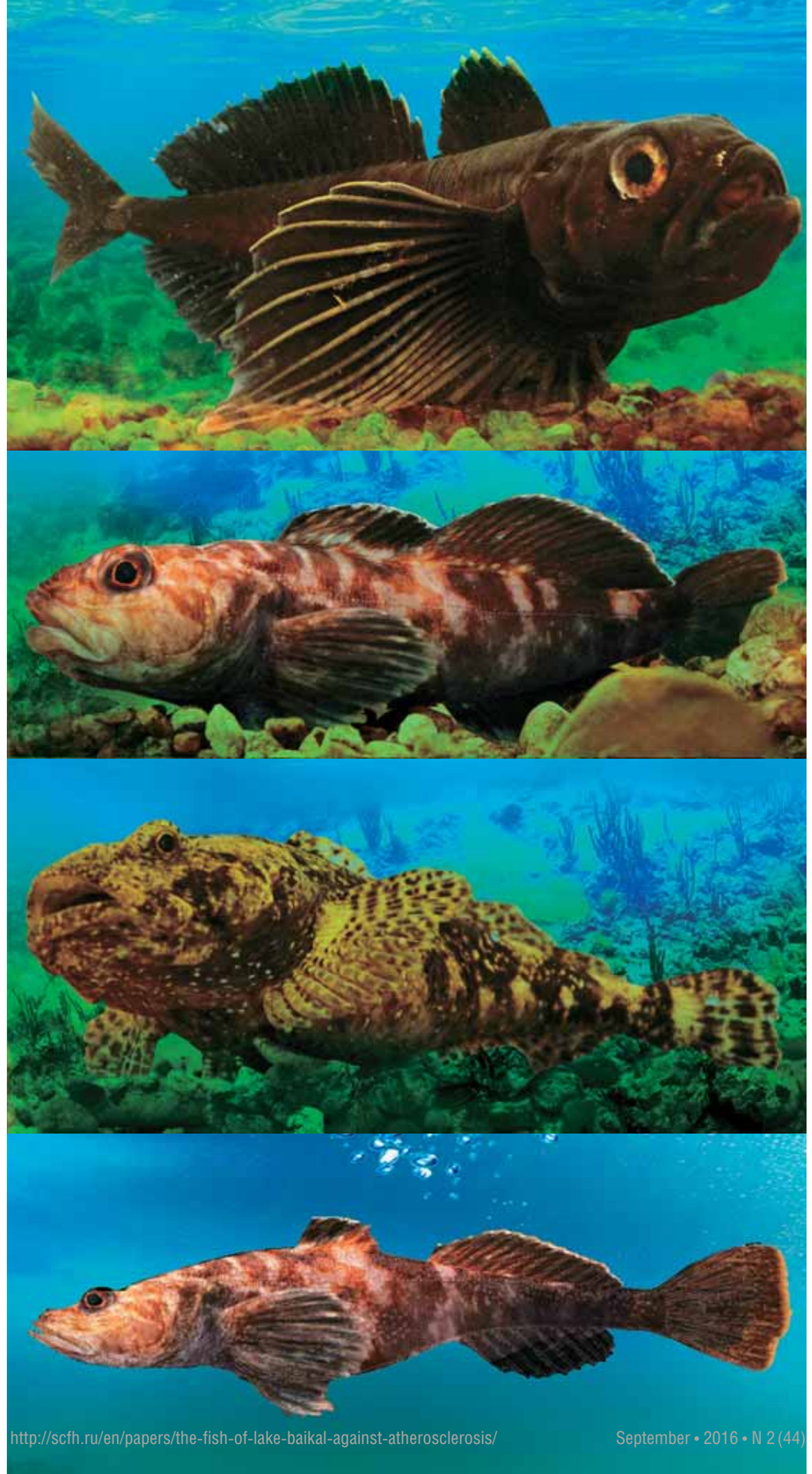
Cholesterol metabolism disorder is mainly an increase in its level in the blood; in addition, the ratio of its fractions changes. There are several types of lipoproteins, or cholesterol fractions. One type unites *very low density lipoproteins* (VLDLs) and *low density lipoproteins* (LDLs); they are atherogenic lipoproteins, or, as patients say, "bad" cholesterol, which is responsible for the developing of atherosclerotic plaques. These particles carry cholesterol from the liver to the cells of blood vessels. The other type, "good" *cholesterol*, or antiatherogenic lipoproteins, referred to as *high density lipoproteins* (HDLs), transports cholesterol in the opposite direction, from blood vessels to liver cells, thus hindering atherosclerosis development. The liver is the major regulator in the metabolism of cholesterol and other fats and is able to eliminate this compound from the body with bile.

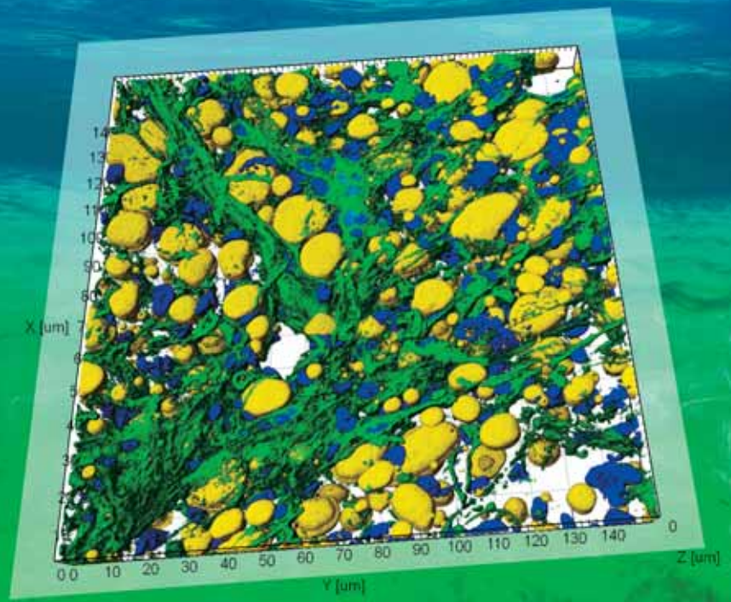
The body maintains fine equilibrium between the fractions of "bad" and "good" cholesterol in the blood with the help of intricate biochemical and genetic mechanisms, some of which are yet vague. This equilibrium can be disturbed; therefore, it is of the utmost importance to know the mechanisms that control the adaptation of blood cholesterol metabolism and keep the balance between the "bad" and "good" fractions when they are influenced by various adverse factors. The factors are numerous and include, in particular, the diet with high cholesterol content, smoking, and fat accumulation in liver cells (Klimov and Nikul'cheva, 1999).

Baikal Model

All animal species have their own specific features of cholesterol metabolism; this determines the degree

Top to bottom:
longfin Baikal sculpin (*Cottocomephorus inermis* Yakovlev, 1890);
red Baikal sculpin (*Procottus major* Taliev, 1944);
bighead sculpin (*Batrachocottus baicalensis* Dybowski, 1874);
and Berg's sculpin (*Limnocottus bergianus* Taliev, 1935)





Numerous large lipid drops in the liver cells of the red Baikal sculpin (*Procottus major*). The cell nuclei are stained with DAPI (*blue*); fat drops, with Nile Red, a dye specific for lipids (*yellow*); and actin cytoskeleton, with FITC-conjugated phalloidin (*green*).
Laser confocal microscopy

of resistance to the development of lipid metabolism disorders. The species-specific differences in the systems controlling cholesterol metabolism are a unique material for clarifying the mechanisms that underlie resistance to pathological changes as well as for using them to prevent and treat human cardiovascular diseases. For example, the comparative analysis of the ratio of cholesterol fractions in the blood of animals resistant to atherosclerosis has made it possible to discover the important role of HDLs (Klimov and Nikul'cheva, 1999), giving the HDL cholesterol the name of "good" cholesterol.

For such research, the disease is artificially reproduced (simulated) in animals. Unfortunately, the model species currently used for this purpose belong to different systematic groups, such as mammals, birds, and fish (Getz and Reardon, 2012); they are very remote from each other from the evolutionary and, correspondingly, genetic standpoints, which interferes with understanding the general pattern of cholesterol metabolism adaptation. In order to solve this problem, it is necessary to examine the groups of genetically related organisms that occupy different ecological niches and, thus, have different characteristics of their lipid metabolisms.

An appropriate model for this purpose is endemic closely related species of sculpins (Cottoidei), living in Lake Baikal. This fish group comprises 26 species that originated from a small number of ancestral forms (Sideleva, 2003). Different Cottoidei species display a wide diversity and are adapted to different habitats and diets with different risks of atherosclerosis development. It is important that anthropogenic pollution in Lake Baikal is minimal as compared with other water bodies (Shimaraev *et al.*, 2000), which excludes the data distortion associated with pollution.

Different Species, Different Lipids

Four Cottoidei species differing in their diets and behavior were chosen for this research (Sudakov *et al.*, 2015); namely, the red Baikal sculpin (*Procottus major* Taliev, 1944), longfin Baikal sculpin (*Cottocomephorus inermis* Yakovlev, 1890), Berg's sculpin (*Limnocottus bergianus* Taliev, 1935), and bighead sculpin (*Batrachocottus baicalensis* Dybowski, 1874). The level of total cholesterol in the blood turned out to be individual for each species. The lowest cholesterol level, in fact comparable to that in humans (Flaim *et al.*, 1981), was observed in the longfin Baikal sculpin, which lives in water. The cholesterol level observed in the remaining three species, which live at the bottom, was higher.

The fractional composition of cholesterol displayed even greater differences. The highest level of antiatherogenic cholesterol was observed in the red Baikal sculpin, and the lowest, in the longfin Baikal sculpin, the content of atherogenic cholesterol in both species being low. On the contrary, the atherogenic cholesterol content in the Berg's and bighead sculpins was high. In other words, "good" cholesterol prevails over the "bad" one in the red Baikal sculpin, while "bad" cholesterol is prevalent in the remaining three species.

Interestingly, the observed differences in the lipid profiles of the fish blood are not associated with their specific diets, suggesting that the blood levels of cholesterol fractions in these closely related species are strictly predetermined at the genetic level. For example, the lipid profiles of the Berg's and Red Baikal sculpins are opposite with respect to the cholesterol atherogenic and antiatherogenic fractions despite the fact that they mainly eat the same amphipods (crustaceans). Amazingly, the lipid pattern of the Berg's sculpin, which feeds mainly on amphipods, is most close to that of the bighead sculpin, the most active predator in the Cottoidei family. Amphipods account for 70% of its diet with the remaining 30% consisting of other Cottoidei species.

In addition, these fish species can be of interest because of the important role of their liver in storing fats (Henderson and Torcher, 1987). Microscopy has shown that the Cottoidei liver tissue contains numerous cells with large lipid drops. The high concentration of lipids in the liver of some sculpins has been also demonstrated by biochemical assays (Kozlova, 1998). Surprisingly, the large volume of fat drops in the fish liver cells is not accompanied by the development of cholesterol disorders and atherosclerosis, which would be impossible in the human and other mammalian species. Presumably, fat drops are an integral regular component of the liver cells of the Cottoidei and of many other fish; they are not pathological elements, as is the case with accumulating excess fat in the mammalian liver (Takahashi *et al.*, 2012).

The examined Cottoidei species represent a unique set of model organisms for studying the genetic, physiological, and ecological mechanisms that underlie the resistance to developing cholesterol disorders and atherosclerosis.

Despite their common origin, the representatives of the examined species display a wide range of total cholesterol and its fractions in the blood as well as distinct specific features of the blood lipid profiles. A study of the mechanisms that underlie these differences will provide a deeper insight into the adaptation patterns of cholesterol metabolism and resistance to the developing of atherosclerosis. Moreover, the specific features of the fat content in fish liver will contribute to our understanding of the mechanisms that determine the resistance to negative effects of their excess accumulation in the liver.

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LIVE Silicon OF LAKE BAIKAL

Silicon is one of the most abundant chemical elements in the Earth's crust; however, it is not a structure-forming element of living organisms, its high concentrations being toxic for living cells. Nonetheless, many organisms such as sponges, radiolarians, and higher plants, especially cereals, rather actively utilize silicon in their bodies' scaffolds. Note that silicon plays the most important role in the life of chrysophytes and diatoms, accounting for over 50% of their biomass.

Diatoms are known as skillful architects of manifold silica 3D structures of a nanometer scale. The new term "diatom nanotechnologies" was introduced to describe the way these organisms use to construct their silica exoskeletons. A diatom has to solve several difficult problems concurrently, namely to extract silicic acid from the sea or a freshwater lake\ river, where its concentrations are rather low; then to store the acid in the cell until it is time to deliver it to the special sites of a forming frustule where it will be polymerized. In order to get frustules with a prespecified intricate structure, the overall silica deposition within diatom cells should be strictly controlled.

Silicon technologies form the basis of microelectronics and are in great demand in many areas of modern industry, from power production to metallurgy. Since diatom nanotechnologies do not need any extremely high temperatures and "heavy chemistry", they excite strong interest of experts in different areas.

Diatoms are the most abundant group of algae in Lake Baikal, comprising both widespread and endemic species. Find below the results of molecular genetic studies carried out by young researchers of the Limnological Institute (Siberian Branch, Russian Academy of Sciences, Irkutsk) when they "reconstructed" the mechanisms of silicon "import" and production of silica frustules of Baikal diatoms

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SILICON NANOTECHNOLOGIES IN A TUBE

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Key words: diatoms, morphogenesis, colchicine, paclitaxel, biosilica, microstructures, nanostructures

The ability of diatoms to skillfully manipulate silicon (this ability has been evolving and "optimized" for tens of millions of years) is of great interest to researchers in the epoch of high technologies. The term "*diatom nanotechnologies*" was introduced by R. Gordon (Gordon and Aguda, 1988) in the late 20th century. Currently, we may speak about *silicon nanotechnologies* in a broad sense (Grachev *et al.*, 2008), with regard to all the group of pigmented heterokonts that include both diatoms and chrysophytes.

Thanks to their optical properties and a large surface area, on which antibodies and enzymes can be immobilized, diatom frustules can be used as biosensors (Gale *et al.*, 2009; Sheppard *et al.*, 2012). As has been recently demonstrated, diatoms are most useful for target delivery of poorly water-soluble drugs, particularly anticancer substances (Delalat *et al.*, 2015).

Diatom frustules are also the object of tribology, the science that studies interacting surfaces of solid bodies in relative motion. Here, of particular interest

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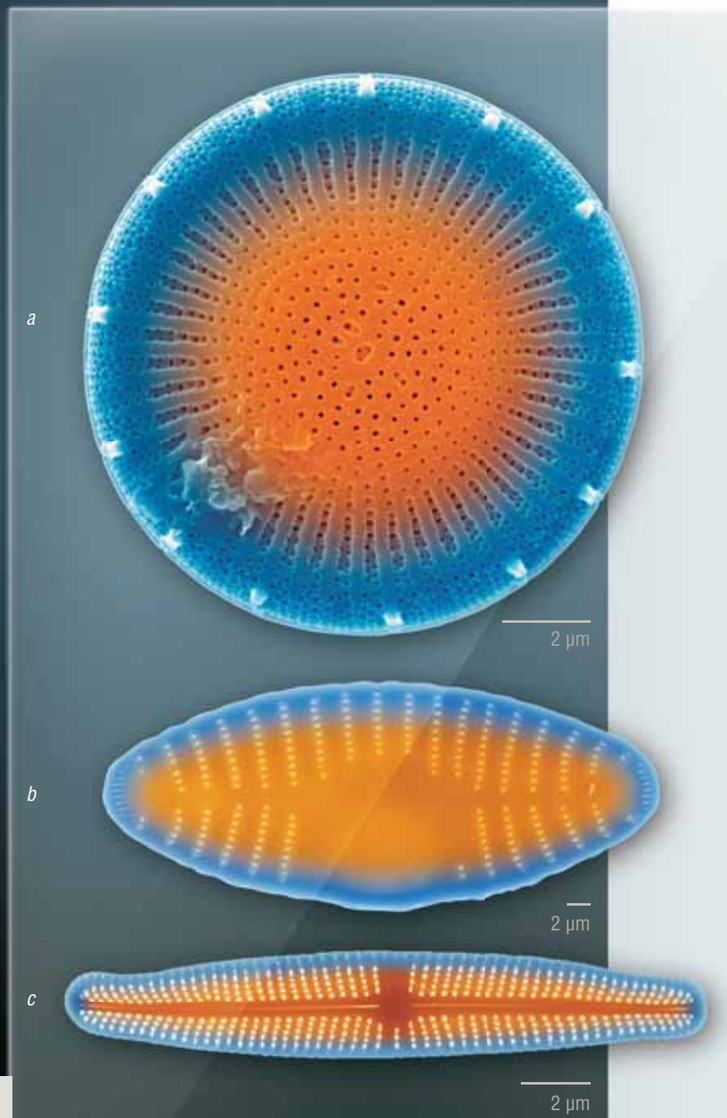


Among all unicellular organisms that synthesize micro- and nano-sized inorganic structures, diatoms are notable for a special diversity of shapes. According to the symmetry of their frustules diatoms fall into three main groups: centric with radial and bipolar symmetries (the most ancient group), and pennate with bilateral symmetry. In turn, pennate diatoms are divided into araphids and raphids (without a raphe on their valve or with it)

Diatoms with different types of frustule symmetry:

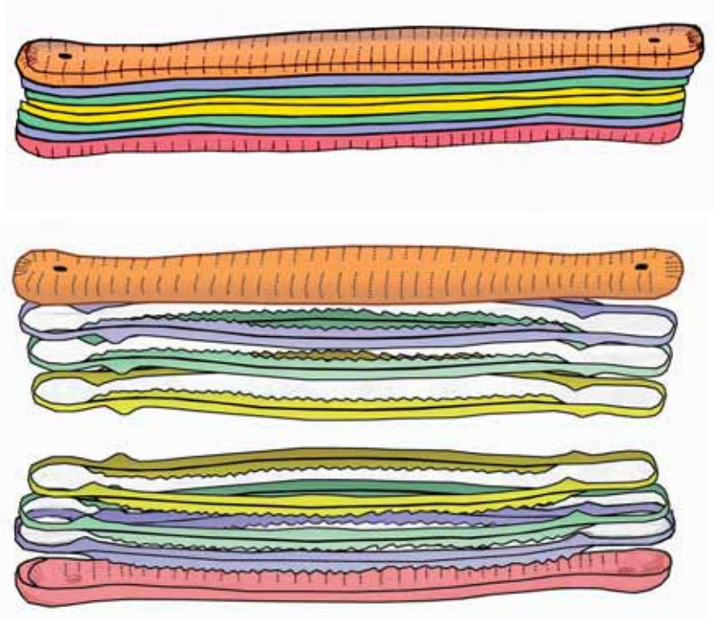
a – centric diatom *Stephanodiscus* sp. with radial symmetry;

b – pennate araphid diatom *Fragilaria vausheriae* var. *capucina* with bilateral symmetry;

c – pennate raphid diatom *Achnantidium sibiricum* with bilateral symmetry

are the mechanisms underlying the formation of colonies of algal cells with the help of silica constructs and adhesive substances they secrete (Crawford and Gebeshuber, 2006; Gebeshuber, 2007). Diatoms could also become an economical substitute for such nanotechnologies as planar lithography, which is used to fabricate "flat" semiconductor devices, microelectronic integrated circuits, and some superconducting nanostructures. One of the stages in this technology is the formation of a raised pattern that repeats the microcircuit topology in the sensitive layer on the substrate surface. If only we could "order" a particular pattern to a diatom!

This dream excites a lot of people: its implementation could become the basis of fundamentally new biotechnological plants. However, though these studies have been conducted since the mid-20th century and despite the prospects of economic and other benefits, we are still very far from a clear understanding of the genetic and cellular processes underlying the morphogenesis of diatom silica frustules.



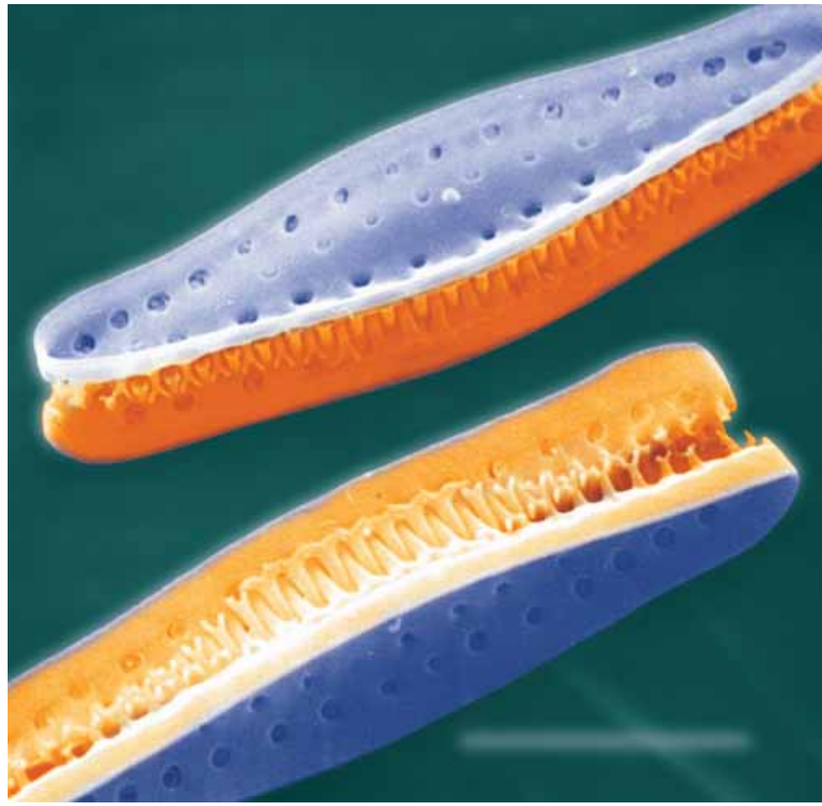
The diatom frustule consists of two overlapping valves connected by a system of griddle bands

Pairs of connected valves of *Cymatoseira* sister cells. *Photo by the courtesy of Crawford and Gebeshuber*

Key Component: Microtubules

The silicon frustule of diatoms is formed in a specialized cell organelle, a silica deposition vesicle enclosed in a specific membrane, the silicalemma. It is now known that the cytoskeleton and particularly microtubules play a major role in the formation of a frustule; the microtubules of some diatom species have been visualized by fluorescence and confocal microscopy. The algae treated with certain substances that inhibit the function of microtubules (colchicine, lumicolchicine, oryzalin, etc.) form frustules with various abnormalities.

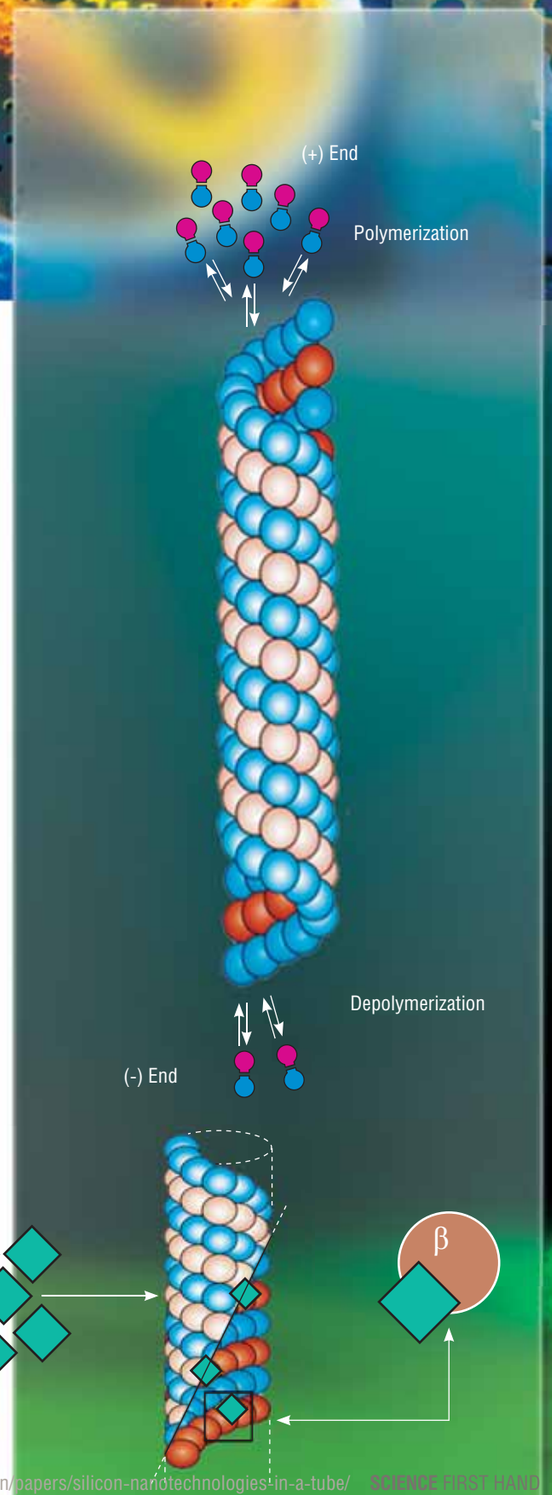
For the first time in the world, the project of the Department of Cell Ultrastructure with the Limnological Institute (Siberian Branch, Russian Academy of Sciences) has given an insight into the role of the cytoskeleton in frustule morphogenesis. The study was performed in a synchronized culture of diatoms where all cells were



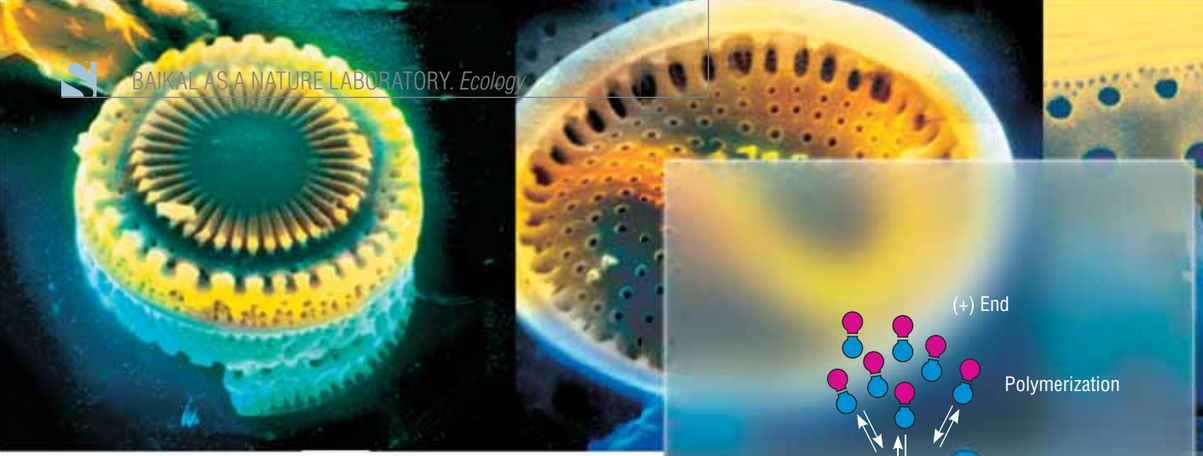
at the same stage of a cell cycle. The diatom cell culture is quite easily synchronizable: it is sufficient to keep the cells for a certain time in a silicon-free medium. Initially, the cells will actively spend the stored silicon on constructing a frustule; once the silicon reserve is depleted, they will stop dividing and "freeze" at a certain stage of their life cycle. After silicon is added to the medium, the cells restart forming new frustules and dividing.

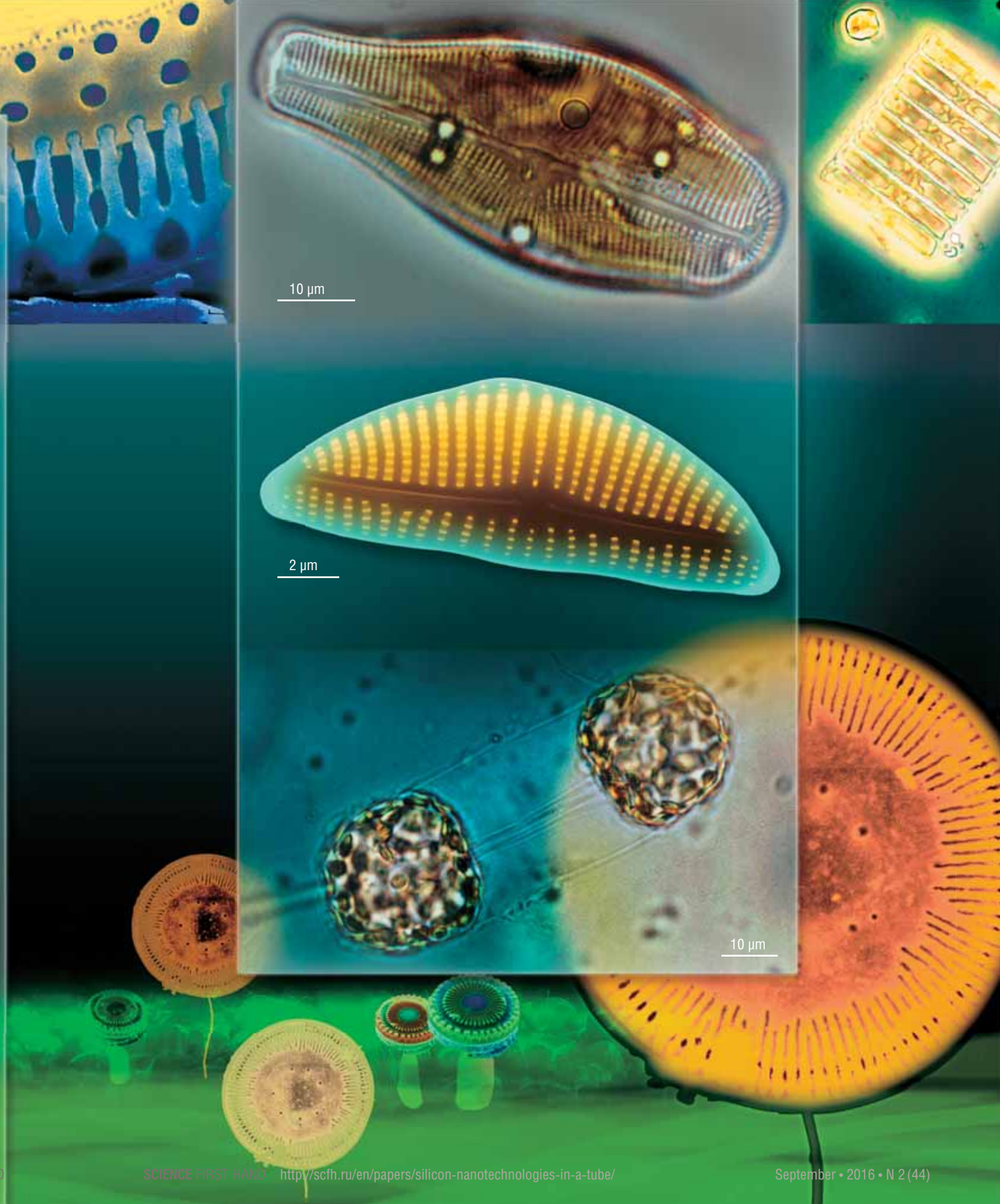
The experimental object was the diatom *Synedra acus* subsp. *radians*; this alga has been a model object at the Limnological Institute for several years. It allows the researchers to study all aspects of frustule morphogenesis, and propagates itself well in a laboratory culture. Two inhibitors of microtubule function with different mechanisms of inhibition, colchicine and paclitaxel (for the first time) were used in the experiments. Colchicine blocks the assembly of new microtubules by binding to their growing ends. Thus, the depolymerized microtubules cannot restore and are soon destroyed; they can recover after removal of colchicine. On the contrary, paclitaxel blocks the depolymerization of microtubules by binding to the protein β-tubulin, which causes the formation of microtubule bundles.

Experiments with synchronized *Synedra* culture have shown that it is possible to get new silica forms by adding colchicine at a certain moment of morphogenesis (Kharitonenko *et al.*, 2015). For example, adding colchicine 1.5 h after the beginning of frustule morphogenesis gives the largest number of valves with uneven and unparallel rows of areolae (pores), while adding it after 0.5 h gives the largest number of crooked valves. The most interesting fact is that valves without pores are formed only if colchicine is added 2.5 h after morphogenesis



Microtubules and the effect of paclitaxel
According to Dumontet and Jordan, 2010





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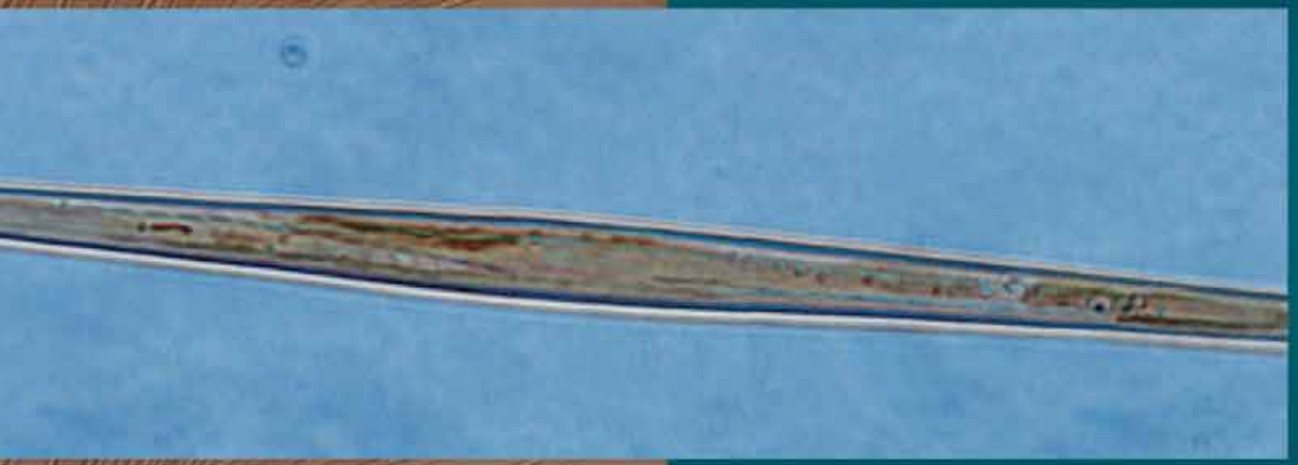
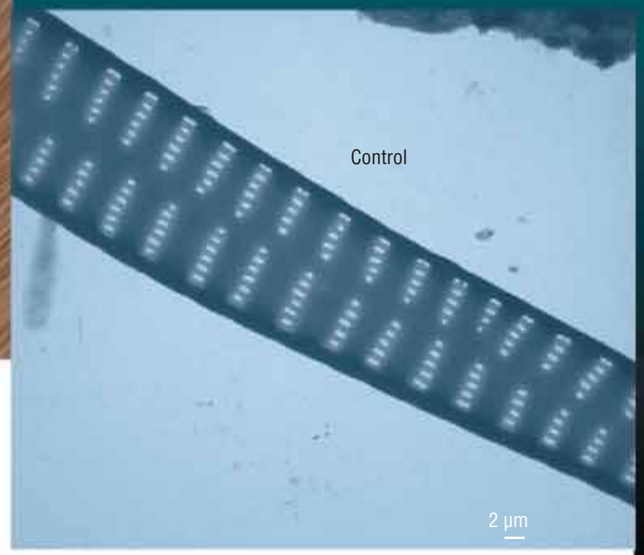




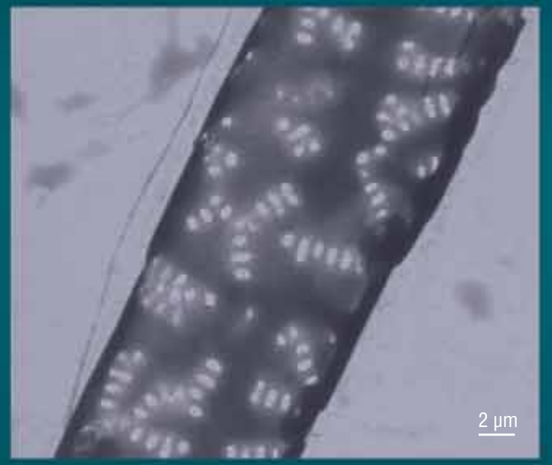
Synedra acus diatom.
Light microscopy

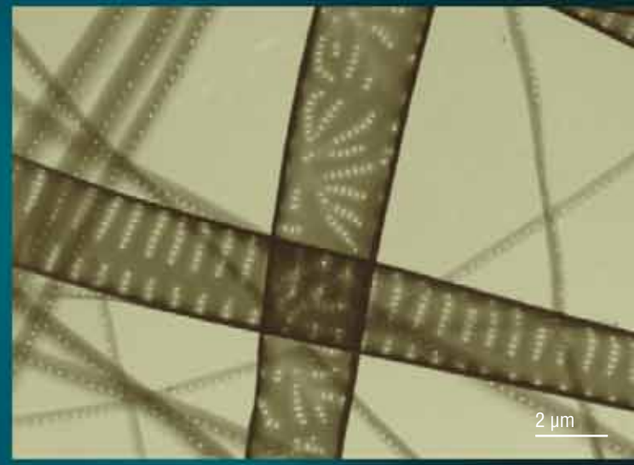
starts. This is also true of paclitaxel. When both inhibitors are used, the share of valves with abnormalities and their patterns of morphological changes depend only on the morphogenetic stage at which the inhibitors are added to the algal culture.

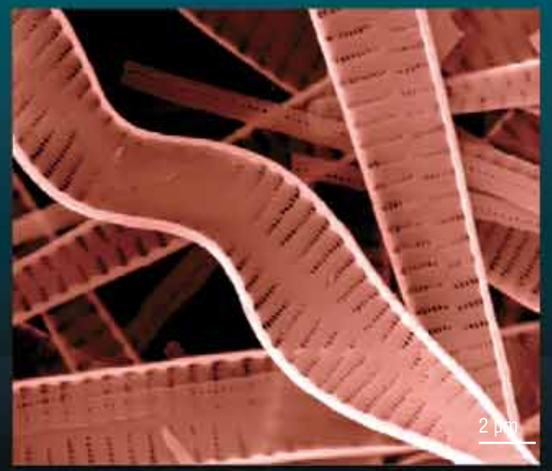
However, paclitaxel can induce such abnormalities in the valve structure that are not observed in the case of colchicine. These abnormalities include large pores (solitary cases) and valve widening, rather frequently observed when paclitaxel acts at early stages of morphogenesis.

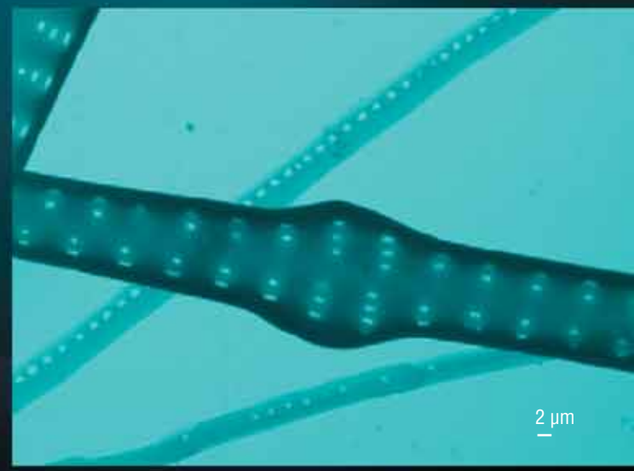
Synedra acus after addition of colchicine

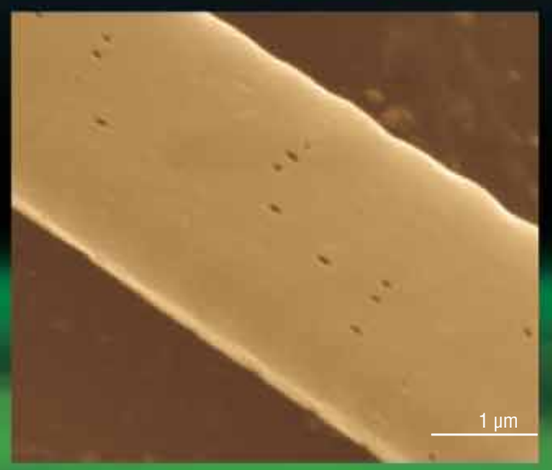
Synedra acus after addition of paclitaxel

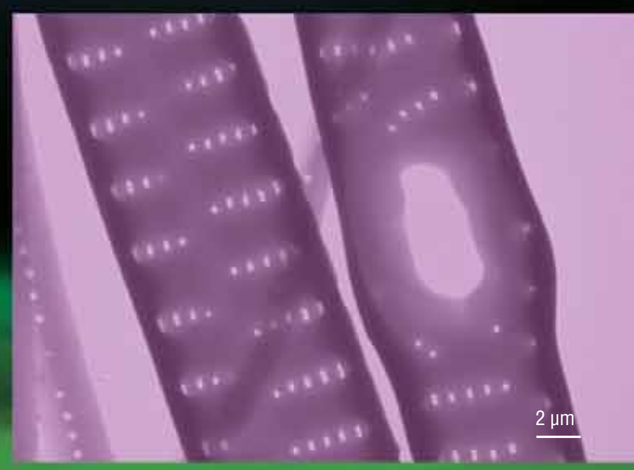




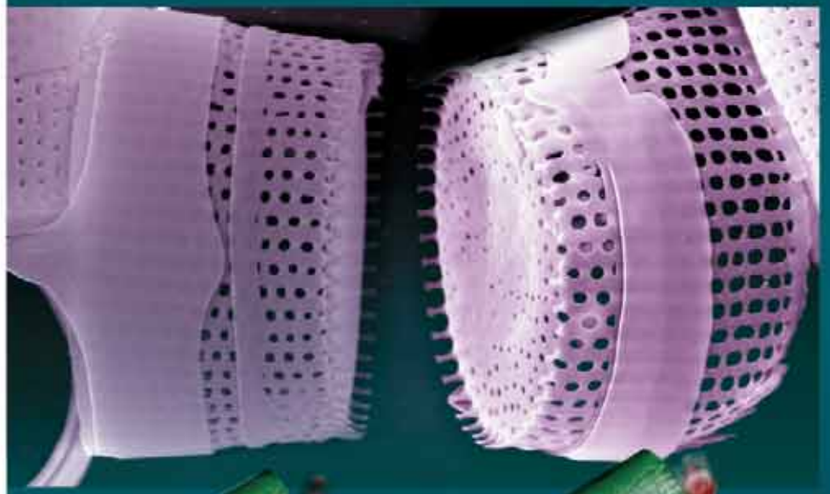


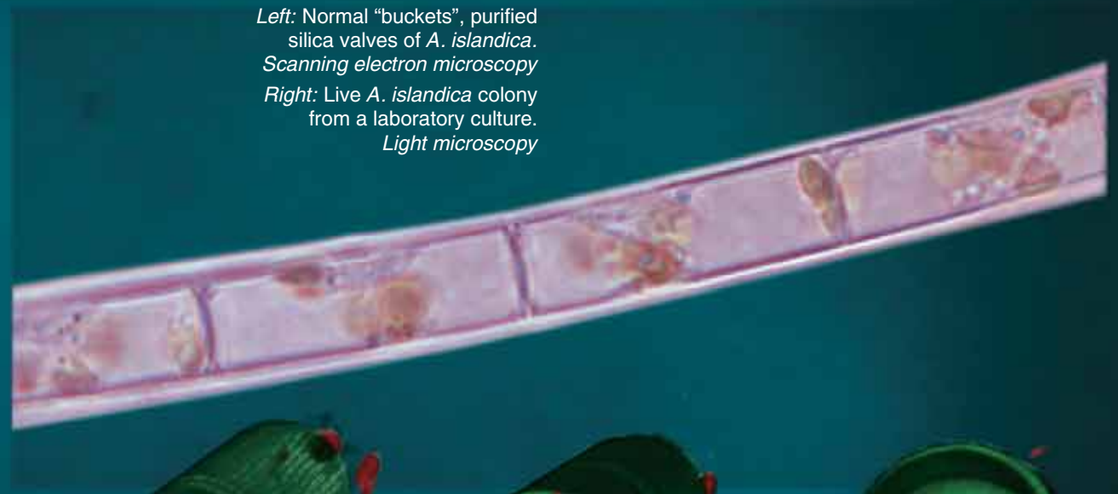






The share of cells displaying various abnormalities in the structure of a silica frustule increases after adding colchicine and paclitaxel to the synchronized cell culture of the pennate araphid diatom *Synedra acus*. When paclitaxel is added, there can occur such rare abnormalities as large pores in the valve.
Transmission and scanning electron microscopy





Left: Normal “buckets”, purified silica valves of *A. islandica*. *Scanning electron microscopy*

Right: Live *A. islandica* colony from a laboratory culture. *Light microscopy*

Addition of colchicine to the cell culture of the centric diatom *Aulacoseira islandica* results in the emergence of fused daughter valves, their silica frustule acquiring the shape of a “microtube” instead of a typical “microbucket”. *Photo*: 3D image of a normal *A. islandica* valve (*above*) and of a valve without its front part (*left*). *Confocal microscopy*

How to Make a “Tube” out of a “Bucket”

Nadezhda Volokitina (Limnological Institute) succeeded in cultivating another diatom species, *Aulacoseira islandica*, prevalent in the Lake Baikal phytoplankton in certain seasons. The morphogenesis of this diatom, unlike *Synedra’s*, is vague. The valve of the *Aulacoseira* diatom is shaped as a “microbucket”, and the cells in a colony are fastened together by special linking spines.

Since this species has a thin frustule which can be crushed and torn during manipulations, a special fluorescent dye is used to assess the effects of inhibitors on its morphogenesis; the dye is incorporated into the forming valves, and it allows the researchers to observe the results of experimental impact with the help of a confocal microscope.

This technology has demonstrated that some daughter valves fuse together in the presence of colchicine so that “microbuckets” turn into “microtubes”. Thus, if a cell is prevented from forming the “bottom” of a “bucket” (the face of a valve) at a certain stage of morphogenesis, it will continue to construct the valve bend according to the programmed scenario. It is as if constructors had not made the foundation of a building, and another team started erecting the walls and roof.

Current studies of the mechanisms that underlie the construction of diatom cell valves will allow us to use these silicon bionanotechnologies for the benefit of mankind, although there is a long way to go yet. Perhaps, further research into the regulation of microtubule function in the diatom cytoskeleton at cellular and genetic levels will make it feasible to obtain mutant algal cultures that could produce “tailored” silica structures with required characteristics.

Photos by the courtesy of the authors

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A. A. MOROZOV

WHY DO WE NEED TO "READ" *the Synedra acus* GENOME?

The diatom *Synedra acus* of Lake Baikal, one of the main research objects for the molecular biologists at the Limnological Institute (Siberian Branch, Russian Academy of Sciences, Irkutsk). *Photo by the courtesy of N. Volokitina*

In 2015, our research team (Limnological Institute, Siberian Branch, Russian Academy of Sciences) published the whole genome sequence of the diatom *Synedra acus*, which lives in Lake Baikal. Although now it is easier and much less expensive to "read" the genome of a living organism than a decade ago, this procedure still requires complex equipment and expensive reagents. So, why did researchers from the Limnological Institute tackle this large-scale project and choose this particular diatom as an object for their study?

Diatoms are of great interest to researchers working in most diverse areas of science. Owing to their abundance, diversity, and wide distribution—from oceans and lakes to peat bogs and Antarctic ice— diatoms account for up to 20% of the primary production in the biosphere; besides, these algal cells are enclosed in a wall of silica with an intricate nanosize structure, well preserved in geological deposits. However, the genomes of only six diatom species have been published, including *Synedra*, which is not enough for such a large group (Armbrust *et al.*, 2004; Bowler *et al.*, 2008; Tanaka *et al.*, 2015; Galachyants *et al.*, 2015).

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Diatoms account for up to 20% of the primary production in the biosphere of the Earth. This means that one of each five carbon atoms involved in the biological turnover is assimilated from the atmospheric carbon dioxide by a diatom cell

Keywords: diatoms, genomics, phylogenomics, evolution, Synedra

For example, consider oomycetes, fungus-like organisms with multinuclear mycelium, which are closely related to diatoms: full-genome sequencing has been completed for four species of only one genus, *Phytophthora*, out of a hundred. The point is that *Phytophthora* species are notorious pathogens of cultivated plants; if the analysis of their genome makes it possible to design methods for their more efficient control, the money spent will immediately pay hundredfold. As for diatoms, they mainly interested basic science until recently. On the other hand, a successful "reconstruction" of the mechanisms underlying the formation of silica shells will be a real breakthrough in nanotechnologies when the necessary research is completed. Currently, fewer than ten laboratories worldwide are involved in diatom genomics.

Genome as a Key to the Evolution of Diatoms

Genome sequencing helps to solve several important problems that cannot be solved by other research approaches, such as microscopy or biochemical analysis.

First, genetic information considerably enhances the search for proteins responsible for particular functions (Galachyants *et al.*, 2015). Once the genome project is completed, several tens of thousands of "read" genes and, correspondingly, predicted proteins are at the disposal of the researcher. Part of these genes is recognizable right away because analogous genes have been already studied and described in other organisms. As for the remaining genes, it is at least possible to estimate the molecular weights of the proteins they encode and search for their "relatives" in other genomes. It is also sufficiently easy to find out whether the protein of interest is a transmembrane protein or not, and to which cell organelle it is delivered after synthesis. Moreover, if transcriptome (the total set of all nucleotide sequences "read" from the genes, including mRNA and noncoding RNA, synthesized during a particular time interval) data are available, it is possible to clarify the conditions when this or that gene is expressed, or starts to work.

First and foremost, our team has focused on the genes involved in silicon metabolism, while the goal of Tanaka's research team, which sequenced the genome of *Fistulifera solaris*, was utilization of this marine diatom as a biofuel producer (Tanaka *et al.*, 2015).

Second, only if complete genomes are available, it is possible to study certain aspects of evolution; note that the evolution of heterocont algae, which include diatoms, is most intriguing.

It is currently regarded as proved that plant chloroplasts, in which photosynthesis takes place, originated via endosymbiosis: once a cyanobacterium cell was taken up by a eukaryotic cell, but was not digested; it started to function within the host, gradually reducing to the current state of an intracellular organelle. In this process, the endosymbiont donated most of its genes to the host genome. As for heteroconts, and in particular diatoms, it is postulated that their ancestors, in turn, "swallowed" a eukaryotic red alga together with its chloroplast. This theory is confirmed by the presence of four (instead of commonly met two) membranes surrounding the chloroplasts of diatoms as well as over 170 genes of red algae discovered in their genome (Bowler *et al.*, 2008). That is why diatom genomes contain genes traced back to the participants of both endosymbiotic events. Diatom genomes also include genes belonging to various prokaryotes (proteobacteria, archaea, etc.), brought there by the so-called horizontal transfer, as well as numerous unique genes that have no analogs in any other living organisms.

To trace the history of an individual gene, it is sufficient to sequence this gene alone for a certain sample of organisms, which is considerably faster and less expensive as compared with whole-genome sequencing; besides, many more species can be analyzed. However, the reconstruction of a complex evolutionary event requires studying the histories of all genes in all representatives of the group; this information can only be obtained through whole-genome studies.

In our case, the selection of an object for research was due to the fact that *Synedra acus* is a freshwater species. The fact that this diatom is able to extract the necessary amount of silicon even from the low- mineralized Baikal water makes *Synedra* an ideal candidate for studying the mechanism of silicon import as well as for learning about other adaptations to freshwater life. Second, this alga has become the first representative of a large group of araphid pennate diatoms, which makes it possible to track the history of development of certain molecular mechanisms and of specific genome features among different diatom taxa.

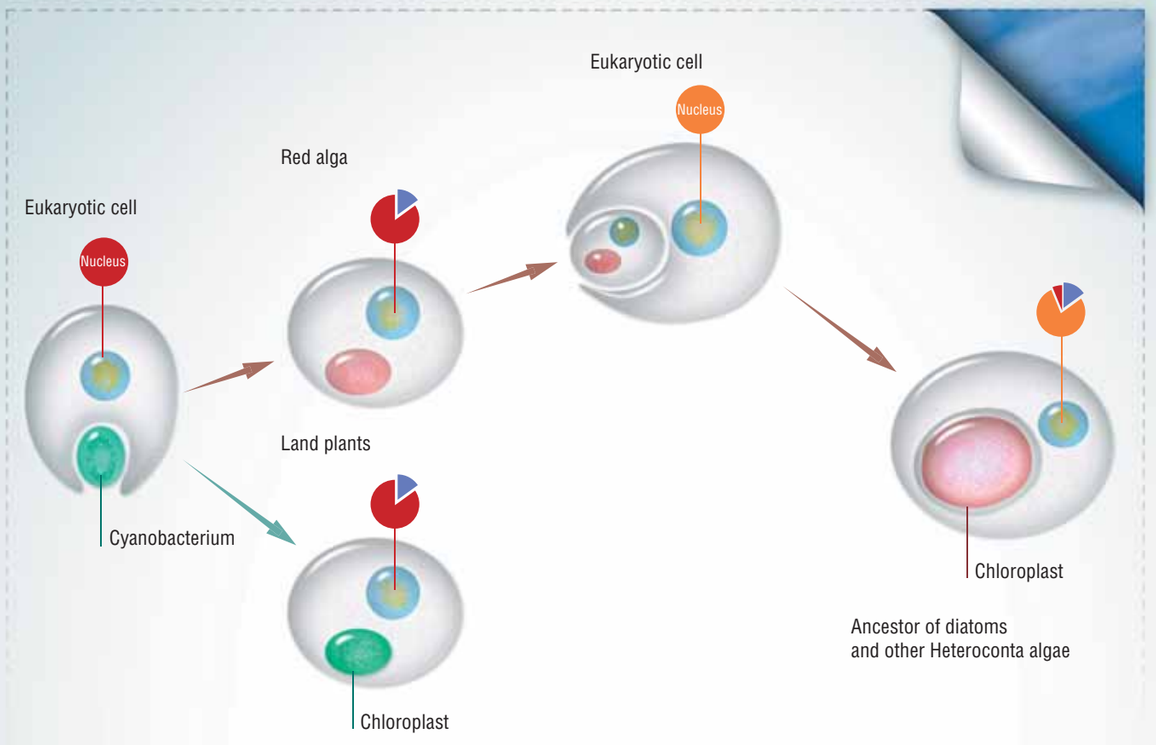
Our work on the *Synedra acus* genome does not end with the publication of its genome sequence. We have already obtained promising data on the structure of individual genes involved in the silicon metabolism, and the study of corresponding proteins is in progress. We intend to obtain transcriptome, which will help to assess the expression of target genes and to gain a deeper insight into their regulation.

After diatoms die, their empty firm silicon shells are perfectly preserved in deposits. Moreover, the finest elements of their structure frequently remain undamaged in the diatom fossils, allowing for their species-level identification millions of years later.

The molecular clock approach has shown that diatoms emerged approximately 230 million years ago. Presumably, the first diatoms were naked flagellate cells; they are currently affiliated with Heterokonta because at some stages of their life cycle they possess a flagellum with finest bristles.

The earliest diatom deposits were found in onshore sediments in Korea. It was hypothesized that the ocean, having stepped back some 230 million years ago, left puddles of water inhabited by flagellate diatoms. They began to use silica, which retards aging, in order to survive the adverse conditions at rest.

Ancient diatoms consumed so much silica that it started to accumulate in cells, possibly as small scales at the initial stage; the scales were forced out of the cells, forming a protective envelope around them, which prevented dehydration when shallow water bodies dried (according to Medlin and Sims, 2006)



The latest genetic data favor the hypothesis that diatoms, like the other Heteroconta algae, emerged about one billion years ago via the symbiosis of a non-photosynthesizing unicellular eukaryote and a unicellular red alga whose photosynthesizing organ (chloroplast) directly originated from symbiotic cyanobacteria

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I. YU. ZAIDIKOV

A tiny copepod—Epishura baicalensis—is one of the most well-known Baikal endemics. This dominant zooplankton species of Lake Baikal is a critical element in the food pyramid of the freshwater ocean. It feeds on bacteria and unicellular algae and is itself food for the Baikal omul and other pelagic fish.
This copepod is capable of filtering about one cup of water per day, thereby participating in the cleansing of Lake Baikal. However, there is also research interest in this aquatic invertebrate itself: its biology and ecology still keep a lot of secrets—from its strong silicon teeth to speciation

WHY DOES the Cleaner of Lake Baikal NEED DENTAL CROWNS?

Epishura in the field of view of a light microscope

Igor Yu. ZAIDIKOV, leading engineer at the Ichthyology Laboratory, Limnological Institute SB RAS (Irkutsk). Author and coauthor of five research works

Epischura baicalensis is a planktonic organism (from the Greek *planktos*, which means "wandering" or "drifting") inhabiting the water column of Lake Baikal. Like most planktonic organisms, it has a relatively small size (about 1.5 mm) and is almost transparent. It also feeds on plankton, but on photosynthesizing species only (small unicellular algae), and on bacteria.

Epishura gets its food by using a set of mouthparts, which create a flow of water from which it picks out edible objects. *Epishura's* feeding process is, in fact, no different from that of other copepods. Nevertheless, the life of this representative of a mots ancient arthropod group remains largely unknown to scientists. The food preferences of this copepod—*Epishura* is a picky eater—were previously described in (Melnik, 2004). Today, I will tell you about the research methods used to study this aquatic crustacean and the new exciting results on its population characteristics and the structure of its mouthparts.

Key words: zooplankton, Copepoda, Epischura, samples of plankton, research methods, Lake Baikal

Taking zooplankton samples with a Juday net

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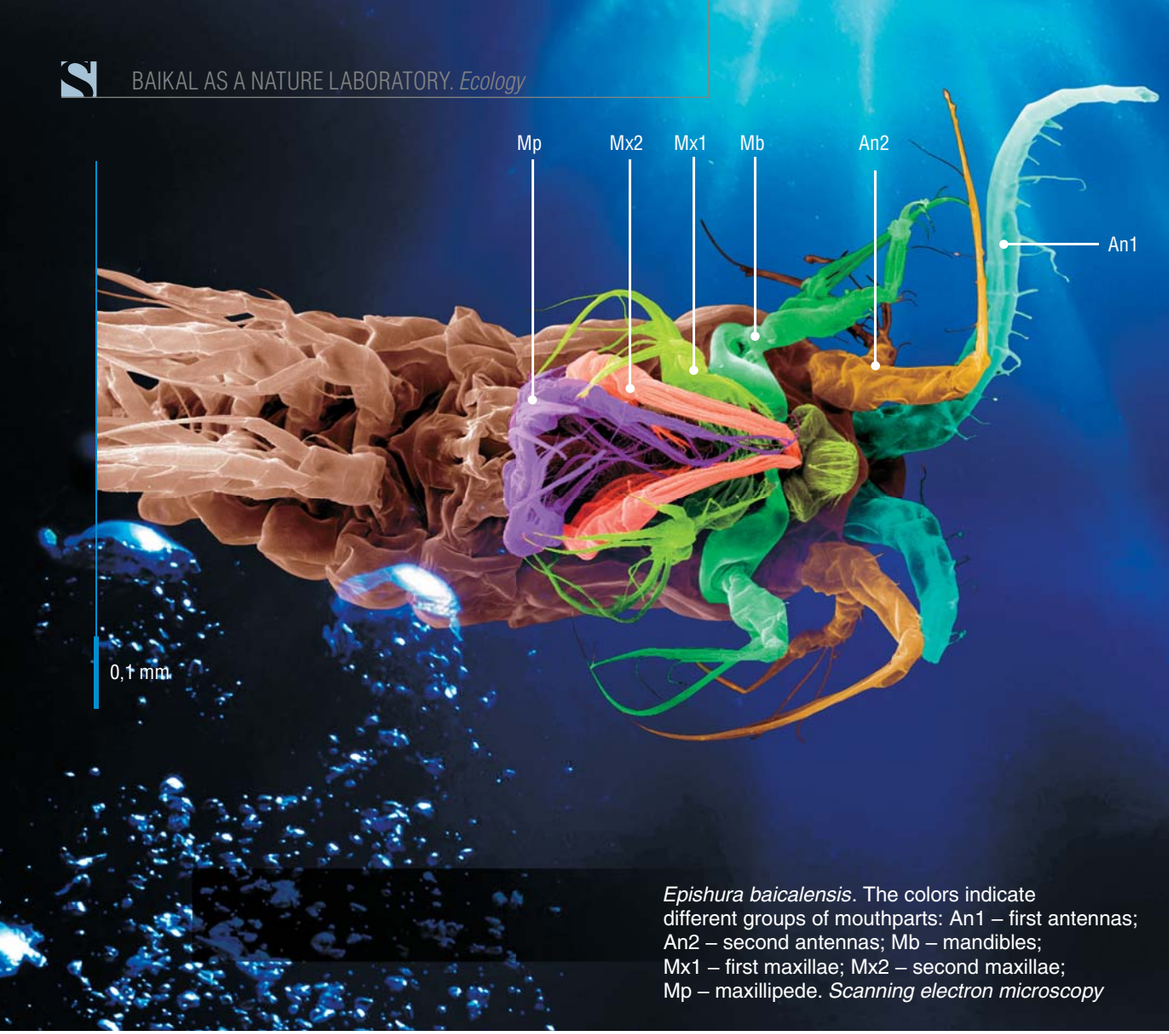


Epishura baicalensis. The colors indicate different groups of mouthparts: An1 – first antennas; An2 – second antennas; Mb – mandibles; Mx1 – first maxillae; Mx2 – second maxillae; Mp – maxillipede. *Scanning electron microscopy*

Epischura is a genus of free-living crustaceans in the subclass _Copepoda_. Members of this genus are found in freshwater bodies across Asia and North America, including in the Great Lakes, in the Russian Far East in basin of the Amur River and, finally, in Lake Baikal, the world's deepest and most ancient lake. The share of _Epischura_ in Lake Baikal is about 80 % of all the crustaceans, and its total biomass in the lake is 60,000 to 950,000 tons, depending on the year and season. _Epishura_ feeds itself by filtering food from the water with several pairs of mouthparts, which create a flow of water and simultaneously form a kind of a filter net to capture the desired food particles. The copepod is able to filter about one cup of water per day, thereby participating in the cleansing of Lake Baikal. _Epishura_ feeds on bacteria and unicellular algae, mainly diatoms, and is itself food for other crustaceans (cyclops and macrohectopus) and for all pelagic fish (omul, golomyanka, sculpin, etc.). Thus, Epishura is an essential link in the energy transmission chain from phytoplankton to predatory zooplankton representatives and fish

How we catch plankton

To conduct a study, we need to catch a sufficient amount of copepods from different parts of the water body. To this end, the ship must have special equipment, i. e., an electric winch with the possibility to control the speed of the rope, special plankton nets, etc.

The shipping season for the fleet of the Limnological Institute starts on Lake Baikal in late May, as soon as the ice is gone. As a rule, the season begins with joint expeditions, when there is a team of chemists, physicists and biologists on one ship. Each of us has their own tasks; mine are to collect zooplankton samples for myself and other researchers. The samples are collected using zooplankton nets, in particular, Juday and JOM (a larger oceanic model of Juday nets), with an attached weight of 8–15 kg (the larger the net, the heavier the weight).

The nets are attached to the winch rope, lowered to the desired depth and then lifted at a certain rate (about 1 m/s). If a plankton net is lifted too quickly, water does not have time to go through the fine holes in the filtering part of the net and begins to push out the plankton we want to catch. On the other hand, if the net is lifted too slowly, the hunted organisms may smell a rat and flee. We also need to control the direction where the net is drifting, as well as the lifting speed, because the net may be pulled under the ship, where it will gather dirt and buildups from the bottom of the ship or tear off altogether.

In some cases, it is important to control the angle at which the net emerges from the water. When we need to take a sample from specific depths, we use a closing release mechanism, i. e., a special device using a messenger weight to close the net at a given depth so as to stop further filtering. In this case the net does not stop, and the researcher must calculate, from the speed of lifting the net and lowering the lock weight, the depth at which they will meet to lock the net.

It takes from 10–15 minutes to a few hours to collect plankton samples, depending on the quantity of samples at a particular point and on the depth to which the net is lowered. Lake Baikal is the deepest lake in the world, but we typically do not lower our nets to all its depth of more than 1,500 km, although we periodically take samples from a depth of down to 700 meters.

It is often windy on Lake Baikal, given a water temperature of about 4 °C, at the beginning of the expedition season. So, a good winter jacket, a hat and warm waterproof pants would be a good choice.

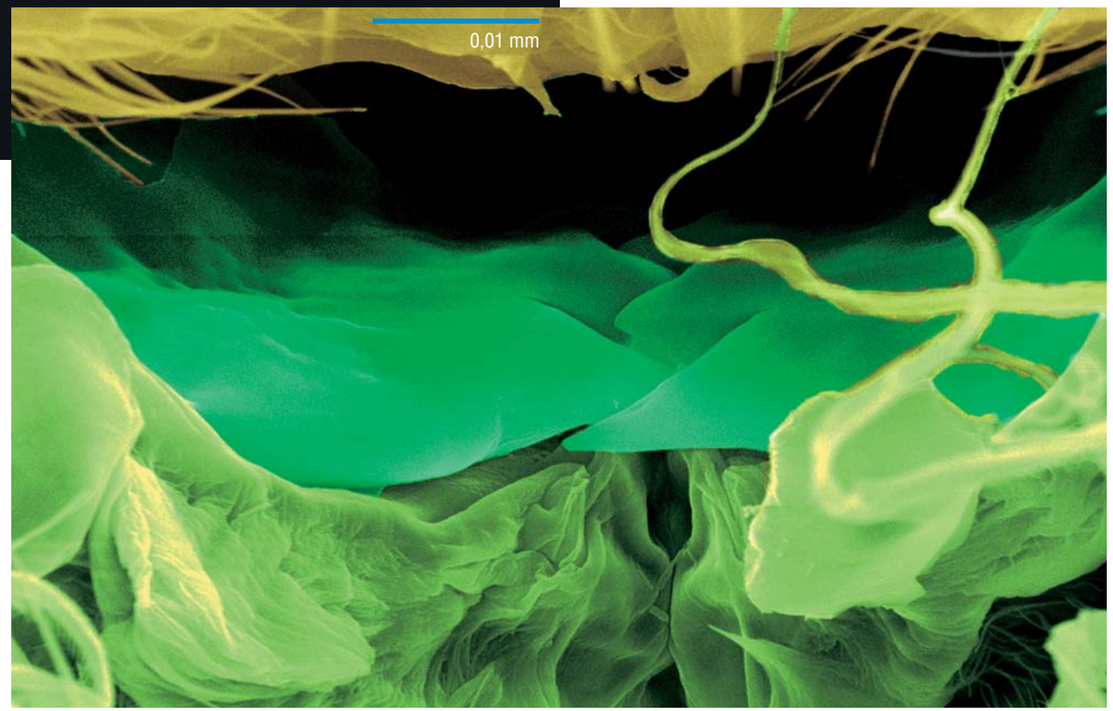
Oh, what big teeth you have!

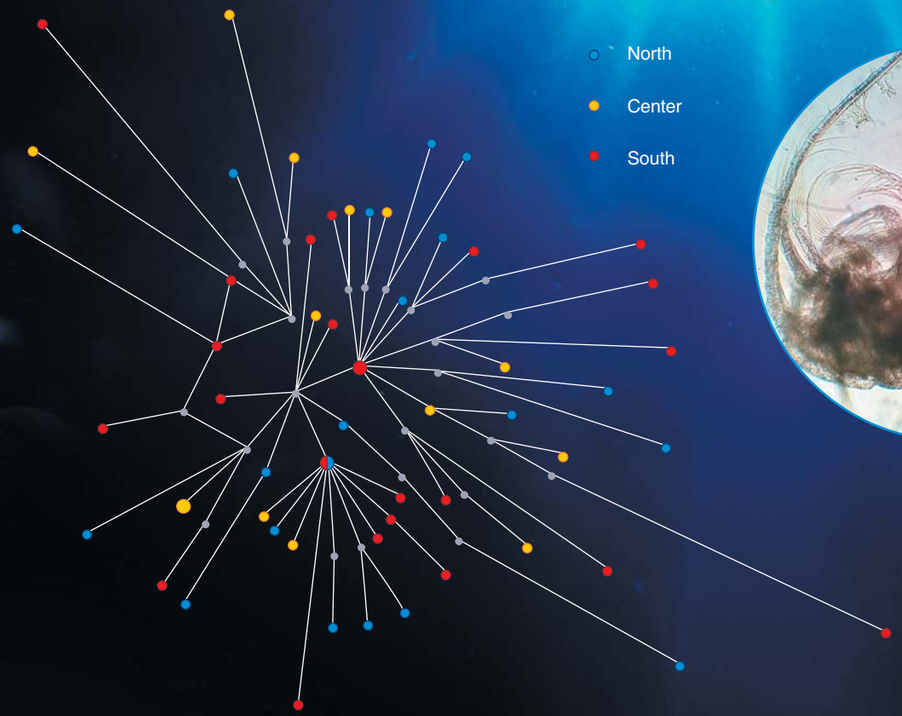
One of the objectives of our research was to investigate *Epischura's* mouthparts with a scanning electron microscope (SEM). There were similar studies in the past, but they used light microscopy. However, the SEM has a higher resolving power, and we were able to discover new facts as well as refine the existing data.

Among the unicellular algae that constitute the diet of *Epishura baicalensis*, the most important are diatomic algae, which are unicellular photosynthesizing organisms covered with a peculiar shell of silicon dioxide. One would need strong teeth to bite through this shell, and Epishura has got such teeth. More precisely, it has a special crown on one of the teeth in its jaw (mandible).

Using a FEI QUANTA 200 SEM and a special probe, we found that the composition of these solid dental crowns

Cutting edges of the mandibles of *E. baicalensis*, which are closed tightly to grind food





A variant of the median haplotype network built in NETWORK 4.5 on the basis of a COI mtDNA gene fragment of *E. baicalensis*. The colors indicate the areas of Lake Baikal (northern, central and southern basin) where the samples were taken. The sizes of the circles are proportional to the number of individuals with a corresponding haplotype

A live *Epishura baicalensis* in the field of view of a microscope

includes silicon. Moreover, when these teeth grind down or break over time, they are replaced by new ones. Similar silicon crowns were found in other species of *Epischura*; only their silicon content was different. It turned out that this difference is due to diet, or rather, to the thickness and strength of the shells of the diatoms that are food to the copepods (Naumova *et al.*, 2015.).

Silicon-containing structures are a rare phenomenon in animals: they more often contain the more widespread calcium. One can observe in different *Epischura* species how individual animals lose silicon if they begin to eat algae with a less strong shell or other planktonic organisms.

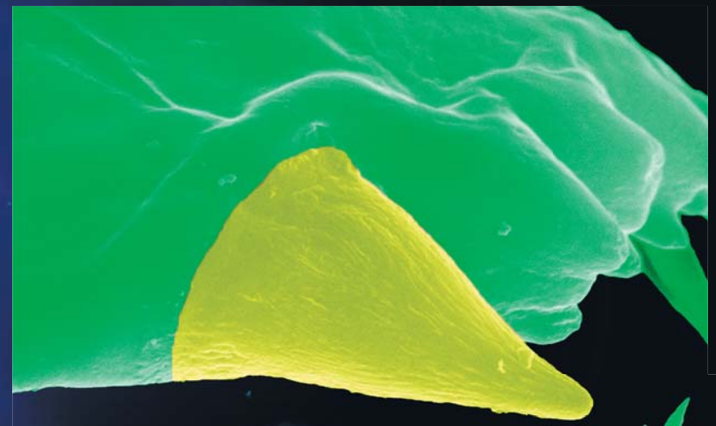
One and undivided

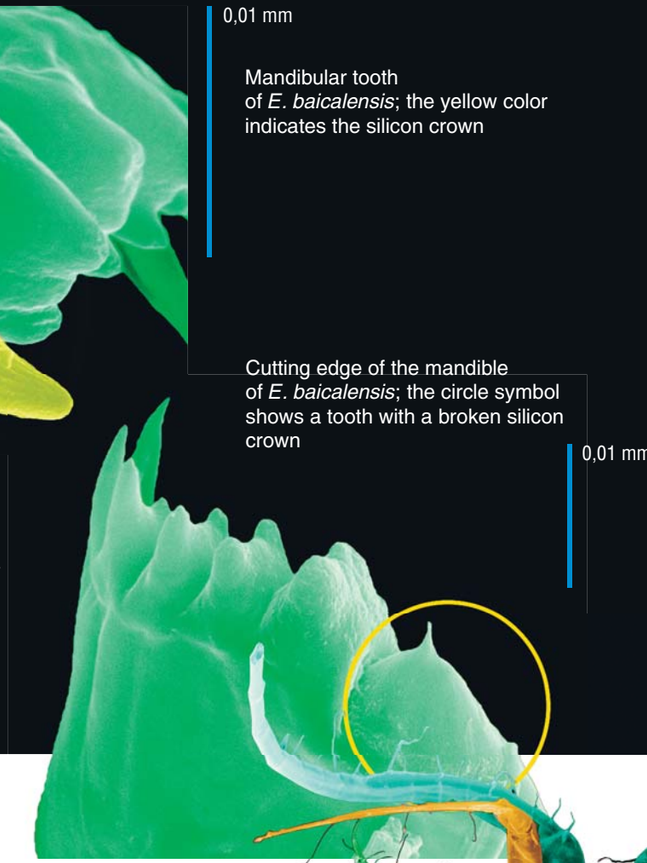
The next question in our research was whether *Epishura* forms one large population in Lake Baikal, or whether it splits into separate isolated or nearly isolated groups.

To answer this question, we compared fragments of the mitochondrial gene that codes the first subunit of one of the enzymes—cytochrome oxidase (COI), which was taken from *Epischura* individuals in different parts of Lake Baikal. The mitochondrial DNA was extracted from the copepods' swimming legs in order to keep, whenever possible, the integrity of their body for further morphological studies.

When we conducted the standard polymerase chain reaction (PCR) and decoded the primary DNA structure, the nucleotide sequences were compared with one another to build the so-called *haplotype trees*. The *haplotype* is a unique set of linked genetic loci, and a haplotype tree unites identical DNA sequences into related groups.

It is known that changes (substitutions) are accumulated gradually in the DNA structure; the fewer such substitutions in organisms being compared, the closer they are to their common ancestor in the genealogical tree. Therefore, if the *Epischura* populations in different parts of Lake Baikal had lived and evolved independently in isolation, their independent evolution would have certainly affected the spatial distribution of the groups and group clusters of different haplotypes. However, the mitochondrial genes analysis showed a very different situation: it turned out that all of *Epishura baicalensis* live in Lake Baikal as a single huge population (Zaidikov *et al.*, 2015.).





The morphological part of this work was carried out within the project "Study of genetic, molecular, evolutionary and ecological aspects of Chromista kingdom representatives as the main producers of biogenic silica and participants of the nutrient cycle in aquatic ecosystems" (VI.50.1.3, N 0345-2014-0009); the genetic part, within the project "Molecular ecology and evolution of living systems of Central Asia by the example of fish, sponges and associated microflora" (VI.50.1.4 N 0345-2014-0002)

The studies of this tiny, almost invisible endemic copepod yielded interesting results for fundamental science. First, this representative of the plankton community has strong silicon teeth, which is extremely rare in the animal world.

Second, Lake Baikal has a length of 600 km and a width in some places as large as almost 80 km and is divided into three large basins by bottom uplifts. For a long time, scientists have had doubts that this copepod can have one single population throughout this vast space, which is cosmically huge for such a tiny being as Epischura. Apparently, it can. And when we figure out the causes of this phenomenon, we will come a little closer to the understanding of speciation on the Earth.

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The publication uses photographs taken by the author

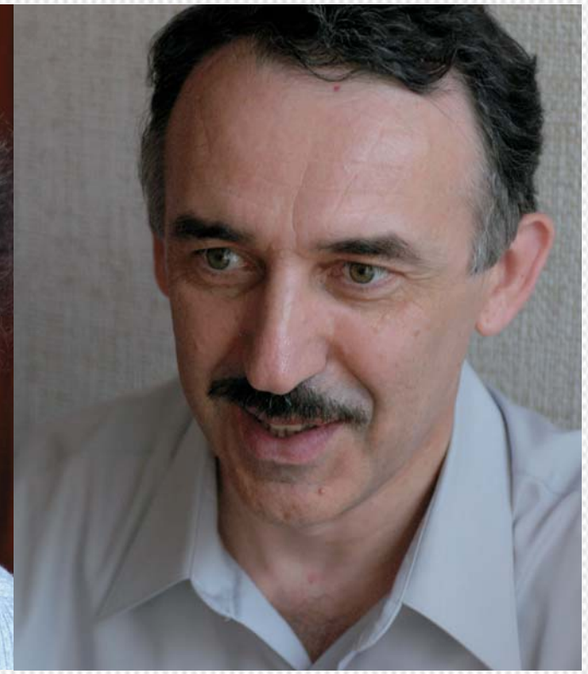
PHYSICIST AND BIOLOGIST:

High Energy Pair

"...The science school of Novosibirsk gave birth to many talented physicists, who now have dispersed around the world yet maintain very close contacts. Graduates of the NSU Physics Department are now working at Fermilab, SLAC, CERN, Oxford... This connection is global, and it works. One can call the Novosibirsk school the global accelerator alma mater. This network has a huge impact on the global accelerator science. I am proud that I belong to this cohort of people who are connected with one another and with Novosibirsk State University..."
In an interview to SCIENCE First Hand, Andrei Seryi, graduate of the NSU Physics Department (1986), Director of the John Adams Institute for Accelerator Science (JAI, United Kingdom), and his wife, Elena Seraia, graduate of the NSU Natural Sciences Department (1986), Research Assistant at Oxford University (United Kingdom) told us about their scientific career and how it was influenced by Novosibirsk State University and the first love...

Key words: Novosibirsk State University, Oxford University, higher education, scientific migration, accelerator physics

Our first selfie: the camera is hanging from a branch of a pine tree



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10th grade of School 1 in Kemerovo.
Andrei is the first on the left in the third (upper) row;
Elena is the second on the left in the first row
with the medal

Today, Andrei Seryi and Elena Seraia are living in Oxford. Andrei Seryi is the director of the John Adams Institute for Accelerator Science; Elena Seraia works at the Department of Medicine, Oxford University. However, their long scientific journey Kemerovo (Russia) – Novosibirsk (Russia) – Protvino (Russia) – Rambouillet (France) – Protvino (Russia) – Chicago (USA) – Stanford (USA) – Oxford (UK) has not ended yet: "We have the feeling that we are cosmopolitans," says Elena, "our home is where we keep our suitcases. We used to say that our home is where our kids and cat are, but now our kids have grown up and live in California, and we are citizens of the world. Our home is where we work, so I cannot say that we have settled anywhere."

What has led a boy from a miners' settlement in the suburbs of Kemerovo to the Big Science?

Catch up and overtake

Until the eighth grade, I went to school in the miners' settlement Yagunovka; my father was a chief engineer at the Yagunovskaya Mine. There was only one school at that small village, and the level of physics at the school left much to be desired. One day my brother showed me a newspaper from which I learned that School 1 in downtown Kemerovo was recruiting pupils to a physical and mathematical class.

Without hesitation, I went there to sign in.

When I first came to the new school, I saw on the board of honor a photograph of a girl who I really liked, and then we happened to be in the same class... The first months at the school were really tough: I had to catch up with the classmates. I was close to getting a "three" ("average") in physics in the first semester, but I finally managed to make a "four" ("good"). All the ninth grade, I was studying like mad and, on top of that, had to commute from Yagunovka to the city. By the end of the school year, I caught up and outdid all my classmates and, later, in the tenth grade, won a regional competition in physics. Apparently, at that time I decided that I was "eligible" to approach such an excellent student as Elena Lebedinskaya. Although there were a lot of contenders for her heart, we were sitting at one desk by the end of the tenth grade.

One day Lena asked me where I wanted to continue my studies after high school. I was thinking about Moscow—Moscow Institute of Physics and Technology, Moscow Engineering Physics Institute, or Moscow State University, but Lena wanted to study only at Novosibirsk State University, at the Natural Sciences Department.

«When I was in the 10th grade, in January we held a competition: the girls cooked something at home to surprise their classmates; then each boy was supposed to come up to one of the girls, who were all sitting in a row, to «reward» her with as many praising epithets as possible. Elena cooked "nuts" from shortcrust pastry with cream inside, for which she was awarded with a round cardboard medal. I was amazed by her cooking talents. But when it came to the epithets, I was so embarrassed that chose to stand in front of Elena and another girl and say my epithets to the space between them so that no one would know to whom they were addressed. This is how I managed to conceal my feelings. Then, on February 23, Elena presented me with an engraving, which showed a horse carved with a cutter on a sheet of linoleum. I was blown away! She was also good at crafts! I was so captivated by her that I made a wooden soldier for her as a gift on March 8."

"There were two pupils from our class at the science competition. I had already solved all the problems, but there was still more than an hour left till the end of the session. So, I drew, on the last page of the notebook where I was doing the drafts of calculations, a portrait of Elena from memory. It did look like her, but was a bit scary, as Lena told me much later... I gave her the portrait, and we still keep it in our home in Protvino. Look, I said, I not only won the first place at the competition but also drew your portrait from memory!"

Regional competition in physics, March,10th grade

"On the board of honor, I saw a photo of Elena, she was the same as she is now: the same curls... smart, shining, it was then that I noticed her!"

Andrei Seryi in a stroyotryad ('construction crew'), 1984.
The summer construction crews were a school of life! After the second year, we went to Chukotka. I fell behind the group, missed the flight and had to get to Chukotka on my own, which took me a week! The last part of the route I covered in a truck, at night. It was so beautiful there in August—the polar day, the lakes in ice... For three months we were making a new channel for the river to turn it away from a newly built plant

Elena after her first year at NSU

Six-month-old Andrei with his parents, brother and grandmother

Raised by the global accelerator *alma mater*

At first, her mother (Elvira, aka Lira Kaminskaya, then Lebedinskaya) was a student of the first intake at the NSU Physics Department, and, second, NSU had a very strong background in genetics, which was the most important thing for her. I thought, let it be Novosibirsk, why not? We would go together, and that was the most important thing for me!

"There were great performances (kapustniks) by the students' club Kvant from the NSU Physics Department. It was very hard to get a ticket. For a freshmen, to obtain the coveted ticket (and we needed two!) was nearly impossible. When we were in our first year, there was an Universiade at NSU. One could organize an entertaining event and get a ticket to Kvant's performance. Andrei and his friends came up with an idea of a comic contest: in one of the classrooms they took out the chairs, got two pairs of boxing gloves and spread matches across the floor. The task was to collect, in boxing gloves, as many matches as possible from the floor in one minute. The main prize was a bottle of Pepsi Cola. That was how we earned two tickets to our first kapustnik."

I was so worried before my first entrance exam that could hardly sleep. However, I got a "five" ("excellent") at the first exam and was enrolled "automatically," without having to take the other exams.

At that time the chairman of the admissions board was Nikolay Dikansky. He then was a very energetic man, always wearing a denim jacket. Someone from the dean's office ran up to me, when I was sitting on a bench near the university and reading a sci-fi book, and asked:

– Are you Seryi?

– Yes, that's me.

– Let's go to the dean's office, we're going to enroll you at the university.

At the dean's office I saw members of the admissions board and secretaries sitting there and drinking tea with condensed milk. They also offered me a cup of tea, and Dikansky began to ask me questions about how I solved the problems at the exam, what my plans were and if it was true that I wanted to become an academician. I don't know how he knew about that, but I confirmed. I gathered that it was a "microinterview."

I came to understand that I wanted to do physics related to accelerators at an age of 13 or 14, when I read a sci-fi book by Valery Agranovsky about the discovery of element 104 of Mendeleev's Table. This element was discovered in Dubna almost simultaneously with US scientists, but recognition for making the discovery was attributed to the Americans. I was so fascinated by this sci-fi detective story, that I decided to do something like that. However, in my dreams I had a highly incorrect idea of my future job: an office with pine trees (a necessary element) outside the windows, I'm sitting at a desk and thinking... So romantic!

The idea of my future job finalized during my university studies. In the first year we had lectures on electrodynamics by I.N. Meshkov. He personally selected the best students and sent them for practical training at different laboratories of the Institute of Nuclear Physics (INP). I was assigned to a lab focused on electron cooling, which was led by Dikansky. My immediate supervisor was Vasili Parkhomchuk. He greeted me, a freshman, showed me the lab, and, as early as in my second year of studies, I spent a couple of days a week working at the institute.

The research conducted by the INP electron cooling group was at the forefront of the world science. So, since my second year at the university, I began to work with world stars: the people who developed this method, demonstrated it experimentally and applied it to real-life projects. It was an unforgettable experience! This training was highly motivating and helped me come to the world level in science. I have always wanted to reach the level of such masters as Parkhomchuk and Dikansky. This bar, which was raised as early as in my student days, I have not yet reached, but I have a goal to strive for.

Elena and I got married when we were in our third year of university studies. Two years later we graduated from

"I often recall a funny story: we were in the fifth year of studies, in the middle of working on our diplomas. Elena and I were on our way back to Akademgorodok from Kemerovo. When we were driving past the Institute of Nuclear Physics, a strange idea flashed in my subconscious mind that there was a hole in place of the INP. I was astonished and told Elena about my vision. Soon after that, we learned that our INP building had burned down, the VEPP-3 and VEPP-4 facilities, as well as the Mosol electron cooling facility, which I used in working on my diploma, were heavily sooted, and some units had burned completely. So, instead of doing the experiments, we, together with the other people working at the Institute, spent several months cleaning the equipment. I came to my diploma paper only at the end of my fifth year and prepared it from calculations. Sometime later we heard a joke that women were talking at a market in downtown Novosibirsk, "There, an accelerator was burned, a VEPP... It pulled three firefighters inside and they are still rolling."

Andrei Seryi and Elena Seraia with Andrei's parents. *Kemerovo. July 2015*

... SASHA CHERNYI, ANDREI BELYI... THAT'S WHY I CALLED HIM ANDREI

Of course, when we sent our boy to the university, we could not imagine that he would be so successful and would go so far from home. He had always been serious and hardworking, got only excellent marks at school, won in science competitions and even helped his older brother with his lessons.

In fact, I tried to persuade him to go to Kemerovo Polytechnic Institute. I did not want him to leave, but he did not hold this institution in high regard.

He learned to read at a very early age and took interest in everything! He wrote letters to the editors of the magazines Modelist-Konstruktor ('Model Designer') and Yunyi Tekhnik ('Young Technician') and received their answers. Since he was seven, he traveled from Yagunovka to the city center to a shop called Yunyi Tekhnik.

When he began to read, he did it upside down. While their granny was reading them fairy tales, he was following the text. That was how he began to read; later we had to teach him the right way. But this does not mean that he was reading books all the time: he spent days outside with his brother and his dog Ryzhik, they ran down the fields, caught susliks, skied, climbed trees, jumped from the roof down into the snow... it is so good that we did not know about that.

When Andrei was 11 years old, we bought a car, and he immediately began to steer, although one could hardly see him from behind the wheel.

He and his brother were tinkering with something all the time. The older son was always inventing guns, and Andrei was fond of wood carving and building model airplanes. Once he gave me, as a present, a very beautiful carved box, and I still keep it in our home.

Evgenia K. Chernova and Anatoly K. Seryi

Elena (*on the left in the front row*) with her parents, grandmother and younger sisters. The grandmother Yunia Kaminskaya, the father Ivan Lebedinsky and the mother Elvira Lebedinskaya. *To the right of Elena* is her sister Veronika. The grandmother and mother are holding the twin sisters Eugenia and Valeria. *Kemerovo, 1969*

Elena in an expedition after her second year of studies (*Altai Mountains, Sarlyk Mount*)

"I KNEW SINCE THE SECOND GRADE THAT I WOULD WORK IN SCIENCE AND BE A BIOLOGIST..."

"I studied at the NSU distance learning school on genetics and biology, which was organized by Anatoly Ruvinsky and Pavel Borodin. It was late when I learned that there was such a school; so I had to go through a two-year course in one year. I had to work a lot. The system was as follows: the schoolchildren received assignments and sent their works to the university. We did not know anything about our teachers, but I was sure that my works were checked, if not by a professor, at least by an assistant professor... One month after I entered the NSU Natural Sciences Department, I was contacted by Olga Gorokhova, a third-year student; it turned out that she had been my teacher. Olga offered me to work with schoolchildren. So, being a first-year student, I became a teacher at the distance learning school. When Olga graduated from the university, I took over her responsibilities and became the principal of the distance-learning biological school.

"The funniest part of these studies was when Pavel Borodin was collecting information on cat genetics. I arrived in Novosibirsk, at the Institute of Cytology and Genetics, to meet with Anatoly Ruvinsky. He gave me a map on which I was to put a mark indicating the exact frequency of a particular feline gene in the neighborhoods of Kemerovo.

"There were no stray cats in Kemerovo in 1980; so we went with Andrei to the suburbs, to a settlement near the Pionerskaya Mine, where our classmate lived. In fact, this was a village where there was a cat in every private house. We were very lucky that everyone in the village knew our friend because in that year, a tax was imposed on cats and dogs. We were collecting information about cats, but the people got scared, thinking that we were collecting money. We reassured them: 'You see, we are asking neither the name nor the number, just show us your cat, please, that's all!' It was absolutely crazy! But we collected really good material: 130 cats. There were about 12 mutations on the list. Then I calculated the frequency of the genes, put the figure onto the map, and brought the map to Novosibirsk. These data were included in Borodin's book"

At the wedding.
To the left and right:
our friends and witnesses
Anna and Anatoly Gusachenko

At NSU one used to say: "Silly girls get married in the first year; beauties, in the second; smart girls, in the third; no one does in the fourth; no one is marriageable in the fifth..."

the university; Elena began working at the Institute of Cytology and Genetics and entered the postgraduate program to defend a candidate-of-sciences dissertation; I stayed with the same laboratory at the INP. In 1988, the institute announced a call to build a linear collider in the science town Protvino. There were construction works underway to build an accelerator-storage complex (the tunnel had almost been finished). An idea came up to also build a linear collider, and the most part of the laboratory staff, including Parkhomchuk, decided to go. We did not evaluate the prospects at that age: it was exciting, my friends were going, so I had to go too...

Leaving Novosibirsk was not an easy decision. First, our elder daughter

In an expedition
to the Altai Mountains
(*Cherga Village*)

In an expedition
to the Altai Mountains.
Elena is on the left in a hooded jacket

Eugenia had just been born, and, second, Elena was at the stage of deciding on the theme and objectives of her dissertation, and it was difficult for her to leave the job that she loved. This held us back, but when we saw that the core members of my group were leaving, we decided to go.

We worked in Protvino for a fairly long time. There our second daughter, Sasha, was born.

In 1994, a colleague from France invited me to work for several months at a laboratory of the Saclay Nuclear Research Center near Paris. At that time I was engaged in research on collisions and beam focusing methods. Eventually, we spent two years In France, in the town of Rambouillet. Elena learned to speak French; the kids went to school and kindergarten, and talked fluently in French.

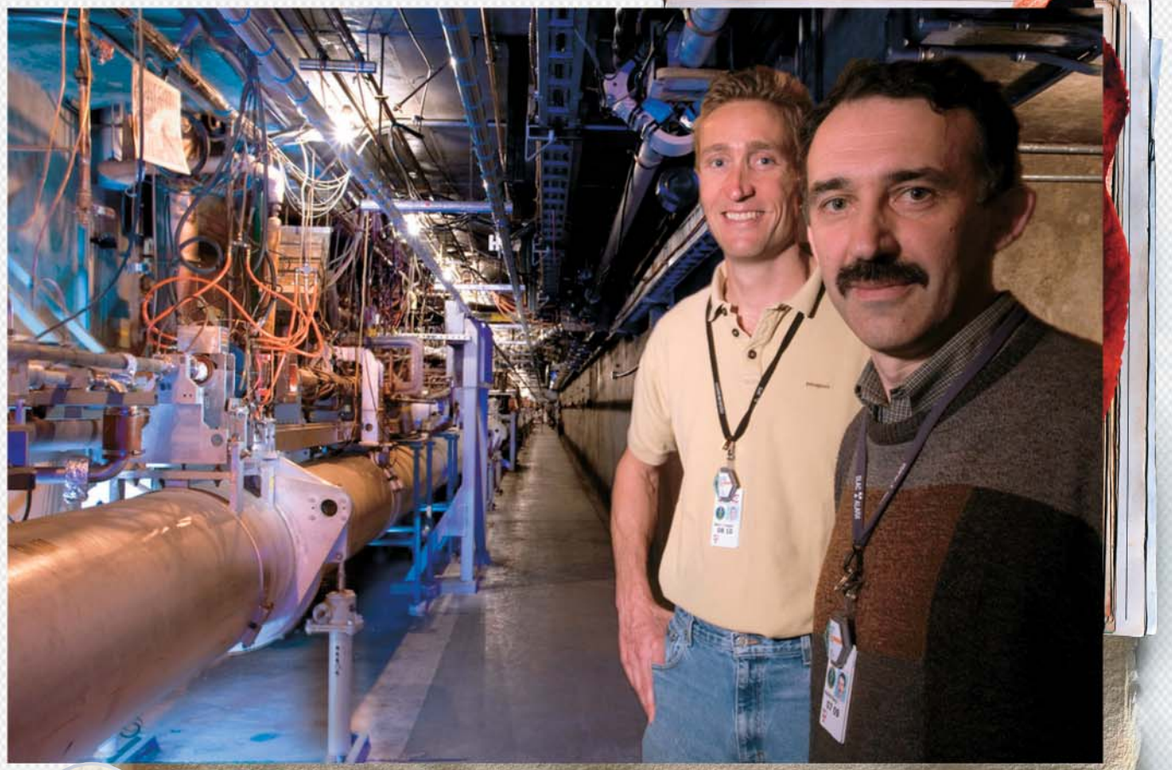
In 1996, we returned to Protvino, and two years later, my friend and colleague Vladimir Schiltsev, with whom we worked together at the INP, invited me to take part in an exciting project run by Fermilab in the United States. This is how we found ourselves in Chicago, with our kids and a Siberian cat.

Multidisciplinary union

At Fermilab there are a lot of physicists from Russia, including from Novosibirsk, over a dozen people. We even called it jokingly an INP branch. One day, sometime in 1998, we decided to set up an international community of friends of Novosibirsk State University and raise money for scholarships. Everyone was excited about the idea. Elena and I decided to encourage natural science "unions" and establish a scholarship for married couples one of whom is a physicist and the other one is a biologist and who show high academic performance. Indeed, a union of a biologist and a physicist can be very rewarding. There was even a joke at the NSU Natural Science Department: "Mathematicians study math; physicists study math and physics; chemists study math, physics and chemistry; and biologists study math, physics, chemistry and biology."

We discussed this idea in the association and sent a letter to NSU, but, to be honest, we thought that they would treat our idea as a joke. However, the university authorities were serious about our proposal, and soon there were six couples that met the scholarship criteria. Later, some of the couples wrote us letters of gratitude and sent wedding photos. However, we did not want to interfere with their private lives and never replied to those letters. The project continued for about seven years; then the situation at NSU began to improve, and, at some point, the project was closed.

We worked for about two years at Fermilab. I was engaged in the development of a facility to compensate the effects of beam collisions at the Tevatron collider, a circular particle accelerator; Elena took part in the development



"My mother was a student of the first intake at the NSU Physics Department. When she entered the university in 1959, the student's dorms in the Pirogova Street had not been built yet, and the students were temporarily accommodated in a house on the corner of the Morskoy Prospekt and Institutskaya Street (now Prospekt Akademika Lavrentyeva). Students were given simple canvas shoes and blue tights with 'baggy' knees, and they wore this 'uniform' to the classes, which were held at a school near the covered market. But at first they were taken to a *kolkhoz* because there was nowhere to live; this was how their first year at the university began.

When I entered the Natural Sciences Department, the beginning of the first year was also funny: all the departments were sent to a *kolkhoz* to harvest potatoes, but we worked at a vegetable warehouse in Kainka. In the morning, we attended lectures on botany and physical chemistry, and in the afternoon we worked at the warehouse, unloading cars and sorting the potatoes harvested by students from the other departments!

"The potatoes were brought to the warehouse, and we were sorting them in any weather. When it rained, the conveyor was giving strong electric shocks to those who did not wear rubber boots"

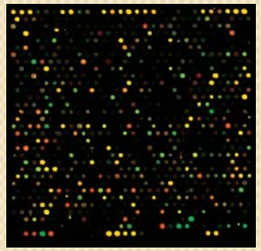
Andrei Seryi with a colleague in the accelerator tunnel at SLAC

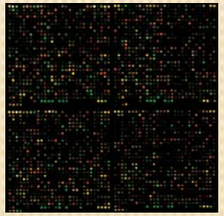
of a new system of silicon detectors for the collider. Then I was invited to the Stanford Linear Accelerator Center (SLAC).

We worked for 11 years at Stanford. I was engaged in designing a linear collider and also in developing the plasma acceleration experimental facility.

Elena worked for over ten years at the Stanford Functional Genomics Facility. Although she had no PhD degree, but only the MSc degree from Novosibirsk State University, the head of the facility believed in her and gave her a job, and he never regretted doing that.

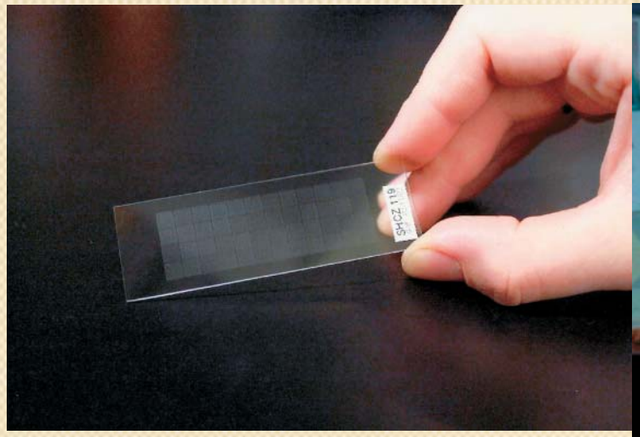
However, her love for genetics has remained unfulfilled. The decision to abandon her candidate-of-science dissertation and go together to Protvino came at a cost of her academic career, and we knew it. I have always said that Elena is a Decembrist wife, except that they followed their husbands to Siberia, but Elena followed me around the world. Nevertheless, she is an excellent specialist and always finds a job in biology or medicine. There are professors who write research papers, and there are people without whom they cannot do that, i.e., those who prepare and conduct experiments and collect material for research





Left: one of the 48 units of the microarray with mouse oligonucleotides

Right: four of the 48 units of the microarray with human oligonucleotides



60,000 GENES ON ONE MICROSCOPE SLIDE!

At the university I had a wonderful research supervisor, Larisa Gunderina. It was she who taught me how to work, and this skill helped me to find a science-related job in every city and in every country where we lived, although each time I had to start from scratch...

When we were leaving for Oxford, the head of laboratory at the Stanford Functional Genomic Facility, with whom I had worked for 11 years, said, "I was so happy every day that I hired you blindly because, for more than ten years, you've been a key member of our laboratory."

We printed microarrays, which allow researchers to analyze the expression of thousands of genes simultaneously on a single glass slide. The microarray is a 1x3 inch microscope slide carrying "pieces" of double-stranded DNA or oligonucleotides, each of which is a separate gene.

We had to print about 60,000 genes, i.e., 60,000 points with a diameter of 50 microns, on one slide. I was working on a technique how to do that with a high print density (at first we printed only 28,000 genes on one slide). Our work was successful, and we were selling the microarrays to 26 universities in 15 countries.

We had a library of genes, i.e., pieces of DNA that are built into plasmids. To "replicate" these genes, we conducted a polymerase chain reaction for each piece of DNA, made solutions of a required concentration, and printed the gene library on the slides.

If we add to the denatured DNA fragments printed on a slide the patient's DNA sample (prepared from mRNA) and the control normal DNA (marked by different fluorescent dyes), then the complementary fragments are hybridized.

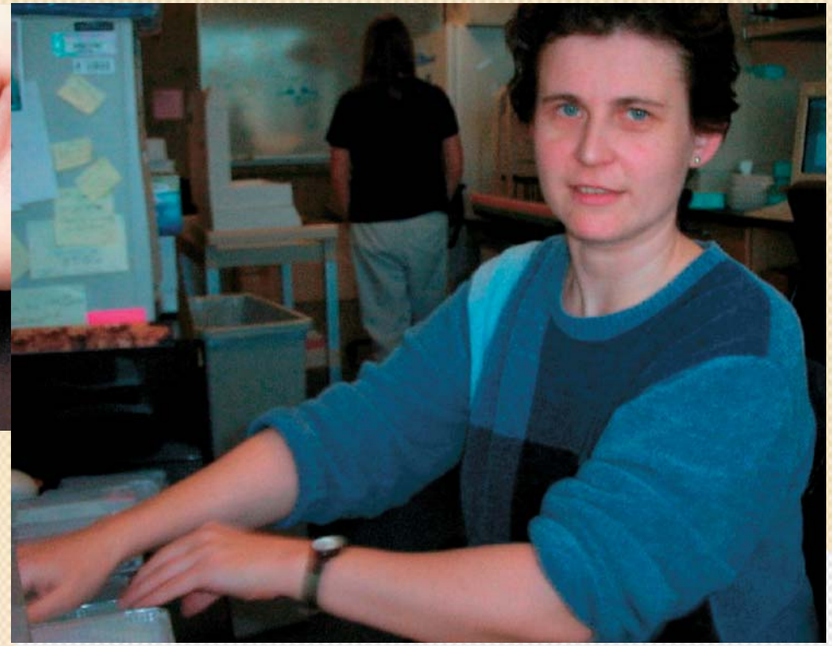
Thus, we can reveal in a patient the expression of a gene that is normally not expressed. We marked the control normal RNA/DNA with, e.g., a fluorescent dye that gives a green color when applied to the specimen, and the patient's RNA/DNA, with the dye that gives a red color. Then we applied the two samples on a microarray, scanned the glow in the red and green regions, and superimposed the results (which gave a combination of different shades of yellow). If a given gene worked in a cancer patient, the sample contained a lot of the corresponding mRNA/DNA, which got bound to the DNA on the slide, and we saw red glow. If the patient's gene did not work, it was only the green-glowing control normal DNA that got bound with the microarray. If we saw a yellow point, it meant that the gene works, to some degree, in both cancer patients and in normal cases.

The robot was printing the microarrays for four and a half days without stopping, 255 slides per cycle. I was responsible for preparing the printing material (125 plates with 16x24 "wells"), starting the process, and organizing the work of the laboratory technicians. If there were problems with the robot, I was called to the lab day and night.

We were the first in this area. There were only five people on our team. Later on, after a few years, this area attracted the attention of large companies, such as Agilent, which assigned hundreds of people to this issue.

Businesses took up the idea and developed new microarray technologies, e.g., for growing oligonucleotides directly on the slide in the cells of a special grid, print samples by the inkjet printer method, or apply them on tiny beads.

However, our glass slides went to academic institutions because they were inexpensive. One microarray cost $130 while those produced by commercial companies cost about $1000. Therefore, universities from the United States to Singapore were using our glass slides.



"No one can work like Russians; this is how we are raised. For instance, this was how we did our diploma projects: according to the safety regulations, a student is not allowed to stay alone in the lab after working hours, but larvae do not ask you when to molt, in the morning or in the night... And when I was working on my diploma and my chironomus larvae were molting, Andrei came after work from the INP to the ICG and stayed with me all night (slept in an armchair)"

Elena Seraia at her workplace in the Stanford Functional Genomics Facility, *2002*

Below: Elena in an expedition, *1983*

work. Elena compares herself with Gosha (an indispensable golden-hand technical professional behind many scientific experiments) from the film Moscow Does Not Believe in Tears.

From the Wild West to Oxford

If anyone had told us that after working for 13 years in the United States, we would move to the United Kingdom, we would have never believed that. However, the feeling that one is "settled" may appear only when everything is done and all problems are solved, but until then, everything is possible.

So, we moved to Oxford. In the United States, I worked at a large laboratory that was focused on basic science; applied problems were a secondary issue. At Oxford, everything was different: the first priority was to think how to implement a scientific idea and how to move from an idea and its experimental

INVENTING INSTRUMENTS FOR SCIENCE OF THE FUTURE

Perhaps, everyone knows about such problem-solving techniques as brainstorming or its improved version, i.e., synectics (one of its approaches is the use of language of fairy tales and legends to describe a problem). However, it is quite possible that the majority of people working in science have never heard of the inventive methodologies developed and widely used by engineers in the industry. And this ignorance is truly astonishing.

One of these approaches is the Theory of Inventive Problem Solving (TRIZ). It was developed by Genrikh Altshuller in the Soviet Union in the mid-20th century. Since 1946, Altshuller, who worked at the patent office, had analyzed many thousands of patents in an attempt to identify the key points that make a patent successful (this work was interrupted for a decade because of dramatic circumstances in his life, but he managed to survive the hard times, find an unexpected opportunity to get a broad education and resume his studies). Between 1956 and 1985, he formulated the TRIZ algorithms and developed this theory together with his team. Gradually, this theory has become one of the most powerful tools in the industrialized world.

I thought that the TRIZ methods can be applied in accelerator science. With this idea in mind, I reviewed the lecture course on accelerator physics that I had been giving for three years at the University of Oxford.

Starting last year, we began to use a new, inventive approach in our lectures. This course was developing gradually and, finally, even changed its name: it is now called in the same way as the book, which will be the main textbook for the course: Unifying Physics of Accelerators, Lasers and Plasma.

I think it is really exciting for students; of course, they have nothing to compare it with since this is a completely new material, but I see that they are truly fascinated by inventive innovations. Moreover, this approach should be interesting not only for students but also scientists from the most diverse fields who wish to expand their horizons.

For us it was very important to translate this book into Russian, so that it would be available in Russian, and each student could buy it, if not at the price of a donut, but at least at the price of a lunch.

We have recently made it through all stages of working with the publishing house URSS, made the last corrections to the text, coordinated the proofs, etc. The book has been released in June of this year. It is interesting to note that the editors from the Moscow publishing house suggested that we change the title so that it would be more "catchy" and better reflect the essence of the book. I agreed with their arguments and came up with a new title: Inventing Instruments for Science of the Future. We also asked our daughter to redraw the cover in a different color scheme: now the spirals are painted in the colors resembling the Russian flag.

Although Russian is our native language, translating the book into Russian was a challenge. We divided between us the odd and even chapters and began translating the text in parallel; however, while Elena was translating consistently and very carefully, I was doing my part from time to time and hastily. So, Elena had to take up my chapters and translate them from my Russian into the literary Russian. In fact, Elena rewrote the whole book; therefore, the Russian book has two authors—Andrei Seryi and Elena Seraia.

The biggest challenge was that the Russian language often does not have the terms that exist in English. In this case, Russian physicists simply pronounce the English words in the Russian manner, e.g., veikfildy for Wakefields. But what sounds good in oral speech, is often unacceptable in serious literature; therefore, we had to put a lot of thinking into it and often introduced new terminology.

While working on the translation, Elena has gained such a profound understanding of the material that she now helps me with everything—with lectures, books and presentations. She helped me with my lecture at the science festival in Moscow by translating and popularizing the material; sometimes, she acted as a scientific editor by revealing inconsistencies in the logic.

While working on the lectures and the book, we got an idea to write another book that would be more into popular science and cover a broader range of topics, i.e., about inventiveness in biology, chemistry, etc. as well as in the field of laser and plasma accelerators. We discussed the idea with the CRC publishing house, but since it is a very complex task, we will be thinking about it till sometime this autumn.

Frankly speaking, the whole process of writing a book is a big pain. The words do not always flow freely and get themselves down on paper. Sometimes you have to force yourself so that you can "squeeze" out one paragraph a day under a great time pressure: after all, no one is going to do your regular job for you. But later, when you read what you have written, all the pain is paid off.

demonstration to specific applications, e.g. in medicine or business. I had to think about it all the time; moreover, one third of the institute funding came from grants, projects, contracts, cooperation with companies, etc.

Then I decided to approach this subject "from afar" and began to explore the process of making inventions and the existing invention methodologies. Apparently, I was driven by my childhood passion for inventions. And very soon I realized that I did not need to reinvent the wheel: the Soviet scientist Genrikh Altshuller developed the engineering methodology called Theory of Inventive Problem Solving (TRIZ). I was curious to apply this methodology in science and teaching by "mixing" it with the physics of accelerators and lasers as an ingredient that binds together different areas of science and gives motivation for new inventions. Then

"Now I am working at the Target Discovery Institute, Medical Department, University of Oxford, where I study the effects of small molecules and small interfering RNAs on cancer cell cultures in combination with the action of other drugs and radiation exposure. In this area, my work intersects with Andrei's research interests. At the Oxford Institute for Radiation Oncology (ROB), biologists ensure high throughput screening, and physics provide radiation exposure using a linear accelerator"

I got an idea to develop a university course on TRIZ. I shared this idea with one of my colleagues, a member of the JAI advisory committee of the John Adams Institute, who is in charge of the accelerator science training of under- and postgraduate students in the United States, and he suggested that I should deliver this course the following year. I bought a lot of books on inventions, lasers, plasma, and began to prepare the course. One day a young lady knocked on the door in my office, who happened to be an editor at a publishing house. It turned out that she was looking for my colleague and knocked on a wrong door, but we got to talking. I told her about my course, and she invited me to write a book.

This was the beginning of a big work: first, we have prepared 14 lectures and then began to write a book. Elena was very helpful to me, wrote the part about the DNA damage by irradiation and drew 256 illustrations! Only two photos in the book were taken from other sources; all the rest were made by Elena. And the book cover was created by our daughter Sasha.

The book has already been published in English; we have recently completed a translation, and it has recently been published and now available in Russian too.

In the introduction to the book, I thanked the NSU rector Mikhail Fedoruk for the invitation to deliver a lecture to NSU freshmen. I sent him our book, and when there is a chance, we will discuss the opportunity to organize an intensive course "Combining the Physics of Accelerators, Lasers and Plasma" at NSU.

I would love to come for a week or two to Novosibirsk and present this course at our university.

In May and July 2015, I went together with a group of external experts to Tomsk with a "friendly inspection." We checked the implementation of the 5/100 project at Tomsk State University and Tomsk State Polytechnic University. This trip was organized by the Ministry of Education in cooperation with SkolTech; those universities who wished to receive experts and get their recommendations, i. e., a view from the outside, took part in the program.

What can I say about the Tomsk universities? They have their own specific features: the two very strong universities, whose activities heavily overlap, spend a lot of effort on internal competition instead of the external rivals. In 2005—2009 an extensive analysis was conducted of the potential of the Tomsk Scientific Center, and the experts argued that the combined research potential of the Tomsk universities and research institutes is greater than that of Moscow State University. Science and education is the main goal of the city of Tomsk, as stated in its Charter. I endorse the merger of Tomsk universities, although I understand that this task is very complicated. There are such trends in the world, e. g., two Manchester universities merged ten years ago. The atomized Parisian universities are also merging gradually. One should not compete with their neighbors; it is better to cooperate with them in order to be competitive on a global level

I owe a lot to Novosibirsk State University. It was there that my attitude towards life and towards physics was shaped. The ability to work hard and to build a tight-knit team to work jointly on a large complex project was also shaped at the university and INP. And I am ready, for the best of my ability, to help the university in hard times. I hope that NSU will be developing by an exponential trajectory. We have seen photos of the new building and in July 2016 had a chance to visit it. I think that it will give a new impetus to the university, and the relations between the SB RAS institutes and the university will become even stronger and continue to develop. The graduates who are now working abroad sincerely support their Alma mater.

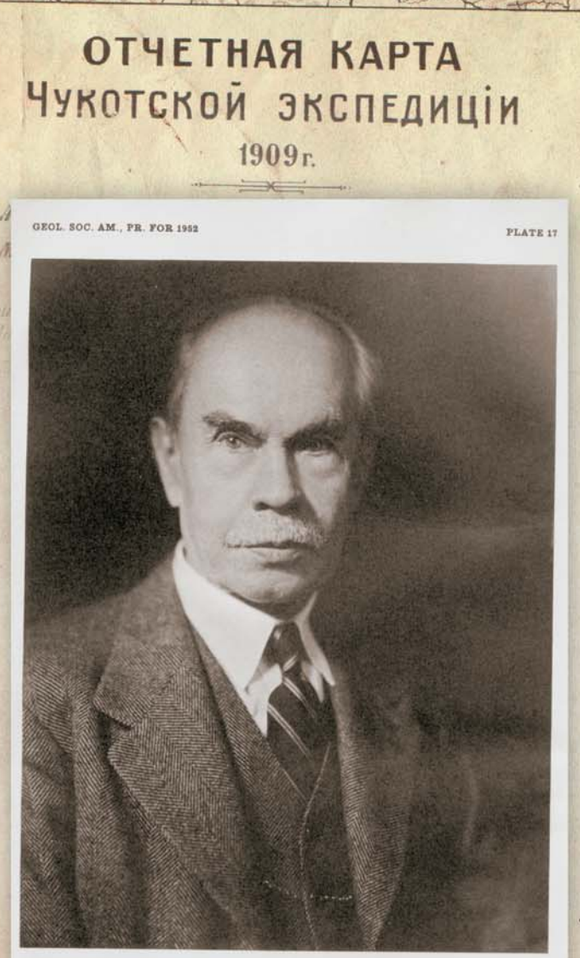
I am a co-chair of RuSciTech, an association of Russian-speaking science and technology professionals abroad, which is trying to attract the attention of Russia's government to the problems of science and contribute to the development of science and education in Russia.

I keep saying that Novosibirsk State University is the best university in Russia. I believe that its chances for a leading position among the Russian universities within the 5/100 program are very high, and I think that it should be at the top of the list. NSU has an enormous potential; if it is fully realized, our university will have all chances to be one of the best universities in the world!

The Chukotka Expedition of I. P. Tolmachoff: in Search of the Northern Route

O.A. KRASNIKOVA

In 2013, they celebrated a centenary of the discovery of a large archipelago called the Land of Emperor Nicholas II (since 1930, the Severnaya Zemlya) by the Geographical Expedition of the Arctic Ocean), which marked the finale of the Age of Discovery. This important event initiated the foundation, in 1914, of the standing Polar Commission at the Russian Academy of Sciences aimed at coordinating the investigations conducted by several ministries in the Arctic.
Not many people, however, know that the driving force behind this project was Innokentiy P. Tolmachoff, an expert in geological research in Siberia and head of a few important Polar expeditions, including the Chukotka Expedition of 1909–1910 initiated by the Department of Trade and Industry to study the feasibility of the Northern Sea Route, the shortest seaway between European Russia and Russian Far East. In 1922, Tolmachoff emigrated from Soviet Russia, which is why for decades the name and achievements of this outstanding Polar explorer have been forgotten



Innokentiy Pavlovich Tolmachoff.
Late 1940s, USA

Key words: Nothern Sea Route, I.P. Tolmachoff, B.A. Vilkitsky, the Arctic Ocean Hydrographic Expedition , the Chukot Expedition 1909-1910, North Siberia coast, Yakutia, Polar Commission of the Academy of Sciences

"The idea of the [Chukotka] expedition and partially its plan originated from the administration, whereas as a rule the initiator is the explorer himself," I. P. Tolmachoff will write later (Tolmachoff, 1911). "The expedition was, so to say, initiated by life itself, by the aroused interest in our half-remembered remote areas, particularly in the North, by the awareness of the weak bonds between these areas and the monopoly, and the need to strengthen these bonds. Among the first actions planned in this field was an improvement of the Siberian transport routes." This project was a common interest for two ministries, the civil Department of Trade and the military Navy Office.

The Government's interest in "half-neglected borderlands" was triggered by the tragic outcome of the Russo-Japanese War of 1904—1905. A virtually total absence of transport links with the Russian Far East – impassable overland roads and a long and unsafe single seaway across the Indian Ocean – made cargo deliveries almost impossible.

An alternative to the costly overland link and southern shipping lane could be the north-eastern sea route along the Russian Arctic coast. The nautical survey started by the Navy Office in 1894, which in ten years covered the vast expanse stretching from the Kola Peninsula to the Yenisei estuary, showed that an annual voyage across the Arctic Ocean from Europe to the Yenisei and Ob was practicable. However, further research was hampered by the Russo-Japanese War, and so knowledge about this part of the northern seaway remained exceptionally scarce.

Moreover, Russian presence along the Arctic Ocean coast, especially in Chukotka and the Russian Far East, was low profile whereas vigorous trade across the Bering Strait almost posed the menace of the Russian North-East detachment (Garusova, 2001). Hence the urgent need to start commercial navigation there and to provide conditions for the guard ships in this area: Russia's economic and political interests had to be defended.

on p. 82

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И. П. Толмачевъ.

Innokentiy Pavlovich Tolmachoff, 1914. *From the Siberian Trade and Industry Annual for 1914—1915, Petrograd, 1914*

INNOKENTIY TOLMACHOFF – A SCIENTIST AND A TRAVELER

Innokentiy Pavlovich Tolmachoff (1872—1950), a well-known scientist and polar explorer, was the first explorer of the Kuznetsk Alatau (1898), head of the Khatanga (1905), Chukotka (1909—1910) and Zhetysu (1914—1916) Polar expeditions, and researcher of the geology of Northern Caucasus and the Kola Peninsula (1917). He is the author of several treatises on paleontology and geology, many of which, like his writings on the petrified remains of the Kuznetsk coal basin, have become classics.

Tolmachoff developed his scholarly interests quite early. Upon graduation from St Petersburg University with First Class Honors, the talented young scientist was invited to work in the Geological Office of the Imperial Yuriev University (today, Tartu University, Estonia). He did not stay there long though: in spring 1898, he received an invitation from the Land and Industry Division of the Cabinet of His Imperial Majesty to set out during the vacation to the Altai *okrug* (region) for geological studies. The results of the three-month trip were presented in the geological study report and journals, supplemented with the lists of the samples collected, determined elevations and tables of meteorological observations conducted in Barnaul, Tomsk, and at the Neozhidanny mine. The following year, Tolmachoff again carried on three-month investigations in Altai (Archive of Tartu University, Estonia); a result of his studies was the *Geological map of the Altai okrug* (Geol. Part of the Cabinet…, 1905).

Almost immediately after the completion of the expedition, Tolmachoff accepted the office of academic custodian in the Geology Museum of St Petersburg Academy of Sciences. The circumstances weighted in his favor, and soon Tolmachoff launched an expedition funded by the Russian Geographical Society to the upper reaches of the Tom' River with a view to exploring the mountain lakes of the Kuznetskiy Alatau.

Shortly, in 1905, the Russian Geographical Society entrusted Tolmachoff with leading an expedition to the unexplored areas of northern Taimyr, to the Turukhanskiy *krai*, to investigate the basin of the Khatanga River. Together with the topographer M. Ya. Kozhevnikov, he constructed the first map of the huge – over 1 million square meters – area, having elaborated the hydrographic system of this region. The most notable achievement of the expedition was the discovery and description of the Anabar Plateau.

The impressive results obtained by Tolmachoff, as well as the careful preparation of the expedition and prudence with which the expedition was conducted made him famous among scientists and specialists. This is why it was he, an experienced traveler and a thoroughgoing investigator, who was invited to lead the expedition directly relating to the development of the Northern sea route

Geological map of the Altai okrug (region). Scale: 1/420000. The map was constructed by B. K. Polenov, I. P. Tolmachoff, and Ya. A. Makerov basing on the results of the expeditions conducted in the Altai okrug in1898—1899, launched by the Geology Section of the Land and Industry Division of His Majesty Office. Geology Section of His Majesty Office, 1905
Archive of the Cartography Section of the Library of the Russian Academy of Sciences, St Petersburg

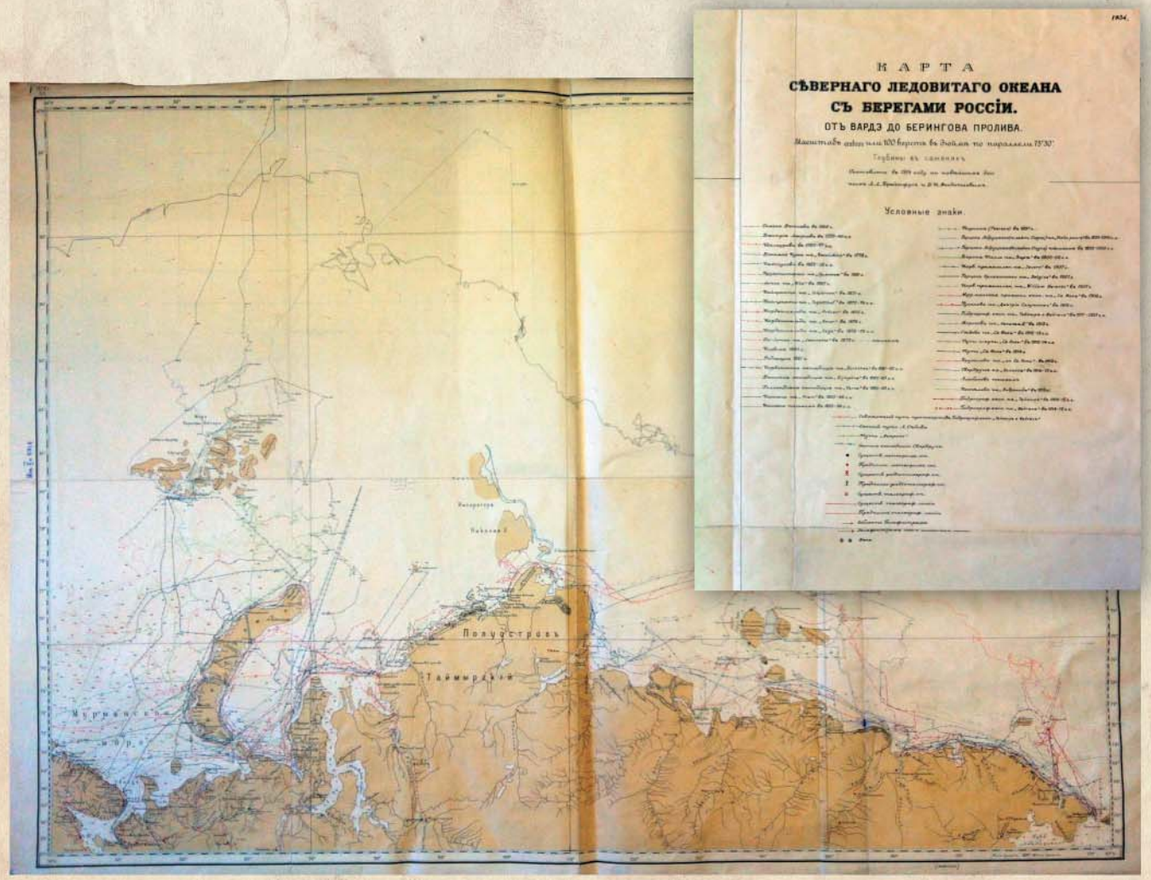
Public matter

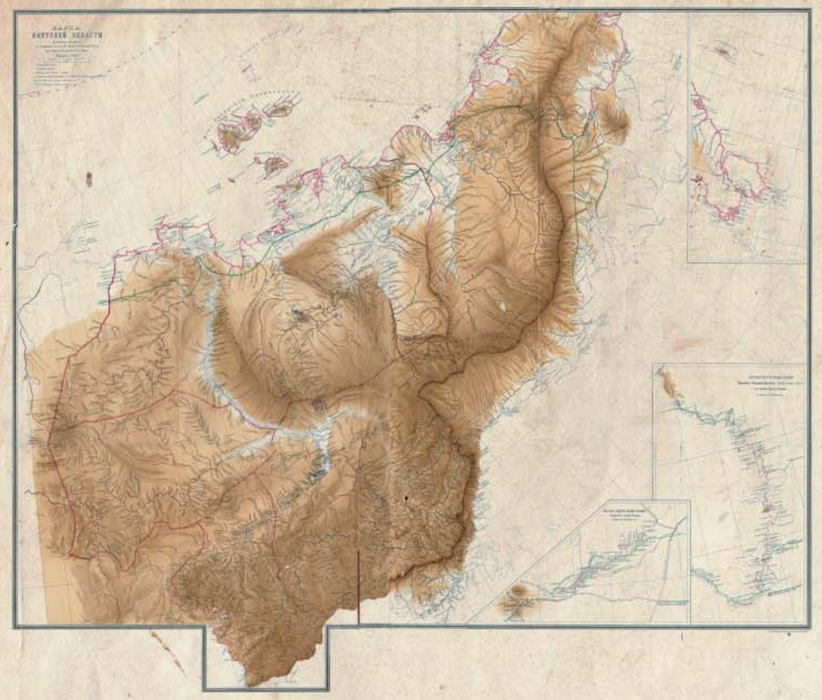
In June 1906, the Minister of the Navy Vice Admiral A. A. Berilev commissioned the Admiralty Council to explore the possibilities of continuing nautical survey in the Arctic Ocean. Nine months later, Nicholas II was submitted the report"... On the necessity to continue nautical survey in the Arctic Ocean with a view to opening the Siberian Sea Route, the so-called North-Eastern Pass, located in our territorial waters, which is very important for Russia's strategic and economic interests" (Evgenov, Kupetsky, 2013, p. 3).

At the same time, a decision was made to construct two icebreakers; their design was to be developed by a special committee set up for this purpose, and Tolmachoff became a member of this committee, alongside other eminent hydrologists and hydrographers. Primarily, it was planned to explore the navigating conditions in the vicinity of the Taimyr Peninsula (Vilkitsky, 1911). However, soon the issue of the necessity of commercial navigation from the Pacific Ocean to the estuaries of the Kolyma and Lena rivers came to the fore; as a consequence, the exploration of the coast from the Lena River estuary to the Bering Strait became vital.

Promotion of navigation along the Siberian northern coast was also discussed by the Council of Ministers, which charged the Governor-General of Irkutsk with setting up, in Yakutsk, a special committee of "local and invited experts in the North of Siberia" to discuss navigating conditions. According to the members of this committee, the first thing to do was to set up base stations with provisions depots and necessary implements all along the northern coast of East Siberia. However, since "the choice of the location of such stations was purely hypothetical," it was proposed

Map of the Arctic Ocean with the Russian shores from Varde to the Bering Strait. The map shows the routes of Russian and foreign expeditions in the Arctic from 1648 to 1915. Scale: 1/ 4200000 or 100 versts in an inch along the parallel 75°30'. Constructed by L. L. Breitfuss and D. N. Fedotiev in 1914 based on the newest data. L., 1922.
Archive of the Cartography Section of the Library of the Russian Academy of Sciences, St Petersburg





Map of the Yakutsk Oblast. Drawn and supplemented by G. Maidel in 1890 on the basis of Sheets III and IV of the map of Asian Russia (General Headquarters Publishers, St Petersburg, 1884). Scale: 1/4200000. St Petersburg: A. A. Ilyin's Cartographic Company, after 1890.
Archive of the Cartography Section of the Library of the Russian Academy of Sciences, St Petersburg

to organize as soon as possible two reconnaissance land expeditions along the Arctic shore of the Verkhoyansk and Kolyma regions. Simultaneously, the issue of steamship navigation to the estuaries of the Kolyma and Lena rivers across the Bering Strait was raised (Tolmachoff, 1911).

Shortly, the Council of Ministers initiated the discussion of these proposals at a special meeting in the Commercial Navigation Department of the Ministry of Trade and Industry, which declined "the immediate establishment of commercial navigation in these unexplored seas" as risky and untimely. At last, it was decided to organize only a land expedition, in 1909, led by Tolmachoff.

In the same year (1908), the Finance Committee of the State Duma considered the establishment of steam communication between Vladivostok and other ports of the Far East, with an option of extending the Vladivostok – Chukotka Peninsula line to the Kolyma *krai* (region). To this point, it was needed to obtain as accurate data as possible on the physics, geography, geology, and especially topography of the Arctic Ocean coast. One of the primary tasks of the expedition was the land survey of the coast from the Lena River estuary to the Bering Strait. At a meeting of the Physics and Mathematics Department of the Academy of Sciences, Minister I. P. Shipov, who submitted the request to assign Tolmachoff to the Ministry of Trade and Industry, made a point of surveying the entire coastline again (Shirina, 2001).

Difficult start

In summary, the urgent need to survey the Arctic Ocean coast was attributed not only to commonsensical scientific interest but above all to practical need.

This huge section of the country had been the least studied by the beginning of the 20th century (Krasnikova, 2009). The existing maps of this region were based on the data found by the expedition of 1821–1824 led by Lieutenant, Baron F. P. Wrangel, who together with the warrant officer F. F. Matiushkin, succeeded in generating the maps of the coastline from the Kolyma River estuary to the Kolyuchin Bay in a most severe environment, "from the land and in the winter from the ice" (Wrangel, 1841).

Even on the resulting "Map of the Arctic Ocean within the borders of the Russian Empire constructed on the basis of Russian hydrographic studies from 1734 to 1871," which contains the data obtained by 22 hydrographic expeditions organized all along the Russian northern coastline, the section from the town of Nizhnekolymsk to Cape Chukotsky is shown based on the data obtained by Wrangel's expedition. The relatively small section of the northern coast of the Bering Sea, from Cape Serdtse-Kamen to Cape Vostochny is marked as explored by Captain Lieutenant G. S. Shishmarev back in 1821.

No less important was the geological exploration of north-eastern Siberia. The geological study plan prepared by a special subcommittee with the participation of Tolmachoff was conveyed to the Mining Department (*Izvestiya Geologicheskogo komiteta*.1909.Vol.28. No 1. St Petersburg, 1909). Initially, the expedition was planned

Map of the Arctic Ocean in the borders of the Russian Empire, based on the Russian hydrographic explorations from 1734 to 1871. Constructed in the Drawing Office of the Hydrographic Division of the Navy Office in 1872. Completed and printed from stone in 1874.
Archive of the Cartography Section of the Library of the Russian Academy of Sciences, St Petersburg

to explore the area from the Lena estuary to the Bering Strait. Tolmachoff considered it possible provided that the expedition started not later than in February 1909: then, the distance from the Lena to the Kolyma could be covered on sledge in the three spring months, and the coast of Chukotka, in the summer.

However, even though key ministries and government structures were interested in the results of the expedition, launching it took much longer than anticipated. The first meeting dedicated to the organization of the expedition took place as late as December 20, 1908, whereas it took about two months to get from St Petersburg to the nearest point of the route. As a result, the idea of one team making the whole way had to be discarded, and Tolmachoff was commissioned to explore the most complicated part of the coastline, from the Kolyma estuary to the Bering Strait, as well as to raise the funds needed for the enterprise.

During the second meeting, on January 30, 1909, it became clear that the necessary funds could not be raised... The question arose: should the survey area be reduced or should the plan to have the expedition in the current year be abandoned at all? Yet the scientists decided to put in for the financial support of the original plan (the route from the Lena estuary to the Bering Strait) but to divide the study area between two teams. Tolmachoff was charged with the overall management of organizing the expedition.

The financing issue was resolved only on February 5, 1909 (almost the latest possible departure date from St Petersburg set by Tolmachoff!). In effect, its preparation began a month later, when the funds were finally appropriated. "Until then, the expedition could not be considered resolved and, strictly speaking, we could neither make the necessary orders and purchases without a certain risk...nor issue instructions or make orders locally, in the Yakutsk *oblast* (region)... Naturally, the question as to whether it was possible to launch the expedition in this situation was raised more than once" (Tolmachoff, 1911, p. 3–4).

There was virtually no time left to outfit the expedition; however, thanks to the assistance of interested individuals and institutions, they managed to do it within the shortest possible time. Head of the Chief Hydrographic Department A. I. Vilkitsky ordered to furnish maps, books and most instruments, and taught Tolmachoff how to perform astronomical observations. The geodesy division of the War Topography Department supplied instruments for the survey, two transit instruments and several chronometers.

The Yakutsk governor I. I. Kraft sent a telegram to Yakutsk ordering the Captain of Kolyma to make a stock for the expedition, purchase goods, hire reindeer and guides, and arrange a warehouse in the estuary of the Chaun River (a similar telegram concerning the assistance to the western team of the expedition was sent to the Captain of Verkhoyansk). Regrettably, these turned out the only governmental orders intended to help the Chukotka expedition, which worked in the area "very little familiar even to the local population and administration, where Russian influence amounted virtually to nothing" (Tolmachoff, 1911. p. 5).

Eventually, the Chukotka expedition comprised two detachments: the Chukotka team led by Tolmachoff, with the topographer M. Ya. Kozhevnikov and geodesist E. Weber, and the Lena-Kolyma team led by K. A. Vollosovich, with the astronomer E. F. Skvortsov and topographer N. A. Iyudin.

At the request of the Chief Hydrographic Department, another team was added to the expedition: Deputy Minister of the Navy, Admiral I. K. Grigorovich, commissioned a naval officer to "perform a detailed nautical study of the Kolyma estuary and of the approach route to it from the ocean, and construct the newest sea maps" (Sedov, 1917, p. 3). The head of this team was G. Ya. Sedov, who had participated in the Arctic expeditions before, and his assistant was boatswain's mate V. Zhukov. This small detachment was to encourage the resumption of the work of the Arctic Ocean Hydrographic Expedition suspended six years before. By the beginning of 1909, the expedition vessels, called the *Taimyr* and the *Vaigach*, had nearly been constructed, though they failed to put out to sea at once because of some minor loose ends. The plan of their work was revised a few times, and only in August 1909 they set out to the Far East by the southern route, through the tropics.

Three months on the way

In the long last, Tolmachoff's expedition set off. Now we cannot do without a frequent citing of his "Preliminary Report..." entitled "Along the Chukotka coast of the Arctic Ocean" (1911), which has been mentioned above more than once.

On March 3, Tolmachoff with his team, E. F. Skvortsov from Vollosovich's detachment, and G. Ya. Sedov made their way from Petersburg to Irkutsk via Moscow. There, provisions and warm blankets had been prepared for the expedition, as well as wide and deep sledges with a high tail, lined with fabric. The astronomers Weber and Skvortsov set to work at once.

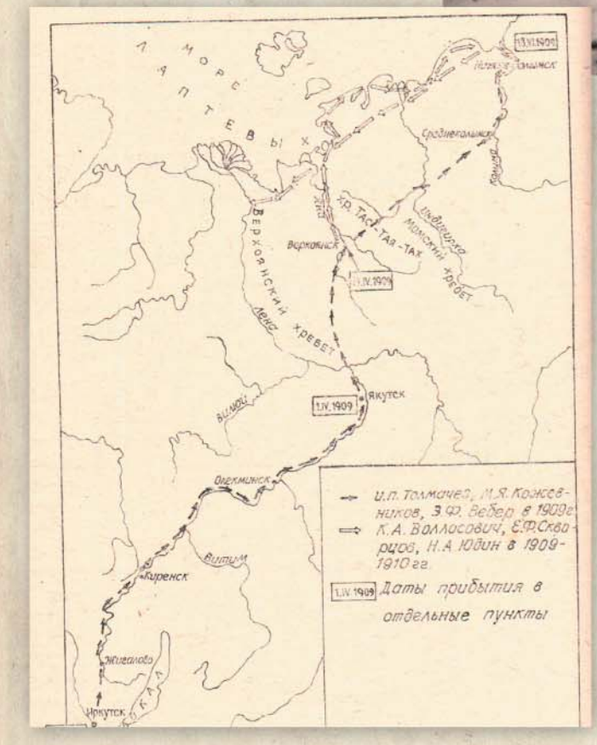
Because of a lack of horses and bad roads, it was decided to go to the expedition area in several teams. Tolmachoff came to Yakutsk on March 31, and the astronomers of the expedition, on April 2 and again took observations. Thanks to the assistance of the local administration and some individuals, the necessary goods and provisions were purchased quite quickly and the swollen luggage of the expedition was prepared for forwarding: "Unexpectedly, the purchases had to be essentially increased as nobody in Yakutsk could warrant that I would receive in Sredne-Kolymsk all the goods I ordered from St Petersburg... I could not risk staying without goods there because you cannot visit the Chukchi just with money. So I had to take three hanks of tea and a pound of Cherkess tobacco, which together with other snacks increased our luggage in Yakutsk by six sledges, and we had brought about the same number of sledges from Irkutsk.

I. P. Tolmachoff's Chukotka expedition (1909). Along the Kolyma tract on reindeer. *Photo: St Petersburg Branch, Archive of the Russian Academy of Sciences. Collection 1053. Finding aid 2. # 47, # 132*

Map of the routes of the Lena-Kolyma expedition from the estuary of the Ilyin Shar stream of the River Yana delta to the estuary of the Alazeya River, led by geologist K. A. Volossovich. Scale: 1/700 000. 1909. Astronomical points determined by E. F. Skvortsov. Eye work by N. A. Iyudin. Constructed and drawn by the military topographer N. A. Evenbakh. Leningrad: State Cartography Institute, R&D Dept., Supreme Soviet of the National Economy, Pryazhka, 5, approx. 1924 (Leningrad oblastlit). *Photo: St Petersburg Branch, Archive of the Russian Academy of Sciences. Collection 138. Finding aid 2. # 52, Sheet 10*

Along the Kolyma tract. A stopover (Sedov, Tolmachoff, a Yakut coachman). *Photo by G. Sedov. From: (Tolmachoff, 1911)*

Routes of the parties of I. P. Tolmachoff and K. L. Vollosovich's Lena-Chukotka expedition (from Irkutsk to the Kolyma estuary). *From: Danilin Ye. L. To unbeknown lands. Krasnoyarsk, 1998*



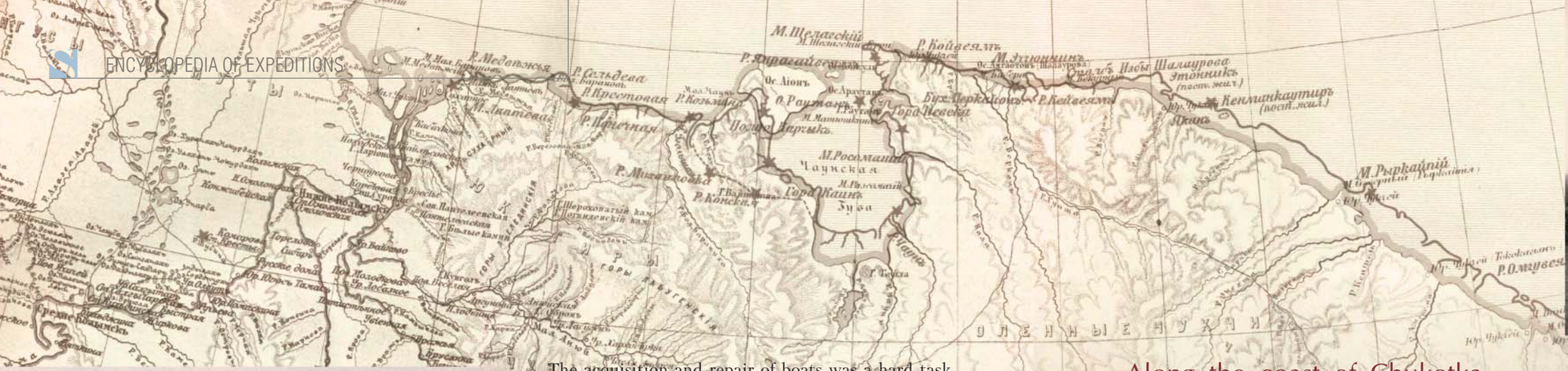
Plus we had three sledges of our Cossacks and the sledges of three coachmen, so our expedition borrowed more than twenty sledges. All in all, the expedition (including K. Vollosovich's party) together with G. Ya. Sedov had about forty sledges" (Tolmachoff, 1911, p. 8–9).

The journey to Yakutsk went very well but after that there was nothing but trouble. Postmasters said the post house horses were for post and not for expeditions - *ulus* (settlement) carts should be used for that purpose. When Tolmachoff wondered why there were no carts, the Yakuts assured they had not heard about the expedition, and the special messenger who had come to Sredne-Kolymsk in March carrying the travelers' dispatches had left no orders concerning the journey. "The conclusion they must have made was that the expedition was an inane matter, not worth of being cared about" (ibid, p.14).

The muddy season began, and things went from bad to worse: Tolmachoff and his fellow travelers got stuck at the Dirin-Olomsk post house, 120 *versts* * from Verkhoyansk, where there were neither deer nor horses. Having got hold of the only horse available, he sent a Cossack with an official paper to seek for a means of transport. "The main symbolic point of this paper was my wax seal with a feather stamped to it – a symbol of urgency and importance of a paper, applied throughout the north of Siberia and well known to non-Russians" (ibid, p.16). Thanks to it, after new adventures, they managed to move on...

Tolmachoff arrived in Verkhoyansk on the night of April 18, and a day later Sedov joined him – almost without luggage, just with three sledges loaded with instruments. Sedov's arrival changed Tolmachoff's plans: originally, he intended to wait for his fellow companions; now,

* A *verst* was a Russian unit of distance equal to 1.067 kilometers



Crossing the Alazeya River. *Photo by Sedov*. *From: (Tolmachoff, 1911)*

the explorers decided to move on taking any opportunity and at the same time making sure that their colleagues would be able to follow them. As there were not enough horses for the entire caravan, it was agreed to split into several groups.

The next leg of the journey was completed only by May 14. Tolmachoff wrote, "It took us 37 days to get from Sredne-Kolymsk to Yakutsk, which, in the opinion of Kolyma citizens, was very quick as in such circumstances it often takes more than two months" (ibid, p.30). The Captain of Kolyma V. Dushkin informed about the approaching expedition, saw about the deer and horses. Also, they managed to make some purchases for the expedition, as a result of which "Sredne-Kolymsk's stock of butter and sugar became depleted – so slender is the store of the most vital provisions here by spring. Dozens of *puds* **of dried bread made on our order had only just been baked and sent to Nizhne-Kolymsk..." (ibid, p.30).

**A pud was a Russian unit of weight equal to sixteen kilograms

The acquisition and repair of boats was a hard task. Dushkin's letter to Tolmachoff mentions the repair of a boat by the craftsman Gambaev, who was paid 15 roubles and "S" bottles of spirit: "only thanks to the latter we managed to talk Gambaev into it; he promised a good job but insisted that he had S bottles. I have no spirit, so I'm sending Gambaev to you with this note, you can do as you please" (St Petersburg Branch, Archive of the Russian Academy of Sciences. Collection 1053. Finding aid 2. # 27). The spirit did not help though: the fixed boat filled with water as soon as it was put afloat.

On May 25, Tolmachoff and Sedov left Sredne-Kolymsk on two boats: "We didn't have a word from our companions, and the local inhabitants thought they had been held back by freshets and wouldn't reach the town soon. G. Sedov improved his karbass as much as he could by raising the boardsides and equipping it with more comfortable oars and a small gaff-sail, which really dropped a bomb in Kolyma" (Tolmachoff, 1911, p. 44). Despite the wind and high wave, they got to a new arm of the Kolyma River, the death place of the well-known explorer of Siberia I. D. Chersky, marked with a plain wooden cross.

They arrived in Nizhnne-Kolymsk on the night of June 1, and managed to hire an interpreter, Rumiantsev, a Yukagir by nationality. On the morning of June 8, Tolmachoff was going by boat down the Kolyma, and in four days he made it to Sukharny, where he joined his fellow travelers who had arrived there the day before. On June 22, the expedition set off to the Laptev light house, where they were to start their observations.

It took the travelers three months and a half just to get to the start point of the planned route. The nightmare with roads and transport was aggravated by adverse weather: an early mud season, river overflows, and strong winds. As a consequence, the expedition made it to the Laptev light house a month and a half later than planned. The biggest problem was to hire Lamut workers: with great difficulty, Tolmachoff talked six men and a woman into taking part in the expedition. According to local practice, the latter was charged with putting up a raw-hide tent and looking after the clothes and footwear of all expedition members (ibid, p. 42—43).

Along the coast of Chukotka

On June 23, the expedition members finally set to work. Load was distributed among the horses and deer, and the expedition headed east. The caravans were a nuisance: the deer were mostly old and exhausted, and half-wild horses were trained to get used to the bridle right before the journey.

The first stopping place was near the estuary of the Medvezhaya River, where the expedition took its final shape: "Apart from the three of us, there were two horsemen, an interpreter, a Cossack and seven Lamuts–14 people all in all. We three stayed in two tents, the bigger of which, where E. F. Weber and M. Ya. Kozhevnikov slept, served as a common area when we camped. The Lamuts lived in the raw-hide tent, and the Russian workers were lodged in the so-called "canopy" – a small tent of daba, almost cubical in shape, fit only for sleeping because of its size but giving protection against the rain, wind, and most importantly, mosquitoes" (ibid, p. 46).

"The expedition now moved as follows. I set out on a deer in the company of a Lamut, also riding a deer, and a pack-deer carrying the tools and collections we gathered. I rode or walked along the shore, very close to the water. M. Ya. Kozhevnikov also went along the coastline with another Lamut, but in a sledge, though he had to leave it even more often than I had to dismount the deer. The caravan led by E. F. Weber, as a rule, went in the depth of the tundra as the shore was sometimes cliffy and impassable... there were many small rivers... M. Ya. Kozhevnikov and I used our canoe. Sometimes, when it was heavy ground, we walked and the pack-deer carried the load. When we were discussing the expedition beforehand, we assumed that advancement along the coast would take longer than the progress of the caravan. In fact, it has turned the other way round. Thanks to the unwinding coastline, the way along the shore would be almost the shortest way were it not for the hurdles mentioned above. Because of them, the caravan had to move far from the shore, going round the rivers or coastal mountains. Moreover, without proper supervision, people halted unnecessarily often, as though passively protesting against this summer march, totally weird for them.

Expedition's camp on the River Medvezhaya. *Photo by I. Tolmachoff. From: (Tolmachoff, 1911)*

As a result, M. Ya. Kozhevnikov and I, moving not faster than you can go on foot working all the time, not only did not hinder the progress of the expedition but very often came to the agreed place for the night much earlier..." (ibid, p. 47—48).

Later on, Tolmachoff and Kozhevnikov separated: Tolmachoff went with the worker Shkulev, who led a horse with a load and a box with a chronometer. When there were outcroppings on the shore, Tolmachoff dismounted and walked for many miles.

Delineating the coastline more accurately was not an easy task: "We got entangled in numerous large and small lakes, little bays and river arms, extensive marshes and so on. It was very difficult to see where the coastline actually was, and in our survey we marked the shore with a dotted line" (ibid, p. 55). The turmoil with tundra rivulets ended before the town of Kain, where the mountains approach the shore... Among the locals hired for the expedition, Tolmachoff singled out the Chukchi Yermankau and his stepson, whom he called "a lucky exception." They "found fords, if there were any, helped to take the load across, looked after me when I, observing the outcroppings on steep shores, waded round cliffy bays, helped with the deer and horses when we stopped for the night and when we broke camp and moved on – in a word, they behaved like members of the expedition, and all that they did absolutely selflessly unless one counts the meals I gave them" (ibid, p. 57).

On August 3, the travelers stopped for the night on the left bank of the Chaun River, and on the morning of the following day they were at a subsistence warehouse, where the Cossack Kipriyanov and the interpreter Berezhnov had been waiting for them all summer. There, Tolmachoff began preparations for the winter journey: bought the hides of young reindeer for good winter wear and chamois leather for a tent. The changeable weather did not afford tours about the surrounding area, and one had to watch out for the clear sky to perform astronomical observations.

On August 16, Tolmachoff sent the Lamuts and deer with a small load to Cape Shelagsky, under the supervision of Kipriyanov, having left all the horses for Kozhevnikov and himself, and in two days two heavily loaded bidarrahs controlled by Weber and Berezhnov continued their way.

Right before the departure, the horseman Shkulev was taken seriously ill. The work could not wait, so Tolmachoff decided to go with Kozhevnikov, leaving Shkulev on the Chaun on the hands of Rumiantsev. Now his small team had just one horseman who had to look after "14 half-wild horses which had had a good two-week rest and had half forgotten their short-term training, and loads for eight horses" (ibid, p. 62). Now Tolmachoff had to lead four pack-horses: "... We slowly moved on, the more so that the southern and south-eastern shores of the Chaun Bay are low-lying, so I could fully devote myself to being a horseman, not distracted by geological exploration (ibid, p. 63).

On September 2, the expedition got to the River Yanragayveyam near Cape Shelagsky. It was necessary to think about the winter transport and to purchase sledge dogs. Part of the load and comprehensive natural science collections was sent back, to the Kolyma estuary. In the second half of October, the team approached Cape Ryrkarpiy (Northern), from where Kozhevnikov, who had frostbitten hands after the Khatanga expedition of 1905, returned to the Kolyma, taking with him the gathered ethnographic collections.

Tolmachoff and Weber moved on, and on November 11 reached Cape Serdtse-Kamen. Extremely long distances, continual moves and adverse weather made the travelers virtually stop the survey, which had been done systematically up to this time. For the same reason, Tolmachoff's geological exploration "lost any consistency and coherence." Fortunately, this part of the coast "was more accessible for a traveler" and had been surveyed before, and the explorers managed to provide the missing astronomical points.

There, the explorers found out that the *Shilka* vessel, sent by the Navy Department, had already been at the cape and had left. It was charged with taking the members of the expedition on board at the beginning of September and bringing them to St Petersburg. Not having found Tolmachoff and his fellow travelers, the vessel went back to the Arctic Ocean, where it ran into ice, turned back and went to the southern waters (Starokadomsky, 1915. p. 66).

The travelers went on, and on November 19 arrived at a small Russian settlement, the Dezhnev station, where they received a warm welcome from a small Russian colony. They stayed there till December 5 because of the continuous blizzard, Weber's disease and the necessity to hire new dogs as the Chukchi who had come with the expedition immediately went back.

Tolmachoff's Chukotka expedition was scheduled to go east from the Kolyma River estuary, rounding the Chukotka Peninsula. However, because of the great difficulties faced by its members, the itinerary was completed at the Bolshaya Kuropatochya River (St Petersburg Branch, Archive of the Russian Academy of Sciences. Collection 47. Finding aid 2. # 152. Sheet 3).

On December 6, Tolmachoff and Berezhnov set off home. "We submitted entirely to Chukotka practices, leaving long before dawn and took the ordinary way. The whole coast was familiar to us now, and everywhere we were welcomed amicably" (Tolmachoff, 1911, p. 71). On the way, Tolmachoff found out about the famine, which Kozhevnikov had experienced together with the local population, near Cape Shelagsky. A few sledges with new dogs were sent to Kozhevnikov and to Weber, who was catching up with a big load.

On February 11, Tolmachoff left Sredne-Kolymsk. The way back turned out very easy: everywhere, the travelers were provided full cooperation to the extent that "it was difficult to recognize that these helpful and eager to please post house keepers were the Yakuts we had met previously. A circular letter about the expedition by the Yakutsk Governor had been sent all along the way, and it was a totally different story" (ibid, p.14—15).

On April 3, 13 months after the departure, Tolmachoff and Kozhevnikov came back to St Petersburg. In August, having made his journey via Vladivostok, Weber came back (ibid, p. 82).

Results

Organizational issues prevented Tolmachoff from the immediate processing of the expedition results. As there was huge interest in the data obtained, Tolmachoff had to speak about the expedition again and again, beginning from the way back home. "One can see what great interest the local residents have in potential navigation from the following fact: In February 1910, on their way back through Yakutsk, members of the Chukotka expedition shared their insights on potential trading along the Chukotka coast in the Kolyma estuary and on their hopes that such trading was feasible. On April 15, i.e. six weeks later, several young businessmen inspired by the results of the Chukotka expedition started a commercial association named Kolyma-Chukotka Partnership" (ibid, p.117).

As early as in 1911, the first passage from Vladivostok to the Kolyma River estuary took place, executed by order of the Ministry of Commerce and Industry by Rear Admiral P.L. Troyan on the ordinary merchant ship Kolyma, which carried the government-owned cargo of provisions and essentials.

М. Рыркайпій или Сѣверный оканчивается двумя обособленными безъимянными утесами, которые я назвалъ въ честь моихъ товарищей по экспедиціи — западный «утесомъ Кожевникова», восточный — «утесомъ Вебера», какъ это показано на прилагаемой выкопировкѣ изъ нашей съемки. Утесъ Кожевникова изображенъ, кромѣ того, на рисункѣ 1 таблицы 11, гдѣ онъ снятъ, приблизительно, съ юго-востока. М. Рыркайпій является важнымъ насе-

Мысъ Рыркайпій по съемкѣ экспедиціи. (Въ 1 дюймѣ 5 верстъ). А. П.—мѣсто астрономическихъ наблюденій экспедиціи.

ленныхъ пунктомъ Чукотскаго побережья и въ исторіи нашей экспедиціи игралъ большую роль. Для моихъ спутниковъ это былъ предѣльный пунктъ, откуда М. Я. Кожевниковъ, во время движенія экспедиціи къ востоку, долженъ былъ возвратиться на м. Шелагскій и Колыму, а позднѣе отсюда же Э. Ф. Веберъ возвратился на м. Дежнева, гдѣ дождался пароходовъ.

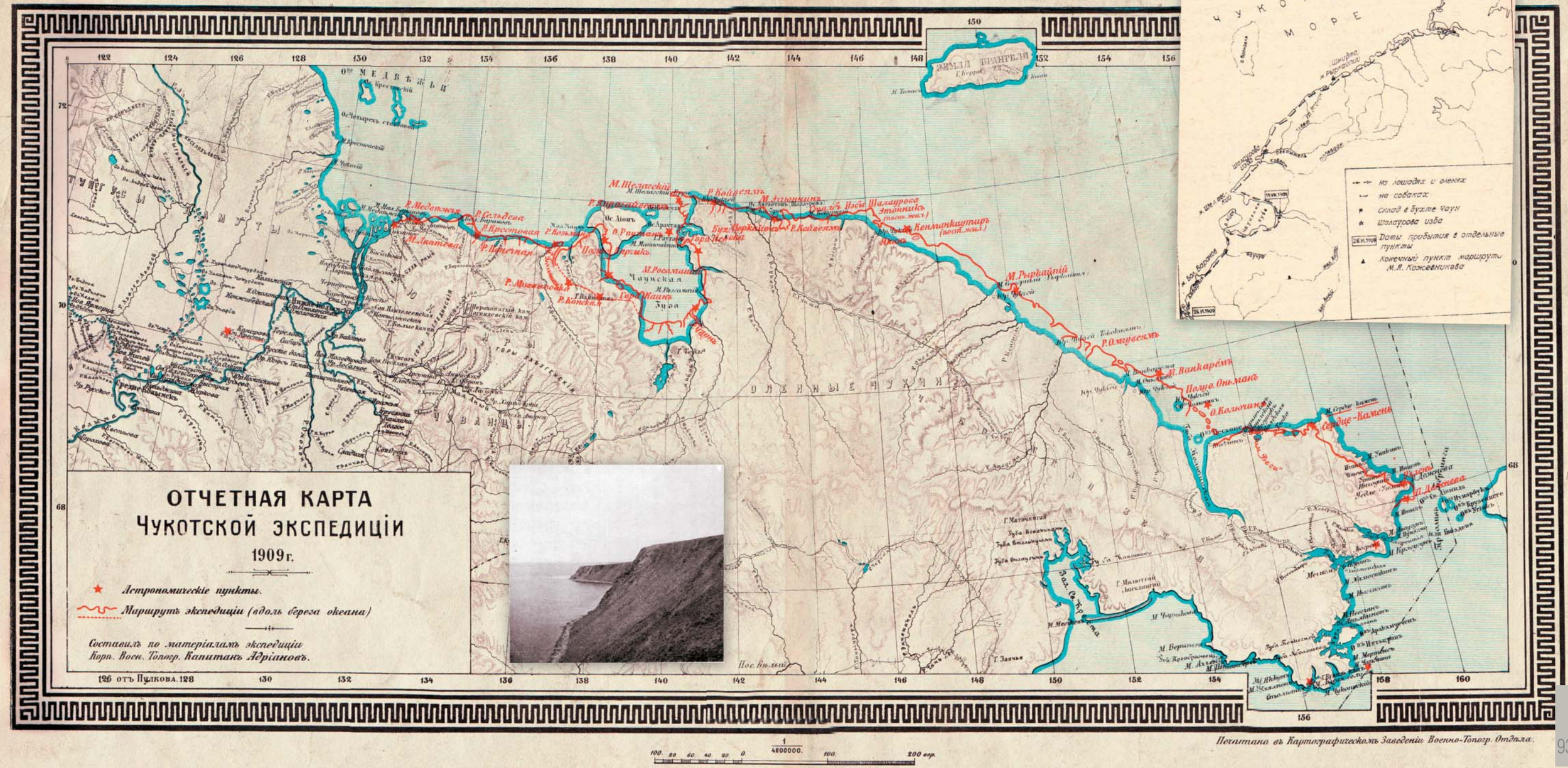
Cape Ryrkaypiy as surveyed by the expedition (1 inch is 5 versts). *From: (Danilin, 1998)*

Kozhevnikov at work on the shore of the Chaun Bay (*top*). In the Konveyam area. Preparations for a sleighing trip. *Photo by I. Tolmachoff. From: (Tolmachoff, 1911)*

The events of the recent years – the Chukotka expedition, resumed Hydrographic expedition of the Arctic Ocean, and passage from Vladivostok to the Kolyma estuary – were so important that on December 3, 1911, the Chief Hydrographic Department held a meeting dedicated to the Northern Sea Route, attended by ministers and members of the State Council and State Duma (Russian parliament, 1905—1917). In his talk, Tolmachoff emphasized the contribution made by the Chukotka expedition, establishing its connection with the results of Hydrographic expedition of the Arctic Ocean designed to find the Northern Sea Route. The greater part of his talk, however, was dedicated to the urgency of research into the Taimyr and description of the condition of the area he had explored (St Petersburg Branch, Archive of the Russian Academy of Sciences. Collection 269. Finding aid 3. # 6).

Tolmachoff with interpreters on the Chaun.
Photo by Kozhevnikov. (*From: Tolmachoff, 1911*)

I. P. Tolmachoff's Chukotka expedition on Dezhnev Post. Rumiantsev, Tolmachoff, Weber, and Kozhevnikov next to a store of the trading house I. Ya. Churin & Co (1909)
Photo: (St Petersburg Branch, Archive of the Russian Academy of Sciences. Collection 1053. Finding aid 2. # 47. Photo # 136



Apart from the many talks, Tolmachoff as the head of the expedition did routine work: calculated the expedition's expenses and amounts intended for gifts to the Lamuts; counted the expenditures on prepress of expedition photographs and maps, on copying the diary and so on (St Petersburg Branch, Archive of the Russian Academy of Sciences. Collection 1053. Finding aid 2. # 4).

Nor did he leave his science and popular science activities – within a short period, he published several important works. Most importantly, in April 1911 he completed the journal of the expedition so frequently quoted above, "Along the Chukotka coast of the Arctic Ocean: a preliminary report by the leader of the expedition that explored the Arctic Ocean shore from the Kolyma estuary to the Bering Strait, launched in 1909 by the Commercial Navigation Department of the Ministry of Trade and Industry."

This detailed narration abounding, among other things, in the details of everyday life and supplied with a lot of remarkable photographs was published by Tolmachoff at his own expense and was not for sale – he just gave the book to those who were interested...

The journal dwelt on the expedition's everyday life: the colossal non-stop organizational work the leader of the expedition had to do from hiring people and purchasing provisions to the delivery of equipment

Operation map of I. P. Tolmachoff's Chukotka expedition of 1909—1910. Published in the preliminary report of the expedition "Along the Chukotka coast of the Arctic Ocean" (St Petersburg, 1911).
Archive of the Cartography Section of the Library of the Russian Academy of Sciences, St Petersburg

Itinerary of I. P. Tolmachoff's expedition along the coast of the Arctic Ocean (*top, right*).
From: (*Danilin, 1998*)

and gathering collections... Tolmachoff had no time to write in detail about his geological explorations and made brief notes such as "As I was waiting for the colleagues, I decided to start geological works from Sredne-Kolymsk and managed to make a brief acquaintance with the structure of the Kolyma banks, or its right bank, to be exact, since the left bank is lowland and alluvial along the whole length" (Tolmachoff, 1911, p. 33, 64).

And yet, the scientific results of the expedition were impressive. The reconnaissance survey of the five-*verst* scale was conducted along the entire length of the coast from the Kolyma estuary (Laptev light house) to Cape Chaplin, and a survey from the River Bolshaya to the Chaun River estuary. The survey was made based on 24 astronomical points; its aggregate length was 2,550 *versts*. Also, astronomical points were determined and the contour of the shoreline from the Kolyma River estuary to Cape Dezhnev was drastically edited (ibid).

Tolmachoff compared the results obtained with Wrangel's maps, which proves again that at the time there

URGENT RUSSIAN BUSINESS

It is a sad thought that important geographic discoveries in the Yenisei Province can be made not by the Russians, who have owned Siberia over three hundred years but have not edited the maps yet. Apparently, exploration of the Northern route is no longer considered a theoretical matter devoid of any practical application; in my opinion, without the exploration of Taymyr, this is not possible. The recent war has demonstrated that the Arctic Ocean is a matter of a nationwide scale, though way back in the 18th c. Lomonosov dreamt about defending the Russian Pacific coast via the Arctic Ocean. We can now hope that these dreams will eventually come true. Moreover, there is another immediate and important goal closely connected with the establishment of the Northern route: improving the well-being of the North Siberian population through the delivery of cheap goods, which can only be done by sea.

Speaking about the Chukotka Peninsula, I said nothing about its population, and so I intend to do it now. The entire north of Siberia is populated with nomadic and vagrant indigenous dwellers. On the Chukotka Peninsula live the Chukchi, who wander to the west of the Kolyma. In the basin of this river, you can also find the Lamuts (the Evens) and a few tribes now almost extinct. To the west, the Lamuts give way to the Dolgans and Tungus, who, to the west of the Khatanga, in their turn, give place to the Samoyedic people. Besides, throughout the north between the Anabar and the Kolyma there are quite a few Yakuts.

Russian population is present on the Kolyma, in the estuaries of the Indigirka, Yana, Lena and on the Yenisei. On the Khatanga, Anabar and northern Yenisei Russians have died out, as they are dying out presently on the Indigirka.

The conquest and, to a certain extent, colonization of Siberia went through the north, and trading with Europe was partly done by sea, with Russian and foreign ships going as far as the Yenisei. The Cossacks-conquerors and their descendants settled down along this way close to the northern coast, apparently because it was profitable for them. However, the government soon stopped navigation in the Arctic Ocean and directed all traffic to Siberia by the southern Vladimir Highway. As a result of this decision, the North was impoverished straightaway as it had to receive whatever was required from the south, which in view of the huge and desolate territory is even today a Herculean task. The first to go were Russian settlers as the most maladjusted and living in most remote habitations. Indigenous dwellers, thanks to their subsistence economy, were in a less vulnerable position, though they had acquired some habits from the newcomers and could barely manage without tea and tobacco, indispensible for any Siberian indigenous dweller, and this is why for them, too, the abolishment of the Northern route was a heavier blow than one could have anticipated.

Except for the shoreline Chukchi, who live to the east of Cape Shelagskiy and survive mainly on soap [apparently, fat is meant – author's note] of the sea animals, all north Siberian indigenous dwellers are reindeer herders, with the exception of the poor and those who settled near Russians. For all of them, the northern tundra is a foster-nurse, and they move to the forests in the south only for the winter.

All this population relies exclusively on the Siberian railroad, and the enormous distance from it boosts megalomaniacally the cost of goods brought to the North, on the one hand, and, on the other hand, prevents taking out low-value commodities. Vladivostok imports meat from Australia while on the Arctic coast propagate herds of many thousands of reindeer, which nobody can either cure or control. The Arctic Ocean is a natural base for indigenous people in their subsistence economy. It goes without saying that it should be the base of their commodity exchange too, and this can be achieved only through the proper shipment of goods by sea to the northern coast, where these goods will quickly oust the expensive goods coming from the south.

It can be expected that regular navigation along the Arctic coast will result in an increase of the Russian population, or its appearance in the places where it is absent. The North

M. Ya. Kozhevnikov trading with the Chukchi (*left*).
Post-Pliocene sands on the ocean shore, to the west of the Bolshaya River (*right*). *Photo by I. Tolmachoff*.
From: (*Tolmachoff, 1911*)

is not as poor as many think but to live there relying only on the faraway railroad is very difficult and expensive. The Americans benefit from supplying their commodities to the eastern part of the Chukotka Peninsula and actively make their way to the west, towards the Kolyma, where one of them even got an exclusive commercial privilege, which he did not use though. Therefore, the establishment of commercial enterprises is not just a matter of industry – it is a national business, which is not as costly as may seem. If we count how much it costs to provide annual assistance, not nearly sufficient, to starving Kolyma and expenses to ensure provisions, not sufficient either, for the relatively large Cossack population, and take into account the difference in the prices of goods shipped by sea and by land, the extras will not be high, and will be needed only at first; shortly, there will not be any extras, and the northern routes will transport cheap commodities in good supply and will not cost the state an odd kopeck.

Advocating the northern sea route, I am happy to realize that I am not alone because I know that among those present here there are people who are in favor of the idea of the Northern Sea Route and there are many advocates of this idea behind these walls. We are all ready to promote this idea to the best of our ability and knowledge, in word and deed, without regard to our own life, if necessary. This way is strewn with graves, but it does not scare us – what scares us is the indifference of the society, which is much more difficult to overcome than the polar conditions. However, here, too a new era must be dawning. The representatives of the society present at this meeting were, largely, the initiators of the meeting.

I hope to God that the interest in the Northern Route does not subside and the society regard the efforts made towards this end as an urgent matter and a Russian business. This is our belief, our hope and our award for the work done and for the past disappointments" (Tolmachoff, [1911], St Petersburg Branch, Archive of the Russian Academy of Sciences. Collection 269. Finding aid 3. # 6)

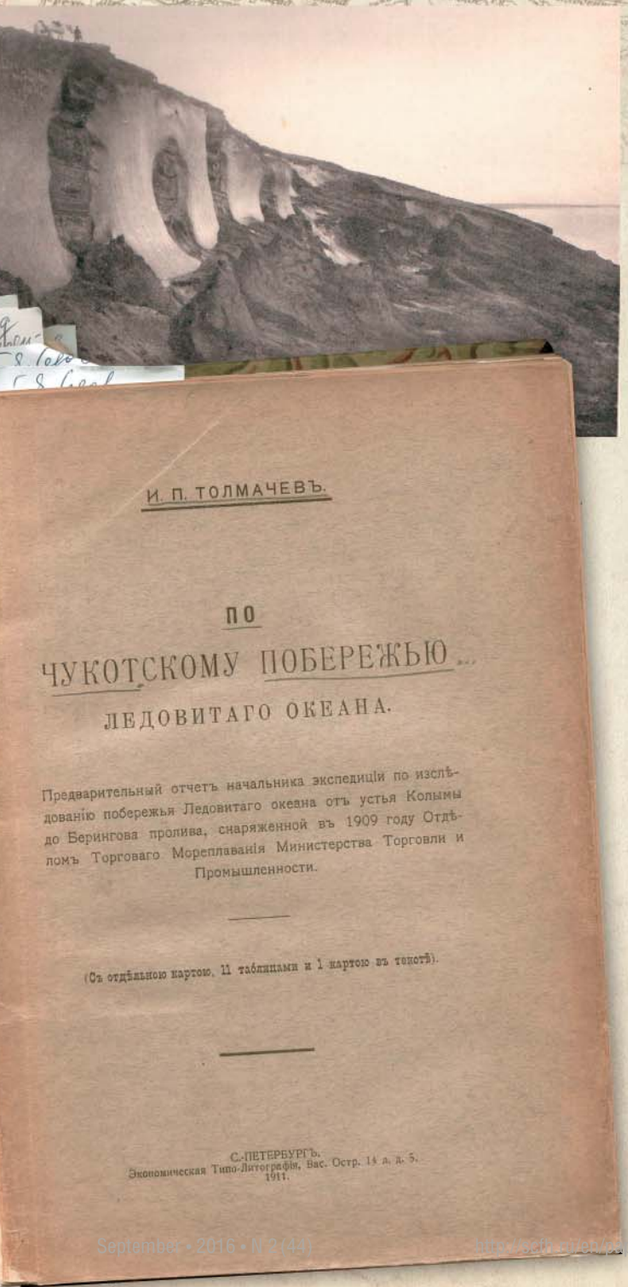
were no later cartographic documents related to this area. Tolmachoff enclosed to the *Preliminary Report* the Operational map of 1909 Chukotka Expedition, constructed based on the expedition materials by the Corps of Topographical Engineers, which showed the profoundly altered position and contour of the shoreline all along the coast from the Kolyma River to the Bering Strait.

Also, data on the condition of the sea ice and possibility of navigation along these shores were obtained; physical and geographical features of the "Chukotka land" (Tolmachoff, 1910), as the part of north-eastern Siberia to the east of the Kolyma River was then called, were described. Virtually all along the expedition route, geology observations were conducted, and, among other things, the issue of the presence of oil deposits in this region was raised.

The lithologic collection gathered by Tolmachoff and paleontological material including wood debris from the post-Pliocene deposits of the Arctic Ocean coast, fossil moose and mammoth from the same deposits and Devonian petrified remains from the rivers Kolyma and Dogdo were sent to the Geological Museum, the same as the collections brought by G. Ya. Sedov, where they were partly catalogued and studied.

The slow movement of the expedition caravan allowed Tolmachoff to make "in passing" most interesting ethnographic observations relating to the everyday life of the Lamut and Chukchi, their family life, customs and trade relations with other peoples including Americans. As a result, he concluded that it was necessary to start importing Russian goods and organize commercial voyages between Vladivostok and Kolyma, which would serve "not to strengthen but to restore the Russian influence and involve this remote region in cultural life," without, however, revolutionizing the traditional way of life of the Chukchi, which had formed over centuries and perfectly suited local conditions (Tolmachoff, 1911, p.104).

Ice in the soil on the oceanic shore near the River Bolshaya. *Photo by I. Tolmachoff*. *From: (Tolmachoff, 1911)*



Soviet time

On the completion of the expedition, Tolmachoff started preparing the expedition materials for publication: a detailed draft report comprising the journal notes is kept at the St Petersburg Branch, Archive of the Russian Academy of Sciences (Collection 1053. Finding aid 2. # 3). He intended to publish the scientific results of the expedition and an expanded report with an ample historical background and extensive bibliography later on, but the First World War and then the events that followed the October Revolution of 1917 interfered with these plans. In 1922, Tolmachoff emigrated to the USA, leaving his motherland for good, and there had been no call for the scientific results of the Chukotka expedition until the mid-1920s.

In his correspondence with his son, geographer and explorer of the North A.I. Tolmachoff, Tolmachoff the emigrant often came back to the issue of completing the processing and publishing of the expedition results. Meanwhile, the well-known Soviet geodesist and hydrographer V.V. Akhmatov took up processing the astronomical determinations of the expedition, and the famous hydrometeorologist L.F. Rudovitz was engaged in the meteorological determinations.

By 1924, when this work had been almost completed, at the First Congress of Soviets of Yakutia, an idea of the scientific study of the territory of the Yakut Republic came up, which would improve its economy and culture of the peoples inhabiting it. It was the Secretary of this congress to whom Kozhevnikov filed an application to the effect that "in connection with the planned activity of the Yakutia expedition of the Russian Academy of Sciences," it was imperative to publish the proceedings of the Chukotka expedition led by I.P. Tolmachoff, which had been conducted exclusively within the borders of the present-day Yakut Republic.

Thanks to energetic activity of the full-time ambassador of the YASSR (Yakut Autonomous Soviet Socialist Republic) at the Presidium of *VTsIK* (All-Russia Central Executive Committee) M.K. Amosov, the Academy of Sciences started publishing the works about the YASSR "concerning all aspects and not published yet" including the materials of the 1909 Lena-Chukotka Expedition led by I.P. Tolmachoff and K.A. Vollosovich. The materials of the Kolyma detachment led by K.A. Vollosovich were published in 1930 and made Volume 15 of the *Commission's Proceedings of the Studies of the Yakut ASSR*. Because of the name of the expedition the 1909 Lena-Kolyma Expedition led by K.A. Vollosovich it was almost impossible to relate them to Tolmachoff's Chukotka Expedition.

The collection of drawings of the Chukotka expedition entitled *The Chukotka Expedition of 1909—1910. An album of illustrations and maps* was published only in 1935 as an appendix to Issue 18 of the *Polar Commission Proceedings*. There is nothing surprising about it as the Polar Commission was set up on Tolmachoff's initiative, and he was the Commission's secretary up to his departure.

The story of this publication is connected with an interesting discovery made a few years ago in the Cartographic Archive of the Polar Commission, St Petersburg Branch, Archive of the Russian Academy of Sciences, of several dozen drawings showing the northern coastline from the Kolyma River estuary to the north-easternmost tip of the Chukotka Peninsula. The sheets were in prime condition, the coastline was detailed, a lot of local geographical names were plotted but none of the sheets was dated (Krasnikova, 2012). Further research showed that these maps were indeed processed results of the survey conducted by the military topographer M. Ya. Kozhevnikov and geodesist E. F. Weber during the Chukotka expedition of 1909—1910 led by the geologist I. P. Tolmachoff.

Data about the time when these drawings were printed were obtained from the *Index of the cartographic materials of the Arctic ocean (from North Cape to Cape Dezhnev) from 1734 to 1914 kept at the Depot of Navigator Charts and Books of the Chief Hydrographic Department (compiled in chronological order)*, which was compiled by Staff Captain B. Ewald and came out in 1917. This index was the first in the series conceived for those interested in a detailed study of Russia's water basin and contained information about all available cartographic materials concerning the Arctic Ocean up to 1914.

It has turned out that the Department of Navigator Charts also had copies of these drawings: "# 546. Copies of the drawings of the expedition that explored the Arctic Ocean coast from the Lena River estuary to Bering Strait led by I.P. Tolmachoff in 1909, lithographers..." (Ewald, 1917). This fact suggests that the drawings were processed at the beginning of the First World War.

Why was the publication of these drawings important in the mid-1930s? Apparently, because these cartographic materials retained their relevance and were used to construct new base and detailed maps of the USSR Arctic territories. "Prior to drawing the route, it was used by the Chief Hydrographic Department for map correction. Subsequently, astronomical points were added to the route, and as a result, the route was specified. In 1932, it was used to construct the map of the Yakut ASSR" (Kozhevnikov, 2012, p.15). Note that the drawings were published after the maps based on the data from the drawings had appeared. This must be why the "source document" had to be published.

Materials of the Chukotka expedition were used for other maps of the Soviet Arctic region constructed in those years.

The adverse conditions under which the expedition was organized and conducted, so vividly and in much detail described by I.P. Tolmachoff, profoundly affected its schedule. Instead of a detailed exploration of the coast, "the expedition reduced itself to travelling along and exploring the shoreline from the Kolyma to Cape Dezhnev" (Tolmachoff, 1911, p. 83). The results of the expedition, however, disagree with Tolmachoff's modest evaluation of his achievements.

And in any case, was it possible to do more in those conditions and at that time? The members of the expedition were the first to walk all along the incredibly extensive stretch of the Arctic coastline with an extremely complicated natural environment. A most important achievement of the expedition is the survey of one of the most difficult to access areas of Russia's northern coastline, which has allowed a substantial refinement of the maps of the Arctic and obtaining additional physical and geographic data to demonstrate the feasibility of navigation from Vladivostok to the estuaries of the Northern rivers.

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Panorama of the middle basin of Lake Baikal from a coastal cliff. Photo by V. Korotkoruchko

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