Lavrentyev as the Vice-President of the Academy of Sciences of the Ukrainian SSR. 1948. The SB RAS photo archive

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SCIENCE First Hand

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A Good Journal for Inquisitive People

SCIENCE

First Hand

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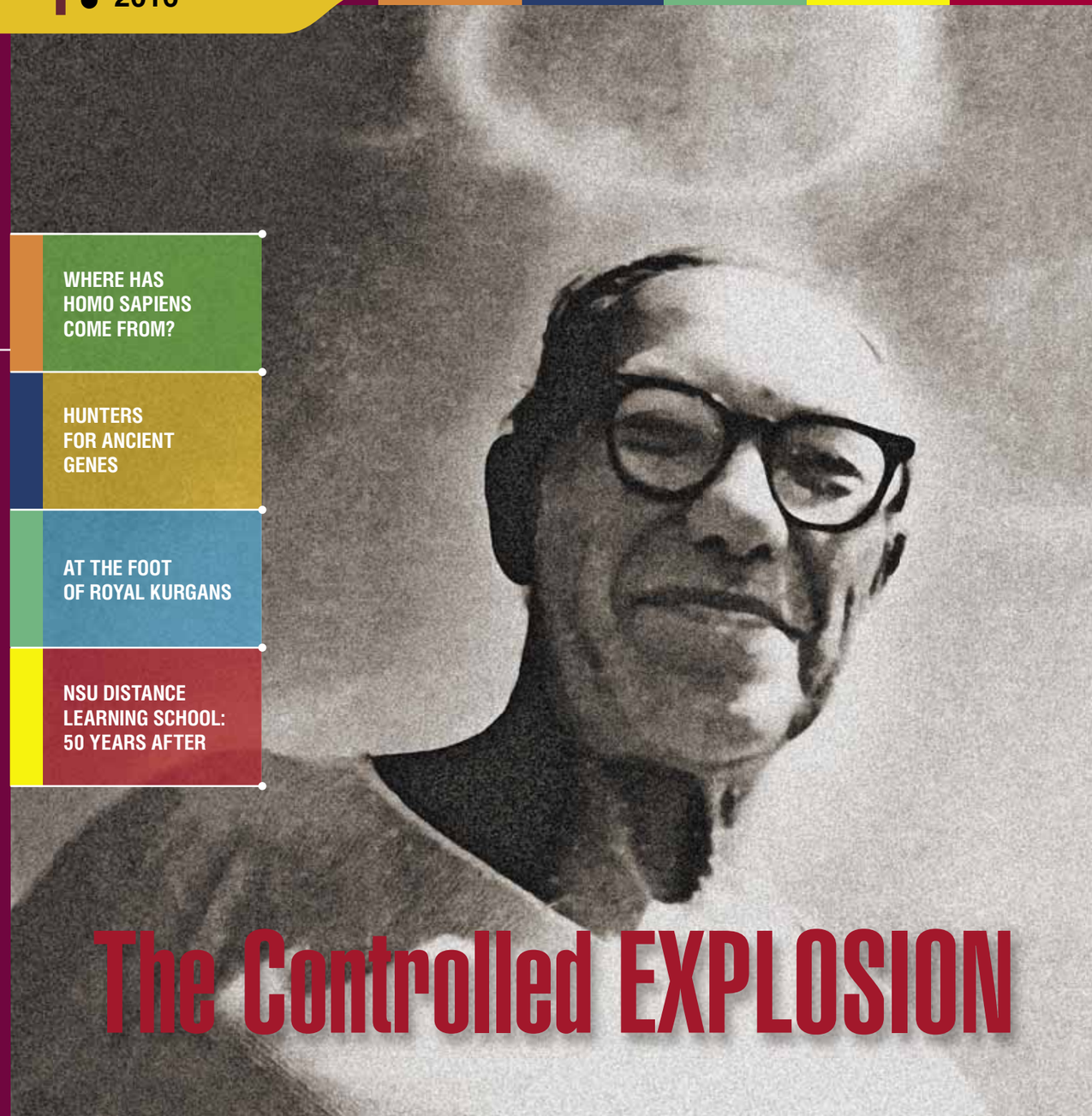


The Controlled EXPLOSION

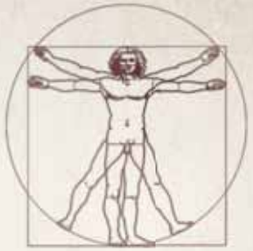
1. 2016
popular science journal

SCIENCE First Hand

IN THIS ISSUE:

Academician N.N. Moiseyev: "When I think of M.A. Lavrentiev, to my mind spring the figures of the Renaissance: the same scope of interests and activities, the same rage of ambitions and passions, the same lack of fear in his endeavors. People of this caliber are so rare. They are the cream of the nation; they create the image of an epoch

The Distance learning School of Physics and Mathematics at Novosibirsk State University, which marked its 50th anniversary in 2015, was "illegal" for many years, supported only by the enthusiasm of the University students, and the first official documents was the decree of their dismissal from the University



A Journal
for Inquisitive People

"The natural desire
of good men is knowledge"

Leonardo da Vinci

Periodical Popular Science Journal

Published since January 2004

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Dear Friends,

This issue of our journal has come out by the 115th anniversary of Mikhail Alekseevich Lavrentiev, an outstanding scientist of our days, who is for a reason compared with an iconic figure of the Renaissance, Leonardo da Vinci. Today, we remember him not only as a most prominent mathematician, mechanician, and founding father of the Siberian Branch of he USSR Academy of Sciences – a revolutionary project not only for Russian but for the world science, too. As we know, a basic component of the famous "Lavrentiev's triangle" is personnel, that is, purposeful, multi-stage training of young scientists that starts from school-days. One of the ways of engaging talented youth in scientific research was the All-Siberia Olympiad of School Students in Physics and Mathematics started in the early 1960s. The third round of the Olympiad implied participation in the Summer School conducted in Akademgorodok of Novosibirsk, where school students could get in touch with "live science."

Once, in 1961, the well-known physicist G.I. Budker, who was the head of the Sumer School organizing committee, put forward a proposal, surreal for the timeC, to organize a permanent school of physics and mathematics at Novosibirsk State University. Lavrentiev became an ardent advocate of this idea: according to the memoirs of Gennady Fridman, one of the first students of this school, which are published in this issue, "during the first six months, it was an illegal educational establishment funded through an undoubtedly unauthorized use of funds by M.A. Lavrentiev, who wasn't afraid of anything because he acted in the name of an idea, ... and only in August 1963 the USSR Council of Ministers issued a decree on boarding schools, and later such schools were set up in Moscow, Leningrad, Kiev, and in other cities."

The continuation of this story became a vivid example of the feasibility and huge potential of the ideas laid in the foundation of the Novosibirsk center for academic research. The same Fridman, when he was a second-year student of Novosibirsk State University, together with his friends literally "retried" the organizational experiment performed three years earlier by the founding fathers. This is how, fifty years ago, the distance learning school of physics and mathematics was started, which gave inquisitive and talented teenagers from towns and villages all over the Soviet Union, including the most remote areas, a rare chance to assess their abilities and essentially improve their standards in physics and mathematics. Unbelievably, this one of the best national distance learning schools was, in fact, illegal and supported only by the enthusiasm of its organizers. According to Gennady Fridman, "The first official document that showed that the Distance learning School did exist appeared only six or seven years later. Ironically, it was a University decree that G.Sh. Fridaman and other organizers should be fired from University for ruining the Distance learning School."

In the same issue, we are publishing materials dedicated to the fundamental problems of cultural and historical processes that have taken place since high antiquity to these days. The specific occasion is the 25th anniversary of the Institute of Archaeology and Ethnography (IAE), SB RAS, a most important national center for research in humanities – in the last 15 years, the scholars working in the Institute have been awarded three State Prizes of the Russian Federation for achievements in science and technology.

If we follow the letter of law, the IAE SB RAS was formally awarded the status of an independent research institution 25 years ago, in the end of the year 1990. However, if we look at the Institute's "evolutionary tree," we will see that its roots go down the faraway 1960s, the very start of academic research in the humanities, and the Institute's "immediate ancestor" is the Institute of History, Philology and Philosophy, Siberian Branch, USSR Academy of Sciences, established in 1966 by a prominent Soviet historian and archaeologist Aleksey Pavlovich Okladnikov, the founding father and head of the school of research into the history, archaeology, and ethnography of Siberia, Russian Far East, and Central Asia.

The remarkably broad chronological, thematic and geographical range accounted for the enormously wide array of issues tackled by the Institute: from the spread of Paleolithic traditions in Eurasia and development of ancient arts to the ethnogenesis of indigenous Siberian peoples and development of Russian culture in Siberia.

We will get the readers acquainted only with some of the research conducted in this originally multidisciplinary institute. Even judging from this limited selection, we can see that each of the authors remembers well the words once said by A.P. Okladnikov: "Go for it but bear in mind the three simple recommendations borne by the history of scholarly research. As you move forward, keep in touch with the experience of the previous generations. Value your heritage, the contribution made by your predecessors. Beware of the lure of an easy way towards ambitious goals, adventurism in elaborations and the phony glitz of false gems."

Academician Nikolay L. Dobretsov,
Editor-in-Chief

The **NEANDERTHAL** gene variant that occurs in modern humans and that is responsible for the lipid transport through cell membrane has been found to provoke **DIABETES** but in the old times it could have offered an advantage in case of chronic starvation. **C. 40**

According to the analysis of mitochondrial **DNA** and the male **Y-CHROMOSOME**, the expansion of the “Andronovans” across West Siberia in the 2nd millennium BC was accompanied by **NUMEROUS ALLIANCES** between them and the local female population. **C. 60**

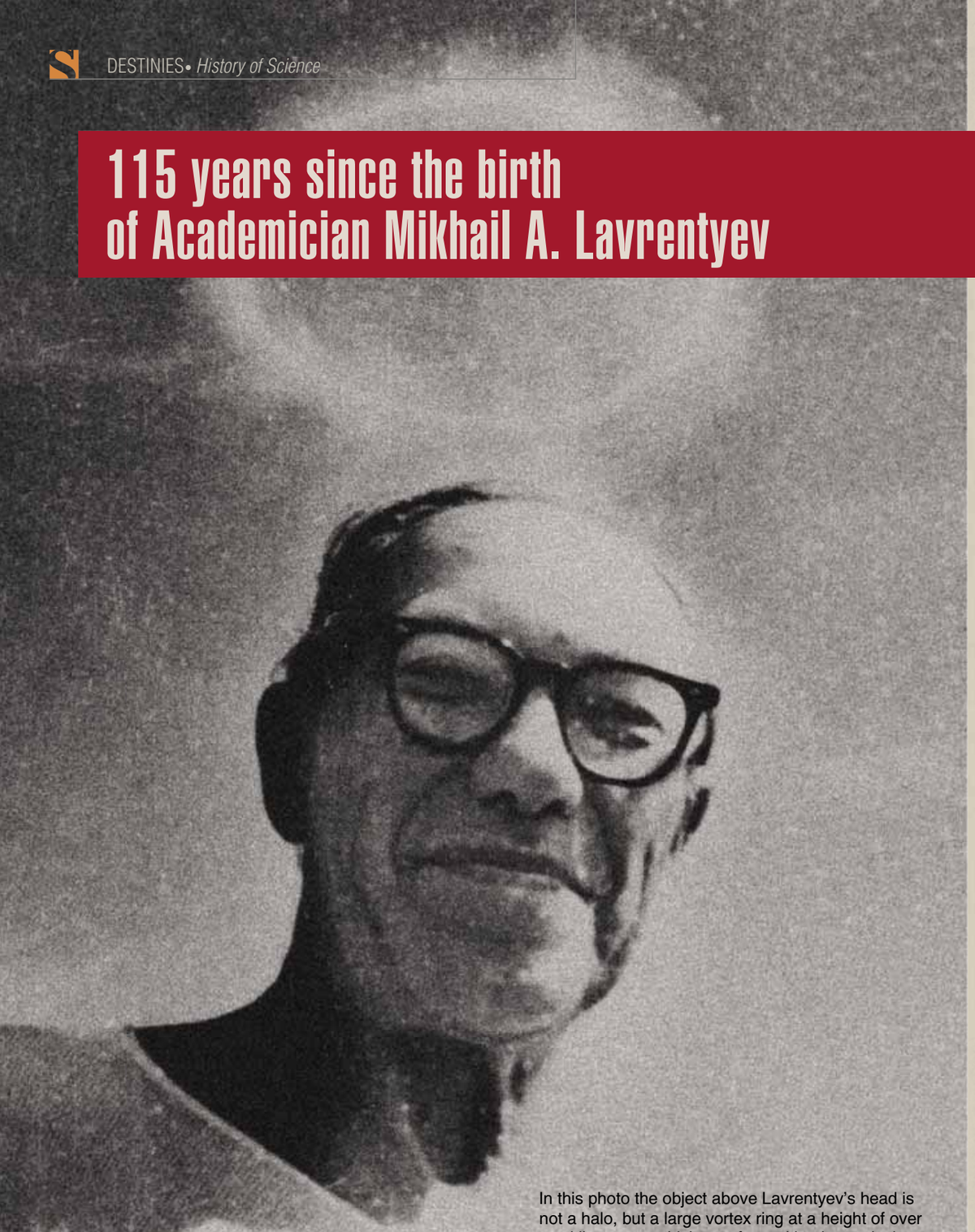
Large **SCYTHIAN** kurgans appear to have been used also as **TEMPLES** for commemorating the dead and offering up sacrifice, including human sacrifice, to gods. **C. 74**

Recent archaeological studies have shown that the ancient tumuli of the **EURASIAN STEPPE** are not just mounds but structures of complex **ARCHITECTURE BESPEAKING** the high level of the construction technologies of the ancient nomads. **P. 90**

A.A. VASILIEV

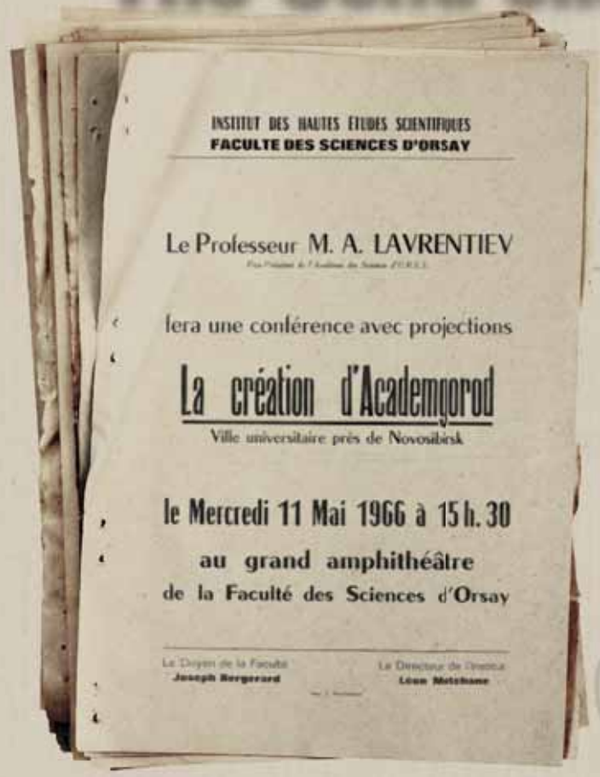
115 years since the birth of Academician Mikhail A. Lavrentyev

The Controlled Explosion



In this photo the object above Lavrentyev's head is not a halo, but a large vortex ring at a height of over two kilometers, which was formed by the explosion of three tons of gasoline sprayed in the air above the island in the Ob Sea. *July 1966*

Key words: M.A. Lavrentyev, Siberian Branch, explosion, cumulation, hydrodynamics



INSTITUT DES HAUTES ÉTUDES SCIENTIFIQUES
FACULTE DES SCIENCES D'ORSAY

Le Professeur M. A. LAVRENTIEV

fera une conférence avec projections

La création d'Academgorod

Ville universitaire près de Novosibirsk

le Mercredi 11 Mai 1966 à 15 h. 30

au grand amphithéâtre

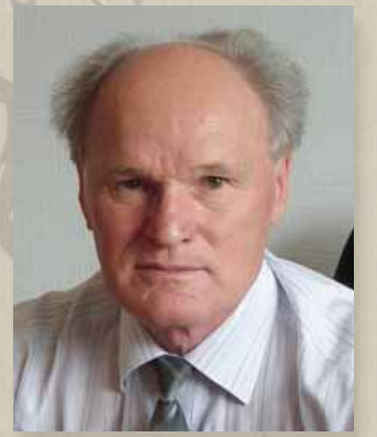
de la Faculté des Sciences d'Orsay

Le Doyen de la Faculté
Joseph Bergerard

Le Directeur de l'Institut
Léon Motchane

Announcement of a lecture by Academician Lavrentyev, which was preserved and kindly handed by the French friends to the KVN team of Novosibirsk State University, who visited France in October 1989. *The NSU Museum*

The name of Academician Mikhail A. Lavrentyev is forever inscribed in the annals of Russian science, in particular, the history of the Siberian Branch of the Academy of Sciences. One of the main themes at the recent conference "Lavrentyev Readings on Physics, Mechanics and Mathematics," which is held every five years by the Institute of Hydrodynamics SB RAS, the firstborn of the Novosibirsk Science Center, was the theory and applications of explosion, which were of great interest to Lavrentyev himself. His contributions to science include the hydrodynamic theory of cumulation with a paradoxical hypothesis that, at high pulse loads, the metal behaves like a liquid; the works on directed explosion, which are associated with the problem of crushing and moving of monolithic materials into a given direction; and the little known works on the development of a nuclear artillery projectile. To commemorate 115 years since the birth of Academician Lavrentyev, SCIENCE First Hand presents an article on the physics of explosion, a most diverse and multi-faceted theme, which has been developed for many years at the Institute of Hydrodynamics and continues to be popular today



Anatoly A. VASILIEV, Doctor of Physics and Mathematics, Professor; Head of the Gas Detonation Laboratory, Lavrentyev Institute of Hydrodynamics SB RAS (Novosibirsk, Russia). Director of the institute in 2010—2015. Awarded with the State Prize of the Russian Federation. Author and coauthor of 250 research papers and 9 patents

Scientific literature understands explosion as a rapid conversion of an explosive material from the original state into the gaseous state, which is accompanied by a powerful dynamic and thermal impact on the nearby bodies. Widely circulating in the media, today the word explosion is primarily associated with severe devastation, and the term TNT equivalent is known even to preschoolers.

Indeed, uncontrolled explosions in the workplace and in the home are a danger because of possible deaths and injuries as well as damage to material objects. Throughout its multimillion-year history, the humankind suffered from forest and steppe fires caused by lightning strikes, although the man has always wanted to rein over the forces of nature and use them for their own benefit. The tamed fire proved to be a great helper; today heat and electricity is still produced mostly by controlled burning of various hydrocarbon fuels. Another part of our everyday lives is the tamed explosions: one can hardly imagine the life of modern people without the millions of tiny explosions that occur every second in the various internal combustion engines, including in such "explosive" devices as cars.

However, the human civilization owes not only its modern comfort but its very existence to an explosion. In search of an answer to the eternal question about the origin of the Universe, scientists could not do without explosion either. According to one of the theories, called the Big Bang theory, the Universe originated about 13.77 billion years ago. After being born in an explosion, it was a highly homogeneous and isotropic medium with an extremely high pressure, density (about 1093 g/cm^3), and temperature (about 1032 K), and has been continuously expanding and cooling ever since. (For comparison, the maximum density of matter on the Earth is only 23 g/cm^3 (in iridium), and the temperature on the Sun's surface is 6 · 103 K.)

What unique measuring instruments must be in place for researchers of explosive processes to cover this enormous range of parameters, from superdense solids to high-temperature gases! Scientists specializing in one narrow field would not cope with all the research tasks posed by explosion physics; this science requires a holistic approach. Lavrentyev and his colleagues were well aware of that when they created the Siberian Branch within the USSR Academy of Sciences. The principle of diverse and interdisciplinary research underlies the works of the Institute of Hydrodynamics, named after Mikhail Lavrentyev; a substantial contribution to the institute's bank of achievements comes from researchers of explosive processes.

The goals set by the founding fathers are replaced by new ones; life goes on. Peering into the future, I would like to, once again, pay tribute to the older generation, who created the Siberian Branch more than half a century ago. Their principles (science—people—implementation) have never been forgotten by the subsequent generations of Siberian researchers and have proved to be highly important today. The present and future generations should know their history, especially the history of science, and take pride in its achievements. This article presents a brief history of explosion science and is dedicated to the 115th anniversary of the birth of Mikhail A. Lavrentyev, one of the brightest scholars who worked in this field.

Peaceful explosions

Lavrentyev developed a sustained interest towards explosion-related problems during World War II, while he was working on new weapons. In the years after the war, he pursued in-depth research into explosion processes and their applications in the national economy.

From the recollections of B. E. Paton, Academician of the RAS:

"When Lavrentyev returned to Kiev in 1945, he continued to be the head of the Institute of Mathematics, Academy of Sciences of the Ukrainian SSR, and pursue research in explosion science. He set up an experimental laboratory to investigate the quality of explosives and their applications, in particular, to determine the strength of welded structures of large thickness. There were also experiments on explosive forming of metal items. These works used pyroxylin powder waste... as a result, in the 1940s—1950s, with the direct participation of Lavrentyev, Ukraine began to use explosion for peaceful purposes, e.g., for building channels, tunnels, and roads; in the construction industry and agriculture."

Lavrentyev continued to take interest in explosion processes in the subsequent years, when he moved to Moscow and began to teach at Moscow Institute of Physics and Technology. His student, a former researcher at the All-Russian Research Institute of Experimental Physics (Arzamas-16) and winner of the Lenin Prize, M. V. Sinitsyn reminisces: "...when in 1951 we completed our fourth year of studies, M. A. organized for us, as a pre-degree practical training, a trip to Kiev. There, at the Institute of Mathematics, he supervised the laboratory for explosive processes. Now I cannot remember the exact name of the laboratory; its head was N. M. Sytyi, a major specialist in blasting operations. The laboratory was located in a suburban settlement Feofaniya ... That settlement housed, apart from the resident population, two or three laboratories of academic institutes and a few summer cottages for high-level academics. In this serene, paradisaical place, we conducted our experiments right on the path the locals used to go to Kiev... The charge was usually suspended between the trees, and we walked in the opposite directions: if there were passers-by, we asked them to wait in a gully where they could not see the charge. After the explosion, we all returned to our business: the people went to the city, and we came back to our measuring instruments.

"Our week schedule was as follows: we received an assignment from M. A. (e.g., to determine the pressure field of a charge of a given configuration) and discussed the measurement techniques and the expected result. After that, M. A. often went away to Kiev. We made the necessary devices from the scrap materials we could find in the laboratory and in the neighborhoods. Used tanks, scrap pipes, lead seals and what

Lavrentyev as the Vice-President of the Academy of Sciences of the Ukrainian SSR. 1948. *The SB RAS photo archive*

Below: Studies of the piercing of the tank's armor. 1944. *The SB RAS photo archive*

not were rolled out in the laboratory workshop to make instruments for measuring pressure and momentum. We pressed explosive charges of the needed shape and size and conducted the experiments. Then we analyzed the results and prepared a report to M. A., who arrived at the appointed time.

"This approach showed us how one can use ingenuity and resourcefulness to obtain practical results even from most primitive means."

Barrier against mudslides

Lavrentyev's explosion studies gained a new impetus in 1957, after establishing the Siberian Branch of the USSR Academy of Sciences. As early as in the first months of his Siberian life, Lavrentyev laid the foundation for the further, extremely successful research in this area.

The main focus was the so-called directed explosion. An important thing in blasting operations is that the ground should move in the right direction. Lavrentyev had an idea how to arrange the explosives to achieve that result. Two of Lavrentyev's students—V. M. Kuznetsov and E. N. Sher—were entrusted with putting this idea to practice. Experiments carried out in 1960 on the banks of the Ob Reservoir showed that the solution was correct.

From the recollections of B. G. Novikov, Institute of Thermal Physics SB RAS:

"One day, closer to autumn, I was walking past Lavrentyev's cottage and saw him busy doing something at one of the many stumps near the side wall of his house. The stumps were high and thick. Apparently, the area for the house was prepared in winter, and the trees were sawed above the snow level. Lavrentyev stood up and walked over to the wall. I heard a clap, not very loud. The stump lifted up and then fell down slowly straight away from the house. The situation repeated with a few more stumps. I realized that the claps were small explosions... Later, in 1960, Mikhail Alekseevich made, at his very modestly celebrated anniversary, a brilliant scientific report that briefly yet clearly outlined a number of ideas and results, both his own and those of his students... One of them was the idea of directed explosion, which ensures the movement of medium of a given mass into a given direction without changing its shape during the movement. Only then I realized that in autumn 1958, near his house, Mikhail Alekseevich was testing the idea of directed explosion."

Sometime later, under the supervision of Mikhail Lavrentyev, directed explosion was used to make a tremendous antimudflow dam near Alma-Ata.

Here is how Lavrentyev himself reminisced about the building of this grand protective structure in Medeu:

"On my initiative, in 1959, the Academic Council on the Economic Use of Explosion was established within the USSR Academy of Sciences. I became the council's chairman, and Academician M. A. Sadovsky was my deputy. Setting up this council expanded our opportunities in the implementation of scientific methods in technology and in the national economy. We established a good relationship with Soyuzvzryvprom and their chief engineer M. M. Dokuchaev.

"Right at that time, we were working on a project of using explosion to build an antimudflow dam on the Malaya Almaatinka River near Medeu, 15 km from Alma-Ata. Quite rarely, once in 20—30 years, under certain climatic conditions, the melting of snow in the mountains leads to the formation of lakes. At some point, the snow dam cannot withstand the pressure and breaks apart, and a huge mass of water (up to a million cubic meters), carrying rocks and boulders, slides down the river valley. The power of this flow of water and rocks is such that it can destroy a half of Alma-Ata (over 100 years, the city suffered three times from mudslides). In 1962—1963, we received warnings from hydrometeorological and seismic stations: large mudslides were expected. Blasting was the only way to quickly make a dam in the way of the mudflow and protect the city.

"Dokuchaev suggested that we make a dam by double explosion; a group of young people (led by Sadovsky and myself) conducted the calculations; and the project was submitted to the Council of Ministers of Kazakhstan. The Council of Ministers and the Central Committee of the Communist Party of Kazakhstan endorsed the project, but a number of academicians of the Kazakh Academy of Sciences as well as scientists specializing in various fields raised strong objections in the press. They insisted that the proposed blasting of 10,000 tons of explosives is itself more dangerous than the mudflow.

"The expert assessment was entrusted to the Explosion Council. We gathered several times in Akademgorodok and in Moscow; between the sessions, we made calculations for various explosive location options and the possible seismic, explosive and smoke implications (which the opponents of the explosion feared most).

"The decision in favor of the blasting was strongly influenced by the mudslide near Lake Issyk, 70 km from Alma-Ata... On July 7, 1963, Lake Issyk was visited by one of the republic leaders with his guests. A motorboat was waiting at the pier to take them to the other side of the lake so that they could see a recently built resort. The boat was ready, but the driver was absent. While they were waiting for him, they heard a roar and rumble from the mountains—a mudslide was coming. It was clear that the guests had to be taken away immediately. A few minutes after they left, a flow of mud and rocks fell into the lake. The lake overflowed; a hole formed in its natural stone dam; and a new mudslide, together with water from the lake, rushed down the gorge. The settlement of Issyk, located at the end of the gorge, was badly damaged, but there were almost no casualties since the residents had been warned about the danger.

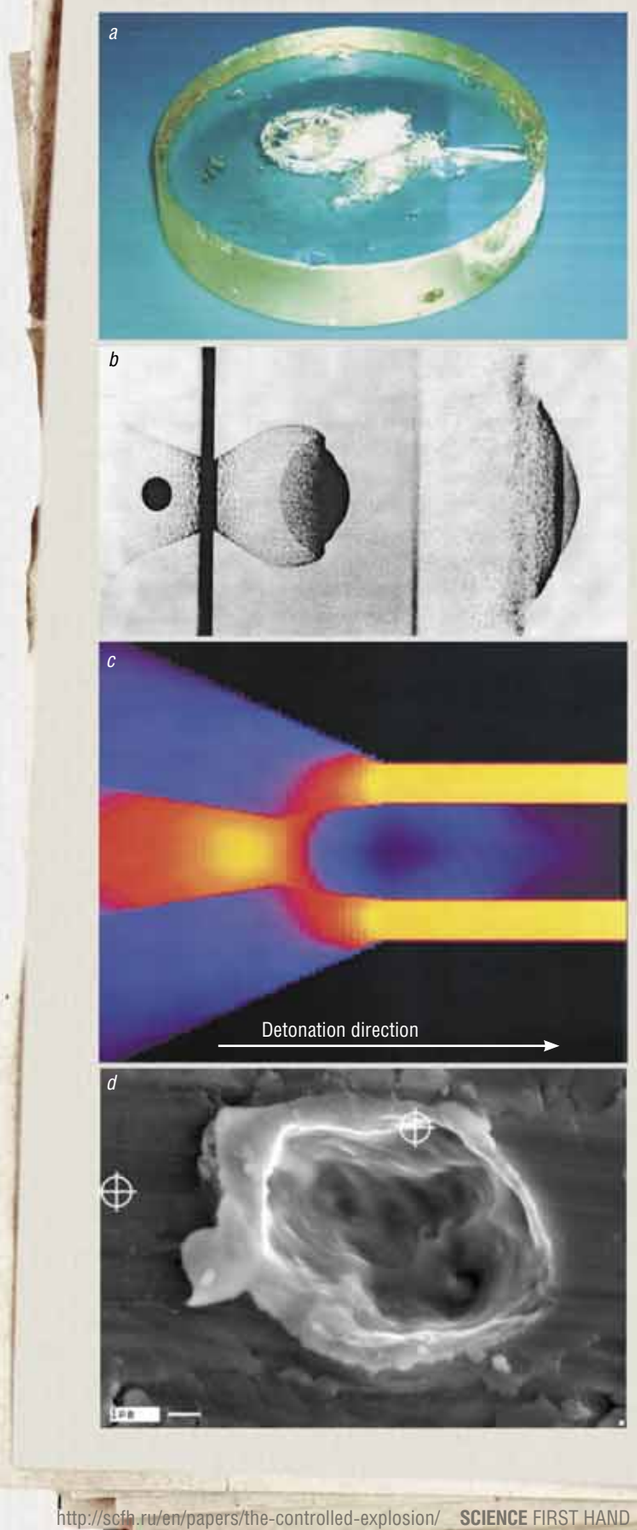
"Soon we were again summoned by D. A. Kunayev, who requested additional information about the explosion safety to make a final decision. A model explosion was performed in an area near the future dam. In haste we forgot to secure a shelter for ourselves and got hit by a shower of stones weighing 10 to 100 grams—we all tried to hunch down our heads and protect them with our hands...

Successive stages in the development of the explosion on the right bank. Images taken from the downstream wall of the dam (from the Medeo rink).
Left: View of the gorge before the explosion and eight seconds after the explosion.
Above: Cloud of glowing gas and dust 30 seconds after the explosion and a view of the gorge 2 minutes after the explosion.
Photos taken by the expedition organized by the Institute of Physics of the Earth, USSR Academy of Sciences

"The blasting was performed in autumn 1966. We were standing on a mountain and saw everything—from the fire to the fractured rock mass that came off slope and fell into the valley...

"Seven years after the construction of the dam... there mas a mudslide in the Almaty Gorge, whose power was greater than that of all the previous events (it was carrying rock debris weighing up to 120 tons). All the traps above the dam were swept away. The reservoir formed by the dam and planned for 100 years was filled nearly to three quarters. The drainage pipes were clogged; the lake level was rising steadily; water began to leak through the dam.

"A commission was urgently called from Moscow; Sadovsky and me represented science... Headed by Kunaev, the republic leaders, representatives of industry, dam builders, military people and scientists gathered together on the dam. The main question was whether the dam could withstand the pressure of millions of cubes? Although everyone was convinced that it would and did not worry about the leakage (ordinary filtering through the riprap), measures were taken to drain water from the lake through the pipes... Two days later, one could safely go home."



A good antimeteorite shield is a vital contribution to the safety of space objects and operations. The Institute took up this problem upon the direct request from Korolev to Lavrentyev.

In the photo:

a – a sample of glass for spacecraft portholes, which was damaged during experiments with flying spherical microparticles;
b – experimental image of a microparticle piercing though a barrier (1960s);
c – meteorite or space debris simulations, i.e., metal or glass particles ranging in size from 0.1 to 5 mm are accelerated by a high-velocity cocurrent flow of detonation products from 1 to 8—14 km/s;
d – crater on a steel plate exposed in open space aboard the Mir International Space Station; the crater as formed by the impact from a particle of space debris

Mikhail A. Lavrentyev, 1958.
Left: One of Lavrentyev's students Yury Fadeenko, who took an active part in the works associated with space exploration. *Photo from the book Ya – FIZTEKh, Moscow, 1996*

Space tasks

Explosion studies were also relevant for the strategically important goals of space exploration. In the early 1960s, with the rapid development of space research, scientists faced a challenge associated with spacecraft being hit by meteorites. The future Academician V. M. Titov, a student of Mikhail Lavrentyev, volunteered to solve the problem of meteorite impact simulation under the terrestrial conditions. Using the principles of cumulative charge, the scientist managed to accelerate small metal balls to space velocities. This made possible not only to study the possible consequences of rendezvous of meteorites and spaceships but also to assess the effects of meteorite impacts on the Earth and on celestial bodies.

The history of these studies is given in the recollections of Yu. I. Fadeenko (Institute of Hydrodynamics), who was directly involved in the development of a technique for high-speed throwing of bodies:

"At the beginning of 1958, the Institute of Hydrodynamics was preparing to leave for Novosibirsk Akademgorodok... The Moscow scientific community had a most encouraging attitude towards the New Siberians; academicians suggested exciting research problems for the young scientists that were going to Siberia. It was the first time that the institute had got a space-related research theme. The country was about to launch the third artificial Earth satellite (ISZ-3), and Academician S. P. Korolev proposed Lavrentyev to work on a relevant task—to create artificial meteorites, i. e., rapidly moving particles that could be used to calibrate the meteorite sensors installed on ISZ-3. The velocity of these particles had to be no less than the first cosmic velocity, 7.8 km/s.

"The departure was a matter of months, but during that time, the student L. A. Lukyanchikov, who was then working on his degree paper, managed to obtain, by means of a cumulative explosion, a gas stream with a velocity of 13—14 km/s. However, there was no time to use it to accelerate solids particles; we had to load on the train...

Neil Armstrong on a picnic with the Soviet cosmonauts Beregovoy and Feoktistov.
Right: Academician Mikhail A. Lavrentyev
Photos from the SB RAS archive

Lavrentyev's students from MIPT, who moved to Novosibirsk in 1958 to work at the Institute of Hydrodynamics. Left to right: Yu. A. Trishin, M. E. Topchiyan, V. V. Mitrofanov, B. V. Voitsekhovsky, L. A. Lukyanchikov, Yu. I. Fadeenko, V. L. Istomin, and V. M. Titov. The photo was taken in 1970 at the anniversary of the establishment of MIPT.
From the archive of the Lavrentyev Institute of Hydrodynamics SB RAS

"In summer 1958, we began settling into our new place in the woods near Novosibirsk. At times, Korolev's task was forgotten, then it appeared again on the institute's agenda, in concordance with the launch schedule of the objects carrying meteorite sensors. Each new attempt enhanced our respect for the difficulty of the task; we were like travelers in the mountains, where every trek uncovered new aspects of the ridge we were preparing to cross. At the same time, our 'sport ardor' was growing, and the bets grew higher. Until the director established a firm condition: 'One gram, 20 km/s, and you get the State Prize.' During one of these waves of enthusiasm, I remember, a recent MIPT graduate took part in the competition. A young father of twins, he had just been granted private accommodation space, which was in great deficit at the beginning of the construction of Akademgorodok,—two rooms in a simple wooden cottage. Inside, the walls were covered with cardboard and froze thorough during the 50-degree frosts. In the back room, the young mother was feeding the babies. In the front one, the young father (V. F. Minin, who later was appointed the director of the Institute of Applied Physics, Novosibirsk) arranged a powerful capacitor bank with a discharge energy of several grams of TNT equivalent. All the cardboard walls in that room were dotted with scraps of wire flying out of the electromagnetic accelerator at speeds of up to 3 km/s.

"It took much time to solve the problem. It pleases me to recall that I was able to contribute to its solution. I really liked one of the acceleration schemes that were tested on Lavrentyev's recommendation. The explosive gas-cumulative accelerator captured my imagination with the amazing simplicity of its design. It consisted of a single piece, a pipe cast of explosive substance and shaped like a short barrel of a small-caliber gun. At one end, the charge was initiated by a detonator, and the body to be accelerated—usually a steel bearing ball—was placed at the other end. Then, a high-speed gas jet appeared along the axis of the detonating charge. The 'meteorite' was invariably destroyed, but its fragments flew off at a decent speed, up to 5 km/s. During one of the calm periods, when a fellow researcher engaged in these works (V. M. Kuznetsov, now deceased) switched to other things, I decided to bring my favorite scheme to fruition. I applied 'item-by-item search' through all possible combinations of parameters of the charge and the particle.

"It was the time of enthusiasts and workaholics. Almost no one counted the working hours, and we were able to make up to 10—12 experiments per day. A few months later, we achieved a success. We came to understand a fundamental thing: the particles to be accelerated must be an order of magnitude smaller in size than those we used before. Too big ones disintegrated during the acceleration; too small ones melted and burned in the gas cumulative jet. The optimum size was 0.15—0.25 mm.

"Fractions of a millimeter—it is easier said than done! Where could we get them? The industry produced metal balls of only 1 mm in diameter or larger; a special order would be prohibitively expensive. Powders did not suit our needs: particles with even a small deviation from the spherical shape were spun up in the gas jet and destroyed by the centrifugal forces. We had to make spherical particles ourselves, as a 'kitchen-table' effort, a well-known technological principle. The original material—metal wire—was transformed, by means of an electric explosion in water, into particles of various shapes and sizes. We used sieves to screen out the desired fraction. Then, the balls were separated from the trash by 'racing' on a sheet of glossy paper: the more regular the shape of the particles, the faster they roll down the slope... Soon we had a range of tubes filled with ideal particles of different fractions from a variety of metals. Particularly good-looking were the shiny nickel and tungsten balls; those would have fitted well into the showcase of a jewelry store...

"However, as soon as the microballs parted with the accelerating jet, they rapidly decelerated in the air... This called for a vacuum chamber, a pump, a dedicated room, staff... in short, the institute set up a special laboratory (headed by V. M. Titov), and things went smoothly. The very first experiment in the vacuum chamber yielded, as if on cue, the desired result: 7.9...8.0 km/s. We managed to do it by the time of manned flights.

"Soon we began to receive parcels from Moscow, one after another, with most unusual contents: portholes, skin of the Vostok spaceship, helmet and details of the astronaut's suit. We fired our 'meteorites' at them and then sent back to the 'customer' for analysis and conclusions. The meteorite research experienced a short yet rapid boom until the end of the 1960s, when the Soviet space projects were cut sharply. During this time, we achieved throwing speeds of 12—14 km/s, established contacts with dozens of Soviet and foreign research organizations, and attained considerable progress in the study of high-speed impact events. Our blast test bench was visited by many delegations, including Soviet and American astronauts.

"I remember especially well the two polar opposites: Georgy Beregovoy and Neil Armstrong. Despite his age, Beregovoy was full of energy and desire for immediate action; he always wanted to stand as close as possible to the explosion demonstration bench. When examining the samples after the explosion, he was always inquiring eagerly for details; looking back at the Americans, he once asked in a low voice: 'When will you shoot these things at the villains in space?' Armstrong, the first man to walk on the moon, was impassive and silent as a moonstone...

I asked him to sign a booklet, and his attendant said in surprise, 'Well, lucky you are! Armstrong never signs autographs.'

"Years had passed before we could properly evaluate the place of our work in world science. It turned out that, in those days, laboratories of different countries conducted classified research to obtain jets and streams of substance with a mass and speed much higher than those of our artificial meteorites. Perhaps, the most impressive results were achieved by the developers of the so-called implosion design for nuclear bombs, who obtained huge velocities and energy concentrations during explosions of conventional explosives, which were directed 'inward,' towards the center of the nuclear device. When such a scheme was misaligned, at the time of maximum compression, jets escaped at speeds that could be higher than 20 km/s. But what kind of jets—vapor, foam, or liquid? It was impossible to use these designs to accelerate individual particles of known size and shape, to say nothing about calibration shootings and measurements.

"For several years, we were almost the only team who set for themselves a goal to obtain cosmic velocities with particles of known size and shape. Moreover, we sought to do that in a laboratory, not on a missile test site, where one can accelerate multiton blocks to cosmic velocities. In that area, our small team was, for a few years, on top of the world. Now, we know that we had reached the world level (at about 5—6 km/s) rather quickly and then moved up the record to 13—14 km/s. Alas! I did not contribute to that...

"Here, it makes sense to recall that this work, like many other exciting initiatives of that time, was started by students and thoroughly developed by 30—35-year-old men. How much can the energy and enthusiasm of the young, guided by the experience and wisdom of the old, give to science! ('If youth knew, if age could.')

"Of course, all these achievements have become outdated over the past three decades. Our records were beaten by the Americans, who first used a light-gas gun to accelerate a weighty 'pellet,' not a microball, 11 km/s and then used a special beryllium-coated cumulative charge for throwing. The higher the speed of sound in the coating material, the higher the speed of the cumulative jet. In this respect, beryllium is the champion among the metals; the head of a beryllium jet can reach speeds of 19 km/s. The Americans have learned to cut off by means of an explosion this head element from the beryllium jet and use the former as a calibrated impactor. Then, the time of meteorite studies and explosive acceleration methods was gone altogether. There was a dramatic change in the nature of the interest towards space research and, hence, in the goal-setting. The accumulated experience had long been sufficient to cope with the meteorite hazard during space flights and construct, where necessary, anti-meteorite shields. In the future, if researchers ever decide to revive the 'high-velocity' theme, they will do it for a yet unknown reason and, certainly, in a completely new form. Electrostatic dust accelerators for dozens of km/s? Miniature multistage rockets? Time will tell. The stagnation in this area cannot last forever. Sooner or later, the time will come for a new generation of young enthusiasts...

"P. S. The above was written in April 1999. Some things have changed since then. There has been much progress in the design of the telescopes and observational techniques. Our understanding of the 'hard component of cosmic matter' has changed radically. It seems that the new interest towards the cosmic-velocity impact is beginning to emerge within the assessment of the potential hazard of from comet and asteroid impacts on the Earth (January 23, 2007)."

Ice-breaking explosion

Explosion has proved to be a master of all trades; such a conclusion follows from the results of the studies conducted at the Institute of Hydrodynamics. Often they were a continuation of the works carried out long before and resumed at the request of industry organizations, which were addressed to the leaders of the Siberian Branch of the USSR Academy of Sciences.

One of the practical applications of explosion, which was of interest to Lavrentyev, is related to breaking the ice cover on rivers.

From the recollections of S. V. Malashenko, winner of the State Prizes of Ukraine and the Russian Federation:

"Experiments were usually timed to coincide with the beginning of the flood on the Dnieper and were made ahead of the bridges in order to protect them from the damage associated with the drifting ice. Here, the researchers also studied the work of long charges, which were made either in the form of gunpowder 'sausages' in a textile casing, or the gunpowder was poured into a long ditch cut in the ice.

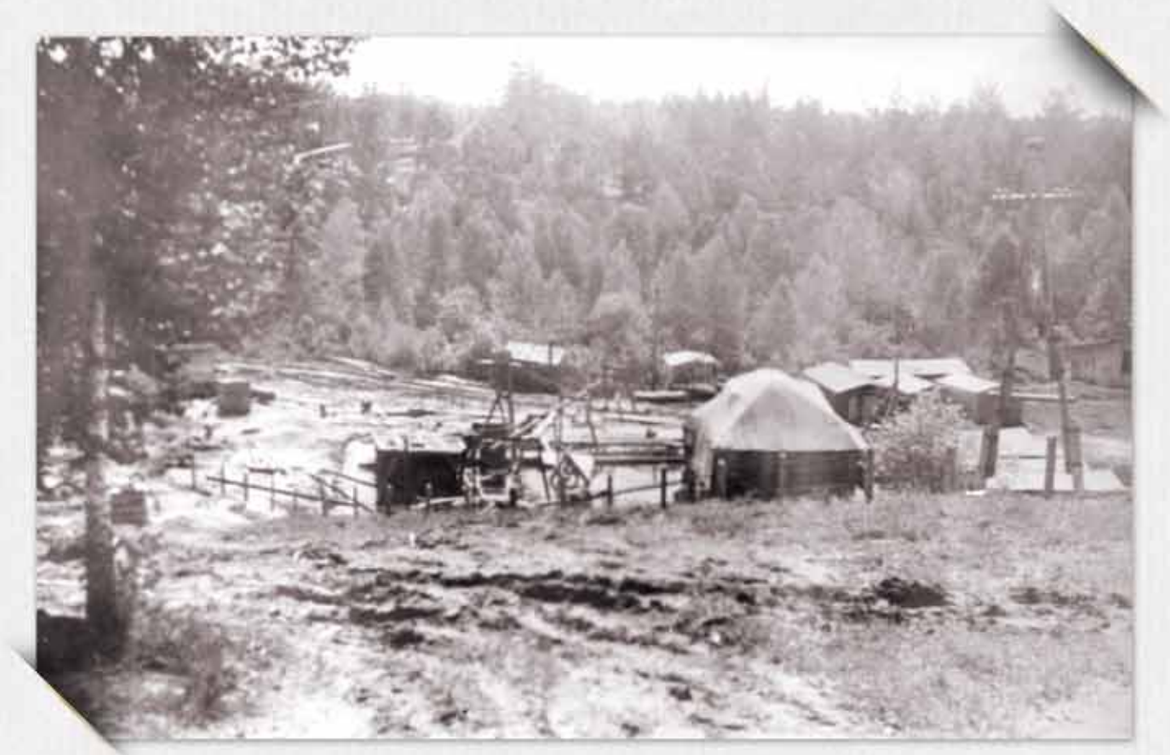
"I well remember the image: M. A. is somewhere on the ice at a distance, in the middle of the river, chopping with an ice pick. On the riverbank, worrying about him, are his wife Vera Evgenievna and his little daughter Vera, who have come to see the ice fireworks and... to protect the father.

"Vera Evgenievna's favorite flowers wilted prematurely on the windowsill because the cone-shaped clay flowerpots behaved perfectly in the simulations of cumulative jets in water... The experiments with flowerpots and vases were made in the so-called frog pond, in a group, always with guests. A pot with the closed bottom hole and a charge tied to the bottom was let swimming in the pond and then blasted. The cumulative jet was clearly visible; the experiment was evaluated by its height, 'above the aspen' or 'above the birch.'

"As a rule, two scientific results were derived from such an experiment. The guests began to believe into the existence of a special phenomenon—the cumulation, and M. A., together with the participants of the experiment, were amazed to find out that the frogs living in the pond could survive the explosion. They were thrown out on the bank, but they were alive."

The Dnieper ice-breaking experiments were not forgotten in Siberia, but here researchers had to deal with the northern ice and much more ambitious tasks.

This work is detailed by G. S. Migirenko, winner of the Lenin Prize, Deputy Director of the Institute of Hydrodynamics in 1958—1973:



The first group of scientists to work at the Institute of Hydrodynamics arrived in Novosibirsk on June 27, 1958.
Photo: Zolotaya Dolina ('Golden Valley'), 1958

Below: One of the working buildings in Zolotaya Dolina—here researchers were doing world-level science. Winter 1958/1959

First winter in Siberia: 1958/1959

Below:
Mikhail Alekseevich with his wife Vera Evgenievna, winter 1958/1959

Many years later, another team of researchers from the Institute of Hydrodynamics went to a place near Severnaya Zemlya in the Arctic to solve another important problem associated with ice dynamics (*left to right:* A.R. Berngardt, V.M. Titov, V.T. Kuzavov, V.K. Kedrinsky, the rover driver Slava, V. Bondarenko, and N.N. Chernobaev). For these studies, A.R. Berngardt was awarded with one the first Lenin Komsomol Prizes for Young Scientists

"Our laboratories huddled near the Zyryanka creek in temporary premises. We were happy, though, to have even those premises and tried to do research as much as we could. In particular, under the guidance of Academician Mikhail Aleskeevich Lavrentyev, our scientific youth studied the feasibility of applying explosive charges for breaking ice. It was important to establish a correspondence between the size of the charge and the ice thickness and determine what charges are necessary to make ice holes of a given size.

"In 1958/1959 we had a truly Siberian winter. The thermometers at the barracks that served as our homes sometimes showed –50 degrees centigrade. The ice on the Ob Sea was a meter thick. As the ice thickness was growing gradually, we were able to apply explosions to a whole range of thicknesses and derive a pattern.

"Mikhail Alekseevich was passionate about this work and often took us with him to the ice... He worked with an icepick, fetched charges, measured the holes... The experiments were to answer plenty of questions: What if we put the charge on top of the ice? What if we put in the ice? Or under the ice? At what distance? In short, they all boiled down to one question: How to make a maximum hole with a minimum charge?

"...Soon we came to the conclusion that, for our study to be complete, we needed to try blasting thicker ice.

However, near Novosibirsk, winter was coming to an end, and the ice was not growing. To make things worse, the snow that had accumulated on it began to melt and gradually erode the ice. At that time Mikhail Alekseevich came up with a suggestion: what if we go to the Kara Sea ice?

"I remember we were very confused, not without a reason... Now I think, we should have talked Mikhail Alekseevich out of this scientifically tempting idea or convinced him that we go alone. But once we tried to raise the subject, it became clear that any further discussion was pointless...

"We had to get to Dikson Island and, from there, to the ice near Sibiryakov Island, at the mouth of the Yenisei River. This area was of particular interest for us: the prevailing ice thickness was as large as 2 m... When there was navigation almost all over the Yenisei, at its mouth, obstructed by the Sibiryakov Island, there still was an ice bridge, which remained there for a long time (sometimes for a whole month)... This ice bridge reduced the already short shipping season... It was particularly challenging to deliver the explosives to the ice; we had to bring around 2 tons TNT, moreover, very quickly. This could only be done by air, but we could only procure one airplane. Without hesitation, Mikhail Alekseevich suggested we carry the explosives along. So, we first took them to Krasnoyarsk, then loaded onto the plane that brought us to Norilsk, from where the polar aviation carried us along the route Norilsk—Dikson—the ice bridge. We had to do the loading and unloading all by ourselves, for the involvement of outsiders might have revealed our secret. Mikhail Alekseevich was the most active participant of all the rigging works.

Photo showing a fundamentally new and highly efficient way of fire suppression for oil and gas fountains that arise from accidents on the wells. The fire is suppressed through a pulse impact of an air vortex ring filled with dispersed extinguishing powder

Left: Episodes in the vortex–powder extinguishing of an oil flame consuming 6,000 tons of fuel a day. It took only 6 kg of explosives and 500 kg of fire extinguishing powder to suppress this fire

"The spring was in full swing in Krasnoyarsk. Having made ourselves comfortable on the trotyl, we headed along the Yenisei to the north... Soon we were on the ice, together with polar explorers from Leningrad.

"...Soon, everything became easy and rootine. We had very little time to sleep: we had to rush, as ice drifts on the Yenisei can be swift and turbulent. We could not protect ourselves from these hazards of nature. The mouth of the Yenisei River has a width of up to 15 km; only by straining eyes hard could we discern the outlines of the Sibiryakov Island. In case of trouble, it would not be easy to get to the land...

"Our neighbors from Leningrad were investigating the tension in the ice bridge. It turned out that the ice was contracting in some places and stretching in the other ones. We could not help but infer that the charges had to be put in those places where the bridge was stretching. In this case, after the explosion, it would fall apart and drift to the Kara Sea.

"We had found that under-ice explosions required much less explosive material. However, putting a charge under the two-meter ice was far from easy: we had to use both drills and small charges. The effect of explosions beneath the ice was exceptionally strong; to blow the ice field across, we had to tie charges in chains and float them under the ice with the current. Calculations showed that, using a relatively small total number of charges, we could remove the entire bridge from the river mouth. On the whole, the expedition provided material for both interesting scientific generalizations and useful practical applications" (*Rasskazy ob uchenykh, 1965*).

From detonation coatings to vortex fire suppression

The fundamentals for another, most promising area of explosion studies were laid by Lavrentyev in the mid-1950s, when he returned to Moscow from the Arzamas-16 Nuclear Center, where one of the research areas was a nuclear artillery projectile. Lavrentyev suggested to one of his students—B. V. Voitsekhovsky—that he should consider the "exotic" problem of spin detonation. Eventually, the work on this small task led to the revision of the classical detonation theory with a plane front and the discovery of the transverse wave and the multifront detonation. The results proved to be so fundamental that they were distinguished by the Diplomas of Scientific Discovery as well as the Lenin Prize, and the further development of these ideas in the 21 century, by the State Prize of the Russian Federation.

The subject of current research at the Institute of Hydrodynamics is the combustion and detonation of the so-called heterogeneous systems where the fuel and the oxidizer are initially in different phase states. Examples include droplets of liquid fuel (gasoline, kerosene, etc.) or solid particles (metals, coal dust, flour) in the atmosphere of a gaseous oxidizer (e.g., in air). Another example of a heterogeneous medium is gas-liquid mixtures, from foam structures to liquids with a small amount of gas bubbles. The latter system can appear as a result of methane leakage and buoyancy during the development of gas hydrate deposits on the bottom of the sea. (By the way, this phenomenon explains one of the mysteries of the Bermuda Triangle: ships get into a low-density foam column and lose their buoyancy almost instantly, before they send out a distress signal.) There are also diverse porous media in the form of a solid frame with interporous voids filled with gaseous or liquid components (such a structure is typical of rocks in the places of occurrence of oil and natural gas).

The practical application of the scientific results on the combustion and detonation of these multivariate heterogeneous systems is very important. Among the latest discoveries, particularly interesting is the experimentally detected effect of a full breakdown of detonation and combustion of a methane mixture with a curtain of inert fine sand. This method can be used to suppress accidental detonation of the methane–air mixture in mines.

Gas detonation is widely used in the coating technology. The detonation gun is an open-ended barrel periodically filled with a combustible gas mixture, where one injects a portion of a powder material, i.e., the future coating. The mixture is initiated to produce a detonation wave that propagates along the barrel, drawing and simultaneously

Mikhail A. Lavrentyev and Bogdan V. Voitsekhovsky (the man in a light-colored cap who stands with his back to the camera) at a hydrocannon. The mid-1960s. *Photos from the SB RAS archive*

heating the powder particles. Flying from the barrel at a high speed, the particles collide with the sprayed surface to form a detonation coating.

A similar facility without powder is used to remove dust deposits from various surfaces, e. g., from electrodes that pick up cement dust at factories (after the shock-wave impact of the blast wave, this dust returns to the production cycle, which ensures conservation of resources and environmental safety).

Almost simultaneously with the detonation of heterogeneous systems, researchers began to investigate vortex gas motions. An example of the latter is the smoke rings, the blowing of which is considered particularly chic among novice smokers. One of Lavrentyev's many ideas on the use of vortices and explosions was developed by his student B. A. Lugovtsov, who proposed a mathematical model for the motion and structure of vortex rings, which made it possible to calculate the parameters of the turbulent vortex ring.

These studies, included many experiments, such as the blasting of 3 tons of air-dispersed gasoline on the island in the Ob Sea. The detonation of this two-phase gasoline–air mixture resulted, first, in a fireball with a diameter of 80 m, which then transformed into a "mushroom" and then, into a vortex ring, which rose to a height of more than 2 km. Based on these results, Lavrentyev suggested that people can use vortex rings of a large diameter to influence the atmosphere and cause rain.

These studies formed the core for the development of effective methods of fire suppression at oil and gas wells by means of vortex rings and pulsed jets of fire extinguishing powder. In September 1973, at a test site in Nizhnevartovsk, researchers conducted the first successful full-scale tests of the explosive method for the suppression of a burning oil fountain. The method was developed at Lugovtsov's laboratory together with the Novosibirsk Fire Department of the Office of Internal Affairs. Nine years later, the vortex–powder method was used to extinguish a flare at the Yuzhnaya Tandyrcha gas well (Uzbekistan). The height of the flare was nearly 90 m, and its diameter, 15 m. Using 19 kg of explosives

Explosion welding was used to produce trimetallic titanium–niobium–titanium blanks for the nozzle tips of the engine for the Luna-16 spacecraft

Explosion welding techniques are combined with the traditional heating and holding to obtain intermetallic composites.
Photo: Intermetallic Al_3Ti layers obtained by further heating of an explosion bonded composite made of aluminum (light) and titanium (dark) layers to a temperature of 650° C and holding for five hours

and 1,500 kg of fire extinguishing powder, the flare was suppressed within a few seconds, After they had fried for a month to extinguish it by conventional method.

Explosion: exquisite workmanship

In explosion science, the era of nano began long before the promotion campaign in the media. Thus, researchers from the Institute of Hydrodynamics were among the first in the world to publish results on the formation of ultrafine diamond particles in explosion products (Lyamin *et al.*, 1988). This striking effect was observed after Lavrentyev had passed away. Together with NPO Altai, these studies were developed into a practical technology, for which the group of authors received the State Prize of the Russian Federation in 1994.

Another new research area is associated with the so-called explosion welding.

You can read about the history of these studies in Lavrentyev's recollections:

"The railroad switch factory asked us to strengthen the mobile part of the switch by using explosion. The researchers A. A. Deribas, Yu. A. Trishin and E. I. Bichenkov quickly conducted the experiment. The switch that received the explosion treatment was put in place; in six months, it was clear that it could serve twice longer than usual. It was possible to arrange, within six months, the explosion strengthening of all the switches manufactured by the factory and, hence, make a solid profit. Unfortunately, the broad implementation of the technology was delayed due to red tape, and it took almost 15 years to set a factory shop for explosion strengthening.

"The development of the strengthening method led, accidentally, to a new scientific discovery. Desiring to enhance the effect and avoid damaging the surface of the switch, researchers tried to reinforce the switch by throwing a metal plate on it by means of an explosion. The experiments showed unexpectedly that the metal plate often got welded to the switch. Deribas decided to take up the development of the theory and practice of explosion welding.

"A funny thing about this story is that, 15 years before the described experiments, similar 'welding' was obtained by N. M. Sytyi in my laboratory near Kiev. For our experiments we needed a copper blank 10 to 20 cm in diameter. We could not procure such a blank, but we had copper wire. Sytyi took a bundle of wire, wrapped it with a detonating cord and made an explosion. As a result, we had a monolithic blank of the required size (it was the first implementation of explosive compaction of materials). We observed similar welding in experiments with cumulative charges, but we treated these effects as a funny fact.

"Concurrently with our research, the studies on explosion welding began in the United States, and later, on a very large scale, in Sweden, Germany and Japan. Today our country ranks first or second worldwide in the number of different applications of explosion for welding, but remains on one of the last positions in the mass use of this technology for the production of critical bimetallic products, e.g., stainless steel. The reason is that it is inexpedient for the ministries to produce bimetals, which cost a fraction of the expensive metals with the same properties."

Many things have changed since the time of writing these lines. It should be noted that there are two extreme wave propagation modes in a fuel mixture. The first one is laminar combustion with characteristic velocities of several tens of centimeters per second (e.g., the Christmas candle flame or lighter flame); the main underlying processes here are thermal conductivity and diffusion. The second mode is supersonic detonation with velocities of about 2—3 km/s for gas systems and 5—8 km/s (the escape velocity for the Earth!) for solid explosives, whereby the bow shock plays the leading role. In recent years, the Institute of Hydrodynamics has been doing intensive research in the field of the so-called emulsion explosives, where the filler is... tiny hollow balls. These explosives allow wide variations in the intensity of detonation waves and their impact on the surrounding objects.

The new approach has made it possible to upgrade the traditional explosion welding technology so that we can now obtain new bimetallic materials based on metal foils as thin as 100 microns. Could you imagine an explosion producing a thin foil (which is smooth, not warped, as one could expect)?

In recent years, one has found new applications for explosion welding such as the production of multilayer composites. For example, by alternating thin layers of different metals, one can make a composite with improved toughness, which can be used for the protection of military equipment. Combining the explosion welding technology with traditional heating makes it possible to obtain new structural materials such as intermetallic composites.

The Institute of Hydrodynamics has also mastered the technology of spark plasma sintering of powder materials with submicron or nanoscale grains (SPS method). The technology uses the combined effect of high pressure, temperature, and pulse currents and allows one to produce, e.g., dense high-temperature ceramics, with possible applications in the gas-turbine engine technology.

A great contribution to new explosion-related projects is expected from the unique technique of synchrotron radiation based study of explosive processes, which has been developed by the Institute of Hydrodynamics together with the Institute of Nuclear Physics SB RAS and the Institute of Solid State Chemistry and Mechanochemistry SB RAS.

Mikhail A. Lavrentyev with schoolchildren of the School of Physics and Mathematics at Novosibirsk State University, 1960s. *Photo from the NSU Museum*

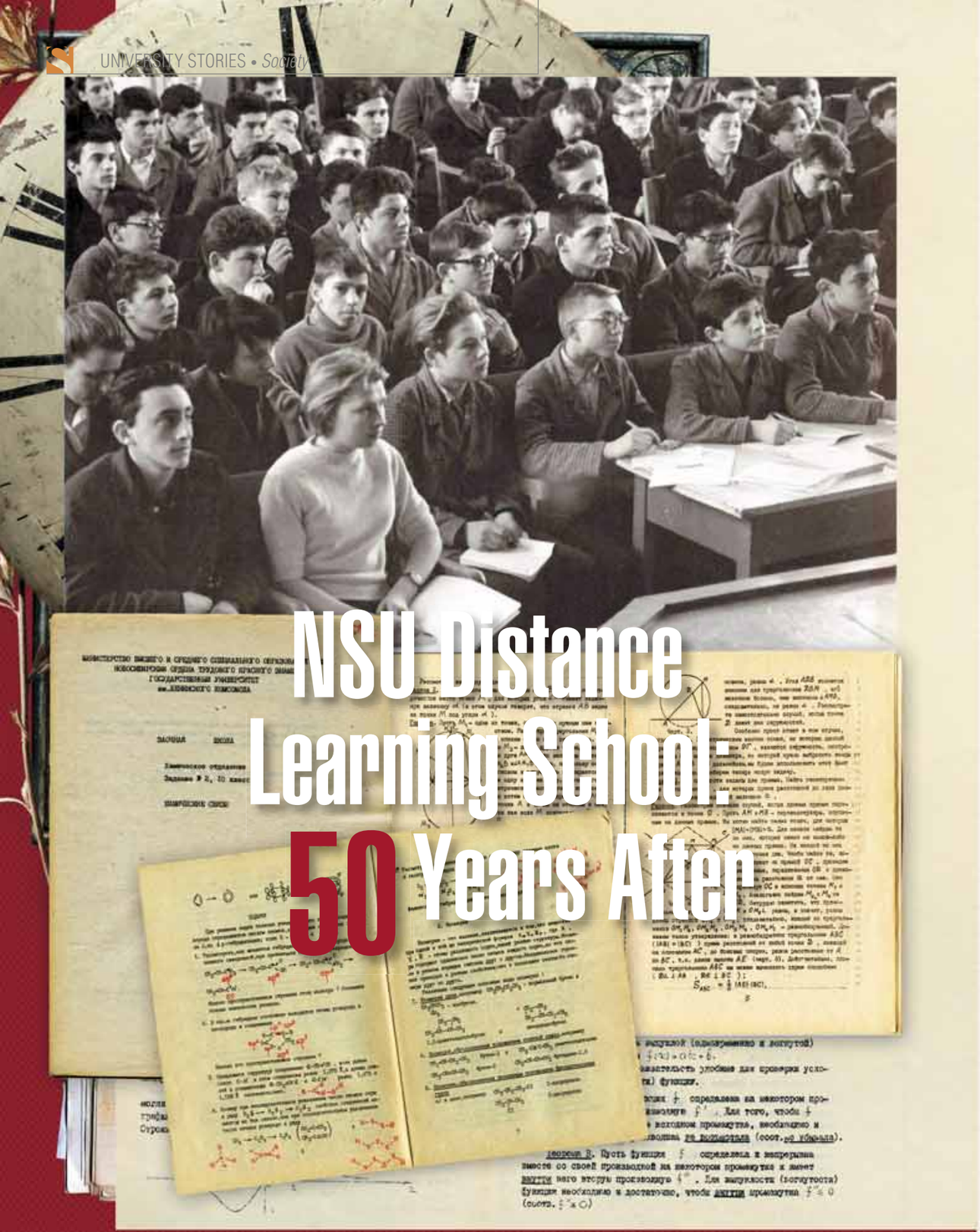
In conclusion, I would like to emphasize that the principles laid down by Lavrentyev as the basis of the first institute of Akademgorodok as well as the entire Siberian Branch of the Academy of Sciences worked successfully in the Soviet era and survived a most challenging test of time during the perestroika.

When in 1965, the Chairman of the USSR Council of Ministers A. N. Kosygin approved the act of acceptance for the first project stage of Akademgorodok, he wrote in ink on the official document: "To be noted that the construction works have kept within the approved budget." Neither Skolkovo, nor RUSNANO, nor the Olympic complex in Sochi, nor the Vostochny Cosmodrome, nor many other objects operated by the modern "effective managers" can claim that. In this respect, the allegation that the Academy of Sciences cannot manage its property efficiently, which has been one of the core reasons for the recent devastating reform of the Russian Academy of Sciences, bursts like a soap bubble.

The founder of the Siberian Branch was not only an outstanding scientist and an excellent organizer but also a true teacher of science and life for several generations of young researchers—his students and followers. Sown in fertile ground, Lavrentyev's ideas continue to evolve: researchers find solutions to the previously posed problems and formulate new ones, which bring forth new generations of scientists. This is Lavrentyev's heritage, whose value is only growing over time. That is why Mikhail A. Lavrentyev is remembered and appreciated by everyone who has ever known him and his scientific search.

We do honor and remember this great man!

The editors thank Natalia Bogunenko for the idea of the publication and the large work on the selection of historical materials



NSU Distance Learning School: 50 Years After

On October 23, 2015, the Distance Learning School of the Specialized Educational Scientific Center (SESC) of Novosibirsk State University (NSU)—the world's first distance learning school on physics and mathematics—celebrated its 50th anniversary. The ceremony in Akademgorodok gathered together more than a hundred people, including the founders of the school as well as its graduates, teachers, and all those people who participated, at different times, in the activities of the distance learning school and contributed to its development.

The Distance Learning School (DLS) of the High School of Physics and Mathematics (the original name of the SECS), affiliated with NSU, has been an important supplement to the system of science competitions ('olympiads') and summer schools and has given inquisitive and gifted children from different, even the most remote, towns and villages, an opportunity to test their abilities and seriously improve their level of training in physics and mathematics so that later they could go to a prestigious university.

More than 20 people made congratulatory and valedictory speeches at the conference "Dialogue of Generations." The former NSU Rector Nikolay Dikansky shared his thoughts on how the school should be developed in the present conditions. The dean of the NSU Physics Department Alexander Bondar told the audience about his experience of studying at DLS and how this knowledge helped him enter the university; he pointed out the obvious benefits of distance education for those wishing to work at the forefront of science. Alexander Markovichev, a professor at NSU, who was engaged, many years ago, in the development of study guides and workbooks for DLS, told an amazing story that happened to him recently at an entrance exam in mathematics: "While listening to a school leaver answering a question on function research, I suddenly found myself thinking that if I had had to speak on that subject, I would have used the same words. After a while I asked him if he had studied at our distance learning school and got an affirmative reply!"

The start of this successful educational project is closely linked with the name of a prominent Russian businessman—the president of the F-Consulting Group Gennady Fridman, Cand. Sci. (Phys.-Math.), who was at that time a second-year student of the NSU Mechanics and Mathematics Department.

In his interview to SCIENCE First Hand, Fridman told an exciting story of how a group of enterprising university students organized, in their spare time, a steady working "distance learning school" in just two months, without any support from university officials.

The further life of the Distance Learning School to the High School of Physics and Mathematics (DLSPM) is described in the reminiscences of Prof. Alexander Markovichev, Cand. Sci. (Phys.-Math.), who was for several decades the head of the mathematics department at the school. Moreover, the editor of SCIENCE First Hand, Sergey Prokopiev, Cand. Sci. (Chem.), who was first a pupil and then a teacher at DLSPM, has also shared his impressions.

Today, the Distance Learning School has eight departments and about 2,000 pupils aged 10 to 17 from twenty regions of Russia as well as from CIS countries, Germany, and the United States. However, the core idea of the educational services provided by DLSPM since 1965 is, in a nutshell, that any schoolboy or -girl who speaks Russian can receive, upon request, educational materials on subjects of their interest and a set of problems to be solved, which vary slightly from year to year, send back their solutions, and surely receive a written review in response. The specialists from different DLSPM departments evaluate the correctness of the solutions and the ingenuity of the child's reasoning and give recommendations for his or her further studies. All this contributes to the development of skills and the selection of gifted young people, many of whom later become students of NSU.

Gennady Fridman, Cand. Sci. (Phys.-Math.), President of the F-Consulting Group:

"In August 1965, on my way back from the All-Russian Komsomol Camp Orlyonok, I visited the Mechanics and Mathematics Department of Moscow State University, where I saw, for the first time, how they prepare assignments for their distance learning school of mathematics. Right at that time, in Novosibirsk Akademgorodok, there was a Summer School on Physics and Mathematics (SSPM), and we immediately decided that we would also set up a distance learning school, but ours (unlike the one in Moscow) would focus on physics and mathematics. So, we notified all the participants of the Summer School, who did not stay at the boarding house, that they became the first pupils of the distance-learning school.

"As an aside, I should say that, in a sense, we repeated the organizational experiment conducted three years

Key words: supplementary education, correspondence schools, mathematics, physics, chemistry

Gennady Sh. Fridman, Candidate of Physics and Mathematics; Corresponding Member of the Russian Academy of Natural Sciences; President of the F-Consulting Group. Winner of the Peter the Great National Public Award (2001) and the Darin Russian Business Academy Award (2004). One of the founders of the Soviet Union's first distance learning school of physics and mathematics. Author and coauthor of over 80 research papers

The first official document that mentioned the Distance Learning School appeared only six or seven years later. Ironically, it was the university order: "To be dismissed for ruining the work of DLSPM: G. Sh. Fridman…" and then followed a list of names of the organizers

earlier by the founding fathers of the first Summer School, of which I was a participant. After 45 days of close communication, they must have felt sad to part with us, and they decided to establish something permanent. After the exams some of us were admitted to the year-round school of physics and mathematics (SPM), although at that time, the implementation of this idea, including the financing, was in serious doubt...

"Nevertheless, SPM opened its doors in January at the address: Detsky Proezd 3 (this building had been built for other purposes, but was used for a few months as a boarding house for the school). During the first six months, it was a completely illegal educational institution, financed through the undoubted misuse of budget funds by Mikhail Lavrentyev, who was afraid of nothing when he was acting for the sake of an idea. Initially, 120 people were admitted to the school, of whom 93 completed it. It was only in August 1963 that the USSR Council of Ministers issued a resolution on boarding schools, leading to the establishment of such schools in Moscow, Leningrad, Kiev, and other cities.

The first lecture at SPM, 1963. *The second one on the left*: Gennady Fridman. *SB RAS Photo Archive*

Ninth-grade pupils at the first Summer School of Physics and Mathematics, 1962. *The sixth one on the left*: Gennady Fridman. *SB RAS Photo Archive*

Gennady Fridman (*on the right*) with his fellow students at the May-day march in 1970. *Photo from Elena Kukina's personal archive*

"Thus, SPM became yet another pioneering project of the Siberian Branch of the USSR Academy of Sciences, whose support helped NSU became a truly all-Union university: we even had students from Ukraine and Moldavia. There were two formats of recruiting pupils to SPM, including by the results of external science competitions. The candidates could come from Moscow, Leningrad, etc., from virtually anywhere. The newcomers were interviewed: not all of them were able to pass the tests, and the majority of the candidates went back. Those accepted to SPM received, post factum, a reimbursement of their travel expenses.

"Many of NSU students began, almost from the very beginning of their university life, to participate in the organization of regional rounds of science competitions ('olympiads') in NSU's 'zone of influence'—from the Urals and Central Asia to the eastern borders of the Soviet Union. In 1965, while a first-year student, I was appointed the leader of the team from the Siberian Branch of the USSR Academy of Sciences to organize olympiads in mathematics, physics and chemistry in the Tyumen Oblast. It was easy for a first-year student to become an ordinary member of the team, but being appointed as the leader of a team two members of which had the candidate-of-sciences degree, including the well-known mathematician L.V. Baev—that was really 'cool'! This is the truly heroic youth of Akademgorodok.

"Baron X, who was robbed by Robin Hood, lost a third of his wealth, and Pinocchio stole two fifths of all the soldi belonging to Barmaley. Who of them stole more?" from DLSPM assignments

Participants of the carnival procession in the back of a truck in the Tereshkovoy Street near School 25 (now Gymnasium 3). *Near the tailgate, at the center*: Gennady Fridman. *Photo by Yu. Shcheglov. SB RAS Photo Archive*

The first graduates of Novosibirsk SPM. *The first one on the right in the first row*: Gennady Fridman, 1964. *SB RAS Photo Archive; photo from the SPM Museum*

much time at research institutes. My first research paper was issued when I was a freshman, and it was published in such a reputable journal as Reports of the Academy of Sciences.

"The students who are now studying at the university must realize that they are studying at a unique institution with unique traditions. However, not everyone understands this, and NSU's prestige is declining. Now we are faced with the task of reviving the university as an outstanding

"The members of our team were the mathematicians Sergey Treskov and Yury Mikheev and the physicists Oksana Budneva, Mikhail Perelroizen, and Semen Eidelman (I had the honor to teach Semen in the Summer School, when I had already been enrolled in the first year of university, and now he is, inter alia, in charge of the Chair of Elementary Particle Physics at NSU). Eidelman and Perelroizen were then freshmen; Oksana was a third-year student, and Treskov, Mikheev, and myself had finished our first year of studies. It was this team that created the Distance Learning School.

"We developed the assignments ourselves and, judging by the feedback, were good at that. Then we found among the freshmen those who agreed to check the works, and the next year, these students became team leaders. In turn, we began to look for teachers among the SPM graduates, and they, together with those who had studied for one or two years at the distance learning school, became, after appropriate training, the teachers at the Summer School. Thus, we established a principle of continuity.

"It should be noted that for many years, the Distance Learning School was fueled only by our enthusiasm. We ourselves, without any support from university officials, organized the printing and mailing of the assignments. The first official document that mentioned the Distance Learning School appeared only six or seven years later. Ironically, it was the university order: 'To be dismissed for ruining the work of DLSPM: G.Sh. Fridman...' and then followed a list of names of the organizers.

"...Recently, at a meeting of the NSU International Academic Council, the rector said that 'the University and the Academy of Sciences should have mutual interests.' But it has always been like that! Moreover, in our time, even we, successful SPM pupils, were given entrance IDs to the Institute of Nuclear Physics, where we could participate in real work and attend real science workshops. I, however, later 'switched' to math, but my classmates Alexander Rubenchik, Evgeny Kuznetsov and Vasili Parkhomchuk stayed at the INP. As to Parkhomchuk, the INP director Gersh I. Budker gave him a position at the institute even before Vasili finished SPM(!), and, when he was in his fourth year of studies, Budker entrusted him to conduct his own experiment with a team of engineers. That is, NSU has always had its own style, and NSU students and even the high-schoolers from SPM spent

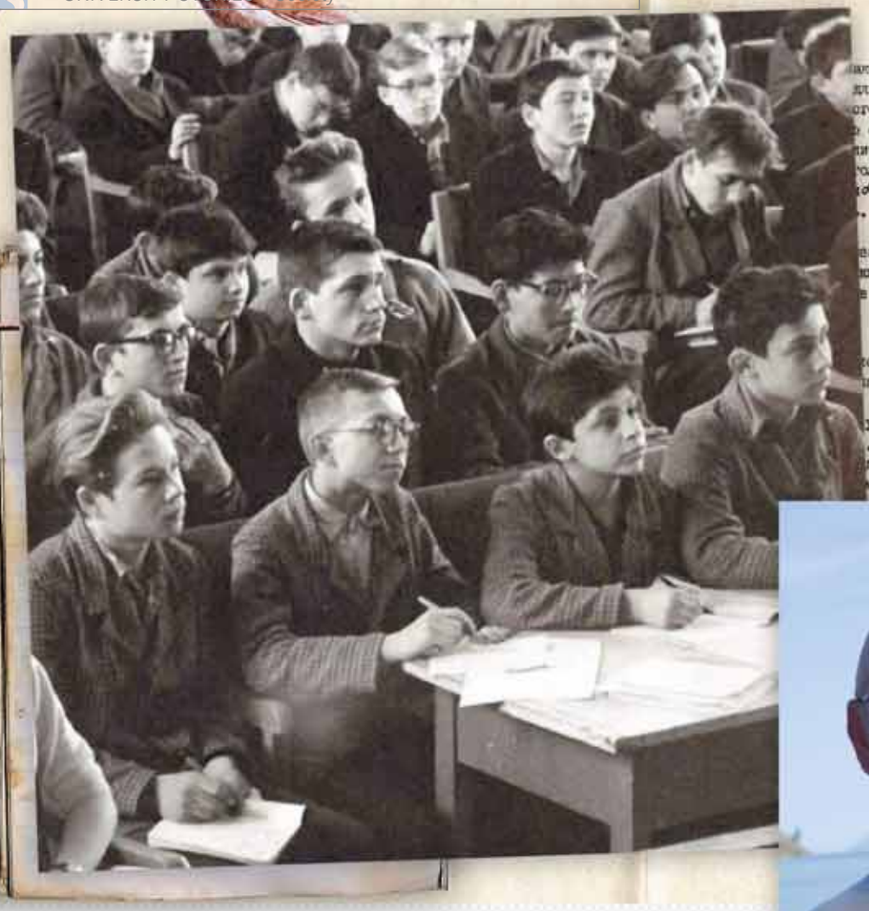
N.S. Dikansky, Academician RAS, Head of the laboratory BINP SB RAS, rector NSU from 1997 to 2007

...WE NEED MORE TALENTED PEOPLE

Nikolay Dikansky
(from his address on October 23 at DLSPM)

"We have implemented the educational-pyramid scheme: the Distance Learning School is the foundation for SPM, and the latter is, in turn, the foundation for NSU, by supplying us with the best graduates. However, in recent years, it has become much more difficult to recruit young people to the university. Firstly, much fewer children are now born; another problem is the regional coverage. We have established a number of regional universities, which are now headed by our graduates. These universities have begun to compete with us and pull over a part of the potential candidates. There are about 2,000 pupils at our DLSPM; that's very few. For comparison: there are more than 5,000 pupils at the MIPT Distance Learning School (which has no boarding school) in Moscow.

"Now there is a tremendous opportunity to address all these challenges: the distance learning system should make maximum use of the Internet, Skype and other communication tools. When I was rector, 15 years ago, we made a special class for distance education, which supported interactive feedback from the instructor. We need to implement such a system at SPM as quickly as possible. Because we need more talented people"



Alexander Markovichev *(the second one on the left, in the first row)* at a lecture at SPM, 1963/64 academic year. *Photo from Alexander Markovichev's personal archive*

Photo of the graduates of Group 511, NSU Mechanics and Mathematics Department, 1970. *The first one on the right in the bottom row:* Alexander Markovichev. *Photo from Elena Kukina's personal archive*

educational institution with a well-established reputation, which we can and must use."

Alexander Markovichev, Cand. Sci. (Phys.-Math.), NSU Professor:

"Akademgorodok of the 1960s is an extraordinary place, extraordinary time and wonderful people!

"In 1963, after the external round of the Second All-Siberian Physics and Mathematics Olympiad, I got to the second Summer School, and after it, to SPM. Our studies at SPM is a special theme. For instance, some of the 'oldies' (pupils of the first intake) organized a Mathematical Society at the school. Every SPM pupil could become a member of that society if he or she passed an exam to one of its 'founding fathers,' among whom were Gennady Fridman, Sergey Treskov and Georgy Karev. I passed this exam to Gennady Fridman and thus got acquainted with him.

"At the school there was an atmosphere of creativity and intellectual freedom; we, young people aged 14 to 18, took interest in everything. We had lectures by such great scientists as Mikhail Lavrentyev, Alexey Lyapunov, Gersh Budker, Spartak Belyaev and others. Of course, it is indecent to write about

Alexander S. Markovichev, Candidate of Physics and Mathematics; Deputy Director of the Institute for Educational Research of Gifted Children, Russian Academy of Education (Novosibirsk); Professor at the Chair of Mathematics of the Mechanics and Mathematics Department, Novosibirsk State University; Professor of the Specialized Educational Scientific Center of Novosibirsk State University. Winner of the Russian Presidential Award for Excellence in Education (2000). Honorary Worker of Higher Professional Education of the Russian Federation. Author and coauthor of over 150 research papers

...I DO MATH WITH MY GRANDSON USING DLSPM MATERIALS

Alexander Nikitin
(from his address on October 23 at DLSPM)

"My work at the Distance Learning School began in the fall of 1966, when DLSPM tutors gave us, NSU students, completed assignments that had to be urgently checked. There were so many notebooks that I was terrified. In addition, we were warned that we had to give feedback in such a way that the school participants would not sent letters saying that 'the explanations were not clear.' And we managed to cope with that.

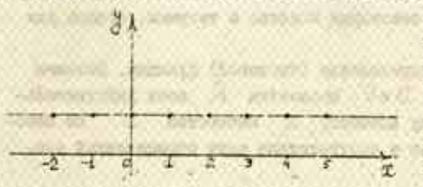
"I remember, when I was the SPM Director, the National Training Foundation (NTF), established by the Russian Government, decided to give financial support to the best distance learning school. It took me a lot of time and effort to prove to the officials that they should support not just one, but several of the best schools. As a result, during the first phase of the project, the NTF supported 30 distance learning schools, and during the second one, 18 such schools. Of course, our school was on the list.

"Today I do math with my grandson using DLSPM materials"

Может статься, что мы возьмем в качестве значения x только целые числа и получим, что

$$\ldots = y(-2) = y(-1) = y(0) = y(1) = y(2) = \ldots = 1 .$$

а отсюда вообразим, что графиком нашей функции является прямая y = I. На это можно возразить – будем находить значения функции в других точках, например, при $x = \frac{1}{4}, \frac{1}{2}, \frac{3}{4}, \frac{5}{4}, \frac{3}{2}$ и т.п. Но как нам заранее понять, в каких точках лучше всего вычислять значения функции, чтобы построить правдоподобный эскиз графика?



Определение некоторых общих свойств функции позволяет ограничиться вычислением значений функции в нескольких точках (а иногда вообще обойтись без таких вычислений) и, тем не менее, точно построить график.

Какие же свойства функции необходимо выяснить в первую очередь? Прежде всего следует:

1) найти область определения функции и исследовать поведение функции в граничных точках этой области;

2) выяснить симметрию графика и его периодичность;

3) найти точки разрыва функции и промежутки непрерывности;

4) решив уравнение $f(x) = 0$, определить точки пересечения графика функции с осью Ox (нули функции);

5) установить промежутки постоянства знака, т.е. промежутки, в которых функция положительна или отрицательна;

6) найти промежутки монотонности и точки экстремума;

7) указать те или иные особенности графика;

8)* определить промежутки выпуклости и вогнутости функции;

9)* найти асимптоты к кривым их существования.

Vladimir Kharitonov and Alexander Markovichev are sorting out the mail from schoolchildren participating in a science competition in a distance format. *SB RAS Photo Archive*

Left: DLSPM materials on Function Research. Developed by A. Markovichev, 1987. *Photo from Sergey Prokopiev's personal archive*

great scientists 'and others,' but it is simply impossible to list them all here. After finishing SPM and entering NSU, many of us craved to share our knowledge with schoolchildren in the same way as the outstanding scientists shared their knowledge with us. No wonder that in 1965, right after my first year of studies, I began, together with some of my fellow students, to work as a teacher at the 4th Summer School, where I taught math to the participants, who were only two years younger than me.

"This was also the first year of the Distance Learning School of Physics and Mathematics,

им. Ленинского комсомола

Elena Seraia (Oxford University), graduate of DLSPM and NSU Natural Sciences Department (1986)

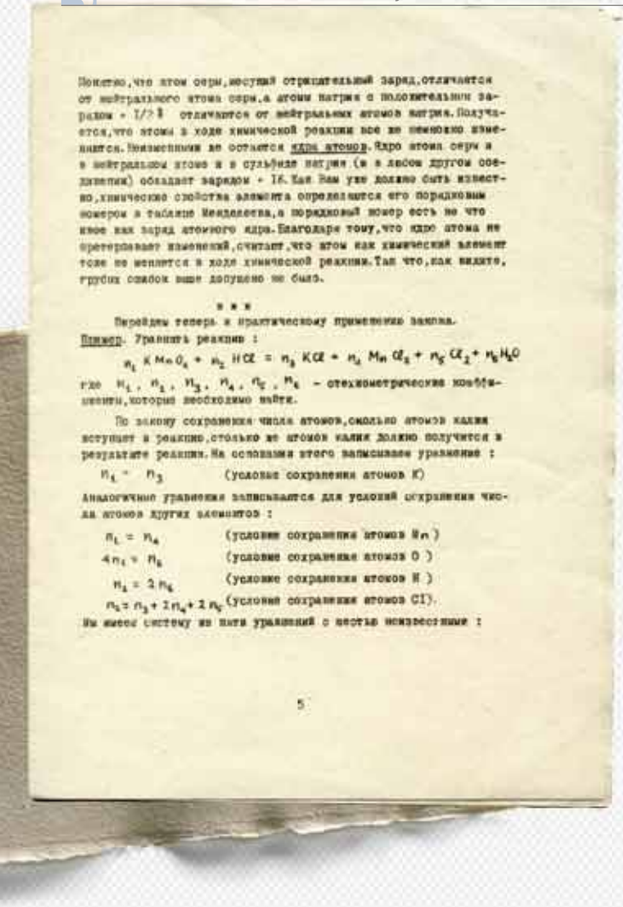
"I WAS SURE THAT MY WORKS WERE CHECKED AT LEAST BY AN ASSISTANT PROFESSOR..."

Elena Seraia
(from the interview to SCIENCE First Hand)

"I studied at the SPM 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 become 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 gene in the neighborhoods of Kemerovo.

"There were no stray cats in Kemerovo in 1980; so we went 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!' There were about 12 mutations on the list. It was absolutely crazy! But we collected really good material: 130 cats. 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"



Понятно,что атом серы,несущий отрицательный заряд,отличается от нейтрального атома серы,а атомы натрия с положительным зарядом + 1/2 I отличаются от нейтральных атомов натрия.Получается,что атомы в ходе химической реакции все же немножко изменяются.Неизменным же остается ядро атомов.Ядро атома серы и в нейтральном атоме и в сульфиде натрия (и в любом другом соединении) обладает зарядом + 16.Как Вам уже должно быть известно,химические свойства элемента определяются его порядковым номером в таблице Менделеева,а порядковый номер есть не что иное как заряд атомного ядра.Благодаря тому,что ядро атома не претерпевает изменений,считают,что атом как химический элемент тоже не меняется в ходе химической реакции.Так что,как видите, грубых ошибок выше допущено не было.

* * *

Перейдем теперь к практическому применению закона.

Пример. Уравнять реакцию :

$$n_1 K Mn O_4 + n_2 HCl = n_3 KCl + n_4 Mn Cl_2 + n_5 Cl_2 + n_6 H_2O$$

где n_1 , n_2 , n_3 , n_4 , n_5 , n_6 – стехиометрические коэффициенты,которые необходимо найти.

По закону сохранения числа атомов,сколько атомов калия вступает в реакцию,столько же атомов калия должно получится в результате реакции.На основании этого записываем уравнение :

$n_1 = n_3$ (условие сохранения атомов K)

Аналогичные уравнения записываются для условий сохранения числа атомов других элементов :

$n_1 = n_4$ (условие сохранения атомов Mn)

$4n_1 = n_6$ (условие сохранения атомов O)

$n_2 = 2 n_6$ (условие сохранения атомов H)

$n_2 = n_3 + 2n_4 + 2 n_5$ (условие сохранения атомов Cl).

Мы имеем систему из пяти уравнений с шестью неизвестными :

5

Sergey I. Prokopiev, Candidate of Chemistry, Senior Editor of SCIENCE First Hand

Self-study guide for eighth-grade pupils, NSU DLSPM Chemistry Department, 1984. Developed by M. Yu. Smirnov and V.S. Muzykantov

an initiative by Gennady Fridman. At that time I already participated in checking the assignments for DLSPM, but my regular work began later, in the 1970s, when I was a graduate student and a teacher at SPM. I was asked to prepare a new assignment on sequences limits; it appears to have been a success since I was then entrusted to prepare three more assignments in mathematics. Three of these four assignments had been used for several decades until Yury Mikheev and myself prepared new ones. There was a time when I was in charge of all the teaching of mathematics at DLSPM and, for nearly a decade, I had been preparing introductory assignments in mathematics, the greatest value of which was the detailed solutions that were sent to the candidates together with feedback on their work.

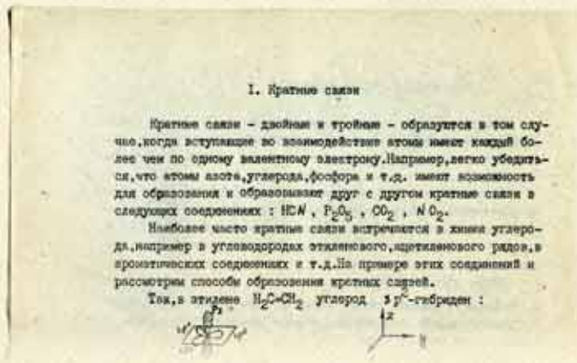
"I should note that nobody forced us to do this work; we were simply interested: we felt we were important and wanted to serve the society, i.e., worked almost for free. By the way, when during the social transition of the early 1990s, one of our university leaders began to popularize the slogan 'Free labor is slave labor,' this resulted in a 'quiet death' of the so-called Sunday School at NSU. Now we are, to some extent, beginning to return to this way of life, but now we call it 'volunteering.'

"Having experienced a lot of changes and gone through good and bad times, DLSPM has now become one of the best distance learning schools in Russia. Working steadily, this school is necessary for both NSU SESC and NSU itself, and, most importantly, it is vital for gifted children who truly strive for knowledge."

Sergey Prokopiev, Cand. Sci. (Chem.), Senior Editor of SCIENCE First Hand:

"My first encounter with the NSU Distance Learning School was in the spring of 1979 in Kurgan, when I saw a DLSPM brochure at the young technicians' club, which I attended with my friends. I must say that I had come across some information about this school in newspaper articles, but newspapers gave, as rule, no full contact details. Even at the district department

им. Ленинского комсомола



I. Кратные связи

Кратные связи – двойные и тройные – образуются в том случае,когда вступающие во взаимодействие атомы имеют каждый более чем по одному валентному электрону.Например,легко убедиться,что атомы азота,углерода,фосфора и т.д. имеют возможность для образования и образовывают друг с другом кратные связи в следующих соединениях : $H{:}C{\equiv}N$, P_2O_5 , CO_2 , N_2O_2.

Наиболее часто кратные связи встречаются в химии углерода,например в углеводородах этиленового,ацетиленового рядов,в ароматических соединениях и т.д.На примере этих соединений и рассмотрим способы образования кратных связей.

Так,в этилене $H_2C{=}CH_2$ углерод sp^2-гибриден :

мого длиной связи) C – C в алкинах.Наличие π -связи в алкинах приводит к невозможности вращения вокруг связи C – C,в то время как вращение вокруг одинарной связи C – C в алкинах происходит достаточно легко.

В ацетилене,имеющем линейное строение (атомы углерода и водорода расположены по химии,соединяющей их центры),углерод sp-гибриден.

12

"…THE DLS TEACHERS WHO CHECKED OUR WORKS WERE VERY STRICT"

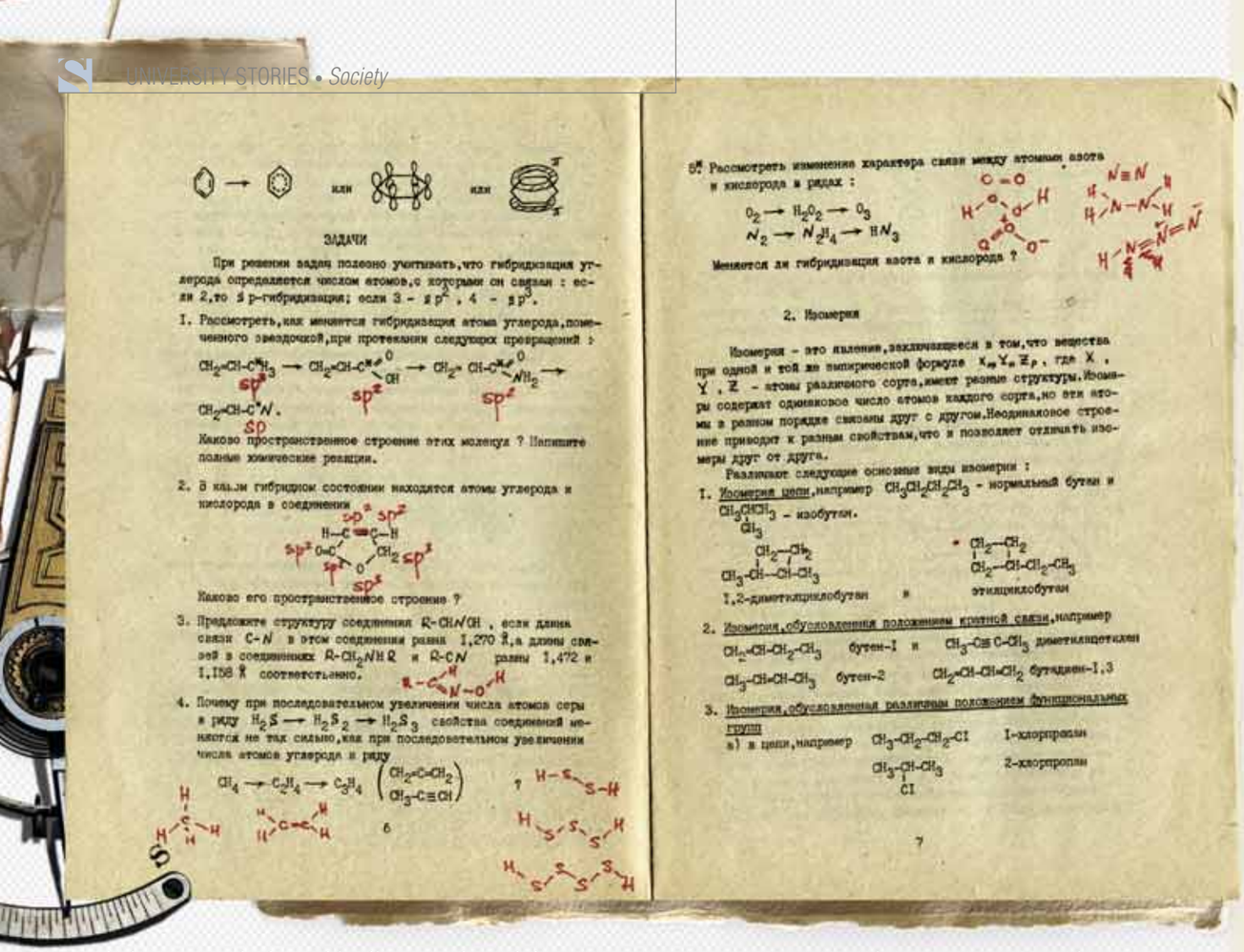
Alexander Bondar
(from his address on October 23 at DLSPM)

"I had been studying at the school of physics and mathematics in Chelyabinsk; we had wonderful teachers of physics, mathematics and even literature. One would think what could a distance learning school give me?

"The reason is that at our school, we were taught physics not from the textbook (I had never opened it in my entire school life), but by the 'folklore' method, i.e., through close communication with our teachers and with peer pupils. It was like in sports: we set problems to one another and solved them with enthusiasm. Although this approach produced an atmosphere of creativity, there was a 'complete mess' in my head. And then I saw an advertisement in Kvant magazine that NSU DLSPM continues to recruit pupils. I sent an application, which was accepted, and I studied there for two years, until 1972. It was my first experience of self-study. No one is looking over your shoulder, but no one will give you a clue. So I had to read books and find solutions all by myself. As a result of the consistent reading of instructional materials and working on assignments, all my diffuse knowledge was brought into a system. The DLS teachers who checked our works were very strict: they revealed any violation of logic in the reasoning and gave a lower grade. Therefore, we had to learn, on our own, the art of what is now called the 'presentation of results,' i.e., the ability to consistently, without omissions, present the solution of a problem. This helped me enroll in university.

"Note that the ability of self-study is an inherent trait of a scientist. Science is developing rapidly, and much of what you were taught at school or university will soon be worthless because it will be outdated. To be successful in real science, you will have to learn a lot from scratch. In order not to get confused by this sudden need for independence, it is better to start training from an early age. The Distance Learning School was a great help for me in that"

Alexander Bondar in 1977 and 2014



ЗАДАЧИ

При решении задач полезно учитывать, что гибридизация углерода определяется числом атомов, с которыми он связан : если 2, то sp-гибридизация; если 3 - sp^2, 4 - sp^3.

1. Рассмотреть, как меняется гибридизация атома углерода, помеченного звездочкой, при протекании следующих превращений :

$CH_2{=}CH{-}C^{*}H_3 \rightarrow CH_2{=}CH{-}C^{*}(=O){-}OH \rightarrow CH_2{=}CH{-}C^{*}(=O){-}NH_2 \rightarrow CH_2{=}CH{-}C^{*}{\equiv}N.$

Каково пространственное строение этих молекул ? Напишите полные химические реакции.

2. В каком гибридном состоянии находятся атомы углерода и кислорода в соединении

Каково его пространственное строение ?

3. Предложите структуру соединения $R{-}CH{=}N{-}OH$, если длина связи $C{-}N$ в этом соединении равна 1,270 Å, а длины связей в соединениях $R{-}CH_2NHR$ и $R{-}C{\equiv}N$ равны 1,472 и 1,158 Å соответственно.

4. Почему при последовательном увеличении числа атомов серы в ряду $H_2S \rightarrow H_2S_2 \rightarrow H_2S_3$ свойства соединений меняются не так сильно, как при последовательном увеличении числа атомов углерода в ряду

$CH_4 \rightarrow C_2H_4 \rightarrow C_3H_4$ $\left(\begin{matrix}CH_2{=}C{=}CH_2\\ CH_3{-}C{\equiv}CH\end{matrix}\right)$

6

5. Рассмотреть изменение характера связи между атомами азота и кислорода в рядах :

$O_2 \rightarrow H_2O_2 \rightarrow O_3$

$N_2 \rightarrow N_2H_4 \rightarrow HN_3$

Меняется ли гибридизация азота и кислорода ?

2. Изомерия

Изомерия - это явление, заключающееся в том, что вещества при одной и той же эмпирической формуле $X_mY_nZ_p$, где X, Y, Z - атомы различного сорта, имеют разные структуры. Изомеры содержат одинаковое число атомов каждого сорта, но эти атомы в разном порядке связаны друг с другом. Неодинаковое строение приводит к разным свойствам, что и позволяет отличать изомеры друг от друга.

Различают следующие основные виды изомерии :

1. Изомерия цепи, например $CH_3CH_2CH_2CH_3$ - нормальный бутан и CH_3CHCH_3 (CH₃ внизу) - изобутан.

1,2-диметилциклобутан и этилциклобутан

2. Изомерия, обусловленная положением кратной связи, например

$CH_2{=}CH{-}CH_2{-}CH_3$ бутен-1 и $CH_3{-}C{\equiv}C{-}CH_3$ диметилацетилен

$CH_3{-}CH{=}CH{-}CH_3$ бутен-2 $CH_2{=}CH{-}CH{=}CH_2$ бутадиен-1,3

3. Изомерия, обусловленная различным положением функциональных групп

а) в цепи, например $CH_3{-}CH_2{-}CH_2{-}Cl$ 1-хлорпропан

$CH_3{-}\underset{Cl}{CH}{-}CH_3$ 2-хлорпропан

7

of education, nobody could tell me anything definitive about this 'secret' school.

"Without thinking twice, I wrote a letter with an application to the 8th grade of the distance learning school to all the three departments—mathematics, physics and chemistry—that the school had at that time. After a couple of weeks, the school specialist replied that I could choose only one department, and I chose math. This choice was dictated by the fact that I had already read and mastered all the available and comprehensible (for a high-schooler) math books.

"The days when I received the feedback on my work and the next assignment were like holidays for me. Firstly, my teacher-by-correspondence was generous with his detailed comments if a problem was solved incorrectly or incompletely. Secondly, it was a pleasure to work though the excellent instructional materials that preceded each new set of assignments.

"In the same year, after my successful participation in the regional science olympiad, I got to the Summer School of Physics and Mathematics and then was enrolled in SPM.

"My next encounter with DLSPM was several years later, when I was a third-year student at the NSU Natural Sciences Department. It turned out that the school had no funding to check the works of the pupils; hence, there was a chronic shortage of professional teachers and this activity was entrusted to students of the respective university departments in the framework of the so-called 'komsomol commitments.' During the year, I checked the works of 20 eighth-grade pupils. The assignments developed by the DLSPM chemistry department were clearly formulated, and it was easy for a good university student to solve the problems and evaluate the solutions proposed by the DLSPM pupils. Recalling my own studies at the Distance Learning School, I tried to be as careful and responsible in my communication with the pupils as my teachers had been. This activity, in which I was engaged until graduation, made a good teaching practice for me.

"After graduation I worked as a researcher at the Institute of Catalysis, and there I met with Nina Bogdanchikova, the organizer and leader of the NSU Sunday School of Physics, Mathematics, Chemistry and Biology.

"MY LIFE WOULD BE DULL AND BORING WITHOUT DLSPM"

Mikhail Liz, first-year student of the NSU Mechanics and Mathematics Department (from his address on October 23 at DLSPM)

"I went to a Novosibirsk school with a concentration on history; the mathematics curriculum at this school was very simple, I felt bored at those lessons. At that time I did not even know that in our city there was a school of physics and mathematics where one could enroll and study. About NSU, they said it was almost impossible to enter this university.

"It was my mother who told me about the distance learning school. At school, we had an interest group where the teacher worked through DLSPM materials on mathematics with the pupils, but I decided not to attend those classes and solved the problems on my own. At first, I studied at the distance learning school; by the results of the second year, I was invited to the Summer SPM, and only there I learned that there was such a school as NSU SESC, where one can study full-time. Two years of study at SESC gave me a most powerful training and helped me pass the entrance exams to NSU, so now I'm a student of the Mechanics and Mathematics Department. Without DLSPM, my life today would be dull and boring"

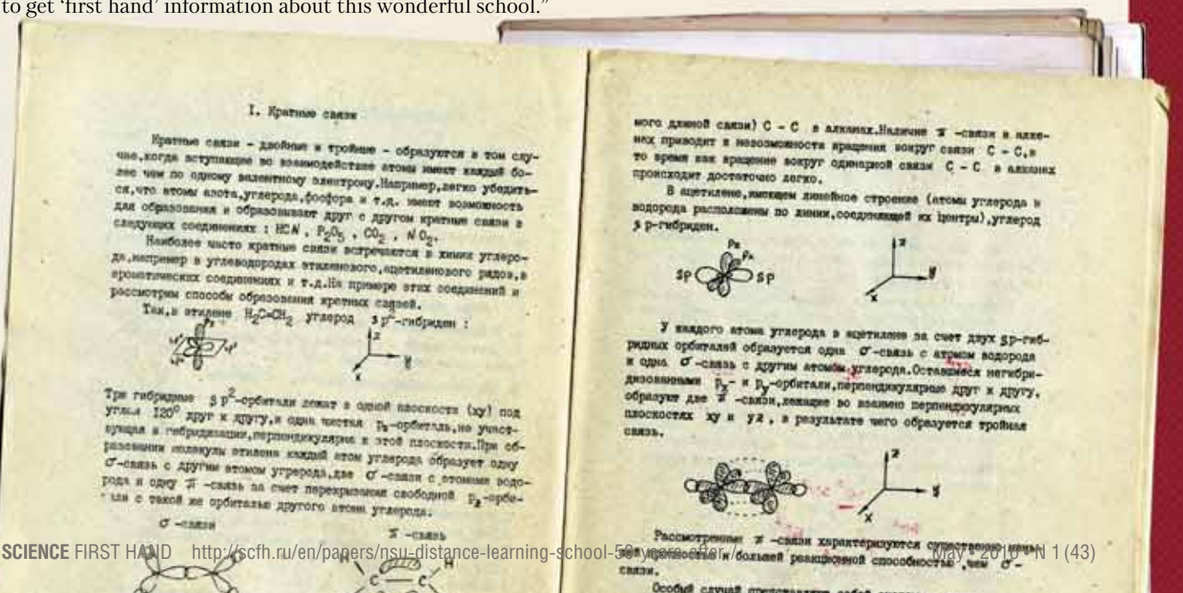
Mikhail Liz, DLSPM graduate

She invited me to take part in 'live' communication with inquisitive children who came to the university on Sundays from different places, including such remote settlements as Cherepanovo and Moshkovo. The children strove to gain knowledge beyond the high-school curriculum, which could help them prepare for the entrance exams to the university. At times there were more than forty people in the classroom! We had virtually unlimited freedom and developed the lecture programs ourselves. I used the DLSPM materials as the core of my lectures, supplementing them with my own assignments on the subjects which were usually difficult for schoolchildren.

"Subsequently, I became involved in the organization of All-Union Science Olympiads for Schoolchildren and had to leave the Sunday School; the baton was taken over by younger teachers—NSU graduates and students. However, at olympiads of any level, I always carried along the DLSPM brochures to show them to the children and teachers—for many of them, it was the only chance to get 'first hand' information about this wonderful school."

Having experienced a lot of changes and gone through good and bad times, DLSPM has now become one of the best distance learning schools in Russia. Working steadily, this school is necessary for both NSU SESC and NSU itself, and, most importantly, it is vital for gifted children who truly strive for knowledge

This publication uses photos of assignments from the archive of the Distance Learning School



I. Кратные связи

Кратные связи - двойные и тройные - образуются в том случае, когда вступающие во взаимодействие атомы имеют каждый более чем по одному валентному электрону. Например, легко убедиться, что атомы азота, углерода, фосфора и т.д. имеют возможность для образования и образования друг с другом кратные связи в следующих соединениях : HCN, P_2O_5, CO_2, N_2O_4.

Наиболее часто кратные связи встречаются в химии углерода, например в углеводородах этиленового, ацетиленового рядов, в ароматических соединениях и т.д. На примере этих соединений и рассмотрим способы образования кратных связей.

Так, в этилене $H_2C{=}CH_2$ углерод sp^2-гибриден :

Три гибридные sp^2-орбитали лежат в одной плоскости (xy) под углом 120° друг к другу, а одна чистая p_z-орбиталь, не участвующая в гибридизации, перпендикулярна к этой плоскости. При образовании молекулы этилена каждый атом углерода образует одну σ-связь с другим атомом углерода, две σ-связи с атомами водорода и одну π-связь за счет перекрывания свободной p_z-орбитали с такой же орбиталью другого атома углерода.

σ-связи π-связь

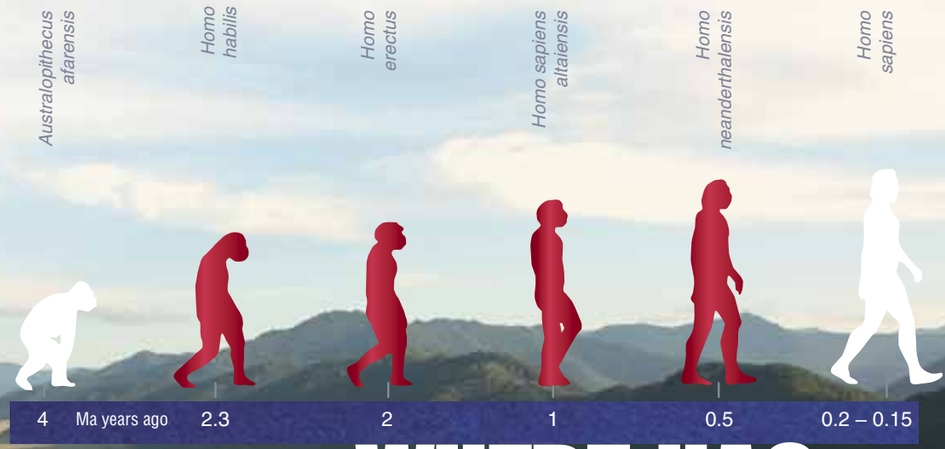
мого данной связи) C - C в алканах. Наличие π-связи в алкенах приводит к невозможности вращения вокруг связи C - C, в то время как вращение вокруг одинарной связи C - C в алканах происходит достаточно легко.

В ацетилене, имеющем линейное строение (атомы углерода и водорода расположены по линии, соединяющей их центры), углерод sp-гибриден.

У каждого атома углерода в ацетилене за счет двух sp-гибридных орбиталей образуется один σ-связь с атомом водорода и одна σ-связь с другим атомом углерода. Оставшиеся негибридизованными p_x- и p_y-орбитали, перпендикулярные друг к другу, образуют две π-связи, лежащие во взаимно перпендикулярных плоскостях xy и yz, в результате чего образуется тройная связь.

Рассмотренные π-связи характеризуются существенно меньшей [illegible] и большей реакционной способностью, чем σ-связи.

A.P. DEREVYANKO, M.V. SHUNKOV



WHERE HAS Homo Sapiens COME FROM?

We – people – are so different! Black, yellow and white, tall and short, dark-haired and fair-haired, brilliant and not very bright… Yet all of us – a blue-eyed Scandinavian giant, a dark-skinned pigmy from the Andaman Islands, and a tawny nomad from the African Sahara – belong to the same and sole mankind. And this is not a poetic figure of speech but a fact established by science and supported by the latest research in molecular biology. But where shall we look for the source of this many-faced living ocean? When, where and how did the first human being appear on the earth? Amazingly, even in our enlightened time, almost half citizens of the USA and a large share of Europeans vote for the divine origin, and many of the others believe in extraterrestrial interference, which, in fact, is not too different from the Divine Providence. However, even a firm advocate of evolution cannot give an unambiguous answer to this question

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Key words:
paleogenetics, mitochondrial DNA, nuclear DNA, hominines, Neanderthal, Denisovan

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Numerous traces of the early man were discovered in Kazakhstan and Central Asia. In particular, on the dry eastern coast of the Caspian Sea, tens of thousands of primitive stone tools were found: in the Mugodzhar Hills alone (top), dozens of ancient hand axes – bifaces – can be collected on an area of one square meter

Unfailing outcrops of flint on the eastern Caspian coast were an attractive source of raw materials for making stone tools

"A man has no reason to be ashamed of having an ape for his grandfather. If there was an ancestor whom I should feel shame in recalling it would rather be a man — a man of restless and versatile intellect — who not content with an equivocal success in his own sphere of activity, plunges into scientific questions with which he has no real acquaintance."

Thomas Huxley (1869)

Not everybody knows that the non-Biblical version of human origin is rooted in the hazy 1600s, when the works of the Italian philosopher Lucilio Vanini and the English lord, barrister and theologian Mathew Hale, with the speaking titles *On the Primitive Origin of Man* (1615) and *The Primitive Origin of Mankind, Considered and Examined According to the Light of Nature* (1671), were published.

The baton passed by the philosophers who acknowledged the kinship of humans and apes was taken up in the 18th c. by the French diplomat B. de Mallier, and then by James Burnett, Lord Monboddo, who put forward the idea of the common descent of all the anthropoids, including man and chimpanzee. The French naturalist Georges-Louis Leclerc, Comte de Buffon, in his voluminous *Histoire Naturelle*, published a century before Ch. Darwin's scientific bestseller *The Descent of Man and Selection in Relation to Sex* (1871), boldly asserted that man had originated from an ape.

In summary, by the late 19th century, the idea of man as a product of a long evolution of more primitive anthropoid beings had germinated and ripened. Moreover, in 1863 the German biologist and evolutionist Ernst Haeckel even classified the hypothetical being, the intermediate link between man and the ape, as Pithecanthropus alatus, i. e., an ape-human devoid of speech (from the Greek *pinthecos*, ape, and *anthropos*, man). Just one small thing was lacking – to discover this pithecantropos "in flesh," which was done in the early 1890s by the Dutch anthropologist Eugene Dubois, who found the remains of a primitive hominin on the island of Java.

Since that time, the planet Earth has been recognized as an official place of residence of the early man, and another issue, as topical and controversial as man's descent from apelike ancestors, was placed on the agenda: geographical centers and development of anthropogenesis. Thanks to the amazing discoveries made in the recent decades by the cooperative efforts of archaeologists, anthropologists, and specialists in paleogenetics, the problem of the development of the modern human, like in the days of Darwin, has generated a lot of public interest and moved beyond mere scientific debates.

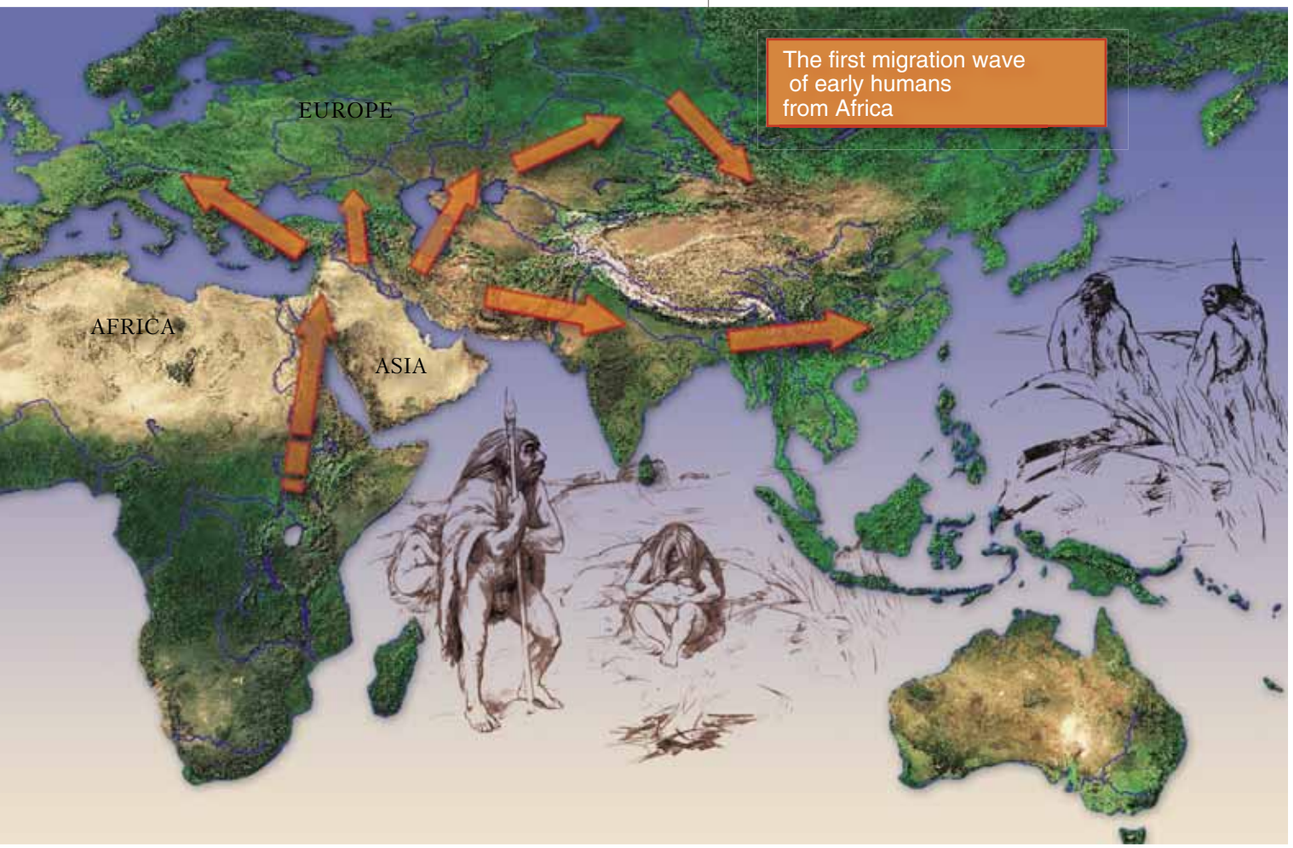
African cradle

The history of the search for the ancestral homeland of the modern human, a plot with many twists full of astonishing discoveries, looked at first like a list of anthropological findings. In the first place, natural scientists became interested in the Asian continent including Southeast Asia, where Dubois discovered the osseous remains of the first hominin, later called Homo erectus. Then, in the 1920s—1930s, archaeologists found numerous fragments of the skeletons of 44 individuals who lived in Zhoukoudian Cave in Northern China, Central Asia, 460,000—230,000 years ago. These people, referred as Sinanthropuses, were once considered the oldest link in human genealogy.

Gradually, however, Africa pretended to the title of "mankind's cradle." In 1925, in the Kalahari Desert, the fossil remains of a hominin called Australopithecus were discovered; in subsequent 80 years, hundreds of similar remains, aged from 1.5 to 7 million years, were found in the south and east of the continent.

In the Great Rift Valley, running from the Dead Sea depression through the Red Sea and on through Ethiopia, Kenya and Tanzania, more ancient sites were discovered with stone artifacts of the Oldowan Industry (choppers, choppings, roughly retouched flakes, etc). Excavations

In the history of science you can hardly find a more exciting and controversial problem that would stir up common interest than the problem of life origin and development of its intellectual peak – humanity



About two million years ago, Homo erectus left Africa and began to settle in Eurasia. It was the first wave of the oldest migrations of man

in the basin of the Kada Gona river led to the discovery, under a layer of tuff 2.6 Ma old, of more than 3000 primitive stone tools made by the first representative of the Homo genus - *Homo habilis*.

Mankind has become much older – it became evident that at least 6—7 Ma ago the common evolution tree split into two separate branches: anthropoid apes and Australopithecus, and the latter marked the beginning of the new, "sensible," development path. The world's oldest fossil remains of modern people – Homo sapiens, who appeared about 200,000—150,000 years ago – were also discovered in Africa. In this way, by the 1990s, the Recent African origin model, supported by recent genetic studies of various human populations, became universally accepted.

However, in between the two extreme reference points – the most ancient ancestors of humans and modern mankind – there is at least six million years during which the man not only developed his present look but also occupied virtually the whole territory of the planet fit for living. If Homo sapiens first appeared only in the African part of the world, when and how did he settle on the other continents?

Three exoduses

About 1.8—2.0 Ma years ago, the ancient ancestor of modern humans – *Homo erectus* or close to it *Homo ergaster* – first left Africa and began his conquest of Eurasia. This was the beginning of the first Migration Period, a long gradual process that took hundreds of millenniums and which can be traced by the fossil remains and typical tools of ancient stone industry.

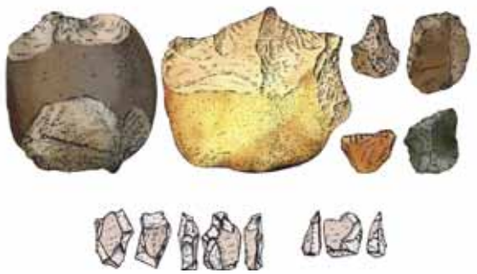
The first migration flow of the oldest populations of hominins branched into two main directions, northward and eastward. The former went through the Near East and Iranian Plateau towards the Caucasus (and, probably, Asia Minor) and on to Europe. This is evidenced by the oldest Paleolithic localities in Dmanisi, East Georgia, and Atapuerca, Spain, dated 1.7—1.6 and 1.2—1.1 Ma, respectively.

In the east, an early testimony of human presence is pebble tools dated 1.65—1.35 Ma, found in the caves of South Arabia. Further migration to the east took two paths: the northern way went to Central, and the southern way went to East and Southeast Asia across the territory of modern Pakistan and India. Judging by the dating of the deposits of quarzitic tools in Pakistan (1.9 Ma) and China (1.8—1.5 Ma) and of the anthropological findings in Indonesia (1.8—1.6 Ma), the early hominins settled on the expanses of South, Southeast and East Asia not later than 1.5 million years ago. On the border of Central and North Asia, in Altai, South Siberia, an early Paleolithic Karama site was discovered – its deposits contained four layers with an archaic pebble industry aged 800,000—600,000 years.

All the oldest sites of Eurasia left by the first wave migration had pebble tools characteristic of the most ancient Oldowan Industry. About the same time or a little later, representatives of other early hominines came from Africa to Eurasia. They were carriers of a microlithic stone industry, where small tools dominated, and they took virtually the same ways as their predecessors. These two oldest technologies of stone working played the key role in the development of ancient tool making.

The second global wave of African migration spread to Near East about 1.5 Ma ago. Who were these new migrants? Probably, *Homo heidelbergensis* – a new type of people that combined both Neanderthal and sapiental features. A distinguishing feature of "new Africans"

The ancient site of Karama in the Altai Mountains: primitive pebble tools discovered in multilayered Pleistocene sediments.
Photograph by A. Postny and S. Zelenskiy

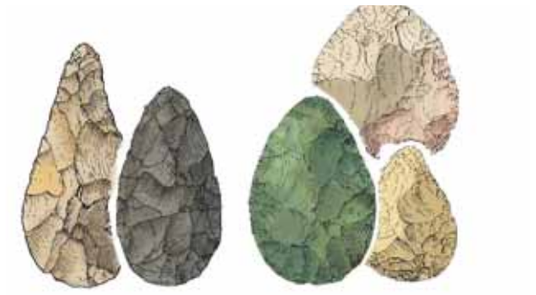


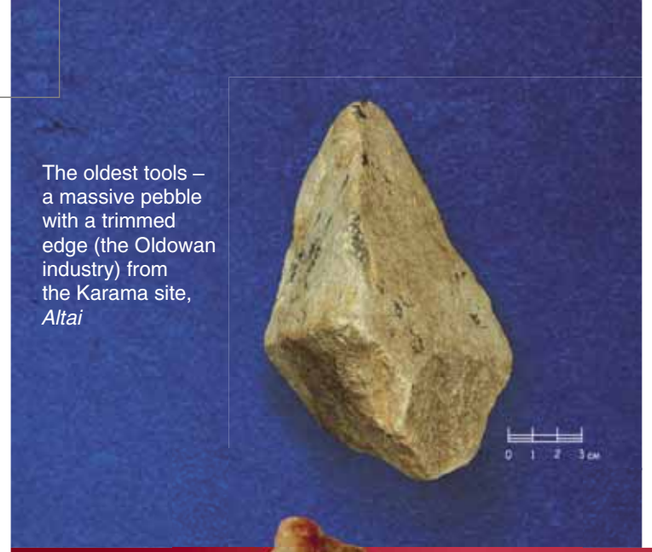
So far, not many osseous remains of primitive humans have been found. The bulk of material accessible to archaeologists is stone tools. From them, they can trace how the stone working techniques improved and human intellectual abilities developed

was stone tools of Acheulean industry made using more advanced stone working technologies – the so-called Levallois technique of stone knapping and methods for bilateral working of stone on both sides. Moving to the east, this wave met the descendants of the first wave hominines, which involved a mix of the two industries, pebble tool and Late Acheulean.

Approximately 600,000 years ago, these migrants of African descent reached Europe, where the Neanderthals – the type closest to modern humans – later developed. About 450,000—350,000 years ago, the bearers of Acheulean tradition penetrated the east of Eurasia, reaching India and Central Mongolia but they did not go as far as the eastern and southeastern regions of Asia.

The third exodus from Africa is related to the anatomically modern humans, who came to the evolutionary arena 200,000—150,000 years ago, as it was mentioned earlier. It is supposed that about 80,000—60,000 years ago, Homo





The oldest tools – a massive pebble with a trimmed edge (the Oldowan industry) from the Karama site, *Altai*

Samples of a microlithic industry aged 600,000—800,000 years, the Darvagchai river, *Dagestan*

Stone tools of the more advanced Acheulian industry (bifically worked tools) from the Tsagan-Agui cave, *Mongolia*

sapiens, traditionally believed to be the bearer of Upper Paleolithic culture, began settling on other continents: first in the eastern part of Eurasia and Australia and then, in Central Asia and Europe.

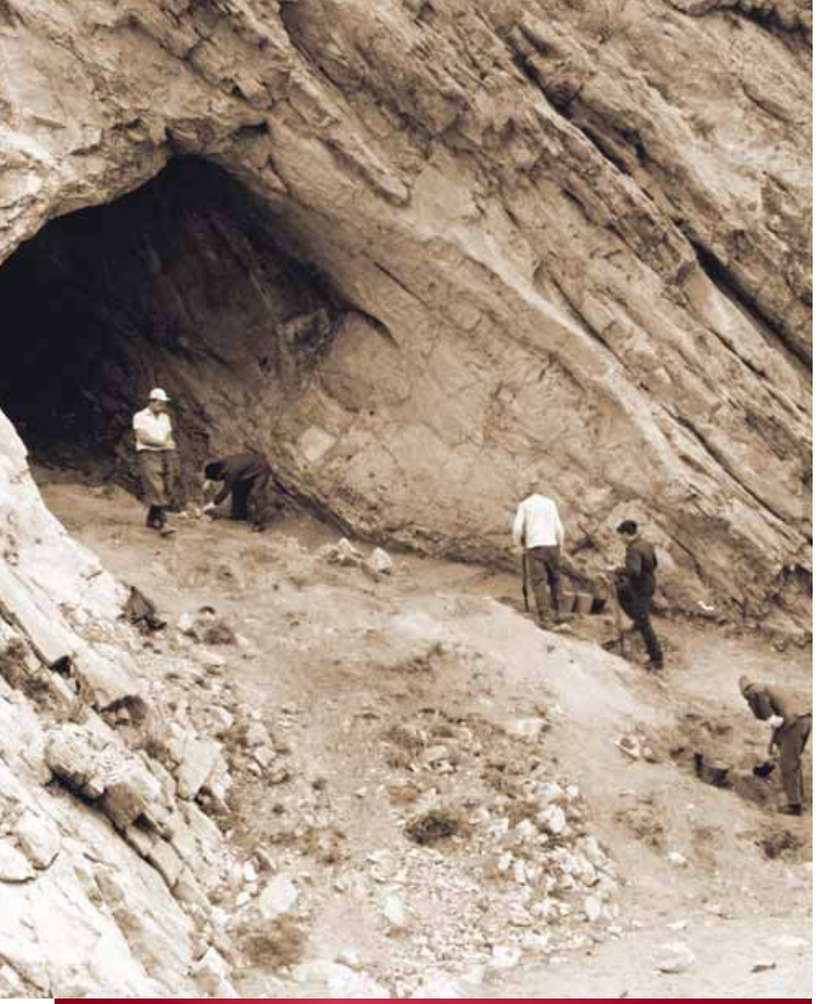
Now we have approached the most dramatic and controversial part of our story. Genetic research has proved that all modern mankind descends from the same species of Homo sapiens, provided that mythical creatures like Yeti are disregarded. Then what happened to ancient human populations, descendants of the first and second migration waves from Africa, who lived in Eurasia for tens or even hundreds of thousands of years? Did they leave a trace in the evolutionary history of our species and if yes, how important was their contribution to modern humanity?

Depending on the answer to this question researchers can be divided in two groups, monocentrists and polycentrists.

Two models of anthropogenesis

In the end of the last century, the monocentric point of view on the appearance of *Homo sapiens* ultimately prevailed – the hypothesis of the African "exodus," according to which the only ancestral home of *Homo sapiens* is the "black continent," from where he settled all around the world. Basing on the results of the study of genetic variability of modern people, its advocates suppose that 80,000—60,000 years ago there was a demographic explosion in Africa, and as a result of a sharp growth in the population and lack of food, a new migration wave swept over Eurasia. Failing to withstand competition with a more evolutionarily advanced species, other hominines existing at that time, such as the Neanderthals, fell out of the evolutionary race some 30,000 – 25,000 years ago.

The second wave of the earliest migrants from Africa moved eastwards through the western regions of Asia. They are supposed to have taken two ways: one to the south of the Himalayas and Tibetan Plateau through Hindustan to East and Southeast Asia, and the other through the West Asian Uplands to Central and North Asia



The *Tsagan-Agui* cave in Gobi Altai is among the few well-dated Mongolian archaeological monuments; it contains the remains of the cultures of all Paleolithic stages and of later epochs

Monocentrists have a variety of opinions on the progress of this process. Some believe that the new human populations exterminated or drove out the aboriginal populations to less comfortable regions, where their mortality grew, especially among children, and their birthrate dropped. Others do not rule out the possibility of occasionally long coexistence of the Neanderthals and modern humans (for example, in the southern Pyrenees), which could result in cultural diffusion and at times hybridization. According to the third point of view, acculturation and assimilation took place whereby the aboriginal population dissolved among the newcomers.

It is difficult to fully accept all these circumstances without convincing archaeological and anthropological evidence to support them. Even if we agree with the debatable presumption that the population grew very quickly, it is inexplicable why the migration flow did not spread initially across the nearby areas but went a long way off to the east, reaching Australia. As an aside comment, though Homo sapiens must have covered a distance of over 10,000 kilometers, so far no archaeological evidence has been discovered to prove it. Moreover, archaeological data suggest that in the period from 80,000 to 30,000 years ago no change occurred in the local stone industries of South, Southeast and East Asia, which should have happened in the event the newcomers actually replaced the aborigines.

This absence of "road" proofs has led to the version that *Homo sapiens* moved from Africa to the east of Asia along the sea coastline, which today is under the water together with all Paleolithic evidence. If this is true, however, African stone industry must have been almost the same on the islands of South-East Asia, while archaeological materials aged 60,000—30,000 years do not support this idea.

Today, the monocentric hypothesis has given no satisfactory answers to many other questions either. In particular, why did anatomically modern humans appear at least 150,000 years ago and the Upper Paleolithic culture, traditionally connected exclusively with *Homo sapiens*, almost 100,000 years later? Why this culture, which emerged virtually simultaneously in far-away regions of Eurasia, is not as homogenous as it should be expected in the case of a single carrier?

These "dark spots" in man's history may be accounted for by another, polycentric concept. According to this hypothesis of interregional human evolution, *Homo sapiens* could develop both in Africa and on the vast expanses of Eurasia, inhabited at that time by *Homo erectus*. It is the continuous development of the ancient population in each region that explains, in the polycentrists' opinion, the striking difference between the Upper Paleolithic cultures of Africa, Europe, East Asia and Australia. Even though from the standpoint of up-to-date biology the formation of the same species (strictly speaking) in such different and geographically remote areas is unlikely, it is possible that independent, parallel evolution of the primitive man into Homo sapiens, with his developed material and spiritual culture, was taking place there.

Below we will provide some archaeological, anthropological and genetic evidence to prove this thesis, connected with the evolution of the primitive population of Eurasia.

Homo orientalis

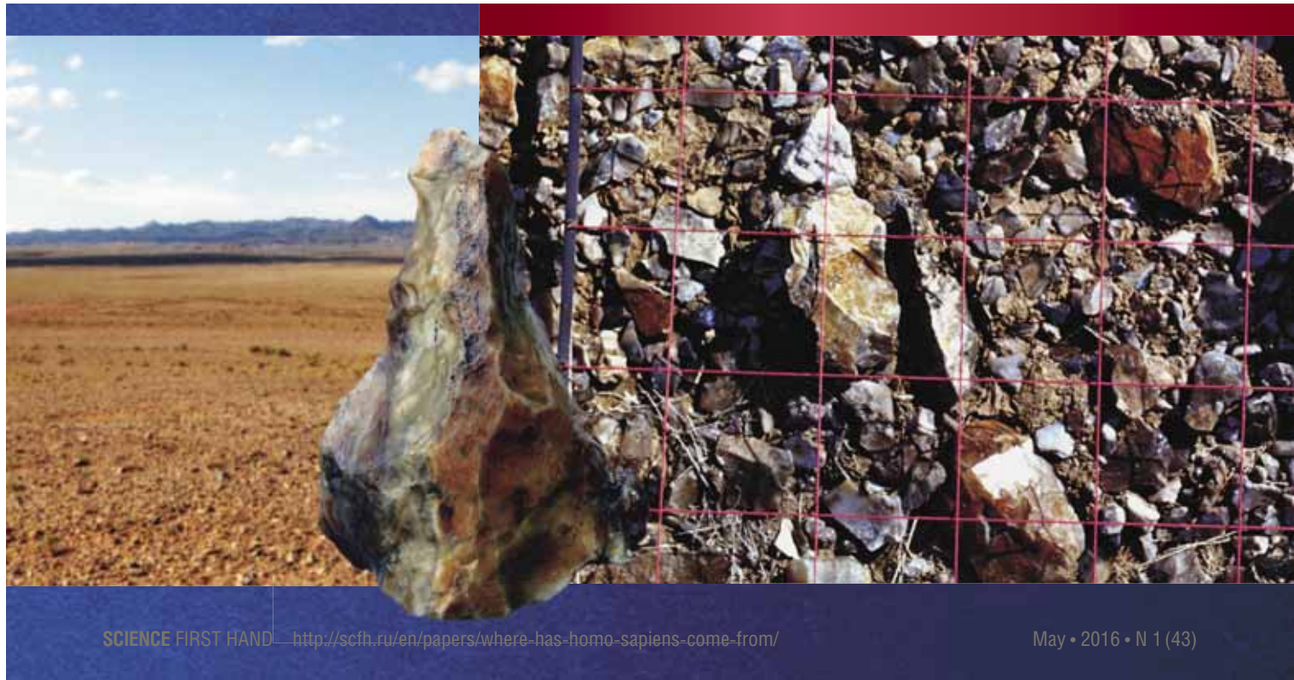
Judging by the numerous archaeological findings, approximately 1.5 Ma ago stone industry in East and Southeast Asia took a development path that was entirely different from the rest of Eurasia and Africa. Surprisingly, during more than a million years, tool-making technology in the Chinese-Malaysian zone did not undergo any marked change. Furthermore, as it was mentioned above, in the period of 80,000—30,000 years ago, when anatomically modern humans should have appeared here, no radical innovations took place: neither new stone working technologies nor new types of tools emerged.

As for the anthropological evidence, most of the known skeleton remains of *Homo erectus* were found in China and Indonesia. Despite some differences, they make up quite a homogenous group. Of special interest is the volume of the brain of Homo erectus (1152—1123 cm^3), found in the Yungxian District, China. Evidence of the advanced morphology and culture of these ancient people, who lived about a million years ago, is the stone tools discovered next to them.

The next link in the evolution of the Asian Homo erectus was found in Zhoukoudian caves, Northern China. This hominin similar to the Java pithecanthropus was classified in the *Homo* genus as a subspecies, *Homo erectus pekinensis*. Some anthropologists argue that all these remains of the earlier and more recent types of primitive people form a continuous evolutionary line extending almost up to *Homo sapiens*.

Thus, it can be taken for granted that over a span of more than a million years in East and Southeast Asia the Asian type of Homo erectus evolutionally developed independently from the rest of the world. This, however, does not rule out the possibility of migrations of small populations from the adjoining regions and, consequently, of genetic exchange. At the same time, the process of divergence that took place in these primitive humans themselves could have led to pronounced differences in morphology. An example is paleoanthropological discoveries from Java Island, which differ from the analogous

For 300,000 years, the unique Flint Valley in the desolate Gobi Desert served as a workshop for ancient stone craftsmen. There, at the outcrop of large siliceous breccias, there is a true "store field" of stone tools, over 20 square meters in area, where tens and hundreds of millions of tools are found – up to 600 per square meter!



Chinese findings of the same time: though Java hominin has preserved the primary features of Homo erectus, some characteristics of his were similar to these of Homo sapiens.

As a result, in the beginning of the Upper Pleistocene in East and Southeast Asia, on the basis of the local type of Homo erectus, a hominin anatomically close to a modern human formed. Supporting this view are the new datings of the Chinese paleoanthropological findings having the features of "sapiens," according to which 100,000 years ago this region could have been inhabited by anatomically modern humans.

Neanderthals come back

The first representative of archaic people that became known to science is the Neanderthal, *Homo neanderthalensis*. The Neanderthals mostly lived in Europe but traces of their presence have also been discovered in Near East, West and Central Asia and in the south of Siberia. These short stumpy people, physically strong and well adapted to the severe conditions of the northern latitudes, in terms of the brain volume (1400 cm^3) were on a par with modern humans.

In a century and a half that have passed since the first Neanderthals' remains were discovered, hundreds of their sites, settlements and burial grounds have been studied. It has turned out that these archaic people not only made quite advanced tools but exhibited some aspects of behavior typical of *Homo sapiens*. For instance, the well-known archaeologist A. P. Okladnikov in 1949, in Teshik-Tash Cave (Uzbekistan) discovered the tomb of a Neanderthal with the traces of what was presumably a ritual burial.

Prior to the beginning of the 21st century, many anthropologists classified the Neanderthals as an ancestral form of modern humans; however, after mitochondrial DNA from their remains was examined, they were treated as a dead end. The Neanderthals were considered to have been forced out and replaced by modern humans of African descent. Further anthropological and genetic studies have shown, however, that the relations between the *Neanderthals* and *Homo sapiens* were not as simple as that. According to the latest evidence, up to 4% of the modern humans' (not Africans') genome was borrowed from *Homo neanderthalensis*. Currently, there is no doubt that on the border of the areas populated by these humans not only cultural diffusion but also hybridization and assimilation took place.

Today, the Neanderthals are classified as a sister group of modern humans, and their status of "man's ancestors" has been restored.

In the rest of Eurasia, the development of the Upper Paleolithic followed a different path. Let us trace this development through the example of Altai region, which has produced some astonishing results obtained with the help of the paleogenetic examination of the anthropological findings from Denisova and Okladnikov caves.

One more member for the club

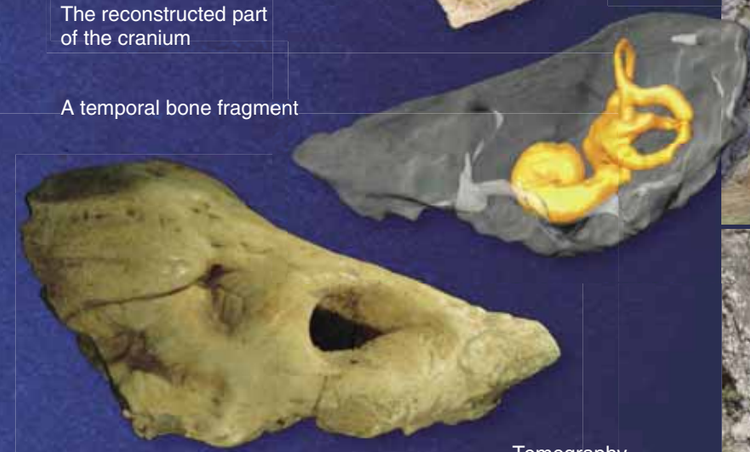
As mentioned earlier, man first came to Altai not later than 800,000 years ago, during the first migration wave from Africa. The uppermost occupation layer of the Paleolithic site of Karama in the Anui River Valley (the oldest site in the Asian part of Russia) formed about 600,000 years ago, after which the development of Paleolithic culture in this area took a long break. About

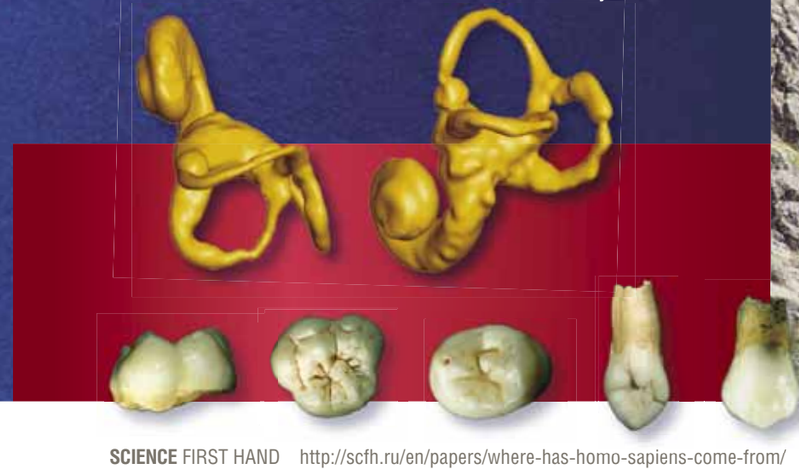
The results of the study of the cranium and teeth from the Obi-Rakhmat Grotto have proved to be sensational: the Obi-Rakhmat hominin has revealed mixed Neanderthal and modern human features, and many of its morphological characteristics have no paleoanthropological analogs

In Obi-Rakhmat Cave, Uzbekistan, stone tools dating back to the turning point – the Middle Paleolithic to the Upper Paleolithic transition – were discovered. Moreover, the fossil remains found here give a rare chance to restore the habitat of the humans who carried out technological and cultural revolution

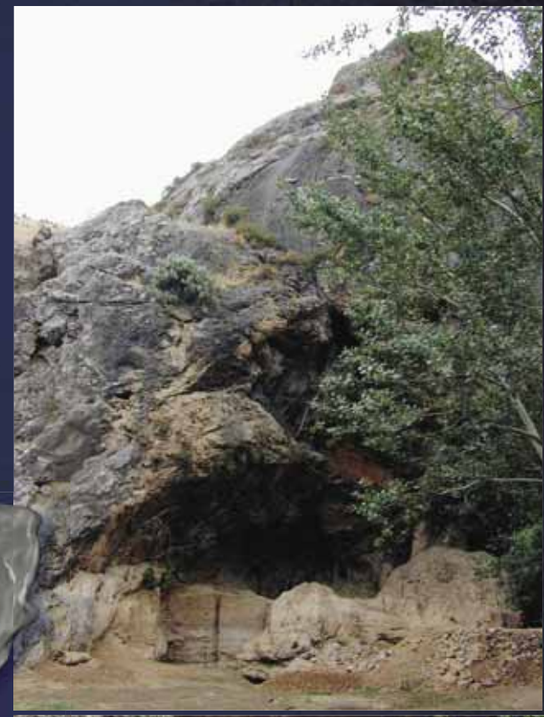
The reconstructed part of the cranium

A temporal bone fragment





Tomography reconstruction of the periodic bone labyrinthine



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280,000 years ago, carriers of more advanced stone working techniques came to Altai, and since then Paleolithic culture developed continuously.

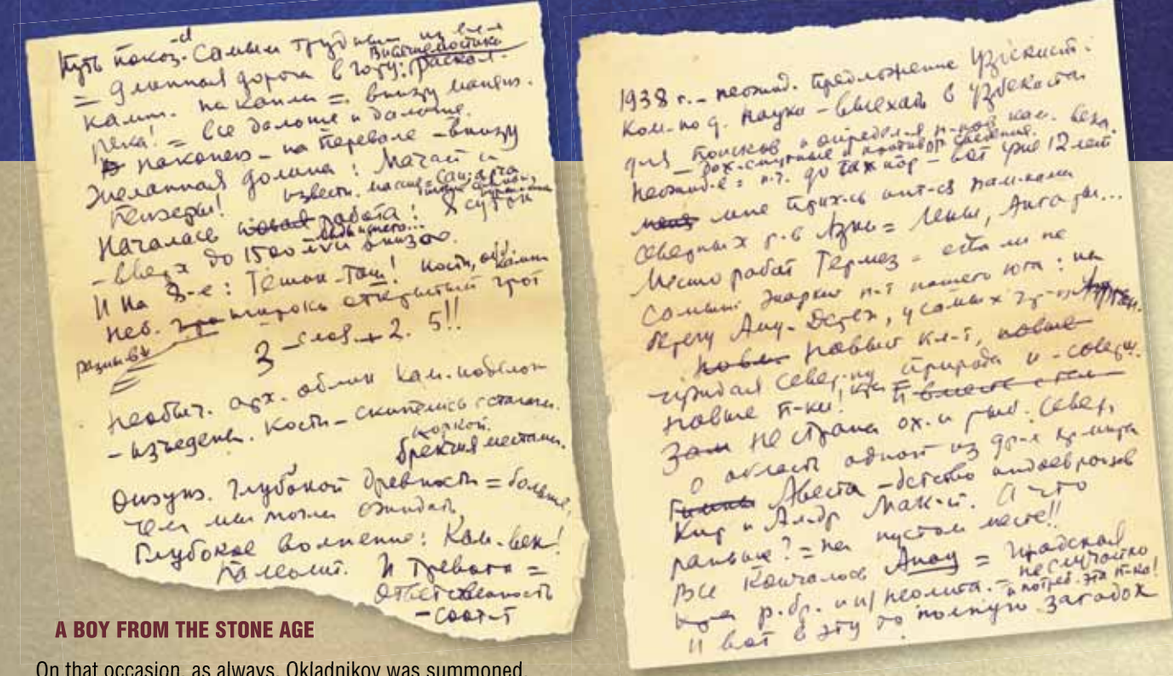
In the last twenty-five years, about 20 sites located in the caves and on the slopes of valleys in the Altai Mountains have been studied, and over 70 occupation layers of the Early, Middle and Upper Paleolithic have been examined. For example, in Denisova Cave alone 13 Paleolithic layers were distinguished. The oldest findings, dated the early period of Middle Paleolithic, were discovered in the layer aged from 282,000 to 170,000 years; Middle Paleolithic artifacts were found in the layer dating back to between 155,000 and 50,000 BP, and the Upper Paleolithic findings were dated to between 50,000 and 20,000 years ago. This long and "continuous" chronicle allows us to trace the changes that occurred in stone artifacts in many tens of thousands of years. It has turned out that it was a gradual process, a step-by-step evolution without any external "perturbations" – innovations.

Archaeological data testify that as early as 50,000–45,000 years ago Upper Paleolithic era began in Altai, and the sources of the Upper Paleolithic cultural traditions can be easily traced back to the final stage of Middle Paleolithic. Artifacts supporting this statement are miniature bone needles with drilled eyes, pendants, beads and other non-utilitarian things made of bone, ornamental stone and clamshell, as well as the truly remarkable finds: fragments of a bracelet and a stone ring with traces of grinding, polishing and drilling.

Regretfully, Altai Paleolithic localities cannot boast of many anthropological findings. The most impressive are the teeth and skeleton fragments from two caves, Okladnikov and Denisova, were studied in the Max Planck Institute for Evolutionary Anthropology (Leipzig, Germany) by an international team of genetic scientists led by Professor Svante Pääbo.

Fragment of a field journal of A. P. Okladnikov *Uzbekistan, 1938*. Branch of the Archive of the Russian Academy of sciences, St Petersburg

The cranium of a Neanderthal, *Teshik-Tash, 1938*. Archive of the Institute of History of Material Culture, Russian Academy of Sciences, St Petersburg



A BOY FROM THE STONE AGE

On that occasion, as always, Okladnikov was summoned.

— A bone.

He came up, bent over it and began brushing it carefully. And then his hand trembled. This was not just one bone, there were many of them. Fragments of a man's skull. Heaven! Of a man! It was a find he had not dared to dream of.

Though could this person be buried here not long ago? It takes a few years for bones to decompose, and to expect that they will stay intact for dozens of millennia… Actually, it happens but very rarely. There is only a handful of such finds in the entire history of humankind.

But what if..?

— Verochka!

He called his wife below his breath.

She came up and bent over.

— This is a skull, she whispered. — Look, it's crushed.

The cranium was lying with the crown down. It must have been crushed by a falling clot of earth. The skull was small! A boy's or a girl's.

With a spade and a brush, Okladnikov began widening the dig. The spade hit against something hard. A bone. Another one, and one more…It was a small skeleton, the skeleton of a child. An animal must have found its way into the cave and picked the bones. They were scattered, some of them gnawed and bitten.

But when did this child live? In what years, centuries, millennia? If he was a young master of the cave when people who worked stone lived here … The thought was terrifying. If it was so, the child was Neanderthal. A man who lived tens of thousands or even a hundred thousand years ago. He must have a very pronounced brow ridge and no chin.

The easiest thing to do was to turn the cranium to have a better look but this would have disrupted the excavation plan. They had to complete the excavations around it leaving the child's bones untouched. The dig around them will deepen, and the bones will remain as though lying on a pedestal.

Okladnikov consulted Vera Dmitrievna, and she agreed with him....

... The child's bones were left untouched. They were even covered. The archaeologists dug around them, and the bones were on a ground pedestal, which became higher every day. It appeared to be growing from the underground.

The night before that memorable day Okladnikov had trouble falling asleep. He was lying on his back, hands behind his head, looking up at the black southern sky. Far above, the stars were swarming. They were so many that it seemed there was not enough room for all of them. That faraway world inspired awe and at the same time instilled serenity. You felt like thinking of life, eternity, the faraway past and the faraway future.

What could the ancient man be thinking about when he was looking up at the sky? It was the same as it is now. Maybe, sometimes he also had trouble falling asleep, was lying in the cave and looking up at the sky. Did he only have memories or did he have dreams as well? What was that man? The stones told a story but there were many things about which they remained quiet.

Life buries its traces deep underground. Overlaying them are new traces, which with time also go down. And so it happens century after century, millennium after millennium. Life puts layers of its past in the ground. Paging through them, an archaeologist can learn about the doings of the people who used to live here and to determine, virtually without mistake, the times when they lived.

Drawing the curtain above the past, they removed land layer by layer, as time had put them."

From the book *Along the path of faraway millennia* by Ye. I. Derevyanko and A. B. Zakstelsky

Paleogenetic studies confirmed that the remains discovered in Okladnikov Cave were Neanderthal whereas the results of the sequencing of mitochondrial and then nuclear DNA from the bone samples discovered in the occupation layer of the Upper Paleolithic early stage in Denisova Cave sprang a surprise on the researchers. The bone fragments proved to belong to a new fossil hominin, unknown to science, who was given the name of Homo sapiens altaiensis, or Denisovan, after the locality where he was discovered.

The genome of the Denisovans differs from the reference genome of a modern African by 11.7%, and that of the Neanderthal from Vindija Cave, Croatia, by 12.2%. This similarity testifies that the Neanderthals and Denisovans are sister groups with the same ancestor, who branched off the man's mainstream evolutionary trunk. These two groups separated approximately 640,000 years ago, taking the path of independent development. Another proof is that the Neanderthals share some genetic variants with modern Eurasians whereas some of the Denisovans' genetic material was borrowed by the Melanesians and indigenous inhabitants of Australia, who stand apart from other non-African human populations.

Judging by the archaeological data, 50,000—40,000 years ago, in the northwestern region of Altai two different groups of primitive people lived next to each other: the Denisovans and the easternmost population of the Neanderthals, who came there at about the same time, probably from the territory of modern Uzbekistan. The roots of the culture whose carriers were the Denisovans can be traced back to the earliest sequences of Denisova Cave, as it was mentioned earlier. Interestingly, according to the panoply of archaeological findings reflecting the development of the Upper Paleolithic culture, the Denisovans were not

A most rare find of Denisova Cave – a tooth of one of the first Asian *Homo sapiens*

These unique artifacts of the Upper Paleolithic culture (a necklace, needles and a bracelet) testify that in Altai the Upper Paleolithic began earlier than in Europe

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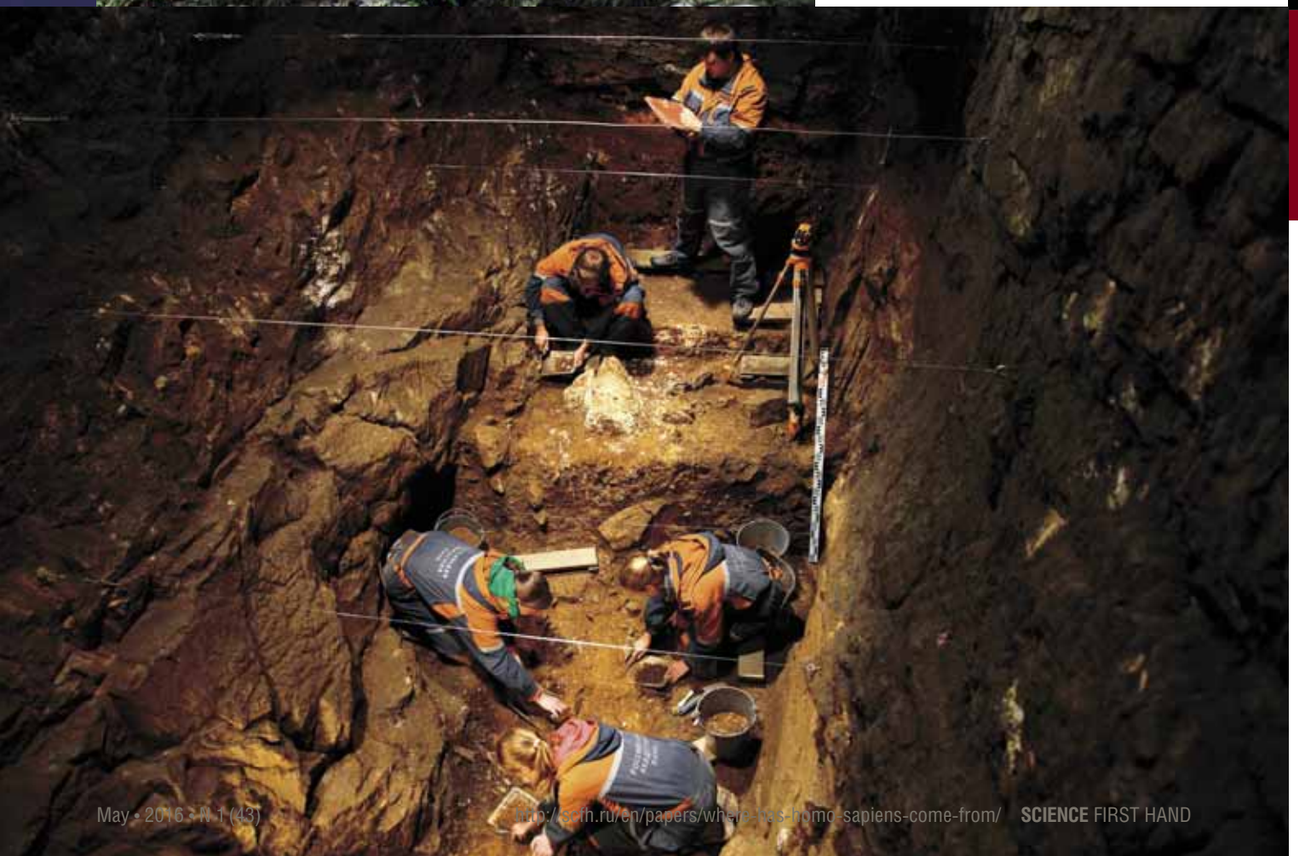
Novosibirsk archaeologists have been excavating Pleistocene sediments in Denisova Cave, the Altai Mountains, where man first appeared about 300,000 years ago



Denisova Cave is a dependable repository of the ancient history of Altai
Photograph by M. Shunkov

only on a par with the anatomically modern humans inhabiting at that time other territories but in some respects were superior to them.

To sum up, during the Late Pleistocene there were at least two other forms of hominines in Eurasia: Neanderthal in the western part of the continent and Denisovan in the eastern. Taking into consideration the gene drift from the Neanderthals to Eurasians and from the Denisovans to the Melanesians, we can take it that both these groups have contributed to the formation of anatomically modern humans.

The third upper molar, a wisdom tooth of a Denisovan, discovered in the lithologic layer 11 within the sediments dating back to 50,000-40,000 BP

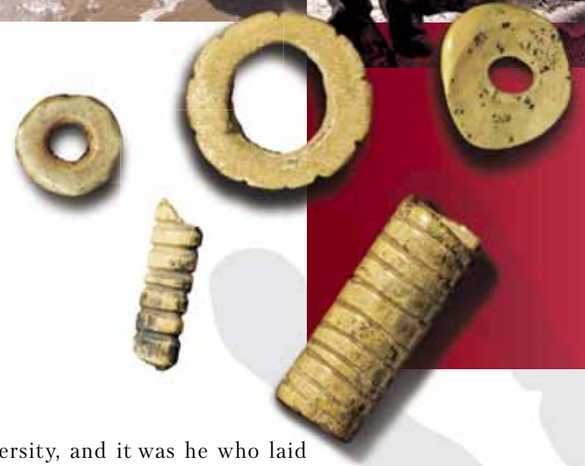
In the eastern gallery of the cave, a small fragment of the terminal phalanx of the minimus of a child, presumably, a girl 5—8 years old

Taking into account all the available archaeological, anthropological, and genetic materials from the oldest localities of Africa and Eurasia, it can be presumed that the globe had several areas where Homo erectus populations and stone working technologies developed independently. Respectively, each of these areas generated its own cultural traditions and its own models for the transition from the Middle Paleolithic to the Upper Paleolithic.

Thus, the basis of the evolutionary sequence crowned with the anatomically modern humans is the ancestral form of Homo erectus sensu lato*. Probably, in the Late Pleistocene it ultimately developed into the humans of the anatomically and genetically modern species Homo sapiens including four forms that can be referred to as Homo sapiens africaniensis (East and South Africa), Homo sapiens neanderthalensis (Europe), Homo sapiens orientalensis (Southeast and East Asia) and Homo sapiens altaiensis (North and Central Asia). In all likelihood, the idea to unite all these primitive people into a single species, Homo sapiens, can give rise to doubt and objections but it has to be remembered that it is based on a large body of analytical information, only a small part of which was given in this paper.

Evidently, not all of these subspecies have contributed equally to the formation of anatomically modern humans: Homo sapiens africaniensis featured the greatest genetic

* *Homo erectus sensu lato – Homo erectus in a general sense*



In archaeology everything matters down to the last detail. Chief of the Laboratory of Mammals, Prof. A.K. Agadzhanyan (the Paleontological Institute, Russian Academy of Sciences, Moscow) and his assistant are examining the cave ground on the bank of the Anui River
Photograph by S. Zelenskiy

diversity, and it was he who laid the foundation for the modern human. However, the most recent data of paleogenetc research dealing with the presence of Neanderthal and Denisovan genes in the gene pool of modern mankind have shown that the other groups of ancient people did not stand back either.

Currently, archaeologists, anthropologists, experts in genetics and other specialists interested in human origin have accumulated an enormous number of new data basing on which new hypotheses, sometimes diametrically opposite, can be formulated. It is high time to discuss them in detail under the essential condition that man's origin is a multidisciplinary problem and new ideas should be based on a complex study of the results obtained by the specialists of a wide variety of sciences. Only this way will ultimately give us the answer to one of the most controversial questions that has stirred people for centuries – the development of intelligence. According to Thomas Huxley quoted above, "each of our firmest convictions can be overthrown or, at least, revised by further successes in knowledge."

Drawing by N. Kovalev

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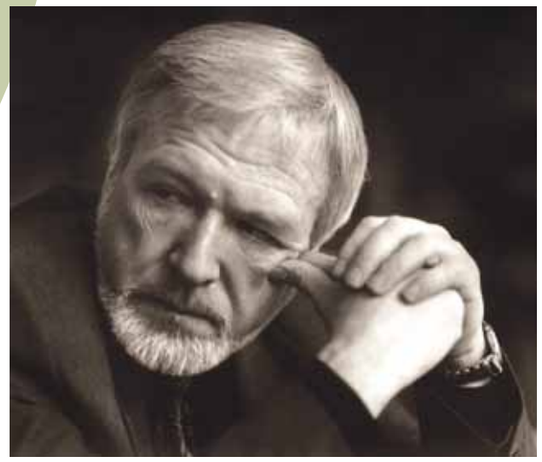
V.I. MOLODIN, A.S. PILIPENKO

Hunters for Ancient Genes

Genetic Chronicle of the West Siberian Population in the Paleometal Age

Paleogenetics, which was born as an independent field of study only in the early 1980s, has now matured into a full-fledged discipline within human molecular genetics. Paleogeneticists have their own arsenal of methods to resolve almost any issue associated with robust analysis of ancient human DNA.
This opens up prospects for cooperation between researchers specializing in paleogenetics, archaeology, and physical anthropology on a wide range of issues---from determining the kinship, gender, and phenotypic characteristics of individual representatives of an ancient population to reconstructing the large-scale ethnogenetic processes that took place in different parts of Siberia in the Holocene



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Author and coauthor of over 50 research papers

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Author and coauthor of over 1,260 research papers

For science, the man has always been the most fascinating object of research, studied in an intense and versatile way. In recent years, increasing attention has focused on the advances in molecular genetics, a field that studies the genetic diversity of human populations and the principles of organization and functioning of human genome. The success of the international program "Human Genome" made molecular genetics a leading research area among all biomedical research.

However, despite all these achievements, there is a huge number of unresolved problems related to the origin and evolution of the human species and human physiology. Therefore, scientists are always in search of new methods and approaches. The continuous improvement of methods for obtaining and analyzing the DNA structure has made it possible to conduct genetic studies using samples from human remains of different ages, even from fossilized materials, as well as from currently living individuals.

DNA aged thousands of years

Paleogenetics as an independent field of study was born only in the mid-1980s, when scientists performed the first analysis of a fragment of the mitochondrial DNA (mtDNA) extracted from the museum remains of quagga, an extinct representative of a species closely related to the horse and zebra, about 140 years old (Higuchi *et al.*, 1984). Next year, the first paper was published on the analysis of DNA from ancient human remains, a 2,400-year old Egyptian mummy (Paabo, 1985).

In the second half of the 1980s, molecular geneticists began to apply a new method – the polymerase chain reaction (PCR), which allowed them to obtain a virtually unlimited number of copies of a short DNA fragment even for extremely low concentrations. This innovation expanded the range of sources for the isolation and analysis of ancient DNA and led to a boost in the number of publications on molecular genetic analysis of fossil remains of not only humans but also animals, plants, and microorganisms that lived hundreds, thousands, and even millions of years ago (Thomas *et al.*, 1989; Golenberg *et al.*, 1990; Cano *et al.*, 1992).

However, the initial optimism aroused by the visible potential of this research area and the seeming simplicity of the methods soon vanished owing to the studies into the DNA degradation processes, especially, the contamination of ancient samples with modern DNA, as they may lead to false research results. Subsequent studies on the biochemistry of the DNA degradation processes after the body's death and the effect of different environmental conditions on DNA preservation provided evidence that DNA suitable for analysis can "survive"

Key words: Prehistoric human migrations, paleogenetics, ancient DNA, mitochondrial DNA, stable isotopes

in remnants thousands of years old even in a temperate climate zone (Poinar *et al.*, 1996). Since that time, proving the authenticity of experimental results has become the primary task of every paleogenetic study.

The development of methods of high-performance parallel DNA sequencing has become an important milestone in the development of paleogenetics. These methods allow researchers to obtain a lot of genetic information from a minimum amount of the initial DNA-containing material, which helps avoid the destruction of the unique sample during the analysis. These methods have almost equalized the informative potential of ancient and modern DNA samples.

Thus, nowadays, paleogenetics has developed into a full-fledged discipline within human molecular genetics. Paleogeneticists have their own arsenal of methods to resolve almost any issue associated with robust analysis of ancient human DNA. One can investigate the almost complete genome of an ancient individual as well as an individual "letter" (position) or a short part of ancient DNA. However, the analysis of ancient DNA is more expensive than that of modern DNA. Moreover, paleogenetic methods cannot be applied to any material because some of them contain highly degraded or heavily contaminated DNA; the latter is particularly common in the remains of anatomically modern humans. However, most of the well-preserved paleoanthropological materials are quite suitable for paleogenetic studies.

It all started with "Pazyryk"

The Institute of Archaeology and Ethnography SB RAS (IAE, Novosibirsk) was one of the first research institutions to engage in paleogenetic studies, when the new science was making its first steps. In this area, it became partners with the Institute of Cytology and Genetics SB RAS (ICG), its nearest neighbor in Novosibirsk Akademgorodok.

The starting point of the joint paleogenetic studies was the international research program "Pazyryk," implemented in the mid-1990s. At that time, Academicians Anatoly Derevyanko (IAE Director) and Vladimir Shumny (ICG Director) initiated molecular genetic studies of the mummified remains of the Pazyryk culture bearers from the unique "frozen" burials on the Ukok plateau in the Altai Mountains (Russia). The burials had been discovered and explored by the IAE expedition teams headed by Natalia Polosmak and Vyacheslav Molodin. In that period, paleogenetic studies were conducted by the team of molecular geneticists from the ICG under the direction of Mikhail Voevoda, Corresponding Member of the Russian Academy of Medical Sciences, and Aida Romashchenko, Cand. Sci. (Bio.). On the part of the IAE, the studies were headed by Vyavheslav Molodin.

The unique preservation of the paleoanthropological material from the burials found in permafrost allowed researchers to analyze the mitochondrial DNA of several individuals (Voevoda *et al.*, 1998). The studies performed by the cross-institute collaboration formed the core of a series of integration projects on paleogenetics, which were organized by the SB RAS. The integrated analysis of the archaeological, anthropological, and paleogenetic data was published in a major overview and detailed study on the various aspects of the history of the Pazyryk population in the Altai Mountains (Molodin *et al.*, 2003).

Since the mid-2000s, the scope of paleogenetic research at the IAE and ICG has substantially expanded to involve new materials, explore new avenues of research, and tackle more complex tasks. During this period, the institutes have taken major decisions to develop the infrastructure for paleogenetic studies at the ICG (supervised by Academicians Nikolai Kolchanov and Vyacheslav Molodin) and build a team of young paleogeneticists who receive special training for the ICG–IAE collaborative studies on ancient DNA. By 2009, the collaboration had started experimental works in the new dedicated premises for paleogenetic research at the ICG. In 2010, a decision was made to establish a special research department for paleogenetic studies, leading to the establishment of the Interinstitutional Center of Molecular Paleogenetics (ICG), which is now headed by Cand. Sci. (Bio.) Alexander Pilipenko. The research staff are young paleogeneticists, who have been trained during the implementation of the IAE–ICG joint research projects.

Currently, the IAE and ICG continue to develop the infrastructure and instruments for joint research. The achievements include a new laboratory building that meets all modern standards, an increase in the number of researchers working at the Interinstitutional Center of Molecular Paleogenetics, and a more intense collaboration with Russian, and international science institutions interested in conducting paleogenetic studies.

A significant concern for paleogenetics, as well as genetics as a whole, is the difficulty associated with the identification of clear genetic markers related to specific phenotypic characteristics. Unfortunately, over the past decade, the set of genes that can be used in paleogenetic studies has virtually not expanded; even when researchers determine the color of hair, skin, or eyes of ancient people, they can only talk about probabilities

The mummified body of a woman from the "frozen" burial associated with the Pazyryk culture in the Altai Mountains (*Ak-Alakha 3* Tumulus 1)

Reconstruction of the female costume from Ak-Alakha 3 Tumulus 1. *Drawing by D. Pozdnyakov*

Baraba as a paleogenetic model

The close cooperation of our specialists in paleogenetics, archaeology, and physical anthropology during all the phases of the research process allowed us to obtain original, highly objective and reliable data on the ethnic history of the population of Siberia and other regions of Eurasia from the Stone Age to the modern and late modern period. The range of issues that can be explored by paleogenetic methods is extremely wide – from determining the kinship, gender, and phenotypic characteristics of individual representatives of an ancient population to reconstructing the large-scale ethnogenetic processes that took place in different parts of Siberia in the Holocene.

Today, we can directly estimate the gene pool in ancient population groups that were replacing one another over a long chronological period and compare the genetic composition of a population in different historical epochs.

The first impulse of external influence on the population of the West Siberian forest-steppe is detected at an early stage of the Krotov culture (beginning of the 2nd millennium BC). The burial complexes of this period have objects typical of the cultures of Central Asia (knives of a specific shape, decorations, etc.) (Molodin, 1988). The physical anthropology and paleogenetic data suggest that this influence was not accompanied by migrations of genetically contrasting population to the Baraba forest-steppe

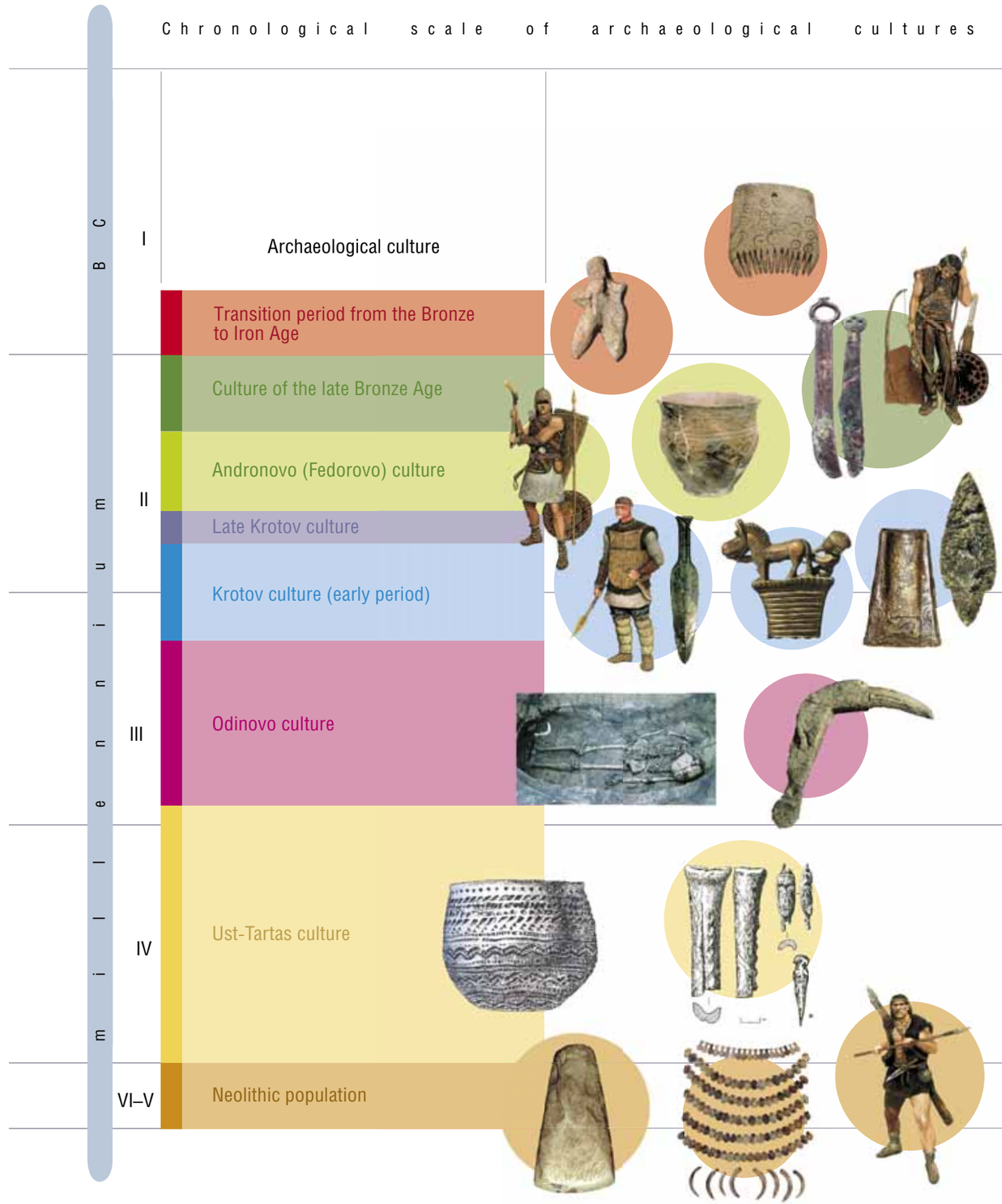
Chronological scale of the Baraba forest-steppe archaeological cultures of the Neolithic and Bronze Ages, which have been studied by archaeology, paleogenetics, and physical anthropology methods

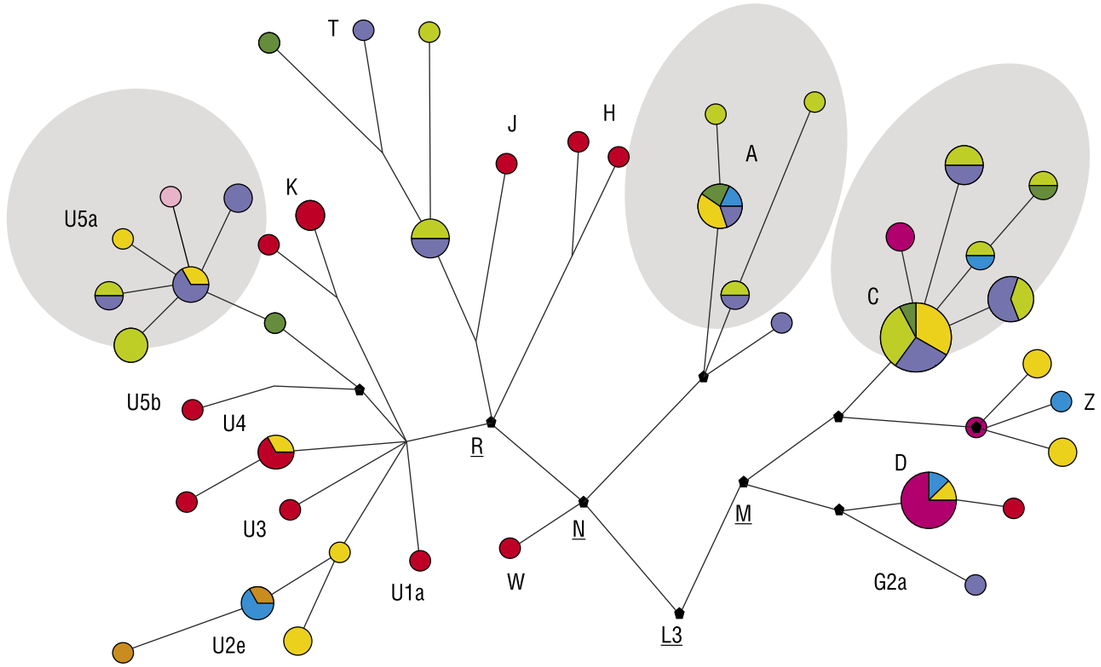
Materials for these studies are collected from sufficiently local territories to ensure the representativeness of the samples. The success of this work depends almost entirely on the joint efforts of different experts in the selection of the most appropriate material and the subsequent interpretation of the data. This a highly laborious work, but it provides an accurate pattern of population genetic changes. This pattern can be compared with the data from other sciences to gain an insight into the historical processes leading to these changes.

The Baraba forest-steppe, a territory in the forest-steppe zone between the Ob and Irtysh rivers, was the pilot region for the implementation of this approach. This region had been intensively researched by IAE archaeologists for over 40 years to develop a classification system for the ethnic and cultural groups of the Holocene, which reflects the chronology, material culture characteristics, possible directions of migrations, and cultural and demographic relations (Molodin, 1983). In addition, researchers had already collected extensive and sufficiently well preserved anthropological material.

By now, researchers have analyzed the mitochondrial DNA gene pool (which is transmitted only maternally and reflects, first of all, the history of the female part of the population) for the Baraba population of different historical periods: the Neolithic Period, Bronze Age, Iron Age, and the Middle Ages. The analysis revealed many details of the genetic history of the regional population.

Chronological scale of archaeological cultures





Schematic view of the phylogenetic tree for the mitochondrial DNA from the remains of Baraba individuals associated with different periods of the Bronze Age. The circle symbols indicate specific structural variants of mtDNA. The size of a circle is proportional to the number of individuals with a particular structural variant of mtDNA. The colors showing the ethnocultural association of the samples are similar to those used in the chronological scale of archaeological cultures. The contour lines show the mtDNA groups that are used as genetic markers for the succession between the populations of different periods

The likely direction of the migration of the Andronovo (Fedorovo) culture bearers into the Baraba forest-steppe (first half of the 2nd millenium BC; from anthropological and genetic data). On the territory of Baraba, the migrants coexisted with the indigenous late Krotov population and interacted with them at the level of material culture (Molodin et al., 2009), mitochondrial DNA (Pylypenko et al., 2009), and genetic contacts

Vessel of the Andronovo (Fedorovo) culture

Natives and migrants in West Siberia

The Neolithic populations of the Early Metal Age, who lived in Baraba from the early 4,000 BC to 6,000 BC, are the earliest groups of the Baraba population to be studied by paleogenetic methods. These groups had served, for about 5,000 years, as a genetic base of all the subsequent population processes.

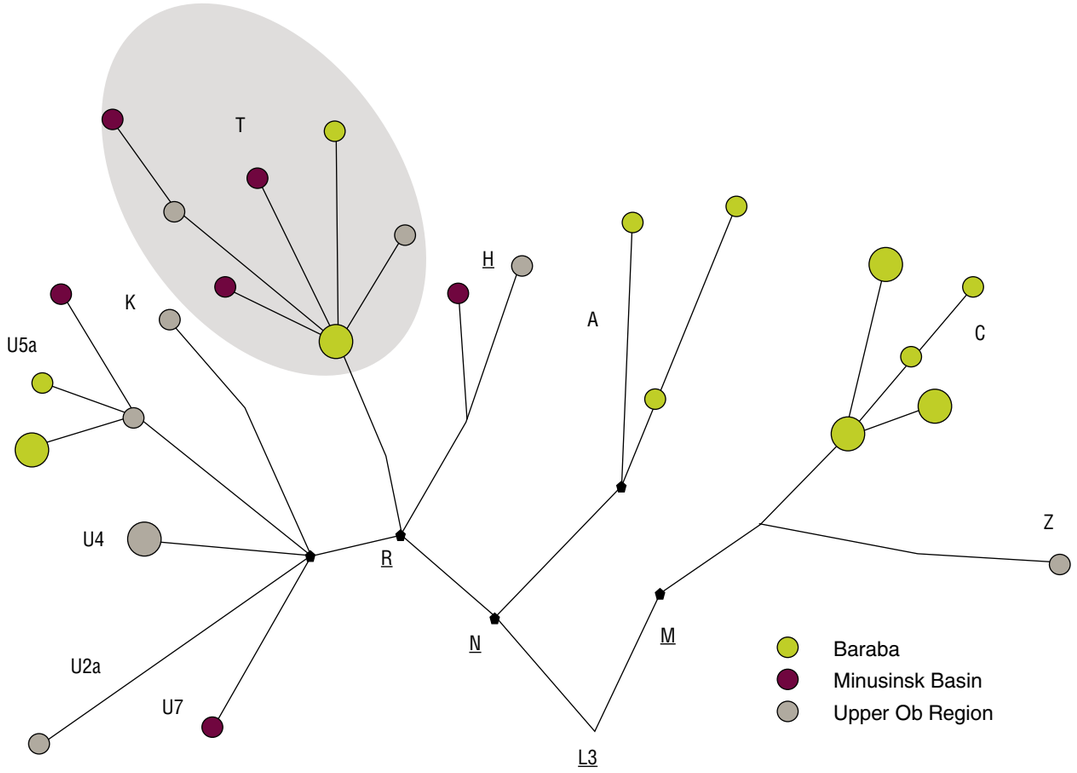
The mitochondrial gene pool of this Baraba population was found to have relic features making it similar to the gene pools of the hunter-gatherers inhabiting the vast territories of Northwestern Eurasia. These features had likely been inherited from the people of the modern physical type, who had inhabited the region as far back as in the Upper Paleolithic. Interestingly, in Baraba these features persisted for a long time, until the beginning of the developed Bronze Age, which is why scientists were able to detect them (Molodin *et al.*, 2012).

A major scientific achievement was the discovery of genetic evidence for a long independent evolution of the West Siberian population. This hypothesis was put forward by anthropologists as early as in the middle of the last century, but until recently, there was no genetic proof. The study of the mtDNA gene pool of modern populations detected alien elements that penetrated from other territories. The studies conducted by Novosibirsk paleogeneticists have proved that the specific mtDNA haplogroup A10 is a "local" component. It appears to have come to West Siberia before the Holocene epoch, i.e., more than 10,000 years ago, and have evolved here over several millennia (Pilipenko *et al.*, 2015).

Now we know why researchers were unable to make such a discovery from the data on the modern populations. Over the last millennia, West Siberia was flooded with migrants moving from the west and east, which attenuated the relic structure of the gene pool. However, these late migration flows themselves proved to be an exciting object of research.

Over the last 4,000 years, each of the main migration waves, which were first determined from archaeological and anthropological data, has had its effect on the gene pool of the regional population as well as the material aspects of people's lives. For example, the large-scale wave of migration of the Andronovo (Fedorovo) population, who

The most part of the materials in paleoanthropological collections are skeletal remains, whose most suitable components for molecular genetic analysis are teeth and the long bones of the limbs. Remains of soft tissue and hair are only rarely preserved in particularly favorable environments, such as permafrost or very dry climate, and initially, they were the focus of paleogenetics. Now, soft tissue, unlike bones and hair, are not considered a good source for ancient DNA analysis. Much information can be obtained from coprolites (fossilized feces) but they are rare



Schematic view of the phylogenetic tree for the mitochondrial DNA from the remains of the Andronovo (Fedorovo) culture bearers from Baraba (West Siberia) who had come from different regions of the south of West Siberia. The circle symbols indicate specific structural variants of mtDNA. The size of a circle is proportional to the number of individuals with a particular structural variant of mtDNA. The colors show the association with local groups (see the key). The contour lines show the T mtDNA haplogroup, which serves as a genetic marker of the migration of the Andronovo population to the West Siberian forest-steppe

came here presumably from the territory of Kazakhstan in the first half of the 2nd millennium BC, led to a drastic change in the material culture of the population, who had been developing on local resources for thousands of years. However, the changes at the level of mitochondrial DNA were much less apparent.

We, however, have been able to detect the genetic marker of this migration wave – the T haplogroup – and the changes in the occurrence of some other haplogroups, which is evidence of migration activity in the south of Siberia. However, many of the components of the mitochondrial gene pool remained unchanged. This gives reason to believe that the local population was actively engaged in marital bonding with the alien representatives of the Andronovo culture. Moreover, the first data on the nuclear genome, i.e., the male Y-chromosome, give reason to believe that these contacts were typical mainly of the alien male population and the local female contingent. On the whole, these models can provide data not only about migrations as such but also about the features of the cultural and genetic interactions between different populations.

Southerners on Chicha

Thus, by analyzing the changes in the gene pool, we can infer about the patterns of the territorial expansion and the mixing of the local and alien population. In this sense, of great interest are the results of studying the famous ancient city Chicha 1, also located in Baraba on the shores of Lake Baraba.

The ancient settlement Chicha is a proto-city associated with the transition period from the Bronze to Iron Age: excavation works revealed a clay figurine of a distant ancestor, which was hidden under the floor in a dwelling

At the beginning of the 1st millennium BC, there was a large settlement with streets and a complex system of fortifications in the form of walls and ditches. Archaeologists have found traces of different cultural groups, and the city organization has many features typical of more southern centers of civilization. All this suggests that this city was a hub bringing together different cultures and communities.

We were able to analyze the mtDNA of a small sample of Chicha 1 population. The specimens for the analysis were taken from a nearby necropolis and the skeletons of children who were buried under the floors of many houses in different parts of the settlement. It turned out that the population of Chicha-1 was genetically very different from the previous local population and was close to that of Central and Southwest Asia. Obviously, in this period, Siberia experienced the first echoes of the large-scale population processes that had been initiated in the steppe zone of Eurasia by the early nomads. This conclusion agrees well with the archeological and anthropological data.

Further studies have shown that this "invasion" of the genetically contrasting population from the south was a comparatively lasting process. The Sargatian population of the West Siberian forest-steppe (the second half of the 1st millennium BC to the first centuries of the 1st millennium AD) also proved to be predominantly southerners in origin. Since archaeological evidence suggests that the Sargatians could have born relationship to the Sarmatian world, our next step was to study the Sarmatian populations of the Lower Volga...

All our results suggest that the south of Siberia was an "arena" for key events in the history of many of the peoples inhabiting Central and Northern Eurasia. Now we have initiated a large-scale study of the ancient population of this region using the Y-chromosome markers to obtain data on the male part of the gene pool and, thus make a complete picture. The approach, which has been tested in Baraba, is now used in other regions of Siberia, in particular, the Minusinsk Basin and the Altai Mountains.

Another approach to ethnogenetic reconstructions, which we are now using for the nomads of Eurasia, is the analysis of synchronous materials obtained from vast territories. In this case, we investigate the paleogenetic materials for the nomadic tribes of the early Iron Age, Hun-Sarmatian period, and early Middle Ages, from not only Siberia but also many parts of the Eurasian steppe zone and neighboring regions, from Central Asia to Eastern Europe. We are working on this project together with colleagues from the Johannes Gutenberg University of Mainz (Germany); the German team is led by Prof. Dr. Joachim Burger.

How the female Amazon warrior... changed sex

For archaeologists, it is very important that paleogenetics allows accurate determination of the sex and kinship of ancient individuals.

Previously, the sex of ancient individuals was determined by physical anthropology methods (i.e., skeletal

morphology) and from the analysis of the archaeological context, e.g., the burial inventory. However, these methods have their limitations: e.g., it might be very difficult, sometimes impossible, to determine the sex of a young individual or child from the skeletal remains, or in the case of the poor preservation of a skeleton.

As regards the degree of kinship, it is almost impossible to determine it from anthropological data. Researchers succeeded only in those exceptional cases where the buried individuals had some rare, genetically determined abnormalities of the skeleton. Archaeologists usually make reconstructions using the simplest models of kinship. If they study a burial of a woman and child, then they assume that they are a mother and her child. This was really so in the case of Olon-Kurin-Gol-6 Tumulus 1 (northwestern Mongolia), where this fact was confirmed by paleogenetic analysis (Pilipenko *et al.*, 2010). However, there may be other situations where paleogenetics is the only tool to obtain objective data in this complex and largely speculative field of archeology.

A striking example supporting this view is the results of the study of the skeletal remains from Ak-Alakha 1 Tumulus 1, which were discovered in 1990 on the Ukok Plateau in the Altai Mountains. This paired burial with rich inventory and a full range of weapons contained, presumably, the remains of a mature man and a young girl, both of whom belonged to the elite of the Pazyryk society.

Since the bodies had not been mummified, their sex and age were established from the skeletal remains using physical anthropology methods. The sex of the person buried in the first woodblock, a man aged 45 to 50, raised no doubt, but the individual buried in the second woodblock was a different story... Although anthropologists were convinced that those were remains of a girl aged 16 to 17, they emphasized her "unfeminine" features: "...the skull is very large and looks massive... the lower jaw is very massive... The postcranial bones are very long, almost the same in terms of absolute size and massiveness as male skeleton bones... The body length is very large" (Chikisheva, 1994).

The anthropologists' conclusions were confirmed by the features of the accompanying inventory: the woodblock, the wooden cushion, the quiver, etc.—all these items were smaller in size, compared to the man's burial. In addition, researchers found near the pelvis of the buried person 34 cowrie shells, which might have been belt decorations. Shells were an extremely rare find in Pazyryk graves. They were usually found in handbags together with beads and seeds of exotic fruits; researchers believed that the shells served as amulets. In addition, these shells were known to have a semantics of a symbol of female fertility.

Over the many decades of dedicated research of archaeological sites, archaeologists have accumulated large collections of human remains of different geological age, geographic origin, and cultural affiliation, i.e., with different archaeological contexts. The representatives of ancient population groups have been described, in varying degrees, in terms of their material and spiritual culture, demographics, phenotypic traits, etc. However, this huge array of materials is almost unexplored in terms of molecular genetics

The buried persons also had different hairstyles: there was long dark brown hair on the man's skull, and his forehead and crown were open. On the skull of the second person, there was a little thin braid.

Discovering the burial of this girl—a rider and warrior—became one more argument for the hypothesis that the Pazyryk society may have had a tradition of teaching young girls from the elite prone to the art of war how to use weapons (before they got married), although this was a unique case for the Pazyryk culture (Polosmak, 2001).

However, 25 years later, to clarify the phylogenetic and phylogeographic characteristics, the possible degree of kinship, and the sex of the buried persons, scientists investigated their remains by paleogenetic methods.

The main method was molecular genetic analysis with four systems of genetic markers (mitochondrial DNA, a polymorphic fragment of the amelogenin gene, STR-loci of autosomes, and STR-loci of the Y-chromosome). The investigations were carried out at the ICG (Pilipenko, Trapezov, and Polosmak, 2015).

In the experiments, scientists have obtained ample evidence for the different degrees of preservation of the DNA in the remains of the two individuals. The preservation of the DNA in the remains of the young individual was much lower than in those of the aged man. However, scientists have obtained reliable molecular genetic evidence that both of the individuals from Ak-Alakha 1 Tumulus 1 were male, although these data are at odds with the physical anthropology results for the gender identification of the younger individual.

Scientists believe that "...it could be due to the young age of the deceased individual: gender identification of remains of adolescents from the skeleton morphology may, in some cases, be very difficult." However, the genetic analysis of this individual was not that simple either. The new data were a reason for revising the possible kinship between the buried persons. Previously, researchers believed that this paired burial of an aged man and a young woman was a burial of spouses or a father and a daughter.

Items found in Ak-Alakha-1 Tumulus 1: an earring from the female burial (a wooden plate pasted with gold foil); cowrie shells; a detail of the gorytos; and a felt hat. *Reconstruction of the felt hat by E.V. Shumakova; drawing by Cand. Sci. (History) D.V. Pozdnyakov (IAE)*

Reconstructing the degree of kinship of individuals buried in collective graves or burial sites and determining their sex is one of the most promising areas for the application of paleogenetic methods in archeology. By analyzing uniparental inheritance markers (mtDNA and Y- chromosome), we determined the probability of close kinship between the individuals from the paired burial in both the female and male lines. The data on the profiles of autosomal STR-loci show that the investigated individuals were not direct relatives; in this case, taking into account the sex of the buried, they could not have been father and son (Pilipenko, Trapezov, and Polosmak, 2015).

Having established a sufficiently close kinship between the buried persons (they could have been uncle and nephew), the geneticists have confirmed the conclusions made in 1994 by Balueva, who created reconstructions of the faces of the two individuals: "From the front, the noses of the man and woman from the Ak-Alakha 1 burial site are very similar... The chins of the male and female skulls are very similar in shape."

Another piece of evidence for the close kinship of the individuals was the similarity of the pathological processes in the cervical vertebrae, which was reported by Balueva: "...the man had spondylosis of the cervical vertebrae, which obstructed the head movement; in the female skull in the area of articular condyles of the occipital foramen, there are traces of the same deformation processes that we have mentioned above. The identical signs of illness may indicate a kinship of those buried in the mound."

There is another striking fact: by the time of his death, the older man had long been a sedentary disabled person, unable to get on a horse on his own. According

to Chikisheva, his skeleton had signs of severe damage with one of the varieties of chronic polyarthritis: "The general pathological process involves almost the entire osteoarticular apparatus... the disease of the deceased individual can be identified as ankylosing spondylitis, also known as Bekhterev's disease... The etiology of the disease is unknown... The disease affects mostly males and begins in the second or third decade of life." His death could have been due to the development of the disease. As to the cause of the young man's death, neither anthropologists nor geneticists have been able to find it yet.

Today, the methods and approaches of paleogenetics have become a powerful tool with which archaeologists can trace the actual demographic processes in ancient populations. Moreover, researchers can use them to obtain or update information about specific individuals in those cases where the conventional methods of archeology and anthropology are not successful, which has been proved by the works of the interinstitutional team of paleogeneticists from Akademgorodok.

From the perspective of genetics and archeology, it is equally relevant and promising to study the molecular-genetic mechanisms of human adaptation both to the natural environment and to the level of economic development and material culture. Indeed, it is important to know how people in Siberia were adapting to the harsh climatic conditions and to the changes in dietary patterns related to their cultural development. For example, now we are engaged in a study of the lactase gene, which is responsible for the ability to digest lactose in adulthood.

No less interesting are reconstructions of the phenotypic parameters of ancient population representatives, e.g., a particular pigmentation of eyes and hair. Currently, paleogenetics offers ever more opportunities for the reconstruction of the "portraits" of ancient humans in the literal and figurative sense.

In addition to human remains, our team pays particular attention to the study of the remains of animals from archaeological sites. Currently, there is a large-scale research program focusing on the remains of domesticated animals in the south of West Siberia, which is expected to shed light on the penetration and use of domesticated animals by the ancient populations of Siberia. Equally promising is the study of the remains of wildlife species used by ancient humans in their economic activities.

The implementation of such a wide range of research projects has only been possible thanks to the close integration of the efforts of the multidisciplinary team created by the IAE and ICG, who collaborate at all stages of the works. Thus, the staff of the Interinstitutional Center of Molecular Paleogenetics take part in the expeditions organized by the IAE to obtain new materials with maximum caution and better understand the specific features of ancient groups. We strongly believe that the development of the int erinstitutional team towards closer integration of the efforts of professionals with different backgrounds will lead to new fascinating discoveries in the history of the Siberian population. The paleogenetic research at the IAE and ICG is sure to have a bright future.

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H. PARZINGER, A. GASS, J. FASSBINDER

The latest geoarchaeological and geophysical studies

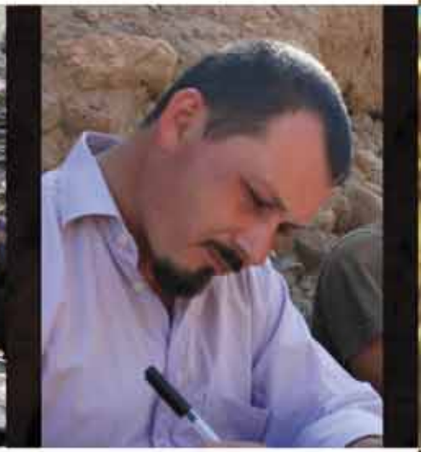
AT the Foot of ROYAL KURGANS

Above: small plowed mounds against a large kurgan. Vinogradny-1 necropolis (Stavropol krai, Northern Caucasus). *Below:* Alexandropol kurgan encircled by a ditch *(lower reaches of the Dnieper, Ukraine). View from the west (Polin, Daragan, 2011, Abb. 2)*

Tens or maybe even hundreds of thousands of burial mounds in the Eurasian steppes are silent witnesses to the past. Nobody knows their exact number since more and more new kurgan sites are discovered every year. Burial mounds were constructed throughout the Eneolithic Period and the Bronze Age (4th to 3rd millennia BC) to the Early Middle Ages. However, most of the burial mounds that remain today could be dated to the first millennium BC or to the Early Iron Age.
The majority of the Early Iron Age kurgans were built by the members of the Scythian-Saka cultural-historical community, who lived in the Eurasian steppe and in forest-steppe zones, from the Middle Yenisei in the east to the Middle Danube in the west, from the early 9th–late 8th century BC to the 3rd–2nd century BC. Burial mounds of a large size stand out among the so-called Scythian kurgans. Rising above the regular steppe landscape, the large kurgans served as landmarks to the travelers; besides, they were boundaries of the territories belonging to different communities of the ancient nomads

Key words: Early Iron Age, kurgan, periphery, Scythians, Saka, geophysics, cesium magnetometer

Large Scythian kurgans (also called “elite” or “royal”) are more than just simple burial mounds. For the ancient communities they were meeting places used for tackling vital problems, for commemorating the ancestors, for sacrificial offerings to gods during religious ceremonies and for various other celebrations; in other words, the mounds were used as a kind of temples and ceremonial places. In fact, the kurgan-temple and surrounding areas could be considered a place of cultural self-identification of ancient nomads. Not without reason did the Scythian king Idanthirsus respond to the challenge from the Persian king Darius, saying that Scythians had neither towns nor cultivated land, that they were not afraid of ruin or devastation of their lands. But “if you [Persians] desire to fight us [Scythians], mind that we have here graves of our



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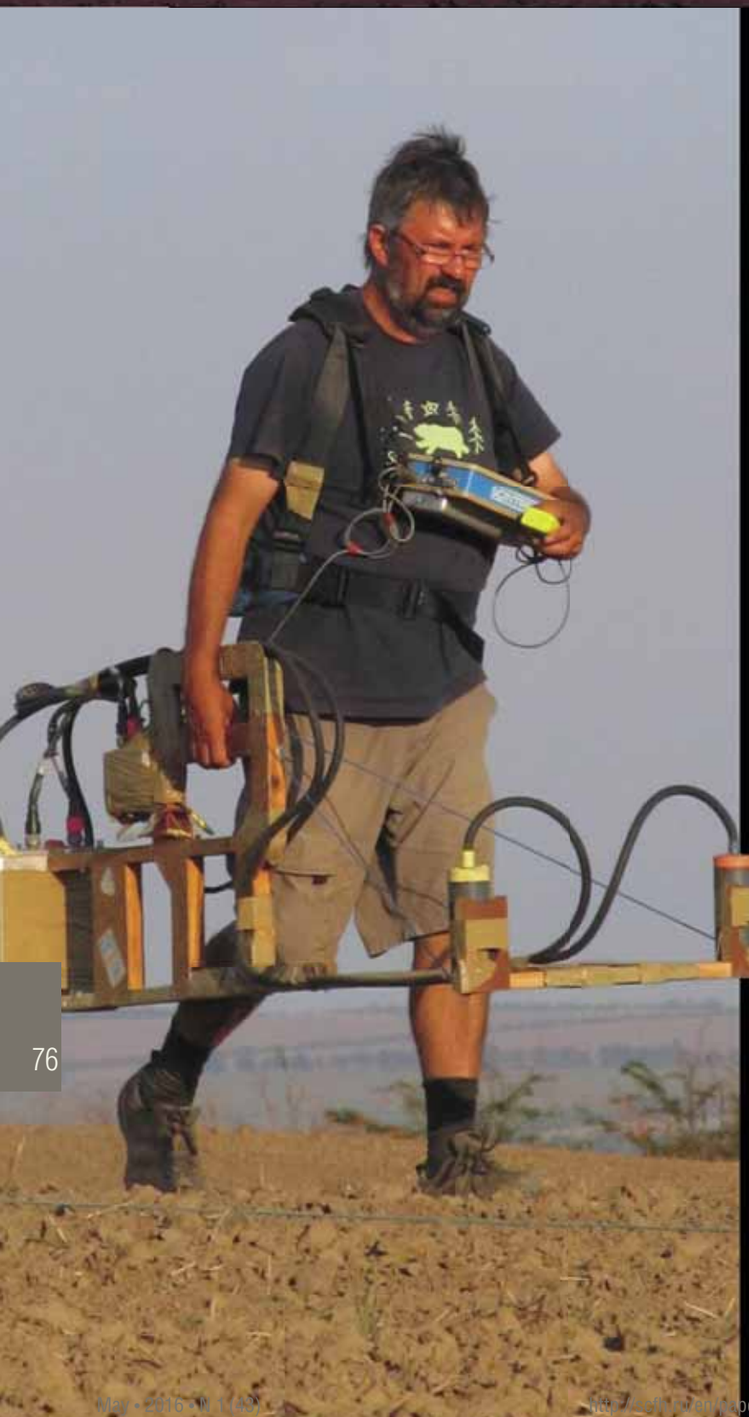
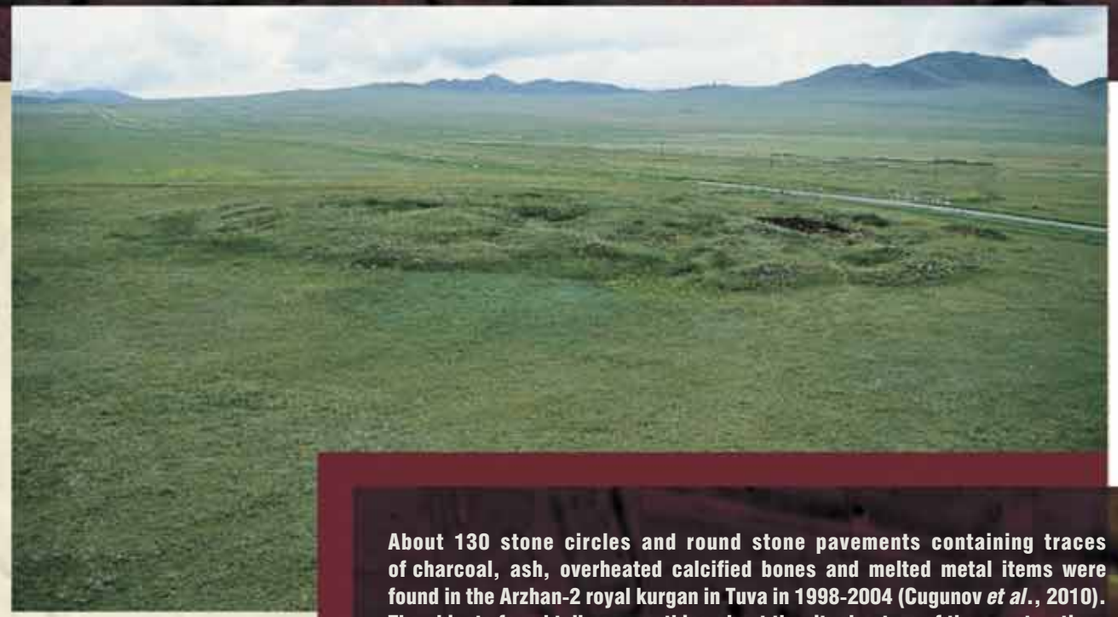
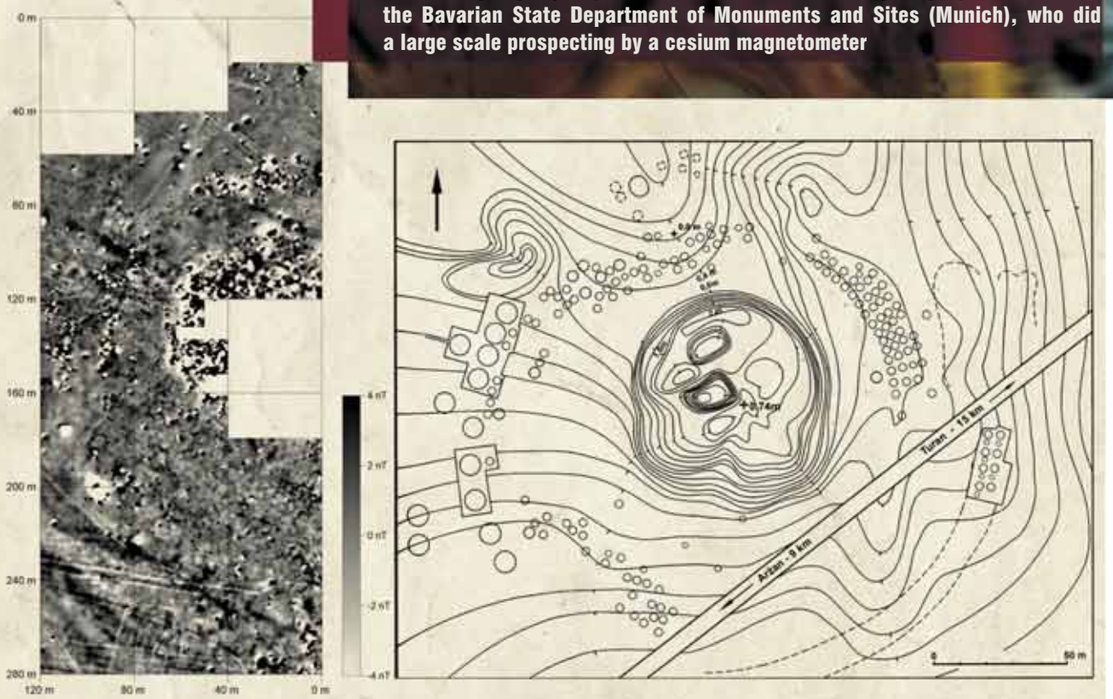


Golden objects from the Arzhan-2 kurgan (Tuva).

Left: Jörg Fassbinder performs magnetic prospecting.
Below: plan of the mound and the magnetogram made in 1998.
The size of the square is 40×40 m.
The North is on the right.
The magnetic dynamics is ±3.0 Nanotesla from black to white.
Adapted from: (Čugunov et al., 2010, Abb. 17, 23)



About 130 stone circles and round stone pavements containing traces of charcoal, ash, overheated calcified bones and melted metal items were found in the Arzhan-2 royal kurgan in Tuva in 1998-2004 (Cugunov *et al.*, 2010). The objects found tell us something about the ritual nature of the constructions around the large kurgan, though to find their exact chronological correlation appears impossible. Part of the constructions around the Arzhan-2 kurgan were visible above the surface before the excavations. To obtain a complete picture of the kurgan periphery, it was decided to involve expert geophysicists from the Bavarian State Department of Monuments and Sites (Munich), who did a large scale prospecting by a cesium magnetometer



fathers. Find them and try to destroy them and you will know whether we will fight for those graves or not" (Herodotus, Book 4, § 127).

In the 18th to early 20th centuries, it was widely assumed that the aboveground, visible part of the mound had been made by spreading soil in a heap. However, according to the modern knowledge about kurgan burial mounds, this opinion is not entirely correct. Today, we know that the monumental burial mounds of ancient nomads are complex architectural constructions built of various materials according to a prearranged plan.

Previously, we also discovered ramparts, rings of stones, small mounds of rocks and ditches around the large mounds. All those elements are objects of the kurgan mound periphery that played an important role during the construction and after the completion of the burial. Perhaps, a ditch, a rampart, or a ring of stones marked the boundary of the burial mound, which had the sacred duty to separate the world of the living from that of the dead (Mozolevsky and Polin, 2005). The remnants of commemoration feasts allowed archaeologists to conclude that various religious ceremonies were held on the periphery of the mound. This is confirmed both by the ancient written sources, for example, by Herodotus' narration about royal funeral feasts at the mounds (Herodotus, Book 4, § 72), as well as by the results of the latest archaeological excavations of such large kurgans as Arzhan-2 in Tuva (Southern Siberia) and the Alexandropol kurgan (Lugovaya Mogila) in the lower reaches of the Dnieper River (Ukraine) (Čugunov *et al.*, 2010; Polin and Daragan, 2011).

Similar signs of the intensive use of the space around the large kurgan mounds by the Early Iron Age nomads in different places

Ditch around kurgan 4 on the Kegen plateau (*Southeastern Land of Seven Rivers, Kazakhstan*)

Conducting geophysical measuring with a cesium magnetometer on the inclined surface of the large mound slope of the Vinogradny-2 burial grounds *(Stavropol krai, Northern Caucasus)*

that lie far from each other, provoked us to study the kurgan periphery of other Scythian-Saka sites in the areas between Arzhan-2 burial grounds and Alexandropol kurgan. Taking into consideration the huge size of the area of our interest, studies were carried out selectively, at a number of sites in Southeastern Semirechye (Land of Seven Rivers), Western Kazakhstan and North Caucasus (Stavropol krai).

To carry out these studies, we decided to consign the geophysicist Jörg Fassbinder and an expert on archaeogeophysical prospecting who had done similar research in these areas (Fassbinder, 2009; Korobov *et al.*, 2014). The geophysical approach was essential in this study because it allowed us to obtain, very quickly, detailed information about the structure of the kurgan periphery beneath the soil and about the burial ground as a whole. Using a highly sensitive cesium magnetometer, we were able to generate a magnetogram image that was very similar to a computer tomogram or an X-ray image of the subsurface. This magnetogram reveals even the weakest and smallest magnetic differences in the soil down to a depth of about 3 m and uncovers even the smallest archaeological structures. As a result, it was possible to draw a detailed archaeological map of all the ancient features beneath the ground caused by former and ancient digging and covering pits, by old building hollows, by stone constructions, as well as to detect kilns or fireplaces and any other traces of human activities. It was also possible to detect traces of natural phenomena such as ancient river beds or lightning strikes.

To sum it up, magnetometer prospecting enables archaeologists to obtain information about any constructions on the periphery of the mound that are not visible from above the ground. This makes the fieldwork for archaeologists much easier. Of course, the results of the magnetometer measurements itself cannot replace a dating method and thus cannot prove whether the sites under study belong to the same or to another period. This can be done only by means of archaeological excavations.

Issyk burial grounds against the background of the Trans-Ili Alatau Mountains (*Southeastern Land of Seven Rivers, Kazakhstan*)

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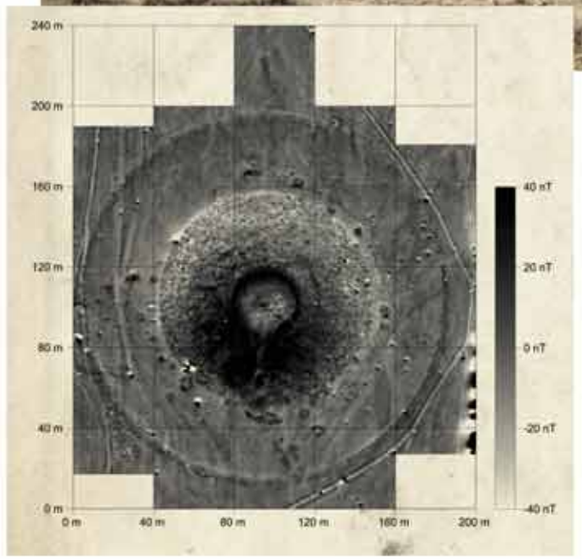


Kurgan 1 of the Žoan Tobe burial grounds. *Southeastern Land of Seven Rivers. View from the east. Right:* a ritual road around the kurgan (eastern sector). *Kurgan 1 of the Žoan Tobe burial grounds. Photo by R. Boroffka*

Magneto-gram of kurgan 1 of the Žoan Tobe burial grounds and the periphery, 2008. *The size of the square is 40×40 m. The North from above. Greyscale dynamics is ±40 Nanotesla from black to white. Magnetic prospecting was done by J. Fassbinder and T. Gorka*

In the land of seven rivers

In 2008–2009, the first step in the archaeogeophysical study of the kurgan periphery was made in Southeastern Kazakhstan, in a place called Land of Seven Rivers, which is mostly known for the impressive discovery of "The Golden Man," a Saka warrior from the Issyk mound near Almaty. Most "elite" kurgans in this region are located in steppe plains, at the foot of the Tian Shan, along the Trans-Ili Alatau. The research materials from the Land of Seven Rivers mounds became known to the scientific community back in the 1960s–1970s, but no attention was paid to the periphery of the mounds because the area around the kurgans had been significantly damaged by repeated plowing.

While examining the sites of southeastern Land of Seven Rivers, we paid attention to the ditches, ramparts and stone rings around the large mounds that were located singularly or in groups. Of particular interest were the double stone rings located at a distance of 0.5 to 5.0 m from each other, with single middle-sized river pellets between them. The periphery of one of those large kurgans was studied in the framework of the joint Kazakhstan-German expedition headed by Z. Samashev (Kazakhstan) and by H. Parzinger and A. Nagler (Germany). It was the largest and, presumably, major mound among the nine kurgans of Žoan Tobe burial grounds located to the east of Almaty.

The double stone rings were located at a distance of 33 m from the foot of kurgan 1, the distance between them being 3.0 to 3.5 m so that the overall diameter of the construction reached 185 m. In the area between the double rings and the foot of the mound, we also discovered 28 round stone constructions—small mounds with a diameter of 4 to 7 m. Some of them were visible on the surface, but their total number was found owing to the geophysical survey.

Later, it became clear that such smaller stone mounds had been made over burial pits for one single person, but since no burial instruments were found, only radiocarbon analysis could help in dating the bones. The analysis of a phalanx from one of the graves allowed us to date it the 10th–11th centuries BC, which means that at the foot of the large Saka kurgan of the 5th century BC there was at least one burial mound of the early Turkic period, the period of Kara-Khanid Khanate. Whether the other 27 smaller kurgans were constructed in the Early Middle Ages or much earlier is the matter of further studies.

The double stone rings were studied by two trench excavations in the northern and eastern sectors. As shown by the excavations, the stone rings were the elements of one construction—a sort of bordering for the central part rammed and cobbled with middle-sized paving stones. This foundation was covered with a layer of compacted clay mixed with fine gravel. The higher central part of the construction provided excellent water drainage during the rains. Thus, the whole construction could be generally identified as a road.

Since the road stretches around the mound, it is likely to have been built for ritual purposes by the Saka tribes who inhabited this region in the Early Iron Age. Unfortunately, it is impossible to say whether it was built before the construction of the mound or later. Nor is it possible to be quite certain that it was built by the Sakas since

Human skeleton and sculp from a small Early Turkic kurgan at the foot of the large Saka kurgan 1 of the Žoan Tobe burial grounds. *Photo by R. Boroffka*

no items characterizing the time of its construction were found. Yet, the results of studying all the periphery elements of large Scythian-Saka mounds in the steppe and forest-steppe of Eurasia testify to the fact that "ritual roads" were a part of sacred constructions that encircled the burial mounds of ancient nomads.

Similar circular "roads" were discovered at around 18 kurgans of the nine Saka burial grounds located in the foothill areas and in highland valleys of Trans-Ili Alatau in the southeastern Land of Seven Rivers. The scale of the construction was always proportional to the scale of the mound. So far such "ritual roads" have not been found anywhere else in Eurasia within the spread of Scythian-Saka cultural-historical community (Gass, 2011; Nagler, 2013).

Pyramids of the steppes

Going back to Žoan Tobe burial grounds, it is necessary to mention the second largest mound in the eastern chain, shaped as a truncated pyramid, with its slopes oriented to the cardinal points. Similar "steppe pyramids" were discovered in other kurgan chains of the same necropolis. Ten different burial grounds in the southeastern Land of Seven Rivers have 16 square-shaped kurgans with pyramidal mounds and flattened tops. The "ritual roads" constructed around such mounds were also designed in a sub-square shape.

Before our research in the Land of Seven Rivers, similarly shaped mounds were known only in South Siberia (in the Republic of Khakassia and in the south of the Krasnoyarsk krai), where the Tagar culture of the Scythian world had existed. Another square-shaped ditch was found around Scythian kurgan 22 near the village of Volchansk in the Utlyuk Interfluve, north of the Azov Sea. However, as the mound itself had been heavily plowed, it was impossible to reconstruct the initial form (Mozolevsky and Polin, 2005). All this allows us to suggest that large mounds of a square pyramidal shape were constructed by ancient nomads not only in Siberia, but also in Central Asia.

Obviously, the shape of the mound was not accidental, though we cannot give a satisfactory explanation for it yet. The excavations on the site of a similar square shaped mound in the Žoan Tobe burial grounds could not clarify the problem either. Heavily plowed, kurgan 8 seemed to be round, but the geophysical survey revealed clearly that initially it had a square shaped monument. To prove this, we studied a neighboring burial mound, kurgan 9, which turned out to have had a classic rounded shape of the Scythian-Saka burial mound. Regrettably, these kurgans are so heavily damaged that we could not identify any details indicating the reasons for building structures of such different shapes.

Luckily, not all of the ancient kurgans' mysteries remain unraveled. Thus, in 2008, exploring the highland plateau Kegen near the Kazakh-Kyrgyz border, we found a single large mound of the Saka period on the Kazakhstan side; it was based on a one-meter-high square platform with rounded corners, the total height of the construction was 13 m. A topographical mapping by a GPS and an overlay with the satellite image, showed five curious star shaped "rays," which were 8 to 10 m wide and ca. 60–100 m long, extending from the mound west and north. The subsequent geophysical measurements revealed, however, only the traces of the ancient construction activity, but no construction themselves: the cesium magnetometer measurements were able to clarify the situation. We really saw "the rays" only in the satellite image!

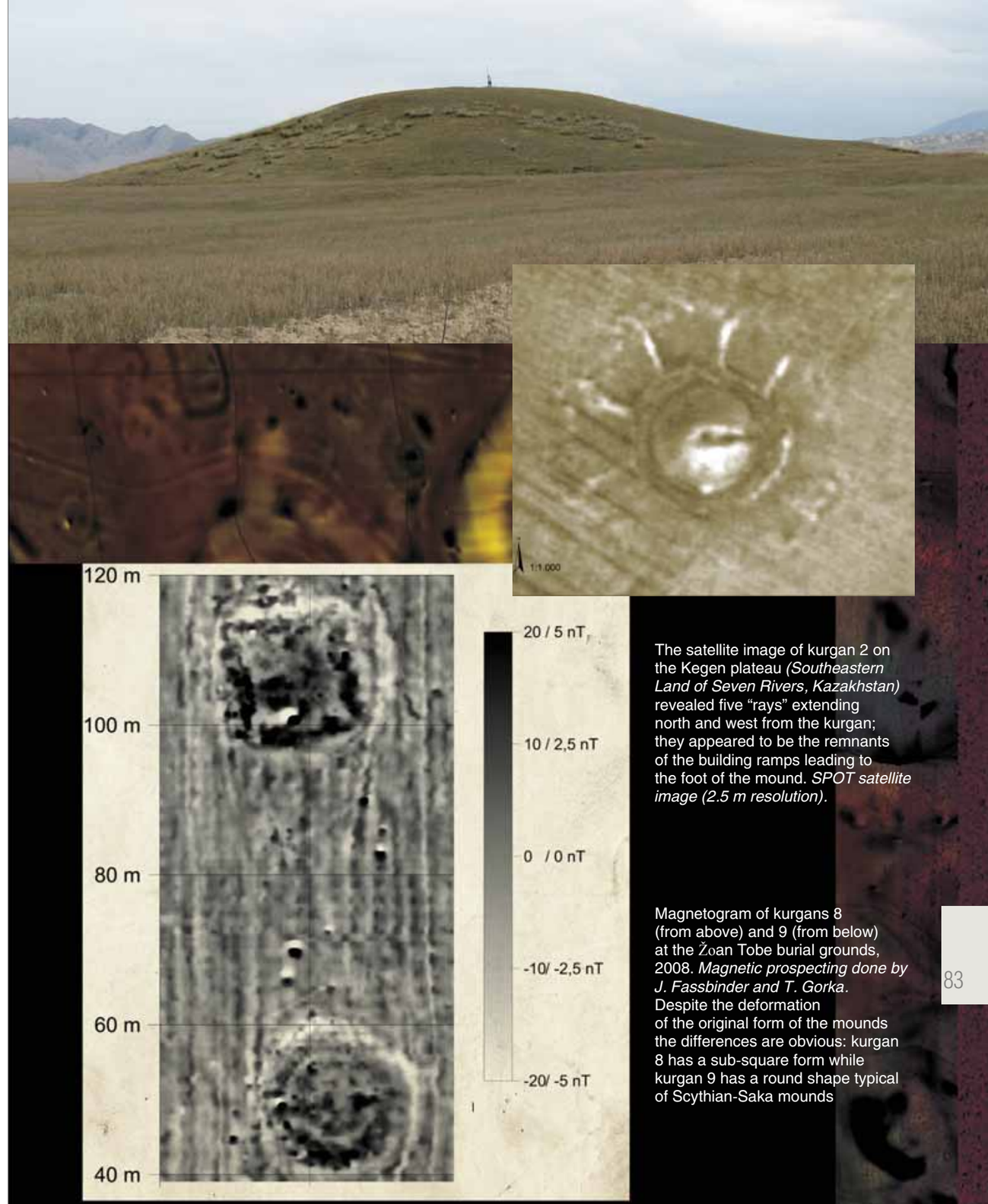
Three excavations in the northern part of the periphery helped to solve the mystery of this situation. The five "rays" were the remnants of building ramps leading to the basement and to the foot of the mound. The earth from the "ray" area was used as building material to construct the mound; after the construction was completed, those ramps were not destroyed. So, the diameter of the whole construction of the mound turned out to be at least 330 m. Perhaps, previously, such ramps had also extended east and south, but intensive plowing completely destroyed all of their traces.

The huge and large burial mound, kurgan 2 on the Kegen plateau, was once, certainly, very impressive, both in size and bright colors: the green of the steppe, the dark black color of the soil, and the yellow color of the loess and clay of the "rays" against a crystal clear blue sky above the Tien Shan. All three elements of the kurgan—the ramps, the platform, and the mound—made it an extraordinary monument, which impressed travelers for over 2,500 years, and it is still impressive today. While Scythian-Saka mounds based on the platform have single analogs in the foothills of Tarbagatai, Eastern Kazakhstan (the Aksuat burial grounds; Samashev *et al.*, 2010) and in Northern Caucasus (Asiatsky Kurgan), the traces of building ramps at the mounds of ancient nomads are actually unique.

The kurgans of Semirechye keep many other secrets and archaeological mysteries, but our interest in exploring the periphery of large mounds inspired us to move further, following the Saka trail towards the "sunset."

Looking to the west

In 2010, Zeynolla Samashev (Astana) drew our attention to the Tört Oba burial grounds near the village of Zhirenkopa in the northwest of the Aktobe oblast (Kazakhstan), located near the border with the Orenburg oblast. The burial grounds include five mounds forming a line from west to east. Each kurgan was surrounded



The satellite image of kurgan 2 on the Kegen plateau *(Southeastern Land of Seven Rivers, Kazakhstan)* revealed five "rays" extending north and west from the kurgan; they appeared to be the remnants of the building ramps leading to the foot of the mound. *SPOT satellite image (2.5 m resolution)*.

Magnetogram of kurgans 8 (from above) and 9 (from below) at the Žoan Tobe burial grounds, 2008. *Magnetic prospecting done by J. Fassbinder and T. Gorka*. Despite the deformation of the original form of the mounds the differences are obvious: kurgan 8 has a sub-square form while kurgan 9 has a round shape typical of Scythian-Saka mounds

by a ditch, the kurgans located so close to each other that some ditches joined and partly crossed one another.

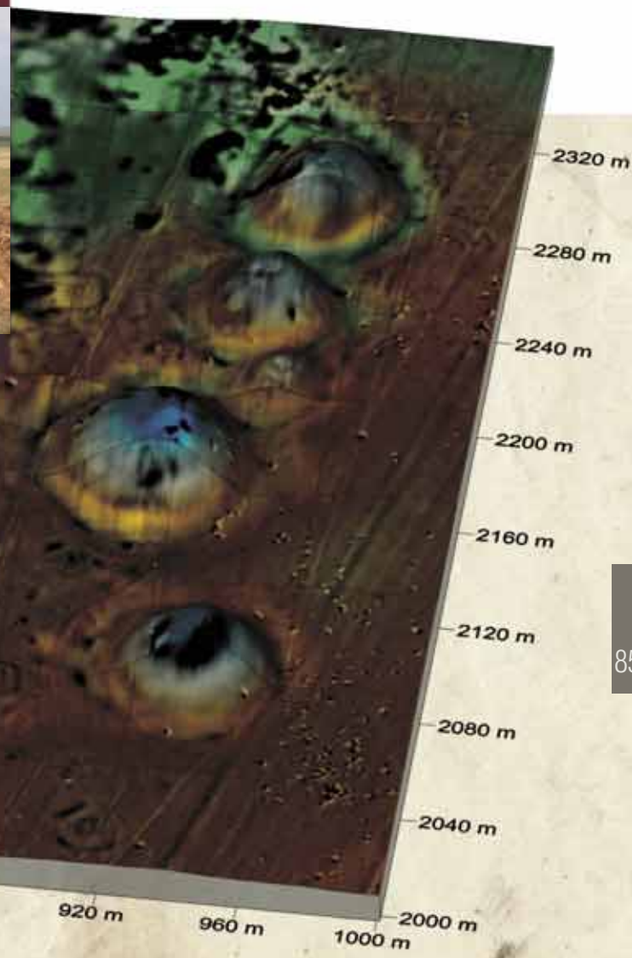
The 2011 results of the geophysical prospecting of the kurgans' periphery exceeded all expectations. Many small mounds not visible on the surface, single graves, ritual pits and sacrificial complexes were detected around every kurgan. Moreover, on the south side of each kurgan, we detected a rectangular ditch construction beneath the soil. Such features were previously unknown to science; the size of the ditch was ca. 13 × 39 m, extending from north to south. The excavations of the periphery of the easternmost kurgan discovered sacrificial complexes with the remnants of ceramics, items of harness and a bronze cauldron. Here we also studied a number of burial mounds.

The examination of the rectangular construction of an unknown purpose showed that the ditch was 1.0 to 1.8 m deep with a bottom width of 1 m. The material which filled the ditch contained ash, wood charcoal and animal bones arranged in a particular way. Since no traces of the ditch dislodging were detected, it was concluded that the ditch had been filled by ancient builders after a short-term use. Obviously, we can talk about a ritual construction erected for a particular ceremony held at the foot of the kurgan. The results of the radiocarbon dating of the animal bones demonstrated that the whole structure had been created at the same time as the mound (7th–5th century BC).

The 2011 test magnetic prospecting of the neighboring Besoba burial grounds gave a magnetogram image nearly identical to the one of the previously studied necropolis. The natural question was whether the ritual platforms constructed by the ancient nomads on the southern periphery of the large Scythian-Saka burial mounds for certain religious beliefs and ceremonies were a local variation typical only of Western Kazakhstan and the bordering the Orenburg oblast, or we have simply not yet discovered such constructions due to the lack of knowledge about the periphery of large kurgans. Surprisingly, the answer to this question was found in Northern Caucasus.

Scythians of Northern Caucasus

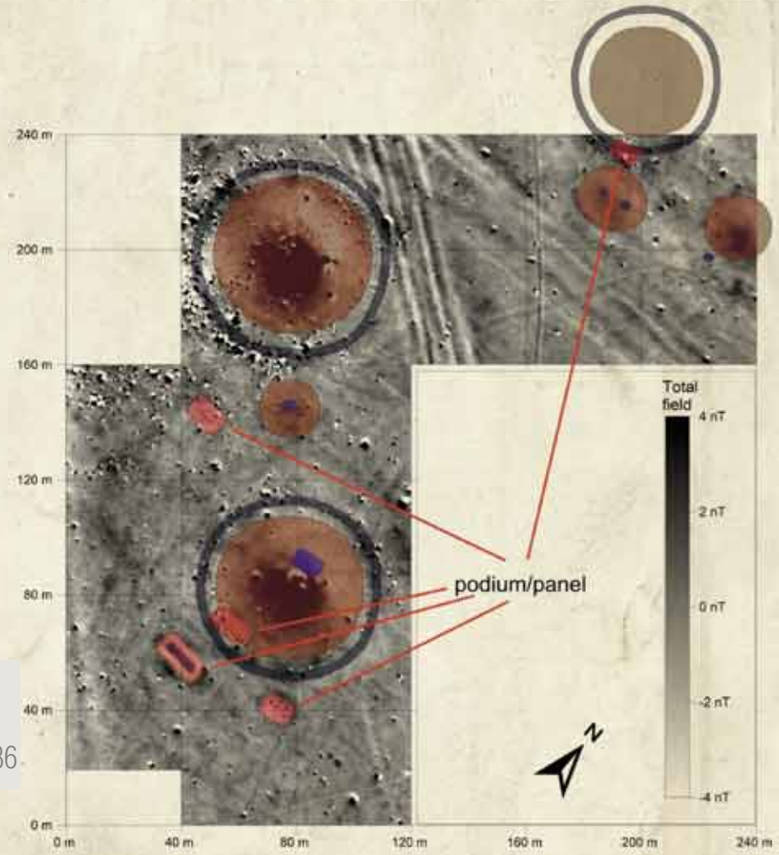
From 2012 our research group participated in the joint Russian-German archaeological expedition in Northern Caucasus (Stavropol krai) together with the SUE Heritage headed by A.B. Belinsky (Russia) and by H. Parzinger and A. Gass (Germany). While planning our activities we also used every chance to go and observe unfamiliar sites. One of them was Zunkar-2 burial grounds in the Nogai steppe in the easternmost part of the Stavropol krai.



Tört Oba burial grounds in the Aktobe oblast (*western Kazakhstan*) are formed by five mounds encircled by ditches and located very close to each other. *View from the north-west (above)*

*3*D-model of the Tört Oba burial grounds displays small mounds, ritual pits, as well as stretched sub-rectangular constructions of unknown purpose. *The model was made by J. Fassbinder, who superposed the magnetogram onto the topographical map*

Sub-rectangular construction south of the eastern kurgan of the Tört Oba burial grounds reveals its ritual character. *Photo by R. Boroffka*



Magnetogram of the Zunkar-2 burial grounds and its interpretation showed ditches around large mounds, additional small kurgans, pits of unknown purpose, and sub-rectangular constructions similar to the ritual platforms near the Saka kurgans in western Kazakhstan. *Magnetic prospecting by J. Fassbinder and I. Hofmann*

Prospecting of the Vinogradny-1 and Vinogradny-2 burial grounds with a cesium magnetometer (*Stavropol krai, Northern Caucasus*)

The first impression of the necropolis was like a *déjà vu:* it was as if we were on the famous Issyk burial grounds in Semirechye again; the only thing missing would be the Trans-Ili Alatau mountain ridge on the horizon. In fact, we were able to start exploring the Nogai steppe only in the spring of 2014.

Zunkar-2 consists of three kurgan chains aligned from north to south, each including 5 to 10 mounds. It is located on a small hill protected from melt water during spring floods. To the north of the necropolis, there is a field where earlier there were small mounds now completely ploughed down. Along the border between the steppe and the field, there is an electric power line causing heavy interference in the magnetic signal; as a result, the magnetometer was applied only to the southern area of the burial grounds, which included three mounds of 30–50 m in diameter and one smaller mound.

The magnetogram image of the necropolis showed that the large mounds were surrounded by ditches, and that there were additional small mounds and several pits of unknown character. Of particular interest were sub-rectangular constructions to the south of the large mounds, which were quite similar to the constructions found in western Kazakhstan. However, there were a number of external differences between similar constructions in north-eastern Caucasus and commemoration platforms in the Aktobe oblast. The rectangular constructions of Zunkar-2 were much smaller (the size being 10×15 m and 10×20 m) and oriented east–west, i.e., along the mound rather than north–south, as in Tört Oba and Besoba.

Since no search boreholes or trench excavations on the periphery of the large mounds of the Zunkar-2 necropolis have yet been made, one cannot say for sure whether the periphery rectangular constructions of these kurgans are similar to the ritual platforms near the Saka kurgans of western Kazakhstan. For the same

Magnetogram of the Vinogradny-1 burial grounds, 2012. Zooming in on the horseshoe-shaped and round ritual constructions. The magnetic intensity and characteristics of the magnetogram reveals that the constructions and the ditches were exposed to high temperatures of man-made fires or contain ashes

reason we cannot say whether these constructions were erected at the same time as the mounds. But the fact of their discovery, similarity of the shape and the location of the large mound on the periphery allow us to presume that the religious beliefs of the Early Iron Age nomads both in the Nogai steppe and in the western Kazakhstan steppe were the same, and they practised similar burial rituals. We will be able to know if this is true only after excavating the periphery of the Zunkar-2 mounds.

Thus, throughout the Eurasian steppe belt, from Tuva to Northern Caucasus, almost every investigated Scythian-Saka necropolis with burial mounds of the ancient nomadic elite showed the traces of intensive cultic activity embodied in various constructions on the kurgan periphery. It can be assumed that throughout the Eurasian steppe and forest-steppe every large mound of the Scythian period had a spot of "intensive" ritual activity on the periphery.

The 2012 results of geophysical measurements of the Vinogradny necropolis (Stavropol krai) became a vivid confirmation of this assumption. The Vinogradny 1 kurgan is composed of one large kurgan (5.4 m high and 58 m in diameter) and at least 14 smaller burial mounds. As the entire burial grounds are arable land today, only the large mound remains untouched while its foot and the encircling ditch are significantly damaged.

The magnetometer measurements of the necropolis revealed again outstanding results: not only the area around the kurgan, but all the area of the burial grounds (5.2 hectares) was densely covered with the objects and constructions on the periphery. We found many small mounds not visible on the surface, semi-circular extensions of large mounds with ditches, pits, single burial mounds, horseshoe-shaped and round constructions of unknown purpose. Besides, there was a system of rectangular ditches connected with each other and forming a kind of fence with catacombs inside, which has parallels with the Alan period burial mounds in the Kislovodsk hollow (Korobov *et al.*, 2014). Some of these constructions were identified as ditches filled with organics, ash and wood charcoal. Whether there had been a fire in the ditches or only highly magnetic ashes, is hard to say if we rely only on the magnetometer data. According to the radiocarbon dating, at least one of these constructions, the horseshoe-shaped ditch, was erected in the Scythian period of the Northern Caucasus history, which links it with the large mound of the burial grounds.

As for the rest of the cultural-religious constructions, it is difficult to identify their age without excavations. The only exception is the central burial mound of the kurgan with an extension in the southern part of the necropolis; examining its bone material made it possible to date it the end of the 4th millennium BC. Thus, we can imagine a picture of ritual activity in the limited area, connected with the burial cult, covering the period from the Early Bronze Age (Maykop culture) to the Early Iron Age (Scythian period) and, possibly, to the period of the Middle Ages (Alan culture).

However, quite a different use of the mound periphery was discovered at the Vinogradny-2 necropolis, located 3 km from Vinogradny-1. These two burial grounds are very much alike, though Vinogradny-2 includes nearly 80 mounds, and its "royal" mound is larger. Starting the geophysical prospecting of the necropolis, we expected to surpass the results obtained in Vinogradny-1. But except the clear outline of the ditch around the large mound and the plowed ramp encircling it, as well as several small mounds and grave pits at the foot, the periphery of the mound turned out to be almost "empty." The periphery of the large mound of the Vladimirovka necropolis to the east of Budennovsk was also "empty."

Thus, we discovered two different types of ritual use of the periphery of large mounds in Northern Caucasus. Without carrying out excavations, it is impossible to determine if this was due to the social status of the buried, to sex or age differences, or to their cultural differences, to say nothing about the chronology of constructions. Despite the many years of our efforts there is still a long way to go, and the Scythian kurgans in the boundless steppes of Eurasia will still keep their secrets...

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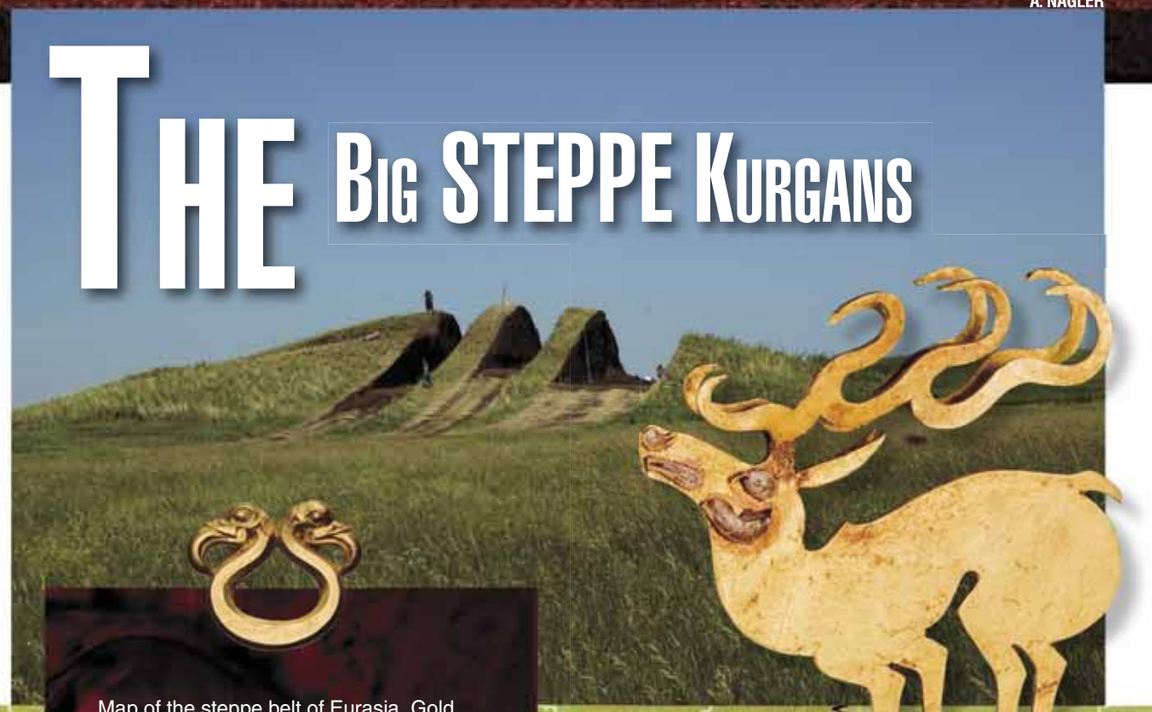
A. NAGLER

THE BIG STEPPE KURGANS AS ARCHITECTURAL MONUMENTS

The steppes of Eurasia, a wide belt stretching from the Central Asian plateau, the Ordos, in the east to the Danube in the west have been inhabited, throughout the whole history of mankind, by numerous tribes and nations. Burial complexes or, as they are commonly referred to, kurgans are a striking illustration and often the sole evidence of their unique and expressive culture that reached our time. The mounds grouped in bigger or smaller clusters are the most numerous archaeological monuments on the continent and in the course of the past thousands of years have turned into an integral part of the steppe landscape. Yet, in the last two hundred years a great number of these unique burial architectural monuments have been irretrievably lost



Map of the steppe belt of Eurasia. Gold jewelry from the Arzhan 2 Tumulus: top part of the male headdress from the “Great” tomb and a golden torque covered with relief images of horses, deer, camels, goats, and feline predators, which belonged to the man from the “Great” tomb.

Top right: Arzhan 2 Tumulus *(Tuva)*

Key words: Eurasian steppes, *mounds, tumulus, excavation methods, Baikara, Arzhan, Barsuchy Log, gold, finds*

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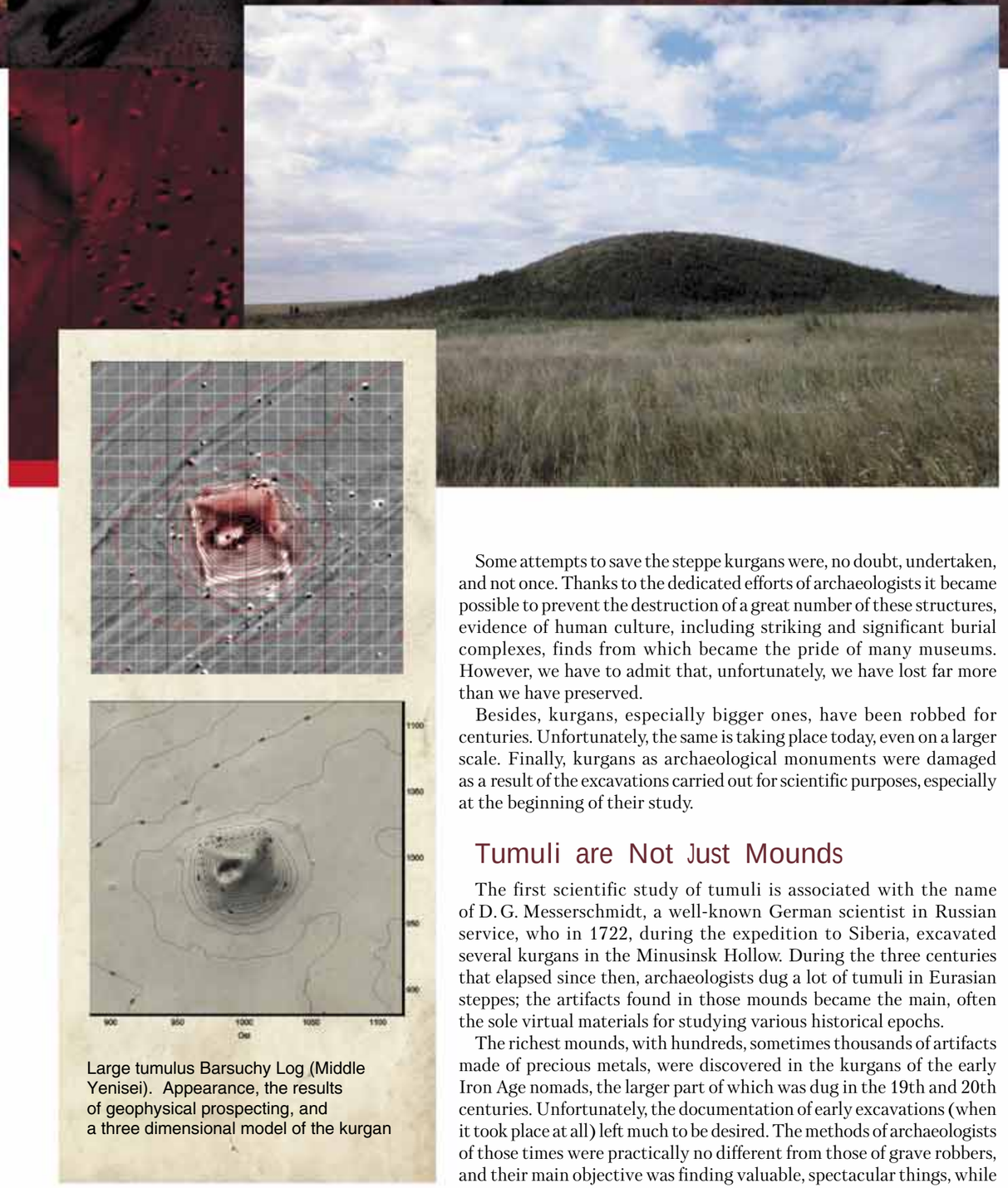
Above: Large tumulus Baikara *(Northern Kazakhstan)*.
Below: Golden plaque in the shape of a bird of prey and stone sinkers for a fishing net, found on the edge of a burial pit of the Scythian time.
Large tumulus Baikara (Northern Kazakhstan)

The number of tumuli in the Eurasian steppes may reach many thousands. German archaeologist H. von Merhart, one of the first discoverers of the archaeological treasures of "the big steppe," described the monuments of the past found in the steppes of the Middle Yenisei as far back as in the early 20th century as follows: "... one mound, another, followed by a long row of mounds, then another field studded with black hailstones – then another mound – more and more graves, yet another field with burial grounds after other burial grounds stretching for miles..." (Merhart, 1926). The same, or similar, landscape was typical of the whole Big Steppe, its European and Asian parts.

When these areas were included in the Russian state, they became involved in active economic activity which caused the destruction of many tumuli. By the second half of the last century, the scale of destruction had become tremendous: dozens of thousands of mounds were demolished, made even with the ground and ploughed up. In Siberia, Kazakhstan, Northern Caucasus, Ukraine, Moldova, and in other regions the tumuli were destroyed as a result of the so-called development of virgin lands or else as a result of gigantic land melioration construction work. Everywhere, the building of large and small water reservoirs, roads and other projects led to the destruction of tumuli.



Large tumulus Barsuchy Log (Middle Yenisei). Appearance, the results of geophysical prospecting, and a three dimensional model of the kurgan

Some attempts to save the steppe kurgans were, no doubt, undertaken, and not once. Thanks to the dedicated efforts of archaeologists it became possible to prevent the destruction of a great number of these structures, evidence of human culture, including striking and significant burial complexes, finds from which became the pride of many museums. However, we have to admit that, unfortunately, we have lost far more than we have preserved.

Besides, kurgans, especially bigger ones, have been robbed for centuries. Unfortunately, the same is taking place today, even on a larger scale. Finally, kurgans as archaeological monuments were damaged as a result of the excavations carried out for scientific purposes, especially at the beginning of their study.

Tumuli are Not Just Mounds

The first scientific study of tumuli is associated with the name of D. G. Messerschmidt, a well-known German scientist in Russian service, who in 1722, during the expedition to Siberia, excavated several kurgans in the Minusinsk Hollow. During the three centuries that elapsed since then, archaeologists dug a lot of tumuli in Eurasian steppes; the artifacts found in those mounds became the main, often the sole virtual materials for studying various historical epochs.

The richest mounds, with hundreds, sometimes thousands of artifacts made of precious metals, were discovered in the kurgans of the early Iron Age nomads, the larger part of which was dug in the 19th and 20th centuries. Unfortunately, the documentation of early excavations (when it took place at all) left much to be desired. The methods of archaeologists of those times were practically no different from those of grave robbers, and their main objective was finding valuable, spectacular things, while

Part of the central edge. Some bluish-grey layers of washed silt clay which was used as mortar during the construction of the central burial structure are clearly visible between the pieces of sod. *Large tumulus Barsuchy Log*

Beginning of excavations of the large tumulus Barsuchy Log. The laying of stratigraphic edges

Bronze dagger. *Large tumulus Barsuchy Log (Khakassia)*

Golden plates of wooden objects. *Large tumulus Barsuchy Log (Khakassia)*

Before the beginning of the excavations the kurgan was a pyramid about 9 m high with a nearly square base of size 55 × 52 m, framed by a massive stone wall. Prior to the beginning of the excavations, geophysical surveys were conducted on the tumulus site

ordinary material was often thrown out. Thus, up to now, only an insignificant part of the finds from the excavated tumuli, even the most well-known, has been introduced into scientific circulation.

Since the mid-20th century the methods of field work have been improving; the researchers have started recording the so-called "mound embankments" more thoroughly, too. Accumulation of new data resulted in a qualitative leap in the understanding of the significance and role of kurgan monuments. Thus, M. P. Gryaznov, a Russian historian and archaeologist, formulated (1961) a concept that kurgans are not just mounds; rather they are very old architectural structures that lost their shapes and took the shape of round hills. However, this promising idea gained support only on the part of those, not very numerous, researchers who came to perceive the tumulus as a holistic archaeological site, including not only the burial objects and tombs, but also the design of the kurgan itself.

Unfortunately, in spite of all the advanced ideas, the concept of a kurgan as a certain additional filling above the tomb prevails in archaeology to this day. Even now, when kurgans are excavated in Eurasia, mound embankments do not get sufficient attention: the researchers are more interested in the finds from the tombs. In the first place, this is connected with the fact that the overwhelming majority of the excavations are "rescue operations." Respectively, they are generally conducted in haste; hence, a lot of significant information, including that which is related to the kurgan structure, is not properly documented. The Issyk Tumulus in southern Kazakhstan and Tolstaya Tomb in the Ukraine may serve as examples of this approach: even the area immediately adjacent to the kurgans was not investigated there. Therefore, no wonder that our knowledge of the kurgan architecture as well as its regional features still remain rather limited.

Luckily, in recent years the situation has been changing, first and foremost in the Central-Asian region, where a few fairly large early Iron Age kurgans (Baikara, Arzhan-2, Barsuchy Log and some others) have been studied by joined efforts of Russian, Kazakhstan and German researchers. Another example is large Bronze Age Marpha Tumulus in Northern Caucasia, where excavations are being carried out now.

Large tumuli like these, usually referred to as élite or great tumuli, yield maximum scientific information because they served not only as burial grounds for nobility, but also as sites for performing some complex, sometimes dramatic burial and funerary ceremonies whose traces may be found on these monuments.

Nowadays such joint investigations are conducted employing a multidisciplinary approach, which means that not only archaeologists, but also geophysicists, soil scientists, palaeobotanists, palaeozoologists, anthropologists, and geneticists, as well as representatives of other sciences participate in field work. As a result, both the volume and quality of scientific information obtained during the excavation of kurgans, increase immeasurably.

Turf Pyramids

One of the first large kurgans that was studied with a variety of modern science techniques, and the burial structure of which was studied in detail during the excavation was the Baikara Tumulus in Northern Kazakhstan. Actually, it is one of the biggest kurgans in the North- Kazakhstan forest-steppe: at the beginning of the excavations its diameter amounted to 85 m, and the height was 7 m.

Built in the 5th century B.C., the large Baikara Tumulus proved to be a complex architectural construction: to build it various materials (stone, timber, clay) had been used, layers of turf in the first place. Everywhere in the steppe, the tumuli were erected employing a similar technology. These are large tumuli in the Ukraine and in Northern Caucasia, the Filippovskii Tumulus in the South Urals, and some others. The size of the Baikara Tumulus, the complexity and thoroughness of its structures testify to the fact that the building required not only a huge expenditure of materials and labor but also careful planning and supervision based on experience accumulated in the course of erecting such structures.

The exterior of the large Barsuchy Log Tumulus in the Minusinsk Hollow (the Middle Yenisei), which was built approximately at the same time as Baikara, differs drastically from the latter. Prior to the excavations, Barsuchy Log had been a pyramid with a rectangular stone wall (this local architectural tradition is characteristic exclusively of the Middle Yenisei), whereas the round stone-shelled Baikara was surrounded by a ditch. But they were both built from pieces of turf in compliance with ancient common practice: three steep slopes and one gentle slope, and a flat top. The tumuli were excavated according to one and the same method: in parallel sections, preserving seven stratigraphic edges, which made it possible to trace in detail the design of the structure, as well as to elucidate traces of ritual ceremonies that accompanied each of the four stages of its construction.

The inner core of the Barsuchy Log Tumulus, a rectangular platform in shape, was made with mortar of well-kneaded blue-grey clay with a lot of river silt. In the Early Iron Age tumuli of Eurasia, such a technology was observed for the first time; this fact makes us re-evaluate the level of development of building practice of early nomads.

Likeness between the two tumuli clearly testifies to similar religious beliefs, traditions, and culture of their

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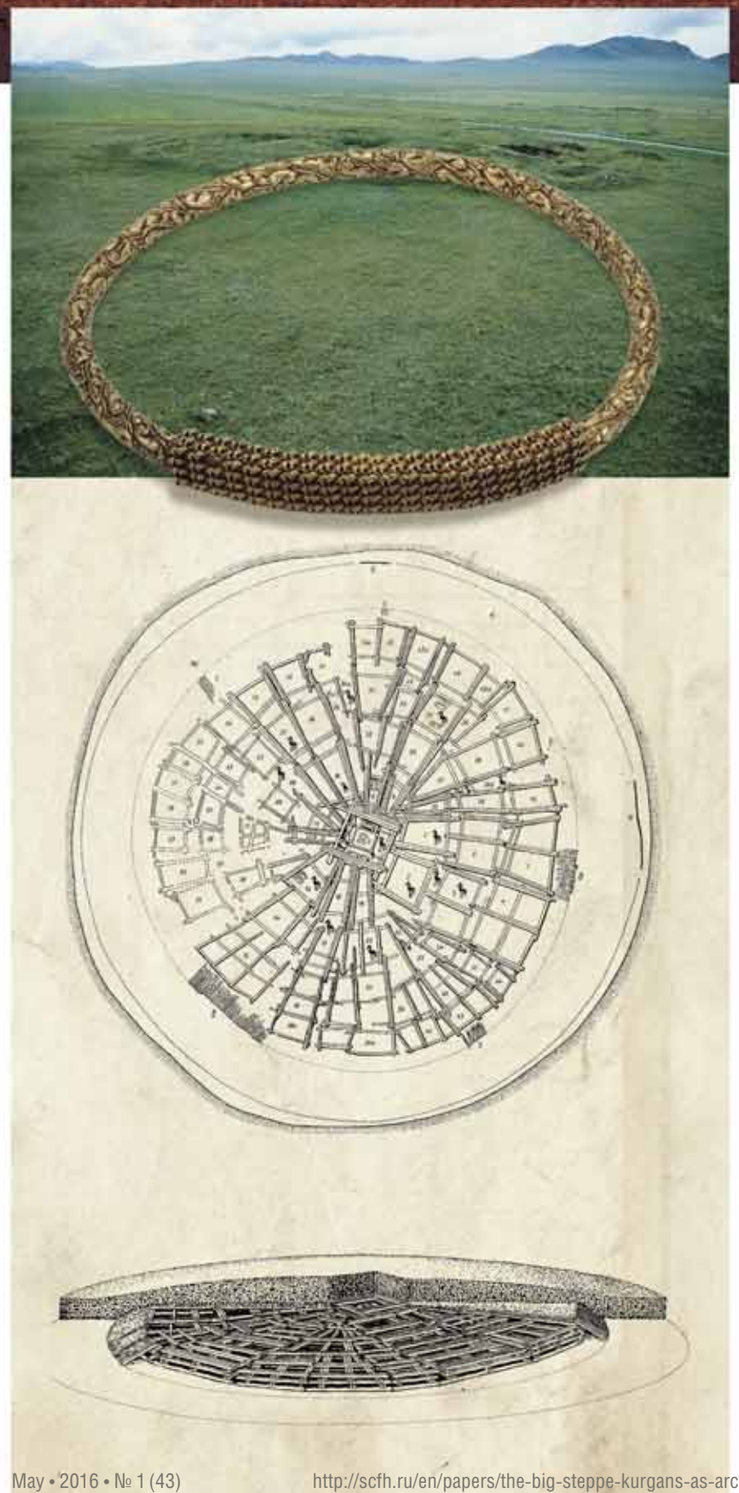
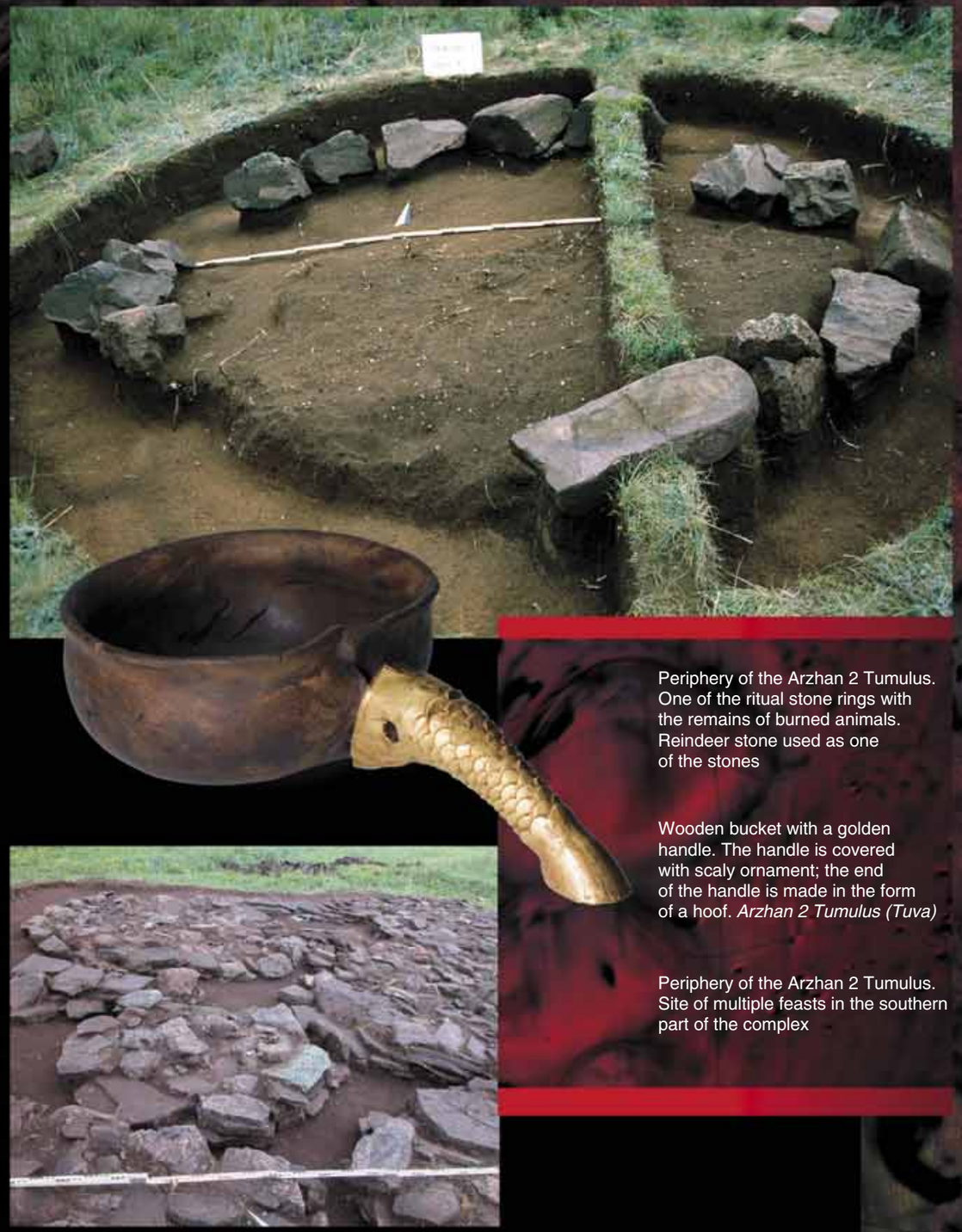




builders. The origins of this likeness should be sought in Central Asia, where the oldest of the monuments known today, that is Saka Burial monuments – Chilikty (Eastern Kazakhstan) and Arzhan (Tuva)-- were studied.

Funeral Feast at the Foot of the Tumulus

In the Uyuk River valley in the Yenisei Basin, a great kurgan necropolis including a chain of four large round stone platforms is situated. The westernmost of them is the Arzhan Tumulus, the most ancient monument of the Saka-Scythian time dating from the late 9th to the early 8th centuries BC. Excavations of the 1970s showed that this tumulus, 120 m in diameter and 4 m high, was a complex wooden structure with radially arranged burial chambers spanned by massive walls of stone slabs, where humans and horses had been buried.

The Arzhan-2 Tumulus, the easternmost stone platform, 80 m in diameter and up to 2 m high,

Arzhan Tumulus in Tuva, the oldest known burial monument of the Saka-Scythian time, dating back to the late 9th – early 8th centuries BC

Golden torque that belonged to the man from the “Great” Tomb *(Arzhan 2 Tumulus, Tuva)*, covered with relief images of horses, deer, camels, goats, feline predators.
Left: Layout of the complex

Periphery of the Arzhan 2 Tumulus. One of the ritual stone rings with the remains of burned animals. Reindeer stone used as one of the stones

Wooden bucket with a golden handle. The handle is covered with scaly ornament; the end of the handle is made in the form of a hoof. *Arzhan 2 Tumulus (Tuva)*

Periphery of the Arzhan 2 Tumulus. Site of multiple feasts in the southern part of the complex

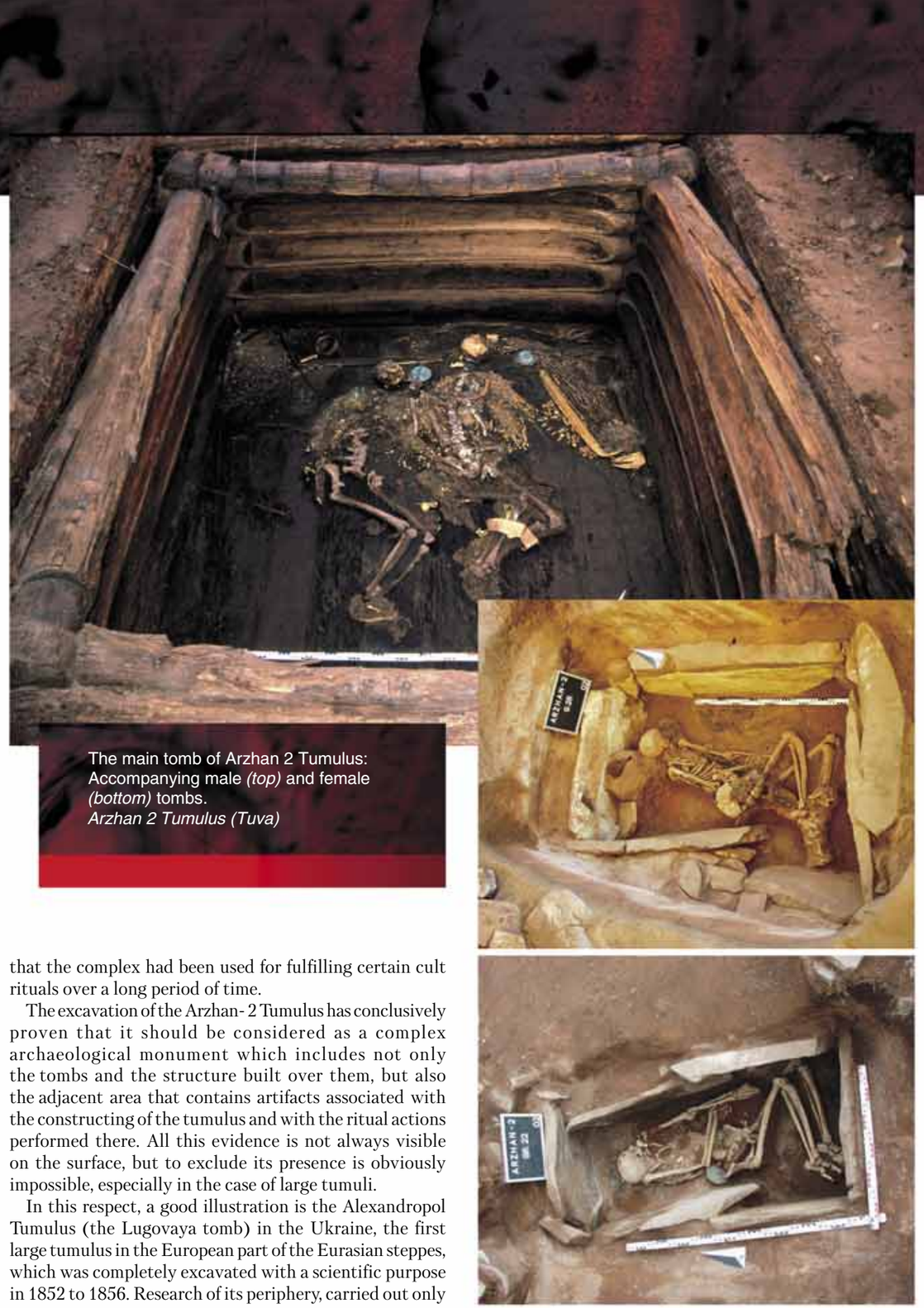
Male dagger from the Great Tomb, inlaid with images of tigers, goats and stylized heads of birds of prey. *Arzhan 2 Tumulus (Tuva).*

Golden pendant in the form of a boiler from the Great Tomb. Its entire surface is covered with relief ornaments with images of animals. *Arzhan 2 Tumulus (Tuva)*

was excavated by the joint expedition of the German Archaeological Institute (Berlin) and the State Hermitage (St. Petersburg) with an active participation of specialists from the Institute of Archaeology and Ethnography SB RAS (Novosibirsk). Prior to the beginning of the excavations, geodetic and geophysical surveys of the tumulus were conducted; they showed that the platform was the central part of the complex monument.

The platform itself was built in four stages from sandstone plates and reinforced at the edges by a massive stone shaft. The central tomb contained the remains of two people belonging to nomadic élite, as well as a large number of the so-called accompanying tombs – men's, women's and children's. Some tombs that contained many weapons and gold ornaments were found under the stone shaft, which is indicative of the fact that those people were buried there before the platform was built. The majority of people buried there are likely to have been killed in a bloody ritual prescribed by religious beliefs. Besides, the archaeologists found the remains of 14 horses, and a cache of weapons and horse equipment in the tumulus.

On three sides the platform was surrounded by numerous stone rings of different sizes; inside the rings there were a lot of pieces of charcoal and ash, melted metal parts of horse harness, as well as fragments of burnt bones of horses and cattle and other live-stock (similar stone ring structures had been previously discovered in the Arzhan Tumulus). It is interesting that the burning took place elsewhere: only the unburned residues were put in the stone rings. The south side of the complex was surrounded by low circular stone structures. The large number of bone fragments of cattle and of other live-stock that were found there is a clear sign that these structures, more than once, served for conducting funeral feasts, the final stage of a burial rite. These finds indicate

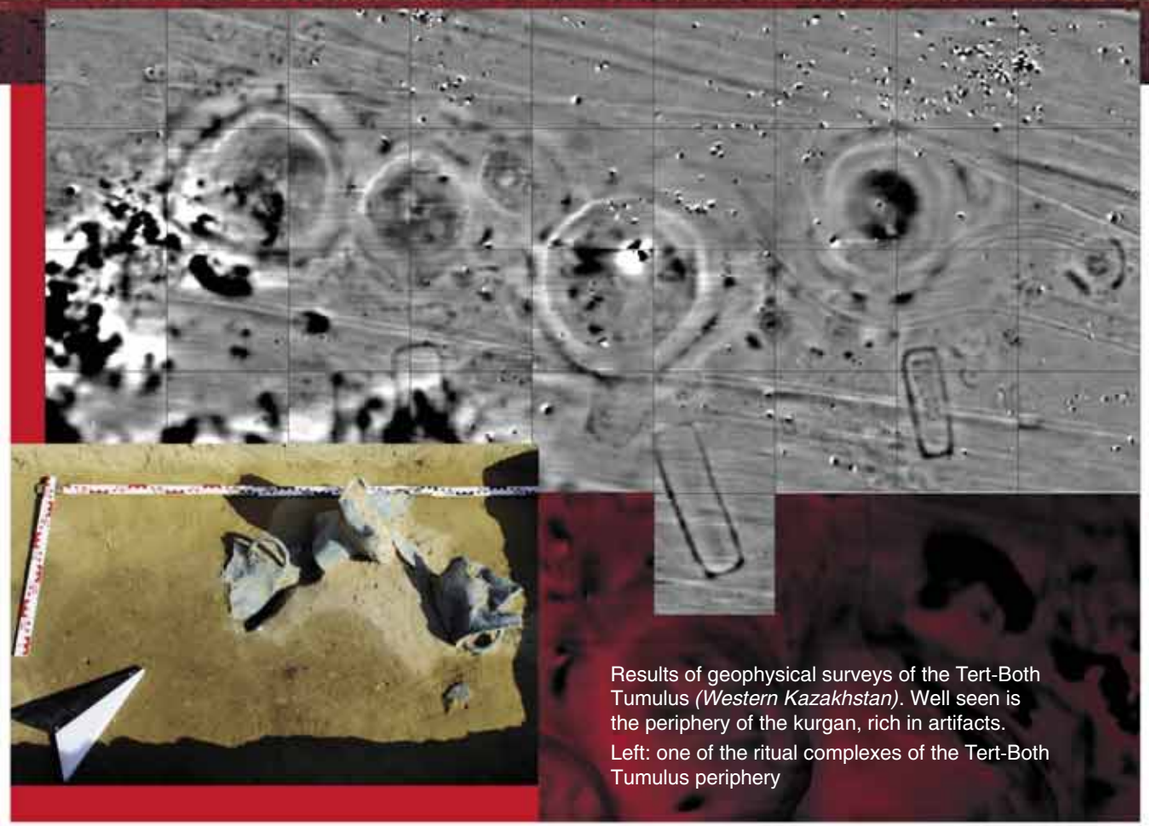


The main tomb of Arzhan 2 Tumulus: Accompanying male *(top)* and female *(bottom)* tombs.
Arzhan 2 Tumulus (Tuva)

that the complex had been used for fulfilling certain cult rituals over a long period of time.

The excavation of the Arzhan- 2 Tumulus has conclusively proven that it should be considered as a complex archaeological monument which includes not only the tombs and the structure built over them, but also the adjacent area that contains artifacts associated with the constructing of the tumulus and with the ritual actions performed there. All this evidence is not always visible on the surface, but to exclude its presence is obviously impossible, especially in the case of large tumuli.

In this respect, a good illustration is the Alexandropol Tumulus (the Lugovaya tomb) in the Ukraine, the first large tumulus in the European part of the Eurasian steppes, which was completely excavated with a scientific purpose in 1852 to 1856. Research of its periphery, carried out only



Results of geophysical surveys of the Tert-Both Tumulus *(Western Kazakhstan)*. Well seen is the periphery of the kurgan, rich in artifacts.

Left: one of the ritual complexes of the Tert-Both Tumulus periphery

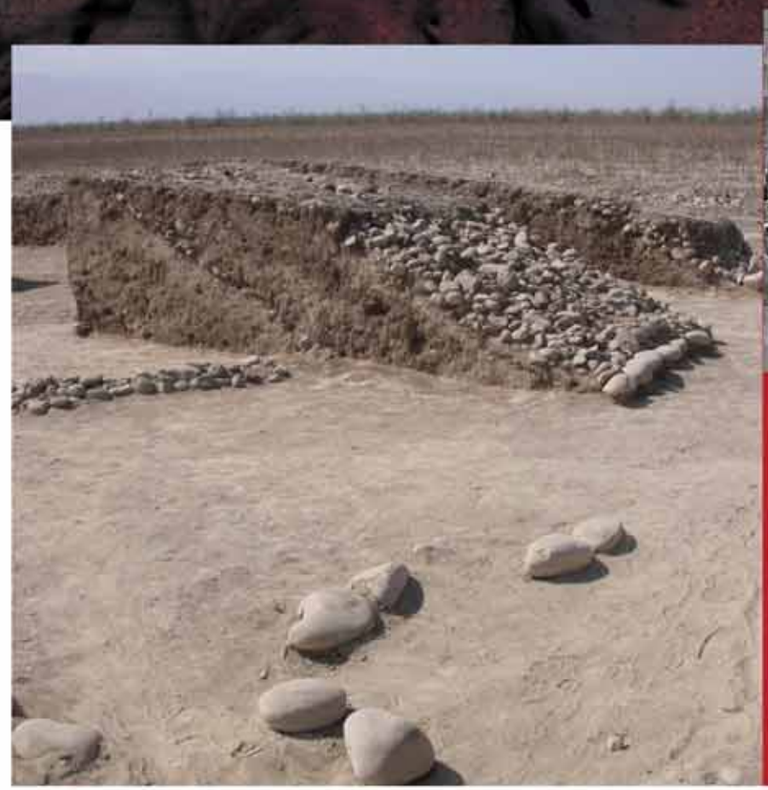
in recent years, discovered behind the ditch surrounding the kurgan some areas with remnants of several feasts. In the largest of them, surrounding the kurgan in a wide strip for approximately 110 m, the researchers found fragments of about two hundred amphorae, bronze, iron and gold jewelry, as well as eleven tombs that contained the remains of people who had been forcibly put to death.

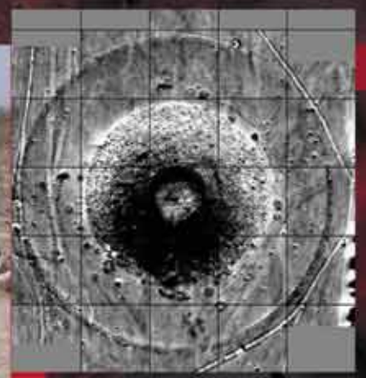
In 2011, geomagnetic exploration helped to discover the periphery of the Tert-Both Tumulus (Western Kazakhstan), rich in artifacts. Though it had no manifestations visible to the naked eye, a real sacrificial complex with remains of horses and people was found there. In this connection, one cannot but recall the large kurgans near the village of Filippovka (Orenburg oblast), not far from Tert-Both; the 2004 to 2007 excavations there yielded unique finds. Near burial structures, the researchers found fragments of bronze cauldrons and bronze finials, but, unfortunately, the periphery of the tumulus was not investigated.

Colossi Made of Clay

Semirechye (Southern Kazakhstan) was one of the most important cultural centers of the early nomads, as evidenced by a large number of tumulus necropolises found there. Even the first examination shows that once these tumuli had a periphery rich in architectural structures, which in most cases was destroyed as a result of economic activity.

One of the exceptions was the Zhuantobe burial site: its main kurgan has a height of 11 m and a diameter of 113 m. Geophysical surveys found around the mound a large number of round stone structures, under which some tombs were then discovered. All the peripheral area was surrounded by a stone-paved road that may have been built for ritual purposes. Such a design of Early Iron Age kurgans in Eurasia had never been seen before. Moreover, this is the first evidence of the existence of the technology of road construction in Central Asia at such an early time (5th century BC); besides, it was a highly advanced technology: the roadbed was first leveled, compacted and paved with medium-sized stones, over which a layer of clay





Results of geophysical surveys of the central tumulus of the Joan Tobe burial grounds. The edges of the structure are surrounded with tombs; the whole area is surrounded by a paved ring road.

Tumulus 8 (Aksuat) is formed of dense hard-packed clay faced with a stone shell. The tomb structure was built in a similar way

mixed with small gravel was then applied and compacted. Analogues of such a highly advanced construction level have not been found yet. It is hard to imagine that such an advanced technology was applied only for constructing funeral complexes, but that is another topic that requires special research.

Not only did the kurgan periphery have its own specific features characteristic of Semirechye, but the kurgans were built not of turf, but of thick compacted clay. Then their surface was carefully coated with liquid clay, and the whole structure was faced with a stone shell “glued” onto the surface. The inner, denser structure of the tomb was built in the same way.

We encountered similar construction technology when excavating the tumuli of the Hun-Sarmatian time in Aksuat (Eastern Kazakhstan), where mud-brick burial structures had existed in the Early Scythian times. The tumuli unearthed in the Chiliktinskaya Valley, dating from the 7th century B. C., looked the same.

Tumulus 8 (Aksuat). Part of the central edge with clearly visible layers of wattle- and- daub structures. The layers were applied sequentially, one after another. Soft wet clay was laid, rammed, and then covered with a layer of clay, sand, and small stones mixture

The Marpha mound (Central Ciscaucasia) before excavation

The Mapha mound's adobe construction made of clay blocks

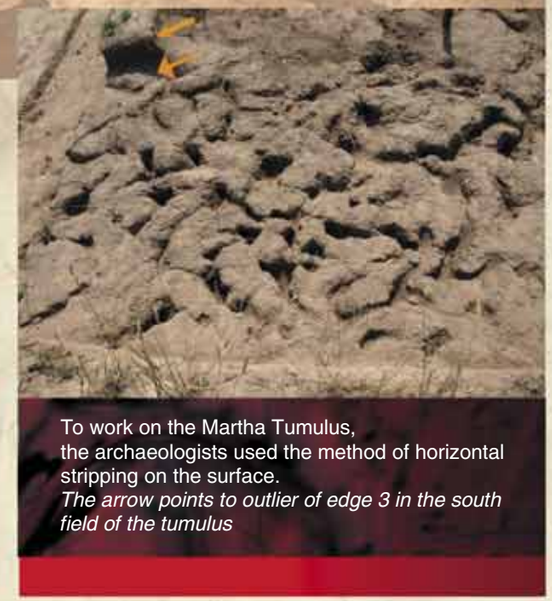
Details of the clay blocks of the Mapha mound

Adobe structures, rather than mounds, were erected over the tombs in the Early Bronze Age. Excavations of the large Martha Tumulus (4,000 years BC) in Central Ciscaucasia are now being conducted by a joint Russian-German team of researchers; the tumulus belonged to the Maikop culture. The Martha Tumulus was also built from clay blocks; on its periphery some sites paved with clay blocks were discovered, and on one of the sites there was a badly damaged structure made of clay blocks similar to the blocks of the tumulus.

Joint Russian-German investigations of recent years have substantially expanded and changed our idea of kurgans. A fundamentally new, multidisciplinary approach to their study ultimately made it possible to give a precise definition to these archaeological monuments. So, a kurgan is a burial and ritual complex which consists of three parts that make a whole. These are graves, hoards, sacrificial complexes; structures built over them, sometimes complex and monumental, that are architectural monuments in their own right; and the areas that are adjacent to the structure, that is the kurgan periphery, where there are moats, memorial complexes, tombs, artifacts, and culture remains associated both with the construction of the complex and with ritual ceremonies carried out there.

A new perception of tumuli requires of the archaeologist certain drastic changes in the methods of study. Participation of other scientists in the research makes it necessary to take into account the specifics of their work during the excavations, such as facilitating sampling for laboratory tests, etc. This enhances the responsibility of archaeologists in carrying out field work and, of course, should be reflected in their officially adopted methods. So far, we only have the excavation methodology adopted by the Moscow Institute of Archaeology of the Russian Academy of Sciences in 2011, according to which the basic elements of a tumulus are a "mound; buried soil, ... i.e. the surface layer of soil with vegetation on which the mound was sprinkled; the "mainland" – the layer of soil below the buried soil." The document does not contain a single word on the kurgan periphery; neither has it raised a question of multidisciplinary studies. And in this sense this methodology is suitable only for tumuli in Ciscaucasia, one of the many regions in the Eurasian steppe zone.

This situation has been corrected by "The regulation on the procedure for conducting archaeological field work and compiling scientific reporting documentation,"



To work on the Martha Tumulus, the archaeologists used the method of horizontal stripping on the surface.
The arrow points to outlier of edge 3 in the south field of the tumulus

A SOIL SCIENTIST'S VIEW

Methods of soil science are now quite commonly used in archaeological research, but in the vast majority of cases we are talking about soils buried under the kurgan structures or under culture layers of ancient settlements. These data are commonly used to reconstruct palaeoclimatic conditions or to detect anthropogenic impacts on the natural environment in the distant past.

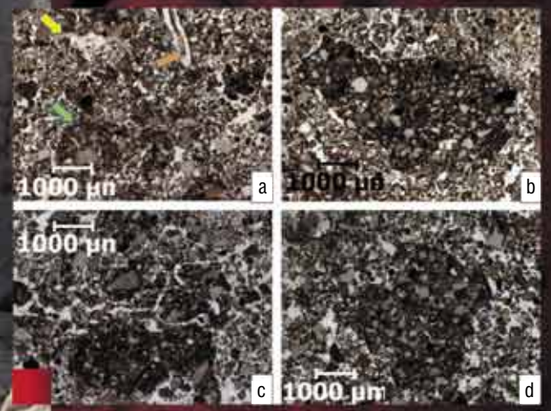
The material from which, in fact, the tumuli are stacked is examined much less frequently. The terms "mound" and "addition" are commonly used in the descriptions, which does not presuppose the study of the tumulus as a single, purpose-built architectural complex. As a result, the structural features of the mound material and the forms of the original structures are practically not studied; hence, no methods or approaches to solving these problems have been developed. The 2013–2014 paleobotanical study of the Martha Tumulus in the Stavropol krai, made in conjunction with the archaeologists, can be called a pioneering investigation. The methodological approaches to the study of earthen tumulus construction had to be developed literally on the move. When working on the Martha Tumulus the archaeologists used a non-standard technology in which the surface was scraped (the soil from the surface was removed layer after layer) manually, with separation of clay construction blocks. In order to study the soil, the same procedure was performed on outlier edge 3 on the south side of the mound.

The upper granular layer appeared not to have been processed by soil-formation and was the result of a recent displacement of the material. It was followed by a sod horizon containing humus, the soil that was formed on the surface of the mound. A horizontal sweep showed that it was ordinary soil of rough-lumpy structure typical of modern virgin soil, penetrated by plant roots, pathways of earthworms and burrowing animals. The next horizon, according to soil science concepts, had to be a subhumus transitional horizon of modern soil, with columnar-lumpy structural separateness, as it actually proved to be.

Thus, the first field study allowed us only to conclude that the surface of the kurgan was so deeply affected by modern soil formation that "by eye" it is impossible to determine whether the material for constructing the kurgan was placed there in the form of specially molded blocks or poured. The next step was chemical analysis and micromorphological study of the samples. Whereas for chemical analysis usual "loose" soil samples were used, the micromorphological study used undisturbed soil monoliths of size 3 × 5 cm, of which, after special impregnation, thin sections with a thickness of 30-50 micron were made. It is in these samples that the specialists were able to detect the presence of obviously "foreign" microfragments which consisted of much more tightly packed "foreign" material saturated with fine-dispersed (clay) substance.

Can we treat these microfragments inside the material of the upper part of the kurgan loosened by soil-formation as the remains of the "bricks"? In other words, can they be reliable evidence that the building material was artificially mixed, compacted and placed in the kurgan in the form of already molded blocks? To answer these questions, we have compared the microfabrics taken from two horizons of soil on the surface of the kurgan with modern soil and with the soil buried under the kurgan. It turned out that such unnatural soil compaction and enrichment in clay are distinctive only of the microfragments from the soil horizons on the kurgan surface.

The next step was a test for phytolites (determining the silicificated residues of vegetation and other biogenic forms) of the most well-preserved bricks from the deeper layers of the Martha Tumulus structure, which was conducted by A. A. Golyeva, Doctor of Geography at the Institute of Geography RAS (Moscow). The analysis showed that no



Micromorphological photographs of samples from the soil horizons on the surface of the Martha Tumulus:
a – "normal" structure of the humus horizon of soil in the mound (orange arrow – fossil vegetation, yellow arrow – humus-clayey-ferruginous inflow in the pores, green arrow – soil mass chopped by animals); *b, c, d* – microfragments of darker and densely packed material.
Optical microscopy

herbal chaff had been added into the clay when it was mixed; otherwise, the samples would necessarily contain large amorphous residues, and the structure of the discovered phytolites would be more homogeneous. However, flint skeletal elements (spicules) of sponges and the fossil plants of cane were quite regularly found in the samples, which may be attributed to the addition of river silt to the "bricks."

So, the work carried out in the surface horizons of the mound structure resulted in identifying some remains of artificially mixed and compacted material enriched in clay. However, intense processes of soil formation have made it impossible to determine the form (bricks, blocks, etc.) in which this material was placed into the structure. To create the structural elements of a tumulus, the ancient builders used the material from lower soil horizons enriched in carbonates (loess), and also, possibly, river mud. All the ingredients were carefully mixed and compacted, while fine clay served as a binder.

It should be taken into account that any kurgan, during its long life on the surface, inevitably changes as a result of various environmental factors: wind, rain, snow, vegetation, burrowing animals, etc. This leads to the destruction and loss of the original appearance of the architectural structures, especially of their surface and upper (0.5—1.0 m) layers. This accounts for the fact that the overwhelming majority of archaeologists who study kurgans still perceive them as mounds, which have no regular design features. Besides, the ancient builders used the wattle- and- daub construction technology, which did not help to preserve the structure either.

At present, archaeologists continue to study the Martha Tumulus. In the deeper layers of the kurgan, its structural elements should be preserved much better, and their detailed study will undoubtedly help shed light on the tumulus building history and reconstruct the original appearance of this ancient architectural structure.

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A. A. Khokhlov (Institute of Cell Biophysics RAS, Pushchino, Russia)

adopted in November 2013. In the document, it is required to make a study of adjacent to the mound"...area on which small ditches, powders, feasts, remains of ancient fields and the like can be detected." However, the kurgan is still referred to as a mound over tombs, not as remains of an architectural structure. As a result, the wrong approach determines, to a great extent, the further fate of the monument. In other words, a large number of tumuli excavated annually are not investigated comprehensively, one of the main elements (the periphery) not being examined at all, and the architectural structure continues to be studied as a "mound."

It is obvious that a new technical and methodological regulation for excavating tumuli should be developed; it should be a law, not a recommendation. At the stage of planning excavations it is necessary to take into account the fact that kurgans, especially big ones, should be examined comprehensively, with the involvement of experts in natural sciences; the work should start with geophysical exploration of the periphery. Finally, it is time to abandon the concept of a "mound." Otherwise, a huge body of scientific information will be irretrievably lost, as has happened to thousands of kurgans, part of the world cultural heritage, that are vanishing before our eyes.

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Mysterious Artefacts

from archaeological sites and ethnographic complexes of the north of West Siberia

Archaeology and ethnography are for romantics, who get an opportunity to explore something unusual, unique and hitherto unknown.
Such finds are often only fragments of long-lost artefacts and are full of riddles and mysterious meanings hidden from an archaeologist or an ethnographer, who are able to solve them relying on their knowledge, experience and intuition, and sometimes restraining their wild imagination

Mansi shrine (I. N. Gemuyev and his guide P. F. Merov), 1983.
Photo by S. Tikhonov

Plate depicting two male figures on the back of a beaver. 16.4 cm long. *Presumably the 6th–8th centuries. Private collection*

Silver badge depicting two anthropomorphic figures on the back of a beaver. Presumably the 6th–8th centuries. *Museum of History and Culture of the Peoples of Siberia and the Far East, Institute of Archaeology and Ethnography SB RAS*

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Fragment of a bear's figure with anthropomorphic, zoomorphic, and ornitomorphic figures. The second half of the first millennium AD *Below:* a bear's figure decorated with animal heads. *Private collection*

Several years ago, a massive plate forged of white bronze was found in the north of West Siberia. It is a classical example of the famous Permian animal style, which was flourishing in the second half of the first millennium AD. It represents two male figures sitting on the back of a mysterious beast; they dropped their paddles while looking at the fish in the water below. The men's hands are like bodies of wriggling animals; their palms are like birds' open beaks. Unfortunately, the plate was broken, and its left part had been lost long ago. The round silver badge found at one of the medieval shrines of the Lower Ob River helped to reconstruct the missing fragment. The badge shows a similar couple of men sitting peacefully on the back of a large animal whose tail, covered with a rhombic grid, makes it easy to identify the animal as a beaver.

Another item of interest was found in the Yamalo–Nenets Autonomous Okrug: it is a half of a large bronze plate. It is likely to have been an image of a bear in profile walking to the right, which resembles a similarly shaped article found on the unknown medieval site in the Tomsk oblast. The Yamal fragment has three paws of a bear, with pictures of two birds and a beaver on them. Thus, the missing paw is sure to have had a picture of an animal on it as well. There are five anthropomorphic figures in the upper part of the plate; the overall size of the article allows us to assume that initially there had to be seven figures.

Faceless

In 2013, the Museum of Archaeology and Ethnography in Novosibirsk received a large round badge split into several slices. It was found in the upper reaches of the Konda River, not far from the confluence with the Ess River (Soviet district, Khanty-Mansi Autonomous Okrug—Ugra). The cultural layer of the unknown site, presumably a small necropolis of the 10th–13th centuries that included several burial mounds, had been destroyed by heavy tractors in the course of logging.

One of the burial mounds contained the remains of a dead person wearing a fur coat of rough black fluff (possibly bear skin). The slices of the silver badge were lying face down in a certain order on the chest part over the fur coat.

Long ago, this article was forged from silver bullion and cut round with metal scissors. The picture on the face side of the badge was made by gilding, embossing, and engraving. Then the article was sold (or delivered) from the workshop to the owner.

Later the badge was improved by the owner himself or by the craftsmen: the edge of the item was ornamented by incusing a row of large-sized "pearls"; then a hole was made to which a brass ring was attached, which made it possible to wear the badge as a pendant.

After the death of the owner the badge was split into slices and put into the grave. In fact, it was destroyed so that it could pass to the other world together with its owner.

Kondian silver badge
Medallion of the Kondian badge. *Photo by A. Baulo, drawing by M. Miller. Museum of History and Culture of the Peoples of Siberia and the Far East, Institute of Archaeology and Ethnography SB RAS*

The fragment of the badge depicting the man's face was never found.

The diameter of the badge is 17.5 cm; the diameter of the central medallion is 10.5 cm. It shows a man sitting in an oriental position; he is pulling a bending woman by her long braid and touching her head with his right palm. The background is gilded.

The man is wearing a robe with sleeves rolled up and high boots with a side seam. The robe is ornamented with circles grouped in three: it is a leopard skin motif well known in Middle Asian toreutics of the 9th–10th centuries.

The woman's figure is depicted more thoroughly: she is wearing a long dress with short sleeves (possibly a mantle, a tunic, or a shirt). Her clothes are ornamented with wavy and parallel lines, which could signify folds or a tabby fabric; the edge of the clothes is decorated with festoons. On her head, she is wearing a fitted polka-dot scarf or cap, revealing some hair. The ankles and the right wrist are adorned with bracelets made of large circles. On her feet, there are thick-soled sandals with a narrow strap and a large button.

The woman has a round face, big almond-shaped eyes with large pupils, long thin connected eyebrows, a straight nose, and small lips. She has a long heavy braid tied with ribbons.

The plot depicted on the badge is hard to interpret mainly because of the missing fragment with the man's head (face). The simplest interpretation is that it is a scene of violence.

The dating of such finds allows us to presume that the badge was made in the 9th–10th centuries. The place of production is also difficult to identify; it may have been Eastern Europe. The Kondian badge, judging by such details as the man's oriental position and the woman's sandals, has a pronounced southern, Central Asian specificity. This is the first time such a plot and a woman's unusual (round) face have been found in this region.

The fragment of the badge with the man's face was never found. I am convinced that it had not been buried there at all.

The badge was destroyed by cutting it into five longitudinal slices, and then the right one was split into three parts by blows across its width. Moreover, it was not just cut into three pieces, but the central fragment with the man's face was cut out from the badge. What for was it done?

It could be assumed that, in his lifetime, the badge owner identified himself with the male character depicted on the badge, and so, apparently, did his tribe. After the man's death, his "portrait," the face, was removed from the funerary accessories, most likely with a specific purpose of making his postmortem image, a vessel for his soul. In the late ritual practice of the Ob Ugrians, the creating of a figurine of the deceased, a temporary receptacle for one of his souls (*itterma*), has been known at least since the beginning of the 18th century.

A tradition of making similar figurines may have existed back in the Middle Ages; for example, anthropomorphic dolls with faces dating back to the 8th–9th centuries were found near Surgut. Their bodies were made of twigs; the faces, made of bronze or wood, were sewn onto the dolls,

Itterma figurine. *Lombovozh settlement, Berezovsky district, Khanty-Mansi Autonomous Okrug—Ugra, 1985. Photo by A. Baulo*

Itterma figurines—temporary vessels for a soul, with photographs of the deceased. *Above: Lombovozh, 1985. Below: Hurumpal settlement, Berezovsky district, Khanty-Mansi Autonomous Okrug—Ugra, 1983. The Mansi Photo by S. Tikhonov*

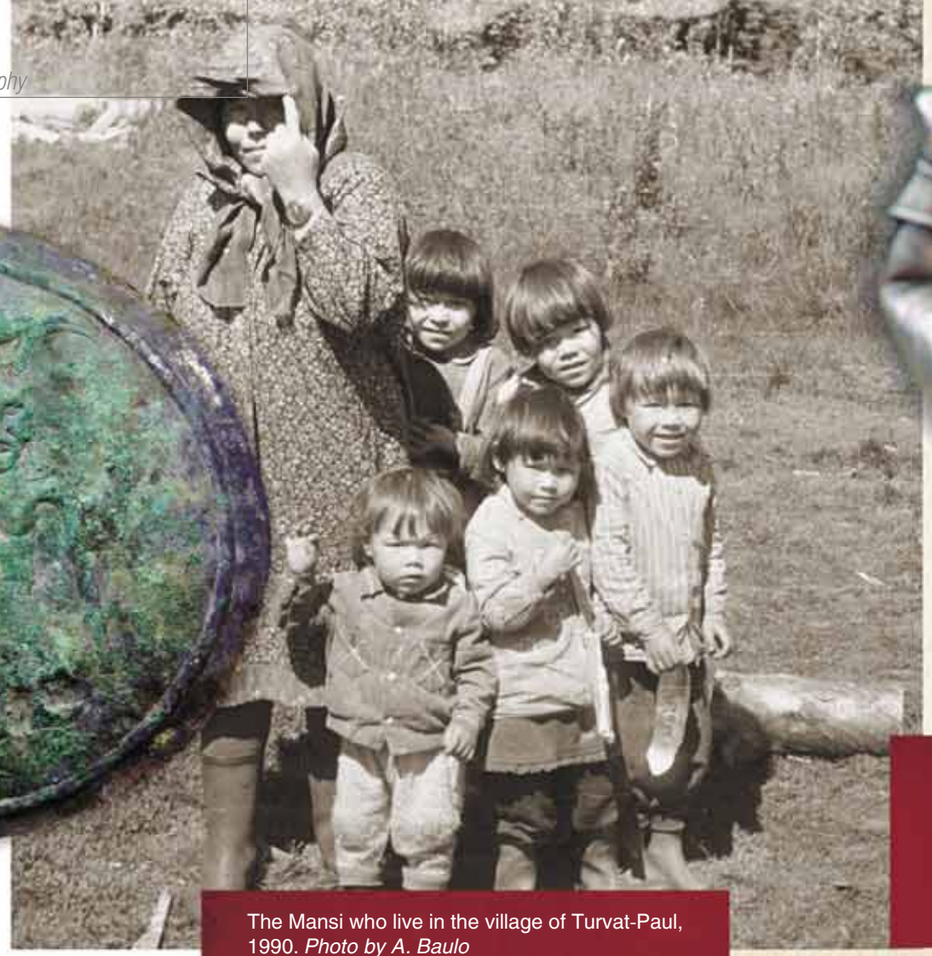
some figurines had strands of hair that may have signified a connection with a particular person. It is possible that such a doll was made for the Kondian man, but his face was to be the fragment specially cut out of the silver badge.

Figurines of the deceased (*itterma, ittarma*) were widespread among the northern groups of the Khanty and Mansi in the 18th–20th centuries. The Lyapin Mansi also had a tradition of attaching (sewing on) the dead person's photograph to an *itterma* doll. Such close semantic similarity (the fragment of the badge and the face—the photograph and the face) combined with the version that the fragment of the badge might have been attached onto a figurine as a postmortem vessel for a soul allows us to make a tentative suggestion that the burial complex found in the upper reaches of the Konda River was Ugric.

Family joys

Another group of riddles is connected with trying to explain complicated visual plots.

In 2015, a very interesting badge was found in the course of undocumented excavations in the east of the Sverdlovsk oblast. It is made of copper (tin-plate) with traces of tinning. Its diameter is 15.3 cm, and it may date from the 12th–13th centuries.



The Mansi who live in the village of Turvat-Paul, 1990. *Photo by A. Baulo*

The silver rhyton in the form of a statuette of a girl holding an antelope's head has been protecting family well-being of Khanty women for three generations, 2001. *Photo by A. Baulo*

Copper tinned badge depicting a family scene. *Private collection*

The face side of the badge depicts two embossed anthropomorphic figures; above them are two birds. Since the plot is unique and has no analogs, we may suggest only a hypothesis.

To the left, there is a woman; the man is to the right. The woman can be identified by her hairstyle and explicit breasts with nipples. She is pregnant, since she has swollen breasts, a large belly (its roundness is underlined by the belt turned down); her hand is over the belly as if defending the fetus. The position of the characters' arms, stretching towards each other, symbolizes an embrace.

The birds might be of different sexes too (the left one has a longer tail and a crest on the head) and could signify a blessing: medieval art is known to have depicted two doves facing each other, which meant peaceful intentions of the parties; the birds usually accompanied the allegoric figure of concord. A couple of cooing doves symbolized family happiness and sexual harmony, while a gentle dove was a metaphor for a loving and considerate wife. Thus, the scene could be understood as a manifestation of marriage and procreation.

Silver idol

In the 16th–17th centuries, the story of a "Golden Woman," the legendary idol of the peoples living beyond the Urals, became widely known in Western European literature. The search for it had lasted for decades, but to no avail. When Russian researchers and adventurers abandoned the hope of finding the Golden Woman, they switched their enthusiasm to the quest for a "Silver Woman." This time their efforts were not in vain. At the end of the 19th century, they recorded a story about the Silver Woman forged as a cast from the Golden Woman. It represented a woman sitting naked; it was kept in a box on the holy shelf in a Vogul yurt in the Urals. When going hunting, the owner wrapped the figurine in an old silk scarf, together with silver rubles, and carried it on his back in a small pouch made from the ear of a young elk. The "woman" was believed to help women and hunters. During the seven- day celebration in its honor, people from the entire neighborhood brought their gifts to the protective spirit: deer, silver, brocade, silk, sables and foxes; women made clothes and decorated it with precious things. The "woman" was offered blood and meat on silver dishes. The Voguls bowed before the deity and prayed to it.

Nearly one hundred years later, in 1962, the Khanty-Mansi Regional History Museum received a figurine of a female protective spirit from the upper reaches of the Kazym River (Beloyarsky district, Khanty-Mansi Autonomous Okrug–Ugra). Eleven silver plates attached to its clothes allowed the researchers to identify it as one of the variations of the Silver Woman. Nearly at the same time P.E. Sheshkin, a descendant of the Mansi princes, spoke about a Silver Woman, a female figurine with an "Indian" face, which he had seen.

In 2000, the members of the Polar Ethnographic Group of the Institute of Archaeology and Ethnography, SB RAS, heard a story from the northern Khanty about an ancient figurine that had been in one house since the good old times when "the Khanty conquered Rome."

According to the family legend, the owner's grandfather, while hunting in the taiga in the late 1930s, stumbled over a trunk lid hidden in the grass. The trunk contained several fetishes including a figurine and small silver figures of animals and birds as well as skins of small animals and scarves–gifts to protective spirits. Since the Ob River Ugrians consider any unusual thing found occasionally to be heaven-sent, the hunter took the items home, thus giving the sacred objects a new life.

The owner of the silver idol demonstrates the rhyton in action, 2001. *Photo by A. Baulo*

In recent years, the figurine has been the family protective spirit; it is kept in the inner porch, in a cardboard box with pieces of cloth as gifts. The figurine itself is wrapped in several scarves and is wearing a miniature deer fur coat. When holidays come, it is offered a glass of vodka and a holiday meal, as are the other protective spirits; then the family members ask it for assistance and blessing. They call it *evi*, a girl.

Interestingly, this is the second hollow silver figurine discovered in the north of West Siberia. The first one was the figure of an elephant in the Mansi shrine of the "Old Eagle Owl," in the upper reaches of the Northern Sosva River; it was there in the late 19th–early 20th centuries. The elephant acted as a secondary idol, the "threshold guardian" of a small barn. The legend about the elephant is much the same as the story of finding the female figurine: an Ostyak went hunting, traced an animal and came to the "mammoth" lying in the snow. It was found so long ago that, according to the Ostyak, "my father's father cannot recall it."

Oriental silver dishes (plates, chalices, salvers, jugs, etc.) are known to have been supplied to the North back in the 7th–8th centuries: Middle Asian merchants exchanged them for fur, walrus tusks and even hunting birds. Due to the utmost value and sacredness of the white metal, most silver articles went to the Siberian shrines to continue their life as ritual accessories. After the places of worship had disappeared or had been destroyed, silver went under the ground to reappear hundreds of years later as buried treasure. The unique medieval items are sometimes kept at home or in settlement worshiping places of the Khanty and Mansi.

Back to our statuette: the girl is holding the head of an antelope in her hands. The statuette is 25 cm long and 12 cm high. It is made of silver, partly gilded and hollow; the eyes are made of carnelian. In the upper part of the head there is a round hole nearly a centimeter wide. She has an unusual hairstyle: most of her head is shaved; only a narrow line around the forehead remains intact. There are several curls on the left and right of the back of the head. She has earrings made from two rings and a round pendent.

She is wearing a tight jacket with a full collar and short sleeves, and there is a belt wrapped around her waist. She is also wearing high boots with short wide tops.

The antelope's head has short spiral horns (only the right horn has remained), an opening in the mouth and open ears pricked up. The antelope' eyes are made of carnelian.

The girl seems to be flying. While the flying anthropomorphic figures depicted on Iranian and Central Asian silver plates have knees bent at different angles, the girl's legs are kept together. According to Professor B. I. Marshak, the girl's position reminds us of the position of an acrobat performing gymnastic exercises. The antelope's head in the girl's hands might be the answer. It is a rhyton, i.e., a vessel for wine. We see a gymnastic exercise with a wine vessel. The acrobat entertains the guests while serving them wine. The shaven head of the girl looks very much like the hairstyles of *putty* in the art of Eastern Turkestan. In this case, however, the head was shaved to ensure a tight fit for a cap so that a pole could be set on it for acrobats to perform various acrobatics.

Not only is the head of an antelope an image of rhyton, but the statuette itself appears to be an intricate silver rhyton. Wine was poured into the opening in the girl's head. Then the statuette was put on the palm, moved aside and upwards, and tilted a little to let the liquid flow along the girl's hands into the antelope's head. Then the wine streamed through the tube, which had once been installed in the antelope's head, into the mouth of a drinking person.

Rhytons, which were once popular in Greece and Rome, were reborn later in the early medieval cultures of Central Asia, especially in Iran. Rhytons made as hollow silver figurines have survived to our days as single copies. For example, there are vessels made in the form of a lying horse in the Cleveland Museum of Art; vessels in the form of a standing horse in the Louvre; and the "Bashkir" horseman in the collection of the Kremlin Armory.

The Khanty family protective spirit

The rhyton was apparently manufactured in one of Central Asian handicraft centers at the end of the 8th century or in the first half of the 9th century. Generally speaking, the decorative rhyton is, first of all, an item of art belonging to the secular and aristocratic culture although its whimsical shape could be associated with some religious symbols. In the course of trade relations, this article was brought to the north of West Siberia and was included into the ritual practice of the local peoples; it has been a valuable and rare image of a female protective spirit for over one thousand years.

To complete our short story about the mysteries of the articles found on the archeological sites and in ethnographic complexes in the northern areas of West Siberia, we should thank our fortune for the admirable finds and for the opportunity to study them, to think about them and to solve the mysteries they hide.

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