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CHRONICLE

THE MELNIKOV PERMAFROST INSTITUTE, SIBERIAN BRANCH, RUSSIAN ACADEMY OF SCIENCES AT THE TURN OF ITS 60th ANNIVERSARY

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2020 marked the 60th anniversary of the Melnikov Permafrost Institute SB RAS. This paper presents a brief history of its foundation and describes the major research achievements and outputs over the last decade. Promising avenues and projects for further geocryological research are outlined. In view of intensive industrial development of the permafrost regions, the authors believe that the Melnikov Permafrost Institute should be accorded a National Research Institute status with relevant government support.

Key words: *permafrost, geocryology, permafrost engineering, buildings and structures, cryogenic processes, climate change, frozen ground.*

THE HISTORICAL BACKGROUND

In 2020 it was 60 years since the foundation of the Melnikov Permafrost Institute SB RAS (hereinafter – Institute) (Fig. 1).

The Institute has been established on the basis of the Yakutsk Scientific Research Geocryology Station that has existed since 1941(since 1956 Northeast Department) of the Obruchev Institute of Geocryology, Academy of Sciences of USSR (INMERO, Moscow).

The principal decision to establish the Institute in Yakutsk was made by the Decree of the Presidium

Fig. 1. The Melnikov Permafrost Institute, SB RAS. Yakutsk, 2020.

of the Academy of Sciences of the USSR No. 899 of September 16, 1960. Council of Ministers of the RSFSR recommended to establish the Institute within the structure of the Siberian Branch of the USSR Academy of Sciences in the letter No. 2.5897-350 of November 2, 1960 to the Presidium of the USSR Academy of Sciences. On December 9 of the same year, the Presidium of the USSR Academy of Sciences decided to create the Institute "with the purpose of the development of regional studies of permafrost soils of Siberia, necessary to meet the needs of the national economy" and approved a structure of the Institute by the decree No. 1043, which was signed by the President of the USSR Academy of Sciences A.N. Nesmeyanov. The formation of the Institute was very successful in all basic fields of geocryological science, including, certainly, engineering-applied studies. In 1969, the Institute was awarded the Order of the Red Banner of Labor for major achievements in the development of national geocryology. In 1995, the Institute was named after Academician Pavel Ivanovich Melnikov, the founder and first Director of the Institute, by the Decree of the President of the Republic of Sakha (Yakutia) M.E. Nikolaev. According to the statute of the Institute, its basic activities are the fundamental research and applied developments in the following scientific areas: the evolution of the cryolithozone under the impact of natural and anthropogenic factors; thermal and mechanical interaction of engineering structures with permafrost soils. The Institute was referred to the Ministry of Science and Higher Education of the Russian Federation according to the Decree of the President of the Russian Federation of 15.05.2018 No. 215 "On the structure of federal executive bodies" and the Order of the Government of the Russian Federation of 30.05.2018 No. 1055-r.

Academician Melnikov Pavel Ivanovich (1908–1994), one of the founders of the geocryological science, was the founder and permanent head of the Institute from 1960 to 1987 (Fig. 2).

Rostislav Mikhailovich Kamenskii (1936–2008), Doctor of Technical Sciences (post-doctorate degree in Russia) was Director of the Institute from 1988 to 2003. Zhang Rudolf Vladimirovich, Doctor of Technical Sciences, was Director of the Institute from 2004 to 2012. Since 2012, Mikhail Nikolayevich Zheleznyak, Doctor of Geological and Mineralogical Sciences, has been Director of the Institute.

The Institute develops geocryology (permafrost science), which is the research area of national importance for Russia and monitors the cryolithozone, which occupies 65 % of Russia's territory. In addition to six research units in Yakutsk, the institute has a number of regional research units (stations, laboratories, observation sites) located in certain regions of the Russian Federation and abroad (Kazakhstan), has a strong material and technical base [*Shepelev, Zheleznyak, 2019, 2020*].

Fig. 2. Pavel Ivanovich Melnikov (1908–1994), the founder and the first director of the Institute, the first president of the International Permafrost Association, the full member of the USSR Academy of Sciences and Russian Academy of Sciences, Hero of Socialist Labor.

The staff members of the Institute have published about 400 monographs, methodological guidelines, and manuals, have received about 150 patents, and have issued more than 500 scientific and technical developments to industrial partners. In 2012, the Institute with the participation of other scientific institutions has established the world-class research station "Island Samoilovskii" (Fig. 3), which currently operates successfully. The unique engineering structure, the repository of federal importance for cryopreservation and long-term storage of the seed gene pool in permafrost soils, has been put into operation (Fig. 4).

The Institute currently employs 207 people, including 83 Researchers, 17 Doctors and 40 Candidates of science (PhD equivalent in Russia). The Institute offers the graduate study program and includes the branch of the Geocryological Department at the Ammosov North-Eastern Federal University and the Doctoral Dissertation Council. The Institute is the founder of the scientific journal "Earth's Cryosphere" and publishes the popular science journal

Fig. 3. The Arctic research station "Island Samoilovskii", 2015.

Fig. 4. A group of participants at the opening session of the Federal Permafrost Seed Repository against the background of an above-mine structure. Territory of the Institute, 2012.

Fig. 5. The Integrated Geocryological Expedition «Main Pipeline "Power of Siberia"».

"Science and Technology in Yakutia". The Institute has three recognized geocryological scientific schools ("Hydrogeology and Engineering Geocryology", "Permafrost-Climatic Studies', "Geothermics of the Frozen Zone of the Lithosphere"). In 2010, the Institute was licensed to conduct educational activities on a specialty 25.00.08 "Engineering geology, geocryology and soil science". The Institute is a member of the self-regulatory organization (SRO) "Russian Geotechnical Association" (AIIS) to promote the engineering survey. The institute has a Certificate of Conformity to the requirements of GOST ISO 9001-2008. Since 2020, the Institute has been granted the rights to perform the survey with respect to highly hazardous, technically complex and unique objects. The staff members of the Institute have carried out the geocryological studies for the scientific support of the following megaprojects: the South Yakutia Hydropower Complex; the Talakan Oil and gas condensate field; the Elkon uranium deposit; iron ore and coal deposits of South Yakutia; "Mir", "Aikhal", and "Udachnyi" diamond-bearing mines; "Eastern Siberia–Pacific Ocean" oil pipeline; "Power of Siberia" gas pipeline; Vankor gas condensate field; Evenkiya Hydropower Plant; railroads of the Baikal–Amur Mainline (BAM), "Ulak–Elga – Tommot–Kerdem–Yakutsk", "Amur–Yakutia Rail Mainline"; "Vilyui", "Amur", "Kolyma" highways; the high voltage Power Transmission Line st. Khani–Tarynnakh Mining and Processing Plant, and others (Fig. 5).

Acquiring of new knowledge and confirmation of theoretical concepts in the geocryological science is impossible without field studies. The fieldworks have been carried out on an annual basis from 2011 to 2020 by 11 integrated expeditions and 15–20 field teams of the Institute. The geography of the expeditions is as follows: Eastern Siberia (Verkhoyanye, Lena River delta, Novosibirsk Islands); Northern Tian Shan; Altai Mountains; Tibet Mountains. The monitoring of the thermal state of frozen soils are conducted at the research stations and test sites in Yakutia, northern Krasnoyarsk Krai, Magadan Region, and Chukotka. The expedition works are supported by the Russian Foundation for Basic Research, contract-based works, and subsidies from the budget of the Russian Federation.

MAIN RESULTS OF THE GEOCRYOLOGICAL RESEARCH OF THE INSTITUTE IN 2010–2020

A role of the geocryological science at the present stage of the development of our country is determined by expansion and intensification the economic development of the northern and eastern territories located in the distribution area of permafrost (cryolithozone) [*Alekseeva, Zhang, 2011*]. Current climate warming, that is observed almost all over the globe, is particularly evident in the circumpolar regions of our planet. The territory of Yakutia as well as all the Arc-

tic and subarctic regions of the country belong to the zone of the greatest impact of global warming. These conditions require a special approach to the impact on the permafrost according to the law on permafrost protection in the Republic of Sakha (Yakutia) adopted in 2019. This low differentiates between the sparing development in unstable permafrost areas and the intensive development in the stable ones.

The Institute has heavily worked and continues to work with various national and federal committees to prepare the federal law "On the Protection and Rational Use of Permafrost". This enactment is very relevant and well-timed, because overwise, the adoption of the republican law will be complicated.

In the modern world, the issues of global climate warming and its impact on the natural environment are more important than ever. In this aspect, the staff members of the Institute carry out the fundamental geothermophysical and geochemical research, study a structure, cryogenesis of ice-bearing formations, and assess risks of their exploration, as well as research dynamics of cryogenic landscapes and hydrogeological conditions of North Asia. The assessment of reliability of engineering structure bases under conditions of climate change and anthropogenic impacts play an important role [*Alekseeva, Zhang, 2011*].

The most important results of these studies are:

1. A rate of degradation of the subsea permafrost has been determined instrumentally for the first time in the shallow shelf of the Laptev Sea. It has been established, that over 30 years, the submarine permafrost table has been lowered at the average rate of 14, 18.5, 13.5, and 6 cm per year at the distances of 0.3, 0.6, 0.85, and 2.5 km from the shoreline, respectively (Fig. 6) [*Grigoriev, 2017; Shakhova et al., 2017*].

2. A mathematical model of the evolution of the cryolithozone of the East Siberian Sea shelf has been developed to estimate the distribution, transformation rates, and morphological parameters of subaquatic permafrost in the Late Cenozoic. The sedimentary deposits, which occur on the shelf of the central sector of the East Siberian Sea, currently include, presumably, six horizons of relict permafrost. On the inner shelf, thermal degradation of the upper permafrost horizons prevails at the estimated rate of 2 to 20 cm/year. On the middle and outer shelf, the permafrost degrades at the rate of 0.2 to 0.5 cm/year due to diffusion of sea salts. This new knowledge makes it possible to take the permafrost boundaries into consideration during the exploration of the shelf zone of the Eastern sector of the Russian Arctic.

3. The permafrost-landscape and engineering-geocryological maps of Yakutia of 1:1 500 000 scale have been prepared. These maps demonstrate the main patterns of natural and engineering-geocryological conditions and serve as a basis for assessing the sustainability of natural and technical systems in the cryolithozone (Fig. 7) [*Shestakova et al., 2016; Fedorov et al., 2018*].

These maps are currently used in the projects on the assessment and forecast of geocryological settings with the recommendations for the construction of the "Power of Siberia" gas pipeline and for the planning of the socio-economic development of settlements of the Republic of Sakha (Yakutia) for the periods up to 2030 and 2050.

4. The specific features of the unsteady permafrost occurrence in the oil-and-gas bearing regions of the Siberian Platform have been identified and characterized. The maps of the distribution and depths of

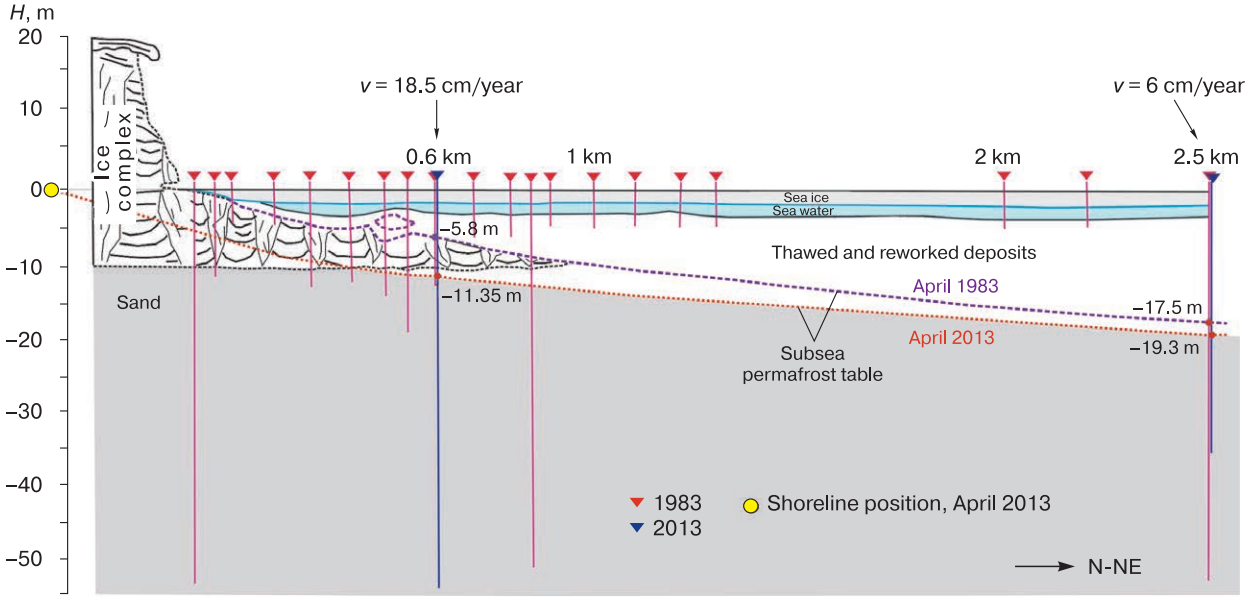

Fig. 6. The drilling profiles in Buor-Khaya Gulf (Laptev Sea) to the north of Muostakh Island, demonstrating the rate of the lowering of the subsea permafrost table (*v*) over 30 years (from April 1983 to April 2013).

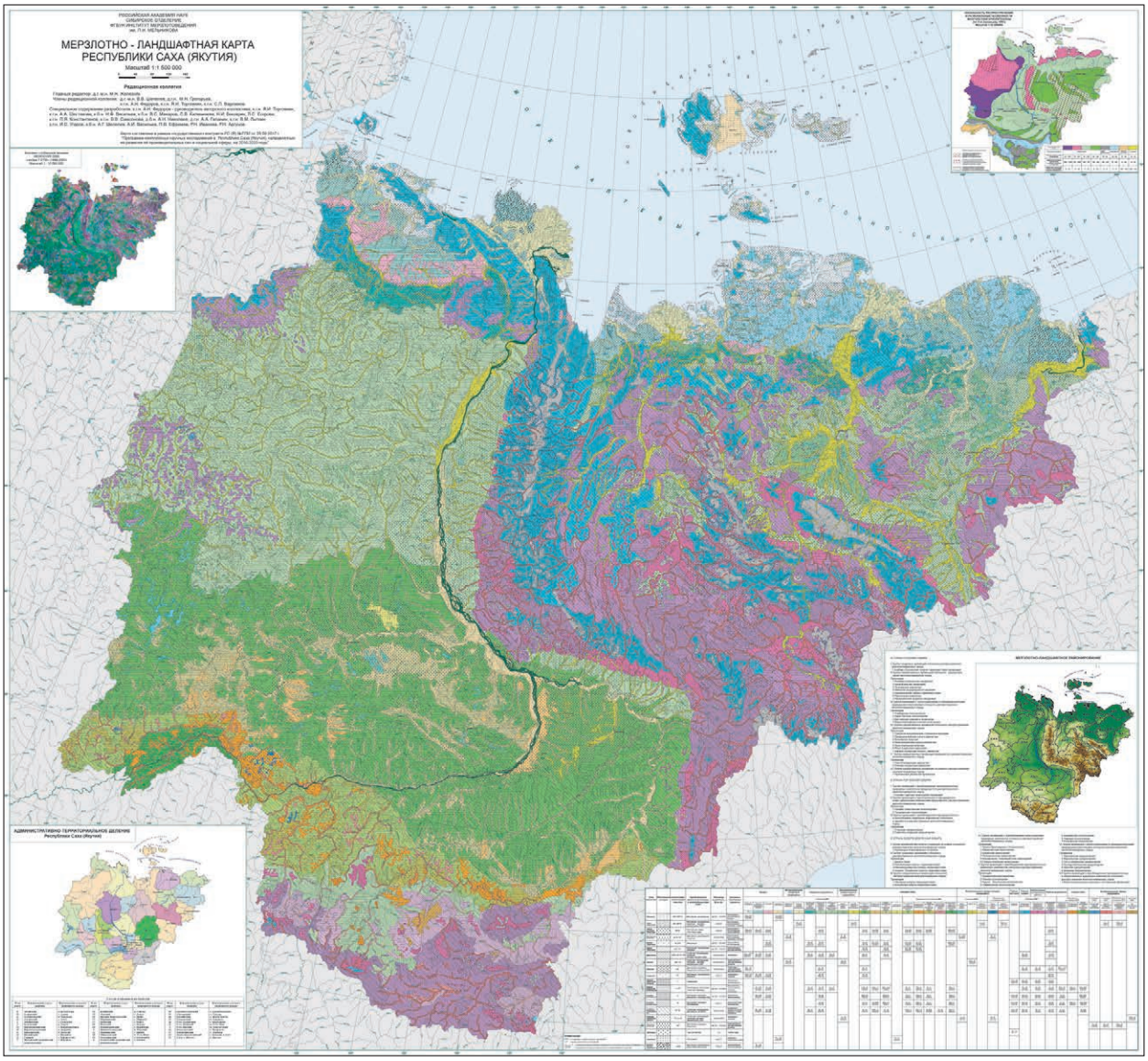

Fig. 7. The permafrost-landscape map of the Republic of Sakha (Yakutia) at a scale of 1:1 500 000 (http://mpi.ysn.ru/images/mlk20182.pdf).

the lower boundary of the permafrost with a series of the permafrost-geothermal sections have been compiled (Fig. 8). The permafrost thickness has been characterized for individual fields, tectonic structures, and within the Vilyui syneclise as a whole. The geocryological databases of the Vilyui syneclise and the Aldan anteclise have been created [*Zheleznyak, Semenov, 2020*].

5. It has been established that during more than 50 years of the operation of the Vilyui HPP, which had been built in the zone of the continuous permafrost, the thermal regime of the cryogenic environment of this hydraulic facility has not reached the stationary regime. The engineering and geophysical monitoring has revealed the changes in the temperature-cryogenic and temperature-moisture regime of the geocryological environment (Fig. 9), as well as the role of rockfill in the heat- and mass-exchange (cryogenic) processes of the artificially created complex natural-technical system. The degradation rate of the cryogenic environment in the areas of the bank adjacencies of the dam and the reservoir bed has been assessed [*Shepelev, Zheleznyak, 2019*].

6. The basic features of the distribution and composition of modern and relict permafrost phenomena in the vast plains and lowlands of Kazakhstan and adjacent regions of Central Asia have been revealed. The basic facies factors of arid (desert) and cryogenic

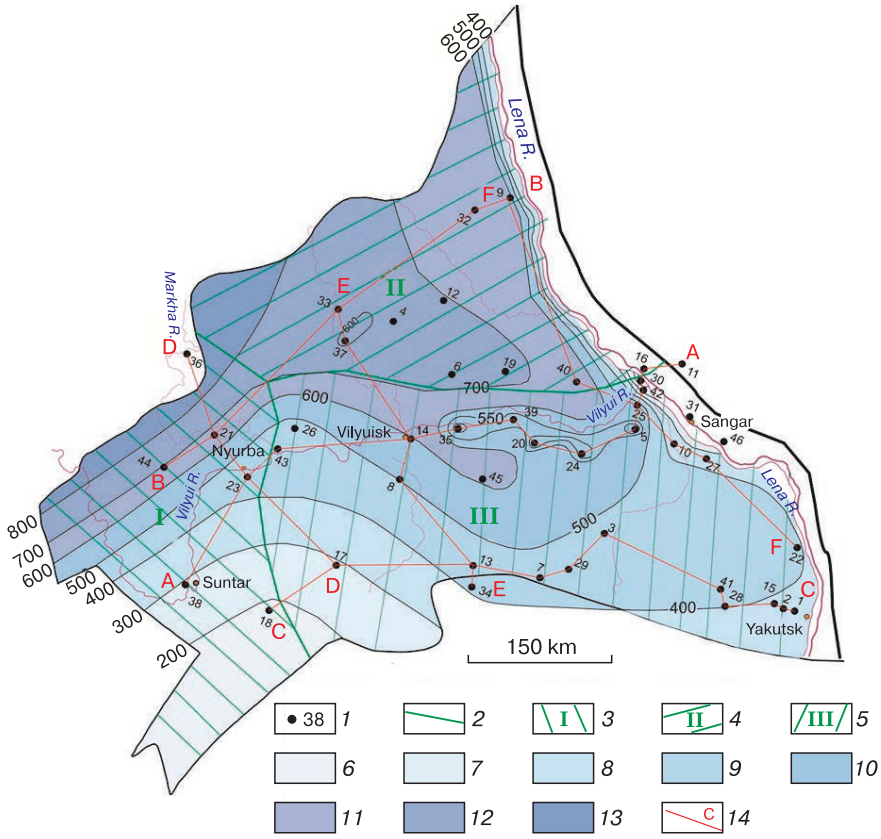

Fig. 8. The map of the depth of the permafrost lower boundary in the Vilyui syneclise:

1 – the exploration area, its number; *2* – the boundaries of the permafrost distribution areas; *3* – I permafrost distribution area; *4* – II permafrost distribution area; *5* – III permafrost distribution area; *6–13* – the thickness of permafrost: *6* – up to 200 m, *7* – from 200 to 300 m, *8* – from 300 to 400 m, *9* – from 400 to 500 m, *10* – from 500 to 600 m, *11* – from 600 to 700 m, *12* – from 700 to 800 m, *13* – over 800 m; *14* – lines of the geocryological-geothermal cross sections.

formations have been identified. The maximum depths, to which zero temperatures have spread, have been established for different types of cryolithogenic deposits [*Shepelev, Zheleznyak, 2020*]. Volumes of ground ice in the mountain regions of the Northern Tian Shan have been estimated for the first time. Dynamics of high-mountain ground ice is being studied.

7. The specific features of the structure, isotopic composition, and age of the glaciers of the Suntar-Khayata Ridge (Northeast Yakutia) have been revealed, and the sizes of the glaciers have been reconstructed for different periods of their degradation.

8. The paleogeography of the formation of the cover dune deposits in Central Yakutia under the conditions of severe desiccating and desert invasion have been reconstructed for the period from the end of the Karginsky thermochron to the beginning of the Holocene. The modern blown dune massifs (tukulans) started to form not more than 1 ka BP. This phenomenon is associated with the climatic events of the Little Ice Age of the 13th–19th centuries. The main types of the Late Quaternary and Holocene dune relief and the areas of its distribution (Dyolkumin Formation) in Central Yakutia have been characterized [*Shepelev, Zheleznyak, 2019, 2020*].

9. The thermal response of the upper horizons of the cryolithozone of Central Yakutia to anthropogenic impacts has been quantitatively evaluated. The 30-year dynamics of the thermal regime of soils has been studied on the basis of a thickness of an active layer and a temperature in an annual heat-turn layer for more than 40 disturbed landscapes in 9 types of terrain patterns.

The monitoring has revealed that climate warming causes the significant increase in the temperature of permafrost at the depth of the annual heat-turn. Thus, the temperature of permafrost in the territory of Yakutsk has increased by 3 °C over the past 80 years. The geocryological and hydrogeological conditions in the near-surface permafrost have been transformed against this background. The formation of multilevel zones of cryopegs (saline waters with negative temperature) has been revealed in the area

a

b

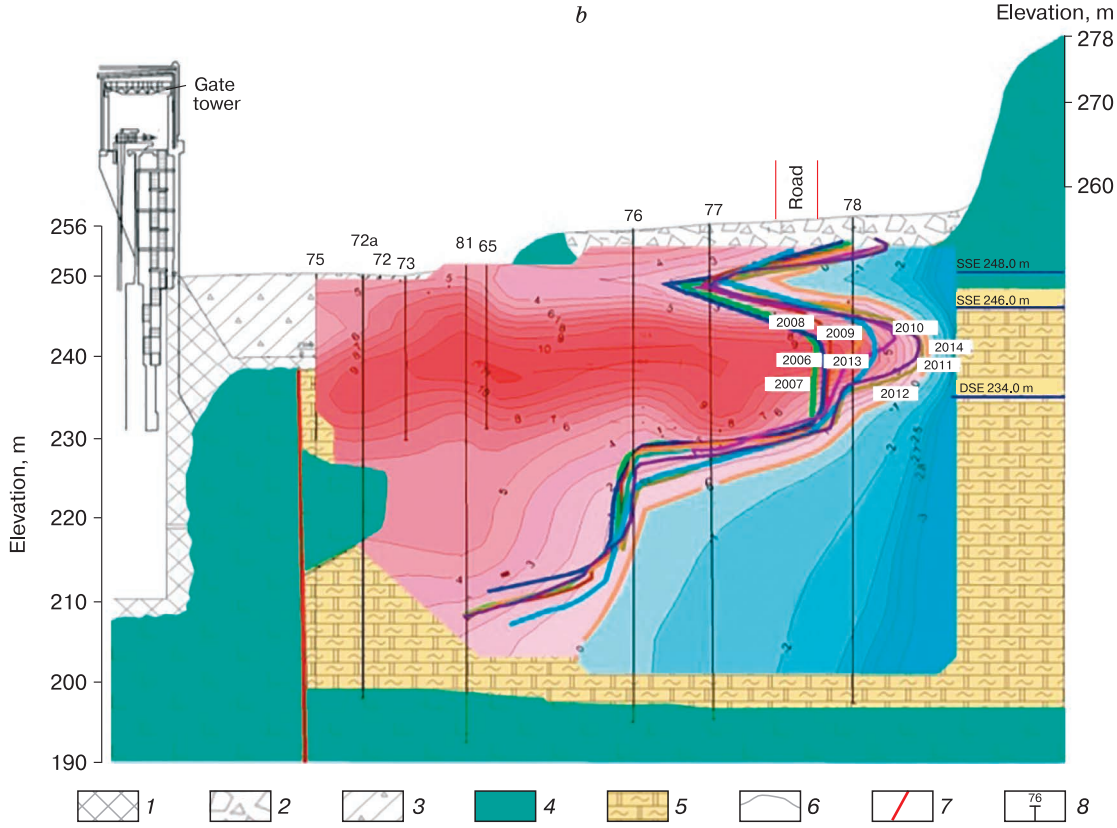

Fig. 9. The general view of the hydraulic facilities of Vilyui HPP-1, 2 (*a*) and dynamics of talik along the transverse profile of boreholes 75–78 for 2006–2014 at the right-bank adjacency of the dam to the mountain frame (*b*).

The talik profile is highlighted in red, shades of red demonstrate dynamics of talik, lines of different colors demonstrate the talik boundary in different years, shades of blue are perennially frozen rocks. *1* – concrete; *2* – blocks, rubble, gruss with sandy loam filler; *3* – gruss soil with loamy filler; *4* – diabase; *5* – xenoliths of carbonate rocks; *6* – geological boundaries; *7* – tectonic contacts of sedimentary rocks and intrusions; *8* – thermometric borehole.

of Yakutsk. The dynamics of their level and variability in their chemical composition indicate that the permafrost, which separate individual horizons of cryopegs, have transitioned into a thaw state [*Shepelev, 2011; Shepelev, Zhang, 2011; Anisimova, Pavlova, 2014*]. Such transformation of the geocryological settings in the northern Russian cities significantly reduces the bearing capacity of frozen bases of buildings and structures, increasing their deformability and accident rate.

The cities of Yakutsk, Mirny, Norilsk, Murmansk, Vorkuta, Apatity, Monchegorsk, Kandalaksha, Kirovsk, Naryan-Mar, and Salekhard are situated in the cryolithozone. The problem of construction of buildings on the frozen bases existed, exists and will continue to exist. It is almost impossible to foresee all the negative features of the thermal and mechanical interaction of buildings and structures with frozen soils in the process of urbanization, but it is a feasible task to minimize them. In this regard, the Institute has developed the techniques, which can provide the reliable operation of the engineering structures under the conditions of climate change and intense anthropogenic impact. The most important of these techniques should include the following:

– the creation of the hardware-methodological complex and the technology of geophysical monitoring to prevent natural and human-induced disasters at large hydrotechnical structures operated in the permafrost zone;

– the creation and implementation of the effective methods for soil stabilization to strengthen the foundation bases in the cryolithozone using nanotechnologies and cryogenic resources;

– the development and implementation of the effective methods for drainage of waterlogged territories in the cryolithozone on the basis of innovative design solutions;

– the development of the territorial construction standards for bases and foundations in the high-temperature cryolithozone;

– the creation of the modern systems to control and manage the stability of headframes in the permafrost zone, etc. [*Velikin, 2012; Alekseeva, 2017*].

Over the period of 2010–2020, the staff members of the Institute analyzed and forecasted reliability of the low-pressure hydraulic facilities in the cryolithozone and developed the design schemes for dams and canals included in them. The comprehensive summary of the dam engineering in the Russian cryolithozone has been made. Results of field studies of the cryogenic-temperature regime of the power and water management structures have been obtained. The temperature regime of the hydraulic facilities is the basis for their static and filtration sustainability. The results of the studies have been applied in design, construction, and operation of many hydraulic facilities, as well as have been included in the regulatory documents. Recommendations for the low-pressure hydraulic facilities on frozen bases have been made. They can be used in construction of new hydraulic and land reclamation facilities in the cryolithozone and reconstruction of the existing ones [*Zhang et al., 2012, 2019*].

Roads and railroads are important objects of the permafrost engineering. Sustainability of road beds remains a crucial scientific and practical challenge. The main ways to prevent their deformations are the lowering of an average annual temperature of the base soils and the keeping them frozen (by means of snow-clearing and painting, with the use of a sun-and-precipitation awning, horizontal (GET) and vertical (VET) systems of soil temperature stabilization, and a film screen) or the preventive removing of ice-rich soils (ice lenses) from the base with subsequent filling of the cavities by non-subsiding soils.

Trunk gas and oil pipelines, as well as roads, are linear structures, the routes of which are laid in the most diverse engineering-geological and geocryological conditions. This requires the acceptance of different schemes for the pipeline laying in certain areas. The underground laying is the most reliable in terms of the impact of external factors on a pipeline. However, even here cryogenic processes (thawing, frost heave) are activated resulting in a loss of sustainability and continuity of the pipe. Therefore, the engineering-geocryological monitoring is very important during the operation of the linear objects [*Alekseeva, 2017*].

The staff of the Institute improve various technologies, which provide the reliable operation of engineering structures under conditions of climate change and intense anthropogenic impact on the territory of their location. This involves the development of the hardware and methodological complex and technologies of the geophysical monitoring on the large hydraulic and mining structures operated in the permafrost zone (Vilyui HPP cascade, “Mir”, “Internationalnaya”, “Udachnaya” diamond pipes, etc.) [*Velikin, 2012; Zhang et al., 2019*].

The Institute has also obtained significant results in the development of the fundamental principles of the use of the cryogenic construction resources of the cryolithozone. The developments in the field of energy-saving technologies are particularly prominent [*Kuzmin et al., 2012a,b; Kuzmin, Kuvaev, 2019*]. During the creation of the seed cryobank in Yakutsk, the new patent developments have been implemented to use the resources of natural cold. This technique is characterized by enhanced sustainability and economic efficiency (minimal energy consumption during operation), providing the stability of the temperature-humidity regime in underground galleries for a long period of time. The uniqueness of the seed cryo-

bank is that it is the first underground facility in Russia, which has been specially built for the long-term storage of plant seeds in the permafrost.

The Institute has also built an experimental garage using the technology of heating based on heat, which is released during phase transitions of water. This technique is effective for the heating of certain types of premises (ice rinks, parking garages, hangars, recreational and sports facilities at children's institutions, various storage facilities, etc.) and for the maintaining of near-zero negative temperatures in the cold season almost all over Russia.

The development of the guidelines for design, construction and operation of structures for various purposes is an important result of the work of the Institute staff members. The guidelines for the design and construction of pile foundations, constructed under conditions of sporadic, discontinuous, and continuous permafrost, with the assumption of their thawing during operation, have been made for the thawing and thaw soils of Magadan Oblast [*Vlasov et al., 2012*].

The guidelines for the design of buildings and structures on spatial ventilated foundations on an intermediate layer (fill) in the areas of perennial frozen soils have been compiled. The guidelines are intended for the calculation of the temperature regime of permafrost soils of the bases, preserved in the frozen state during construction and during the entire specified period of the operation, as well as for the design and technology of the arrangement of the spatial ventilated foundations [*Goncharov, Popovich, 2012; Goncharov, 2016*].

DEVELOPMENT OF INTERNATIONAL SCIENTIFIC RELATIONS

> Close international scientific cooperation in the field of the geocryology is of the utmost importance for the full realization of the modern scientific potential of geocryologists and for the providing of the environmentally safe existence of the modern world.
>
> *Academician P.I. Melnikov*
> [*Klimovskiy, 2008*]

The geocryologists of Yakutia established the first scientific contacts with foreign colleagues in 1963 during the First International Conference on Permafrost (ICP) in Lafayette, Indiana, USA. The Second International Conference on Permafrost was held in 1973 in Yakutsk, Russia, where there were decided to hold ICP every five years. Director of the Institute P.I. Melnikov was the chairman of the founding committee of this major international forum of geocryologists. In the decision of the Second ICP, which was composed and signed by the representatives of the USSR (P.I. Melnikov), the USA (T. Peve), and Canada (R. McKay) it was written: "To consider it expedient to conduct the international integrated studies related to the preservation of the environment in the areas of the distribution of permafrost. They include the exchange of scientific information, reciprocal visits by specialists, effective control over environmental disturbances, and improvement of the methods of the use of natural resources" [*Klimovskiy, 2008*]. Thus, the study of the problems of the environmental protection in the areas of the distribution of permafrost have been launched, especially in relation to the exploration of oil and gas fields and the projects for their development.

In 1983, the International Permafrost Association (IPA) was founded in Fairbanks, Alaska, USA. P.I. Melnikov was elected its first president. All this contributed to the international reputation of the Institute and the growth of the scientific authority of the Yakutia geocryological school. Over the past 37 years, IPA has demonstrated the need of its existence.

Over the subsequent years, the directors of the Institute R.M. Kamensky, R.V. Zhang, and M.N. Zheleznyak have supported and developed the international scientific activities of the Institute staff, achieving success in various fields. Since the 1990s, the international conferences on geocryology have amplified their subjects and increasingly included the cryosphere and other topics in their programs. These are the conferences, which have been annually held in Pushchino, Tyumen, Salekhard, etc. together with the International Associations of geomorphologists, cryosphere sciences, etc.

The Congress of Geocryologists of Russia has been established in parallel with the international conferences at the initiative of geocryologists of Moscow State University and has been held every five years. The Melnikov Permafrost Institute SB RAS has actively participated in these conferences, sending the delegations for presentations in various subforums.

In 1993, R.M. Kamensky, R.V. Zhang, and D.M. Shesternev, together with the Heilongjiang Institute in Cold Region Engineering (Harbin, China), founded and held the First International Symposium on Permafrost Engineering Issues in Chita. It became a complementary event to ICP in the field of engineering. Such symposiums are held every three years in parallel with the Main International Forum of Geocryologists under the aegis of the Council of the Earth Cryology, Russian Academy of Sciences and IPA [*Alekseeva, 2015*].

The Institute maintains mutually beneficial cooperation with many scientists from foreign countries. Research is conducted under contracts, agreements, memorandums of the joint cooperation with institutes and universities in China, Mongolia, Germany, Canada, USA, South Korea, Finland, Japan,

France and other countries. The Institute is the permanent representative in the Arctic Coastal Dynamics (ACD) program of the International Arctic Scientific Committee (IASC), as well as the participant in other international Arctic programs.

Foreign specialists continue to demonstrate great interest in studying permafrost in Siberia. Many institutions actively collaborate with Yakutia geocryologists, in particular:

– The Alfred Wegener Institute (AWI) for Polar and Marine Research (Germany) – the joint studies of the material composition and the history of accumulation of coastal-marine, and frozen alluvial, lacustrine and other continental sediments, their transformation processes in an active layer and taliks of the coastal zone of the Arctic seas, monitoring of the interaction processes in the land-sea-atmosphere system;

– The Swedish Museum of Natural History (Sweden), British University, Oxford (UK) – the joint biogeochemical research in the watershed of the Lena River and its tributaries; the identification of the changes in the transfer of carbon and trace metals in the rivers of the Siberian region due to global climate change;

– The Laboratory of the environment-surface interaction and dynamics, the Paris-Saclay University, Orsay (France) – the study of geomorphological, thermal, and hydrological changes during permafrost degradation, the reactions of the thermal regime of permafrost at depth in response to its degradation;

– The Swedish Meteorological and Hydrological Institute (Sweden) – the study of hydrological processes under conditions of changes in the natural environment of the cryolithozone;

– The Japan Agency for Marine-Earth Science and Technology (JAMSTEC) (Japan) – monitoring of the meteorological, water and heat balance observations, the integrated geocryological and landscape studies at the Tiksi test sites;

– The Institute of Geography, the Ministry of Education of the Republic of Kazakhstan, Almaty, Kazakhstan – the scientific and technical cooperation in glaciology, geocryology, landscape science, geoinformation systems, geomorphology, exogenic and endogenic processes and phenomena, climatology.

The staff of the Institute annually participate in the international conferences abroad: Potsdam, Hamburg (Germany), San Francisco, New Orleans (USA), Frascati (Italy), Brest (France), Brussels (Belgium), Zurich (Switzerland), Fairbanks (USA), etc. (Fig. 10). The Institute, in turn, officially invites from 60 to 100 foreign scientists every year to work under various joint contracts.

The Russian-German expedition "Lena" has been working in the poorly explored East Siberian region of the Arctic for over 20 years. The International Forum "20 Years of the Lena Expedition" was held in St. Petersburg in 2018. The forum was founded by the Arctic and Antarctic Research Institute (AARI), St. Petersburg; the Melnikov Permafrost Institute (MPI) SB RAS, Yakutsk; Helmholtz Center for Polar and Marine Research, AWI (Germany); the German House for Research and Innovation (DWIH, Moscow). Hundreds of articles and tens of monographs, which have explained the current and historical state of the Earth's geosphere and climate change in the Arctic, have been published on the basis of the results of this expedition. The scientific and material and technical base of the Lena expedition, located on Samoilovskii Island, is one of the best Arctic research stations in the world.

In 2018–2019, the Institute established two new analytical laboratories: the Russian–German isotope laboratory to analyze the isotopic composition of water together with the Stable Isotope Laboratory at AWI Potsdam (Germany); the laboratory to determine carbon and water content in soil samples with the use of the LECO RC612 multiphase determinator (USA).

In recent years, the scientific cooperation with the Chinese institutions has been very active. In 2017, the International Research Center for Asian Cold Regions Environment and Engineering (IRC-AACEE) was officially founded in Lanzhou (Gansu Province). The agreement on the establishment of this center was signed between the Northwestern Institute of Eco-environment and Resources (NIEER), the Chinese Academy of Sciences (CAS) and the Melnikov Permafrost Institute, SB RAS. The center focuses on the development the joint research projects in the priority fields including general geocryology, engineering geocryology, and material engineering of cold regions.

Fig. 10. Delegation of the Melnikov Permafrost Institute SB RAS at the XI International Conference on Permafrost, June 20–24, 2016 (Potsdam, Germany).

The International Cooperation Program with the CAS has entered into force. The program includes the following topics: the assessment of the impact of the changing cryolithozone in China, Russia and Mongolia on large engineering structures; the educational exchange of the State Departments of Education and Culture with the People's Republic of China (PRC); the scientific and technical support and preliminary consultations on the Beijing–Moscow high-speed railroad link as part of the project "One Belt and One Road"; the joint studies of the cryolithozone of the Central Asian mountain regions in Altai, Stanovoy Range and Tibet.

The experience of the international cooperation, accumulated by the Institute, demonstrates that it is possible to perform the studies jointly with foreign scientists, including a great deal of field work, laboratory and field experiments, which are related to the study of composition, structure, state of the cryolithozone and the processes of its interaction with other components of the environment, as well as the rapid publication of results obtained in Russia and abroad.

PROSPECTS FOR THE DEVELOPMENT OF THE GEOCRYOLOGICAL STUDIES

To develop the human resources, material-technical and instrumental base of the Institute, as well as the fundamental geocryological study for the future, the application was sent to the Federal Agency for Scientific Organizations (FASO) of Russia in 2016 in order to restructure the Institute and give it the status of the National Research Institute (NRI). The key task of the NRI is to lay the necessary groundwork for new fundamental knowledge in science, providing new opportunities for the implementation of the applied studies and experimental design works in the future. This initiative of the Institute has been supported by the leadership of the Siberian Branch of the Russian Academy of Sciences, the Republic of Sakha (Yakutia), and the Federation Council of the Russian Federation.

The Scientific Council of the Institute has set up the Concept for the Program of the Development of NRI Melnikov Permafrost Institute SB RAS of the Order of the Red Banner of Labor. The strategic goals of the Institute are as follows:

– to achieve a qualitatively new level of scientific knowledge on the distribution, composition, structure of permafrost and the processes of their interaction with the atmosphere, hydrosphere, biosphere and noosphere of the Earth;

– to develop the more technologically advanced and ecologically safe methods of construction of buildings and engineering structures in the northern and Arctic regions of the country;

– to provide the priority development of geocryological studies, taking into consideration the global trends in the scientific development and with active cooperation with scientific institutions-partners;

– to create the support program for the geocryological scientific school to engage talented young people in science, etc.

Current climate change and the increasing industrial development of the cryolithozone put forward new theoretical, scientific, and technical challenges to the geocryological science. They include the identification of zonal and regional patterns of the response of the permafrost upper horizons to climate change and technogenic impacts and the forecast of the development of cryogenic processes, the activation of which significantly increases the ecological hazard of environmental management in the cryolithozone.

Solution of geocryological issues under these conditions is possible with the appropriate support from the State in the course of the reorganization of the Institute into the National Research Institute [*Alekseeva, 2017*].

Unfortunately, the modern scientometric approach of the Federal Agency for Scientific Organizations, and later, of the Ministry of Education and Science of Russia, to the assessment of the efficiency of research institutes does not allow the Melnikov Permafrost Institute SB RAS to achieve the necessary numerical rating of publications to get the NRI status. Although the results of the geocryological studies are primarily needed in Russia for the use of new knowledge in training the specialists in geocryology and for the implementation of the recent innovations in the institutions engaged in the development of the Russian cryolithozone.

In terms of the applied science, the Institute has developed and is ready to carry out the following important initiative projects, subject to availability of funds:

1) sustainability of engineering structures and ecological safety of the northern cities;

2) sustainability of roads in the permafrost zone;

3) optimization of the use of farmlands in the cryolithozone to provide the population with agricultural products;

4) the use of agro-geophysics to control farmlands of the cryolithozone in terms of the increase in soil fertility;

5) dynamics of the continental and subaquatic cryolithozone of the Russian Arctic;

6) the response of cryogenic ecosystems in the Arctic zone of Russia to global climate warming (on the example of the Kolyma Lowland);

7) the development and implementation of the modern engineering-geocryological monitoring of

hydraulic structures (ground dams and dikes) in the cryolithozone of Russia;

8) the cryogenic resources of Russia;

9) the assessment of the prospective use of subpermafrost waters of the cryolithozone as an alternative source of water supply;

10) the building of Akademic town in Yakutsk on the territory of the Melnikov Permafrost Institute SB RAS.

The All-Russian Conference with international participation "Sustainability of Natural and Technical Systems in Cryolithozone" was held in Yakutsk on September 28–30, 2020 to the 60th anniversary of the Melnikov Permafrost Institute SB RAS [*Zheleznyak et al.., 2020*].

The conference program included the following sections:

– the problems of general geocryology; sustainability of natural systems under conditions of climate change and anthropogenic impacts;

– the interaction between surface and ground waters; their role in the formation and dynamics of cryogenic landscapes; geochemical evaluation of cryogenic landscapes;

– the problems of engineering geocryology; sustainability of engineering systems under conditions of climate change and anthropogenic impacts;

– the youth sub-forum "Modern Climate and Permafrost".

Definitely, the results of the geocryological studies have been regularly discussed at various conferences and symposiums, which have been held both in Russia and abroad. However, this conference is significant and relevant because it has been held in Yakutsk, which has been called "the cradle of geocryology" by M.I. Sumgin, the founder of the geocryology.

Over 150 people from Russia (Yakutsk, Moscow, Khabarovsk, Perm, Irkutsk, Novosibirsk, Tyumen, Nizhny Novgorod, Chita, Vladivostok, St. Petersburg) and also from China, Sweden, Kazakhstan and other countries have applied for participation in the conference.

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