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E.I. Petrov
(Federal Agency for Mineral Resources of the Russian Federation)

WE OPEN A NEW CHAPTER OF BRICS COOPERATION

Dear friends!

The key topic in the Russian Federation's BRICS presidency in 2024 is Strengthening Multilateralism for Equitable Global Development and Security. This thesis reflects the striving and desire of all participating countries for constructive cooperation, which is multifaceted and based on the principles of equality, mutual respect, and the sovereign choice of each state's development path.

The expansion of BRICS helps to strengthen its role and influence in global economic relations in the rapidly developing modern world. The dynamics of the global economy development, the introduction of innovative technologies, and the desire to improve the life quality of the growing population of the planet dictate the need for resource and energy support for transformations.

Oil, gas, and coal remain in demand in the near future, as well as copper, aluminium, iron ore, nickel, and platinum due to economy and technology factors. At the same time, demand for lithium, cobalt, rare earths, and other types of strategic minerals is growing.

To ensure that resource scarcity, inaccessibility of production, and rising production costs do not become barriers to progress, we consider it urgently necessary to combine efforts, knowledge, experience, and technology at the international level.

In this regard, the new BRICS states have enormous natural wealth, which can become not only a source of resources for the global economy, but also the basis for technology transformations far beyond the borders of the member states. In order for these minerals to gain economic value, they must be studied, explored, developed, and mined. The pioneers here are undoubtedly geologists.

Therefore, we would like to invite our colleagues and partners — the geological surveys of the BRICS countries — to join forces in order to increase the results of our interaction, to open a new space for cooperation in the field of geology and rational mineral management.

The importance of professional interaction between BRICS geologists lies in the growing significance of geological exploration and mining for the new economy, for strengthening the sustainable national development and ensuring technological progress.

To implement these plans into practical, we propose to hold a round table during Russia's BRICS presidency in 2024 with the heads of geological surveys of the member states, essentially the first meeting of this level in the new composition.

In order to make cooperation regular, the Russian party put forward the initiative to form a permanent mechanism for multilateral interaction — the BRICS Geological Platform.

Prospects for cooperation may include, but are not limited to geological exploration, regional geological studies, innovative technologies in geology, including remote sensing, digital management of mineral resources, harmonization of national resource classification systems, formation of an expert community in the field of mineral management, as well as interaction on other international platforms.

It is important to understand that we are entering terra incognita and will have to work together to develop directions, instruments, and content of cooperation that will be of interest to all participants. I would like to emphasize that interaction will be on a voluntary basis and the degree of involvement will be determined by the national priorities of each participant. We have shared challenges — the exhaustibility of resources, their inaccessibility, issues of financing geological exploration, staffing, etc. At the same time, each participant also has national characteristics, so we will be guided by the principle of «unity in diversity», determining subsequent actions based on the main BRICS principle, a consensus decision.

A lot remains have to be done to establish a mechanism for regular interaction; a new chapter of BRICS cooperation in the field of geology and rational mineral management is being opened to achieve all established goals.

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RESOURCE AND TECHNOLOGY SOVEREIGNTY AS THE FOUNDATION FOR SUSTAINABLE DEVELOPMENT IN RUSSIA

According to the UN and other sources, the growth in global energy consumption will be around 30 % by 2050, even taking into account optimistic energy saving trends. Despite the projected growth in renewable energy production, fossil fuels will continue to be an important part of the global energy mix. It is found that although the share of fossil fuels is expected to reduce from 84 % today to 64 % in 2050, absolute oil production will remain at current levels while 35 % more gas will need to be produced. According to Global Gas Outlook Report by 2050, about 74 % of annual natural gas production will come from approved and new projects, as well as from the development of undiscovered resources. This suggests that current proven reserves are insufficient to meet growing demand and that exploration projects and new discoveries are essential. ***Keywords:*** *energy consumption, fossil fuels, renewable energy sources, hydrocarbons, gas, exploration projects, investments.*

Currently, fossil fuels provide about 84 % of the world and 88 % of Russian energy consumption (Fig. 1) [1,2]. According to the UN and other sources (IEF, IEA WEO 2022, OPEC, WOO), the growth in global energy consumption will be around 30 % by 2050, even taking into account optimistic energy saving trends. Despite the projected growth in renewable energy production (from 86EJ in 2022 to 220EJ in 2050), fossil fuels will continue to be an important part of the global energy mix (Fig. 1). They will account for approximately 64 % of global energy in 2050. [2]. The key regions of energy consumption growth will be South America, Africa and developing countries of the Asia-Pacific Region (Fig. 2). For example, electricity consumption in India will increase by 90 % [3].

Despite the declining share, but taking into account a 30 % increase in energy use, the production and consumption of fossil fuels is expected to increase by about 10 % by 2050. [3]. According to forecasts by the International Renewable Energy Agency (IRENA) [4], onshore wind energy production is expected to increase tenfold and offshore wind energy 43-fold and solar energy 17-fold by 2050. However, even this unprecedented increase in new renewable energy production — 7.5 times in 30 years — would only meet 36 % of the increase in demand when nuclear and hydro are included.

Although the share of fossil fuels is expected to reduce from 84 % today to 64 % in 2050, absolute oil production will remain at current levels while 35 % more gas will need to be produced. This raises the question of whether the existing fossil fuel resource base and the technological capabilities of the oil, gas and coal industries will be able to meet the needs of the global and Russian energy sectors. For example, according to the Gas Exporting Countries Forum's «Global Gas Outlook 2050» [5], natural gas will account for 26 % of the balance, but 27 % of the forecast production has yet to be found (Fig. 3), and the need for investment in hydrocarbon exploration and production to 2050 is USD 9.7 trillion (OPEC estimates USD 12–14 trillion to 2045). The report [5] states that by 2050, about 74 % of annual natural gas production will come from approved and new projects, as well as from the development of undiscovered resources. This suggests that current proven reserves are insufficient to meet growing demand and that exploration projects and new discoveries are essential.

Calculations performed as part of the Russian oil reserves inventory have shown that maintaining current production volumes until 2050 implies the need to increase exploration to ensure the growth of new profitable reserves of at least 4 billion tonnes of oil and 11 trillion m^3 of gas, as well as to create

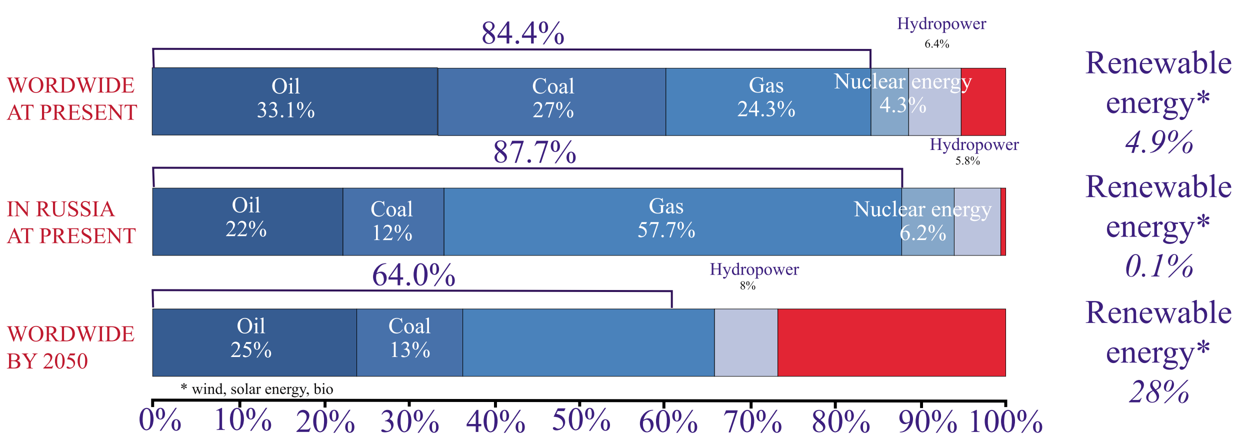


Fig. 1. Energy consumption growth forecast to 2050

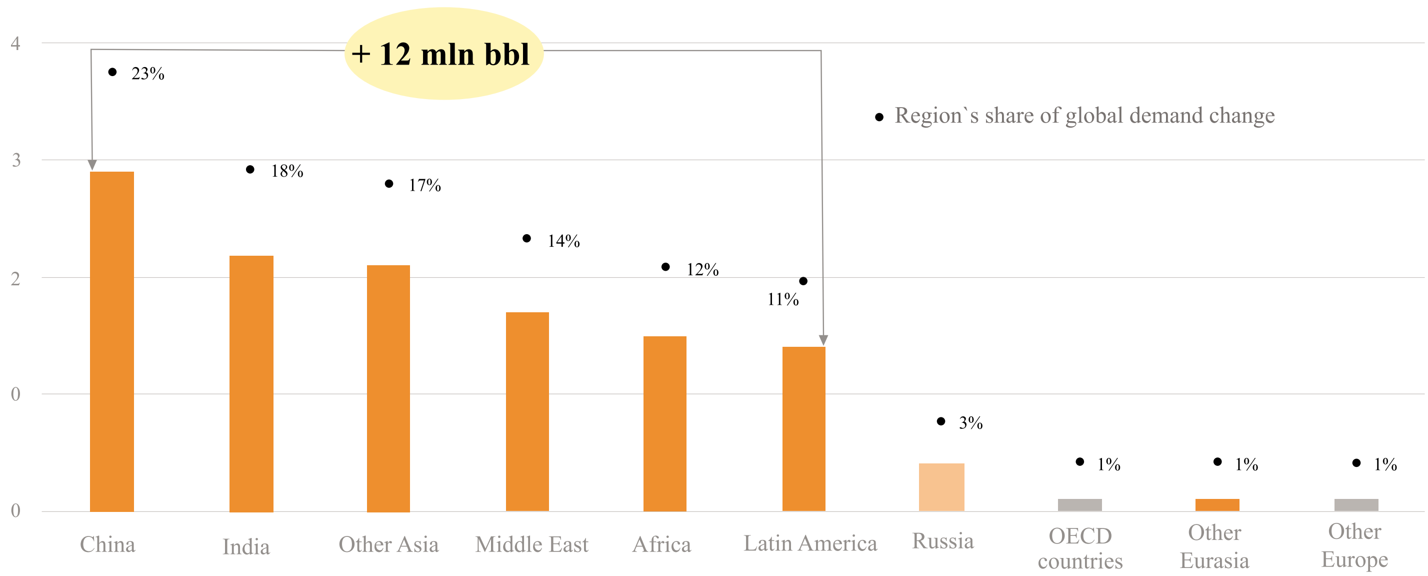
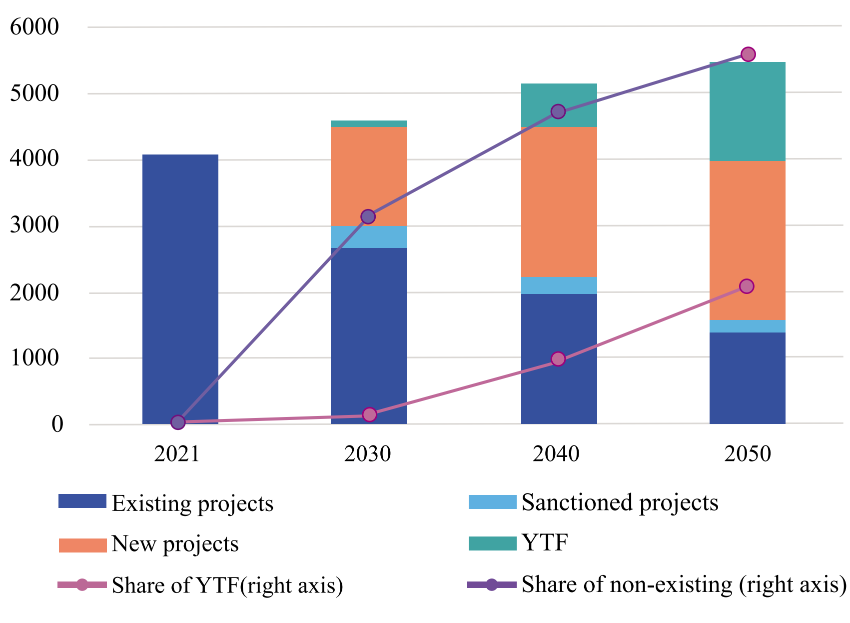


Fig. 2. Oil demand forecast for 2023–2030, million barrels per day



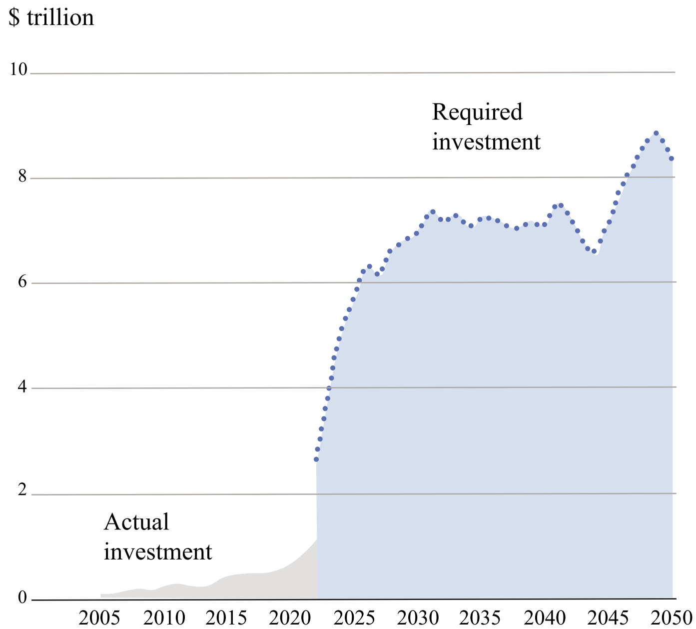
Source: GECF Secretariat based on data from the GECF GGM 2020

Fig. 3. World natural gas production forecast by project status (billion m3, %)

innovative technologies to bring 7 billion tonnes of oil and 5 trillion m3 of hard-to-recover hydrocarbon reserves into development. According to current estimates, the Russian Federation has only about 30 years of economically viable oil and gas reserves. To ensure the necessary level of energy production after 2030, Russia will have to increase hydrocarbon production at the expense of hard-to-recover reserves. By 2030, hard-to-recover oil reserves will account for 36 % of Russian production, and by 2050 they will account for almost half of production. This means that new technologies and efficient production methods will play an increasingly important role. The same trends can be seen around the world. In addition, the growing share of hard-to-recover reserves in the structure of oil and gas production will lead to lower margins and higher prices, which will increase the competitiveness of green energy and stimulate its development.

It is therefore impossible to achieve a global energy balance without hydrocarbons, which, at least until the middle of this century, will determine the trends in energy consumption and thus the main trends in the development of human civilisation.

On the other hand, it is clear that the use of renewable energy will continue to grow, leading to a significant increase in global demand for critical minerals and rare earth elements.



Source: BNEF

Fig. 4. Investments needed to achieve carbon neutrality by 2050 (NZE scenario)

In 2021, the International Energy Agency (IEA) adopted a roadmap to achieve carbon neutrality by 2050, «Net Zero by 2050» [6] (NZE). According to current estimates, the probability of this scenario is extremely low as the required investment growth rate is three times higher than the GDP growth rate forecast (Fig. 4). According to Wood McKinsey [7], a global energy transition to carbon neutrality by 2050 could cost the global economy USD 275 trillion, or 7.5 % of global GDP, which is clearly not feasible.

Of course, it should be noted that energy production from RES in the global economy has more than tripled since 2000, reaching 86 EJ in 2022. However, the share of new RES (biofuels, solar, wind) is still a small fraction of all energy sources, around 7 % of total global energy consumption.

In general, there are two main drivers for RES development: the «green» agenda (long-term industrial development while maintaining a global balance between technological development and minimising man-made environmental impacts) and ensuring energy sovereignty in regions where there are insufficient resources for fossil energy production, which includes coal and hydrocarbons. However, starting from 2022, investments in RES started to decline. 2022 was a period of unprecedented growth in net profits for oil and gas companies, more than doubling from 2021. [2]. However, despite the super profits, some leading energy Vertically Integrated Oil Companies stopped investing in renewable energy. For example, US companies Exxon Mobil, ConocoPhilips and Chevron did not invest in renewables in 2022. BP has slowed its planned cuts in oil and gas production. The company has also reduced its planned annual spending on renewables by 17 % compared to its 2021 plan. A similar trend of slowing RES development is clearly visible in Europe. Between 2000 and 2020, renewable energy production in this region grew from 2. 9EJ to 11.5 EJ, almost quadrupling. By the end of 2021, however, it was only 11.7 EJ, a slight increase over the previous year, and by the end of 2022 it is 12.5 EJ (+6.8 %). Renewables and electric vehicles remain significantly more material intensive than gas, coal and even nuclear power plants (Fig. 5).

Thus, despite assurances from European and American countries about the importance of the «green» agenda, business is showing the first steps towards partial abandonment of RES, which casts doubt on maintaining the current pace of green energy development. The events of 2022 push the energy transition further away, demonstrating the low probability of achieving the goals of the NZE scenario. The NZE scenario requires huge investment, which means funds will be withdrawn from other sectors of the economy. However, it should be borne in mind that maintaining the global energy balance under conditions of uncertainty is impossible without maintaining investment in the oil and gas industry and technology development in this sector.

Nevertheless, according to estimates [8], the demand for metals for «green» energy will increase by more than 50 % by 2030 in the baseline scenario. Demand for lithium, nickel and copper will increase mainly due to the large-scale deployment of renewable energy technologies and the increased use of batteries (Fig. 6). However, there are serious concerns about the sufficiency of current reserves and investment in exploration and production of these metals [9]. In today's world, guaranteed supplies of rare metals are a much more important issue than global oil prices. Experts at the World Economic Forum have identified rare metals mining as the key industry of the near future.

Only about 140,000 tonnes of REEs are mined annually in the world — not much against the background of millions of tonnes and cubic metres of hydrocarbons. But these are critical minerals, as the UNECE calls them, and REEs are the necessary basis for the production of the high-tech products of the XXI century. Demand for these elements is growing rapidly, at around 10 per cent a year, and in a few years' time the growth rate for some of them is expected to be 40 times higher.

Between 2017 and 2022, demand for minerals for the «green» transition doubled. Lithium consumption increased threefold, cobalt by 70 % and nickel by 40 %. As a result of growing demand and rising prices for these metals, the volume of the «green» energy minerals market has doubled in five years. Demand growth for electrical metals will remain strong in the medium term. This will be driven by the energy transition ambitions of a number of countries. According to the IEA [9], a smooth transition to low-carbon energy will require about USD 800 billion of investment in critical mineral production by 2040.

Russia has one of the largest mineral resource bases in the world. Almost all types of minerals are found in Russia: 229 types of solid minerals, oil, gas and gas condensate. The country is among the world leaders in terms of explored reserves of some types of raw materials. Russia ranks first in reserves of gas, diamonds, nickel and gold. It ranks second in reserves of cobalt, tungsten, titanium, silver and platinum group metals. And third in lithium, copper, coal, lead, tin and boron. Russia ranks fourth for uranium and rare earth ele-

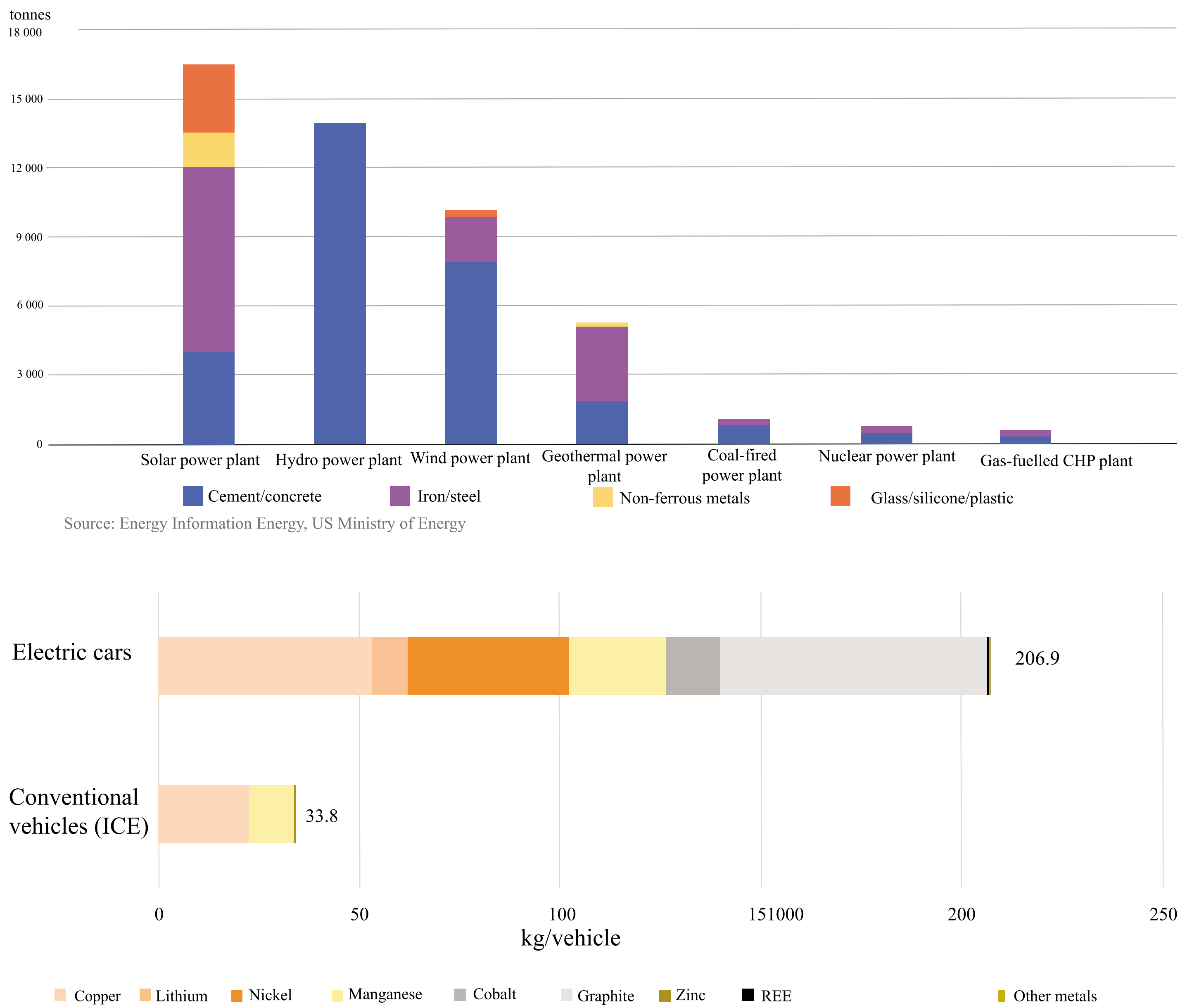


Fig. 5. The amount of metals needed to produce 1 TWh of electricity (top) and to produce different types of cars (bottom)

ments and fifth for recoverable oil and condensate (Fig. 7). Russia's mineral resource base is unparalleled and includes almost all types of rare metals, including lithium, beryllium, niobium, tantalum, titanium, zirconium, rare earth elements, scandium, vanadium and others. However, there are only a few deposits where rare metals are mined to produce finished commercial products. As in many countries around the world, the prospects for profitable extraction are linked to the development of indigenous technologies for geological exploration, production and processing of existing mineral reserves.

One of the critical types of mineral raw materials is lithium, a key resource of the future economy. According to some estimates [10], about 4.5 million tonnes of lithium carbonate equivalent (LCE) are needed to meet the global demand for lithium from battery manufacturers and other consumers. Current and future global supply is insufficient to meet growing demand. This opens up new opportunities for countries with large lithium resource potential, including Russia with its potentially huge brine lithium resources.

Today, the world's lithium resources are mainly concentrated in South America (60 %), Australia (9 %) and China (8 %), while Russia has 1 % of the world's resources (according to the US Geological Survey, which covers only ore lithium). If brine is taken into account, Russia's lithium resources can be increased by a factor of 23 (114 million tonnes of LCE compared to the current 5 million tonnes of LCE of ore lithium), which would put our country in one of the top places (Fig. 8).

Copper is also one of the key metals of the future. According to [11], global copper reserves amounted to 1 billion tonnes in 2023. The largest copper producing countries are Chile (190 million tonnes), Australia (100 million tonnes), Peru (120 million tonnes), Russia (80 million tonnes), Mexico (53 mil-

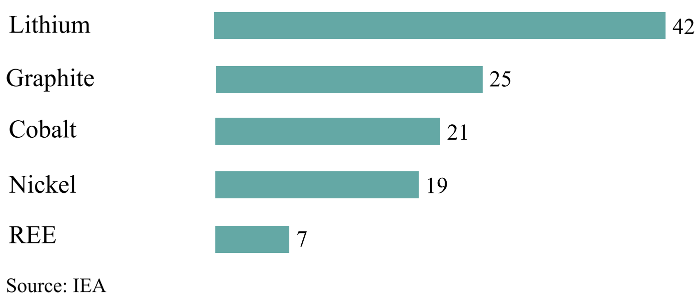


Fig. 6. Expected growth in demand for rare metals relative to demand in 2020 (IEA, 2022)

lion tonnes) and the USA (50 million tonnes). The world's copper supply depends mainly on Chile (27 % of world production) and Peru (10 %). In addition, more than 10 % of the world's copper reserves are located in Africa, where ores also contain cobalt, zinc, uranium, cadmium, germanium, radium, lead, silver, gold, platinum and palladium in commercial concentrations. According to the World Bureau of Metal Statistics [12] and the estimates of Shanghai Metal Market experts, there will be a shortage of copper ore both in China and globally.

Huge reserves of critical mineral commodities and REEs are concentrated in Africa, which leads the world in reserves of platinum group metals, chromium, manganese ores, cobalt, gold,

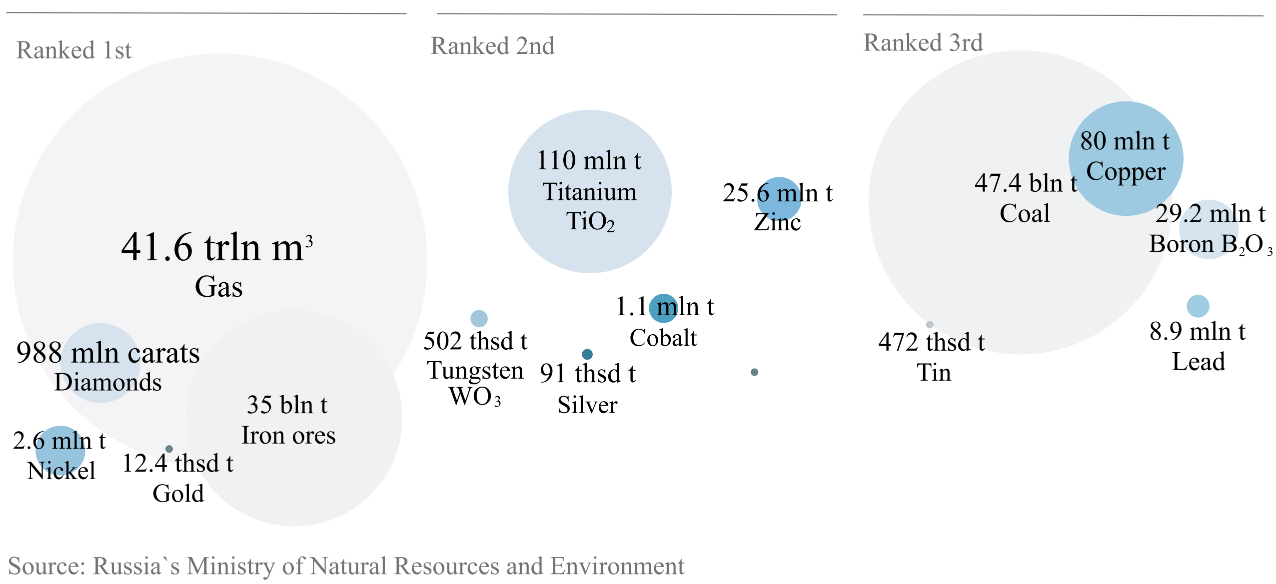


Fig. 7. Russia's position in the world in terms of minerals reserves (Source: Ministry of Natural Resources and Environment of the Russian Federation)

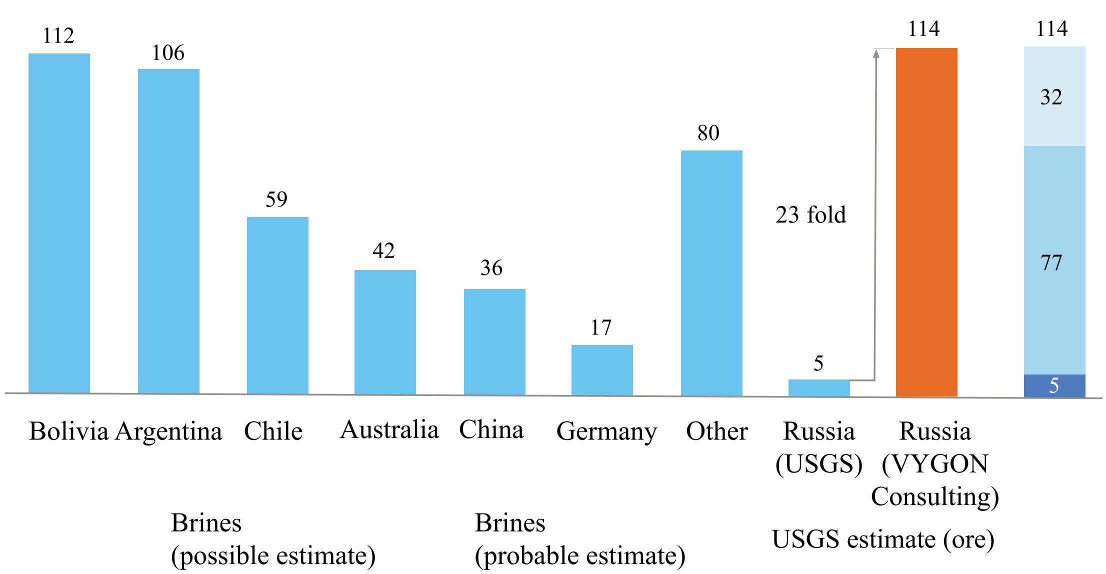


Fig. 8. Structure of world lithium resources by country, including brine resources of the Russian Federation, million tonnes, LCE

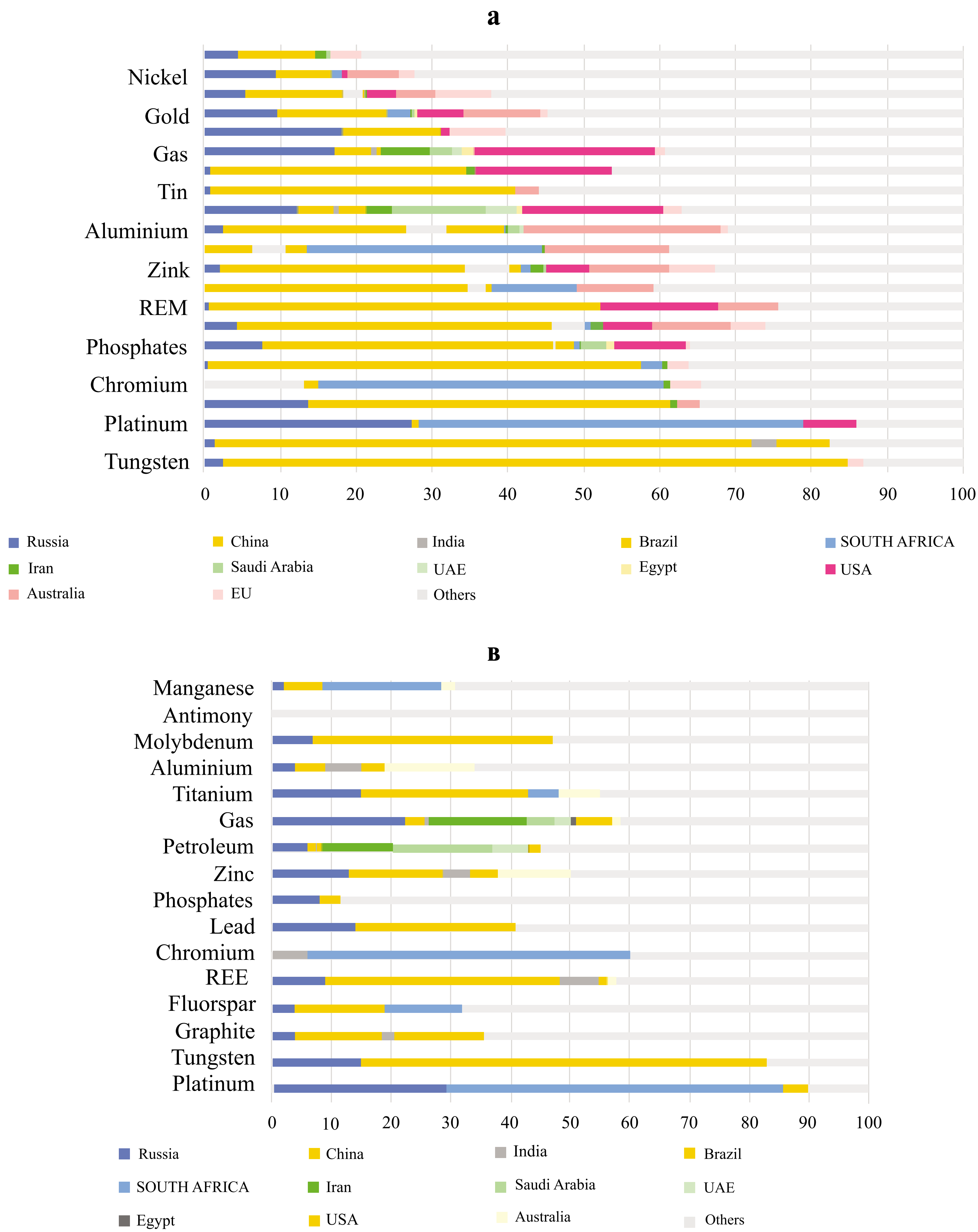


Fig. 9. Share of production (a) and reserves (в) of the world's major critical minerals, including the BRICS countries

diamonds, bauxite, phosphorites. African reserves of fluorite, zirconium ores, uranium, tantalum, beryllium, titanium, nickel, copper, vanadium, lithium, antimony and gemstones are significant. Africa's share exceeds 30 % of global resources in a number of areas: up to 35 % for chromium, over 40 % for bauxite, 50 % for cobalt and manganese, and 90 % for platinum group metals. Africa plays a major role in the global production of chromium and manganese. For example, South Africa's chromium production in 2022 was 44 % of the world total. Only Kazakhstan comes close to South Africa in terms of explored chrome ore reserves (36 and 41 % of world reserves respectively) [11]. Africa produces more than 60 % of the world's manganese, about 30 % of the world's bauxite and more than 75 % of the world's cobalt (68 % of which is mined in the Democratic Republic of Congo).

We can therefore conclude that the main risks to the sustainable development of the global economy lie in the exhaustibility of fossil fuels and the imbalance in reserves of critical mineral raw materials and technologies needed for the successful implementation of the energy transition. On the other hand, the mineral resource sectors of the BRICS countries are complementary in terms of both extraction and production of critical minerals (Fig. 9), and one of the possible directions of their cooperation in this area is to expand their mutual trade in mineral commodities and metals to ensure continuity of supply and price stability. For example, South Africa and Brazil have significantly increased their mineral exports through intra-BRICS cooperation, while China has become the largest buyer of critical minerals and REEs, ensuring continuity of supply from other BRICS countries.

A simple analysis shows that the accession of new members will provide 72 % of the world's rare earth reserves (for example, with the accession of Argentina, three of the top five lithium producing countries are BRICS members). In March 2023, at a meeting between the heads of the Federal Agency for Resource Management Rosnedra of Russia and the Geological Committee of South Africa, Russia proposed a BRICS geological platform, which would strengthen cooperation between the members of the association in the field of geology, in particular in the field of regional geological research, new technologies in geology and resource classification. An important area of cooperation between the BRICS countries in the field of mineral resource sector is the coordination of actions to increase the efficiency of their influence on the global minerals market and to maximise the economic impact from the use of their exhaustible natural resources.

With the aggravation of the geopolitical situation, the issues of resource and technology sovereignty are coming to the fore. Resource sovereignty aims to strengthen the independence of countries in providing themselves with strategic resources, while technology sovereignty aims to ensure efficient technologies for extracting and processing the necessary resources. In this sense, the main goal of Russia and other countries rich in natural resources, first and foremost the BRICS countries, is to commit to both national and global goals of sustainable development and the value of resources, which are threatened by depreciation due to the policies of the G7 countries using various instruments aimed at creating a system of technological dominance over exporting countries and establishing global control over pricing by technologically advanced countries that do not have their own resource base. Russia, like all countries with resource potential, needs a new system of resource management, which implies technological sovereignty in geological exploration, production and processing of mineral raw materials. A few key areas can be emphasised:

- new tools need to be created to attract both traditional and digital investments, using the newly created fair and equitable resource management system based on the UN FC and modern technologies that provide reliable and equal access to the resources of financial institutions;
- defining a list of critical minerals for the BRICS countries, taking into account the concept of sustainable development, as well as forming all components of the technological strategy for their reproduction, production, processing and consumption;
- creation of a unified international bank of modern innovative technologies that would increase the efficiency of mineral production while reducing the costs of geological exploration and extraction.

Ensuring technological sovereignty will also require decisive steps in science and education. This in turn requires the creation and development of an ecosystem that includes leading technology companies, start-ups, universities and research institutes; the provision of funding and favourable conditions for the development and accelerated implementation of new technologies, as well as the speeding up the processes of testing and commercialisation of high-tech solutions; the creation of an effective system for the training of personnel and qualified experts.

The world is already facing unprecedented global challenges. That is why our common goal is to create new opportunities for sustainable development of all countries, not just «elite» ones. This is a key priority for Russia, BRICS and many other countries that believe in a fair future of a multipolar world.

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MINERAL RESOURCE BASE OF THE BRICS+ COUNTRIES: OPPORTUNITIES FOR COOPERATION

This paper provides the analysis of mineral resource base and mining industry of BRICS+ countries and their position in the world mineral commodities markets. Special attention is paid to strategic and critical minerals and metals, which are essential for a range of clean energy technologies and other high-tech industries. There is a significant potential for cooperation in mining sector within BRICS+ member countries. ***Keywords:*** *mineral resource, mining industry, international cooperation, BRICS countries.*

The term BRIC was coined in 2001 by *Goldman Sachs* Investment Bank chief economist Jim O'Neill. Four countries — Brazil, Russia, India and China — were grouped together on the basis of their large national economies and high rates of economic growth. O'Neill predicted a fundamental shift in the balance of global economic power and concluded that by mid-century these four countries would become the leading economic powers, surpassing the G7 countries in terms of GDP [11]. As an intergovernmental organization, BRIC was founded in 2006 at the St. Petersburg Economic Forum with the participation of economic ministers from Brazil, Russia, India, and China [9]. In 2010, the first expansion took place — South Africa joined the organization (after the accession referred to as BRICS). As of August 2023, 40 countries have expressed interest in joining BRICS, about 20 of them have officially applied for admission.

As of January 2024, four more countries have joined the organization: Egypt, Iran, the United Arab Emirates, and Ethiopia (after accession referred to as BRICS+). BRICS summits have been held annually since 2009, with the previous 15th summit held in August 2023 in South Africa. The BRICS+ member countries established the New Development Bank to finance infrastructure and sustainable development projects. The BRICS+ countries have established the BRICS+ Contingent Reserve Arrangement (CRA) for the mutual provision of funds by the central banks of the countries in case of liquidity problems, the BRICS+ currency creation project and other joint financial and infrastructure initiatives are under consideration [2].

According to the *World Bank*, as of 2022, the BRICS+ member states accounted for 45 % of the world's population, 30 % of the land area and 31 % of global GDP.

The alliance members hold complementary mineral resources enabling to resolve problems of minerals and products of their processing supply within the framework of mutually beneficial international trade and economic relations. Together, the BRICS+ countries control 75 % of global resources and 72 % of world chromite production, 61 % of resources and 71 % of coal production, 60 % of resources and 90 % of niobium production, 54 % of resources and 68 % of fluorspar production, 46 % of resources and 78 % of graphite production, 43 % of resources and 49 % of titanium production, 38 % of resources and 53 % of manganese ore production (Fig. 1).

Below is a brief description of the mineral resource base of the BRICS+ member countries in the order in which they joined the association.

Brazil has a lot of different mineral resources wide variety of minerals, supplying the global market with a wide range of mineral commodities — from ores and concentrates to metallurgical products. The country is the world leader in iron ores, tantalum, niobium, graphite resources. It also ranks in the top ten for a range of economically and socially important minerals, including uranium, manganese ores, bauxite, nickel, copper, tin, vanadium, lithium, rare earth elements (REE), gold, and phosphates (Fig. 2) [6].

The majority of mined minerals are sent to the world market after beneficiation. For some of them, Brazil holds key positions, for example, being one of the leading suppliers of iron ore, graphite, alumina. In addition, the country provides a significant volume of the world supply of manganese ferroalloys, refined tin, and vanadium pentoxide. Brazil has a unique position in the niobium market, being a world monopolist and providing up to 90 % of global demand — production of ferroniobium and niobium pentoxide is based on the world's largest niobium deposits. The main buyers are Chinese companies.

There are opportunities to drive the development of a number of commodities in the face of rising demand, such as REE. Brazil REE reserves are tied for third highest in the after Chinese and Russian (21 thousand tons TREO). Most of them are associated with complex deposits, which are mined for niobium and phosphorus, but light group of elements (La, Ce) predominate in REE-bearing ores. Ore processing does not yet recover REE products, but some companies are conducting R&D studies for extraction technologies. Main exploration works are carried out at another type of deposits — «ionic clays», the main source of heavy REEs. They become increasingly important, pilot operations at one of the projects started in 2023.

Brazil is highly dependent on imported coking coal (lignite accounts for two-thirds of the country's indigenous resource

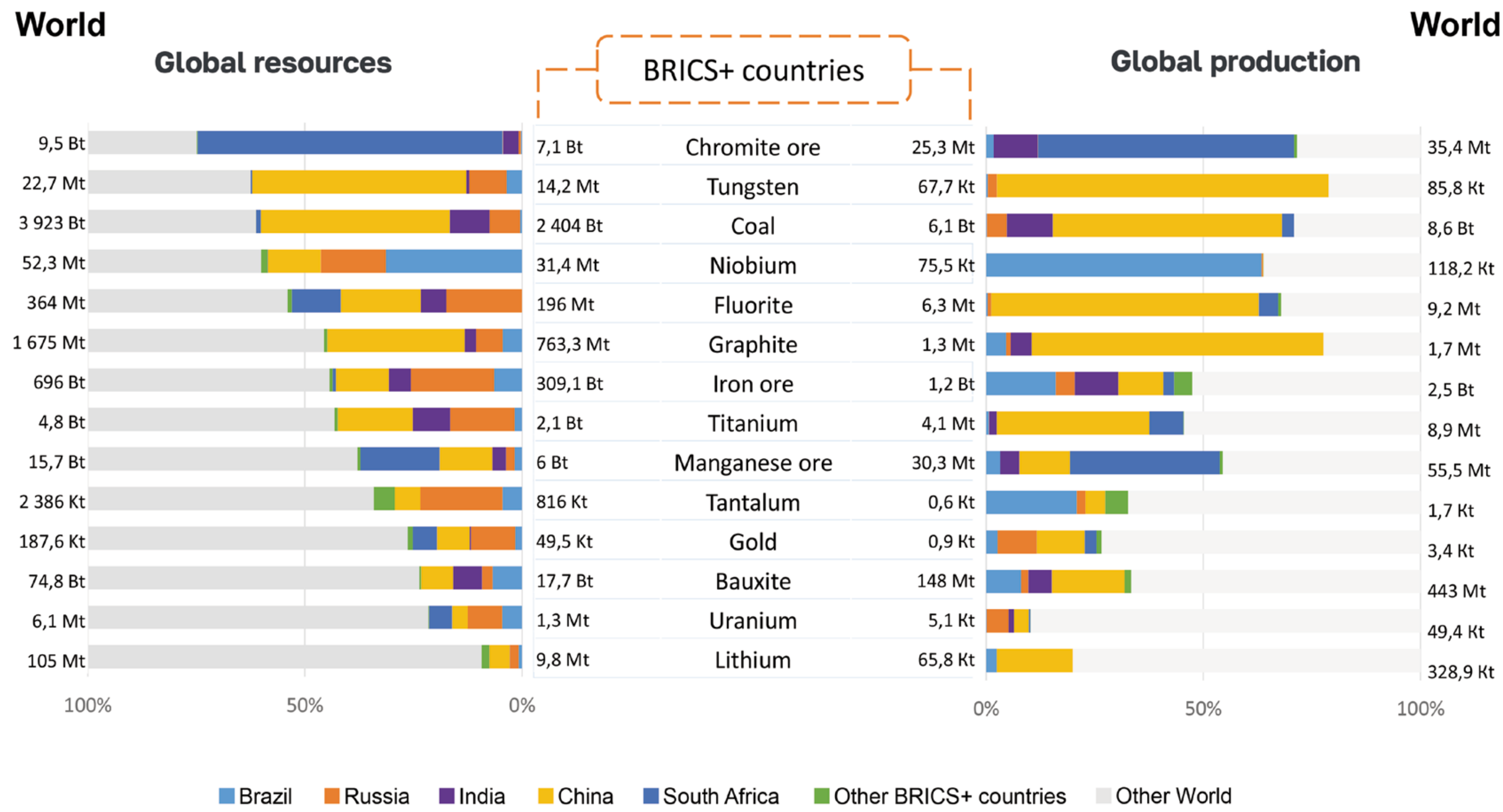


Fig. 1. World's and BRICS+ mineral resource and production

base) and mineral fertilizers (domestic production is insufficient). Among other imported commodities, crude metals and various alloys predominate.

Russia steadily maintains its position as one of the world's leaders in terms of resource base and mineral production, which is in demand both domestically and on the global market. The country's strong resource base is the key to its sustainable position in the global commodity market. Various types of minerals have been identified on the territory of Russia and its continental shelf in varying amounts. The country ranks first in the world in the reserves of natural gas, diamonds, iron ore, nickel and gold, second in the reserves of titanium, tungsten, PGMs (mainly palladium), vanadium, silver, zinc, cobalt and the most important types of agricultural raw materials — potash salts and apatite ores [10] (Fig. 2).

Russia ranks first in the world in the production of diamonds and palladium, second in natural gas, vanadium, platinum and potassium salts, and is one of the world's leading producers of crude oil, gold, nickel, tungsten and cobalt (3rd place in the world), silver and apatite ore (4th place), and iron ore (5th place).

Russia is also the largest supplier of a number of commodities to the world market, sending both minerals directly after primary processing: oil, natural gas, rough diamonds, antimony concentrates, and finished products: metallic aluminum and titanium, vanadium pentoxide, refined palladium, nickel, copper, cobalt, mineral fertilizers.

In addition to the exploitation of its own mineral resources, Russian companies are also active in the purchase of a range of commodities abroad: chromite, manganese and titanium concentrates, fluorspar, uranium, bauxite and alumina, lithium compounds, and some other types of industrial minerals.

Russia has great potential for the development of various metals and minerals required for high-tech industries, such as lithium compounds, tantalum, niobium, separated rare earth elements, scandium, vanadium. Some types of products are already produced — Russia is one of the four producers of scandium oxide and the world's second largest producer of vanadium pentoxide. Mixed REEs, tantalum and niobium pentoxides are produced in small quantities (less than 1 % of the world total), but intensive development and implementation of added-value metallurgy technologies is underway. Given the significant potential of the domestic mineral resource base, Russia has opportunities to take leading positions in these areas as well.

India is called one of the fastest growing major economies in the world after China. The main driving force behind this development is the growth in domestic demand for a wide range of commodities. According to *World Population Review* (*WPR*) estimates, India's population will grow to 1.417 billion in 2023, surpassing China by 5 million. A growing population requires a growing supply of various resources, including mineral raw materials.

India has significant reserves of energy, metals and rock raw materials with a high degree of involvement in development. For most of them, the country is among the leaders in terms of both resources and commodity production (coal, iron, manganese and chromite ores, bauxite, titanium, fluorspar and other) (Fig. 2). To meet enough domestic demand, mineral production is also imported. Other types of minerals do not have a defining influence on the country's economy, the resource base of non-ferrous, minor and rare metals, diamonds, agrochemical materials represent 0.1–2 % for each, except for titanium (8 %), zinc (4 %) and lead (3 %) [4].

India is one of the world's largest importers of fossil fuels (mostly oil), fertilizers and semi-finished goods. In addition, being the largest producer of small diamonds India also most of the world's low quality rough diamonds.

With a strong raw material base and a well-developed processing sector, the country's production volumes of finished metallurgical products allow it to rank the first lines in the production of steel and aluminum metal (2nd only to China), refined zinc and lead production (3rd), ferrochrome (4th) and manganese ferroalloys (5th).

The mineral potential of the metals most in demand on the world market (lithium, nickel, cobalt) has been poorly explored or not identified to date. India has a sufficiently developed graphite resource base (3 % of the world's total), which allows it to produce 5 % of the world's production (5th place in the world); relatively small reserves of copper (less than 1 % of the world's total) have been explored and are being developed.

China has one of the world's largest, rapidly developing integrated mineral resource base (hydrocarbons, coal, ferrous, non-ferrous, minor and rare metals, diamonds, industrial, chemical and construction raw materials), which largely provides a developed industry of mineral processing and production of finished goods with high added value (Fig. 2).

The market for most commodities is determined by the state of China's industry and its development. China produces most of the output of crude steel, bulk and noble ferroalloys, non-ferrous (aluminum, copper, nickel, zinc, lead, cobalt, titanium, tin, tungsten, molybdenum, antimony, bismuth, etc.) and rare (vanadium, gallium, germanium, magnesium, lithium, indium, selenium, tellurium, REE, etc.) metals. In most cases the production is consumed domestically. The shortfall is filled by imports.

China ranks among the top five countries in the world in terms of resource base and production of most types of industrial, chemical and construction raw materials, including fluorspar, graphite, magnesite, phosphorites, potassium salts, cement [8], etc., meeting its domestic needs and exporting these commodities to foreign markets.

Particular attention is paid to the state of the industry for the production of types of commodities responsible for the «green energy transition»: lithium compounds, metallic manganese, copper, nickel and cobalt, vanadium, separated REEs, graphite. China is not only their leading global producer,

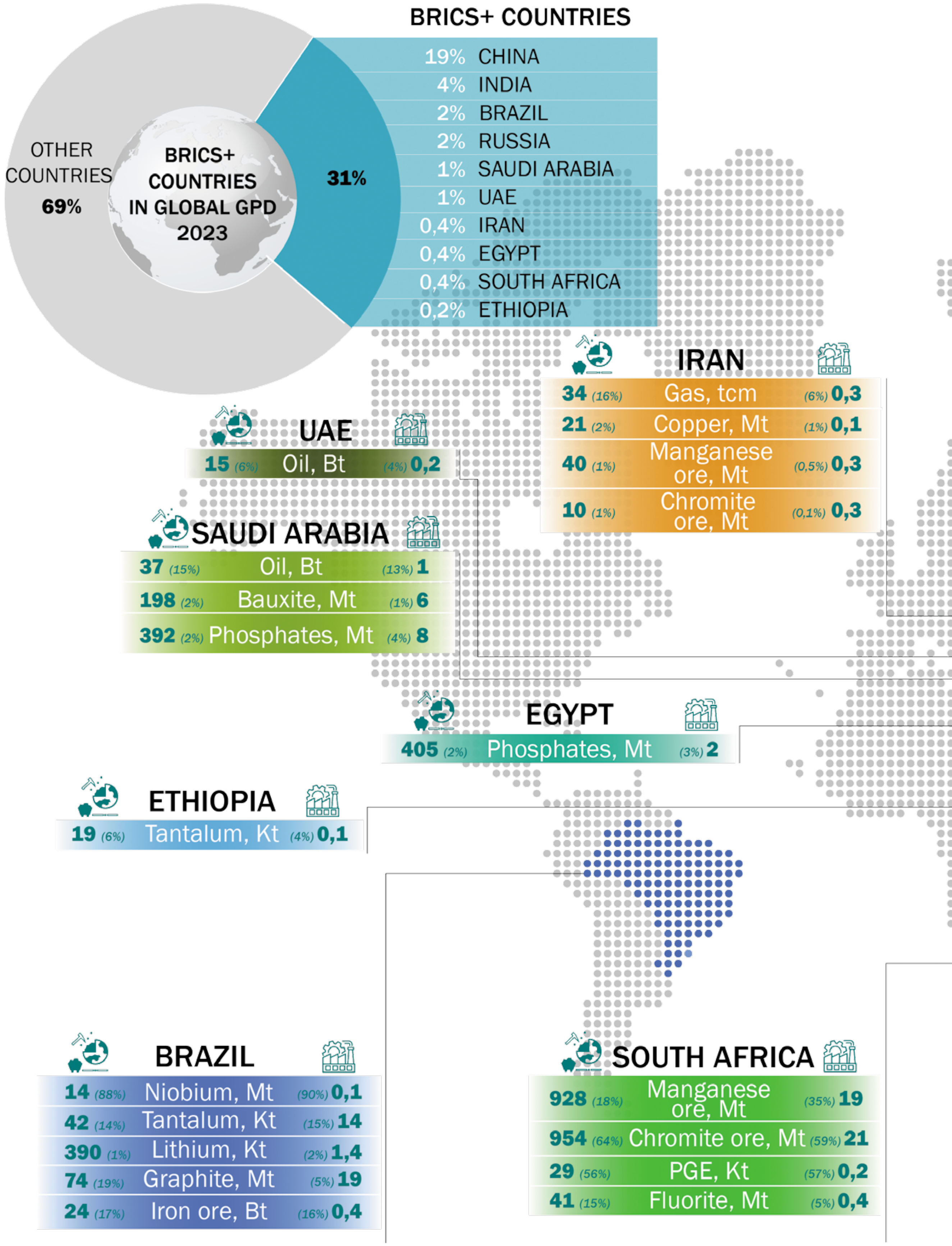
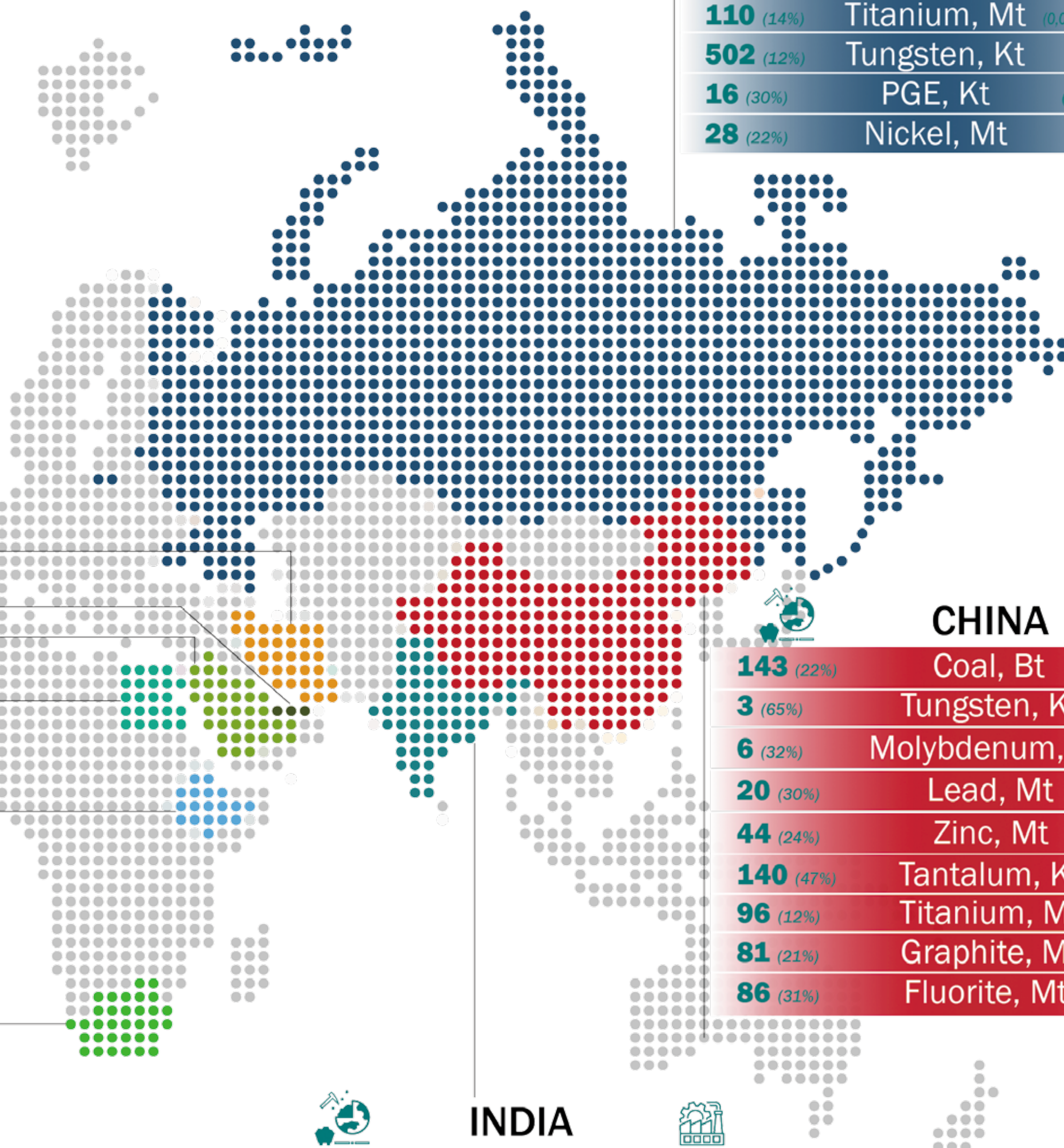


Fig. 2. BRICS+ countries mineral reserves and production



RUSSIA

Reserves		Production
19 (8%)	Oil, Bt	(11%) 0,5
46 (22%)	Gas, tcm	(17%) 1
1 000 (55%)	Diamonds, M carats	(32%) 42
35 (24%)	Iron ore, Bt	(4%) 0,1
12 (23%)	Gold, Kt	(10%) 0,3
110 (14%)	Titanium, Mt	(0,0.3%) 0,004
502 (12%)	Tungsten, Kt	(2%) 2
16 (30%)	PGE, Kt	(27%) 0,1
28 (22%)	Nickel, Mt	(7%) 0,2

CHINA

Reserves		Production
143 (22%)	Coal, Bt	(52%) 5
3 (65%)	Tungsten, Kt	(77%) 0,1
6 (32%)	Molybdenum, Mt	(43%) 0,1
20 (30%)	Lead, Mt	(44%) 2
44 (24%)	Zinc, Mt	(32%) 4
140 (47%)	Tantalum, Kt	(3%) 0,1
96 (12%)	Titanium, Mt	(35%) 3
81 (21%)	Graphite, Mt	(0,1%) 1
86 (31%)	Fluorite, Mt	(62%) 6

INDIA

Reserves		Production
111 (23%)	Coal, Bt	(10%) 1
79 (5%)	Chromite ore, Mt	(10%) 3,6
94 (2%)	Manganese ore, Mt	(4%) 3
64 (8%)	Titanium, Mt	(2%) 0,2
647 (6%)	Bauxite, Bt	(5%) 24

Reserves

Production

(18%) Share of Global, %

but also a supplier to the world market of finished products, without which the possibilities of introducing alternative energy sources into the energy infrastructure of other countries around the world are significantly limited (solar panels, energy storage, elements of wind turbines, electric vehicles, etc.).

Foreign trade serves as an additional source of raw materials to meet the needs of the manufacturing industry. For most commodities, Chinese imports far exceed their exports. The most important imported mineral commodities for China are oil, natural gas, coal, uranium, high-quality aluminum and iron ore, as well as manganese and chromite's ores, nickel, cobalt, rare (lithium, tantalum, niobium, zirconium) and rare earth metals (REE), PGE, diamonds, and potash fertilizers. Despite a strong domestic own mineral resource base and leading positions in production imports of ores and concentrates of titanium, copper, tin, molybdenum, tungsten, metallic copper and silver, rock salt, sulfur, asbestos, cement and other types of mineral raw materials also significantly exceed their exports.

The main commodities for which China's exports substantially exceed its imports are petroleum products, metal titanium, tungsten, molybdenum, tin, phosphate fertilizers, barite, in the reserves and production of which China is the world leader, fully providing their domestic consumption with domestic mining and processing.

In addition to international commodity trading Chinese mining companies are intensively investing in world-class mineral assets around the world, including hydrocarbons, uranium, iron ore, bauxite, cobalt, rare and rare earth metals, graphite.

South Africa is a «treasure trove» of Africa, one of the continent's most developed countries with a unique mineral resource potential: it has the world's largest resource base of chromite and manganese ores, platinum group metals (with platinum dominating); significant amounts of uranium, gold, diamonds, titanium and other types of metallic (iron ores, copper, nickel, lead, zinc, zirconium, REE) and non-metallic minerals have been identified (Fig. 2).

One of the country's most important industries is the mining and processing of mineral resources, which is the basis of the country's exports (24 % of the country's total exports). South Africa ranks first in the world in the production of chromite and manganese ores and concentrates, PGMs (platinum and rhodium), and is second in the production of titanium dioxide in concentrates after China and Mozambique. Diamonds, uranium, gold, vanadium and zirconium are also mined in a significant volume. The country ranks 7th in the world production of coal, but first on the continent: its resource base is represented by hard coal. But South Africa's coal mining sector is in dire need of investment to halt the decline in coal mining capacity and improve the efficiency of the railroad network and other infrastructure facilities [5].

Mined metallic ores are partially processed domestically to semi-finished and finished products: ferrochrome, titanium slags, crude iron, refined nickel and its chemical compounds, aluminum. Due to an underdeveloped domestic consumption sector, processed raw materials and refined products are exported.

Among the products imported into the country from abroad, highly processed products — crude metals and alloys, chemical compounds of metals, and mineral fertilizers — predominate.

The country is in the mainstream of geological exploration: several projects are being developed to prepare for the exploitation of deposits of rare and rare-earth metals (REE, lithium), including the extraction of REE from technogenic feedstock (phosphogypsum).

With the world's growing interest in alternative energy sources, there are possible prospects for the growth of uranium mining in the country: the country ranks 6th in the world in uranium resources and 7th in uranium production. Most of the developed uranium deposits are located in the Witwatersrand area of Gauteng province, where it is mined along with gold. It is processed to U_3O_8 uranium oxide concentrate («yellowcake») and supplied abroad to generate nuclear fuel (about half of it is produced at Russian facilities). The country has two nuclear reactors, which contribute 5 % to electricity generation, but the unstable financial situation in the country prevents the development of the sector.

The countries that have joined BRICS+ in 2024 also have a variety of mineral raw material base. Developing the mining industry and expanding the mineral resource base is a priority for these countries.

Egypt is one of the most steadily developing countries in Africa. A significant part of the country's foreign exchange earnings comes from exports of oil and gas (about 34 % of the value of commodity exports). Production of crude steel from imported raw materials plays a significant role in the country's economy as well. Egypt has large phosphates reserves (2 % of world reserves, 2nd place in Africa, 4th in the world) and ranks 3rd in the production of phosphate concentrates among African countries, after Morocco and Tunisia (10th in the world) (Fig. 2). The country also has resources of copper, tin, tantalum and uranium.

Iron and manganese ores, gold and industrial minerals (kaolin, bentonite, gypsum, fluorspar, barite) are mined in a limited volume (less than 1 % of world production); cement and cement clinker are also being produced. Aluminum is produced from imported raw materials.

The main imported mineral commodities are petroleum products, iron ores and concentrates, refined copper, aluminum products, ferromanganese alloys, metallic zinc, lead, nickel and magnesium, a number of industrial minerals (fluorspar, magnesite, sulfur, barites, etc.).

Iran is one of the Middle Eastern countries with large reserves of gas (2nd in the world after Russia) and oil (3rd). Solid mineral reserves include copper (2.3 % of the world's total), iron (1.9 %), chromium (1.5 %) and manganese (0.8 %) ores, zinc (1.5 %), lead (0.8 %) and fluorspar (1.2 %). Reserves of uranium, bauxite, molybdenum, gold, silver, and other minerals, including non-metallic minerals (kaolin, bentonite, asbestos, talc, etc.) have also been estimated.

The oil and gas as well as mining industries play a significant role in the country's economy: the share of mineral commodities in the country's export is 80 %. Iran ranks 3rd in the world in natural gas production. Metals mining sector are less developed and the scale of production of these commodities is smaller, nevertheless, the country is among the leaders in the production of direct reduction iron products (DRI), ranking 2nd in the world, second only to India (Russia holds 3rd place). In addition to iron ore, the country produces chromium and manganese ores, bauxite and uranium, as well as copper, molybdenum, lead, zinc, antimony, gold, silver. But the national output of these commodities does not represent significant share of the global production. Among non-metallic minerals the leading role belongs to gypsum, kaolin (bentonite and barite (respectively 10.6 %, 7.4 %, 7 % and 4 % of world's production).

Raw materials account for only an insignificant share of country's imports, the main share is accounted for by products from metals and their alloys; zinc and copper concentrates, kaolin and refractory clays, feldspar concentrate, magnesite, graphite, and sulfur.

Ethiopia has a relatively wide range of minerals and holds the 5th place in the world in tantalum reserves (6.5 % of the world, Fig. 2). The country also has resources of niobium and lithium, gold and silver, manganese and iron ore, potash, graphite, kaolin, gypsum and coal, but most of them are either not being developed yet or produced in small quantities (tantalum and niobium, gold, silver) [7]. Agriculture remains the main sector of national economy.

The potential for developing and producing rare metals is quite high, known objects are limited to the unexplored Kenticha tantalum-bearing belt, which is about 100 km long. The largest is the Kenticha deposit, where reserves of tantalum, niobium and lithium have been identified. It is planned to produce spodumene concentrate from its complex ores, but the potential for production of tantalum and niobium products has not yet been investigated.

Mineral fertilizers, petroleum products, brown coal, crude steel, ferromanganese alloys, metallic magnesium and titanium prevail among imported raw materials and finished metallurgical products.

In the **United Arab Emirates,** the main mineral resources are oil and gas, which provide the bulk of government revenues and foreign exchange earnings in the country (Fig. 2). Information about the country's resource base is limited in the public space; there are known some deposits of chromium, manganese and copper. The main commodity products are mined quarry: limestone, sand, technical salt, gypsum, ornamental stones (marble, granite, etc.). The country has a well-developed processing sector: steel and direct iron reduction products are produced here from imported raw materials, refined lead from secondary raw materials, metallic aluminum from imported bauxite.

The mineral resource base of **Saudi Arabia** is dominated by oil (15 % of world reserves, 2nd place in the world) (Fig. 2). The resource base of solid minerals is dominated by non-metallic minerals (phosphate ores, gypsum, feldspar, talc, kaolin, magnesite, etc.). Bauxite and gold deposits occurred, explored potential of silver, copper, zinc, iron ores, zirconium, tantalum, niobium, REE, uranium. Deposits of phosphate, bauxite, copper, zinc, gold and silver, as well as non-metallic minerals (kaolin, gypsum) are being developed. The country has an integrated aluminum industry, including a bauxite mine, alumina and aluminum smelters; ammonia-phosphate fertilizers are produced on the basis of its own phosphate deposits. The rest of the mined raw materials are only processed before they get exported.

There are a few crude steel plants operating in the country using imported materials. In addition, a number of non-ferrous metals and their products (aluminum, copper, tin, zinc, lead, nickel, magnesium), chromium and manganese ferroalloys, lithium carbonates, mineral fertilizers (mainly nitrate) are imported in small volumes.

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BRICS+ members conduct intensive mutual trade in mineral raw materials, semi-finished and finished products (Fig. 3) and have a number of preferences over other countries. The main supplies of mineral products, excluding hydrocarbons and petroleum products, in the BRICS+ countries are provided by iron ore and concentrates, suppliers of which are Brazil (17 % of trade turnover between BRICS+ countries in 2023 in monetary terms), South Africa (3 %) and India (2 %). South Africa is a leading supplier of chromite and manganese ores and concentrates (77 % and 55 % respectively). Brazil and India are significant suppliers of manganese ores and copper concentrates among BRICS+ members.

Gold trade accounts for a significant share of trade between the countries (15 % in 2023). South Africa is the main supplier. Nearly two-thirds goes to consumers in China and one-third to India.

Coal shipments (14 % of trade turnover) are dominated by Russia, supplying its products to China and India It has also surpassed non-Commonwealth countries in exports.

Diamonds and mineral fertilizers each accounted for 8–10 % BRICS+ trade in 2023. The rest is accounted for by supplies of semi-finished metallurgical products, inorganic chemical products, mineral and construction raw materials.

Chrome (mainly South Africa) and manganese (India) ferroalloys, products of direct reduction of iron (DRI, Russia, UAE), metallic manganese (China) and chrome (Russia) are traded in a much smaller quantity, but with higher added value.

Investment contribution to the development of mining and processing industries in the partner countries is an equally important area of cooperation among the BRICS+ countries. For example, one of the main producers of niobium in Brazil is China Molybdenum (CMOC), developing the Catalão deposit.

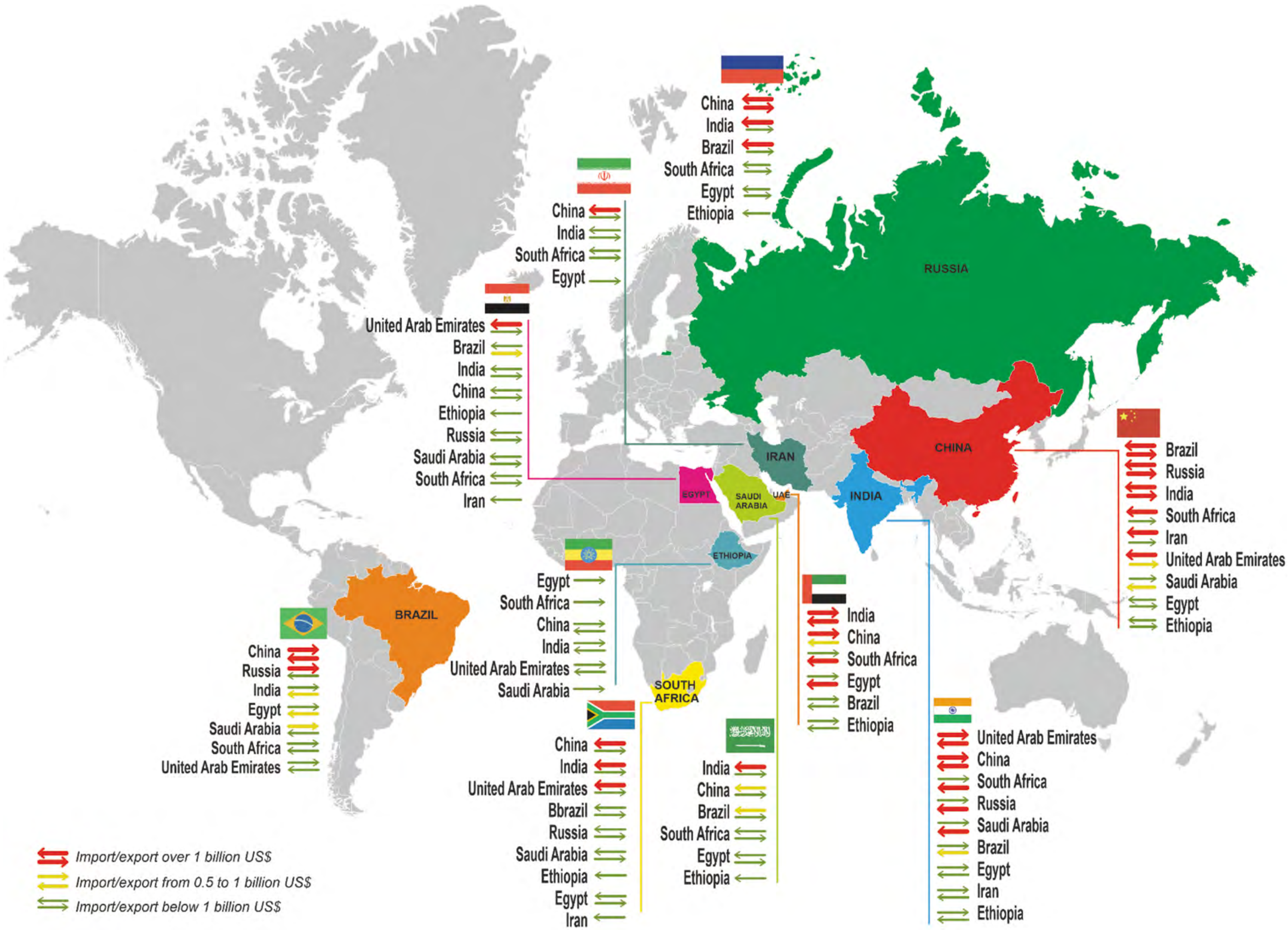

Fig. 3. Main export and import flows between BRICS+ countries in 2023

In Ethiopia, the Kenticha lithium deposit with associated tantalum mineralization is being prepared for development under the management of the Chinese *Yahua International Investment and Development Co., Ltd.* (a subsidiary of *Yahua Group*) [1].

The list of large companies that annually mine 1–2 million tons of chromite ore in South Africa includes the Indian *Odisha Mining Corp.* Ltd. and the Chinese metallurgical giant Sinosteel, owning 50 % of the Tweefontein mine each.

In Russia, companies with Chinese investments are developing a number of large deposits — the Kyzyl-Tashtyg polymetallic deposits in the Republic of Tyva and Noyon-Tologoy in the Trans-Baikal Territory are being developed by *Lunsin LLC (Zijin Mining Group Co. Ltd.) and Baikalrud LLC (Central Asia Silver Polymetallic Group Ltd.)*, respectively.

Russian companies, in turn, work in the BRICS+ countries, in particular, Rosatom State Corporation implements projects for the construction of nuclear power plants in China, India and Egypt. A nuclear power plant is being negotiated in Saudi Arabia. The Russian company Eurochem rampimg-up new phosphate fertilizers complex Serra do Salitre in Minas Gerais; it has produced its first batch of MAP fertilizers in 2024 [3].

The BRICS+ member countries are different with respect to mineral commodities, geological exploration of the territory, availability of technology, access to financial and human capital, and the development of mineral-consuming industries. But in this «unity of unlike ones» there is a potential for mutually beneficial cooperation that can hardly be overemphasized. The BRICS+ countries synergistically complement each other in terms of mineral supply. Thus, almost all BRICS+ members are rich in mineral resources, some have advanced technologies in the field of mining and processing of minerals and have the opportunity to invest, while others need to attract capital and transfer technologies. Some countries have a labor surplus, while others are facing a shortage of working-age population.

Cooperation in mining is of particular relevance at a time when interest in the critical minerals is growing worldwide and many countries are making efforts to provide reliable supply of mineral commodities. These efforts include, among other things, coalition-building and long-term agreements. However to realize the full potential of cooperation in mining industry BRICS+ would require significant efforts for harmonizing and improving legislation, ensuring the free movement of capital, human resources and technology transfer.

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BRICS ENABLES THE DEVELOPMENT OF COMMON PRINCIPLES OF RESOURCE MANAGEMENT

The article examines ranges of all countries for their place in the fourth industrial revolution. It is found that all parties recognise that the energy transition will take decades and will be accompanied by rising energy needs and costs. Risks of raw material shortages and high commodity prices are intensifying competition between countries. The article examines how BRICS can become a key platform for coordinating efforts to protect and promote national interests, as well as to develop common approaches to resource management. ***Keywords:** energy transition, fourth industrial revolution, clean energy, resource management, energy sustainability, RES.*

Today, the whole world is puzzling over how to find its place in the fourth industrial revolution and effectively ensure the energy transition. The development of clean energy, the transition to renewable sources and the complete abandonment of fossil fuels are the subject of much debate. All parties recognise that the energy transition will take decades and will be accompanied by rising energy needs and costs. Risks of raw material shortages and high commodity prices are intensifying competition between countries. In fact, a struggle is unfolding between the owners of technology and the owners of natural resources. Attempts are being made to forcibly divide the world into raw material and industrial zones. This completely contradicts the principle of sovereign equality enshrined in the UN Charter.

From 1 January 2024, Russia holds the presidency of the new, enlarged BRICS, which opens up new horizons. Russia's motto in its work is «Strengthening multilateral relations in the interests of equitable global development and security». At this point, it is important to outline the interests of our countries in the global world. The natural resources we possess are of key importance. The accession to the organisation of states with globally significant resource potential notably increases the role of such potential and its importance on a global scale. Attempts by Western countries to artificially devalue the importance of this factor and turn resource countries into vassals of technological states are contrary to the interests of the member states. To prevent such a scenario, we need a common action plan to address the technological needs of BRICS and partner countries to transform industry and energy based on our competitive advantages. Tectonic changes in global economic linkages and logistics systems also need to be rethought and taken into account in shaping new trade policies in an increasingly competitive environment. Efforts should focus on these challenges in order to offer our partners balanced solutions that meet the national interests of BRICS members.

Growing energy consumption and shortage of energy sources

According to UN forecasts, by 2050, there will be a significant increase in population and a doubling of GDP. According to the International Energy Agency (IEA), energy consumption will grow by at least 30–35 %, despite all energy saving programmes. Existing hydrocarbon and renewable energy (RE) opportunities will not be able to accommodate this growth. How can we meet the ever-growing needs of our planet?

Today, the balance of energy sources in the world is as follows: 33.1 % — oil, 27 % — coal, 24.3 % — gas, 10 % — nuclear and hydropower, about 5 % — renewable energy sources. The energy balance of each country is distinctive, and Russia is no exception; we use twice as much gas as the rest of the world, coal — half as much, and the use of RES is still insignificant.

According to IEA forecasts, by 2050, about 63–65 % of the total balance will come from fossil fuels, 37–35 % will be produced by RES, including nuclear and hydropower. The absolute volume of oil and gas production will remain the same or even increase. In fact, there will be no reduction in the extraction of natural resources, but an increase in RES production to meet growing demand. The growth of RES will occur for objective reasons, the volume of natural resources extraction will simply not be enough for everyone. Increase in energy production is possible only by increasing coal production, there are nearly no reserves for other types of energy. Russia will not be radically different.

Technocracy vs. sovereignty

To ensure energy sustainability given the projected significant growth in consumption, it is obviously necessary to increase the extraction and utilisation of natural resources, both fossil fuels (oil, gas, coal) and the main minerals required for RES production. No one doubts this. The goal of the EU and the US is to subordinate the extraction of natural resources to technological interests. For them, it is important that natural resource exporting countries act as suppliers of raw materials and cannot set their own terms, remaining at the bottom of the production chain. To do so, they use every means possible, up to and including their own interpretation of the internationally recognised Paris Climate Agreement and ESG principles, non-compliance with which they try to link to access to finance and other resources.

As for renewable energy sources: today, there is no alternative due to limited fossil fuel reserves. Therefore, investments are actively channelled into renewable energy sources; in 2020, they will exceed investments in oil and gas exploration and production for the first time. Countries with limited fossil fuel reserves (including Europe) are primarily interested in RES. This ensures their energy security. However, many developing regions (Africa, parts of Asia-Pacific, South America) with natural resources cannot afford this costly transition involving technology imports; it is more important for them to maintain and develop their own capabilities. RES development is not isolated from natural resources. It is based on the extraction of essential minerals needed to produce, store and transport energy. The IEA estimates that the low-carbon energy transition will increase demand for metals and commodities (lithium, graphite, cobalt, nickel, manganese) almost sixfold. However, existing reserves are insufficient, and developed countries have virtually none. Therefore, we should expect commodity and raw material prices to rise, which is already happening. This means that the profit will go to the resource-exporting countries, which does not suit the so-called technological leaders.

Control over pricing

A key challenge for natural resource countries is to retain the ability to participate in the resource pricing. According to UN forecast, achieving a zero greenhouse gas emission world by 2050 will require an increase in the cost of energy from the current 8 per cent of global GDP to nearly 30 per cent by 2035–2040. Consequently, both the revenues of individual industries and the budgets of countries, as well as the sustainability of their economies, depend on access to resources. Against this background, there are international attempts to change the concept of natural resources as a commodity to a service. What does this mean? Countries are divided into leaders and servants. The concept of service implies that exporting countries no longer sell goods or set their price, but play a special role that is reduced to servicing the technology provided to them by technology leaders. Technologically advanced countries are already taking certain steps to control pricing. Various sanctions and restrictions on technology exports, attempts to limit the price cap on natural resources for Russia and Venezuela are the first steps in this process. Another tool is attempts to set out unfavourable conditions in the national legislation of resource countries, for example, in terms of full disclosure of critical mineral reserves and linking their exploration and production to supply and demand chains. Regions of particular interest to technology countries are Central Asia, primarily Kazakhstan, Uzbekistan, Tajikistan, rich in critical minerals, Mongolia, as well as states in Africa, Asia and Latin America. There has been a noticeable increase in interest from the US, the EU and Western countries in general, who are keen to provide technology processes with the necessary resources on their own terms, including openly negotiating legislative changes with some of them.

BRICS as an alliance of sovereign countries and economies

A key challenge for Russia and other resource-rich countries is to create an effective shield to protect their own national interests and support economic development. The BRICS countries can play an important role in this process. Russia, as BRICS Chair, can put on the agenda the defence and promotion of the national interests of the member countries and the preservation of our resource value, which can become one of the main topics of interstate meetings and discussions.

Russia today needs a new strategy of resource and reserve management, involving a transition from extractive to technological sovereignty and the elaboration of common principles of resource management with the BRICS countries. A few key areas can be emphasised:

- ensuring investment in mining and exploration as a basis for further development of the industry;
- establishing domestic financial institutions to ensure a full cycle of financing, supply and settlement for minerals and hydrocarbons, allowing not to depend on the traditional, ongoing policies of unfriendly countries;
- maximum processing of natural resources: from the development of a closed-cycle economy to the maximum depth of processing of raw materials;
- integrated development of the territory with the creation of infrastructure and production centres as close as possible to sales markets (Sabetta port, the Arctic Gateway terminal, the Murmansk transport hub, etc.);
- transition to technological sovereignty through the development of technological solutions that provide access to strategic resources and the creation of a single technology bank on the BRICS platform;
- drafting and adoption of an intersectoral strategy to ensure energy stability and achieve sustainable development goals;
- ensuring resource sovereignty of the country. Today, the international stock audit market dictates the terms of access to financing, influences the capitalisation of companies, the liquidity of their securities and the perception of their reliability. Russia needs its own system based on national interests;
- a common strategy of the BRICS countries to meet the natural resources and technology needs of the BRICS and partner countries. The BRICS countries have the world's dominant raw material base; so, they can join efforts to prevent the imposition of a policy of technological dominance and artificial depreciation of the value of natural resources. Joint geological exploration, promotion of technologies and financial instruments, creation of a knowledge and competence base as well as technological and human resource potential are just some of the possible areas of cooperation.

There is no doubt that the next decade will see fundamental changes in the economic, energy, technological and other spheres of the world, and our task is to become co-authors of these changes, strengthening the economic sovereignty of our countries. This is the key priority around which we must pool resources and interests today. BRICS can become a centre for concerted action to protect and promote national interests and forge agreed principles of resource management».

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UNITED NATIONS STANDARDS — A PLATFORM FOR CO-OPERATION AND THE SUSTAINABLE DEVELOPMENT OF THE PARTNER COUNTRIES

Availability and accessibility of minerals, as well as the technologies that enable their efficient and independent extraction, underpin the development of the economies of all countries and ensure the possibility of meeting the needs of society. Developing cooperation between partner countries to develop on a new basis, combining national interests and international standards is a key step towards achieving sustainable development and creating an effective strategy to meet new global challenges, including energy challenges. For this purpose, it is necessary to know the reliable state of the resource base of partner countries, including for attracting investments in geological exploration and development of mineral resources, development and introduction of new efficient technologies. This can be done on the basis of mutually recognised common principles, standards and approaches for the evaluation of mineral reserves and resources by the partner countries; mutual recognition of competent persons; creation of converters for the translation of mineral reserves between national classifications. All this will create a sustainable and equitable resource management system to achieve sustainable development goals both in individual countries and the world as a whole. ***Keywords:*** *SDGs, resources, UNFC, energy efficiency, critical minerals, fossil fuels, consolidation, converter, mutual recognition of experts and competent persons, harmonization of national reserve and resource assessment systems*

We are involved in the rapid transformation of world economic relations, which is perhaps the largest in modern history. Breakthrough technologies in space and on earth, the fourth industrial revolution and a new energy transition, the creation of fundamentally new materials and the introduction of digital tools, including artificial intelligence and other achievements of the human mind fundamentally change the world around us.

All these changes require resources, first and foremost, to meet human needs, realize their right to a decent existence, which are formulated as the UN Sustainable Development Goals (SDGs) and are enshrined in a strategic document «Agenda 2030» adopted by the world community in 2015.

The doubling of the world's population from 1990 to 2050, as predicted by UN experts, means not only an arithmetic comparison of the number of resources required, but also a qualitative change in the current situation, especially with regard to access to energy, without which it is impossible to imagine the modern world.

Given the existing problems with energy access, this is a serious challenge for the global energy industry as a whole. The latest UN figures show that 840 million people — mostly in sub-Saharan Africa — live without access to electricity, with hundreds of millions more having only very limited or unreliable access. This makes universal access to affordable, reliable, sustainable and modern energy for all (UN Sustainable Development Goal 7) a priority today. To realise this goal, it is envisaged to significantly increase the share of energy from renewable sources in the global energy mix by 2030 (in 2015, the share of energy from renewable sources in total energy consumption was 17.5 %) and to enhance international cooperation to facilitate access to clean energy research and technologies, including renewable energy, energy efficiency, advanced and cleaner fossil fuel technologies.

The growth of the share of energy from renewable sources in the global energy balance is seriously constrained by both the current level of technology development and the amount of exploration and extraction of critical minerals that are the basis for renewable energy. Even for an optimistic scenario, in which renewable energy will account for 28 per cent of all energy consumption by 2050, it is necessary to multiply the production of critical minerals, in particular lithium by 42 times, graphite by 25 times, and cobalt by 21 times. At the same time, the production and reserves of critical minerals and fossil fuels are highly differentiated from country to country.

At the same time, the main risk of using fossil fuels and increasing production of critical minerals lies in their exhaustibility, the need to increase the volume of geological exploration, search and introduction of new, modern and economically accessible technologies for the study and extraction of minerals.

The lack of coordinated cooperation between different countries, based on common approaches and standards, can lead to divergent efforts that fail to meet the energy industry's goals of securing key raw materials, both the fossil fuels — oil, gas, coal — needed for the bulk of the energy sector, and the critical minerals needed for renewable energy.

In addition to their use for energy, minerals underpin the development of countries' economies and are used in a wide range of industrial and manufacturing activities, as well as in the production of goods and services to meet the needs of society. Minerals are thus a necessary and enabling condition for achieving Goal 8 (Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all) and Goal 9 (Build resilient infrastructure, promote inclusive and sustainable industrialisation and innovation) of the UN Sustainable Development Goals. A key target of the latter is to promote a substantial increase in industrial employment and the share of industrial production in gross domestic product, in accordance with national circumstances. In addition, mineral revenues are one of the ways to achieve UN Sustainable Development Goal 10 — reducing inequalities within and between countries in all areas: from health to the economy, from security to social protection.

No country in the world has sufficient quantities of all the critical minerals it needs. Therefore, in order to achieve the UN Sustainable Development Goals, it is necessary to consolidate the efforts of various countries that possess mineral reserves and resources, technologies for their exploration and extraction, and investment potential for their development.

Such consolidation can be based on existing UN standards, the development of which has been supported by almost all BRICS countries and their partners, namely The United Nations Framework Classification for Resources (UNFC) and the Recommendations to UN Qualified Experts.

Despite the fact that there are more than 150 officially recognised classifications of minerals in the world, the approaches and methods of estimating mineral reserves in different countries are generally similar. The existing differences are largely determined by the objectives of their application and planning horizon, historical peculiarities of the discovery and use of a particular mineral, peculiarities of subsoil use, and sometimes customs and national traditions of different countries.

At the same time, structural changes in demand for minerals required for a new technological order and energy transition offer opportunities for extractive countries to fundamentally change their role in the life cycle of production, Strengthen sovereignty over their natural wealth by exercising their right to use the classification that best suits its national interests when assessing mineral reserves and resources. It is important that these classifications are comparable. The United Nations Framework Classification for Resources (UNFC) currently provides such an opportunity. Russia and China have made a strong case for this by signing the Linking Documents between their national mineral classifications and the UNFC.

The UNFC is an effective system for the evaluation and management of mineral resources that allows the creation of a common base of standards, a common language of communication that is equally understandable to all participants in the process and that safeguards the interests of government agencies, businesses and financial institutions. By combining all the diversity of existing national approaches to reserve evaluation, taking into account the specificities of each country's legislation, the UNFC ensures the development of the extractive industries and the sovereign management of each country's own resources.

Harmonisation of national reserve and resource assessment systems with the UNFC allows for effective management of natural resources, guided on the one hand by national interests and the principles of sustainable development, and on the other hand by the basic principles of the UNFC. It is no coincidence that the UNFC is being adopted by an increasing number of countries. For example, it has been adopted as the basis for national classifications in India and Mexico, and as a unified system for the management of mineral and energy resources in Africa (AMREC classification).

The universality of the UNFC makes it possible to create a system of mutual recognition of classifications and estimates of mineral reserves between partner countries and, taking into account the development of digital technologies, to create the possibility of technical transfer of reserves from one classification to another — a converter, a programme that allows the transfer of reserves from one classification to another, subject to harmonisation between them on the basis of the UNFC. The creation of such a converter has already been reported by specialists in China. A similar software product is being developed in Russia. The creation of working tools for the conversion of mineral reserves will reduce the time and inefficient costs of estimating reserves for a project in different classifications and will broaden and strengthen cooperation between partner countries.

Mutual recognition of national classifications between partner countries opens a wide range of opportunities for effective and fair cooperation between countries in the field of mineral exploration and production. Such cooperation should be based on mutual respect for the interests of each party, seeking mutually beneficial scenarios of interaction based on a unified system of recognition of the results of assessment and expertise of mineral reserves.

Another important area of international cooperation is the mutual recognition of experts on mineral reserves and resources and competent persons from different countries. Most resource-extracting countries have established scientific and educational institutions and have highly qualified specialists with the necessary experience and knowledge not only to assess reserves and resources, but also to act as independent experts to confirm reserve estimates, both for government resource management and for attracting investment in the extractive industries.

Mutual recognition of experts and competent persons in the field of reserve estimation and development of mineral deposits on the basis of uniform standards recognised by all is in the interest of all participants. It will protect them from the emergence of unscrupulous experts (competent persons) and companies, unfair competition, unfriendly influence of certain countries and reduce the risks of inaccuracy in reporting reserves to various financial institutions. At the same time, it creates clear and transparent rules and new opportunities for all participants: exchange of experience, training, joint participation in projects, development of new approaches and technologies for participation in the development of hard-to-recover reserves and developing and strengthening national expertise.

The UN Economic Commission for Europe (ECE) with its mandate has taken a very serious step by developing Recommendations for Qualified Experts, known in many countries as Competent Persons. These Recommendations can serve as a basis for experts from different countries to confirm their qualifications regardless of their country of residence, for mutual recognition of these qualifications by partner countries, and for the creation of a single international register of mineral reserve experts and competent persons.

An analysis of the existing practice of using experts in different countries has shown that in the vast majority of cases the requirements for them are consistent with each other and with the UN recommendations. This allowed Russia, together with Belarus, Kazakhstan, Kyrgyzstan, Tajikistan and

Uzbekistan, to develop and approve in 2023 at the level of geological services model requirements for reserve experts and competent persons with the necessary experience and knowledge in the field of assessment and development of mineral reserves and resources. The model requirements will be in line with national circumstances and interests as well as UN standards. At present, the above countries have agreed on further steps to create a single, universally recognised expert community, including the development of: a model code of ethics for experts and competent persons; the concept of creating a single register of experts and competent persons; and a training programme for them. We hope that this initiative will be supported by our partners in other countries, including BRICS members. In order to implement these objectives, we propose to consider the possibility of forming a Task Force on the harmonization of national reserves classification systems within the «BRICS Geological Platform» and are ready to organize its work.

Thus, the availability and/or accessibility of minerals, as well as the technologies that enable their efficient and independent extraction, underpin the development of the economies of all countries, including a wide range of industries and production sectors, and ensure the possibility of meeting the needs of society. Achieving the goals of sustainable development and creating an effective strategy to meet new global challenges, including energy challenges, will allow cooperation between partner countries to develop on a new basis, combining national interests and international standards. For this purpose, it is necessary to know the reliable state of the resource base of partner countries, including for attracting investments in geological exploration and development of mineral resources, development and introduction of new efficient technologies. This can be done on the basis of mutually recognised common principles, standards and approaches for the evaluation of mineral reserves and resources by the partner countries; mutual recognition of competent persons; creation of converters for the translation of mineral reserves between national classifications. All this will create a sustainable and equitable resource management system to achieve sustainable development goals both in individual countries and the world as a whole. A world with equal opportunities for all.

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KEY TRENDS OF DEVELOPMENT OF STATE GOVERNANCE AND LEGAL REGULATION IN THE FIELD OF SUBSOIL USE

The article examines recent trends in state governance related to subsoil use, focusing on key regulatory legislation enacted in the last five years. It also evaluates the outlook for legislation and state governance efforts aimed at encouraging private investment in geological exploration, fostering growth in junior exploration companies, and implementing digital transformation within the industry.
Keywords: *state governance, regulatory legislation, subsoil, subsoil use, private investment, geological exploration, junior exploration companies, digital transformation.*

In 2019, the Federal State-Owned Organization «Rosgeolexpertiza» (hereinafter referred to as Rosgeolexpertiza) celebrated its 20th anniversary. This year we have crossed a quarter-century milestone. During these 5 years, there have been many changes in legislation, while Rosgeolexpertiza has been actively involved not only in the preparation of quite a number of legislative initiatives, but also made a great contribution to the implementation of many projects in various fields, including subsoil use licensing and expertise of project documentation.

Between 2019 and the present a number of federal laws[1] have been enacted, which provide for:

— expanding the grounds for granting subsoil plots for use, including geological exploration in offshore areas, development of technologies for extraction of unconventional hydrocarbons, as well as generally clarifying special grounds for granting subsoil plots for use;

— digitalization of subsoil use licensing, including adoption of electronic auctions, electronic license, introduction

[1] Federal laws dated November 4, 2019 No. 355-FZ, dated December 2, 2019 No. 396-FZ, dated December 27, 2019 No. 505-FZ, dated June 8, 2020 No. 179-FZ, dated November 23, 2020 No. 383-FZ, dated December 8, 2020 No. 429-FZ, dated April 30, 2021 No. 123-FZ, dated June 11, 2021 No. 170-FZ, dated April 1, 2022 No. 75-FZ, dated June 28, 2022 No. 218-FZ, dated June 28, 2022 No. 228-FZ , dated July 14, 2022 No. 343-FZ, dated December 29, 2022 No. 598-FZ, dated February 17, 2023 No. 25-FZ, dated April 28, 2023 No. 146-FZ, dated July 10, 2023 No. 296-FZ, dated December 12, 2023 No. 576-FZ, dated December 19, 2023 No. 619-FZ, dated December 25, 2023 No. 656-FZ, dated December 25, 2023 No. 677-FZ.

of an electronic map of subsoil plots and mineral deposits to replace the archaic procedure of issuing paper certificates on the absence of mineral resources under a building area;

— establishing a special legal regime of subsoil waste use and licensing of technogenic deposits;

— introduction the mechanism for regional geological study through private investment, establishing the procedure for approbation of probable resources;

— expanding the grounds for reissuing subsoil use licenses, including in order to stimulate junior exploration business;

— stimulating the development of deposits containing critical and scarce minerals;

— expanding the powers of state authorities of constituent entities of the Russian Federation in the sphere of subsoil use regulation (in terms of licensing and expertise of mineral resources).

Despite the fact that some of the laws described above will come into force only in September this year, their adoption itself marked a strategic shift in the vector of state regulation of subsoil use today. The new laws are aimed at stimulating investment in geological exploration, increasing transparency and responsibility in the subsoil use, while at the same time providing for stricter requirements for the rational use and protection of subsoil, monitoring of subsoil conditions, environmental protection and rational use of other natural resources.

With the adoption of Federal Law dated April 30, 2021 No. 123-FZ[2], Rosgeolexpertiza was assigned a number of powers in terms of subsoil use licensing, including granting and early terminating of the subsoil use rights, modifying and re-issuance of subsoil licenses, and maintaining the state register of subsoil licenses.

Changes in the legal regulation of subsoil use reflect the regulator's desire for sustainable and responsible use of non-renewable subsoil resources in the context of increasing rates of their development. The role of project documentation for geological exploration is also increasing, in which the environmental measures are becoming more and more clearly manifested [1]. Meanwhile, it seems that in a number of areas it is necessary to continue improving the regulatory framework, including subsoil use licensing, expertise of the project documentation, and expertise of mineral resources [2].

Currently, more and more attention is being paid to business initiatives, support for private investment and stimulation of geological exploration financing. In particular, government regulation is on the way to create favorable conditions for the development of junior exploration business [3].

Junior companies are small exploration companies that are solely engaged in prospecting and evaluation of mineral deposits [4]. In many foreign countries, they play an important role in the industry, as they assume the financial risks associated with the search for new deposits.

In Russia, this mechanism has been implemented with the introduction of the so-called application principle (granting subsoil use rights without an auction)[3]. However, its formation has not been completed so far, as tax incentives need to be further developed (e.g., tax deduction for expenses under an exploration license in relation to taxation of mineral extraction under a mining license, formation of a framework for attracting private investment in geological exploration)[4].

The vector for business support in 2020–2022 was also taken in connection with economic difficulties resulting from the coronavirus pandemic[5], as well as foreign economic sanctions[6]. Moreover, in view of the introduction of such measures, it is worth noting the strengthening of the trend towards import substitution of non-available technologies, intensification of the development of deposits of critical and scarce minerals, as well as the projects for the construction of new and modernization of existing infrastructure, including transport one.

Further improvement of the efficiency of geological exploration, including modern technologies and methods of prospecting and exploration of deposits is also necessary. It is especially relevant for rare metals, scarce raw materials. Improving the accuracy and reliability of geological exploration results is equally crucial.

At the same time, a number of such projects implemented to date are aimed at bringing into development previously explored sites, including in the Soviet period. However, in order

[2] Official Internet Portal of Legal Information http://pravo.gov.ru, April 30, 2021.

[3] See the following regulatory legal acts:

Order of the Ministry of Natural Resources and Environment of the Russian Federation dated March 15, 2005 No. 61 «On Approval of the Procedure for Considering Applications for Obtaining the Subsoil Use Right for Geological Exploration of Subsoil (Except for Subsoil in Subsoil Plots of Federal Significance)». Rossiyskaya Gazeta, No. 98, May 12, 2005;

Order of the Ministry of Natural Resources and Environment of the Russian Federation dated January 27, 2014 No. 37 «On Amendments to the Procedure for Considering Applications for Obtaining the Subsoil Use Right for Geological Exploration of Subsoil (Except for Subsoil in Subsoil Plots of Federal Significance), Approved by Order of the Ministry of Natural Resources and Environment of the Russian Federation dated March 15, 2005 No. 61». Rossiyskaya Gazeta, No. 154, July 11, 2014;

Order of the Ministry of Natural Resources and Environment of the Russian Federation dated November 10, 2016 No. 583 «On Approval of the Procedure for Considering Applications for Obtaining the Subsoil Use Right for Geological Exploration of Subsoil (Except for Subsoil in Subsoil Plots of Federal Significance and Subsoil Plots of Local Significance)». Official Internet Portal of Legal Information http://www.pravo.gov.ru, December 30, 2016;

Order of the Ministry of Natural Resources and Environment of the Russian Federation and the Federal Agency for Mineral Resources dated October 28, 2021 No. 802/20 «On Approval of the Procedure for Granting the Right to Use Subsoil Plots for Geological Exploration of Subsoil, Including Prospecting and Evaluation of Mineral Deposits, on a Subsoil Plot not Included in the List of Subsoil Plots for Geological Exploration of Subsoil, Except for Subsoil in Subsoil Plots of Federal Significance and Subsoil Plots of Local Significance». Official Internet Portal of Legal Information http://pravo.gov.ru, December 13, 2021.

[4] The mechanism of attracting non-institutional (non-professional) investors is widely used in the world, with the use of tax incentives: for example, reducing the taxable base for personal income tax by the amount of investments made.

[5] Decree of the Government of the Russian Federation dated April 3, 2020 No. 440 «On Extension of Permits and Other Peculiarities Concerning Permitting Activities in 2020 — 2022». Official Internet Portal of Legal Information http://pravo.gov.ru, April 6, 2020.

[6] Decree of the Government of the Russian Federation dated March 12, 2022 No. 353 «On the Peculiarities of Permitting Activities in the Russian Federation». Official Internet Portal of Legal Information http://pravo.gov.ru, March 14, 2022.

to form the necessary prospecting ground it seems essential to continue to develop geological exploration at early stages, including for the scarce and critical types of minerals.

It is also promising to strengthen international cooperation with friendly countries in this area in two aspects: on the one hand, the formation of markets for domestic drilling and service companies, and on the other hand, the attraction of foreign investment in Russian projects.

Another important direction in improving legislation and the system of subsoil fund governance has been the introduction of a mechanism for financing regional geological study at the expense of private funds[7]. Taking into account the reduction of budget financing of geological exploration of early stages, as well as the exhaustion of the prospecting ground, this legislative novelty seems necessary and timely. However, in our opinion, it is crucial to retain unified methodological approaches to conducting regional geological works, which have been formed for decades by specialized institutes subordinate to the Federal Agency for Mineral Resources [5]. In order to remain such methodological unity, it is necessary to ensure that private regional projects will involve budgetary institutions subordinate to the Federal Agency for Mineral Resources, which are currently carrying out state geological study of subsoil.

To date, an important trend in the development of regulation is the expansion of the scope of subsoil legislation to other areas. Thus, the terms of subsoil use licenses now include provisions on the priority use of domestic equipment and technologies[8]. In addition, with respect to scarce minerals, the legislation provides for the obligation to produce high value-added goods on the territory of the Russian Federation using extracted scarce solid minerals[9].

In the Soviet period, under the terms of planned economy, mutual coordination between exploration, mining and processing industries was ensured, and economic activities were managed and regulated by the state as the sole owner, using the command method (based on state directives). However, in the current economic realities, the activities of private companies should be regulated through legal and economic mechanisms of incentives and prohibitions. A system based on intersectoral planning and interaction (public procurement, tax incentives, special licensing regimes, customs regulation) needs to be conceptualized.

The measures taken have certainly had a positive effect. The companies are currently active in the preparation and implementation of projects related to geological exploration, the expertise of which is carried out by Rosgeolexpertiza. The total number of project documentation for geological exploration under licenses issued on the application principle is more than 7,700. The total number of valid licenses under the application principle is comparable and also amounts to about 7,750 licenses[10].

Taking into account the structural transformations of the geological exploration industry, modernization of the system of expertise of project documentation for geological exploration, which is an important part of the system of state governance of the industry, is also inevitable [6].

With the adoption of Federal Law dated April 30, 2021 No. 123-FZ and Decree of the Government of the Russian Federation dated April 16, 2022 No. 674[11], there have been numerous changes in the expertise of project documentation for subsoil use:

- the timeframe for the expertise has been significantly reduced from 60 to 29 days;
- all expertise processes have been converted to electronic form — from the of submitting an application to the issuance of an expert decision;
- the environmental component has been strengthened in relation to hydrocarbon projects in the Arctic zone.

For more than 8 years there has been a steady increase in the investment value of projects for geological exploration: about 9 billion rubles in 2015 and about 100 billion rubles in 2023. To compare the growth rate, this indicator in 2021 was about 83 billion rubles, and in 2022 — already 91 billion rubles[12].

In addition, digital transformation of the expertise of project documentation for geological exploration continues, including the preparation of machine-readable sections of such documentation and machine-readable expert decision.

At the same time, the number of applications for the expertise of project documentation received electronically is growing every year. While in 2022, 3,055 applications were received electronically, in 2023 this figure was 4,470, and by the first quarter of 2024, this figure is already 1,590 applications[13].

[7] Federal Law dated December 25, 2023 No. 656-FZ «On Amendments to the Law of the Russian Federation «On Subsoil». Official Internet Portal of Legal Information http://pravo.gov.ru, December 25, 2023.

[8] Order of the Ministry of Natural Resources and Environment of the Russian Federation and the Federal Agency for Mineral Resources dated October 25, 2021 No. 782/13 «On Approval of the Form of a Subsoil Use License and the Procedure for Formation, State Registration and Issuance of Subsoil Use Licenses». Official Internet Portal of Legal Information http://pravo.gov.ru, December 14, 2021.

[9] Federal Law dated December 12, 2023 No. 576-FZ «On Amendments to the Law of the Russian Federation «On Subsoil». Official Internet Portal of Legal Information http://pravo.gov.ru, December 12, 2021.

[10] According to the Federal State Information System «Automated Subsoil Use Licensing System».

[11] Decree of the Government of the Russian Federation dated April 16, 2022 No. 674 «On Approval of the Rules for the Expertise of Project Documentation for the Carrying Out Regional Geological Study of Subsoil, Geological Study of Subsoil, Including Prospecting and Evaluation of Mineral Deposits, Exploration of Mineral Deposits and the Amount of Fees for its Implementation and on Making Changes to the List of Normative Legal Acts and Groups of Normative Legal Acts of the Government of the Russian Federation, Normative Legal Acts, Certain Provisions of Normative Legal Acts and Groups of Normative Legal Acts of Federal Executive Bodies, Legal Acts, Certain Provisions of Legal Acts, Groups of Legal Acts of Executive and Administrative Bodies of State Power of the RSFSR and the USSR, Decisions of the State Commission on Radio Frequencies Containing Mandatory Requirements, in Respect of Which the Provisions of Parts 1, 2 and 3 of Article 15 of the Federal Law «On Mandatory Requirements in the Russian Federation» do not apply». Official Internet Portal of Legal Information http://pravo.gov.ru April 18, 2022.

[12] According to the Module «Expertise of Geological Exploration Projects» of the Federal State Information System «Automated Subsoil Use Licensing System».

[13] According to the Module «Expertise of Geological Exploration Projects» of the Federal State Information System «Automated Subsoil Use Licensing System».

Today the concept of machine-readable electronic project documentation and machine-readable electronic expert decision has been developed.

Digital transformation allows automating repetitive processes without losing manageability [7]. Thus, the process of registering of geological exploration works has been successfully digitalized since 2021 with the entry into force of Order of the Ministry of Natural Resources and Environment of the Russian Federation dated October 29, 2020 No. 865 «On Approval of the Procedure for State Registering and Maintenance of the State Register of Works on Geological Exploration of Subsoil, the State Register of Subsoil Plots Granted for Use, and Licenses for the Use of Subsoil Plots»[14], and today is almost completely automated. Nevertheless, to date, Rosgeolexpertiza has a practice of identifying technical errors and manually correcting such errors in the relevant register.

Strategic decision-making and planning of future projects can be facilitated by creating a more complete picture of the state of the industry and identifying trends of its development on the basis of collection of analytical data on geological exploration, collection, storage, recording of geological information, data on investments and other financial indicators of the industry, as well as other aspects of business activities in the context of incoming data on the rate of growth of the country's mineral resource base. Increasing the transparency of recording, data collection and data management functions and the digitalization of industry processes can also be important tools for businesses investing in geological exploration.

Under these conditions, strengthening the functions of recording, data collection, building a decision-making system based on competent data management and digitalization are the key aspects of modern state governance, which make it possible to optimize the processes of licensing and governance of the subsoil fund, to ensure more accurate and transparent recording in the field of subsoil use and to increase its efficiency.

In this regard, the role of state information systems in the sphere of geological exploration and subsoil use in general is increasing [8]. With the adoption of the Decree of the Government of the Russian Federation dated February 2, 2024 No. 110 «On Approval of the Rules for the Use of Geological Information on Subsoil, the Owner of Which is the Russian Federation» approaches to the use of the Federal State Information System «Unified Fund of Geological Information on Subsoil»[15] are systematized in terms of providing geological information to a wide range of users[16].

It seems that the vector of digitalization of the exploration industry, creation and use of geological information systems for storage, analysis and visualization of data on mineral deposits, mine workings and other objects, simplification of access to information, its search and analysis, will be the key to improving the efficiency of reproduction of the mineral resource base of the country, reducing costs and financial risks of market participants.

With the adoption in September 2023 of a number of new regulatory legal acts on digitalization of geological information[17], the correlation of indicators of project documentation for geological exploration and actual indicators of completed project volumes was adjusted. This mechanism will make it possible, in particular, to more effectively identify so-called dormant licenses (licenses on the basis of which works are not carried out), which in turn will increase the efficiency of management of the fund of granted subsoil plots. Data-based management in general will allow the state to reach a brand new level of decision-making. It seems that a significant step in this direction should be the creation of the so-called digital twin of the subsoil, which is the next stage in the infrastructural development of the industry.

The above allows us to identify a number of strategic objectives for the development of the geological exploration industry, which may be relevant for the next 5 years, among which the following should be particularly emphasized:

continuing improvement of the legal and regulatory framework in the sphere of subsoil use;

- stimulating private investment in geological exploration, including the development of junior business;
- ensuring compliance with the requirements of environmental protection legislation during geological exploration;
- introduction of digital technologies into the processes of prospecting, exploration and mining;
- digitalization of government services and functions;
- creation and development of information systems in the industry.

The implementation of these tasks will improve the efficiency of the geological exploration industry and ensure its sustainable development.

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[14] Official Internet Portal of Legal Information http://pravo.gov.ru, February 3, 2021.

[15] URL: https://www.efgi.ru.

[16] Official Internet Portal of Legal Information http://pravo.gov.ru, February 5, 2024.

[17] See the following regulatory legal acts:

Order of the Ministry of Natural Resources and Environment of the Russian Federation and the Federal Agency for Mineral Resources dated August 23, 2022 No. 547/04 «On Approval of the Procedure for Submitting Geological Information on Subsoil to the Federal Geological Information Fund and its Territorial Funds, Geological Information Funds of the Constituent Entities of the Russian Federation». Official Internet Portal of Legal Information http://pravo.gov.ru, April 10, 2023;

Order of the Ministry of Natural Resources and Environment of the Russian Federation and the Federal Agency for Mineral Resources dated August 23, 2022 No. 548/05 «On Approval of Lists of Primary Geological Information on Subsoil and Interpreted Geological Information on Subsoil to be Submitted by Subsoil User to the Federal Geological Information Fund and its Territorial Funds, Geological Information Funds of the Constituent Entities of the Russian Federation by Types of Subsoil Use and Types of Minerals». Official Internet Portal of Legal Information http://pravo.gov.ru, February 27, 2023;

Order of the Ministry of Natural Resources and Environment of the Russian Federation and the Federal Agency for Mineral Resources dated August 23, 2022 No. 549/06 «On Approval of Requirements to the Content of Geological Information on Subsoil and the Form of its Submission». Official Internet Portal of Legal Information http://pravo.gov.ru, February 28, 2023;

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At the same time, Rosgeolexpertiza is still actively involved in various strategic projects in the industry [9]. In recent years, the organization has already participated in many rule-making initiatives and projects on digitalization of the industry.

Today, we have assembled a team of talented and dedicated specialists who have helped us become leaders in our field. Our goal is to continue to develop and grow while staying true to our values!

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REGIONAL GEOCHEMICAL SURVEY AS A TOOL FOR REPLENISHING THE NUCLEAR ENERGY MINERAL BASE IN THE BRICS COUNTRIES (AS EXEMPLIFIED BY THE U MINERALIZATION IN SOUTHERN RUSSIA)

The paper portrays geochemical features of the sequence underlying the southern part of the European Russia, aiming at prediction of the uranium concentrations and strengthening the uranium mineral base of this region. The 1:1M stream sediment and soil surveys over the L-38 map sheet territory produced the data needed as a knowledge base of the relevant map. The sampling density in both types of surveys was 1 per 100 sq. km. Mobile species of U and related elements, a total of 60, were assayed using ICP-MS. Identification of nine anomalous areas promising to contain payable mineral deposits, probably of the paleo-valley style, made the practical side of the research. This may expand the uranium mineral base of this economically well-developed region with currently limited reserves of such materials. ***Keywords:*** *south of European Russia, uranium, mineral base, geochemically anomalous area.*

The total energy consumption of the BRICS member countries is about 35 % of the world's total. At the same time, the Russian Federation and Brazil are exporters of the energy resources, whereas China, India and South Africa are major importers. Accordingly, the Russian Federation is interested in expanding energy cooperation within the BRICS framework. And, being the largest producer of energy resources, RF is interested in their uninterrupted supplies and stable prices.

One of the most important components of the energy resources is uranium. Its total reserves in Russia amount to more than 650kt. However, their greatest part (95 %) occur in Siberia and Russian Far East [9]. Therefore, increasing the uranium raw material base in well-developed areas of the country is extremely important. The authors believe that one of such regions is the southern part of the European Russia Federation, where uranium deposits are already known, but their reserves are estimated as limited.

This article employs the results of the multi-purpose geochemical survey, scale 1:1M (MPGM-1000 national project) obtained on the territory of the L-38 map sheet that partially covers the Caucasus mountains and adjoining foothills and plains of the Southern Federal District. The authors consider their main task as drawing attention to the possibility of discovering new U deposits here, the highly productive paleovalley-style ones included.

1. **The study area features in brief**

Tectonically [8], the major part of the territory studied belongs to the Mysian–Scythian–Turanian platform; in the northeast there is a minor fragment of the East European platform, and in the southwest — the North Caucasian folded area.

Sediments of the U-bearing complex, the so-called Lower Miocene fishbone horizons, are almost ubiquitous. It comprises a series of small deposits of sedimentary organogenic-phosphate type stratiform uranium-phosphorus-rare earth ore formation (Fig.1).

Miocene sediments of the Karagan-Konsky and Sarmatian complexes occur predominately in the west of the territory. The Karagan-Konsky complex contains subeconomic paleo-valley type U accumulations (Balkovskoye occurrence and numerous showings).

The Sarmatian and Absheron-Akchagyl aquifer complexes contain areal hydrogeochemical anomalies with U content above 1×10^{-5} g/l. An important predictive feature of the paleovalley-type hydromorphous U deposits is the presence of numerous buried watercourse valleys. Figure 1 shows the axes of such largest landforms, the potentially U-bearing anomalous geochemical areas. In connection with zones of formational oxidation in the sediments of the Sarmatian and Absheron-Akchagyl complexes, it is possible to detect economic hydrogenous U mineralization in zones of formational oxidation.

Within the fold-and-block structure of the Greater Caucasus, the Bykogorsk and Beshtaugorsk U deposits of hydrothermal-metasomatic ore formation are known, being associated with intrusive rocks of the Kavminvodsk magmatic complex [3].

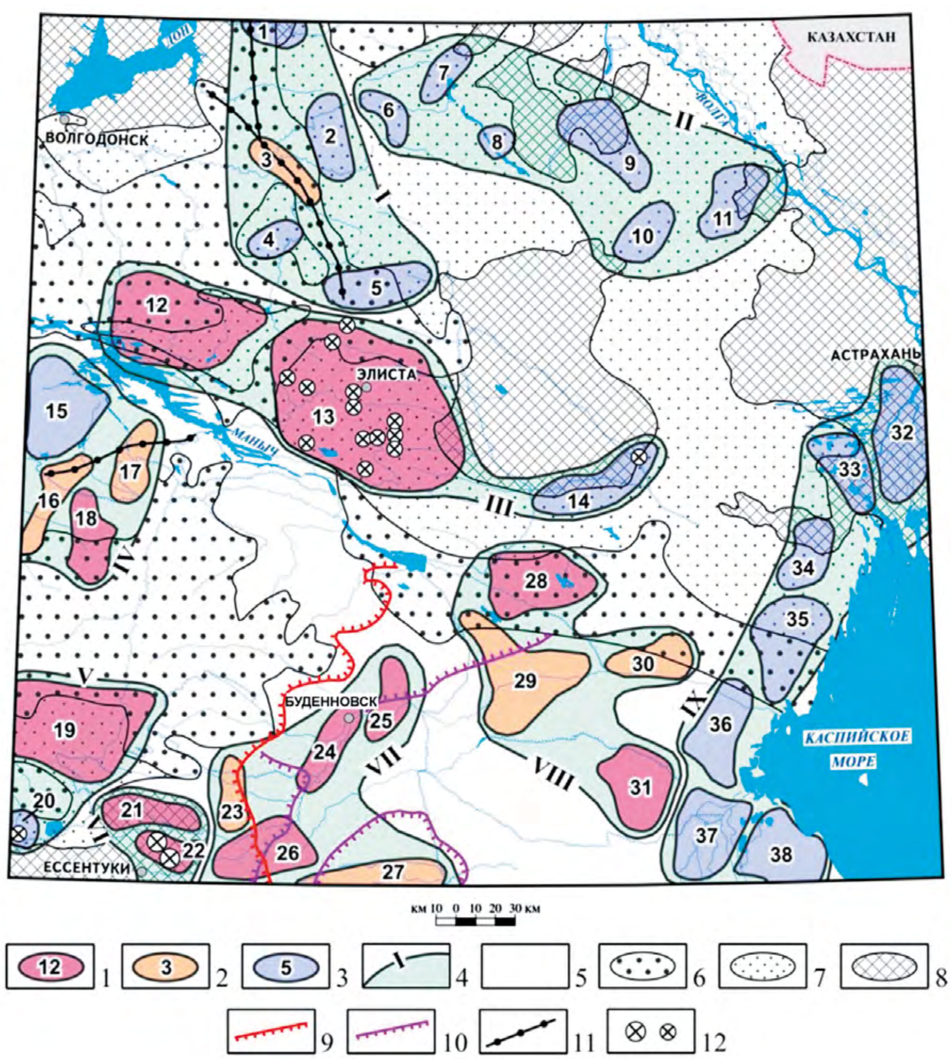

Fig.1. U potential of the southern part of European Russia. 1–3. Prospectivity grade of anomalous geochemical areas and their numbers: 1 — prospective, 2 — uncertain, 3 — low; 4 — Geochemical zones and their indices; 5–7. Distribution areas of the formation complexes prospective for hydrogenic U mineralization: 5 — Absheron — Akchagyl complex: unstable lithologies and impeded groundwater circulation, 6 — Sarmatsk and Karagan-Konsk complexes: lithologies favorable for ground water circulation bearing primary U concentrations in Middle Sarmat and economic U contents in Yashkul series and Bolsheyankul suite, 7 – uraniferous Oligocene-Lower Miocene fishbone horizons, 8 – areas barren of hydrogenic U mineralization-bearing formations; 9–10 — thinning out of the formation oxidation zones, teeth directed towards the oxidation environment: 9 — Sarmatian, 10 — Absheron-Akchagyl; 11 — axes of paleo-valleys; 12 — U deposits (medium and small)

2. **Materials and methods.**

This assessment of the territory's U mineral potential employed the results of a regional geochemical study of the distribution of mobile U species and its geochemical associates in soils and stream sediments of the area. The effectiveness of their use for pinpointing mineral deposits located in the platform cover and even in the basement has been proved by geochemical studies carried out by the Federal State Budget Institution — Institute of Mineralogy, Geochemistry and Crystal Chemistry of Rare Elements (FSBI IMGRE) [2]. The blind-and-buried deposits were indicated on the day surface via their superimposed (palimpsest) geochemical halos in soils and stream sediments.

A total of 2475 samples of soil and 702 stream sediment samples were collected over the map sheet terriory of 193 700 sq. km. According to [4, 11], soil samples were taken from dug holes of 60 and more cm deep, thus providing B or B-C horizon material. Further dry sieving extracted the – 1 mm material from sediments.

The mobile species determination of uranium and its satellites (Th, Mo, Pb, Se, Sc, Re, Tl, TR, etc.) were carried out in 1M HNO_3 solution extracts from the sampled and prepared material using ICP-MS in the FSBI IMGRE analytical center.

Objects of geochemical exploration — anomalous geochemical regions and clusters, were outlined as areas of continuous development of multi-element anomalies (U and its satellites) delineated by the two backgrounds level, i.e., by the concentration index level equal or exceeding 2. The use of local geochemical background in identification and evaluation of potentially productive geochemical anomalies minimized the interference from naturally elevated concentrations of non-metallic chemical elements [6].

Interpretation of anomalous geochemical fields (AGFs) included determination of their mineralization style and qualitative assessment of the prospects. The interpretation of the nature of geochemical anomalies is based on the formation principle, i.e., on the similarity of the chemistries of the AGF and the bedrock source of the substance [10]. A stable connection between the composition of anomalous geochemical fields and their metallogeny is a consequence of the fact that ore-forming elements and their satellites generate the most extensive fields and are characterized by more intense accumulation and high heterogeneity of geochemical fields in comparison with other elements. As a rule, these are the head members of the geochemical assemblages that characterize the AGFs.

In case of blind-and-buried occurrence of the mineralization under consideration, a reliable assessment of its resource potential using geochemical data is impossible, so the assessment of the prospects of anomalous geochemical areas is carried out by comparing their geochemical characteristics with reference ones [5]. Criteria that take into account the geochemical features (composition, complexity, intensity and degree of heterogeneity in the distribution of the contents of ore-forming elements and their satellites) of AGFs, their size, geological position, the presence of U deposits and occurrences in certain formations, etc., make it possible to overcome the AGFs interpretation issues.

Geochemical assemblages are series of anomaly-forming chemical elements ranked by the accumulation intensity defined as the concentration ratios (Kc), i.e., the local background-normalized average contents of the elements (Table 1). Three accumulation intensity levels of chemical elements were used: high (Kc > 4. 0), moderate (2.0 <Kc < 4.0) and low (1.0 < Kc < 2.0), The degree of heterogeneity in the distribution of uranium and its satellites was assessed by the coefficient of variation: high (V > 75 %), medium (50 % <V < 75 %) and low (V < 50 %). High heterogeneity in the elements' contents is a known feature of the ore deposits' geochemical halos [1].

Table 1 presents geochemical assemblages as ranked series of promising objects. Here, the subscripts correspond to the value of the accumulation coefficient (Kc), and the superscript stands for the coefficient of variation (V %) of the elements contents.

3. **Results and discussion.**

As established, anomalous geochemical fields of U and its associates in soils exist in every known uranium region and cluster and are widespread beyond their borders. In stream sediments, their anomalies are localized in a similar way, but normally are of lower contrast.

On the territory of the map sheet considered, 9 geochemical zones (GZs) have been identified, including 38 anomalous geochemical fields with established and potential uranium mineralization of the mineral region or mineral cluster rank, which mineralization style varies (Fig. 1).

The following geochemical zones are specialized for the stratiform organogenic-phosphate style of the sedimentary uranium-phosphorus-rare earth terrigenous formation in the fishbone remains hosted by Oligocene-Lower Miocene deposits: Ukhtinsk (II), Elistinsk (III) and Cherkessk (V)

The Elistinsk (III) GZ is the most productive one. Its boundaries comprise the anomalous geochemical field(AGF, 13) that corresponds to the Elistinsk U district (Fig. 1) with known deposits, occurrences and showings of the ore formation described below.

Uraniferous bodies in the area consist of clay (60–70 %), Fe sulfides (20–25 %) and fish bone detritus (15–20 %). The phosphate substance contains up to 0.2 % U; the sulfide component of the ores associates mainly with rare earth elements of Ce and Y groups (0.5–1 %), Sc (tens, sometimes hundreds of g/t), Ni, Co , Mo, Pb, Zn, As ($n\times10^{-1}$ — $n\times10^{-2}$ %) and Re (up to $n\times10^{-4}$ %). In the well-studied Yashkul deposit, the productive horizon occurs in the northern flank of the region within the depth interval of 340–406 m. The prognostic uranium resources of the Elistinsk zone are highly estimated [8].

The Elistinsk AGF (13) is spatious (6471 sq. km); its soils and stream sediments are quite reliably characterized (73 and 43 samples, respectively).

Uranium halos predominantly mark the periphery of the area, what is explainable by the occurrence of its mineralization in a depression on which flanks the productive horizon approaches the surface. The composition of the anomalous geochemical field in soils and stream sediments is complex.

Table 1
Geochemical features of prospective and reference anomalous geochemical taxa

Number (Fig.1) and name of a geochemical taxon (areal extent, sq. km)	Environmental component studied (number of samples collected)	Geochemical assemblages of accumulated chemicall elements (subscripts – accumulation indices; superscripts – coefficients o f variation)
U – P – TR ore formation		
Elistinsk GZ (III)		
12. Proletarsk GR (2841)	Soils (20)	$Mo_{7,2}^{201}\ Th_{4,6}^{122}\ U_{2,4}^{93}\ Cs_{2,1}^{61}\ Bi_{1,7}^{45}\ As_{1,7}^{65}\ Tl_{1,7}^{53}\ Sr_{1,6}^{55}\ Rb_{1,6}^{63}\ Zr_{1,5}^{56}$
	Stream s. (14)	$U_{1,8}^{99}\ Te_{1,8}^{58}\ Re_{1,8}^{86}\ Sr_{1,7}^{117}\ Mo_{1,5}^{81}\ Fe_{1,5}^{75}$
13. Elistinsk GR (6471)	Soils (73)	$Mo_{3,9}^{131}\ Th_{3,8}^{113}\ Ag_{2,4}^{95}\ Bi_{2,1}^{56}\ U_{1,7}^{83}\ Zr_{1,7}^{91}\ Se_{1,6}^{78}\ Sb_{1,5}^{68}\ W_{1,5}^{146}$
	Stream s. (43)	$Mn_{2,2}^{272}\ Se_{2,1}^{65}\ Ag_{2,1}^{64}\ Mo_{2,0}^{133}\ Fe_{1,8}^{67}\ Re_{1,7}^{51}\ Bi_{1,7}^{87}\ Sr_{1,7}^{82}\ Sn_{1,6}^{77}\ Sc_{1,5}^{79}\ U_{1,5}^{64}\ Tl_{1,5}^{134}\ Th_{1,5}^{67}\ Te_{1,5}^{55}$
Cherkessk GZ (V)		
19. Bolsheyansk GR (2913)	Soils (95)	$Th_{7,9}^{125}\ Au_{7,4}^{235}\ Bi_{3,4}^{88}\ U_{3,0}^{65}\ Mo_{2,6}^{177}\ Re_{2,4}^{59}\ Fe_{2,1}^{57}\ Sc_{2,0}^{65}\ Se_{1,8}^{54}\ Te_{1,7}^{66}\ Cu_{1,5}^{50}\ Ge_{1,5}^{37}\ Zr_{1,5}^{68}\ Co_{1,5}^{42}\ Zn_{1,5}^{63}\ Ce_{1,5}^{31}$
	Stream s. (38)	$Th_{1,9}^{71}\ Sc_{1,8}^{46}\ Lu_{1,6}^{34}\ Yb_{1,6}^{34}\ Ce_{1,6}^{38}\ Tm_{1,6}^{33}\ Er_{1,6}^{33}\ Cs_{1,6}^{69}\ Co_{1,6}^{36}\ Nd_{1,6}^{33}\ Re_{1,6}^{69}\ Ho_{1,6}^{33}\ Pr_{1,5}^{32}\ Sm_{1,5}^{32}\ Eu_{1,5}^{31}\ Y_{1,5}^{30}\ Dy_{1,5}^{32}\ Te_{1,5}^{46}\ La_{1,5}^{32}\ Be_{1,5}^{31}\ Gd_{1,5}^{31}\ U_{1,4}^{40}$
20. Cherkessk GR (236)	Soils (4)	$W_{4,7}^{88}\ Mo_{4,5}^{74}\ U_{4,3}^{125}\ Ta_{4,1}^{111}\ Th_{2,6}^{99}\ Zn_{2,5}^{51}\ Cu_{2,4}^{44}\ Ti_{2,1}^{67}$ $Te_{2}^{50}\ P_{1,9}^{115}\ Bi_{1,7}^{57}\ Cs_{1,7}^{28}\ Sc_{1,6}^{57}\ Sr_{1,5}^{46}$
U hydrothermal metasomatic ore formation		
Pyatigorsk GZ (VI)		
21. North Minvodsk GR (2913)	Soils (40)	$Mo_{4,8}^{131}\ U_{3,7}^{85}\ Au_{3,0}^{217}\ Re_{2,9}^{79}\ Cd_{2,6}^{177}\ Th_{2,3}^{93}\ Cu_{2,0}^{92}\ Bi_{1,9}^{91}\ Sb_{1,8}^{76}\ Sr_{1,7}^{94}\ (Pb^{106}\ Fe^{50}\ Se^{87}\ Te^{56})_{1,6}\ (Zn^{60}\ Tl^{71})_{1,5}$
	Stream s.(7)	$Re_{24,6}^{159}\ Mo_{7,1}^{94}\ Sc_{5,4}^{99}\ Th_{4,0}^{125}\ Cd_{2,6}^{77}\ U_{2,5}^{64}\ Zn_{2,4}^{119}\ Zr_{2,4}^{71}\ Bi_{2,3}^{84}\ Cu_{2,2}^{52}\ V_{2,2}^{65}\ Tl_{2,1}^{118}\ Fe_{2,0}^{59}\ Sb_{2,0}^{49}\ Lu_{1,9}^{52}\ Ag_{1,9}^{72}\ Yb_{1,9}^{49}\ Ho_{1,9}^{48}\ Tm_{1,8}^{50}\ Dy_{1,8}^{48}\ Be_{1,8}^{21}\ Er_{1,8}^{45}\ Tb_{1,8}^{46}\ W_{1,8}^{46}\ Sm_{1,8}^{45}\ Pb_{1,8}^{57}\ Gd_{1,8}^{42}\ Eu_{1,8}^{42}\ Co_{1,7}^{44}\ Ga_{1,7}^{35}\ Se_{1,7}^{57}\ Nd_{1,7}^{41}\ Y_{1,6}^{35}\ Pr_{1,6}^{40}\ Cr_{1,6}^{43}\ Ce_{1,5}^{39}\ As_{1,5}^{67}\ Ni_{1,5}^{33}$
22. Pyatigorsk GC (236)	Soils (19)	$U_{3,2}^{83}\ Mo_{2,9}^{78}\ Au_{2,1}^{56}\ (Sr^{80}\ Cu^{127}\ Re^{64})_{2,0}\ Pb_{1,9}^{113}\ (Bi^{70}\ Cd^{106}\ Sb^{63}\ Sn^{190})_{1,8}\ Te_{1,7}^{69}\ (Tl^{79}\ Th^{58})_{1.6}\ (Be^{152}\ Cs^{121}\ Zn^{82})_{1,5}$
U terrigenous paleo-valley ore formation		
Yashaltinsk GZ (IV)		
18. Kugultinsk GC (825).	Soils (15)	$Au_{3,9}^{88}\ Mo_{3,8}^{125}\ W_{1,9}^{89}\ As_{1,8}^{111}\ U_{1,7}^{111}\ Bi_{1,6}^{109}\ Sr_{1,6}^{82}\ Th_{1,6}^{95}$
	Stream s. (11)	$Re_{2,5}^{145}\ Au_{2,5}^{67}\ Mn_{2,3}^{107}\ As_{2,3}^{68}\ Mo_{2,2}^{120}\ W_{2,2}^{110}\ Se_{2,1}^{116}\ Sr_{2,0}^{53}\ Te_{1,9}^{70}\ U_{1,5}^{50}\ Zn_{1,5}^{129}\ Ti_{1,5}^{47}$
Achinero-Neftekumsk GZ(VIII)		
28. Svetlovsk GR (1443)	Soils (12)	$Mo_{12,2}^{150}\ Ag_{5,4}^{79}\ Zr_{3,8}^{70}\ Se_{3,0}^{73}\ As_{2,8}^{86}\ Sr_{2,8}^{100}\ U_{2,7}^{116}\ Tl_{2,5}^{82}\ Sb_{2,4}^{56}\ Th_{2,2}^{76}\ Bi_{2,2}^{57}\ Cr_{2,1}^{55}\ Sc_{1,9}^{63}\ Fe_{1,9}^{28}\ Ni_{1,9}^{40}\ Cu_{1,8}^{33}\ W_{1,8}^{69}\ P_{1,8}^{59}\ Pb_{1,7}^{30}\ V_{1,6}^{42}\ Mn_{1,6}^{42}\ Co_{1,6}^{38}\ Yb_{1,5}^{26}\ Lu_{1,5}^{26}\ Be_{1,5}^{37}\ Tm_{1,5}^{23}\ Ho_{1,5}^{24}$
	Stream s. (5)	$Re_{4,2}^{11}\ Sr_{2,6}^{50}\ As_{2,2}^{90}\ Sc_{2,2}^{77}\ Bi_{1,9}^{63}\ Mn_{1,7}^{105}\ V_{1,7}^{75}\ Ag_{1,7}^{60}\ Cr_{1,7}^{77}\ Zr_{1,6}^{64}\ Mo_{1,5}^{58}\ U_{1,5}^{68}$
31. Kyzylkolsk GR (1214)	Soils (14)	$Mo_{6,4}^{147}\ U_{4,2}^{113}\ Sr_{3,2}^{69}\ Zr_{3,1}^{67}\ Ag_{2,9}^{52}\ Th_{2,9}^{79}\ Bi_{2,7}^{65}\ Cr_{2,3}^{44}\ As_{2,3}^{47}\ V_{2,0}^{61}\ Ti_{1,8}^{62}\ Fe_{1,8}^{41}\ Sb_{1,8}^{52}\ Cu_{1,8}^{41}\ Tl_{1,7}^{37}\ Te_{1,6}^{61}\ Ni_{1,6}^{37}\ Cd_{1,6}^{46}\ Zn_{1,6}^{37}\ Ge_{1,5}^{33}\ Sc_{1,5}^{50}\ Pb_{1,5}^{41}\ Be_{1,5}^{41}\ Ba_{1,5}^{57}\ W_{1,5}^{44}\ Ga_{1,5}^{35}\ Co_{1,5}^{40}$
U in terrigenous formational oxidation zones		
Budyonnovsk GZ (VII)		
24 Budyonnovsk GC (719)	Soils (8)	$Mo_{5,9}^{69}\ Th_{5,4}^{76}\ Bi_{4,5}^{77}\ Sr_{3,7}^{19}\ U_{3,5}^{23}\ Re_{2,7}^{78}\ Rh_{2,7}^{42}\ Tl_{2,6}^{45}\ Fe_{2,5}^{25}\ Cr_{2,2}^{57}\ Ni_{2,2}^{52}\ Pd_{2,1}^{45}\ Sc_{2}^{29}\ W_{1,9}^{66}\ Cs_{1,9}^{31}\ Cd_{1,9}^{37}\ Te_{1,8}^{29}\ Zr_{1,8}^{53}\ Ba_{1,7}^{45}\ As_{1,6}^{28}\ Ge_{1,6}^{20}\ Se_{1,5}^{34}\ Mn_{1,5}^{18}\ Zn_{1,5}^{26}\ Nb_{1,5}^{50}$
	Stream s. (6)	$Cr_{3,6}^{89}\ Re_{3,3}^{73}\ Mo_{3,1}^{68}\ Au_{1,9}^{50}\ Tl_{1,8}^{19}\ Cs_{1,8}^{61}\ Zn_{1,8}^{35}\ W_{1,8}^{98}\ Fe_{1,8}^{43}\ Ni_{1,8}^{64}\ Sn_{1,7}^{52}\ Sb_{1,7}^{46}\ Cd_{1,6}^{35}\ U_{1,6}^{50}\ Rh_{1,6}^{22}\ Cu_{1,6}^{45}\ Se_{1,5}^{31}\ Sr_{1,5}^{20}\ P_{1,5}^{46}$
25 East Budyonnovsk GC (607)	Soils (7)	$Th_{6,2}^{82}\ Mo_{5,7}^{88}\ Re_{5}^{181}\ Bi_{3,7}^{54}\ U_{3,7}^{47}\ Rh_{3}^{50}\ Se_{3}^{154}\ Sr_{2,5}^{47}\ Nb_{2,4}^{100}\ Tl_{2}^{44}\ Fe_{1,7}^{58}\ Zr_{1,7}^{33}\ As_{1,6}^{28}\ Te_{1,6}^{51}\ Sb_{1,6}^{56}\ Cd_{1,5}^{52}\ Pd_{1,5}^{31}$
	Stream s. (3)	$Cr_{1,8}^{39}\ Cs_{1,8}^{29}\ Au_{1,7}^{31}\ Zn_{1,5}^{65}$
26. Georgievsk GR (1233)	Soils (19)	$Mo_{7}^{97}\ Th_{6}^{184}\ U_{3,4}^{87}\ Bi_{2,7}^{63}\ Sr_{2,2}^{50}\ Rh_{2,1}^{52}\ Te_{2}^{66}\ As_{1,9}^{66}\ Se_{1,8}^{56}\ Cd_{1,8}^{43}\ Sb_{1,8}^{51}\ Re_{1,8}^{81}\ Fe_{1,8}^{54}\ Tl_{1,7}^{54}\ Zn_{1,5}^{38}\ Zr_{1,5}^{68}\ W_{1,5}^{92}$
	Stream s.(14)	$Cs_{5,8}^{120}\ Mo_{3}^{102}\ U_{2,5}^{161}\ Zn_{2}^{88}\ Au_{2}^{49}\ Tl_{1,9}^{24}\ Re_{1,8}^{75}\ Cu_{1,8}^{138}\ Bi_{1,8}^{91}\ Sb_{1,6}^{40}$

Note: GR – geochemical region, GC – geochemical cluster

Common here are the indicator elements of uranium mineralization — U, Mo, Th, Ag, Se, Bi, Fe, Re, Sc (Table 1).

The chemical elements concentrations in soils and stream sediments of the area are relatively low, probably due to the buried occurrence of the source ore deposits. However, the maxima of the variation coefficient of uranium and some of its satellites (Mo, Th, Ag, Zr, Se) in soils mark the area. Comparatively to the soils, in stream sediments the accumulation of uranium and its satellites is somewhat lower; only Mo, Sc, and Tl demonstrate high heterogeneity in their spatial distribution.

A fairly good geological and geochemical knowledge on the Elistinsk AGF (13) opens a possibility to use its characteristics as reference ones for other AGFs specialized in uranium-phosphorus-rare earth style revealed by surveys. These AGFs primarily include Proletarsk (12) and Tsubuksk (14), located in the same geochemical zone as the Elistinsk one.

Of these, Proletarsk AGF is considered promising (12). It is of a fairly large size (Table 1); its geological position is similar to that of the Elistinsk one (Fig. 1), but differs by higher accumulation and heterogeneity of U and its satellites' distribution in soils and stream sediments.

Within the Tsubuk (14) AGF, a small uranium–phosphorus–rare earth Tsubuk deposit (14) occurs. A geochemical specialty of this AGF is the wide representation of uranium satellites in it, rare earths included. However, they are characterized by low values of the accumulation index (Kc) and V, which, given the locality of the AGF, prohibits a prediction of a significant increase in the U resource potential here.

The Cherkessk GZ (V) is confined to the South Stavropol uplift in the area of attenuation of the Central Caucasian fold-and-fault zone. The small Cherkessk uranium-phosphorus-rare earth deposit occurs in the fishbone horizons of the Karadzhalga formation. The productive body, composed of clays rich in iron sulfides and uranium-bearing fishbone detritus, lies within the depth interval 11 to 200 m. The average U content in ore is 8×10^{-3} %, and in fishbone detritus concentrate 0.7 %. Besides, the ore is rich in Mo, Pb, Zn, Ni, S, P_2O_5, Sc, and TR [3].

The Cherkessk GC (20) in soils displays sufficiently high and variable contents of U and its satellites for a positive forecast, but the locality of the AGP does not allow a positive assessment of the prospects for expanding the resource potential of the uranium of the well-known Cherkessian deposit. Of interest here may be the possible continuation of the AGCP in a westerly direction outside the area studied.

The Bolsheyankulsk AGP (19) has been geochemically studied quite reliably (Table). In its soils, U and some of its satellites are characterized by high accumulation and pronounced spatial heterogeneity. This, along with a favorable geological position and a significant areal extent (2913 sq. km), allows to consider the Bolsheyankulsk (19) AGP as a promising one for the discovery of economic fishbone-associated U deposits.

The uranium lagoonal-alluvial ore formation predicted in the AGP of the Caspian (IX) GZ, localized in the coastal zone on lagoonal-alluvial sediments, is also classified as a sedimentary organogenic type. However, taking into account unfavorable geochemical characteristics of the anomalous uranium fields and low (just a few meters) thickness of potentially uranium-bearing deposits, the prospects of the Caspian GZ are considered as low.

The Pyatigorsk GZ (VI) is related to the hydrothermal-metasomatic granosyenite-porphyry U ore formation that associates with intrusions of the Kavminvodsk igneous complex [3].

The geochemical zone lies within the Mineralovodsk fold-and-block structure of the Greater Caucasus. The territory of the zone is fairly well exposed what favors the estimation of the resource potential of localized geochemical structures.

The Pyatigorsk (22) AGF corresponds to the Kavminvodsk U cluster with moderate reserves of the Beshtaugorsk and Bykogorsk U deposits. Local mineralization occurs in granite porphyries and dacites of Pliocene laccolith. Ore bodies (lenses, veins and stockworks) occur in fault zones. The U content in ore bodies is up to 1 %. Pyrite, galena, fluorite, oxides of iron and manganese are associated with U minerals. In the outer zone of U mineralization, Pb, Zn, and Hg minerals occur [8].

The soil geochemistry within the AGP has been studied in detail (Table 1). A feature of the ranked series is the head positions in it of U, Mo, Au, Cu, Re, what reflect not only the mineragenic specialization for U, but also opens an additional possibility to predict auriferous Re-bearing porphyry copper mineralization. The presence of lead and zinc in lower concentrations in the ranked series may be associated with polymetallic mineralization, which is typical of the outer zones of hydrothermal-metasomatic uranium mineralization.

The resource potential of uranium according to geochemical data is assessed as moderate, which, given the presence of two medium-size uranium deposits, does not imply a significant increase in uranium reserves in the Pyatigorsk (22) AGF. The resource potential of the Pyatigorsk (22) AGF for Cu, Mo, Pb, Zn and Au is also assessed as moderate.

The geological position of the North Minvodsk AGF (21) is analoguous of the Pyatigorsk AGF (22) and its prospects as estimated by geochemical data are positive (Fig. 1).

The anomalous geochemical field has been reliably studied in soils, where it is characterized by an association of elements similar to that of the Pyatigorsk (22) AGF (Table 1). The ranked row is headed by the same elements. Bottom sediments are characterized, as a rule, by higher concentrations of uranium and its satellites and a low level of accumulation and uniformity of distribution of rare earth element contents.

The composition of the ranked series of the North Minvodsk (21) AGKhP in soils and stream sediments opens a possibility to predict not just the deposits of the U granosyenite-porphyry ore formation, but also the Cu-Mo and gold-bearing porphyry granite formation. According to geochemical data, the resource potential of U and Se is high, whereas that of Mo, Cu and Au is moderate.

Uranium hydrogenous mineralization in the studied area is expected to be of two styles: paleovalley and zones of formational oxidation.

The following geochemical zones are specialized for mineralization of the uranium terrigenous gray-colored paleovalley formation: Oktyabrsk (I), Yashaltinsk (IV) and Achinero-Neftekumsk (VIII).

Uranium mineralization of this type is represented by one Balkovsky occurrence (a member of the Oktyabrskaya GZ) and a number of showings in the middle part of the Yashkul series (Miocene, over the rest of the territory). Five ribbon-shaped mineralized bodies were identified within the depth interval of 128–140 m, their length varied from 500 to 1500 m and width from 50 to 250 m. The U content ranged as 0.005–0.023 %, occasionally 0.09–0.15 %. The proportion of the mobile U species makes 70–93 % of its total content. The prognostic U and Se resources are small [8].

The geochemical assemblage of the Balkovska AGF demonstrates low accumulation intensity of U and most of its satellites. But this AGF has been poorly studied geochemically. Therefore, the characteristics of the anomalous field of the Dolmatovsky and Khokhlovsky districts, specialized for the paleovalley type of U mineralization were used as reference for assessing the prospects of hydrogenic type objects [7, 12]. Their geochemical assemblage in the stream sediments is quite complex: U3.6117, Th3.0115, Hf2.475, Zr2.473, Pb2.4155, (Be72, Sr69)2.3, Co2.1108, (Bi82, Ag83) 2.0, (Cu51, Sc77) 1.9, V1.875, Ba1.7, 96, TR1.9-1.554-58. The soil assemblage is more simple: U4.5167, Zn4.0208, Mo2.2183, Sr2.297, Th1.990, Hf1.978, Cs1.796, Zr1.678. Both assemblages display a wide range of accumulated indicator elements and high heterogeneity in the distribution of their contents ($V > 75$ %).

The Oktyabrsk (I) geochemical zone is confined to an extended paleovalley of submeridional strike. The only known mineral object of the paleovalley type is the Balkovsk U occurrence, described above, located in the Balkovskaya (5) AGF.

In comparison with the geochemical assemblages of the reference objects, the AGPs of the Oktyabrsk GZ are poor in U and most of its satellites, which, given a small size of their anomalies, predetermines their low prospects.

The Shebalinsk (3) AGF confined to the paleovalley filled out with the Karagan-Konsky sediments, sets some exception . Soils here bear high accumulations and are quite variable in Mo (7.9131) and Th (3.588) and moderate values of U, Bi, and Zr. Despite the moderate geochemical characteristics of the AGP and its location, the favorable geological position and poor grade of geochemical knowledge (6 samples) give no grounds to completely exclude the possibility of detecting economic U mineralization of the paleovalley type here. That is, the prospects for the Shchebalinsk AGF remain uncertain.

The Yashaltinsk (IV) GP sits at the northern slope of the Stavropol uplift. The Burukshun canyon is mapped on its territory, represented in the figure by the axial part of the paleochannel. A favorable prerequisite for a positive forecast of uranium paleovalley mineralization in the Podlesnaya (16), Dzhalginsk (17) and Kugultinsk (18) AGFs is the confinement of their northern flanks to the Burukshunsky paleo-canyon.

Kugultinsk (19) AGF is considered as a promising one. The list of indicator elements forming its geochemical assemblage is relatively short, but they are, as a rule, characterized by moderate accumulation and high heterogeneity of spatial distribution (Table 1).

The prospects for Podlesnaya (16) and Dzhalginsk (17) AGFs are uncertain because of the high degree of differentiation in the contents of a number of indicator elements of U mineralization, even with moderate and low accumulation, does not completely exclude the possibility of detecting economic mineralization.

Achinero-Neftekumsk GF (VIII) lies on the continuation of the Manych river valley., which, on the territory of the geochemical zone, breaks up into a number of branches filled out with recent sediments, to which the identified AGFs are confined.

The Svetlovsk (28) and Kyzylkolsk (31) AGFs with the highest geochemical characteristics are classified as promising for discovery of economic paleo-valley U deposits (Table 1). The prospects of the Neftekumsk (29) and Kumsk (30) AGFs are assessed as unclear due to unfavorable geochemical characteristics.

U mineralization in terrigenous gray-colored zones of formational oxidation is predicted in the Budyonnovsk GZ (VII), on the territory of which the extended oxidation zones in the sediments of the Sarmatian and Absheron-Akchagyl formation complexes pinch out, is mapped

According to geochemical data, Georgievsk (26), Budyonnovsk (24) and Vostochno-Budyonnovsk (25) AGFs are promising for U mineralization. Moreover, of these, the Georgievsk (26) AGF displays the maximum accumulation of U and its satellites within the geochemical zone (Table 1). The prospects of the Sablinsk (23) and Terek-Kumsk (27) AGFs are low, for these are characterized not only by low accumulation and differentiation of U contents and its satellites in soils, but are also located in the oxided zones depleted in uranium.

Conclusions

Major results of the regional geochemical soil and stream sediment surveys are as follows:

- anomalous geochemical areas with U mineralization of different styles are outlined;
- their distribution patterns are described;
- the scale of the ore deposition processes is estimated, and promising U objects are outlined.

The discovery of potentially economic U deposits of the styles known in the territory is predicted: 1) in the Proletarsk and Bolsheyankulsk GZs promising for the fishbone U-P-TR terrigenous ore formation remains, and 2) in the North Minvodsk AGF — for a uranium hydrothermal-metasomatic U formation.

Hydrogenous uranium paleo-valley mineralization is predicted in the Kugultinsk, Svetlovsk, and Kyzylkolsk AGFs; zones of formation oxidation are expectable in the Budyonnovsk, Vostochno-Budyonnovsk and Georgievsk AGKhP. The prospects for organogenic uranium mineralization of the lagoon alluvial style of the Caspian (IX) cause very moderate optimism. However, their identification may be of scientific and practical interest for environmental studies and geochemical exploration both in Russia and other BRICS countries.

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PREDICTION OF BASE AND PRECIOUS MINERAL DEPOSITS BASED ON MINERALOGICAL-GEOCHEMICAL STUDY AND MAPPING OF HYDROTHERMALLY ALTERED ROCKS

The article addresses the objectives and basic procedures of the petrographic-geochemical approach to the mineralogical-geochemical study and mapping of hydrothermally altered rocks with the aim of predicting mineralization during prospecting and assessment work at 1:25,000 (1:10,000) scale. The features of field, petrographic, geochemical, and mapping work are considered. Using the example of the Chumysh gold ore field (Magadan Region), the resulting component of this approach to the mineralogical, petrographic, and geochemical study of alteration types in predicting blind mineralization is shown. ***Keywords:*** *mapping, metasomatites, forecast, deposits, base and precious metals.*

One of the key issues of large-scale geological survey at the present stage is to increase its prospecting efficiency. The relevance of this issue is beyond doubt due to the fact that the limit of easily discoverable base and precious metal deposits in our country is almost completely exhausted. New ore targets can only be discovered through blind ore deposits that do not reach the surface.

An increase in the reliability of prospecting for potentially ore-bearing areas during geological surveying at 1:50,000 scale and larger (1:25,000 — 1:10,000) can be reached by the widespread use of both such traditional methods as lithogeochemical survey by secondary and primary dispersion halos, heavy concentrate mapping, dispersion flow mapping, magnetic prospecting, gravity prospecting, electrical prospecting, gamma spectrometry, hyperspectral survey, etc., and methods based on the mineralogical-geochemical study and mapping of hydrothermally altered rocks and wallrock metasomatites.

In our country, the issue of using alteration types for local prediction and assessing the ore content prospects was addressed in different years by such famous scientists as D.S. Korzhinsky, V.A. Zharikov, D.V. Rundqvist, L.N. Ovchinnikov, B.I. Omelyanenko, V.L. Rusinov, G.P. Zaraisky, G.N. Shcherba, E.V. Plyushchev, S.I. Naboko, V.A. Vlasov, A.A. Beus, G.L. Pospelov, D.I. Tsarev and many other researchers, who made a significant contribution to the buildup and development of the Russian scientific school studying metasomatism and ore formation.

Great progress in the study of alteration types at the end of the last century was facilitated by the All-Union conferences held in Leningrad in 1963, 1966, 1972, 1976, 1982, and 1987 and reflected in the relevant proceedings: «Metasomatic alterations in wallrock and their role in ore formation» [17], «Issues of metasomatism» [26], and «Metasomatism and ore formation» [12–16]. During the same period, a number of fundamental monographs and articles were published characterising certain varieties of hydrothermally altered rocks — ferruginous and magnesian skarns, alkaline metasomatites, greisen, phyllisite, beresite-listvenite, secondary quartzite, argillic alterations, propylites, quartz-feldspathic hydrothermalites, etc. which generally determined a very high scientific level in the study of hydrothermally altered rocks in our country [1–11, 17–21, 25–33, 37 etc.].

At the Karpinsky Institute at the end of the last century, under the leadership of E.V. Plyushchev, an original procedure for prospecting and assessment at 1:50,000 scale (1:25,000 and larger) was developed and successfully applied in practice

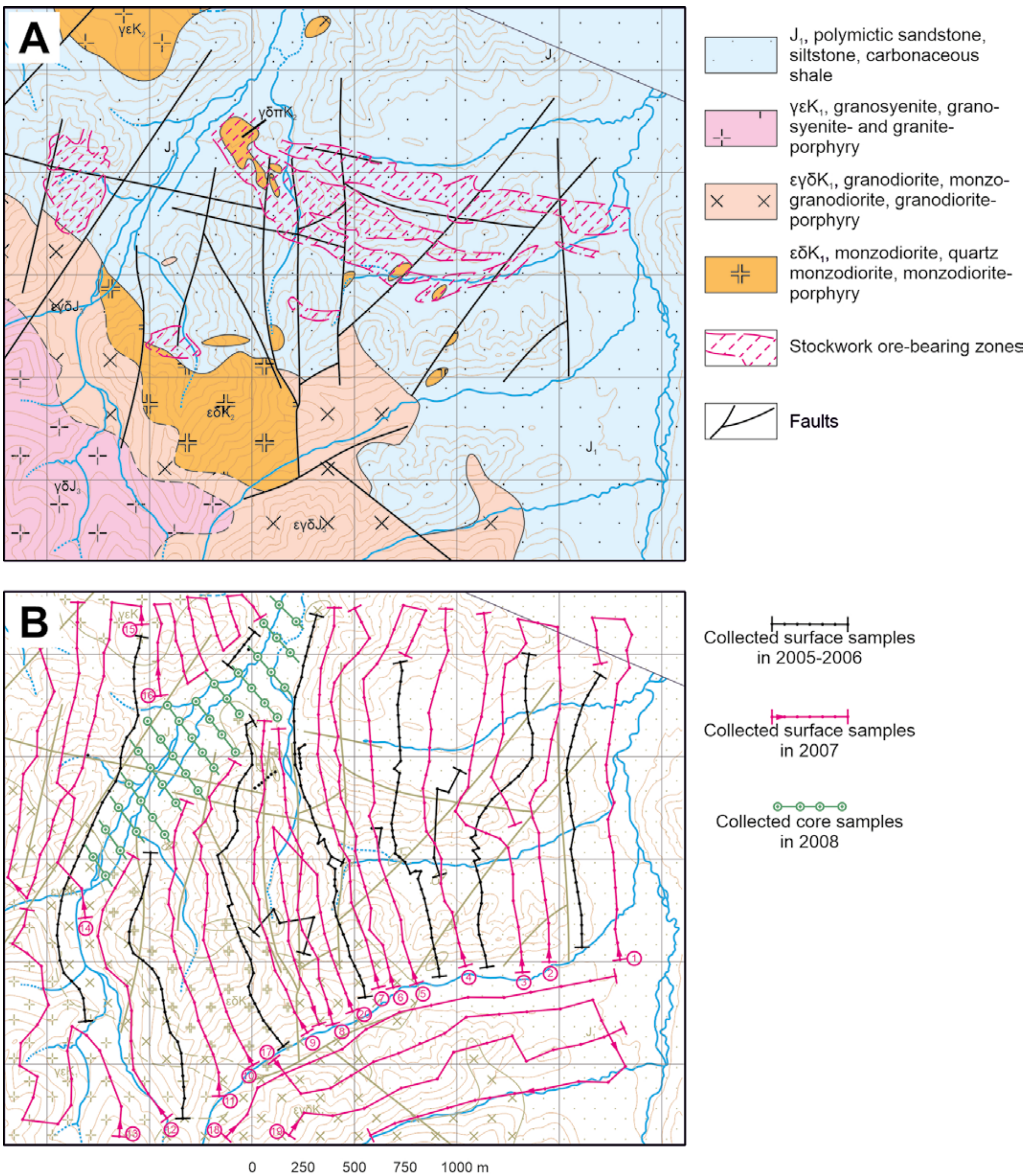


Fig. 1. Sketch geological map of the Chumysh gold-bearing ore field (Magadan region) — A, distribution of collected surface and core samples for mineralogical and geochemical study B

based on mapping hydrothermally altered rock fields and a comprehensive study of their mineralogical, petrographic, and geochemical features [22–24, 34]. This procedure is based on an integrated approach to the study of mineralogy, petrography, and geochemistry of alteration types, including wallrock metasomatites and well developed hydrothermalites.

This procedure is recommended for use at 1:25,000 (1:10,000) scale at prospects in the rank of potential ore fields, localized based on geological surveying at 1:200,000 or 1:50,000 scale. It is desirable that the size of such prospects does not exceed 20–30 km². It is most rational to study them when running both geological survey and prospecting traverses, which will minimize additional labour and money costs.

The basis for studying well-developed alteration types (including external zones of weak hydrothermal alterations) is their geological mapping at 1:25,000 (1:10,000) scale. What is meant here is not so much registering halos of well-manifested metasomatic rocks, infilling veins, or other pronounced but sporadically occurring hydrothermalites (which is necessarily done in any prospecting traverses), but a systematic study of the entire prospect for detecting alteration types in rocks. Considering that the latter, as a rule, are distributed almost everywhere in mobile areas of the earth's crust, but mainly in the form of scattered inclusions of epigenetic minerals, the task of mapping hydrothermally altered rocks actually comes down to identifying and delineating in space zones of moderately and weakly manifested alteration types.

Field work. During field work aimed at petrographic-geochemical study and mapping of well-developed alteration types, the performers are given the following tasks: 1) creation of a relatively uniform sampling network for the entire area at study scale (*area work*), and 2) research in hydrothermal deposit sites and other well-developed hydrothermalites (*detailed work*).

Area works. In accordance with the requirements for large-scale mapping of alteration types, the main task of field work is to run prospecting routes 2–5 km or longer, oriented considering the actual exposure of the work area, cross-strike to the main geological structures, intrusive contacts, and hydrothermally altered rock zones.

The main task of the routes is to conduct geological observations and petrographic-geochemical sampling of bedrock involved in the structure of the study area. The work is being carried out on the existing geological base map at 1:25,000 scale (1:10,000 and larger) with reference to topographic maps and GPS.

The observation network is selected according to the mapping scale (on average, 1 observation point per 1 cm² of map).

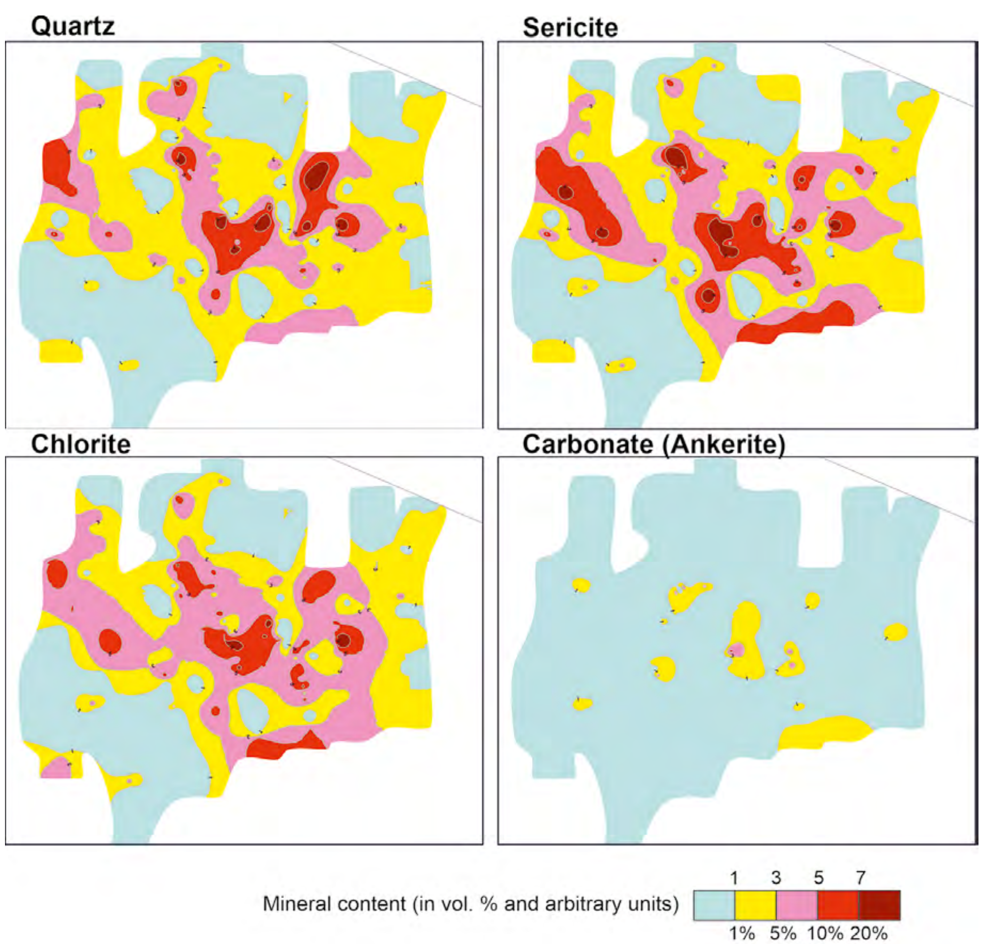


Fig. 2. Distribution of main epigenetic minerals of phyllic altered rocks within the Chumysh ore field

The boundaries of the mapped zones are drawn according to the change in specific characteristics of various facies of hydrothermally altered rocks. Development of a relatively uniform network of observation bases throughout the entire mapped area is the main condition for studying well-developed alteration types (Fig. 1).

In this case, it is necessary to clarify the concept of an observation point. In conditions of natural bedrock exposure or eluvial erosion, an observation point is understood as an area measuring 5–10 by 20 m, within which the most representative rock in composition, structure, and alteration degree is identified. This rock (or several rocks equally characteristic of the outcrop) is sampled. A small sample with fresh chips is taken and from it — a chip for making a transparent thin section, as well as a geochemical grab sample weighing 300–500 g. In this case, the following important rule must be observed: the sample, the chip for making a thin section, and the geochemical grab sample must correspond as closely as possible to each other both in the source rock composition and in the nature and degree of development of the superimposed hydrothermal mineralization. Otherwise, all subsequent mineralogical-petrographic and petrographic-geochemical constructions will not make much sense.

Detailed work. Local alteration zones, veins, and veinlets are sampled additionally if necessary. If possible, rock material not affected by weathering is selected. However, due to the lack of obvious signs of distinguishing between supergene and hydrothermal alterations, samples must be rejected carefully.

Office work. The office period of field materials processing assumes:

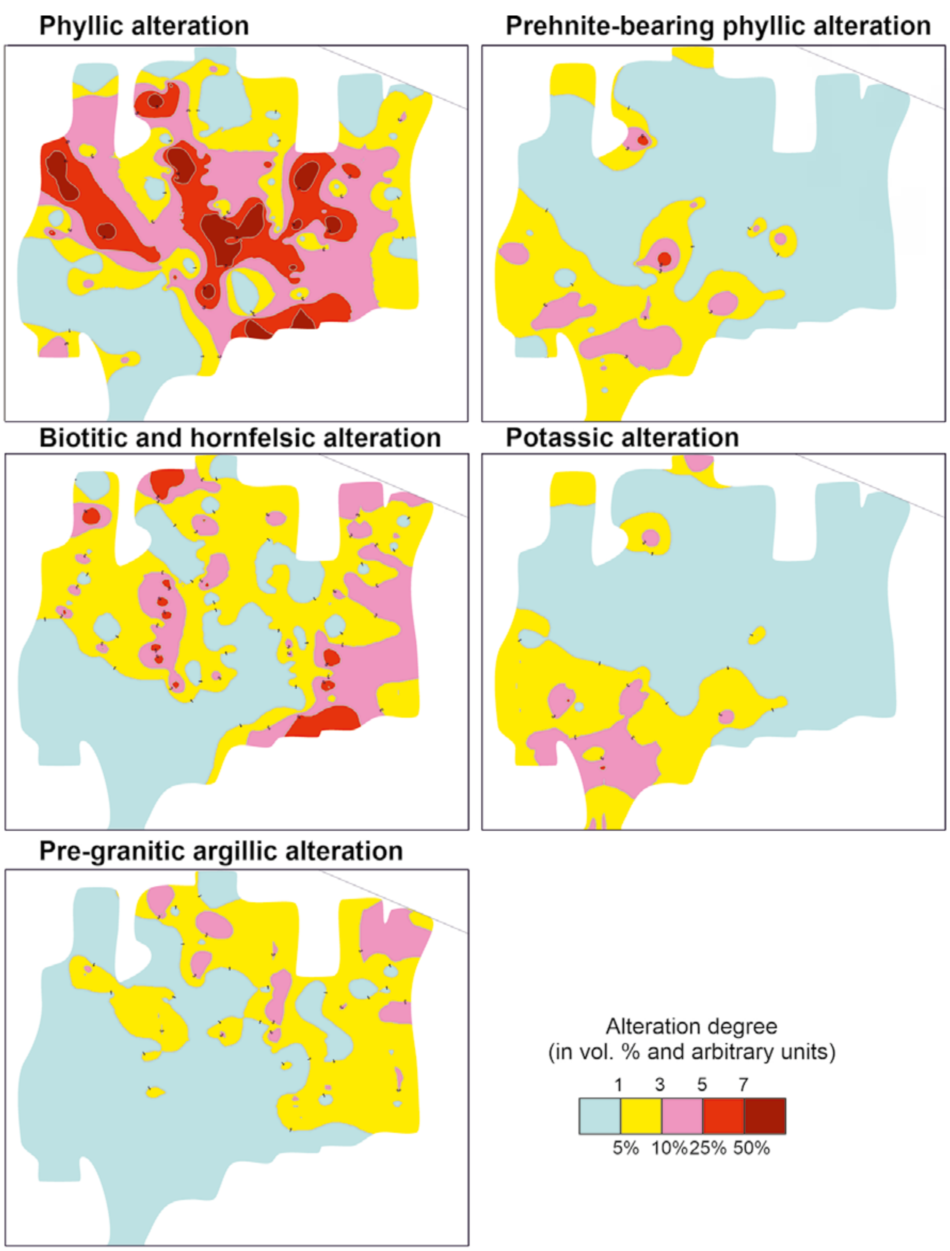


Fig. 3. Distribution of alteration types of different composition and age within the Chumysh ore field

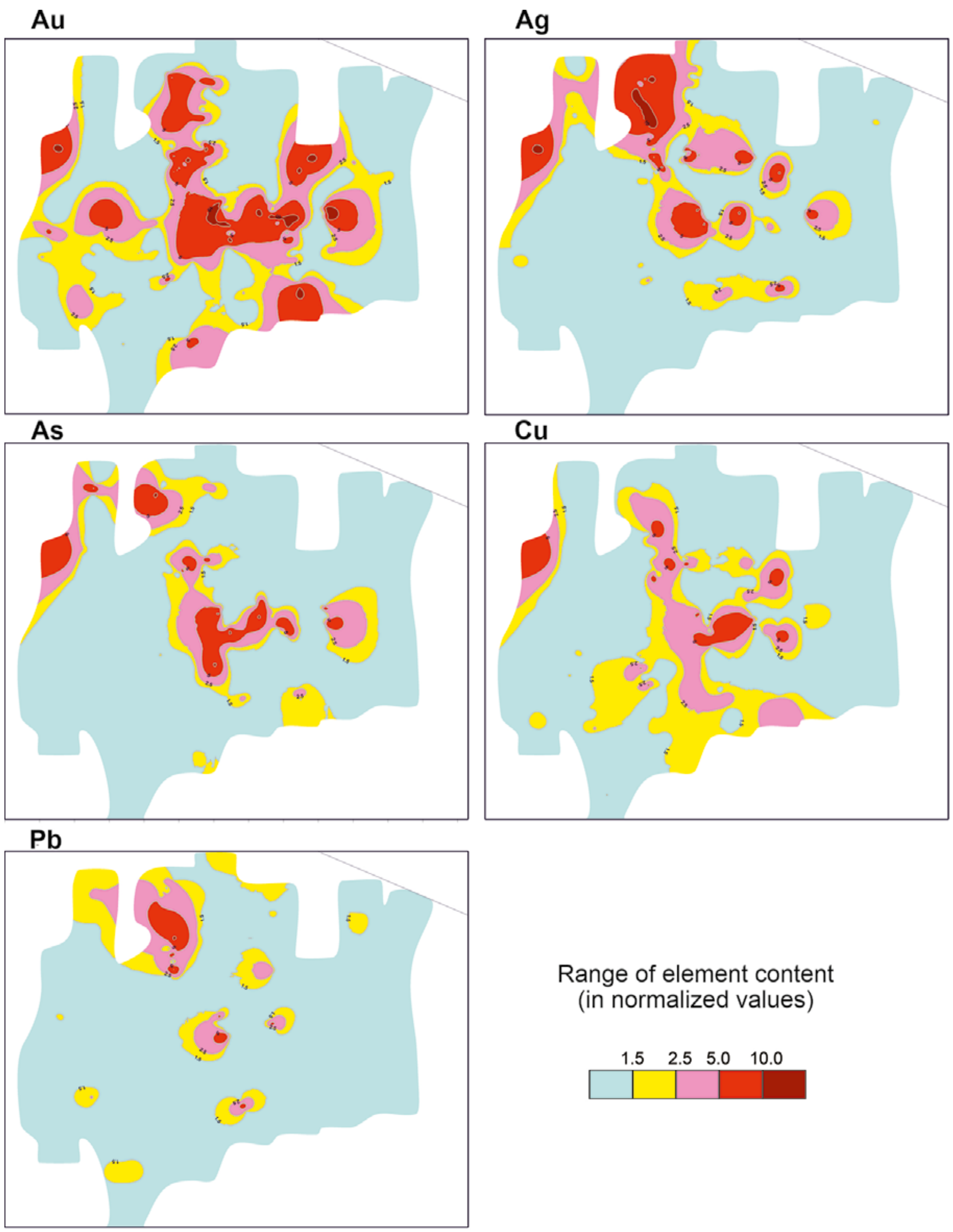


Fig. 4. Distribution of positive geochemical haloes of Au, Ag, As, Cu and Pb in hydrothermally altered and mineralized rocks of the Chumysh ore field

— mineralogical-petrographic description of alteration types and wallrock metasomatites,

— preparing a mineralogical-petrographic database,

— compiling intermediate computer maps of the distribution of individual minerals, as well as various alteration types in the prospect area (Fig. 2–3),

— distinguishing structural elements of hydrothermal zoning,

— preparing a geochemical database,

— compiling intermediate computer maps of the distribution of individual elements indicating the expected mineralization, as well as multi-element geochemical maps (Fig. 4–5),

— determining geochemical features (geochemical orientation) of alteration types of various facies.

Based on the processing and analysis of the above materials, a set of specialized predictive metallogenic maps at 1:25,000 (1:10,000) scale is being prepared for the entire prospect area, including:

— map of hydrothermal alterations intensity in rocks (Fig. 6),

— map of hydrothermal zoning (Fig. 6),

— map of geochemical anomaly field (based on bedrock sampling data) (Fig. 7),

— schematic geological-genetic model of alteration and geochemical ore zoning development in the work area (Fig. 8),

— mineralization forecast map (of the expected commercial type) — as the main study result, summarizing all the predictive and prospecting information (Fig. 9).

Processing and analysing all the information received will enable to «decipher» the history of hydrothermal activity in the prospect area and to assess the erosional truncation level of various parts of the ore-forming alteration system in the area under consideration.

Based on the cumulative mineralogical, petrographic, and geochemical criteria, it becomes possible to identify within the study area more local sites in the rank of potential ore deposits in order to carry out detailed prospecting and evaluation.

Procedure evaluation. From 1974 to 2022, this procedure was tested within many ore regions of both the Russian Federation (Urals, Yenisei Range, Altai-Sayan region, Transbaikalia, Central Aldan, Yana-Kolyma province, Primorye, etc.), and countries of the former USSR and far abroad (Kazakhstan, Uzbekistan, Kyrgyzstan, Tajikistan, Bulgaria, Turkey, Sudan, Niger, Mongolia, Mauritania, etc.).

From 1979 to 1993, this procedure was widely used in the production geological association system of the Ministry of Geology of the Kazakh SSR, where it was successfully introduced into the practice of many prospecting survey and geological exploration expeditions at the stage of geological surveying at 1:50,000 scale with general prospecting. In total, more than 20 nomenclature sheets at 1:50,000 scale within the Kazakhstan fold system were studied using this procedure, with the compilation of sets of maps of hydrothermally altered rock zoning, geochemical anomaly field, and mineralization forecast.

It helped the Karpinsky Institute to accumulate a wealth of experience in predicting blind hydrothermal mineralization of various commercial types: gold-uranium, molybdenum-uranium, copper-pyrite, pyrite-gold-polymetallic, skarn gold-polymetallic, stratiform barite-polymetallic, greisen rare metal, vein gold-quartz low-sulphide, gold-sulphide, epithermal gold-silver, gold-copper-molybdenum-porphyry, etc.

To date, more than 70 identified and potential ore clusters and fields have been studied using this procedure. It helped to discover several promising ore deposits, including the Tama gold deposit in Central Kazakhstan and the Morozkinskoye deposit in the Central Aldan ore region.

In recent decade, Russian and foreign geological service enterprises and mineral managing companies, such as OOO Stannolit, OOO Khuzhir Invest, OOO Khuzhir Enterprise,

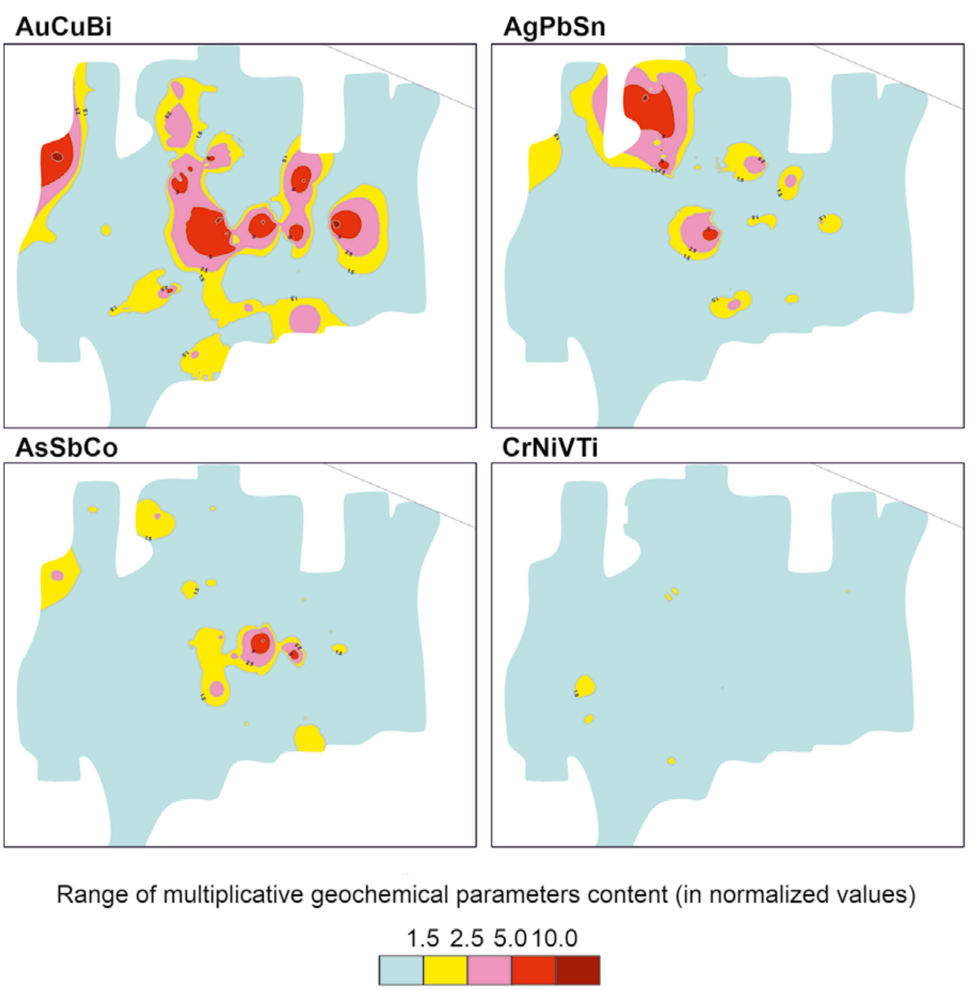


Fig. 5. Distribution of multiplicative positive geochemical haloes of AuCuBi, Ag,PbSn, AsSbCo and CrNiVTi composition in hydrothermally altered and mineralized rocks of the Chumysh ore field

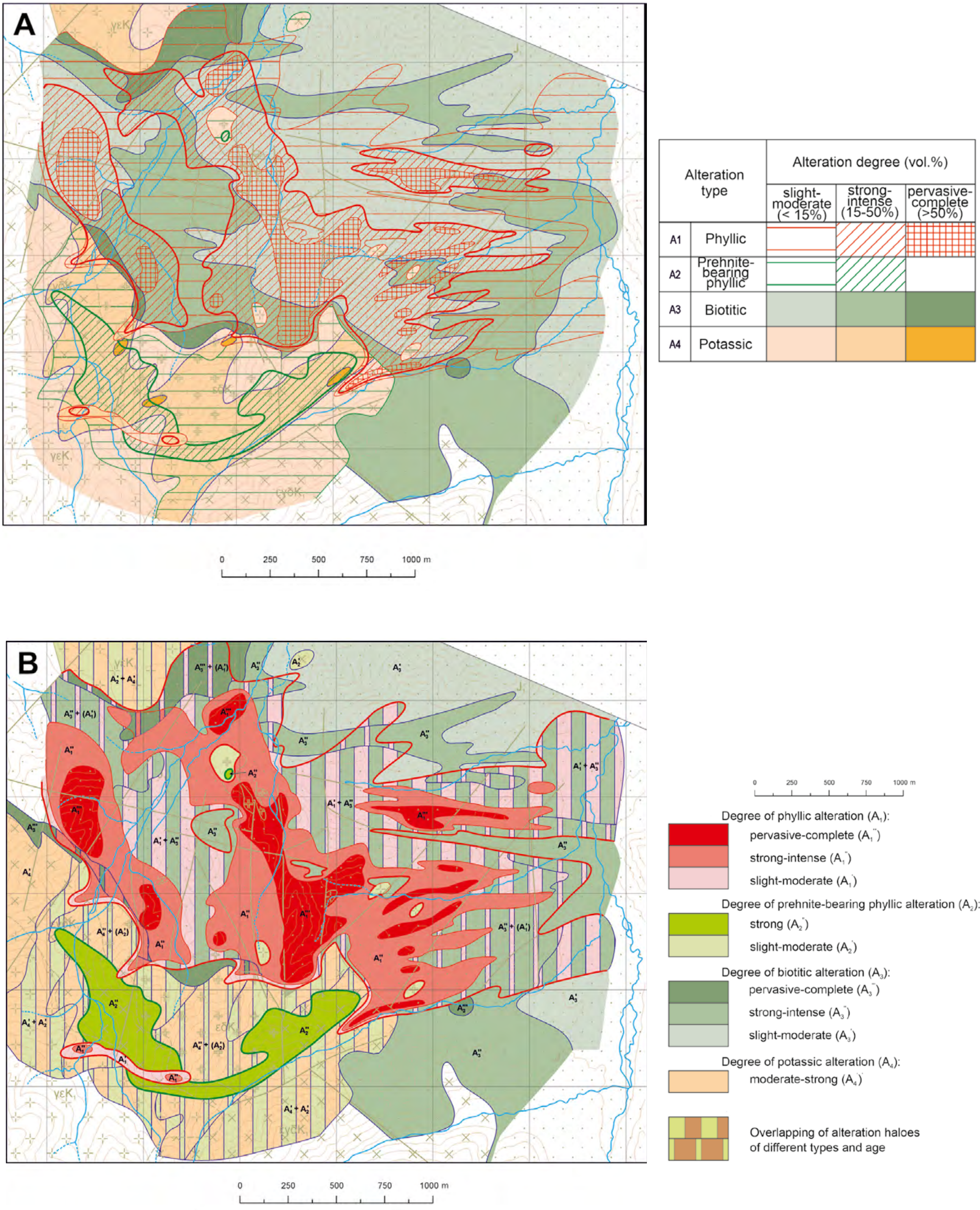
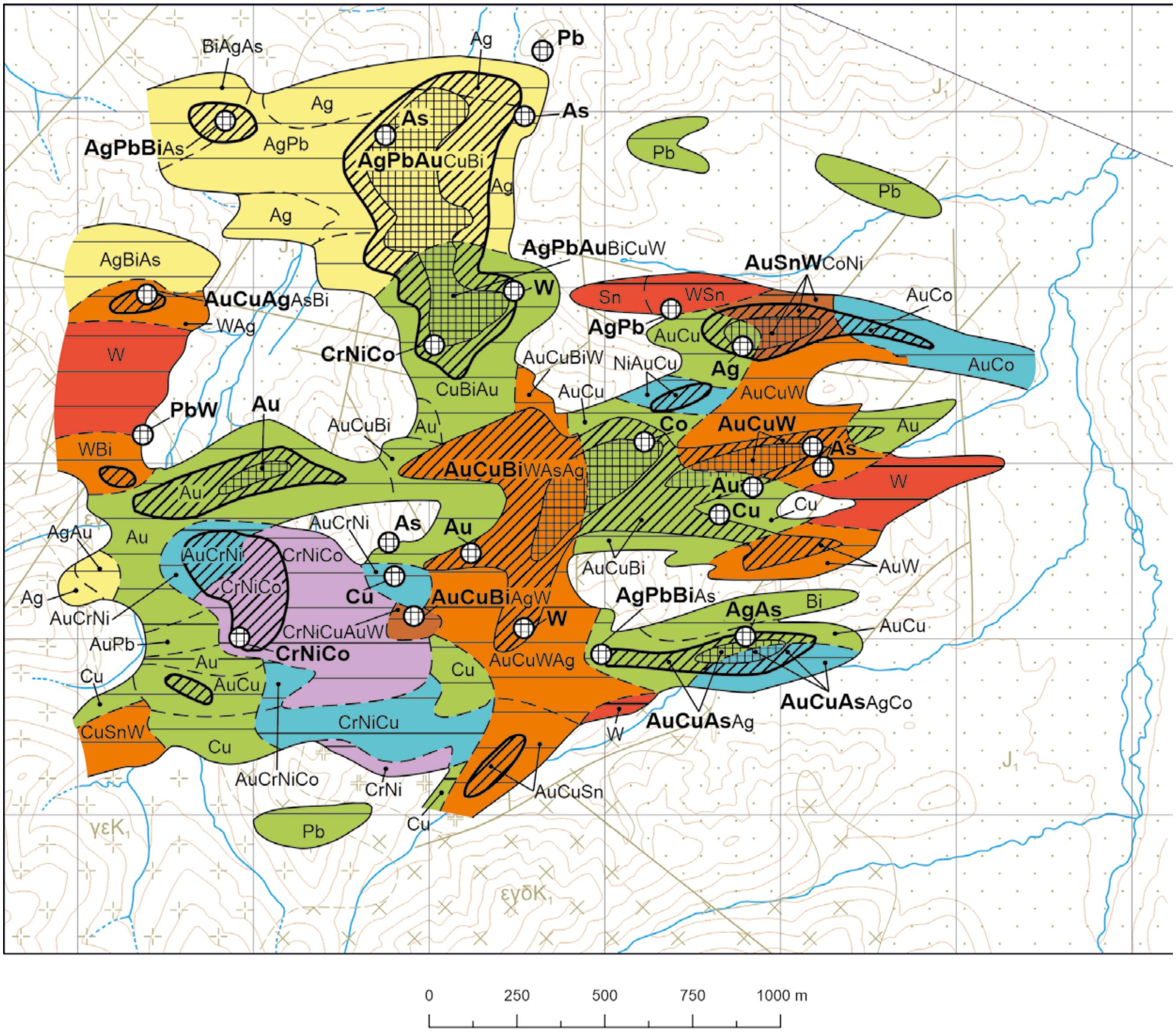


Fig. 6. Map of alteration degree (A), alteration zoning map (B) of the Chumysh ore field



Structure of positive geochemical anomalies

	Anomaly significance (in normalized values)	Areal anomalies	Point anomalies
I	First 1.5÷2.5	Pb	
II	Second 2.5÷5.0	Au	
III	Third ≥5.0	AuCu	As

Composition of positive geochemical anomalies

Geochemical type	Color index	Composition
Chalcophile-II		AgPb(SnAuCu)
Chalcophile-I		AuCuBi(AsPb)
Chalcolithophile		AuCuBiW(As)
Lithophile		W(Sn)
Siderolithophile		AuCuWSnCrNi
Siderochalcophile		CrNiCo(CuAu)
Siderophile		CrNi(Co)

Fig. 7. Map of anomalous geochemical haloes of the Chumysh ore field

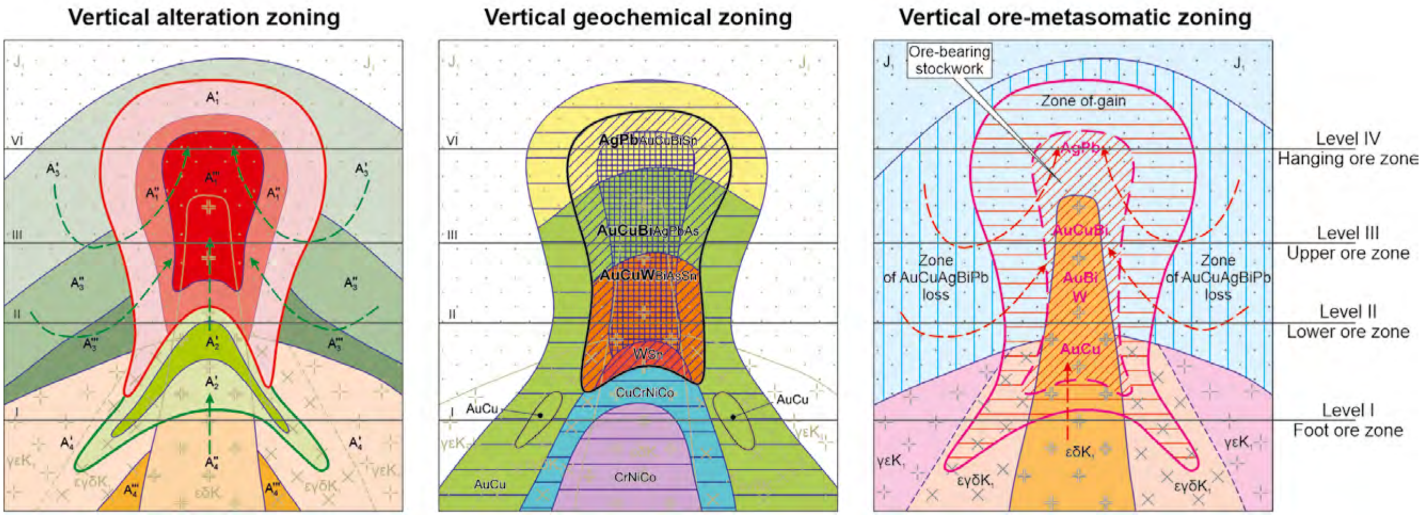


Fig. 8. Interpretative formation models of vertical hydrothermal alteration, geochemical and ore-metasomatic zonings of the Chumysh ore field. See for legend to Fig. 6-B

OAO Mikhailovsky GOK, AO ZRK Pavlik, OOO GPB Neftegaz Services B.V., AO Polymetal, MMC Norilsk Nickel, AO Polyus Krasnoyarsk, Management Company Polyus, TOO Kazzinc, AK ALROSA , ZAO Rosgeofizika, State Enterprise Mineral, AO Almazy Anabara, ApexSilverMine Ltd, SUN Mining Ltd, Kush-ep Co. Ltd, EMIRAL Mining SARL. Ltd, FEC Maden Enerji A.S. Ltd and others have actively used this procedure in practice in assessing the ore content prospects.

During these same years, within the framework of the State Assignment of the Federal Agency of Mineral Management (Rosnedra), work was carried out by order of the territorial bodies of Rosnedra at the Surich ore field and in the Zmeinogorsk ore district of the Altai Krai, as well as in the Republic of Sakha (Yakutia) — in the Taryn district at the Drazhnoye deposit and in the Central Aldan district at the Ryabinovoye deposit and within the Elkon horst, well known for its gold-uranium ore targets.

During these many years of work, considerable progress was achieved in studying alteration types. In particular: 1) the development degree of hydrothermal processes is comparable with other petrogenetic processes — with magmatism, metamorphism, sedimentation, etc., 2) a classification of alteration types at rock and formation levels was developed, as well as methods for their geological mapping, 3) original maps reflecting the spatial distribution features of alteration types and their association with endogenous ore targets were compiled, 4) methods for estimating predicted resources based on petrographic-geochemical data were proposed.

The Karpinsky Institute has a group of highly skilled experts in the field of geochemistry, petrography, and mineralogy of ore-bearing alteration types. It is expected that this group will be able to perform the following specialized works at 1:25,000 (1:10,000) scale in order to predict blind hydrothermal mineralization of various commercial minerals:

(1) field investigations to collect representative rock material,

(2) mineralogical-petrographic study of alteration types in thin sections,

(3) analytical studies of geochemical grab samples,

(4) computer processing of materials with the creation of a single bank of petrographic-geochemical data for the study area,

(5) mapping with the compilation of geological and geochemical map sets based on the use of GIS technologies,

(6) predictive metallogenic analysis of the studied area based on the aggregate of petrographic-geochemical criteria,

(7) local forecast of hydrothermal mineralization (with quantitative assessment of predicted resources) within individual prospects in the rank of potential ore fields and clusters.

Duration of work: from 1 to 1.5 years, including field work and office processing of materials.

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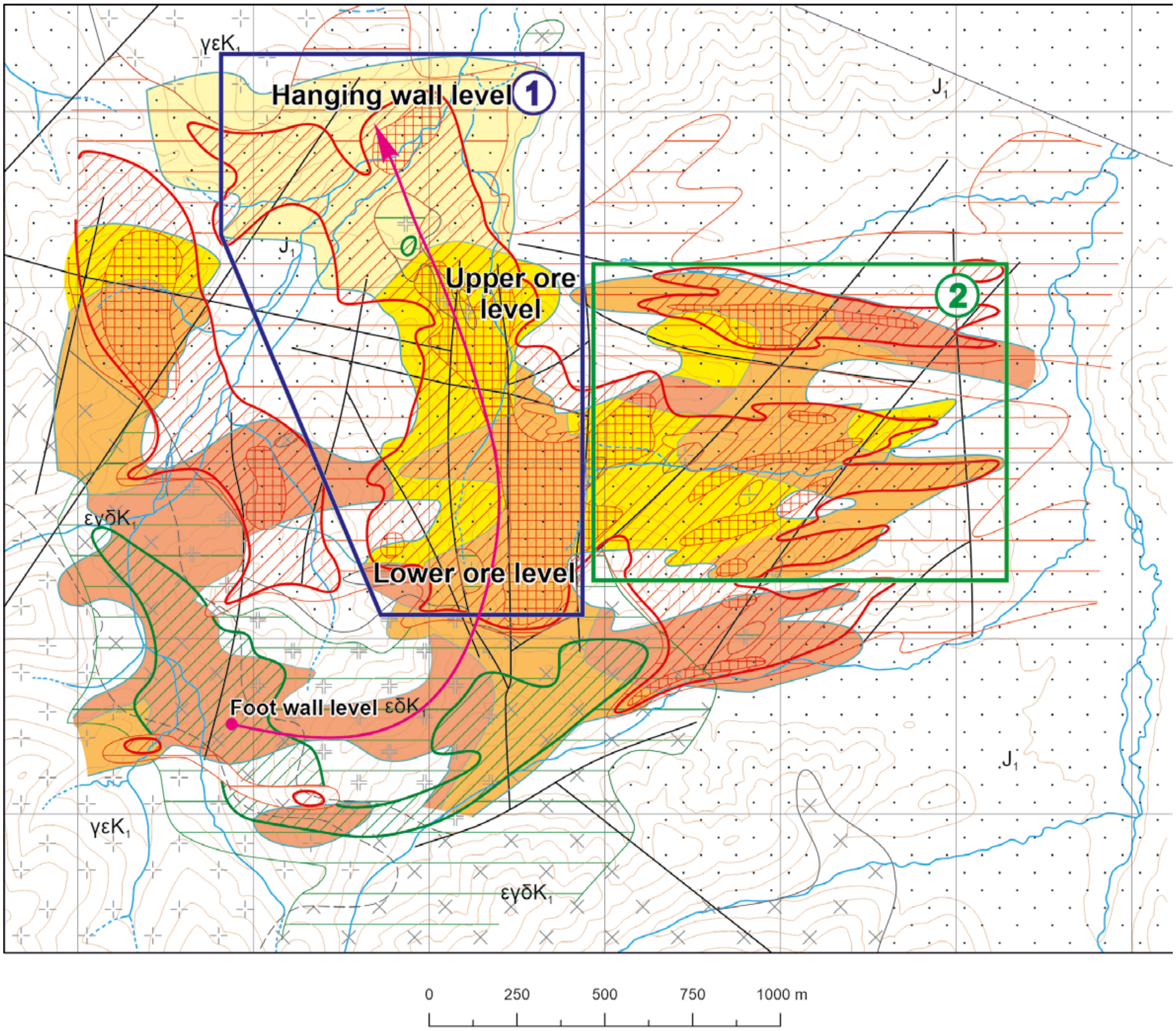

Prognostic criteria for gold mineralization

Alteration criteria

Alteration type	Alteration degree (vol.%)		
	slight-moderate (< 15%)	strong-intense (15-50%)	pervasive-complete (>50%)
Phyllic			
Prehnite-bearing phyllic			

Geochemical criteria

Levels of vertical ore-metasomatic zorning

Level		Color index	Geochemical composition
IV	Hanging wall		AgPbAu
III	Upper ore		AuCuBiAg
II	Lower ore		AuCuWBi
I	Foot wall		CuAuCrNi

Prospecting areas:

1 for Cu-Au-porphyry mineralization

2 for sedimentary-hosted orogenic gold mineralization regenerated by more younger porphyry system

Arrows indicate vector directions of maximum element variability in the porphyry ore-metasomatic hydrothermal system

Fig. 9. Prognostic zoning map of the Chumysh ore field territory focused to gold mineralization assessment

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INTERNATIONAL PROGRAMME OF THE KARPINSKY INSTITUTE: THE GEOLOGICAL CLASSES PROJECT AS AN EDUCATIONAL BASIS FOR THE RUSSIAN GEOLOGICAL SCHOOL ABROAD

Karpinsky Geological Classes is a unique educational project of the Karpinsky Institute aimed at developing and implementing joint initiatives with friendly countries in the field of geology, mineral management and geoscience. To date, the Karpinsky Classes have been opened and are operating successfully in Cuba, Ethiopia, Ghana and Mozambique. In total, the project is aimed to set up an educational network of 25 classes around the world. The practical result of the Karpinsky Geological Classes will be the creation of an effective mechanism for scientific support of joint applied projects in geology and mineral management with friendly countries.
Keywords: *Russian Geological School, Karpinsky Class, geology and mineral management*

The All-Russian Russian Geological Institute of A. P. Karpinsky (Karpinsky Institute), the leading institution in the Federal Agency of Mineral Resources (Rosnedra) in regional geological studies, is the initiator and operator of the project to return the Russian Geological School to friendly countries after more than half a century of interruption. With the support of the Federal Agency of Mineral Resources, the Institute is opening Karpinsky Geological Classes around the world.

The Karpinsky Geological Classes is a unique project aimed at developing joint initiatives in geology, mineral management and Earth sciences with Russia's friendly countries. This project is unique in terms of its content, its methodological approach, its scale and its importance to the international geological community. It should be noted that these are not just events and conferences, but a permanent cultural basis for many years to come, including the creation of the language environment, personal professional development of each participant, transfer of knowledge, skills and approaches to the study of geology. Over time, this will provide an additional effective mechanism for scientific support of joint applied projects in geology and mineral management.

Fig. 1. Head of the Federal Agency of Mineral Resources Evgeny Petrov and Director General of the Karpinsky Institute Pavel Khimchenko at the opening of the Karpinsky Geological Class in Accra, the Republic of Ghana

Fig. 3. Signing of the Cooperation Agreement between the Karpinsky Institute and the National Geological Museum, the Republic of Mozambique

Fig. 2. Lecture by P.V. Khimchenko, Director General of the Karpinsky Institute, in Addis Ababa, Ethiopia

Pavel Khimchenko, Director General of the Karpinsky Institute, characterises the initiative as follows: «Geology is not just a science, it is something that unites all people living on the planet. Geologists not only study the Earth's past and present, they are also able to look into its future, predict future changes and, if necessary, influence them. Soviet geologists made a great contribution to the development of geology in various countries. Today, after a break of many years, we are glad to return to this cooperation, to share our knowledge and to strengthen our friendly and professional relations. By implementing this project in cooperation with our partners, we are opening new opportunities for everyone who wants to become a part of the geological world, inviting them to join the knowledge already accumulated and perhaps make their own contribution to the geoscience advancement».

The Karpinsky Geological Classes are primarily aimed at promoting Russian geological practices in the field of mineral management, exchange of professional experience between specialists from different countries, internships and joint fieldwork. The overall result will be the building of the necessary scientific infrastructure for further study and development of the regions' potential in geology and mineral management.

To date, four Karpinsky Geological Classes have been opened: on the African continent at the Ministry of Tourism, Arts and Culture, Accra, the Republic of Ghana (Fig. 1); at the Russian Centre for Science and Culture, Addis Ababa, Ethiopia (Fig. 2); and at the National Museum of Geology, Maputo, Mozambique (Fig. 3, 4) and at the Institute of Geology and Palaeontology, Havana, the Republic of Cuba (Fig. 5).

A year before opening first classes, Karpinsky Institute experts undertook a huge amount of work to build a scientific and methodological basis and a detailed curriculum to ensure effective year-round work of the Geological Classes. They studied existing curricula in various countries, collected the necessary information and analysed in detail the educational process. Then, with the participation of the Institute's experts a detailed curriculum for the Karpinsky Geological Classes was developed, main topics were identified, and methodological material and thematic exhibitions were developed.

Fig. 4. Russian and African colleagues at the opening ceremony of the Karpinsky Geological Class in Maputo, Mozambique

Fig. 5. Participants of the Karpinsky Geological Class course in Havana, the Republic of Cuba

Sets of lectures, seminars and practical training are regularly held for visitors and students of the Geological Classes, presenting the history of geological science, its current state and achievements of the Russian Geological School. In the near future, it is planned to expand the range of lecture topics from classical palaeontology, stratigraphy, tectonics and geophysics to IT and artificial intelligence.

Geology lectures are held regularly, both face-to-face and online, for geologists and anyone interested in the geoscience. Face-to-face scientific and educational lectures for the general public are held every two quarters, while in-depth geology lectures are held at least once every three months. Events for the general public are aimed at popularising the geoscience: watching feature films and documentaries on geological topics, getting acquainted with exhibition projects and the Open Library collection, which is regularly replenished with new acquisitions.

Today, Ghana, Ethiopia, Mozambique and Cuba are united not only by the fact that they have huge mineral reserves, but also by a new project of Geological Classes of the Russian Geological School. And Karpinsky Institute experts will have a huge theoretical and practical work to open several more classes in friendly countries. Kyrgyzstan, Vietnam, Algeria, Mongolia, Myanmar, Vietnam and others are next on the list. In total, it is planned to open up to 25 geological classes around the world.

It is very important that the work programme of the Karpinsky Classes is also production-oriented and aimed at the development of joint projects in the field of geology and mineral management. They include, first of all, general geological and metallogenic studies, exploration and evaluation of mineral deposits. The deposits will be explored and developed in cooperation with local organisations and mining companies. At the first stage, geological mapping is planned at a scale of 1:200,000, with the possibility of further mapping at a scale of 1:50,000 and 1:25,000 by our geologists and local experts. This will make it possible to update the existing state of country's resources, make a proper assessment of the state of its mineral resources and formulate specific proposals for further development and exploitation.

Work with some countries has already begun. For example, in the Republic of Cuba, Karpinsky Institute experts are actively working with representatives of the Institute of Geology and Palaeontology of the Geological Service of the Republic of Cuba (IGP-SGC) to produce the 1:500,000 scale metallogenic map of Cuba.

The primary objective of compiling the 1:500,000 scale metallogenic map of Cuba is to generalise previously produced medium scale geological and metallogenic maps and potentially identify new regional patterns of ore deposit distribution in Cuba. As a result, common approaches to map production have been developed and an understanding of project milestones has been achieved. The 1:500,000 scale metallogenic map of Cuba is expected to be published later this year.

In addition to compiling the metallogenic map of the Republic of Cuba, Karpinsky Institute staff are already carrying out the first stage of development and filling of the «Digital Twin of Cuba's Mineral Resources», an open resource that will be available to all scientists.

Karpinsky Geological Classes will help our experts to conduct a dialogue with foreign geologists based on Russian standards and approaches to the geological study of mineral resources. After all, high quality geological mapping requires highly skilled geological personnel.

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SEARCHING FOR HIDDEN DEPOSITS OF BASE AND PRECIOUS METALS USING THE ION-SORPTION METHOD IS A PROMISING DIRECTION OF INTERNATIONAL COOPERATION IN THE FIELD OF GEOLOGICAL EXPLORATION

Lithogeochemical prospecting of hidden deposits of base and precious metals using the ion-sorption method is described. Specific examples from the practice of geochemical exploration and experimental methodological work are given. ***Keywords:** lithogeochemical, ore deposits, base and precious metals.*

As the degree of detail geological exploration of the territories increases, the likelihood of detecting new ore deposits by traditional methods by their direct signs on the day surface is steadily reduced. Therefore, the main trend in the modern development of search geochemistry is the development of methods for forecasting deep-sited hidden and buried ore deposits. Most of the proposed solutions of this problem are based on the replacement of the traditional bulk analysis of lithogeochemical samples by the analysis of mobile forms of chemical elements with a highly sensitive method of mass spectrometry with inductive-coupled plasma (ICP-MS). This provides the possibility of identifying the superimposed halos of scattering — weak exogenous geochemical signals caused by modern upward migration of ore elements and concomitant compounds from the depths to the surface through the thickness of the rocks and eluvial-deluvial cover.

The mechanisms of such migration of the ore substance are not finally installed. It should be noted that in gases, soils and rocks above the buried ores using an electron microscope, metal particles and their clusters with dimensions of 10–200 nm were found [6]. At copper-nickel deposits, they are represented by native copper and complex mixtures Cu, Ni, Fe, etc. In gold deposits it is Au, Cu-Au, Cu-Fe. The structure of the particles indicates that their source in rocks and soils is the endogenous ores hidden at a depth. According to existing ideas, the most likely mechanism of the effective migration of metal particles from depths to the surface is their adsorption on the gas bubbles that pop up in the aquatic environment. Therefore, in the soils, part of these particles is found in the gases, the other is delayed here on geochemical barriers. This model of the metal migration process quite explains the facts of localization of superimposed geochemical halos strictly over buried ore bodies.

While the models of the formation of superimposed halos of scattering over the ore deposits serve as the subject of discussion, the very existence of such anomalies is proved by the practice of exploration and doubt is not subjected to doubt [4, 7, etc.]. It is assumed that the accumulation of metals in the soils is due to the presence of a sorption-active absorbing complex — a combination of mineral, organic and organomineral compounds that are insoluble in water and capable of concentrating and exchanging metal cations.

For desorption of elements from soils, with the aim of their further analysis, a fairly wide range of methods is proposed. The most intense research in this area of geochemistry are conducted in Russia, China, Canada, Australia and in some other countries. In the general case, the detection of the overlayed halos on the day surface is determined by the choice of such a methodology for analysis of lithogeochemical samples, which would enhance the contrast of anomalies, i.e. the ratio of a useful signal to the level of background. The identification of geochemical anomalies is carried out by selective extraction into a solution of easily mobile forms of the ore elements. The analysis can include water, soda, acetate, pyrophosphate and other hoods that extracts mobile forms of elements, the share of which over deposits is significantly higher compared to background areas. A fairly complete and thorough review of the existing methods for the preparation of samples for ICP-MS analysis when searching for deposits of base and precious metals in complex geological and landscape environments is contained in work [4].

Lithogeochemical prospecting using the ion-sorption method is one of the ways of searches based on partial extraction of metals from soil samples. The method was developed at the Federal State Budgetary Institution «TsNIGRI», was patented (patents No. 2713177 dated 08.16.2019 and No. 2801428 dated 07.04.2023) and was successfully tested on many search area within the Russian Federation, Kazakhstan and Tajikistan. In some cases, work ended with the discovering of new ore bodies.

The ion-sorption method method is based on the use of a weak solution of nitric acid for the extraction procedure. It was experimentally established that the diluted solution of nitric acid has the best ability to leaching the majority of chemical elements. The upper soil layer (A1), having high dispersion state, serves as a good sorbent of cations. The hydroxonium ions (H3O+) in a nitric acid solution can actively replace cations (Cu, Zn, Pb, etc.) in the soil absorption complex. Nitric acid also actively interacts with metals oxides and carbonates, forming soluble nitrates. Only gold is an exception. To leach Au, a special reagent is added to nitric acid, which provides the transfer of all gold from the sample to the solution.

When conducting ion-sorption survey, samples from the upper soil horizon from a depth of 5–10 cm are taken for analysis. The sample is dried to an air-dry state and sifted through a sieve of 0.25 mm. From the fraction <0.25 mm (1–5 g sample) in disposable plastic tubes, an extract is prepared by wetting the sample with an extracting solution. The hoods are subjected to ICP-MS analysis on Au, As, Sb, Cu, Pb, Zn, Cd, In, Ba, Ni, Co, Cr, V, W, Hg, Bi, Te, Tl. Standardization of the methodology of sampling and analysis pro-

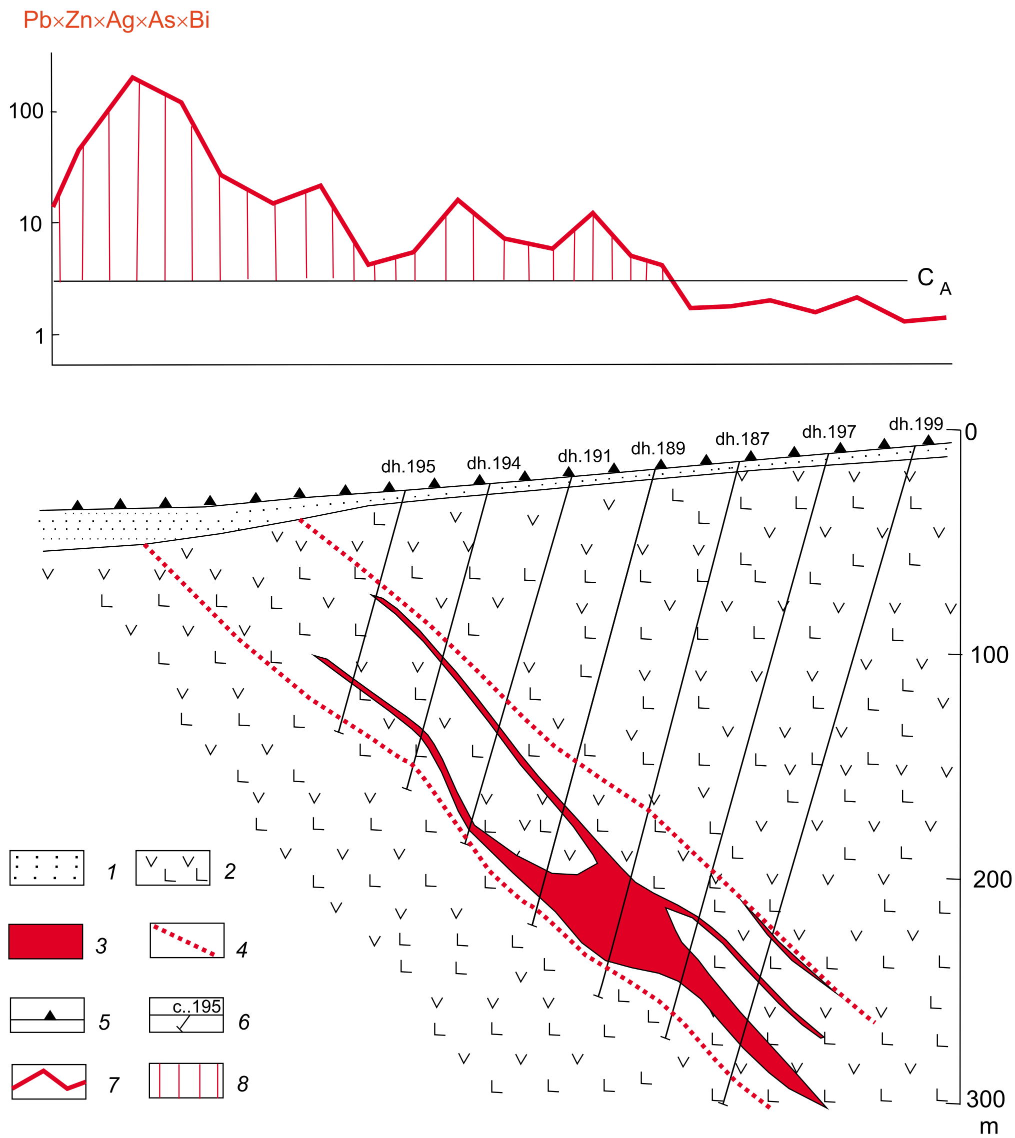

Fig. 1. Results of ion-sorption survey at the Noyon-Tologoy deposit. 1 — solifluction sheet; 2 — basaltic andesites; 3 — ore bodies; 4 — ore zone boundary; 5 — sampling points; 6 — exploratory wells, their numbers; 7 — graph of the multiplicative indicator; 8 — area of anomalous values of the indicator. (After [2])

vides maximum error compensation. The resulting analytical data on the values of relative random errors ($\delta = 1.1^{\pm 1}$–$1.3^{\pm 1}$) can be attributed to the results of quantitative analysis. To allocate weak sorption-salt anomalies over deep-sited objects and suppress natural and technical interference, mathematical processing of search data is carried out [1, 5], which reduces random fluctuations of the geochemical field and increases the regular component of ore anomalies. As a rule, ore anomalies are multicomponent, so their contrast increases with the multiplication of the content of elements of the typomorphic complex. As a result of smoothing and multiplier, anomalia contrast indicator increases several times. For multiplication, elements with maximum concentration clarks are selected compared to the local geochemical background. For the convenience of comparing sorption-salt anomalies, chemical elements are normalized on their average background content.

Methodological work repeatedly carried out in various search results has shown that compared with the traditional method of analysis of solid powder lithogeochemical samples, anomalies obtained by analyzing hoods have 2–3 times large sizes and indicators of contrast.

The appropriate scale of the ion-sorption survey is 1:50 000 (network 500×80 m) with the details of the survey on the identified anomalies up to 1:25 000 (network 250×40 m).

The method was tested in ore areas that differ in various landscape environments (mining, steppe, forest-steppe, etc.), as well as the geological conditions of the development of geochemical anomalies (areas, covered with a case of young sediments; ancient cortexes of weathering; modern eluvio-deluvial covers; etc.).

Below are examples of executed methodological and search work at hidden ore deposits of various types.

Polymetallic deposits

The most favorable conditions for the formation of secondary geochemical halos occur in connection with sulfide, in particular, polymetallic deposits that have a multicomponent composition and relatively high coefficients of the concentrations of chemical elements in ores [2, 3].

Noyon-Tologoi field in East Transbaikalia is a new and very promising type of stratified Zn-Pb deposits for the region. The deposit is timed to the board of consedimentation block-syncline, composed of Jurassic volcanogenic- terrigenous and terrigenous strata. The main part of lead-zinc ores is represented by gently dipping deposits in a «blind» location. The main ore minerals are galena, sphalerite, pyrite, arsenopyrite, secondary — tetrahedrite, chalcopirite, molybdenite, bornite, bulangerite, jemsonite. According to the natural-climatic conditions, the area in question belongs to the mid-mountain steppe landscapes of the peripheral part of the cryolitosis with brightly manifested within the lower parts of relatively gentle slopes by the processes of solifluction.

In the western section of the Noyon-Tologoi field, two profiles of ion-sorption survey have been passed. The thickness of solifluction sheet ranges from 5 to 20 m. The upper edge of the ore bodies is at a depth of 50–70 m from the surface (Fig. 1).

Complex sorption-salt halo clearly fixes the output of the ore zone and are characterized by a wide range of elements that meet the composition of hypogenic ores. The maximum values of the multiplier indicator Pb×Zn×Ag×As×Bi are two orders of magnitude exceed their lower anomal values. The effective width of the anomaly is more than 400 m. In addition to the main ore elements, anomalous concentrations are Cd, Sb, Cu, Tl, Hg, Ba, Mo.

It is important to note that the processes of solifluction can partially or completely screen the mechanical residual halo of scattering, as well as lead to their displacement over signif-

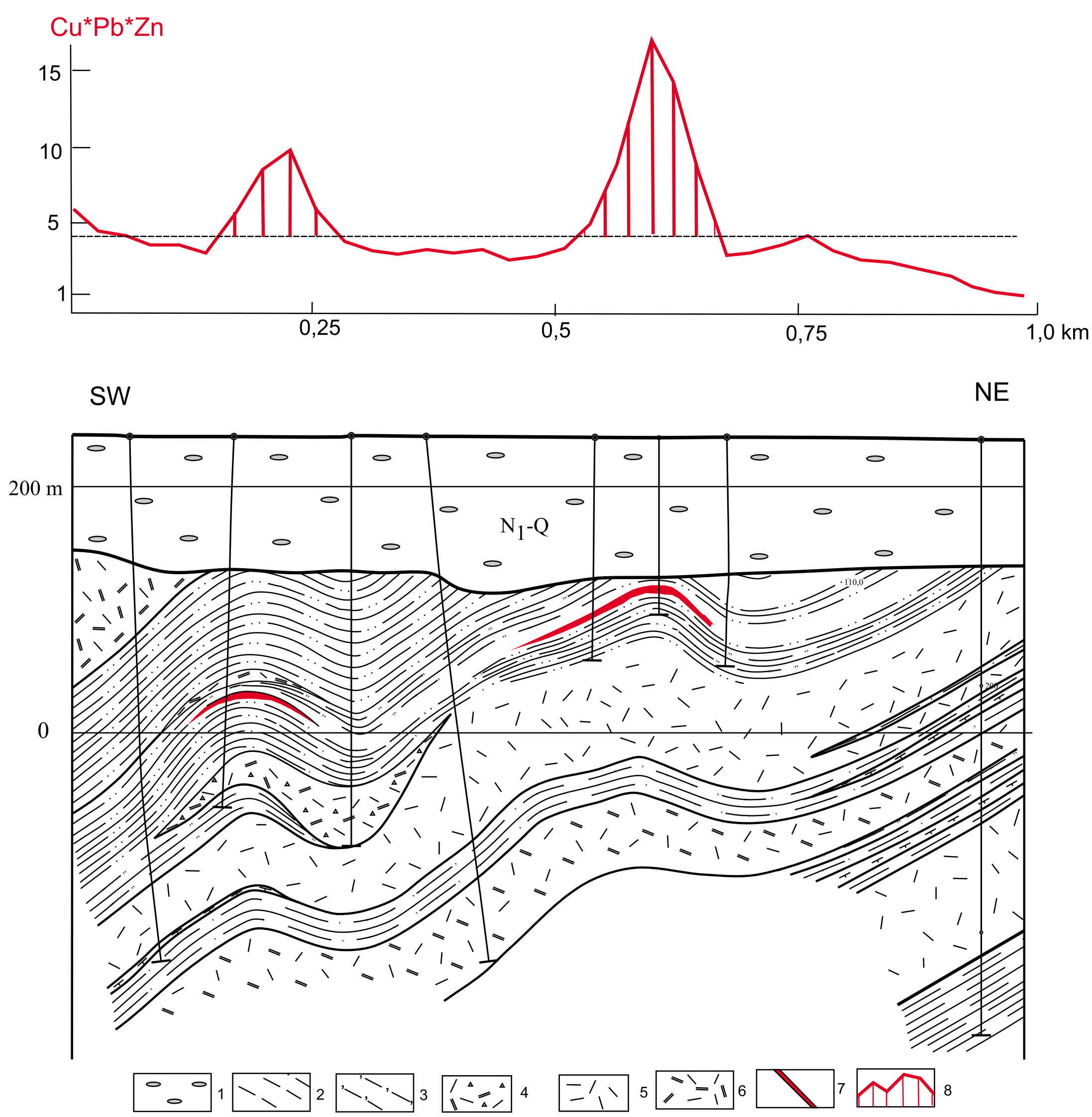

Fig. 2. Results of ion-sorption survey at the Zapadno-Zakharovskoye deposit. 1 — Neogene-Quaternary sediments; 2 — siltstones, argillites; 3 — siliceous siltstones; 4 — lava breccias of rhyodacitic composition; 5 — rhyolites; 6 — rhyodacites; 7 — ore bodies; 8 — area of anomalous values of the multiplicative indicator. (After [2])

icant distances [5]. In contrast to mechanical, sorption-salt halo records at their central points the position of the epicenter of ore zones, which matters when setting the first mining and wells.

Rubtsovsky district of Rudny Altai is one of the completely closed by a case of Neogene-Quaternary sediments with a thickness of 70–150 m. In closed and half-closed areas with various landscape-geochemical conditions, deep lithogeochemical searches are recommended based on the detection of buried secondary residual halos. However, the widespread use of this method is restrained by the significant cost and labor intencity of the work.

Methodological work was carried out on the South-Bobkovsky and West-Zakharovsky manifestations, represented by conformable stratified bodies of the pyrite-polymetallic ores dedicated to the early Givetian strata (alevrolytes, argillites, tuffites with the interbeds of riolite and riodacite lavas). Both areas are characterized by leveled relief with a steppe landscape and well-developed soil cover represented by chernozem. A distinctive feature of chernozems is a high soil capacity of cation exchange (the total amount of all absorbed cations that can be replaced from the soil).

A sorption-salt and salt halo of Cu, Zn, Pb, Ba, Ag, were identified over the hidden- buried South Bobkovsky and West-Zakharovsky deposits. Exceeding the maximum values of the Cu×Pb×Zn indicator above the background was 10–30 times. Effective width of anomalies from 120 to 300 m. Fig. 2 show an example of sorption-salt halo highlighting in the West-Zakharovsky deposit with the thickness of the overlapping Neogene-Quaternary sediments of 100–110 m.

During search work in the *Zmeinogorsk* district of the Rudny Altai, the use of the ion- sorption method contributed to the identification and opening of new industrial ore bodies. As an example, we give the results of geochemical work on the Petrovsky section. The site is represented by the steppe and forest-steppe landscapes of the foothills and gentle slopes of

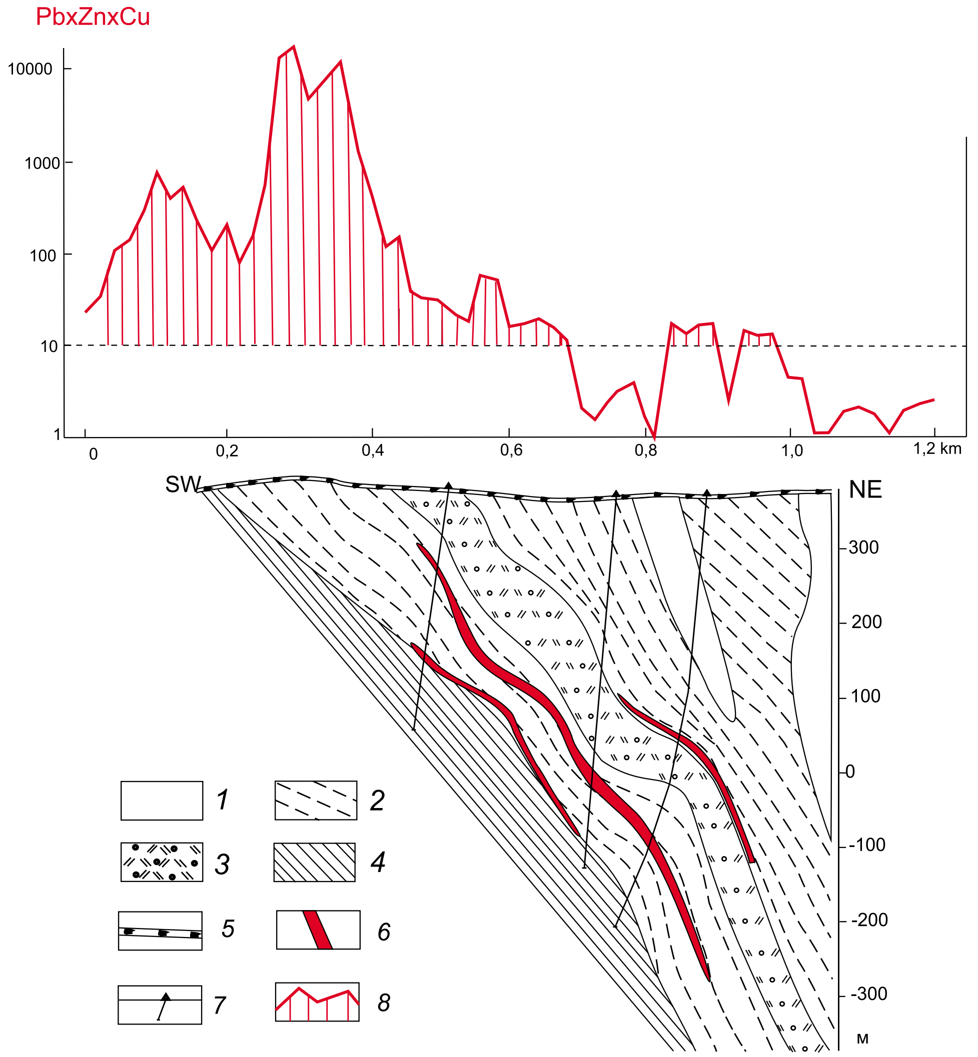

Fig. 3. Results of ion-sorption survey at the Petrovsky site. 1 — rhyolites; 2 — siltstones; 3 — interbedding of acidic tuffites, siliceous and tuffaceous siltstones; 4 — metamorphic schists of the Early Paleozoic; 5 — eluvium-deluvium; 6 — ore bodies; 7 — exploration wells; 8 — area of anomalous values of the multiplicative indicator. (After [2])

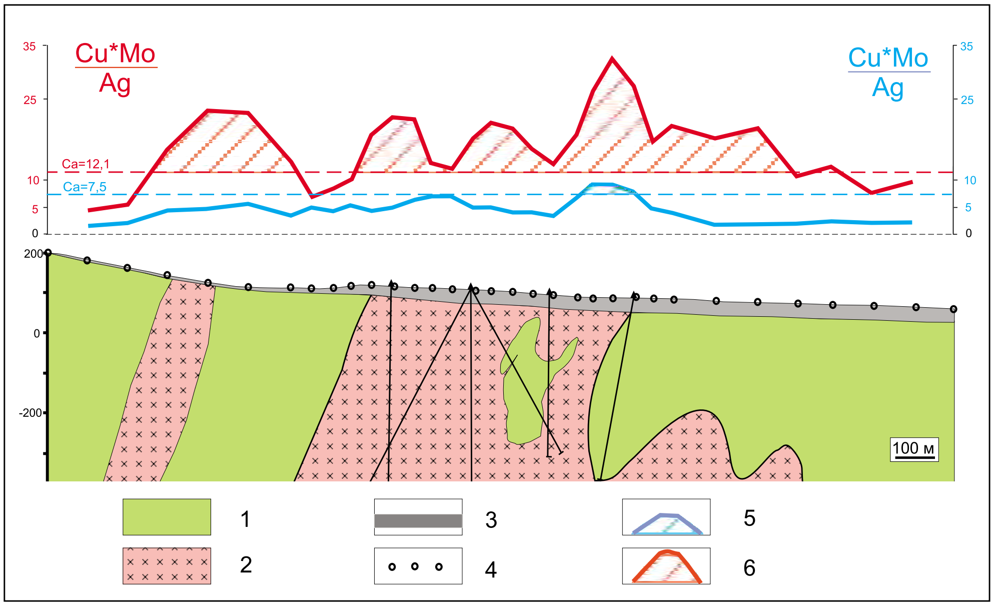

Fig. 4. Results of ion-sorption survey at the Malmyzh porphyry Cu-Au deposit. 1 — metaterrigenous rocks; 2 — mineralized stocks of diorite porphyrites; 3 — Quaternary sediments, 4 — lithogeochemical sampling points; 5 — graph of the multiplicative indicator for bulk element contents in samples (10^{-2} %); 6 — graph of the multiplicative indicator for mobile forms of elements in samples (10^{-4} %)

the lowlands with chernozem soils. The promising area is highlighted on the basis of a comprehensive analysis of geological data. The high degree of detail geological exploration of the site with exploring opening did not allow us to count on the detection of ore bodies overlooking the daily surface. Search work was aimed at identifying ore bodies on deep horizons of a productive volcanic-sedimentary early Givetian strata.

After conducting an ion-sorption survey, an extensive contrasting anomaly of ore elements Pb, Zn, Cu, a length of > 2.5 km, a width of 200 to 600 m, is installed on the area. In addition to the main elements, anomal concentrations are Cd, Ag, As, Sb.

In Fig. 3 shows a schedule for the distribution of the content of ore elements according to one of the profiles of the Petrovsky site. Ore elements are characterized by two distinct peaks. The first is dedicated to the contact of the early Paleozoic and early Givetian stratas, the second — to the productive strata of the early Givetian. In the latter case, the maximum content of the Pb×Zn×Cu indicator is more than 1000 times higher than its lower anomal values. The width of the anomaly is not less than 300 m. The wells, drilled taking into account geochemical data, revealed three «blind» ore bodies located at depths of 80, 200 and 250 m from the surface.

Porphyry Cu-Au deposits

The ion-sorption method was successfully tested at a large Malmyzh deposit (Sikhote-Alin), showing quite high efficiency (Fig. 4). It was established that with the low thickness of Quaternary sediments (2–3 m), standard lithogeochemical testing and the ion-sorption method as a whole duplicate each other. But at the same time, the width and amplitude of the anomalies of mobile forms of metals is significantly greater than lithogeochemical anomalies along the secondary halos of scattering. Above the ore body, covered with a thick mass of Quaternary sediments, the emission spectral analysis of lithogeochemical samples made it possible to distinguish only one very weak anomaly, while the ion-sorption method confidently fixes the ore bodies by the wide intensive anomalies of mobile forms of copper and molybdenum.

Gold deposits

For methodological studies, a profile for ion-sorption survey was chosen on Kundat-Talanovskaya Prospect (Kuznetsk Alatau). The profile passes over the well-known gold zones facing the surface and buried by a cover of Quaternary sediments (5–10 m thick), as well as «blind» ore bodies under the same cover (Fig. 5). The sampling was taken from the upper humus horizon (depth 10–20 cm) and from the under-lying loams (depth 20–40 cm) in order to study the distribution of mobile forms of gold in the cover section.

The results obtained indicate that Au anomalies are recorded in all the studied cover section. At the same time, in half the cases the gold content in the humus layer were higher, which confirms the assumption of the concentration of metals on this geochemical barrier. In addition to Au, anomal content As, Ag, Sb, Hg, Cu, Ni, Tl are also installed over ore bodies.

Conclusions

The world experience in applying the «method of mobile forms» indicates its high efficiency in solving the tasks of predicting hidden and buried deposits of base and precious metals of almost all geological and industrial types and in almost all geological and landscape conditions of search work. Ion-sorption survey, as one of the simplest and most effective ways to implement this search technology, compared with traditional geochemical testing, has the following advantages:

— the dimensions of the superimposed halos of scattering are two to three times higher than the sizes of halos detected by traditional lithogeochemical survey, which allows geochemical work on a more discharged samping network;

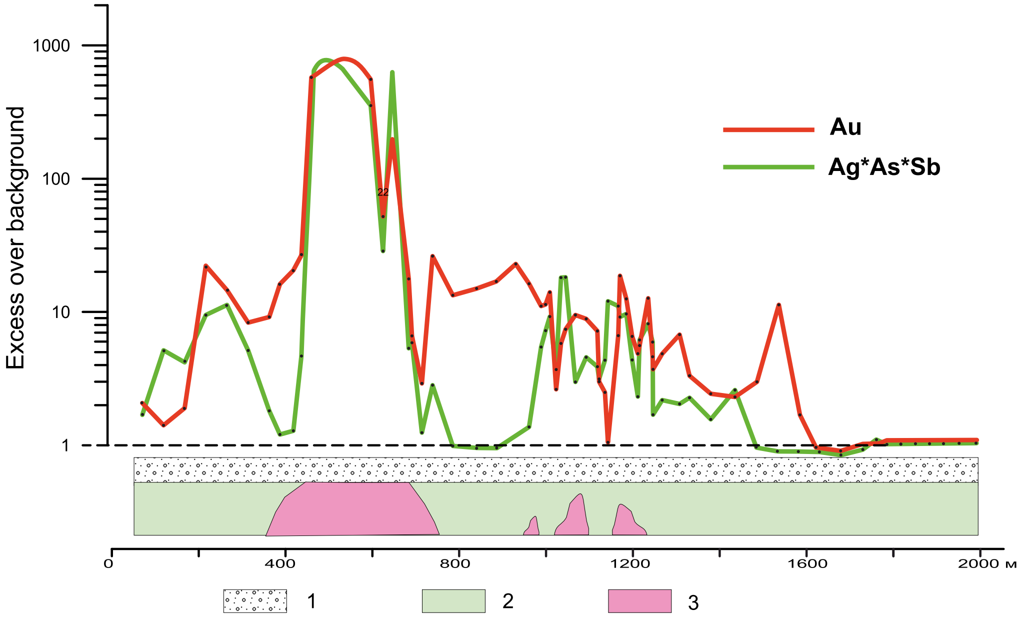

Fig. 5. Results of ion-sorption survey at the Kundat-Talanovskaya gold-bearing area. 1 — Quaternary sediments (5–10 m thick); 2 — host carbonate and volcanic rocks; 3 — gold ore bodies

— on the basis of the contrast of the identified anomalies, the search for the ion-sorption method is more informative in comparison with traditional lithogeochemical survey;

— increasing the reliability of assessments of the identified superimposed scattering halos is achieved due to the extensive spectrum of elements-indicators, allowing them to preliminary sorting through the set and ratio of elements. The analysis includes such important elements as Bi, Te and Tl, which when using multiplicative indicators sharply increases the likelihood of detecting weak geochemical anomalies;

— a direct analysis of the weakly coupled forms of elements in soil samples eliminates uncontrolled losses of volatile elements (As, Sb, Hg, Tl, etc.), which are inevitable during thermochemical decomposition of geochemical samples;

— simultaneous analysis of gold and all satellite elements without exception with a minimum possible threshold of detection from one representative sample with a significant increase in performance and reducing the cost of work;

— movable forms of metals are analyzed, which makes it possible to identify the blind deep-sited and buried by a eluvial-deluvial cover ore bodies. On the surface of the cover, the superimposed scattering halos over polymetallic ore bodies that lie at a depth of 200–250 m, as well as buried by a eluvial-deluvial cover of 100–110 m, are revealed.

Thus, economic costs during ion-sorption survey are reduced by reducing the number of samples taken (with the same geological results), sampling from minimal depth and simpler sample preparation technology. Search ion-sorption surveys are especially effective in the «cloused» areas, where ordinary lithogeochemical testing in most cases is not effective.

The positive results obtained in the process of methodical and exploration work in various landscape and geological settings allow us to recommend the method of ion-sorption method for wide use in lithogeochemical searches of hidden and buried deposits of base and precious metals. The introduction of the ion- sorption surveys into the practice of exploration in the territories of friendly countries can contribute to the development of mutually beneficial international cooperation in the field of modern search technologies.

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CONTRIBUTION OF FSBI «TSNIGRI» TO THE INTERNATIONAL COOPERATION OF ROSNEDRA WITH THE BRICS COUNTRIES IN THE FIELD OF THE GEOLOGY AND MINERAL RESOURCE STUDY

The article presents an overview of participation of the Federal State Budgetary Institution «Central Research Institute of Geological Prospecting for Base and Precious Metals» (FSBI «TsNIGRI»), subordinated to the Federal Subsoil Resources Management Agency (Rosnedra), in the international cooperation, in both the historical and modern aspects. The role of the institute in the implementation of Rosnedra's international cooperation programs is shown in the framework of activities of the relevant bilateral and multilateral intergovernmental boards, commissions, and specialized working groups. The main directions of the international activities and current tasks facing FSBI «TsNIGRI» in the international cooperation in sphere of the geology and mineral resource study are considered. The growing importance of the interaction between countries incorporated into the BRICS association in the sphere of geology and subsoil mineral resource use is noted. ***Keywords:*** *BRICS; Rosnedra; FSBI «TsNIGRI»; international cooperation; geology and mineral resource study; bilateral intergovernmental commissions on trade, economic, scientific and technical cooperation; Great Altai.*

International cooperation of modern Russia with foreign countries in the field of geology and subsoil mineral resource use has a solid foundation laid during the period of the former Soviet Union. During this period, a systematic geological study of the territory of the present CIS was carried out, and a unified mineral resource base of the domestic metallurgy was created. Soviet geologists provided significant assistance to the countries of Africa, Asia, and Latin America that had freed themselves from colonial oppression. Geological and forecasting metallogenic maps were compiled; dozens of mineral deposits were discovered; numerous mines were constructed in China, Mongolia, Algeria, Angola, Guinea, Egypt, Mali, Mozambique, and other countries. Geology students from many countries studied at universities in the Russian Federation and other republics of the USSR, and our professors worked at the various national universities. Relations with scientific geological organizations in Western countries were gradually established, accelerating in the late 1980s.

The changes that occurred in the early 1990s had a significant impact on the international position of Russia and the former Soviet republics in the field of geology and subsoil resource use. Interstate contacts with developing non-CIS countries in the mineral resources sector were inhibited for almost a whole decade. The interaction here was mainly limited to the level of private companies of Russian origin, operating at their own risk.

However, already from the beginning of the 2000s, a gradual restoration of the interstate contacts in the mineral resources sector began, which have now come close to the stage of full-scale cooperation.

The main mechanism of such the interaction at the present stage is the activities of international organizations for scientific, technical, and economic cooperation. Currently, these are, first of all, bilateral intergovernmental commissions on trade, economic, scientific and technical cooperation (IGCs), which connect Russia with many dozens of countries. The main goal of the IGCs is effective government support for business in Russia and friendly countries at the international level.

The activities of intergovernmental commissions are regulated by the relevant regulatory documents of the Government of the Russian Federation and the Executive Committee of the CIS countries and are controlled by the Ministry of Economic Development of Russia. Currently, Decree of the Government of the Russian Federation of August 26, 2020 No. 1292 «On the Russian parts of the Intergovernmental Commissions on Trade, Economic, and Scientific and Technical Cooperation between the Russian Federation and Foreign Countries» is in force, approved by the Chairman of the Government of the Russian Federation M. V. Mishustin.

The IGCs for cooperation with countries characterized by a significant role of the mineral resource complex are headed on the Russian side by the heads of the Ministry of Natural Resources and Environment of the Russian Federation (Angola, Guinea, Zimbabwe, Cambodia, North Korea, Sudan, South Africa) or Rosnedra (Ghana, Mozambique, Ethiopia). For a number of other countries, specialized working groups have formed the IGCs on cooperation in the field of geology and subsoil mineral resource use, also headed on the Russian side by the leadership of Rosnedra and the Ministry of Natural Resources (Algeria, Venezuela, China, Kyrgyzstan, Cuba, Tajikistan, Uzbekistan).

TsNIGRI, as the leading institute of the Ministry of Geology of the former USSR, responsible for the scientific and methodological support of all the governmental geological exploration projects for gold, silver, platinum group metals, diamonds, copper, nickel, cobalt, lead and zinc, has always been at the epicenter of geological exploration activities in these spheres, including the foreign works (Fig. 1). During the Soviet period, especially in 1970–1990, the institute carried out systematic thematic and expert work at ore deposits and promising sites in Transcaucasia, Kazakhstan, and Central Asia. By means of the system of the Soviet foreign economic association «Zarubezhgeologiya», dozens of specialists of the

Fig. 1. Reproduction of the map «Geography of TsNIGRI's work abroad», compiled at the Federal State Budgetary Institution «TsNIGRI» for the 85th anniversary of the institute (M.I. Vakhrushev and others)

sNIGRI» OVER THE WORLD COUNTRIES

institute participated in foreign geological exploration projects. In the 1980s, the Soviet government-initiated cooperation in the field of geological study of subsoil mineral resources within the framework of the Council for Mutual Economic Assistance (CMEA), where the specialists from TsNIGRI also played a key role. Joint events were held with organizations of geological surveys of Canada, China, and the USA. Scientists of TsNIGRI made presentations at international geological congresses and sessions of the International Association for the Genesis of Ore Deposits (IAGOD) [1].

In the post-reform period (1992–2010), TsNIGRI's specialists also found themselves in demand in foreign work. On a contract basis, geologists and technologists of the institute participated in the exploration and evaluation of mineral deposits of gold, lead and zinc, copper, and diamonds in Algeria, Guinea, Morocco, Mongolia, Myanmar, Alaska, Utah, Peru, Venezuela, Cyprus, and Colombia.

At the beginning of the next decade, the institute was mainly involved in solving internal Russian problems due to a significant reorganization of the national geological service.

A new phase began in 2017 in connection with Russia's general course towards strengthening international cooperation in the field of the geology and mineral resource study. In 2017, the Division of International Cooperation was formed in structure of the FSBI «TsNIGRI». Since the basic competence of the division is realization of the Government Order in terms of monitoring the state and main trends in the world mineral resource base dynamics, the division is subordinate to the Department of Mineral Resources Base of FSBI «TsNIGRI». In terms of the international cooperation tasks, the activities of the division are personally supervised by directors of the institute [2].

FSBI «TsNIGRI» currently remains the leading expert and research center of the Russian State Geological Survey, the Federal Subsoil Resources Management Agency (Rosnedra) in the field of forecasting, prospecting, and evaluation of mineral deposits of precious metals (gold, silver, platinum group metals), base non-ferrous metals (copper, nickel, cobalt, lead and zinc), and diamonds. Being a subordinate organization of Rosnedra of the Russian Ministry of Natural Resources, the institute operates in the field of international cooperation in accordance with the State goals and objectives, determined by these offices.

FSBI «TsNIGRI» carries out the following kinds of work:

— metallogenic analysis of large regions and assessment of their ore-bearing potential;

— development of forecasting and prospecting models for various types of mineral deposits;

— identification and delineation of promising areas and sites for the geological prospecting and exploration;

— preparation of prospecting and appraisal projects in order to identify promising areas and ore occurrences (potential mineral deposits);

— conducting a quantitative assessment of potential mineral resources;

— supervision and methodological support of geological exploration projects, including those under the programs.

When performing all of the above types of work, the institute develops and applies a wide range of geophysical, geochemical, mineralogical, and petrographic techniques.

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The main goal of international cooperation within the competence of FSBI «TsNIGRI» is the reproduction and safe development of mineral resources of Russia and its friendly countries on a mutually beneficial basis and in the national interests of all interested parties.

The main areas of international cooperation of FSBI «TsNIGRI» in the field of the geology and mineral resource study and subsoil use at the present stage include the following.

(1) Monitoring of the mineral resources industry of foreign countries:

— monitoring resource base and production of solid minerals of the world as a whole, individual countries, and leading mining companies; within the framework of the study of the global mineral resource base, special attention is paid to countries with which mutually beneficial cooperation can be established, or has already been established, in terms of expanding and developing the mineral resource base of these countries;

— monitoring of foreign achievements and innovations in the field of equipment and technologies of geological exploration for diamonds, precious and base metals, development of proposals for their use in the geological exploration industry of Russia.

(2) Participation in activities of the bilateral intergovernmental commissions, primarily under the jurisdiction of the Russian Ministry of Natural Resources and Rosnedra:

— participation in activities of the working groups on geology and subsoil mineral resources use;

— informational and analytical services for the activities of the intergovernmental commissions regarding tasks in the field of geology and subsoil mineral resource use;

— development of proposals for cooperation in the field of geology and subsoil mineral resource use between geological services of the Russian Federation and foreign countries, participation in the planning of such work;

— development of proposals to attract Russian mining and investment companies to the geological study, development, and exploitation of mineral resources of foreign countries;

(3) Research and geological exploration work on the territory of foreign countries and cross-border territories:

— organization and participation in the implementation of joint experimental and methodological work on the development and promotion of innovative techniques;

— organization and participation in joint work on the geological study of promising areas and objects on the territory of foreign countries;

— performance of commercial work in the field of forecasting, prospecting, and evaluation of mineral deposits of diamonds, precious and base metals under contracts with subsoil user companies.

(4) Scientific organizational activities:

— participation in organization and conduction of international scientific and methodological conferences, forums, exhibitions, excursions;

— preparation of publications, reports, presentations on the areas of the international activity of TsNIGRI and foreign objects of interest to the Russian subsoil resource user.

FSBI «TsNIGRI», within the framework of international cooperation in the field of geological and mineral resource study with friendly foreign countries, in accordance with its competencies, is ready to participate on mutually beneficial terms in the following types of work:

1. Analysis and assessment of the mineral resource base of interested countries in terms of gold, platinum group metals, nickel, cobalt, copper, lead, zinc and diamonds; identification of priority promising areas for the geological prospecting and appraisal work, determination of the optimal set of geological exploration methods, etc.; development of recommendations for Russian and foreign companies on carrying out the prospecting and appraisal work and developing the most promising objects.

2. Carrying out expert and revisional geological, geophysical, and geochemical work in the promising areas to determine the directions and methods of prospecting and assessment work on occurrences of diamonds, base and precious metals. In the course of carrying out such work, it is possible to use geological, geophysical, geochemical methods and technologies developed at TsNIGRI, including the patented ion-sorption method of geochemical searches for polymetallic and gold deposits poorly manifested on the modern surface, and other effective mineralogical and geochemical search methods based on vector principle of local forecast. In addition, it is possible for the Institute to participate in studies of the material composition of ores from mineral deposits and occurrences of various types in order to study their technological properties.

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At the present stage of international cooperation with the participation of Russia, the task of expanding and strengthening interaction between the countries participating in the BRICS association, including the interaction and cooperation in the mineral resources sector, is becoming increasingly important.

Currently, the BRICS (BRICS+) association includes 10 countries: Brazil, Russia, India, China, South Africa, Egypt, Iran, UAE, Ethiopia, and Saudi Arabia. Applications for the membership were submitted by Algeria, Venezuela, Bahrain, Pakistan, and Thailand. A number of other countries are considering the possibility of joining this association. Russia will become the next BRICS chairman in 2024.

The BRICS countries dominate the world in hydrocarbon reserves and production. They also have a developed mining industry and a powerful mineral resource potential for solid minerals, leading, in particular, in gold, platinum group metals, diamonds, lead, zinc, and nickel. In this regard, the development of interaction with the countries of the association is an important task of the Russian Ministry of Natural Resources and Ecology and Rosnedra.

FSBI «TsNIGRI», as part of the activities of Rosnedra to form the BRICS geological platform, actively participates in events aimed at establishing working contacts with geological organizations of the national geological services of the countries of this association. First of all, such countries include China, South Africa, and Ethiopia.

The participation of FSBI «TsNIGRI» in cooperation with organizations of the China Geological Survey is carried out in accordance with medium-term programs coordinated from the Russian side by the Government of the Russian Federation, the Ministry of Natural Resources and Ecology of the Russian Federation, and Rosnedra.

In July 2016, a Memorandum of Cooperation was signed between Rosnedra and the China Geological Survey (CGS). As part of this process, the geological surveys of the two countries exchanged delegations that visited international scientific and industrial meetings and typical mines. In April 2018, a delegation of Chinese geologists took part in the VIII scientific and practical conference «Scientific and methodological foundations for forecasting, prospecting, and evaluation of mineral deposits of diamonds, precious and base metals» on the basis of the FSBI «TsNIGRI», and visited Mikheevskoe and Sibaiskoe operating copper mines in the Urals as part of this event (Fig. 2).

In November 2018, a delegation from FSBI «TsNIGRI» visited China at the invitation of the Center for Science and Development of the China Geological Survey. The purpose of the visit was to establish relationships and identify opportunities for cooperation in the field of scientific and production work. Meetings were held with the leadership of the Center for Science and Development, the Mining and Geological Association of China, and the China University of Geosciences in Beijing. The delegation took part in an excursion to the Jiaojia gold mine in the Shandong province (Fig. 3).

As a result of the exchanges of visits and negotiations, a number of agreements were reached to conduct joint research at sites in Russia and China. However, due to the ensuing pandemic, the contacts between the geological organizations were suspended.

Fig. 2. Russian and Chinese geologists at the Mikheevskoye porphyry copper deposit, Southern Urals, 2018

Fig. 3. A group of geologists from FSBI «TsNIGRI» and the Chinese Geological Survey in the underground gold mine of Jiaojia, China, 2018

Resumption of the cooperation began in 2022. From this moment, the ongoing implementation of the International Cooperation Program «Greater Altai — a unique rare metal-gold-polymetallic province of Central Asia» has become the main area of participation of the FSBI «TsNIGRI» in Russian-Chinese cooperation. The goal of the program is to intensify geological research and develop the mineral resource base of metallurgy within the cross-border Altai region. Representatives of geological surveys from four countries — Russia, Kazakhstan, Mongolia, and China — participate in the work program for the «Great Altai» (Fig. 4).

In April 2022, Rosnedra and the Committee of Geology and Subsoil Use of the Republic of Kazakhstan had organized a meeting of the working group on this project, that was held on the base of FSBI «TsNIGRI» in the on-line format. The international meeting was also attended by representatives of the China Geological Survey.

Results of the 1st stage of the Program realization were considered, that were as follows. Preliminary versions of structural-formational and metallogenic maps and the structure of an electronic catalog of geological, geochemical, and geophysical information were developed for the Altai region by Russian and foreign specialists. Forecasting minerogenic maps in various scales for metallogenic zones, ore regions, and clusters; forecasting geological prospecting models of reference ore deposits; and other materials were prepared for the Russian territory of Rudny Altai by FSBI «TsNIGRI» and other organizations of Rosnedra.

Further development of the «Great Altai» project will expand the exchange of experience between Russian and Chinese geologists and more fully reveal the ore potential of the cross-border Altai region in relation to rare, precious, and base metals.

In agreement with Rosnedra, a series of working meetings between the leaders and specialists of the FSBI «TsNIGRI» and Chinese organization took place as part of the Russian-Chinese interaction:

Fig. 4. International program «Greater Altai»

Fig. 5. Meeting of participants of the China Geological Survey delegation and the leaders of the FSBI «TsNIGRI» at the International Conference of FSBI «TsNIGRI», April 2023

April 12, 2023 — with representatives of the China Geological Survey (Fig. 5);

March 11, 2024 — with delegation of the China Geological University (Beijing);

April 11, 2024 — with representatives of the Xi'an Center of the China Geological Survey (Fig. 6).

During the meetings, the participants considered opportunities and areas of cooperation in the field of geology and subsoil use. Both sides presented reports reflecting the capabilities of FSBI «TsNIGRI» and the China Geological Survey organizations when carrying out forecasting and prospecting work for base and precious metals.

In accordance with the invitation from the China Geological Survey, a representative of the FSBI «TsNIGRI» took part in the «Forum on International Cooperation in the Field of Geosciences and Investments in the Mining Industry of the SCO Countries 2023» at the Research Center for Cooperation in the Field of Geosciences, Xi'an Center of the China Geological Survey (Xi'an, September 21–25, 2023), that was held as part of the 2023 Eurasian Economic Forum (Fig. 7). FSBI «TsNIGRI» presented the report «New discoveries and directions of geological exploration for base and precious metals in the Russian Federation».

The agreements reached as a result of the meetings were taken into account for proposals to the medium-term development plan of the Russian-Chinese economic cooperation, being prepared within the framework of the activities of the Intergovernmental Russian-Chinese Commission on Investment Cooperation.

In accordance with this plan, FSBI «TsNIGRI», in cooperation with organizations of the China Geological Survey, is expected to participate in the following activities: (1) comparative studies of the Greater Altai and other cross-border and near-border metallogenic belts with the compilation of transboundary maps of metallogenic content and assessment of resource potential; (2) comparative characterization and development of geological prospecting models for ore deposits of precious, base, and rare metals in cross-border regions, based on comparison with reference objects in other regions, for the purposes of regional and local forecasting, prospecting, and exploration of the mineralization.

An agreement was reached with the Xi'an Center of the China Geological Survey on a meeting within the framework of the SCO Cooperation Conference in the Field of Geosciences and a scientific seminar dedicated to the 10th anniversary of the establishment of the China-SCO Research Center for Cooperation in the Field of Geosciences, and at the Working

Session on the project «Greater Altai», which are planned for early July 2024 in Xi'an, China. It is planned that a representative of FSBI «TsNIGRI» will participate in the Working Session of the Great Altai Project with reports corresponding to the topics proposed by the organizers of these events (in video conferencing format).

In order to intensify cooperation in this area, FSBI «TsNIGRI» proposes to carry out in China in 2025 the project «Expert forecasting and metallogenic work in order to select priority objects for joint development by Russian and Chinese companies in the near-border and cross-border territories of Russia and China, including those within the framework of the implementation of the program «Greater Altai — a unique rare metal-gold-polymetallic province of Central Asia». In this case, the following types of work are expected to be performed: collection and analysis of geological, geophysical, and geochemical information on promising objects from various sources; visiting promising sites with their geological reconnaissance and specialized sampling; carrying out experimental and methodological lithochemical sampling on secondary dispersion halos within promising areas using the ion-sorption method of geochemical prospecting for deep-lying deposits; laboratory and analytical studies by FSBI «TsNIGRI» and in commercial laboratories; geological and geological-economic interpretation of the collected materials and the results of the research performed; compilation of technical reports on the results of work.

As a result of the proposed activities, the following will be carried out: assessment of the resource potential of the near-border and cross-border territories; selection of priority objects promising for deficient commodities for the geological prospecting and exploration by Russian and Chinese companies.

In the future, similar studies can be carried out in the Far Eastern Federal District of the RF and adjacent territories of the People's Republic of China.

The participation of FSBI «TsNIGRI» in Russian-South African cooperation in the field of the geology and mineral resource study is carried out in accordance with the instructions of the Government of the Russian Federation, within the framework of the activities of the Mixed Intergovernmental Committee on Trade and Economic Cooperation between the Russian Federation and South Africa, headed from the Russian side by the Minister of Natural Resources and Ecology of the Russian Federation A.A. Kozlov.

It is planned to implement joint research and prospecting projects on the territory of South Africa (comprehensive study of ore deposits and technogenic raw materials; development of new techniques of geological prospecting; geological analysis of prospecting data and mineralogical studies on promising areas in South Africa; implementation of projects in the field of geological mapping and geological study of the territory of South Africa).

To date, FSBI «TsNIGRI» within the framework of this area has completed expert and analytical work on the collection and analysis of available data on the geology and mineral resource base of the Republic of South Africa. The institute have prepared proposals to the draft medium-term program of cooperation in the field of geology and mineral resource study between the Federal Subsoil Resources Management Agency (Rosnedra) and the Council for Geoscience (CGS)» (the Council for Geosciences performs the functions of the South African Geological Survey). The program is at the stage of coordination with the South African side.

Fig. 6. Meeting of the leaders and specialists of the Xi'an Center of the China Geological Survey and FSBI «TsNIGRI» at the International Conference of FSBI «TsNIGRI», April 2024

Fig. 7. Participants of the Forum on International Cooperation in the Field of Geosciences and Investments in the Mining Industry of the SCO Countries 2023.» Xi'an, China, September 2023

In cooperation with South Africa, it is planned that FSBI «TsNIGRI» will participate in the following activities: (1) comprehensive study of mineral deposits and technogenic raw materials and the development of techniques for geological exploration for PGMs, gold, base metals, and diamonds; (2) mineralogical and geochemical study of rough diamonds at promising sites; assessing the possibility of jointly using Russian methods for studying the typomorphic characteristics of diamonds for the purposes of certification and control over the circulation of diamond products; (3) study of the isotope-geochemical characteristics of minerals to determine their typomorphic properties, primary sources, and genesis of the mineral deposits; (4) organizing joint geological excursions to large reference deposits of diamonds, platinum group minerals, gold, copper, nickel, cobalt, and other minerals to exchange experience in the study and development of such objects.

Fig. 8. Head of the Council of Geosciences of South Africa Mosa Mabuza in the museum of FSBI «TsNIGRI». December 2022

The competencies and capabilities of FSBI «TsNIGRI» in the international cooperation in the geology and mineral resource study were presented to the African partners in the form of reports and presentations during previously held official meetings at various levels, including the meeting of the leaders of Rosnedra and subordinate institutes and the South African Council for Geosciences (CGS) (videoconferencing, 14.11.2022) and the visit of the CGS delegation to the institute TsNIGRI (15.12.2022) (Fig. 8).

The report and presentation of FSBI «TsNIGRI» with proposals for cooperation with the South African side were also presented at the 17th Session of the Mixed Intergovernmental Committee on Trade and Economic Cooperation between the Russian Federation and South Africa. The session was held in March 2023 in Pretoria, the capital of the Republic of South Africa, under the chairmanship of the Minister of Natural Resources and Environment of Russia Alexander Kozlov and the Minister of International Relations and Cooperation of the Republic of South Africa Naledi Pandor (Fig. 9).

The key topic of the meeting was the discussion of the Russian initiative to create the «BRICS Geological Platform». As emphasized by the chairman of the Russian part of the committee A.A. Kozlov, the creation of this mechanism will

Fig. 9. Plenary meeting of the 17th session of the Mixed Intergovernmental Committee on Trade and Economic Cooperation between the Russian Federation and South Africa. Pretoria, March 2023

allow to develop the international cooperation in the field of geology; will give impetus to the development of mining technologies, the exchange of knowledge and experience on an ongoing basis; and will ensure the launch and implementation of joint programs and projects. As practical steps to create the «BRICS Geological Platform», it was proposed to begin preparing a joint Memorandum of Cooperation between the heads of geological departments of the BRICS member countries, to develop and approve a comprehensive cooperation program that would include specific areas of joint activities and selected projects [3].

Proposals from FSBI «TsNIGRI» for cooperation with the Council for Geosciences (CGS) and the Council for Mineral Technologies (MINTEC) of South Africa were included in the final Protocol of the 17th Session of the Mixed Intergovernmental Committee.

The participation of FSBI «TsNIGRI» in Russian-Ethiopian cooperation is carried out in accordance with the activities of Rosnedra, within the framework of the Russian-Ethiopian working group headed from the Russian side by the head of Rosnedra E.I. Petrov.

With the informational participation of FSBI «TsNIGRI» and other subordinate organizations, Rosnedra conducted negotiations with the leadership of the Geological Institute of Ethiopia (GIE) of the national Geological Survey under the Ministry of Mining and Petroleum of the country. The goal of the talks was to intensify cooperation in the field of geology and subsoil use, according to the medium-term cooperation plan that had been developed. In accordance with the decisions of the 8th Session of the Russian-Ethiopian Intergovernmental Commission (IGC) on economic, scientific, and technical cooperation and trade (Addis Ababa, December 2022), and with agreements based on results of the meeting of the co-chairs of the IGC, a series of working meetings took place in Addis Ababa on June 19–21 of a representative delegation of Russian specialists led by Advisor to the Head of Rosnedra D.N. Oleynik with specialists from the Geological Survey of Ethiopia. A representative of FSBI «TsNIGRI» took part in the delegation of Rosnedra as an expert on solid minerals of the diamonds, base and precious metals (DBPM) group. The purpose of the meetings was to determine specific directions for further Russian-Ethiopian cooperation in the field of geology and subsoil use. Based on the preliminary results of the event, one can expect significant progress in the practical implementation of the cooperation between Russian and Ethiopian geologists.

In order to exchange experience, participants from the Ethiopian and Russian sides presented reports on urgent areas of cooperation. FSBI «TsNIGRI» presented the report «Modern applied mineralogical and geochemical techniques of prospecting for mineral deposits of base and precious metals», based on examples of geological prospecting fulfilled by the institute in Russia and a number of foreign countries. These methods and technologies, including the patented ion-sorption method of prospecting for unexposed or overlain ore deposits of base and precious metals, were developed at FSBI «TsNIGRI». They have repeatedly confirmed their exploration efficiency and are recommended for widespread use both in Russia and foreign countries.

During the working meetings, it was proposed to consider the issue of testing and applying these and other prospecting technologies of the Rosnedra institutes at the sites of the Federal Democratic Republic of Ethiopia for searching for ores of base metals and gold.

In addition to the cooperation with the above-mentioned countries, for which the main directions for further action have already been outlined, representatives of the FSBI «TsNIGRI» have recently, in accordance with the international cooperation program of Rosnedra, taken part in a number of events to prepare the cooperation with other BRICS countries. Proposals have been prepared on areas of cooperation between Rosnedra and the geological surveys of the UAE, Saudi Arabia, Brazil, and India. Representatives of FSBI «TsNIGRI» took part in the meeting of Rosnedra with the leaders of the Geological Survey of Egypt (videoconferencing), in meetings of the working groups on cooperation with the geological surveys of the potential BRICS participants, Algeria, Venezuela, Cuba.

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A striking example of international cooperation between FSBI «TsNIGRI» and foreign counterparts, including organizations from the BRICS member country China, is the project «Great Altai — a unique rare metal-gold-polymetallic province of Central Asia». The study of Greater Altai was proposed as part of the international project «Atlas of geological maps of Central Asia and adjacent states on a scale of 1: 2 500 000» (participants in the work were Russia, Kazakhstan, China, Mongolia and Korea), and has recently been considered as part of the program «Metallogeny without borders» (Fig. 10).

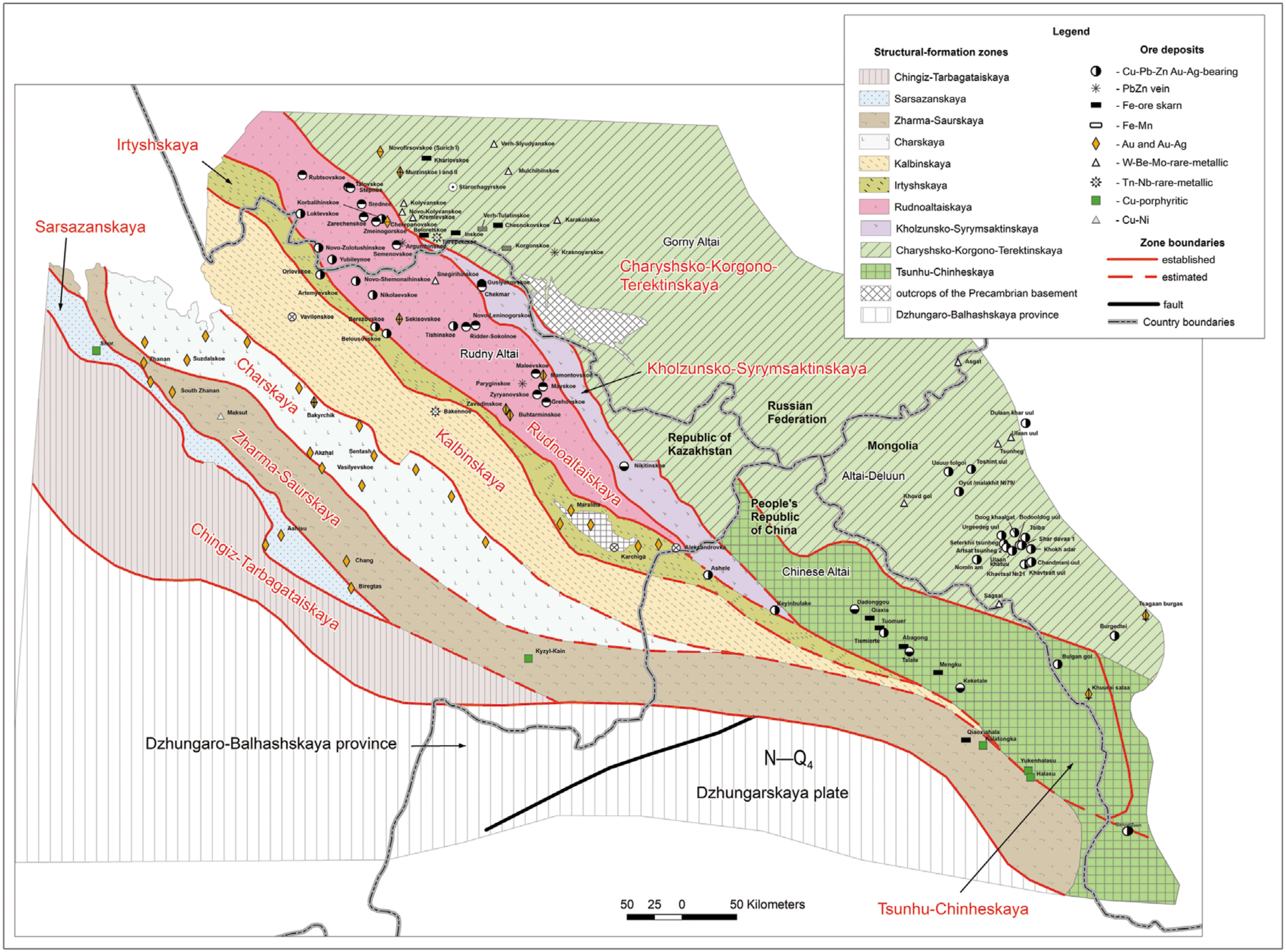

Fig. 10. Schematic map of Greater Altai (Kudryavtseva N.G. *et al.*, 2024, FSBI «TsNIGRI» (in press))

Greater Altai is one of the reference areas for understanding the geology and metallogeny of Central Asia. It is a territory that has a large mineral resource base for metallurgy in Russia, Kazakhstan, China, and Mongolia (see Fig. 4). Despite the long-term intensive exploitation of the gold, polymetallic, and rare metal ore deposits, the potential opportunities of this region are far from exhausted. The main reserve for the discovery of new deposits lies in ore objects that do not reach the surface. Therefore, the most important task is the further development of geological genetic criteria and the introduction of modern prospecting technologies into the practice.

The main direction of work on the project is the joint scientific, methodological and technological research based on the use of interdisciplinary knowledge, new geological information, and digital technologies of converting the knowledge and information into the mineral forecasts.

It should be noted that results of geological exploration in the Greater Altai, achieved in recent years, have not led to a radical improvement in the situation with the raw material base of this region. Not a single large deposit has been discovered here in the last few decades. The depth and effectiveness of the used forecasting and prospecting methods, the actual study of the material composition and of the structural and genetic conditions for the formation of ore deposits based on the exploitation results are insufficient. The research currently being underway is scattered and not systematic, as it is carried out by different institutions on short-term one-time projects. There is no unified plan for studying the Greater Altai.

To implement this project, the international conference «Great Altai — a unique rare metal-gold-polymetallic province of Central Asia» was held in 2010 in Ust-Kamenogorsk, and a working meeting was held in Almaty in 2019.

In 2022, a meeting of the working group was organized on the basis of the FSBI «TsNIGRI». The purpose of this event was to coordinate and enhance interstate cooperation within the framework of the Great Altai project, to discuss current work results, and to determine directions for the further activities. The meeting was attended by specialists from the People's Republic of China (Xi'an Center of the China Geological Survey, Chinese Academy of Sciences), the Republic of Kazakhstan (OO «Academy of Mineral Resources of the Republic of Kazakhstan», NJSC «VKTU named after D. Serikbaev», MD «Vostkaznedra»), and the Russian Federation (FSBI «VSEGEI», FSBI «TsNIGRI», FSBI «IMGRE», FSBI «Rosgeolfond», JSC State Research and Production Enterprise «Aerogeofizika», IGM SB RAS, OOO «Cosmo-Geopro», and the Tomsk Polytechnic University).

Based on the presented reports, taking into account the decisions of the 2010 conference (Ust-Kamenogorsk) and the 2019 meeting (Almaty), the participants prepared a Decision of the meeting of the working group of the Great Altai project. The results obtained during the implementation of the project indicate the need to continue the work and demonstrate additional opportunities from the joint research in the geological study of territories of the different countries. The approaches and directions of work, developed during the implementation of the project, can be effectively used in the development and implementation of one of the programs of activity of the Intergovernmental Council for the exploration, use, and protection of subsoil resources of the CIS countries, the program «Metallogeny without borders». To achieve the goals and objectives of the Great Altai project, the participants considered it necessary to hold such meetings regularly (once every two years). As noted above, the next meeting of the working group will be held by the Xi'an Center of the China Geological Survey in July 2024.

FSBI TsNIGRI is actively working on the Great Altai project and interacts with colleagues from China and Kazakhstan. The main directions of the institute's work on the project in recent years have been:

— analysis of formation conditions of the base and precious metals ore deposits in the Greater Altai territory;

— forecasting and revisional studies for gold-silver-bearing polymetallic mineralization within the Zolotushinsky ore district (Rudny Altai zone);

— substantiation of the metallogenic zonality patterns for the Zmeinogorsk and Zolotushinsky ore districts;

— development of the structure and content of an electronic data catalog of geological, geochemical, and geophysical information on the Russian part of the Greater Altai;

— development of a methodology for preparing multifactor geological prospecting models of promising geological and industrial types of precious and base metals deposits, taking into account the specifics of work within the Greater Altai, and compilation of the geological prospecting models for a number of Russian polymetallic deposits of the region considered;

— participation in joint international events;

— conducting geological excursions «Metallogeny of Rudny Altai» within the Russian part of Greater Altai.

The purpose of the forecasting and revisional work begun in 2023 in the Zolotushinsky ore district of Rudny Altai is to determine the patterns of placement of gold-silver-bearing polymetallic mineralization and to localize promising areas located in the hidden and covered occurrence. During field seasons, geochemical (ion-sorption technique) and geophysical works are carried out within the forecasted promising areas. Currently, based on the analysis of the relevant geological, geochemical, geophysical, remote sensing, and metallogenic materials on a scale of 1:100 000, the following ore clusters have been identified within the Zolotushinsky ore district: Loktevsko-Removsky, Nikolaevsky, Zolotushinsky ore clusters of the Emsian-Early Eifelian level of the mineralization localization, as well as the Kamensko-Aleksandrovsky and Titovsko-Gerikhovsky ore clusters of the Late Givetian-Early Frasnian level, including ore occurrences and deposits of the same names. It is necessary to strive to ensure that similar work in the future is carried out jointly throughout the Greater Altai.

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The development of such an area as international cooperation is impossible without taking into account modern requirements: mandatory practical returns from any activity and

Fig. 11. Participants of the XXV Session of the Intergovernmental Council on Exploration, Use, and Protection of Subsoil of the CIS. Dushanbe, September 2022

the use of effective methods for collecting and processing information in real time for decision-making. In this regard, the FSBI «TsNIGRI» faces the following urgent tasks in this area:

— creation, development, and maintenance of highly informative databases in all areas of the global mineral resources industry in order to increase the efficiency and reliability of information for decision-making at the government level;

— establishing direct contacts on an ongoing basis with institutes of geological services, public and private geological exploration and mining companies of friendly countries, including the BRICS countries;

— facilitating the exchange of available geological information between Russia and countries that are members of interstate organizations (CIS, EAEU, SCO, BRICS, and others);

— strengthening the practical orientation of the ongoing scientific, methodological and expert-analytical projects in order to increase the investment attractiveness of mineral resource objects in foreign countries for Russian specialized companies and investors.

As already noted above, the urgent task facing Rosnedra is the creation of the «BRICS Geological Platform» as a basis for cooperation between the geological departments of the BRICS countries, the development and approval of a comprehensive cooperation program that will include specific areas of joint activities and certain projects. Apparently, it is advisable to use the experience of interaction between the CIS countries in the mineral resources sector as the basis for the structure and mechanism of such cooperation. Thus, in the interaction of the CIS member countries, the main role is played by the Intergovernmental Council for the Exploration, Use, and Protection of Subsoil Mineral Resources (Intergovernmental Council) (Fig. 11). Within the framework of the Intergovernmental Council system, current directions for the development of geology and subsoil resource use in modern conditions are discussed, long- and medium-term plans for cooperation in the field of the geology and mineral resource study are drawn up and adopted, and their implementation is monitored. Information support for the activities of the Intergovernmental Council is provided by subordinate organizations of the national geological services, including FSBI «TsNIGRI» of Rosnedra, acting within the framework of their competencies.

The planned meeting of the heads of geological surveys of the BRICS member countries is expected to be a decisive step in the creation of the «Geological Platform» for cooperation in the field of geology and subsoil use of our countries.

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THE GROUNDWATER MONITORING SYSTEM IN RUSSIA. DEVELOPMENT PROSPECTS

The state monitoring of the state of the subsoil is an integral part of the state environmental monitoring and monitoring of water bodies. Groundwater monitoring is carried out at observation points in order to assess the current state of groundwater and forecast its changes under the influence of natural and man-made processes.

Keywords: *State monitoring of the state of the subsoil, groundwater, exogenous geological processes, state reference monitoring network for groundwater monitoring, observation point.*

In the Russian Federation, groundwater monitoring of the unified system of state monitoring of the state of the subsoil (GMSN) is an integral part of the state environmental monitoring and monitoring of water bodies, and is carried out within the framework of the implementation of the State Program «Reproduction and Use of Natural Resources» (Decree of the Government of the Russian Federation dated april fifteenth, two thousand and fourteen, number three hundred and twenty-two (04/15/2014 No. 322)).

It should be noted that in addition to groundwater, within the framework of state monitoring of the state of the subsoil, dangerous exogenous and endogenous geological processes are monitored, as well as monitoring of coastal shelf zones of the seas of the Russian Federation.

The basis for conducting state monitoring of groundwater are: the Law of the Russian Federation «On Subsoil» (Article thirty-six paragraph two State monitoring of the state of the subsoil and monitoring of the state of the subsoil in the subsoil area provided for use), the Federal Law «On Environmental Protection» dated January tenth, two thousand and two Federal law number seven (10.01.2002 No. 7-FZ), «Strategy for the development of the mineral resource base of the Russian Federation until two thousand thirty-five years old (2035)», approved by Government Decree dated dated december twenty-second, two thousand eighteen, number two thousand nine hundred and fourteen — r (12/22/2018 No. 2914-r.) , «Rules for the implementation of state monitoring of the state of the subsoil and monitoring of the state of the subsoil in the subsoil plots provided for use», approved by Decree of the Government of the Russian Federation dated november twenty-ninth, two thousand twenty-three, number two thousand twenty-nine (11/29/2023 No. 2029), effective on the first of September, two thousand and twenty-four.

The goals and objectives of state monitoring of groundwater are to obtain reliable information about the state of groundwater; assessment of the state of groundwater and forecast of changes under the influence of natural and man-made processes; informing public authorities, commercial organizations, and the public about changes in the state of groundwater.

Within the framework of the unified GMSN system, which provides accumulation, processing and analysis of information in order to assess the current state of the environment and forecast its changes under the influence of natural and (or) anthropogenic factors, state monitoring of groundwater is carried out on the territory of the Russian Federation, federal districts and constituent entities of the Russian Federation. Special attention is paid to the Arctic zone of the Russian Federation, transboundary groundwater bodies (Russia-Estonia, Russia-Belarus, Russia-Azerbaijan), Resorts of federal significance in the Caucasian Mineral Waters region (CMW), the territory of the Sochi landfill, border territories with the republics of Belarus, Kazakhstan, Azerbaijan, Estonia.

The Ministry of Natural Resources and Ecology of the Russian Federation pays special attention to issues related to the use, protection and reduction of negative pressure on water bodies. Regulation of economic activity on water bodies and their protection are important tasks, especially in border areas where the use of surface and groundwater ensures the livelihoods of the population. In addition, surface and groundwater are the determining factors in the development of exogenous geological processes, which are the erosion of rocks, their displacement and sinkholes. These engineering and geological processes occur under the influence of water, changes in climatic factors and human economic activity and can lead to negative consequences on settlements and infrastructure facilities.

In this regard, remote monitoring methods for dangerous exogenous geological processes are being actively introduced, including using unmanned aircraft systems and space monitoring. Methods of forecasting rapidly developing dangerous geological processes are being improved. Remote sensing of the Earth using artificial Earth satellites and unmanned aircraft systems is a very promising method capable of solving many exploration tasks with efficiency significantly exceeding ground-based methods. At the same time, the optimal data for remote sensing of the Earth are optical and radar images, materials from aerial laser scanning and aerogeophysical surveys, etc.

State monitoring of underground water bodies is carried out through regular observations at the points of the state reference observation network and hydrogeological surveys of the territories of existing water intakes, deposits of undistributed subsoil resources, as well as territories with detected pollution or contaminated groundwater. Along with the observations, various information is collected on the state of groundwater, its analysis, generalization and systematization.

In the subsurface areas provided for use, local monitoring of the state of groundwater is carried out, the results of which are taken into account in the system of state monitoring of groundwater. Reports on local monitoring are submitted by subsurface users in electronic form through the personal account of the subsurface user, and are stored in the automated subsurface use licensing system of the FSBI Rosgeolfond (ASLN).

The monitoring network of the state monitoring of groundwater is concentrated in the European part of Russia, where, because of intensive extraction of groundwater, depression funnels of groundwater levels have formed, significant in area and depth, which are constantly monitored. There are about three (3) thousand points of the state reference groundwater-monitoring network (GONS) on the territory of Russia (Fig. 1).

The complex of determined indicators of the state of groundwater includes hydrochemical and hydrodynamic characteristics, such as: flow rate, level and temperature of groundwater, chemical composition. Some of the GONS points are equipped with automatic measuring complexes (AIC) with a telemetry data transmission system (cellular or satellite), allowing round-the-clock remote access to data on groundwater status indicators, such as: groundwater level, temperature, water conductivity, atmospheric pressure (Fig. 2, 3, 4)

In the territories of the subjects and federal districts, monitoring work is carried out by branches of the Federal State Budgetary Institution «Hydrospetzgeologiya» — the regional Centers of the State Budgetary Educational Institution and

Fig. 1. The layout of the observation points of the state monitoring of groundwater

Fig. 2. Well of the state reference monitoring network for groundwater monitoring

Fig. 3. Automatic measuring system for monitoring groundwater in the well of the state reference observation network

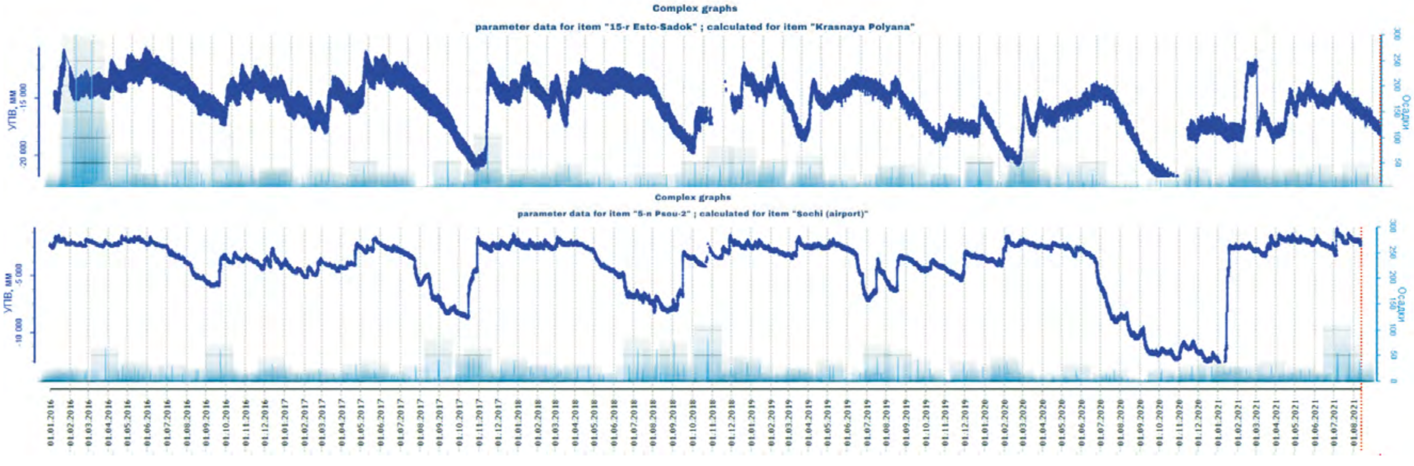

Fig. 4. Graphs of changes in the groundwater level, obtained from the data of automated measuring systems

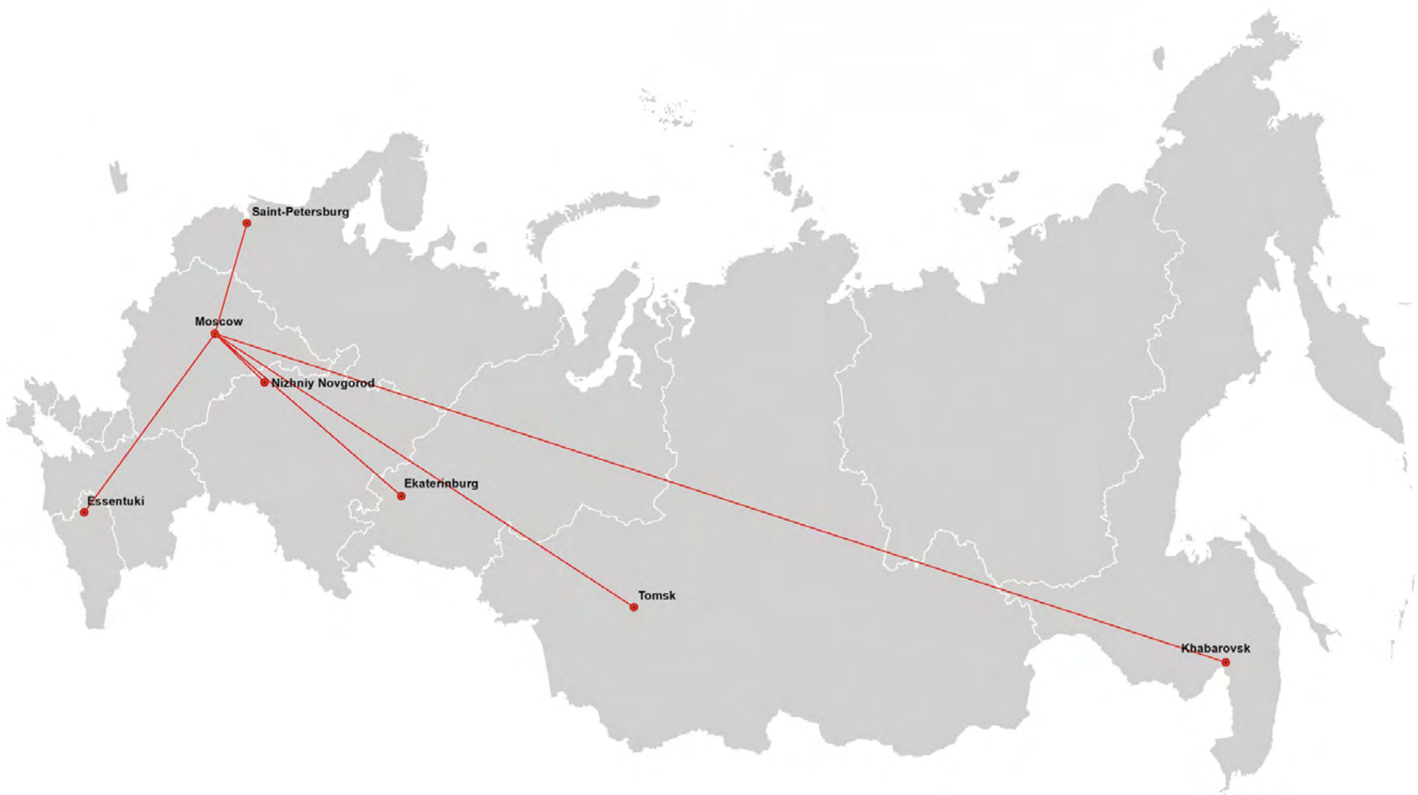

Fig. 5. Geography of the presence of the Federal State Budgetary Institution «Hydrospetzgeologiya» and its branches in the conduct of state monitoring of groundwater

their branches (Fig. 5). Summary, analysis and generalization of information on the territory of Russia as a whole is carried out in the FSBI «Hydrospetzgeologiya» (Moscow).

The results of the state monitoring of groundwater are open data and are published in various reports, certificates, annual newsletters on the state of the subsoil, forecasts of groundwater levels, and are posted on the official Internet resource of the state monitoring of the state of the subsoil — www.geomonitoring.ru.

In conclusion, it should be noted about significant changes in the system of state monitoring of the state of the subsoil, which will occur from the first of september, two thousand twenty-two (01.09.2024) in connection with the entry into force of Government Decree number two thousand twenty-nine (No. 2029). Monitoring will be conducted by government agencies, subjects of the Russian Federation, and subsoil users. Thus, the number of participants in groundwater monitoring will increase significantly, the efficiency and quantity of information received will increase. It is planned to expand the network of state monitoring of groundwater by drilling new wells for the organization of points of the state observation network, restoration and repair of existing points of the state observation network, registration of land and property relations for the subsequent transfer of FGBI «Gidrospetsgeologiya» to operational management.

In accordance with the Decree of the Government of the Russian Federation dated October seventh, two thousand twenty-three, number one thousand six hundred forty-nine in an experiment was launched to create a single information resource containing information about underground and surface water bodies used for drinking and household water supply, using the example of three subjects of the Russian Federation, on the territory of which various types of groundwater are distributed. Currently, an analysis of existing surface and groundwater systems has been carried out, indicators of surface and underground water resources have already been determined, and work is underway to identify threats to information security and requirements for the information protection subsystem. The unified resource will include data from the state monitoring of groundwater. In in the year two thousand and twenty-four (2024), the experiment will be completed, according to the results of which it will be possible to plan the implementation of this single resource throughout the territory of the Russian Federation.

The integration of information resources for monitoring surface and underground water bodies will expand the field of possibilities for forecasting the state of groundwater and increase the effectiveness of measures to protect the main type of strategic mineral raw materials of the Russian Federation — groundwater.

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GEOLOGY OF DATA — GEOLOGY OF THE FUTURE

The article discusses the main tasks and key achievements of information technologies of the FSBI «Rosgeolfond», implemented during the digital development of the subsoil use industry in 2022–2024. ***Keywords:*** *digitalization, data analysis, subsoil management, electronic license, State information systems of Rosnedra, Rosnedra.*

Today, a wide range of external as well as internal industry-related factors contributes to accelerated subsoil use digitalization. The rapidly changing legal framework has a lot to do with this process. Thus, while in 2015 the Law of the Russian Federation «On Subsoil» was amended once in a few years in order to e-transform certain subsoil fund management processes, in 2023, for instance, four Federal Laws (amendments to the Law «On Subsoil») were adopted at once to advance and digitalize industry management. This article will discuss major progress in digitalization made over 2022–2023 and prospects for 2024–2025.

Since 2022, the Federal State Budgetary Institution (FSBI) «Rosgeolfond» together with other budgetary institutions (Federal State Institution «Rosgeolexpertiza», FSBI «VIMS», FSBI «VNIGNI», FSBI «GKZ», and other) and under the auspices of the Federal Agency for Subsoil Use (Rosnedra) has been systematically and consistently building a unified digital environment with the digital flow of structured and standardized documents for state subsoil fund management at its core (Fig. 1).

Federal State Information Systems of Rosnedra are the technological foundation for digital state management transition.

The digital ecosystem is based on the two federal state information systems (FSIS) functioning not only under the core Federal Law «On Subsoil», but also in line with provisions of the Federal Law «On Information, Information Technologies and Information Protection» no. 149-FZ of July 27, 2006 and the Regulation of the Government of the Russian Federation no. 676 of July 6, 2015 «On requirements for the procedure of creation, development, commissioning, operation and decommissioning of state information systems and the further storage of information contained in their databases», they are:

— FSIS «Automated System for Licensing Subsoil Use» (FSIS ASLN);

— FSIS «Unified Fund of Geological Information on Subsoil» (FSIS EFGI).

FSIS ASLN provides for the subsoil fund in-process control, FSIS EFGI is to ensure digital flow of geological information (Fig. 2).

Besides licenses, this environment now includes state and geological reporting of subsoil users, state examination of reserves, technical development project approvals, and fully electronic auctions.

As of April 1, 2024 using Rosnedra FSIS:

— More than 22,000 licenses were issued in e-form only;

— More than 20,000 license applications were submitted on-line;

— More than 500 e-auctions were held;

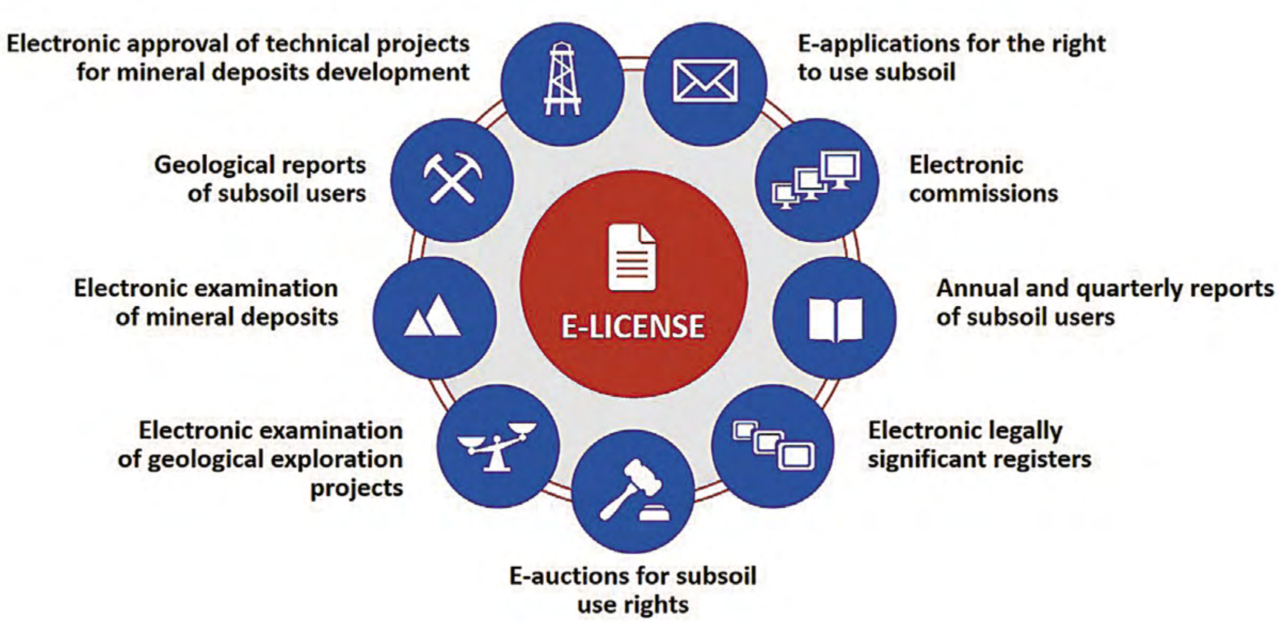

Fig. 1. Digital initiatives in subsoil use management

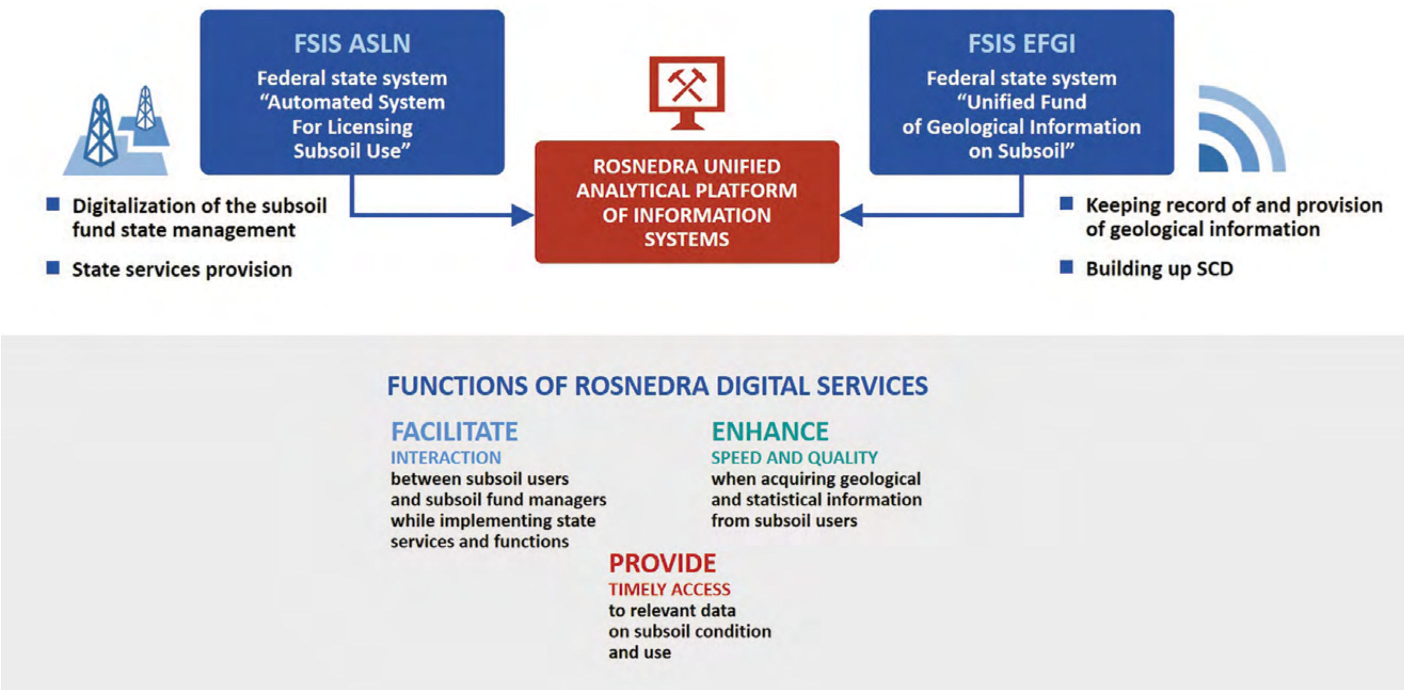

Fig. 2 Rosnedra information systems designed and maintained by Rosgeolfond

— More than 4,000 applications for technical project approvals of field development were submitted;

— More than 1,500 applications for state examination of mineral reserves were submitted;

— More than 40,000 packages of state and geological reports of subsoil users were submitted on-line;

— More than 1,600 packages of final geological reports, including primary and interpreted information were provided.

Rosnedra FSIS make four public state registers available for use: two of them, license register and the register of geological exploration, were put into operation in 2021; in 2023 two more registers were added: the register of expert opinions and the register of technical project approvals for field development.

Notably, the latter two are assigned ERUL numbers (a unified register of licenses operated by the Ministry of Digital Development, Communications and Mass Media of the Russian Federation). Starting from 2022, Rosnedra has been consistently focusing on integration with the state servers of the Ministry of Digital Development, Communications and Mass Communications of Russia.

A digital license is the foundation for building a digital ecosystem of subsoil use management.

An electronic license is a key element of the digital ecosystem — it is an XML file signed with an advanced qualified electronic signature by an authorized person and listed in the unified register of licenses (Fig. 3).

Since January 1, 2022, when this provision came into effect, more than 22,000 electronic licenses have been issued, with over 16,000 (16,048) of them being issued by the Russian Federation federal entities. Importantly, since 2022, Rosnedra has defined a unified template and standard format for both federal and regional licenses, which allows for uniform rules for issuing, processing, and monitoring the fulfillment of license obligations.

Over 30,000 amendments have also been made to previously issued licenses, including bringing the existing valid licenses into compliance with the current legislation.

The Subsoil User Personal Account is a «one-stop-shop» to facilitate on-line interaction of subsoil users and the Agency.

To facilitate interaction between subsoil user companies and the Federal Agency for Subsoil Use, the agency set up a Subsoil User Personal Account (SUPA), which is a one-stop-shop for subsoil user interaction to get any subsoil use services and functions.

The Subsoil User Personal Account is an integral part of the subsoil use management digital ecosystem set up by Rosnedra within the shortest possible time — three years only (from 2021 to 2023).

Since September 1, 2023, as a response to rapidly changing legal framework, the Personal Account features have changed significantly: new options previously unavailable to users have been added.

Thus, one of the key functions is subsoil users state geological reporting submission, as well as a feature allowing for submission of geological reports that cover all types of exploration activities results with seamless integration with FSIS EFGI in place for the latter.

Submission of Notifications on beginning of subsoil waste development and submission of Notifications on the beginning of extraction from subsoil waste have also been introduced.

By the end of 2023, the number of subsoil users exceeded 45 000, while back in 2020 there were no more than 300, with about 3000 in 2021.

More than 150,000 documents per year are submitted through the Personal Account system only electronically, and there has been a massive increase in the number of documents submitted annually.

For submitted applications (based on the example of technical development projects, examination of reserves) the average review time is decreased due to digitalization — it takes up to 24 days for technical projects approval (15–18 days for exploration technical projects approval) and up to 43 days for examination of mineral reserves.

Besides, it should be noted that almost all state services of Rosnedra for 2022–2023 have been transferred to the Unified Portal of State Services and Functions (EPGU), but in order to implement the client-centered approach, the functions of Rosnedra services on the EPGU have been significantly downsized to facilitate an application submission by a subsoil user, while making the job of department employees more challenging.

Unified Fund of Geological Information on Subsoil is a tool for data-driven management transition.

The Federal State Information System «Unified Fund of Geological Information on Subsoil» (FSIS EFGI) was set up to provide for a data-based management transition (in compliance with the order of the President of the Russian Federation).

The FSIS EFGI enables a full cycle of geological information flow in e-form: from submission by subsoil users to receipt by the clients concerned.

Федеральное агентство по недропользованию

ЛИЦЕНЗИЯ
на пользование недрами

ХМН	000000	НР
серия	*номер*	*вид*

Выдана	Публичное акционерное общество «Нефтяная компания «Роснефть» (ПАО «НК «Роснефть»), ИНН 7706107510
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Владелец сертификата: организация, сотрудник	Сертификат: серийный номер, период действия
ФЕДЕРАЛЬНОЕ АГЕНТСТВО ПО НЕДРОПОЛЬЗОВАНИЮ	1C155BD09D93CABFF858888B35092364560 4CCF7 с 20.07.2021 17:08 по 20.10.2022 17:08

Fig. 3 New license form — human readable PDF image

In 2022, a pilot operation was carried out to test the functionality of submitting geological reports in machine-readable XML format, more than 200 organizations (subsoil users, subordinate agencies of Rosnedra) were involved, starting from September 1, 2023, this function has been put into full-time use.

Along with this function, the federal and territorial geological information funds managed to integrate geological information submission into a consolidated production cycle. When submitting a report, a subsoil user no longer receives two separate conclusions, but a uniform notice indicating the deficiencies identified by the federal fund (including its marine branch) and territorial geological information funds.

At present, more than 30,000 applications have been processed and fulfilled by means of FSIS EFGI (since it was launched in 2020). More than 180,000 geological documents have been issued electronically for these applications.

Artificial intelligence technologies in subsoil use management and geological information flow.

Given the IT development trends involving artificial intelligence, it is no longer possible to dismiss this dimension in the entire subsoil use industry digital transformation. Artificial intelligence technologies expand the horizons of understanding the potential for multifactor analysis of heterogeneous and multilevel geological data, both up-to-date as part of current business processes and retro-archives accumulated within a range of time periods of geological structure exploration on territory of the Russian Federation.

FSBI «Rosgeolfond» is proactively building up an information and analytical platform using artificial intelligence technologies in order to meet modern development trends and address the challenges of the time.

At present, the following key projects are at various stages of development and roll-out.

1. Digital Subsoil User Assistant.

This module makes possible the interaction with applicants when applying for state services and implementing the agency functions with the use of artificial intelligence. This module was designed to provide all-encompassing text and voice consultations, to enhance information interaction with subsoil users (individuals and legal entities) by providing prompt and appropriate automatic responses to questions received from subsoil users in a chat in a comprehensible Russian language. It provides prompt and relevant responses to frequently asked written (via web chats) questions in a natural Russian language to advise on subsoil use state services and other questions related to FSBI «Rosgeolfond» activities, following the list of question-answer pairs used for neural network question-answer system training.

2. Digital Secretary of the Rosnedra Portal of State Services and Functions.

This module provides for structuring of official requests received on the Rosnedra Portal of State Services and Functions by analyzing the inquiries received on the Rosnedra Portal of State Services and Functions in order to group them by areas, tasks, territories, etc. This goal is achieved thanks to a software performing semantic analysis of incoming requests on the basis of existing question-answer pairs, comparing the incoming request with the knowledge database with the reference to the group of questions where it has been previously placed, and grouping the incoming requests. The requests that do not lie within the scope of Rosnedra's competence are screened out with a recommendation on the redirection address.

3. Digital service of data extraction from retrospective geological information.

The service is designed to extract new data from geological retro-data through machine analysis of retro-reports to reveal structural correlations not previously used in order to broaden the range of information stored in the state information systems of Rosnedra. The service will include software implementation of joint text and image recognition to identify structural correlations based on neural network algorithms.

4. Digital core-drilling.

Artificial intelligence algorithm-based extraction of new information from retro-data on physical media to create a digital twin of the existing data set on physical media using laboratory methods, computer simulation methods and software for searching and identifying structural correlations based on neural network algorithms.

Upcoming digital initiatives.

State geological information support has far-reaching development plans for 2024.

In September 2024, new laws enhancing subsoil fund management procedures come into force:

— State services will no longer include absence of mineral resources under the development site certificates; they will be delivered automatically by means of interactive maps in FSIS EFGI (Federal Law no. 576);

— New evaluation, approbation and record-keeping mechanisms for inferred resources emerge; the approbation cycle will be carried out through FSIS ASLN (Federal Law no. 677);

— Subsoil use companies are enabled to participate in a regional stage of geological exploration (Federal Law no.656). The process will also be controlled via FSIS ASLN.

The relevant bylaws and revisions to Rosnedra's FSIS are currently being drafted.

Geology of data.

FSIS EFGI functionality brough about to date makes for potential transition from collecting and keeping record of paper and e-documents to collecting machine-readable legally significant data sets.

The recent and scheduled upgrades will facilitate transition to the Digital Model of Geological Structure (DMSG) of the Russian Federation territory.

In the near future it is to become a key FSIS EFGI component as a primary information source that can be used for geological information interpretation for any randomly selected area.

DMSG is a geographically distributed digital data representing geological, geochemical, geophysical, petrological, lithological, petrophysical, structural, geochronological, stratigraphic, engineering-geological and other properties in a particular spatial point (and/or area). The digital model should be updated and used remotely with integrated technical and technological services of various subject-matter information collection, processing and presentation, with possible broad combination of methods and forms of presentation. DMSG should use laboratory analytical and instrumental research services, as well as services of big data reception, processing and transmission, formation of spatial and temporal models, including artificial intelligence, reference and expert resources.

To build a digital model of the Russian Federation territory geological structure, solutions to the following problems are needed in the immediate future:

— Setting up requirements for technical, software and linguistic means to support DMSG creation and operation;

— Developing standards and formats for presenting digital primary geological information in the DMSG, including development and implementation of unified models for submitting data on the Russian Federation mineral reserves sites formed when submitting geological information;

— Developing and using artificial intelligence technologies for processing and applying geological information;

— Designing services sought after by the government and companies on the basis of uniform models of data representation for mineral reserves of the Russian Federation;

— Building up and expanding the DMSG data research infrastructure, including a high-performance, fault-tolerant network of sector-specific data centers.

Digitalization plans for subsoil use in 2024–2025. «Gostech» unified digital platform.

As FSIS ASLN has been developed since 2006, some of its technology stack used for development is outdated and does not meet modern import substitution and information security requirements. Therefore, Rosnedra made a strategic decision to transfer it to the unified digital platform «GosTech» (UDP «GosTech») to align it with other agency state systems and seamlessly use state services and infrastructure of the Ministry of Digital Development, Communications and Mass Media of the Russian Federation. A unified module software and hardware platform will serve as a foundation, allowing for, among other things, re-engineering of the agency's business processes, and re-engineering of the FSIS ASLN capabilities and functions.

The transition is scheduled for completion by 2026.

From 2025 to 2027 the agency has scheduled to launch the «Geology of Data» project, aimed at bringing to a new level geological documents collection (as machine-readable data sets) and at transferring the Rosnedra second state system FSIS EFGI to the UDP «GosTech» (Fig. 4).

The transfer of FSIS EFGI to the UDP «GosTech» within the scheduled period of 2025–2026 is underway: the Federal Agency for Subsoil Use, FSBI «Rosgeolfond» and the Ministry of Digital Development, Communications and Mass Media of the Russian Federation have been making significant efforts to include this initiative in the «Data Economy» national project.

Concluding remarks

Since the first e-license was issued in 2022, subsoil use has moved ahead significantly towards key services and functions digitalization over a short period of time. The pace of integrating digital tools for collection, processing and submission of geological data, subsoil use data and subsoil users' data over the past two years is impressive.

Today one can hardly imagine that as recently as two years ago, the average response time to an analytical request might

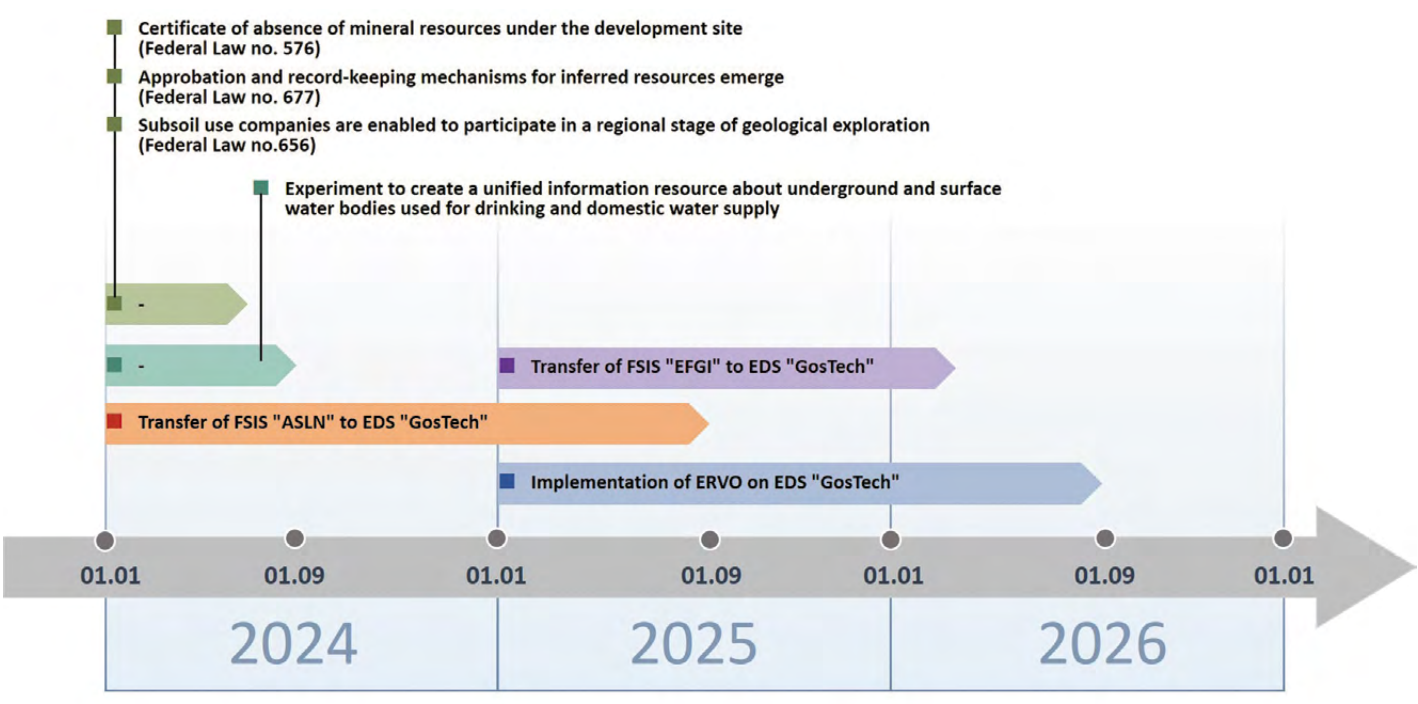

Fig. 4 Roadmap for the implementation of digital initiatives in 2024–2026

have taken one or two weeks. Currently, a request must be responded to within a 24-hour period, with a maximum of two weeks.

The Rosnedra is technologically prepared for this scenario. At the same time, a considerable effort is needed to organize the retrospective data accumulated before 2022, when digital tools for licensing and applications submission first became widely available.

It is essential to organize the metadata on the accumulated array of licenses. Furthermore, it is vital to formalize previously adopted field development projects and reserves approval protocols. It is also crucial to ensure a comprehensive transition to the collection of machine-readable geological data sets, as well as to digitize, structure and formalize the accumulated array of retrospective geological reports (over 600,000 geological documents).

The implementation of the aforementioned set of measures is essential for achieving actual digitalization and ensuring a full-fledged transition to databased management.

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FIRST TARGETED GEOLOGICAL SAMPLING BENEATH THE EAST ANTARCTIC ICE SHEET: JOINT RUSSIAN-CHINESE DRILLING PROJECT

Targeted bedrock sampling was carried out on Princess Elizabeth Land by drilling through a 545 m thick ice. The borehole was drilled using cable-suspended Ice and Bedrock Electromechanical Drill (IBED) designed by the Jilin University (China) and under a joint scientific project between VNIIOkeangeologia, Jilin University and China University of Geosciences (Beijing). The drill site is located on the axis of a high-amplitude linear magnetic anomaly that runs parallel to the coast for more than 500 km from Princess Elizabeth Land to Mac.Rosbertson Land. The nature of this anomaly remained unclear, but it is thought to be related to the suture zone between Proterozoic terrains formed during the Neoproterozoic amalgamation of the Rodinia supercontinent. ***Keywords:*** *Antarctica, drilling, bedrock, ice cores, rocks, magnetic anomaly.*

Over the 99 % of Antarctica is covered by ice, and one of the most exciting investigations of our planet concerns the exploration of Antarctic subglacial environments — «enigmatic world» beneath the ice sheet. Subglacial environments have become central to our understanding of the Antarctic ice sheet's formation and to assessments of possible future climate change and sea level rise. Moreover, to date, we have no reliable information at all about the geology of Antarctica beneath the ice. Indirect information about subglacial crustal structure and geology is provided by geophysical surveys (mainly airborne magnetic data), but this requires confirmation by direct sampling (drilling) of the bedrock. Several ambitious projects of this type are currently underway (e.g, USA's Rapid Access Ice Drilling — RAID project, the Chinese drilling expedition's project in the Gamburtsev Mountains; Goodge and Severinghaus, 2016, Talalay et al., 2018), but none of them has been implemented yet, and no targeted geological core sampling of bedrock has ever been carried out in Antarctica, except for sampling of young sediments in subglacial lakes in West Antarctica, coring of bedrock with known geology for paleogeography based on cosmic isotope studies, and test drilling near scientific stations (Talalay et al., 2023).

In the 2023–2024 season, a joint Russian-Chinese drilling project (with cooperation VNIIOkeangeologia, Jilin University and China University of Geosciences, Beijing) was carried out in the north-western part of Princess Elizabeth Land (Fig. 1). Drilling was aimed at establishing the geological nature a high-amplitude linear magnetic anomaly that runs parallel to the coast for more than 500 km from Princess

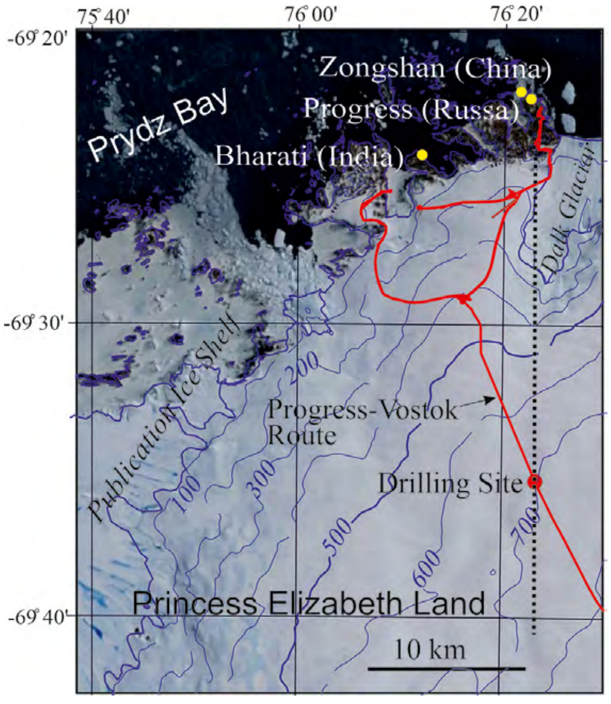

Fig. 1. Position of drilling site in the north-western Princess Elizabeth Land. Dotted line is position of Radio-echo sounding section shown on Fig. 3

Elizabeth Land to Mac.Rosbertson Land, crossing the Lambert Rift Zone, and marks distinct changes in the magnetic field pattern (Golynsky et al., 2018; Fig. 2). The nature of this anomaly remained unclear, but it is thought to be related to the suture zone between Proterozoic terrains formed during the Neoproterozoic amalgamation of the Rodinia supercontinent (Mikhalsy & Leitchenkov, 2018).

The drilling site was selected on the basis of recently derived detailed magnetic and radio-echo sounding data (with 1 km line spacing) and logistical convenience. The optimal place for drilling along the strike of the magnetic anomaly is located at 69.585591S; 76.385165E, on the top of the local bedrock high (Fig. 3) with the ice thickness of 550 +/– 10 m. Ice sheet surface elevation at the drill site is 680 m asl.; ice flow velocity at the drilling site measured by GPS observations is 50–60 meters per year. Radar data suggested a freezing at the base of the ice sheet at the drilling site.

The drilling was carried out using cable-suspended Ice and Bedrock Electromechanical Drill (IBED) designed by the Jilin University. The drilling facilities include movable drilling shelter and workshop (Talalay et al., 2021; Fig. 4). The drilling camp (named «Anomaly»; Fig. 5) was organized from 18 to 24 December 2023 and the drilling itself continued from 25 December 2023 to 26 February 2024. A variety of technologies were used for drilling: auger core set for the snow-firn layer, a cutter drill bit for the meteoric ice, a PDC

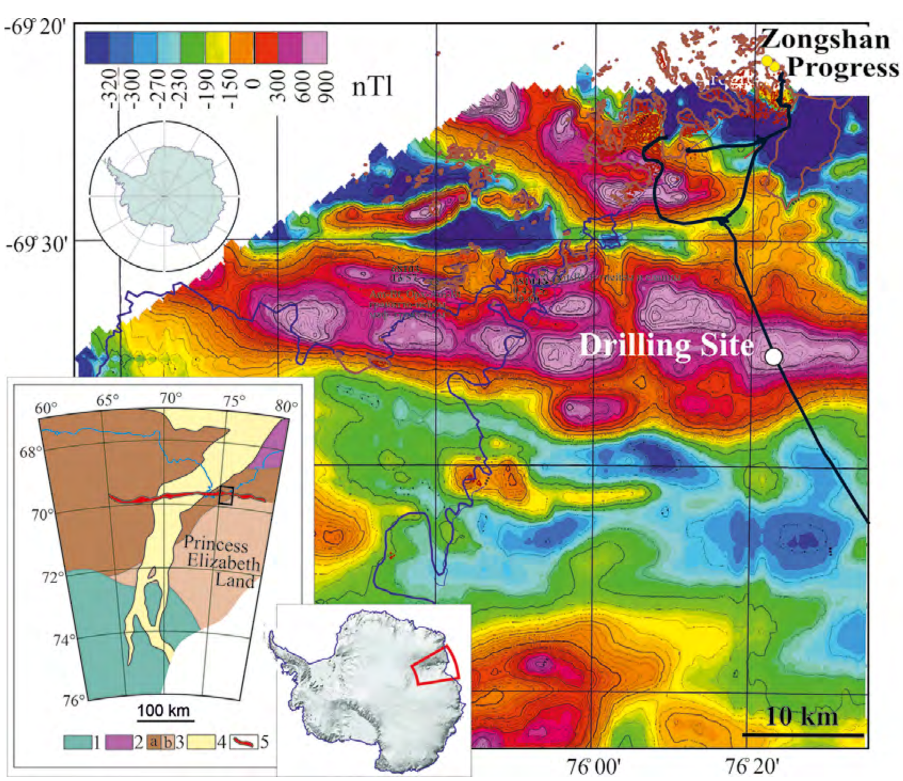

Fig. 2. Magnetic anomaly field of the western Princess Elizabeth Land with position of drilling site. Inset: Tectonic provinces: 1 – Paleoarchean to Paleoproterozoic Ruker Craton; 2 – Neoarchean Vestfold Craton; 3 – Mesoproterozoic to Neoproterozoic Orogen (a – Middle Mesoproterozoic to Early Neoproterozoic Province; b – Late Mesoproterozoic to Early Neoproterozoic Province); 4 – magnetic anomaly; this anomaly is thought to mark changes in crustal composition; orthogneisses dominate south of the anomaly and paragneisses dominate north of the anomaly (Mikhalsky & Leitchenkov, 2018)

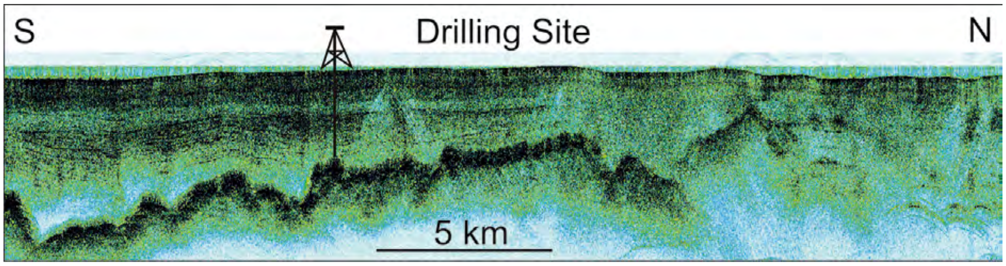

Fig. 3. Radio-echo sounding section showing bedrock morphology and drill site location. See Fig. 1 for line position.

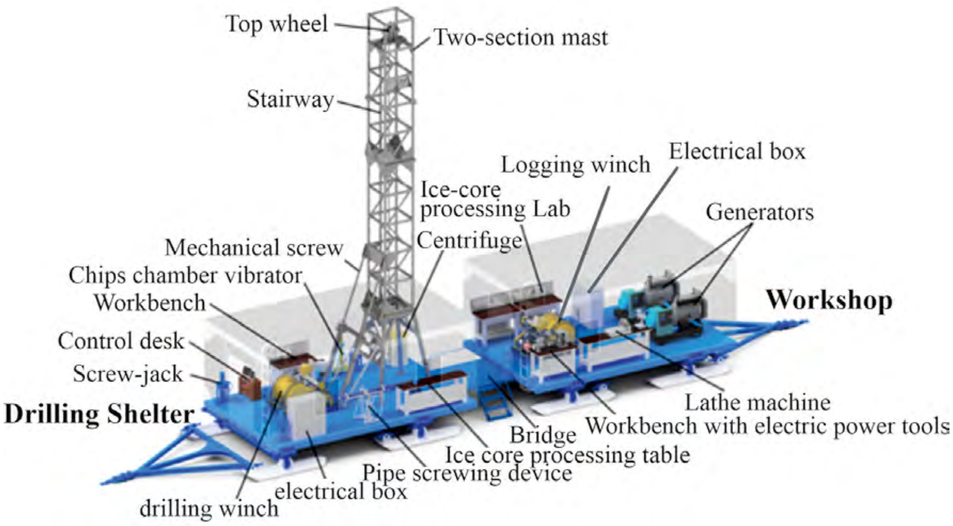

Fig. 4. Three-dimensional scheme of the movable drilling shelter and the workshop connected by the bridge

Fig. 5. Areal view of the field camp «Anomaly» located near the Progress – Vostok logistic route

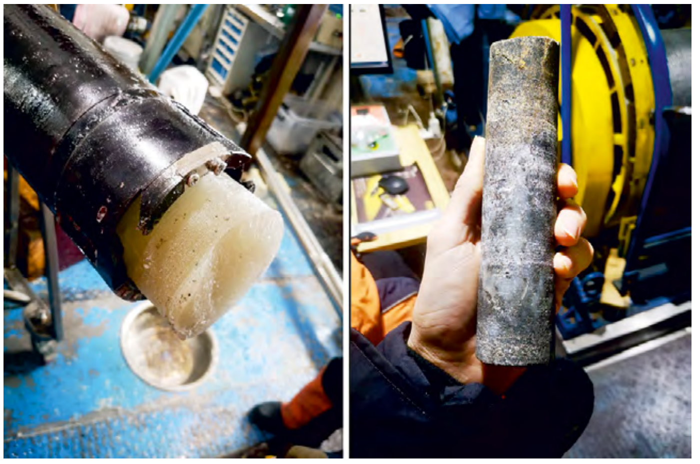

Fig. 6. Core of basal ice (left) and bedrock (right)

cutter for the basal ice with mineral inclusions and a toothed impregnated diamond drill bit for the bedrock. Jet A-1 fuel was used as the drilling fluid. The average daily drilling rate for meteoric ice was 18–24 m/day with an average core yield of 0.9 m per run. At the bottom of the ice, the measuring system in the drill recorded a temperature of -4.5°C, i.e. well below the pressure-melting point.

A total of 545.5 m was drilled, including about 1.4 m of snow, about 60 m of firn (part of the ice cover where the density reaches 830 g/cm^3), about 485 m of meteoric ice, 17 cm of basal ice with mineral particles, and 48 cm of rocks (Fig. 6). Bedrock core sample was recovered in two runs. Based on visual field identification, the core is presented by mafic crystalline schist. The magnetic susceptibility of the sample is about 0.05 SI and this high value confirms that similar rocks produce a prominent magnetic anomaly. Rock and basal ice cores were sawn in half in Antarctica and divided between Chinese and Russian partners for further laboratory research.

During the next Antarctic season (2024–2025), geophysical borehole logging, including inclinometry, cavernometry and temperature measurements will be carried out to study ice sheet conditions in the marginal part of the ice sheet and to estimate geothermal heat flux. The ice cores have been buried in the snow at Camp Anomaly until next season, when they will be transported to Vostok Station for sawing. Half of the ice cores will be delivered to Chinese specialists, and another half — to the Climate and Environmental Research Laboratory of the Arctic and Antarctic Institute, St. Petersburg, for the paleoclimate research.

Conclusions

The experience of implementing the joint project, integrating technical, logistical, financial and intellectual resources, has once again demonstrated the feasibility and effectiveness of international cooperation in Antarctica. The experience gained will contribute to the improvement of ice-bedrock drilling technologies in Antarctica, and will make it possible to outline new projects with more ambitious tasks in the future. One of them, for example, is drilling in the Gamburtsev Mountains, one of the most mysterious regions of Antarctica, where there are places with relatively thin ice (up to 1000 m) that can be drilled with equipment designed in the Jilin University within 1–2 seasons.

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THE RESULTS OF THE GEOLOGICAL EXPLORATION FOR DEEP-SEA POLYMETALLIC SULPHIDES AT THE AXIAL ZONE OF THE MID-ATLANTIC RIDGE

An overview on Russian studies of seafloor massive sulfides (SMS) in the axial zone of the Mid-Atlantic Ridge (MAR) at the Russian Exploration Area (REA) is presented. Geological framework of MAR segment between 12° and 21°N as well as geological settings of discovered SMS deposits are described. Exploration methods and techniques been used during Russian studies (including the period of lasting the exploration contract for SMS between International Seabed Authority and Ministry of Mineral Resources and Environment of Russian Federation) are given. ***Keywords:** seafloor massive sulphides, Mid-Atlantic Ridge, Russian Exploration Area, hydrothermal site, black smokers, deep-sea research, International Seabed Authority*

Introduction

Deepsea minerals including polymetallic nodules, seafloor massive sulfides and cobalt-rich crusts are considered to have high economic potential and are currently the focuse of dozens of the Russian exploration cruises. Exploration of deep-sea minerals in the Area (out of the exclusive economic zone) regulates by the International Seabed Authority (ISA) providing the exclusive rights for contractors to conduct exploration activity in the Area on the basis of exploration contract.

Since 1985 Russian studies for SMS deposits operated by Ministry of Geology of USSR were located in Pacific and Atlantic and aimed to identify promising mineral deposits for further exploration and future mining in accordance with the United Nations Convention on the Law of the Sea (UNCLOS).

In 2010 ISA has adopted the «Regulations on prospecting and exploration for polymetallic sulfides in the Area». The Ministry of Natural Resources and Environment of Russian Federation (MNRE) submitted the «Application for approval of plan of work for exploration for polymetallic sulfides in the Area», which were considered and adopted by the Council ISA in July 2011. In 2012 the 15-years Contract between MNRE and ISA for exploration of the polymetallic sulfides at the Northern Equatorial part of the Mid Atlantic Ridge was signed [4].

Results of exploration activities for seafloor massive sulfides in Russian Exploration Area

Geological framework. Russian Exploration Area for SMS is located from 12°48′ to 20°54′ N at the MAR. This area is a part of large first order segments bounded by Kane (23°35′N), Cabo Verde (15°20′ N) and Marathon (12°58′ N) fracture zones (Fig. 1). These large segments are subdivided by smaller sections (2nd order segments) with the length from 15 to 75 km, which possess a certain internal homogeneity and have fairly pronounced boundaries presented in most cases by non-transform discontinuities of the rift valley. In total, 24 second-order segments have been identified within this segment of the MAR: 11 between the Marathon and the Cape Verde fracture zone and 13 between the Kane and Cape Verde fracture zones. The segments are clearly divided into «magmatic» and «tectonic», characterized by a corresponding magmatic/tectonic processes and, in connection with this, a specific geomorphology feature [5].

Magmatic segments are located mainly in the northern part of the area from 18° to 21° N latitude and characterized by the predominance of volcanic processes over tectonic ones. They are characterized by a symmetrical (from the spreading axis) rhythmic linear-ridge flank structure and a relatively narrow valley floor (mainly up to 10 km) with high steep rift valley slopes (up to 50°).

Tectonic segments are predominantly located in the southern part of the REA, south of the Cape Verde transform fault. Their key feature is the widespread formation of oceanic core complexes (OCC) — blocks of deep-seated rocks of the gabbro-peridotite lower crust association, tectonically exposed during a long-term amagmatic (low magma budget) stretching of the lithosphere onto the ocean floor along large predominantly gently dipping faults (detachments). In the areas of OCC formation, it becomes the main influencing the morphostructure factor of the ocean floor, and therefore such segments are characterized by an asymmetrical structure relative to the spreading axis. The length of individual OCC along the rift valley reaches 35 km. The rift valley limits within the tectonic segments cannot be clearly identified, the width of the ocean floor reaches 15 km.

Volcanic rocks of the area are represented by tholeiitic basalts. Based on petrochemical features, two main associations of tholeiitic basalts were identified — spreading related and plume related [1, 2, 3]. Within the segment between Kane and Cabo Verde fracture zones, most hydrothermal sites are associated with volcanic rocks of the spreading association. An exception is the Pobeda ore cluster, located in the «amagmatic» segment of the 2nd order and hosted by mantle rocks.

Mantle rocks of OCC are represented by serpentinized harzburgite to varying degrees, and less commonly by lherzolites and dunites. Lower crustal rocks are represented by a wide range of gabbroides, from olivine to magnetite/ilmenite-rich gabbro, most of which show signs of amphibolite and greenschist facies metamorphism. In the southern part of the REA between the Marathon and Cape Verde fracture zones all discovered hydrothermal sites are hosted by mantle and lower crustal rocks and located in ridge segments with dominated amagmatic spreading.

Bottom sediments throughout the region are represented by biogenic carbonate oozes — coccolithic-foraminiferal silts and pteropod sands, mainly distributed on the flanks of the ridge. At the rift valley floor, the thickness of sedimentary cover is intermittent and reaches 10 meters in the depressions.

Methods and equipment. Comprehensive geological survey for SMS in REA includes:

— near seabed side-scan sonar survey (SSS) and и sub bottom acoustic profiling performed by «ORETECH-M», and later by «MAK-1M» (designed and constructed by State Scientific Center «Yuzhmorgeologiya»);

— hydrophysical survey performed by SBE 911plus CTD;

— near-seabed electrical survey performed by towed deep-sea complex «Rift» (designed by «Sevmorgeo»);

— geological sampling by dredge, gravity corer, box-corer, TV-controlled grab and.

During the early stage of exploration the most effective method has proven to be the electrical prospecting method, which is also used in the exploration of ancient analogues of SMS on land — volcanogenic massive sulfides.

The self-potential electrical field (SP) was measured in the near-bottom waters. The existing experience of the work carried out has shown that the vast majority of identified SP anomalies are associated with SMS occurrences on the ocean floor. Subsequently, the method was improved by adjusting side-scan sonar sensor to the complex to acquire simultaneously electric field and sonar data, which significantly increased the efficiency of exploration and reduce time expenditure.

Main outcomes from geological prospecting in the REA. In accordance with the Contract, the SMS geological exploration plan consists of three successive stages aimed to obtaining the following results:

1st stage (duration 6 years) to identify promising priority areas for the conduct of more detailed exploration;

2nd stage (duration 5 years) to identify specific hydrothermal sites and assess the potential resources of the ores they contain.

3rd stage (duration 4 years) to explore economics significant hydrothermal sites, estimate the ore reserves, and finally identify the mining area.

In total, by 2024, 32 research cruises were carried out on PMEE research vessels, of which 27 were located within the REA. By the time the Contract was signed with ISA in 2012, 15 hydrothermal sites and 6 mineral occurrences had been discovered and preliminary studied, some of which were combined into ore clusters (Fig. 1, Table 1). After the signing of the Contract, the Yubileinoye, Surprise, Kholmistoye, Molodezhnoye, Korallovoye hydrothermal sites and the Pobeda ore cluster were discovered (Fig. 1, Table 1). To date, as a result of the research carried out, 23 hydrothermal sites and 6 mineral occurrences have been discovered within the REA. Foreign research groups discovered two hydrothermal sites — Puy des Folles [10] and Irinovskiy-1 [11], the remaining hydrothermal sites were discovered during Russian studies.

In addition to JSC PMEE and the FSBI VNIIOkeangeologia, geological exploration within the REA was carried out by a number of institutes of the Russian Academy of Sciences (IO RAS, GEOKHI RAS, IGEM RAS and GIN RAS). These studies had fundamental nature and were aimed to reveal the geological framework of the MAR and discovered hydrothermal sites. Exploration cruise of hydrothermal sites within the REA were also carried out by foreign scientists (GEOMAR, Germany, 2006, 2014; IFREMER, France, 2007, 2013, etc.), including drilling operation and the remote operated vehicles study [8, 9].

Analytical studies of samples of hydrothermal precipitates, rocks and sediments collected during the cruises were carried out in stationary laboratories of various research institutes.

During analytical studies, elemental composition of sulfide ores and hydrothermal precipitates, which can be divided into four categories:

— major ore elements: Cu, Zn, Fe;

— rock-forming elements: Na, Mg, Al, Si, P, K, Ca, Ti, V, Mn, S;

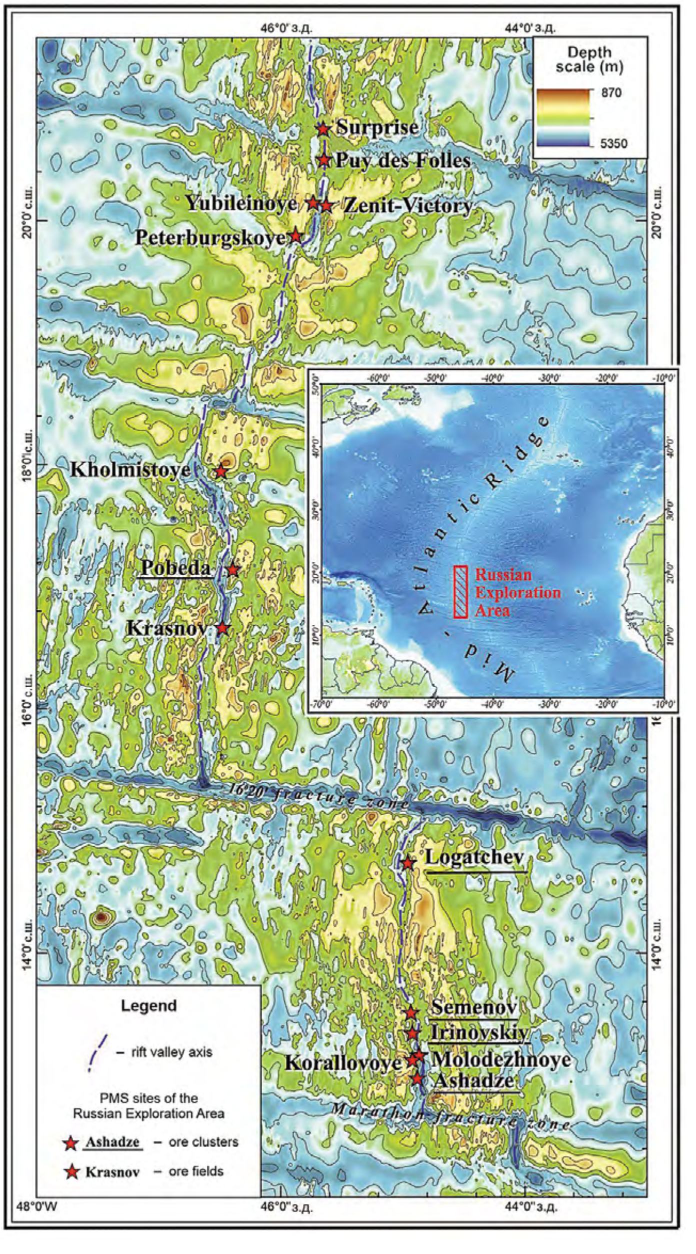

Fig. 1. Location of discovered hydrothermal sites within REA

Table 1
Hydrothermal sites of REA

№	Hydrothermal sites	Depth range, m	Hostrocks lithology
Discovered before signing the Contract with ISA			
1	Logatchev ore cluster (14°45' N), includes 2 hydrothermal sites и 4 mineral occurrences	2665-3045	Gabbro-peridotites
2	Ashadze ore cluster (12°58' N), includes 2 hydrothermal sites и 2 mineral occurrences	3185-4180	Gabbro-peridotites
3	Krasnov hydrothermal site (16°38' с.ш).	3625-3820	Basalts
4	Semenov ore cluster (13°31' N), includes 5 hydrothermal sites	2150-3010	Gabbro-peridotites
5	Zenit-Victory hydrothermal site (20°08' N)	2320-2820	Basalts
6	Puy des Folles hydrothermal site (20°30' N)	1905-2005	Basalts
7	Peterburgskoye hydrothermal site (19°52' N)	2775-3145	Basalts
8	Irinovskiy ore cluster (13°20' N), includes 2 hydrothermal sites	2600-2935	Gabbro-peridotites
Discovered after signing the Contract with ISA			
9	Yubileinoye hydrothermal site (20°09' N)	2270-2585	Basalts
10	Surprise hydrothermal site (20°45' N)	2785-2945	Basalts
11	Kholmistoye hydrothermal site (17°57' N)	2640-2675	Basalts
12	Pobeda ore cluster (17°08' N), includes 3 hydrothermal sites	1940-3050	Gabbro-peridotites
13	Molodezhnoye hydrothermal site (13°09' N)	3375-3580	Gabbro-peridotites
14	Korallovoye hydrothermal site (13°07' N)	2810-2870	Gabbro-peridotites

— minor elements: Au, Ag, Pb, Cd, Co, Ni;

— trace elements: Se, Te, As, V, Cr, Ga, Mo, Sn, Ba, W, Th, U, Sb, As, Ge, Se, In, Te, Bi.

The study of the mineral composition of the sulfides was carried out using optical microscopy (mineragraphic, optical-mineralogical, optical-petrographic) and X-ray phase analysis. Rock samples were tested for rock-forming oxides (SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MnO, MgO, CaO, K_2O, Na_2O, P_2O_5), ore-related elements (Cu, Zn, Pb, Co, Ni), trace and rare earth elements. Sediments study includes analysis of particle size distribution, carbon content and major sulfide-related elements content (Fe, Mn, Cu, Zn, Ni, Co). Revealed metalliferous sediments (sediments which have strong hydrothermal input) were tested for REE content.

The absolute age of sulfide samples and sediment cores was determined by the U/Th^{230} method, as well as lead isotopes by thermal ionization mass spectrometry (TIMS) in rocks and sulfide samples. The range of obtained age of sulfide deposits varies from 7.2 ky (Ashadze-1 hydrothermal site, presently active) to 223 ky (Peterburgskoy hydrothermal site, presently ceased hydrothermal activity) (Fig. 2).

Seafloor massive sulfides are characterized by a heterogeneous composition. The major ore minerals are pyrite, chalcopyrite, sphalerite, isocubanite and marcasite; minor ones are pyrrhotite, bornite, covellite, chalcocite, digenite and other non-stoichiometric copper sulfides. One of the features of the composition of modern SMS includes a wide variety of rare minerals of cobalt and nickel (cobaltine, millerite, etc.), bismuth (bismuthin, native bismuth), native gold, electrum, selenides and tellurides of gold, silver and lead (calaverite , hessite, claustolite) [6]. According to their geochemical features, SMS are divided into sulfur-pyrites, copper-pyrites, copper-zinc pyrites, zinc-copper pyrites and copper ores.

In case of lower crustal and mantle lithology of host rocks, SMS are characterized by increased contents of major (Cu, Zn), minor (Au, Ag, Ni, Co) and trace (Se, Te, In, Bi, Ge) elements, while SMS related to volcanic host rocks predominantly have a sulfur-pyrite composition without increased contents of major and trace elements.

Technological studies of four samples of SMS were carried out in FSBI TsNIGRI (Moscow). A combined hydrometallurgical technology was developed and recommended for implementation, including oxidative-sulfatizing roasting of ore at a temperature of 550–650°C and leaching of useful components from the cinder into productive solutions with their subsequent extraction into marketable products.

Methodological support for laboratory studies of the material composition and properties of SMS were carried out in FSBI VIMS (Moscow). Based on analytical studies, an optimal set of modern mineralogical and analytical methods for studying the elemental composition and properties has been developed.

The physical properties (humidity and density of samples) of hydrothermal precipitates and host rocks were studied during the systematic engineering-geological studies. It includes the testing of physical and mechanical properties of bottom sediments (humidity, soil density, rotational shear resistance, residual strength and specific penetration resistance), hydrothermal precipitates and host rocks (moisture content and rock density, compressive and tensile strength limits, elastic constants and residual deformation), and also the density

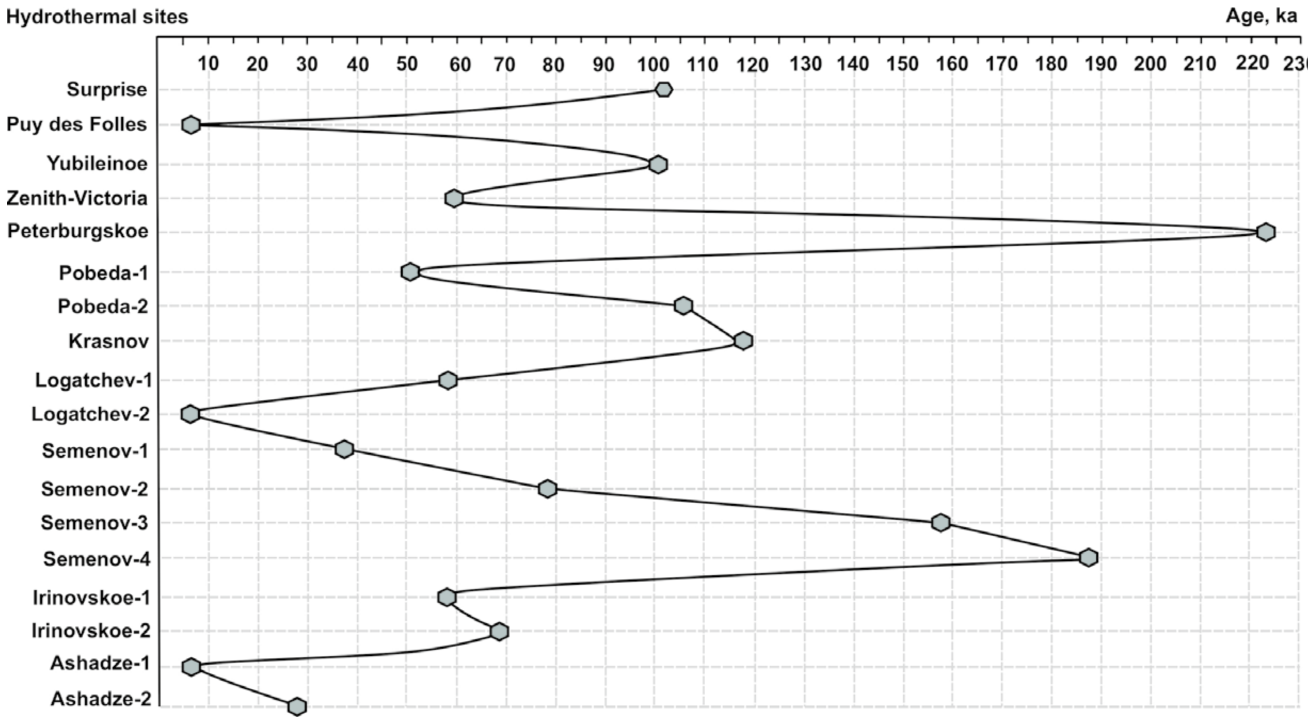

Fig. 2. Maximum age of sulfide samples of hydrothermal sites at REA [7]

of soil particles in bottom sediments. Comprehensive processing and evaluation of engineering-geological data resulted in an assessment of engineering-geological conditions at hydrothermal sites, including the engineering-geological mapping.

Since 2014, the systematic baseline environmental studies of the REA have been carried out, including study of the water column — hydrophysical profiling with water sampling, measurement of the velocity and direction of water currents, biological research, including the study of mega-, macro-, meiofauna, epi- and infauna, hydrometeorological observations.

To systematize a collected data and obtaine comprehensive operational information based on research cruises and analytical results, as well as to fulfill obligations under the Contract, at the FSBI «VNIIOkeangeologia» the development of a relational database in the ACCESS environment were started in 2009. Since 2019, the database has been modernized (in accordance with the recommendations of the ISA) and transformed into the Information and Analytical System (IAS) «Ocean Georesources». Currently, the Data Bank includes the most complete information on all studies conducted within the REA and in the surrounding areas. It includes an information database (IDB), database directories, a database management system, a library of queries and application programs. The main purpose of using the database is to provide scientific and information support for geological exploration work.

In accordance with the «Regulations on prospecting and exploration for polymetallic sulfides in the Area» and the Contract obligations, 75 % of the originally claimed exploration area must be relinquished. By the end of the eighth year from the date of the Contract, no less than 50 % must be abandoned, and another 25 % — for the 10th year of the Contract. In 2022, the selection for relinquishment of 75 % of the REA was fully completed. The final selection of exploration area remaining within the northern part of the REA for further exploration is presented in Figure 3.

The relinquishment procedure was based on the analysis of direct and indirect geological and geophysical evidences of the possible presence of hydrothermal mineralization within the REA. The final exploration area included 2.500 cells measuring 1 × 1 km. All hydrothermal sites and mineral occurrences discovered to date are included in remained exploration area, as well as areas promising for the discovery of new hydrothermal sites. The results of the relinquishment were accepted by the ISA in 2022.

Since 2022, at the FSBI «VNIIOkeangeology» compiling of large-scale maps of geological structure of hydrothermal sites was initiated. It is based on the comprehensive interpretation of near-seabed imaging data (photo and video data), side-scan sonar and acoustic profiling, high-resolution bathymetric survey and geological sampling. Previously the basic type legend was developed for this. Produced large-scale maps of geological structure are both an integration cartographic base for studying discovered hydrothermal sites, and predictive maps for geological prospecting for new hydrothermal sites. The completed work on compiling large-scale maps of the structures of hydrothermal sites is the basis for creating a set of maps of hydrothermal sites in REA, including in GIS format to select hydrothermal sites that are most promising for expoitation.

Russian studies has recently entered a second stage of geological exploration at discovered hydrothermal sites with the SeaBat 7125 bottom multibeam echo sounder beginning to be used to obtain high-resolution bathymetric data in addition to previously used exploration methods.

In the near future it is planned to use new methods based on recently developed techniques:

— sampling and video recording by remote operated vehicle Sperre Subfighter 30K;

— near-seabed magnetic survey with a deep-sea towed magnetometer-gradientometer;

— drilling with the TK-15 deepwater drilling complex.

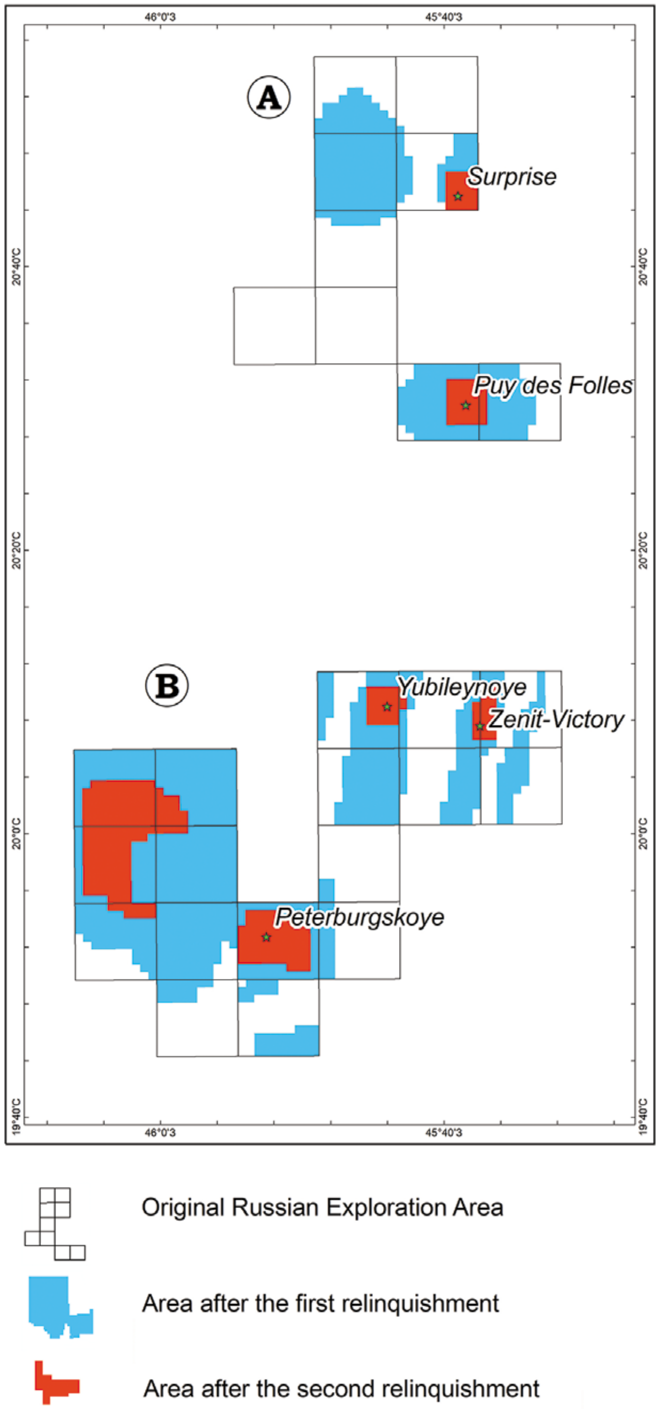

Fig. 3. Northern part of the REA. Areas (red) remaining within REA after completed relinquishment

The main purpose of geological exploration is to assess resources and calculate mineral reserves in order to prepare a feasibility study. In addition to geological data, the feasibility study includes economic, technological and environmental information, as well as mineral processing flow sheet.

Conclusion

The presented materials of scientific research (before the entering of the Contract with ISA) and geological exploration after the signing of the Contract demonstrate the progress of SMS study in the axial zone of the northern equatorial part of the Mid-Atlantic Ridge. The main results over more than 35 years of research are as follows:

1. Based on the research work carried out in the pre-contract period, the MAR segment from 12°48′ to 20°54′ N was chosen as the most promising for SMS exploration.
2. After preparing the application and its approval by the ISA Council, a fifteen-years contract was signed with the Ministry of Natural Resources and Environment to carry out geological exploration in this section of the MAR (Russian Exploration Area) within 100 exploration blocks with a total area of 10.000 km^2.
3. At the moment, within the framework of the REA, geological exploration work has been completed at the first stage. As a result, 23 hydrothermal sites and 6 mineral occurrences, combined into 5 ore clusters, were discovered.
4. In accordance with the Contract, the relinquishment of exploration area was completed and final selection of 25 % of the REA (2 500 км^2) was accepted by ISA. All discovered hydrothermal sites as well as promising areas were included in the selected area.
5. The presented results of exploration indicate the high efficiency of the methodology of SMS prospecting.
6. Data on the composition of sulfides indicate high contents of metals, exceeding their concentrations in land-based VMS deposits, which are ancient analogues of modern SMS.
7. All results of geological exploration, environmental and technological studies will be included in the Feasibility Study for the future exploitation of deep-sea polymetallic sulphides.

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VNIGNI APRELEVKA BRANCH-BASED FEDERAL CORE FUND: CURRENT STATE, EQUIPMENT, AND OPPORTUNITIES FOR INTERNATIONAL COOPERATION

The article discusses the history of the emergence, current state, and achievements of the Aprelevsk branch of the Federal State Budgetary Institution «VNIGNI» in the creation and operation of a modern core storage and the Federal Fund for Core Material, and opportunities for international cooperation. The importance of not only the collection and systematization of core material, but also the information obtained during its study: petrophysical, geochemical, lithological, paleontological, geophysical, etc. is emphasized. state of the art, meet the highest standards and conduct a wide range of research. ***Keywords:*** *Federal Fund for Core Material; core storage; Scientific and Analytical Center; geochemistry; petrophysics; lithology; paleontology; geophysics; oil; gas; core.*

In the world practice of deep studies of the Earth's crust structure, core material is the main and most reliable source of geological information. Because of the high costs of coring, the developed countries consider it a national treasure and store in government-funded national core repositories.

In the USSR, stone material was stored according to the territorial principle, each geological association had one or more core repositories. National mechanized core repository capable of proper core storage and preventing the loss of its geoinformation potential was built in Aprelevka, Moscow Region, in 1975; it has been in operation for more than 45 years.

Reconstruction of the Federal Core Fund

In 2003, the core repository became part of VNIGNI as the Aprelevka branch; in 2016–2019, within the framework of the Russian Federation state program «Natural resource management» and under the supervision of Federal Agency for Subsoil Use (Rosnedra) the institute conducted the large-scale reconstruction of the repository (Fig. 1). To date, the following project targets have already been achieved:

- The core storage volume has been increased by more than 20 times — up to 2,000,000 line meters of core;
- Sustained collection, systematization, study, centralized storage, and making core from wells drilled at the expense of the state budget and subsoil user money available for use;
- Integrated lithological, petrophysical, and geochemical studies of core material is being conducted on the basis of the scientific and analytical centre that includes four laboratories;
- Supplementation, systematization, and studies of paleontological collections and lithological and petrographic thin sections, as well as oil collections making part of Federal Core Fund is ensured on regular basis.

At the moment, the Federal Core Fund (FCF) is a modern research and engineering cluster of Rosnedra, the key objective of which is working with rock material, its integrated studies, systematization and subsequent digitizing of the data obtained. Thus, the main objective of the FCF is to collect the most representative amount of core and collectable material characterising all the oil and gas provinces of the Russian Federation and the neighbouring countries, to accumulate and, if necessary, digitize a wide range of information obtained during core studies, namely: petrophysical, geochemical, lithological, paleontological, geophysical, etc. As opposed to simple core storage, this approach allows solving a wide range of problems, such as reconstruction of depositional settings of potentially promising oil and gas bearing deposits, determination of their structure and reservoir properties distribution throughout their volume, and modelling of specific fields.

Immediately after the rebuilt core storage facility was put into operation, VNIGNI specialists started the well cores from regional core repositories relocation and placement for long-term storage.

In accordance with the procedure defined by the Order of the RF Ministry of Natural Resources dated 29.02.2016 No. 58 «On Approval of the procedure for rock samples, core, formation fluids, fluids, and other physical store media containing raw geological information on the subsoil submission to the national specialized storage facilities, their storage, processing, and description», subsoil users shall voluntarily and gratuitously transfer core into the ownership of the Russian Federation. The Federal Agency for Subsoil Use designates the VNIGNI Aprelevka branch-based Federal Core Fund as a place for permanent storage of this core. Subsoil users, in turn, provide the delivery of core material and accompanying geological and geophysical documentation to FCF.

In the last four years since 2020, about 25,000 line metres of core and collectable material have been relocated from LukBelOil, Tatnefteotdacha, Orenburggazgeofizika, Saratovneftegeofizika, Yakutskgeofizika, and others. In addition, the unique core material from the wells in the Anybsky area of the Timano-Pechora Petroleum Province has been obtained from the VNIGNI St. Petersburg branch, and also a collection of more than 30,000 paleontological samples collected over the past 70 years by Geologorazvedka and VNIGRI specialists.

Currently, the amount of the core received already exceeds 110 thousand line km representing 280 stratigraphic wells from different petroleum provinces. Among all are about 60 wells received form Arcticmorneftegaz-razvedka and describing the geological sections of the Arctic Ocean seas.

FCF affords organizations an opportunity of core bailment on a payment basis. In this case, the core material remains the property of the subsoil user and can be handed over for examination or study only to the core owner or his authorized person. To ensure core safety during transportation, loading and unloading operations and during long-term storage, the core is accepted in strong transport containers, core boxes shall be labelled, grouped and secured on pallets with metal or polymer tie-wraps.

Fig. 1. Appearance of the Federal Core Fund buildings (the Aprelevka branch of VNIGNI) after reconstruction

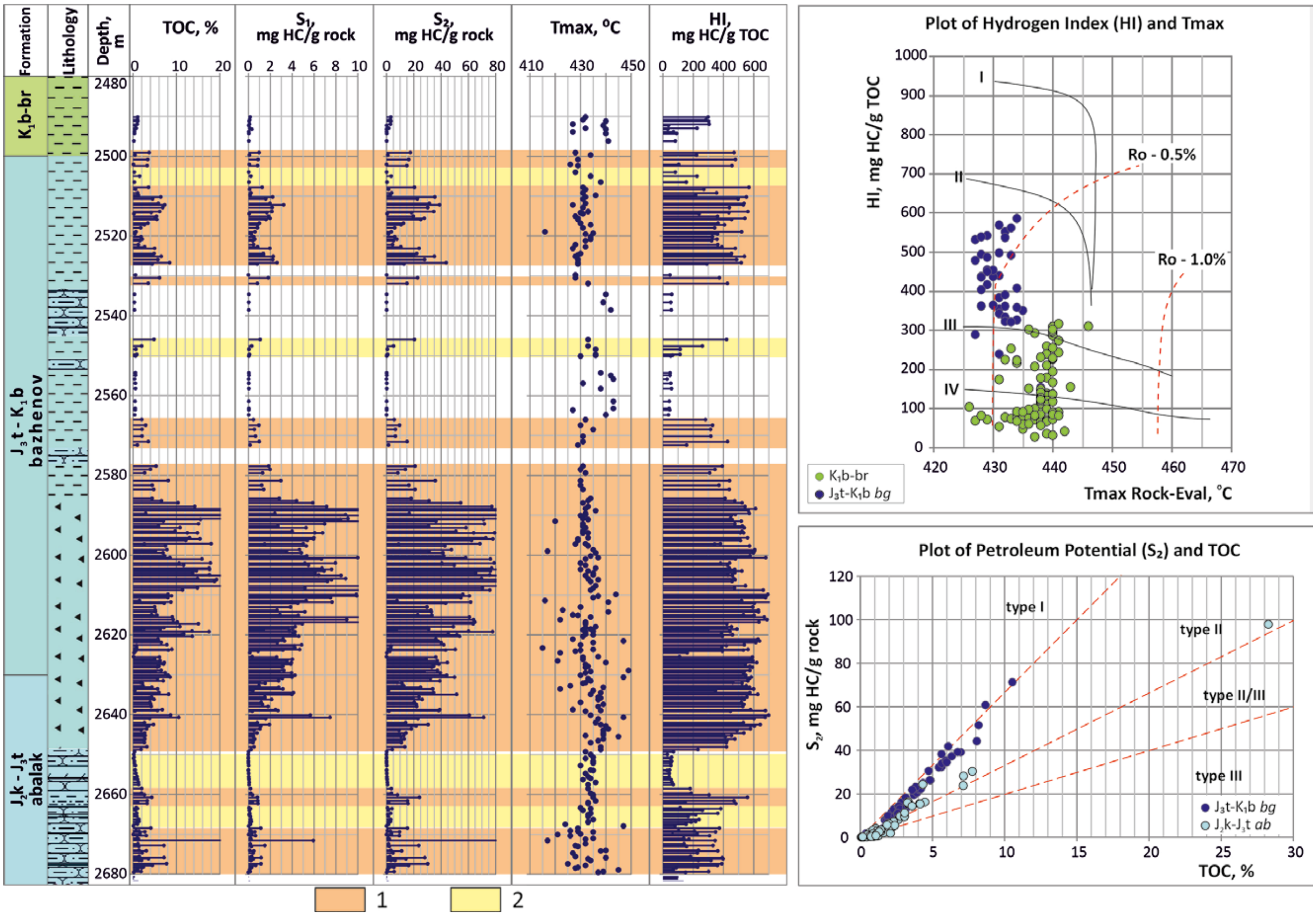


Fig. 2. Fragment of the section and Rock-Eval parameter correlation for Upper Jurassic-Lower Cretaceous deposits in Zaozernaya 1 stratigraphic well. 1–2 — source rock categories (according to K.E. Peters, 1994): 1 — excellent and very good, 2 — good and satisfactory

Research and Analysis Centre

The Research and Analysis Centre (RAC) is a part of the Aprelevka branch; its main task is integrated lithological, petrophysical, and geochemical studies of core taken from key wells to improve reliability of oil and gas occurrence prediction. For this purpose, the Research and Analysis Centre has the following departments:

- Laboratory of sedimentology and lithological collections;
- Laboratory of organic geochemistry;
- Laboratory of flow studies;
- Petrophysics laboratory including Digital core and Geomechanics groups;
- Grinding shop.

86 highly qualified specialists work here, and 17 of them are candidates of science. Being the leading experts, the RAC specialists run CPD training in different industry companies, teach courses and deliver practical classes to Lomonosov Moscow State University, Gubkin Russian State Oil and Gas University, and Ordzhonikidze Russian State Exploration and Prospecting University.

Within the framework of international co-operation, the specialists from the Republic of Belarus, Kazakhstan, the Republic of South Africa, and Iran visited RAC. These delegations were given guided tours of the core repository and the most considerable types of core studies. The RAC specialists answered numerous questions of the foreign guests.

The Research and Analysis Centre is equipped with the leading-edge devices, which allow conducting a full range of core studies — from documenting section, bulk studies, and up to specialized applied researches. Currently, integrated analyses of core from Novoyakimovskaya and Zaozernaya stratigraphic wells drilled at the expense of the federal budget are ongoing.

Laboratory of sedimentology and lithological collections is equipped with the modern scientific instruments, they are: Olympus binocular stereoscopic microscope including the fluorometric adapter; Zeiss smart microscopes with high-quality optics; ARL Perform'X 4200 wavelength X-ray fluorescence spectrometer for determining quantitative and qualitative composition of rocks, complete in set with sample preparation system; TESCAN VEGA 3 LMH scanning electron microscope with energy-dispersive detector in set with an adapter for obtaining cross-sections with ion beam; HORIBA laser light scattering particle size analyser; ARL X'TRA X-ray diffractometer for determining quantitative and qualitative composition of rocks, with an international database of minerals.

Organic geochemistry laboratory. Molecular mass spectrometers, such as tandem, isotope, combined gas chromatography mass-spectrometers, including mass spectrometer with pyrolysis adapter, and gas chromatograph, are used to study in detail organic matter (OM) composition of rocks and oils. These instruments of the leading companies Agilent Technologies, Termo, Perkin Elmer, Frontier allow solving the following main tasks of the organic geochemistry laboratory: identification and characterization of oil source rocks; determining paths and geological time of main oil migration from oil kitchens; prediction of natural reservoir productivity; genetic typification of naphthides and their correlation with source rocks; and coal petrographic studies. Geochemical methods applied in combination with other types of geological and geophysical studies allows improving reliability of prediction of oil and gas content in the studied deposits.

Rock-Eval is one of the methods most widely used in geochemical studies of rock OM. Using the latest Rock-Eval 7 VINCI Technologies analyser, the laboratory of organic geochemistry conducts bulk studies of core samples from key, stratigraphic, and prospecting wells, which makes it possible to promptly obtain information on OM distribution in the section, assess its type and maturity level, identify oil source deposits and productive zones.

Fig. 2 shows a fragment of Upper Jurassic-Lower Cretaceous section in the new Zaozernaya 1 stratigraphic well drilled by VNIGNI within the West Siberian Karabashsky zone in 2020–2021.The section clearly demonstrates source rocks different in type and OM content.

Scale of OM catagenesis in the deposits is updated according to the results of coal petrography investigations using a modern microscope with a photometer adapter (Fig. 3).

Fig. 4 shows typification of bitumoids from Domanik deposits on Chernyshev ridge, the Timan-Pechora Petroleum Province, based on the analysis of molecular parameters of polycyclic naphthenes composition. The analysis conducted demonstrated that the main difference of the identified bitumoid groups is bacterial material share in the initial OM composition.

In the organic geochemistry laboratory there is a unique set of equipment based on the Agilent GCQTof 7250 high resolution time-of-flight combined gas chromatography mass-spectrometer (Fig. 5). Automated sample preparation, high sensitivity and resolution of two-dimensional chromatography allows separating all sample components and avoiding interference caused by incomplete separation of components. The high accuracy of mass detection excludes mistakes associated with identification and does not require expensive standard samples. MS/MS mode used makes it possible to determine chemical structure and molecular/empirical formula of the substance under investigation, and allows increasing validity of the analysis results.

In order to study the physics of multiphase flow, the laboratory of flow studies uses the latest laboratory facilities for modelling two- and three-phase filtration of various fluids in different physical states. The additional equipment is as follows: recombination unit; unit for assessing formation damage caused by drilling muds or acids; thermal unit with steam generator; viscometers; video separators; KRUSS DSA-100 reservoir tensiometer, which allows to determine wettability and surface

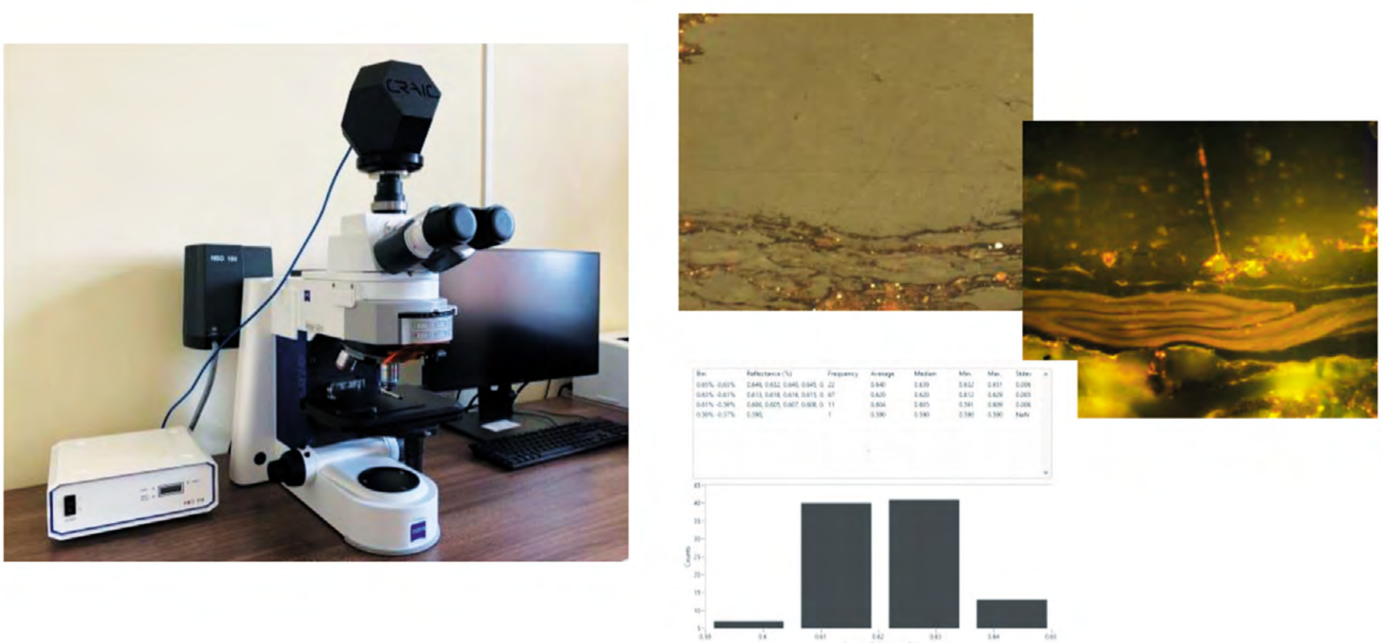
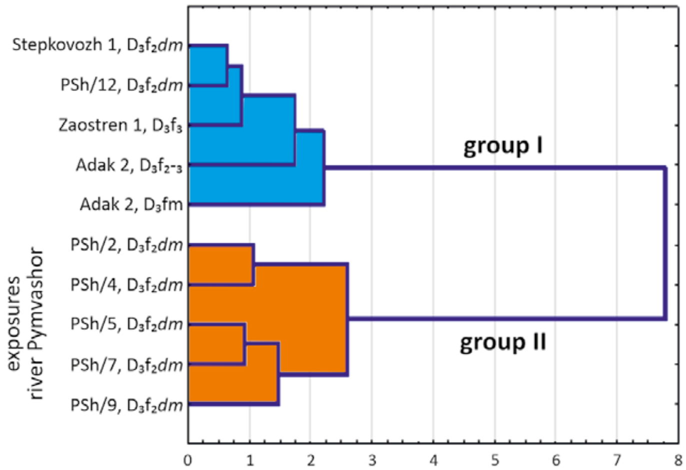
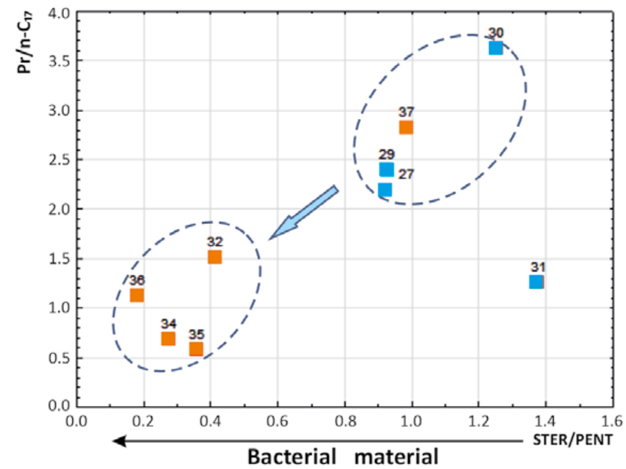


Fig. 3. Axio Imager A2M microscope with CRAIC Coal ProIII.QD1302 (Craic Technologies) photometer adapter and the results of coal petrography investigations



Typization of Domanic bitumens based on a set of molecular parameters using the cluster analysis (Timan-Pechora oil&gas province)



Typization of Domanic bitumens based on molecular parameters reflecting the type of initial biomass (Timan-Pechora oil&gas province)

Fig. 4. Examples of bitumoid differentiation according to biomarker parameters

tension under P-T conditions; a reservoir modelling system (slim model) for miscible displacement studies; and a unique membrane ultrasonic disperser for flow studies of nano-micro-disperse gas-water mixtures.

Petrophysics laboratory is equipped with more than 50 scientific instruments, and AutoScan-II unit for whole core analysis is among them. It is an integrated measurement platform developed by New England Research Company (NER, USA) for on-the-fly automated determination of core physical properties using the profile scanning method. The platform configuration includes an optical scanner, modules for determining probe gas permeability, acoustic properties, strength properties (shock pulse method), Fourier transform infrared spectroscopy, X-ray fluorescence analysis with a software package for data acquisition, curve plotting and interactive analysis of results (Fig. 6).

Integration of images and 2D sensing results allows mapping of physical properties over the entire core surface. Linear distribution of gas permeability and acoustic properties is of primary interest for the needs of petrophysical support of geological exploration. Gas permeability profile is commonly used to delineate reservoir intervals and prioritize sampling levels. Most often, profile gas permeability determination is carried out with discrete depth steps along the core axis (Fig. 7.1); however, the probe capabilities allow studying the entire core surface, which is essential for studies of lithologically heterogeneous rocks (Domanik, «ryabchik», etc.).

Acoustic profiling (Fig. 7.2 — 7.3) is conducted along and across core axis, which allows solving several problems at the same time, namely: core correlation with sonic logs and reservoir delineation, and calculation of dynamic mechanical modules and rock anisotropy estimation. In particular, the measurements shown are indicative of acoustic properties anisotropy in different bedding directions because of differences in compressional wave velocity.

Measurement of hardness (Fig. 7.4) actually means obtaining a profile of the combined Young modulus, which correlates with rock density and unconfined compressive strength. This profile allows determining the promising uniform points of sampling for geomechanical studies, and interpreting sonic and density logs.

Fig. 5. Agilent GCQTof 7250 high resolution time-of-flight combined gas chromatography mass-spectrometer

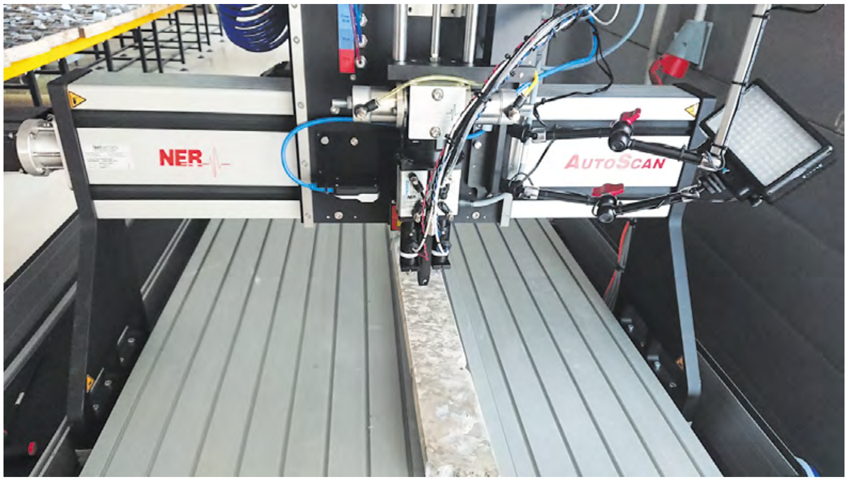


Fig. 6. AutoScan-II integrated measurement platform

X-ray fluorescence and infrared sounding show considerable promise for studying a unique well stock, where preserving the integrity of core material is a priority.

For bulk analyses, the latest BenchLab 7000 model is used to measure porosity and gas permeability on core samples under atmospheric and pressure conditions. Among other things, the laboratory uses the following types of instruments: 360-degree photography system; ultrafast petrophysical centrifuge; capillarimeter unit of unique design developed in VNIGNI; unit for studying diffusion-adsorption activity; device for studying compressibility, acoustic, electrical properties of rocks and gas permeability in P-T conditions on a whole core; GeoSpec 2/53 nuclear magnetic resonance relaxometer in set with a cell for reservoir conditions. The system produced by Kortekh (RF) is used to determine geomechanical properties by static method. The laboratory also actively uses micro-nanotomograph and macrotomograph, custom-designed by ProCon X-Ray GmbH, Germany for the laboratory tasks.

Being a method of non-destructive layer-by-layer study of the internal structure of the object, computer tomography allows studying rocks using X-ray method on the basis of difference in radiation attenuation in different-density parts of the object in order to detect mineral inclusions, voids, fractures, and formation fluids filling them.

Step-by-step operations including acquisition parameter picking, reconstruction, and processing of tomography data (CERA and VG software), and further computation in GeoDict and PerGeos systems allow obtaining petrophysical filtration parameters (porosity, permeability, residual water saturation, pore size distribution, etc.) with the possibility of displaying the calculation model.

Calculations for Lower Cretaceous Sukhodudinsky Fm (K1sd) in Novoyakimovskaya 1 well are conducted in specialized software (GeoDict); permeability, open and isolated pore

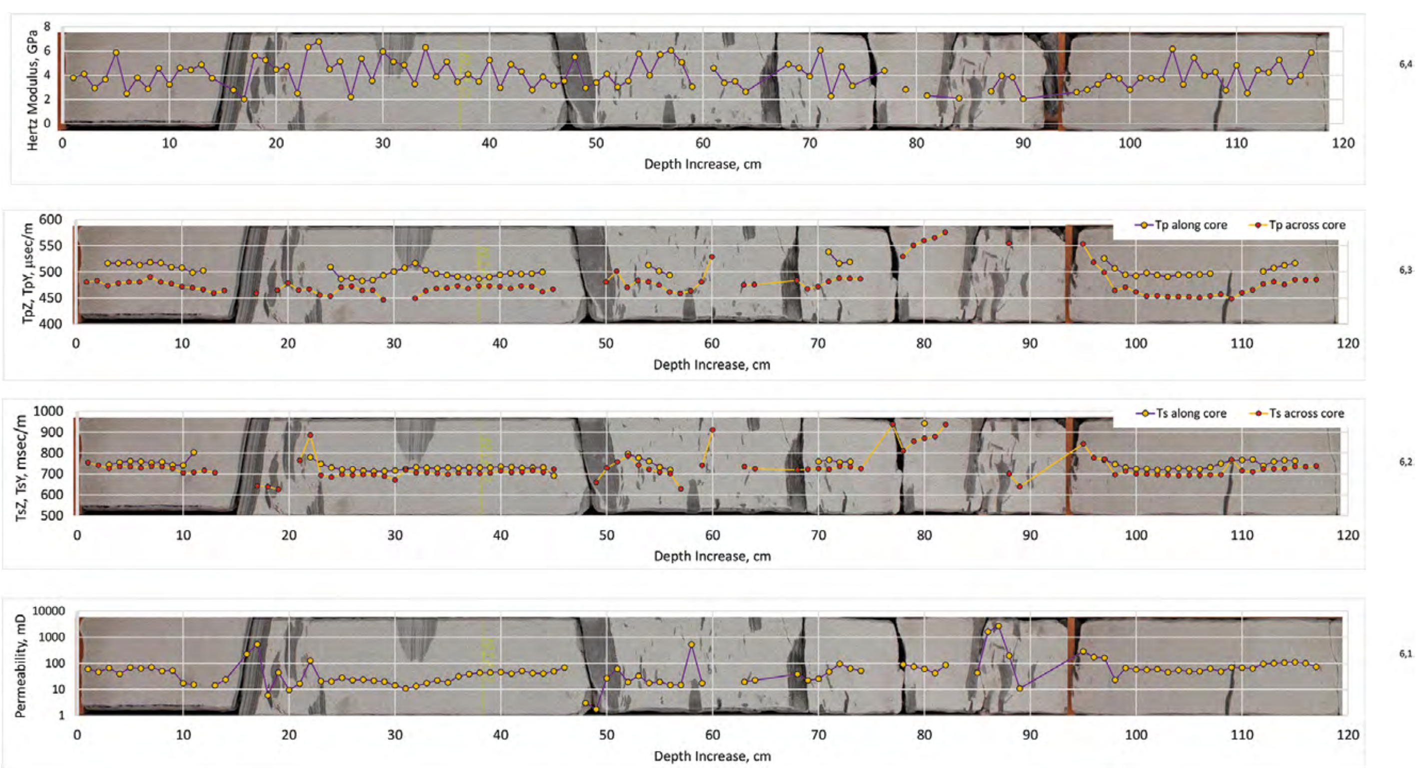


Fig. 7.1 — 7.4 Results of studies on whole core: gas permeability profile; compressional and shear acoustic waves in different directions; and Hertz modulus (Novoyakimovskaya 1 stratigraphic well)

volume, and inclusion and fracture volumes were estimated (Table 1, Fig. 8).

Within the scope of subject and experimental methodological work, a new original technique for determining hydrocarbon composition of kerogen pyrolysis products was developed in the laboratory of organic geochemistry to study the kinetics of rock OM transformation and to create 4-component kinetic spectra based on the results obtained using pyrolysis gas chromatography [1].

Kinetics and dissolution of low-permeability rocks in solutions based on dry acid compositions were studied in the laboratory of flow studies. The results are published in a scientific journal [2].

In 2022, study of CO_2 injection influence on rocks of different lithological composition was started with the purpose to assess the efficiency of UGS filling with carbon dioxide in different aggregate states and to determine changes in rock properties after carbon dioxide injection into reservoirs of different lithological types [3]. The work resulted in development of recommendations on selection of objects for building carbon dioxide UGS and its storage conditions.

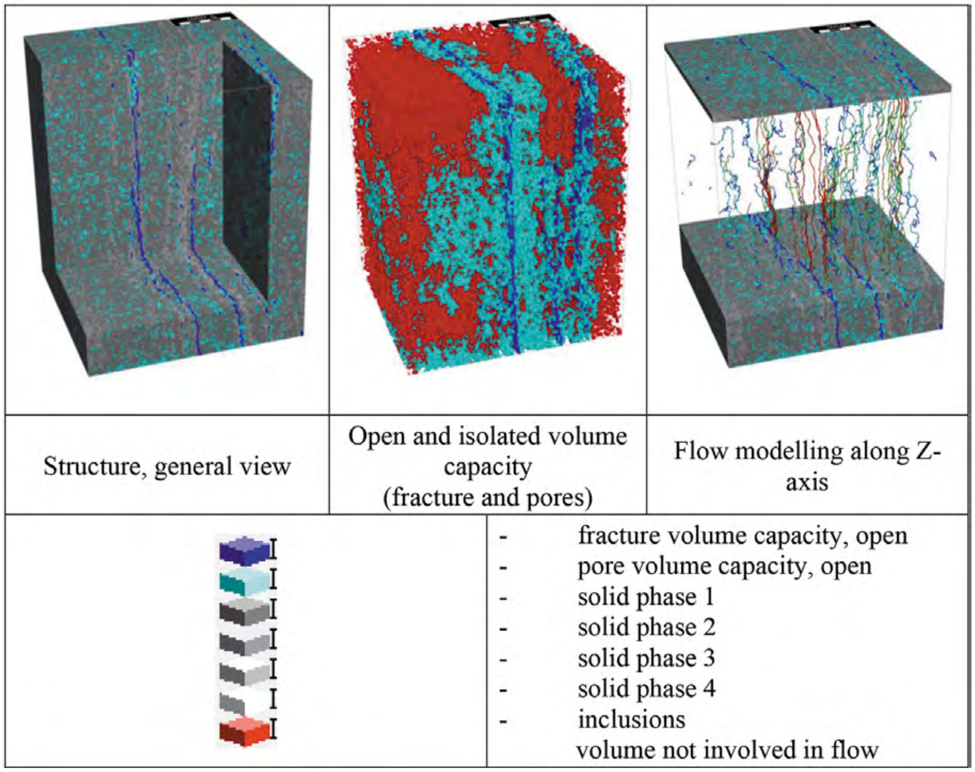


Fig. 8. Novoyakimovskaya 1 well, Lower Cretaceous Sukhodudinsky Fm (K1sd), sample #1186, sampling depth 2535.05 m

The Aprelevka branch conducts more than 240 types of core analysis and actively cooperates with many oil and gas companies and research centres, and Novatek, Rosneft, Tatneft, Gaspromneft are among them. Collaborative research with the specialists of RAS Paleontological Institute resulted in publishing a work [4] on Devonian placoderm nutrition based on morphofunctional analysis of placoderm fish mandibles, which was carried out in the VNIGNI Scientific and Analytical Centre using microtomograph.

The VNIGNI Scientific and Analytical Centre meets GOST ISO/IEC 17025 requirements and criteria for testing laboratory accreditation, which is confirmed by accreditation certificate RA.RU.21PG23 registered in the national accreditation system.

Table 1
Comparison of reservoir properties of Lower Cretaceous Sukhodudinsky deposits obtained using the conventional petrophysical methods and by means of mathematical modelling of tomography data

Reservoir properties, sample #1186	
Conventional methods	Computer Tomography methods (GeoDict)
PERM = 10.1 mD (total gas permeability) PHIo = 16.09 % (fluid saturation) Wso = 42 % (porous plate method)	PERM 8.1 mD (Stokes-Brinkman, Periodic) PHI = 19.82 % (OAC porosity) Wso = 37 % (CapiPressureCurve, Drainage)

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RUSSIAN SOFTWARE AND TECHNOLOGY COMPLEX GIS INTEGRO AND DIGITAL PLATFORM OF VNIGNI FOR COMPREHENSIVE SUPPORT OF GEOLOGICAL RESEARCH FOR OIL AND GAS

The article discusses the Russian software and technological solutions GIS INTEGRO and GEOBANK, developed at the Federal State Budgetary Institution «VNIGNI». GIS INTEGRO is a unique software and technology complex for creating geoinformation projects and comprehensive geological and geophysical modeling of the geological structure of subsoil areas. The GEOBANK digital platform implements information exchange, including the collection, systematization, storage, visualization and delivery of geological and geophysical information in all areas of scientific and production activities of the institute. The article reveals the main capabilities of the above-mentioned software and technological complexes and the advantages of their use in the geological research for oil and gas. ***Key words:*** *information technologies, geoinformation system, systematization, storage, cartography, three-dimensional modeling, classification.*

To effectively solve the problems of assessing the oil and gas potential of the Russian Federation, justifying the directions of geological exploration, developing long-term and operational programs for the development of the resource base of hydrocarbons, it is necessary to quickly analyze significant volumes of various geological information.

Intensive digitalization of the geological industry places high demands on geoinformation and analytical support for the state geological study of subsoil, the state licensing system of use of subsoil for hydrocarbons, geological exploration for reproduction of the mineral resource base of hydrocarbons, therefore, the Federal State Budgetary Institution «VNIGNI» is actively developing domestic software and technological complexes for geological study and use of subsoil.

In particular, it is necessary to make a special mention of the software and technological complexes GEOBANK and GIS INTEGRO being developed at the FSBI «VNIGNI». These complexes provide support for the main tasks solved at the institute.

GEOBANK — a digital platform for organizing distributed storage and access to geological and geophysical information

The GEOBANK software and technology complex is a completely web-based environment for organizing distributed storage and access to geological and geophysical information [1]. GEOBANK provides access to data stored in the DBMS, as well as to external files located in disk storages. The complex has mechanisms for flexible configuration of metadata and includes ready-made data models for storing oil-related objects.

The MGS-Framework platform was chosen as the development environment for the GEOBANK software and technology complex. The platform, the copyright holder of which is VNIGNI (No. 2017660222 dated September 19, 2017 in the Register of Computer Programs), provides the necessary tools for the development of distributed multi-level information systems, and has a certificate of state registration of the program. The platform was developed on the basis of free software using international and domestic standards in the field of geoinformatics, and allows to create distributed multi-level information systems.

The use of the GEOBANK software and technology complex made it possible to create a unified information environment of the FSBI «VNIGNI», which ensures the collection, systematization, storage, visualization and delivery of geological and geophysical information in all areas of the scientific and industrial activities of the institute.

A key component of the information environment of the FSBI «VNIGNI» is the Unified Bank of Geological and Geophysical Information for Oil and Gas, which ensures storage and provision of access to geological and geophysical information accumulated at the institute. The unified bank is a distributed system. Its user interface functions and is displayed identically in all standard web browsers that come with modern operating systems.

The Unified Bank user interface provides a wide range of tools for searching, viewing and downloading data. To select data that meets the necessary conditions, it provides advanced search: full-text (by keywords inside metadata and files), attribute, cartographic and file system search. This allows the user to search for the necessary information by selecting certain sections of the system for search and imposing conditions, as well as limiting the search result geographically. For each found object, the system provides interfaces for viewing more detailed information: a complete passport of the object, its location on an interactive map and the file structure of the available raw and interpreted data on the object.

The structure of the Unified Bank includes the main data repository and segments located in the branches of the institute. The main storage consists of the following sections: seismic data; well data; geological reports; resulting GIS projects; 3D models of territories. An integral part of the Unified Bank is a database of operational information resources, which includes data on oil and gas occurrence and subsoil assets, seismic and drilling exploration degree, a single unified cartographic base for the territory of the Russian Federation and much more.

Within the framework of the developed information infrastructure, distributed workplaces for employees of the institute and its branches are created, providing solutions to various thematic and information-analytical problems. One

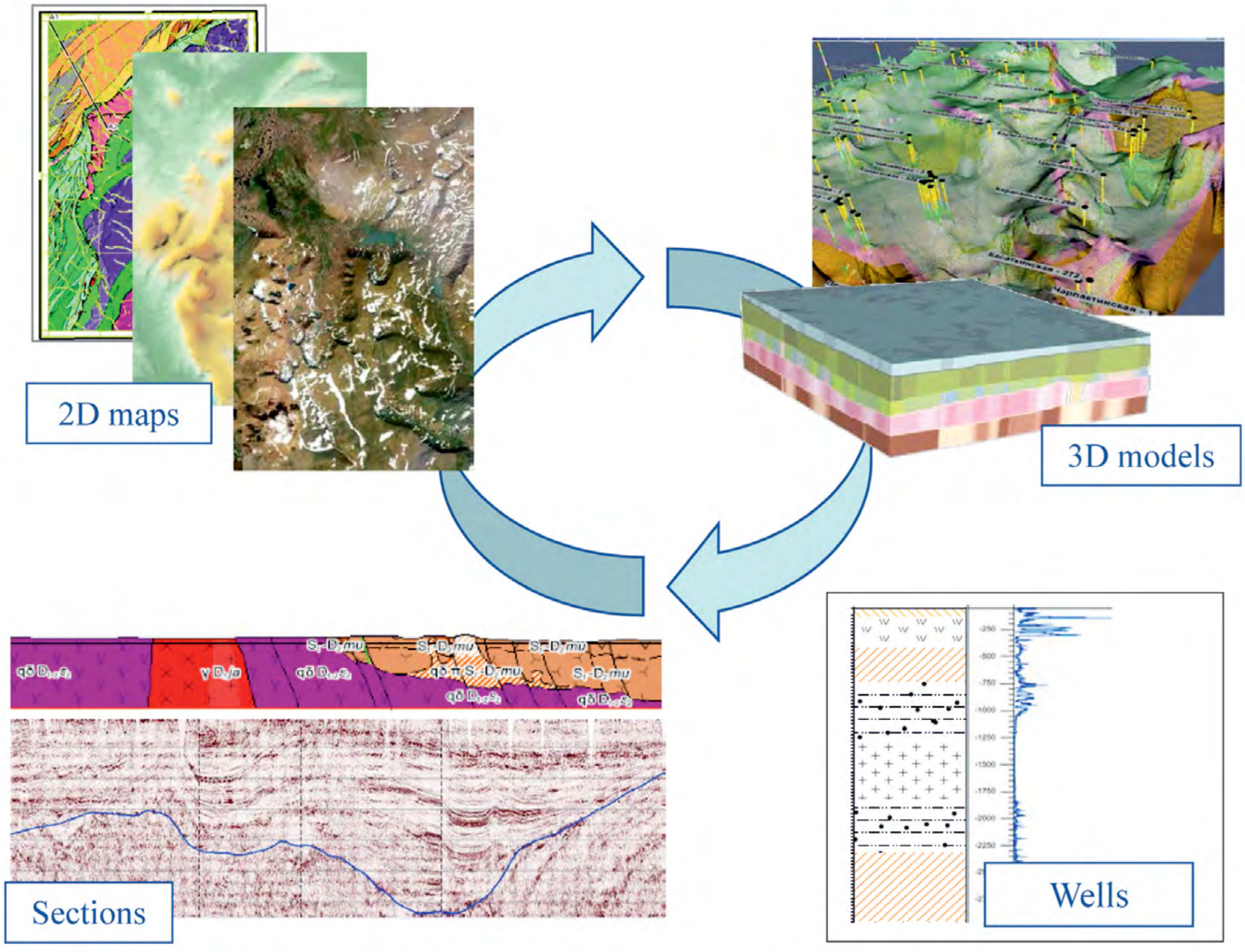

Fig. 1. Types of geodata that can be included in the GIS project in INTEGRO

of the most actual subsystems today is the «Personal Account for Exploration», which provides a single window of access to all information on regional geological exploration for oil and gas. This approach ensured timely transmission and prompt assessment of the completeness of reporting information received for each project site, and made it possible to significantly simplify the operational management of exploration projects. It is necessary to make a special mention of the implemented block of automated generation of reporting documentation for each exploration project for further transfer to fund storage.

GIS INTEGRO — a software and technological complex for geoinformation and analytical support of oil and gas exploration

The GIS INTEGRO software and technology complex is a full-featured geoinformation mapping system with advanced capabilities for solving geological and geophysical problems [2]. The patent holder of this software is VNIGNI (certificate No. 2017660220 dated September 19, 2017 in the Register of Computer Programs).

The INTEGRO GIS desktop application provides a complete set of tools for performing cartographic work, namely:

— all the necessary capabilities for creating and designing vector cartographic layers, regular grid networks and raster data;

— tools for joint simultaneous editing of several layers with automatic control of their topological correctness;

— a complete set of international and local projections and coordinate systems;

— implementation of a multi-user editing mode for a spatial database based on the basis of free PostgreSQL DBMS;

— tools for preparing maps for printing, including the preparation of complex large-format cartographic materials;

— connection to Internet resources based on standard OGC services, tile services and ArcGIS Server services

Thus, the cartographic capabilities of the INTEGRO GIS desktop application are comparable to the functionality of foreign software products (ArcGIS, MapInfo) and open source GIS (QGIS).

To create Internet-oriented projects in INTEGRO a GIS server has been developed that allows to put online standard OGC services for accessing data, as well as put ready-made

GIS projects into the shape of interactive web applications available for prompt viewing in a browser without installing specialized software and programming.

The most important advantage of GIS INTEGRO compared to other geographic information systems is the availability of advanced capabilities for loading, visualizing and converting geological and geophysical data, for example:

— combination of cartographic, profile and borehole data with synchronization by X, Y, Z, three-dimensional visualization of surfaces, sections and data cubes;

— operations with specialized data formats used in geology and geophysics (segy, las, etc.), as well as with formats used in GPS devices and Internet cartography;

— the capability to reproject coordinates for data presented in grid format, seismic data (segy, sps, ukooa), text structured files;

— availability of libraries of symbols recommended for use when preparing geological maps;

— specially developed batch loaders and converters that speed up the process of creating a GIS project.

It is these features that made it possible to effectively use GIS INTEGRO for cartographic support in such key areas of the institute's activities as quantitative assessment of hydrocarbon resources, comprehensive study of oil and gas promising territories and regional geological exploration. The following digital materials are included in geoinformation projects formed in the course of these activities:

— basic cartographic information about geology, subsoil use and geological and geophysical state of exploration, as well as the factual basis of research, that is profiles and wells subject to the processing;

— results of processing and analysis of seismic and magnetic resonance materials: seismic and electrical survey sections, as well as the results of their interpretation, grids of isochrones, isopachs and structural maps, seismic cubes;

— well data: coordinates, stratigraphic sections, correlation schemes, test results, etc.;

— depth-velocity models for wells and seismic sections and volumetric depth-velocity models built on their basis;

— results of comprehensive processing of gravity, magnetic and seismic data: initial fields and their transformants, two-dimensional and three-dimensional density and magnetic models and their sections, maps and diagrams built on the basis of these models.

Such a geoinformation project (Fig. 1) makes it possible to clearly visualize all prepared digital materials and ensures control of the work scope and the quality of the information received. At the same time, not only the desktop version of the project is available, but also its web version in the browser. This approach allows to conveniently and quickly get acquainted with the composition of the project, see the uploaded resulting maps, models and sections, and perform a preliminary analysis of this material without wasting time on downloading and installing software.

The key difference between the GIS INTEGRO and its foreign analogues is the availability of specialized functionality for geological and geophysical research and solving problems of three-dimensional modeling of the geological environment. On the basis of original algorithms and convenient user interfaces, the following essential technologies have been implemented:

— creation of a database and analysis of geological and geophysical information on wells;

— analytical processing of gravimagnetic fields in the plane, in the section and in the volume;

— conversion of time seismic data into depth data and vice versa based on a volumetric depth-velocity model;

— correlation of reflecting horizons on seismic profiles, including composite ones;

— creation of a layered 3D model of the geological environment and three-dimensional editing of its surfaces;

— construction of density and magnetic 3D models with the possibility of including objects of anomalous density and magnetization in them, as well as selecting their geometry in accordance with the observed field [3].

— solving classification (forecasting and diagnostic) problems based on an integrated analysis of heterogeneous and different-scale geological and geophysical data in area, volume and section.

Based on the tools available in the GIS INTEGRO, methods and technological procedures have been developed to solving the geological and geophysical problems described above (Fig. 2). These technologies have been successfully tested in fulfilling the tasks assigned to the institute. These include updating the quantitative assessment of oil and gas resources and reserves in the Russian Federation, as well as thematic

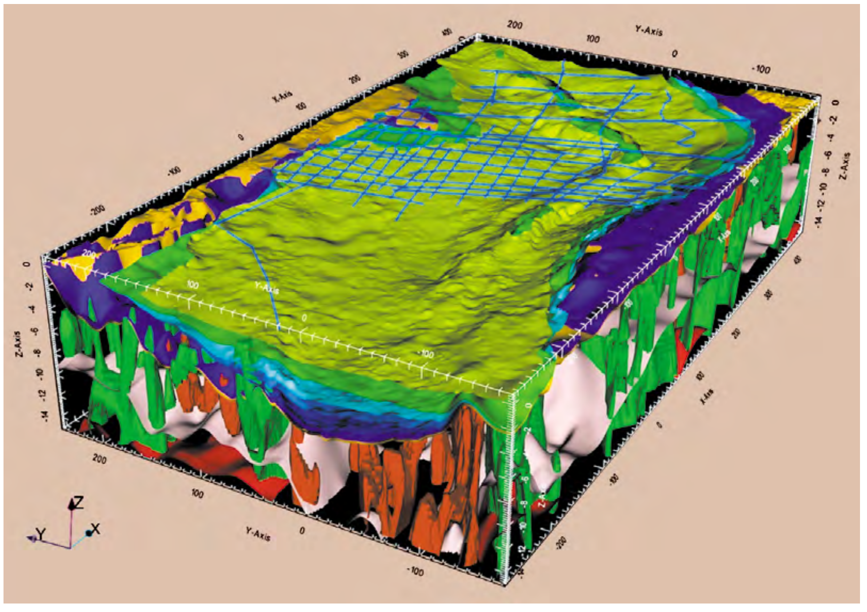

Fig. 2. An example of a complex 3D model of the sedimentary cover and intrusive formations, built in the GIS INTEGRO

and geological exploration work on the Volga-Ural oil and gas province, the Yenisei-Khatanga regional trough, the Leno-Vilyui oil and gas province, etc.

Today, GIS INTEGRO is used as a tool for geoinformation and analytical support in many research institutes and enterprises in the industry of subsoil use. In modern conditions, the interest of business companies in GIS INTEGRO as a Russian import-substituting platform for the implementation of their projects is growing. This led to the active introduction of GIS INTEGRO into the educational programs of universities that train professional personnel for geology and subsoil use. To facilitate the introduction of the software and technology complex GIS INTEGRO, there is a user support service, which consults users, organizes educational seminars and trainings, develops and modernizes educational materials and collections of applied problems.

Prospects for creating integrated digital platforms based on VNIGNI software and technology systems

In conclusion, it is necessary to emphasize the prospects for using the described software and technological complexes GEOBANK and GIS INTEGRO for the development of integrated digital platforms that provide information and analytical support for geological and geophysical research. Developed means of interaction between the components of these complexes, built-in libraries for visualization of geological and geophysical data and GIS projects, the availability of an access delimitation and control system — all this makes it possible to create a modern distributed information infrastructure, including repository and operational databases, desktop workplaces for fulfilling applied analytical tasks and web-oriented applications that provide quick access to information resources, viewing geological and geophysical materials (and specifically on an interactive map) and downloading them for use in working projects.

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ALWAYS ON THE LOOKOUT: GEOLOGICAL EXPLORATION OF THE SUBSURFACE FOR THE REPRODUCTION OF THE HYDROCARBON RESOURCE BASE OF THE WEST SIBERIAN OIL AND GAS PROVINCE

The article shows the effectiveness of the integrated approach of the ZapSibNIIGG to conducting geological exploration of the subsoil and further industrial development of hydrocarbon deposits using the example of the West Siberian oil and gas province.

*The prospects for cooperation with the BRICS countries lie in joint work on the geological study of the subsurface, planning strategic directions for geological exploration aimed at assessing the prospects for oil and gas potential of the territory, searching for hydrocarbon deposits in order to ensure the reproduction of the hydrocarbon resource base.****Keywords:** West Siberian oil and gas province, thematic and experimental methodological work, monitoring of the state of subsoil use, regional geological study of the subsoil, seismic exploration, design activities, corporate database.*

The history of the Federal Autonomous Institution «West Siberian Scientific Research Institute of Geology and Geophysics» is inextricably linked with the history of industrial development of the largest oil and gas producing region of the Russian Federation — the West Siberian oil and gas Province (Fig. 1). For almost 50 years of its existence, the Institute has gone a long way in development, and today it is a unique research enterprise that carries out a full cycle of work related to subsurface use: from strategic planning of exploration activities and geological exploration of the subsurface to the design of the development of open hydrocarbon deposits. All these areas are interconnected within the framework of the Institute's activities and allow for a comprehensive approach to the study and development of the hydrocarbon potential of the studied territories.

Since the foundation of the Institute, ZapSibNIIGG employees have made a huge contribution to the creation of methods and technologies optimal for the conditions of Western Siberia for field work, processing and interpretation of seismic data, geophysical studies of wells, geological and

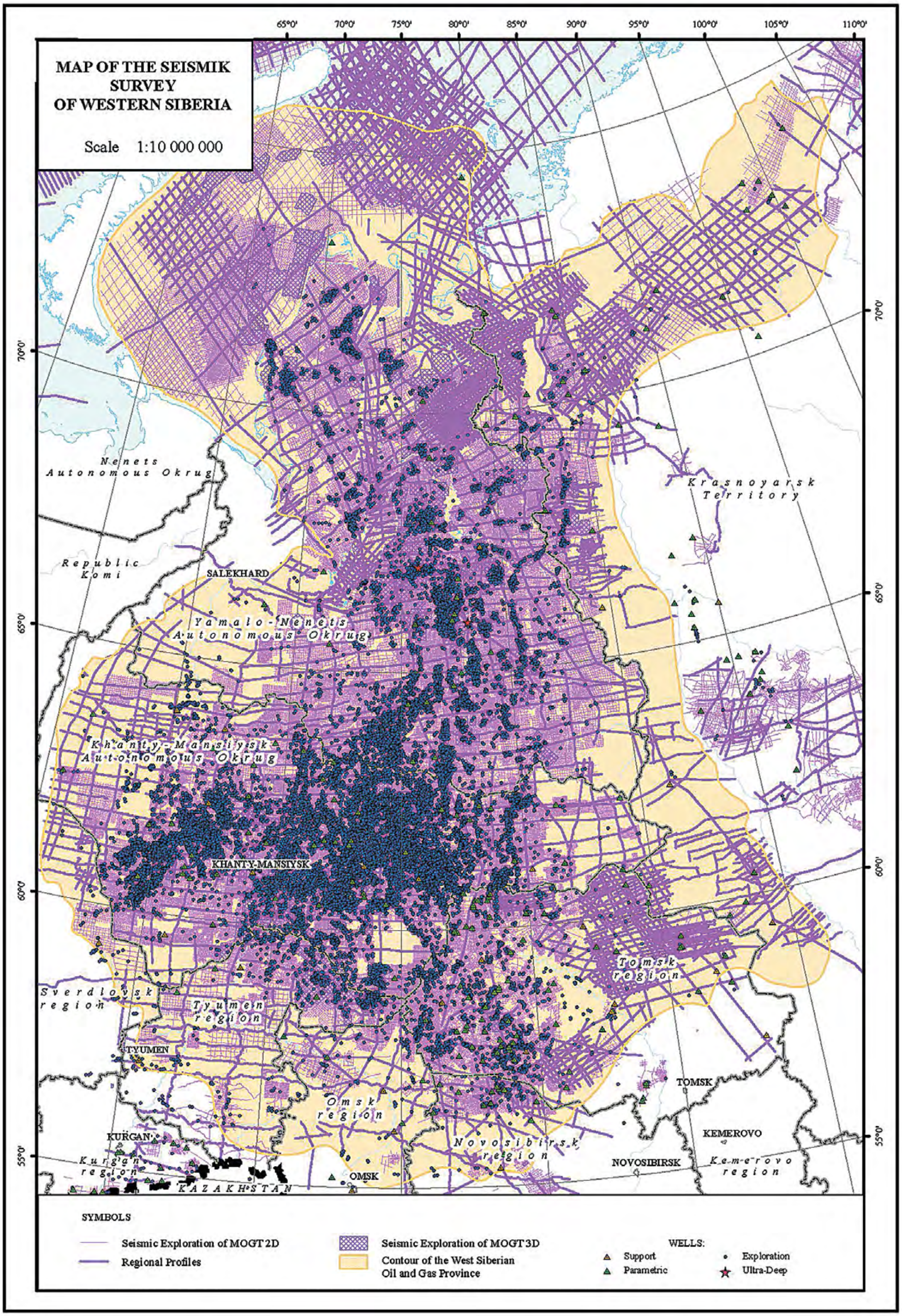

Fig. 1. Map of geological and geophysical studies of the WSOGP

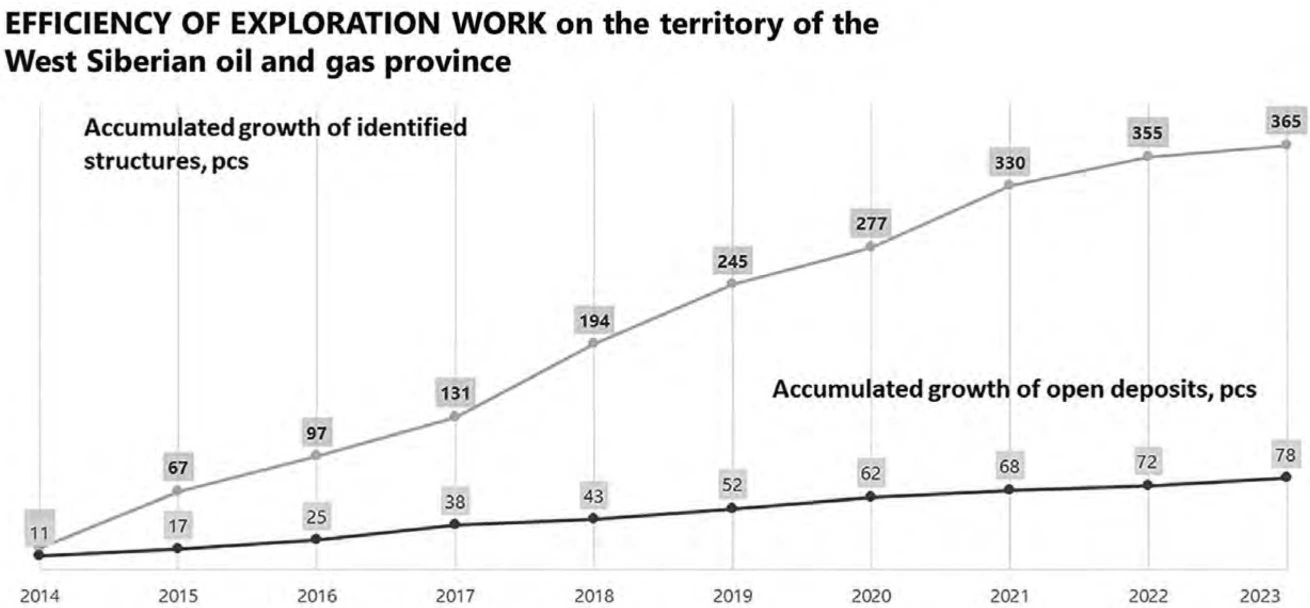

Fig. 2. Efficiency of exploration in the NWFZ for the period 2014–2022, and plans for 2023

In 2015, the Institute became a subordinate institution of the Federal Agency for Subsoil Use (Rosnedra) and, in addition to project activities for prospecting and exploration and design of the development of hydrocarbon deposits for oil and gas producing enterprises, ZapSibNIIGG begins work on ensuring the planning and implementation of the regional stage of the state geological study of the subsoil of the West Siberian oil and gas province.

As a result, the enterprise becomes a center for the accumulation, processing and storage of geological and geophysical information for the entire history of the province's development (Fig. 1). The formed unique data bank allows performing a wide range of work, the results of which are of interest both to the state and to users of the subsoil.

Today, the Institute provides planning and implementation of the regional stage of the geological study of the West Siberian oil and gas province in two main directions.

The first area of work includes monitoring of the state of the subsoil, geological, economic and cost assessment of UVS deposits and subsurface areas according to the WSOGP: on the basis of information received from users of the subsoil on the results of their exploration work over the past period, a generalization, analysis and evaluation of the effectiveness of exploration work carried out at the expense of all sources of financing in the territory of the Western Siberian oil and gas province.

In recent decades, subsoil users have actively begun to introduce and use advanced technologies in the field of seismic exploration and deep drilling, which has significantly increased the efficiency and accuracy of the preparation of promising facilities. This trend can be traced in the graph, which shows the dynamics of the accumulated volume of allocated structures for oil and gas, discovered hydrocarbon deposits and drilled wells in the period from 2014 to 2022 and planned data for 2023 (Fig. 2).

Next, the quantitative assessment of the resources and reserves of hydrocarbons WSOGP is updated, an analysis of the state, study and degree of involvement in the development of hard-to-recover reserves, an analysis of changes in the fund of objects prepared for drilling with traps of resources of category D0, an analysis of the ratio of profitable and unprofitable reserves for the development of the territory (Fig. 3, Fig. 4).

In parallel with the above-mentioned works, complex geological modeling of oil and gas bearing systems is carried out within the boundaries of the studied sites on the territory. Territories with a low degree of geological and geophysical knowledge and a high proportion of the undistributed subsoil fund are selected annually as the object of research (Fig. 5).

In 2017, the staff of the Institute created for the first time a unified structural, tectonic, and basin model sedimentation complexes. This model continues to be updated annually and is supplemented with new regional structures. This comprehensive model allows us to identify the most promising exploration areas and plan their required volumes and types. During the updating of the model, a unified framework with elements of fault-block structures is created within the boundaries of studied sites throughout the province.

Further, based on the determination of petrophysical characteristics using the unique author's technique of frequency-dependent analysis of seismic data (FDPI), a forecast of properties and quantitative characteristics in the inter-well space is carried out to determine the quality of the reservoir. These studies allow us to identify the intervals and the area of occurrence of reservoirs with improved filtration and capacitance properties (Fig. 7).

The next stage is the creation of 1D and 2D representative models within the framework of sites selected for study, which are necessary for accumulating and verifying data obtained to determine the oil and gas potential in poorly studied areas, identifying oil and gas prospects and intervals in the territory, and reducing geological risks and uncertainty during exploration (Fig. 8).

Special attention is paid to the analysis of data from reference and exploration drilling in previous years, with a critical assessment of the quality of the work. It should be noted that gas content in the section reduces the quality of well cementing sharply, therefore, the lack of industrial hydrocarbons in wells drilled in the 1950s and 1960s in the studied area and in the south of WSOGP is due to problems with their cementing. According to this scheme, based on a critical analysis of the previously performed exploration and a detailed analysis of geological and geophysical data, ZapSibNIIIGG FAI recommended opening the Ouryinsko-Evrin oil and gas zone located directly east of Yeremino oil and gas fields. Dynamic anomalies were observed at the Vikulovsk and Leushin formations at regional seismic lines RP 4 and 99. At those stratigraphic levels, insignificant mixed oil-gas-water inflows were obtained from the wells in the Yereminskaya area. As a result, seismic exploration and detailed drilling of exploration wells commissioned by Repsol, Eurotek-Yugra, and ZapSibNIIGG FAI led to the discovery of the Ouryinsky and Yuzhno-Indrinsky oil and gas fields, with total recoverable reserves of more than 90 million tons. The hydrocarbon potential in

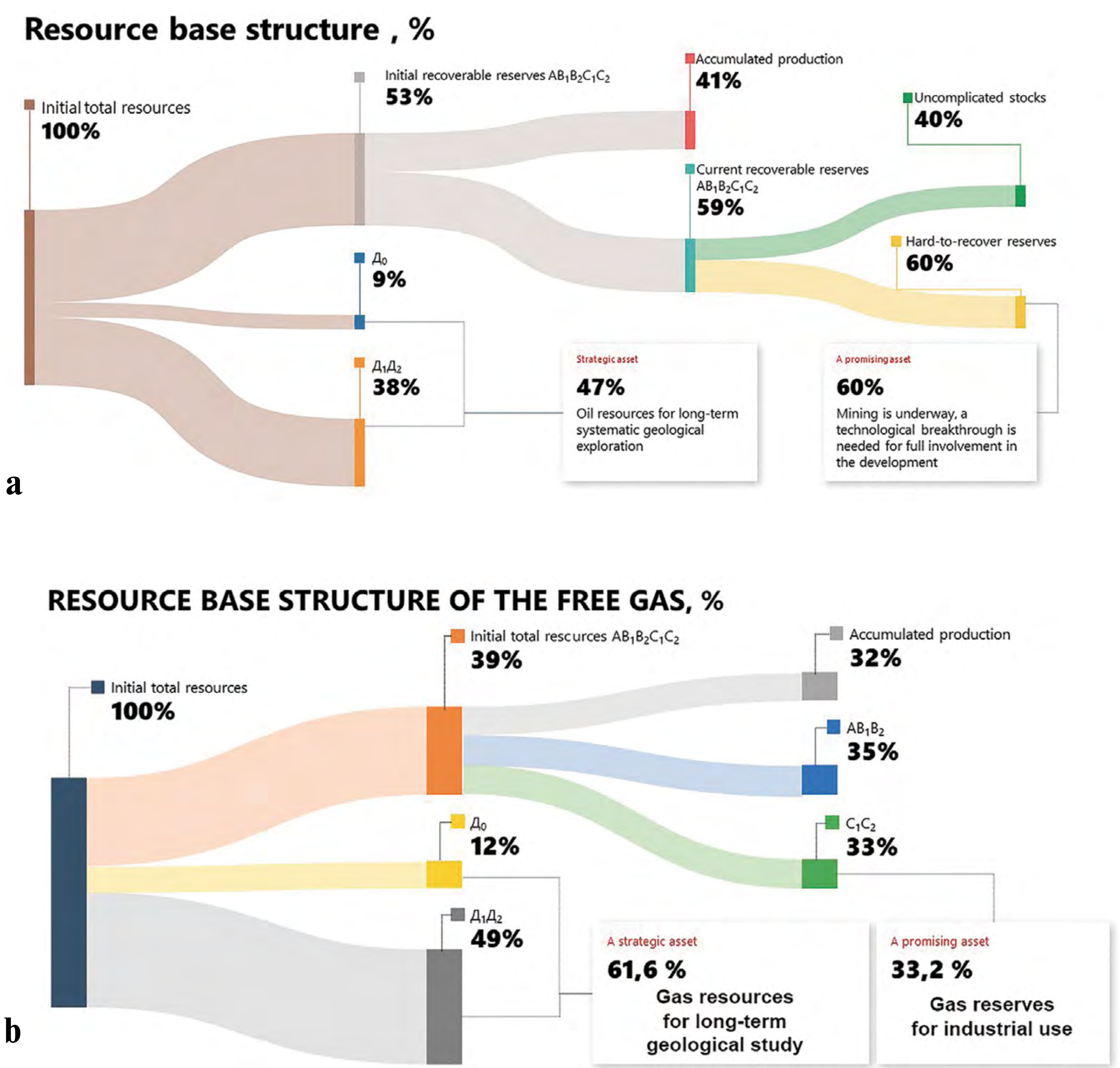

Fig. 3. Structure of the oil resource base (a) and gas (b), as of January 1, 2003 in the West Siberian Oil and Gas Province

this area is far from exhausted (Fig. 9), and we use a similar approach in other areas.

he totality of the results of analytical work on monitoring the state of subsurface geological, economic, and cost assessment of hydrocarbon deposits, as well as iterative integrated geological modeling of oil and gas-bearing systems, forms the basis for forming a strategy for exploring the subsurface in WSOGP to reproduce the mineral resource base for hydrocarbons. After analyzing all the information, ZapSibNIIIG, together with representatives from subsurface users, regional research institutions, and enterprises, prepare proposals for including new facilities in the federal exploration program (Figure 10).

The use of accumulated information allows ZapSibNIIGG to update the quantitative assessment of oil, gas, and condensate resources and reserves. It also allows them to promptly track changes throughout the province, both in the context of individual subjects of the Russian Federation and within the borders of oil-and-gas-bearing regions within the province.

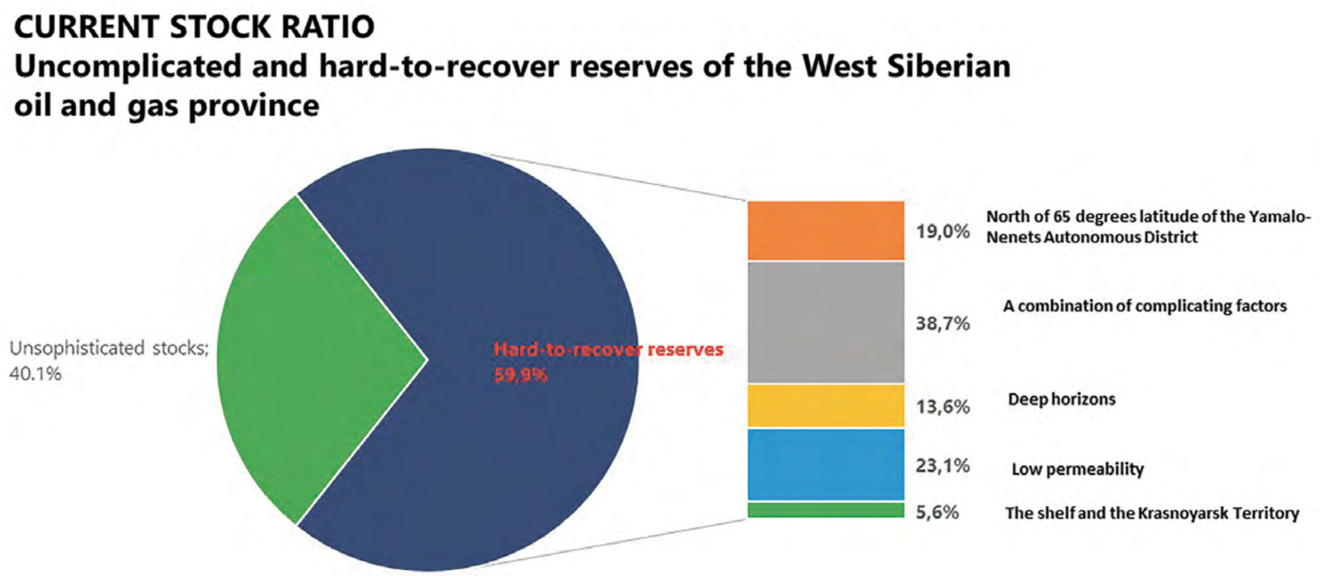

Fig. 4. Ratio of uncomplicated to current hard-to-recover reserves in the WSOGP, as of 1.1.2021, with distribution of hard-to-recover reserves by complicating factors.

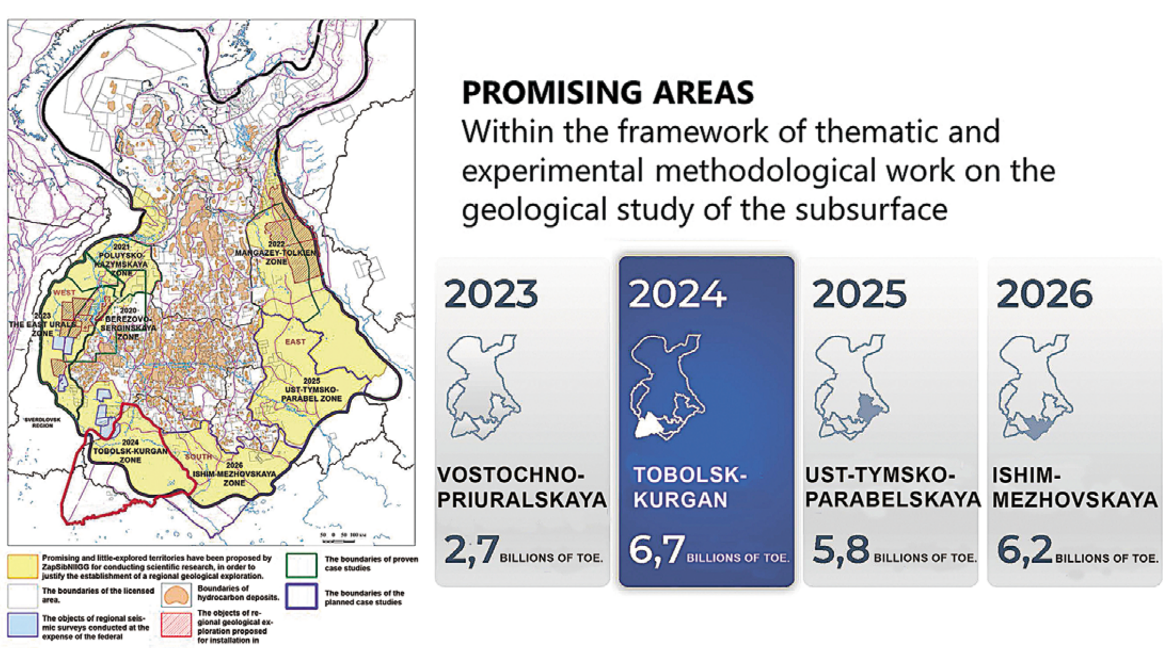

Fig. 5. Stages of creating a comprehensive seismic-geological model for territory of WSOGP in 2020-2026 years.

The second area of work is participation in the implementation of the federal list of exploration facilities approved by Rosnedra related to geological study of subsurface, conducting field seismic surveys using 2D MOGT on the Yuzhno-Berezovsky and Yuzhno — Visimsky sections in KhMAO — Yugra (Figure 12).

Within the boundaries of these sites, field seismic surveys are planned to be conducted, as well as processing and interpretation of the obtained results. The geological structure of the studied area will be clarified, hydrocarbon accumulation zones will be forecasted, and resources in selected promising areas will be assessed. Justification of geological exploration and preparation of reserves for industrial categories will take place. Also, ZapSibNIIGG, on behalf of Rosnedra, monitors the state of subsurface use of hydrocarbon raw materials and analyses changes in the array of licenses in the region. A wide range of work is carried out to prepare various information and analytical materials re-

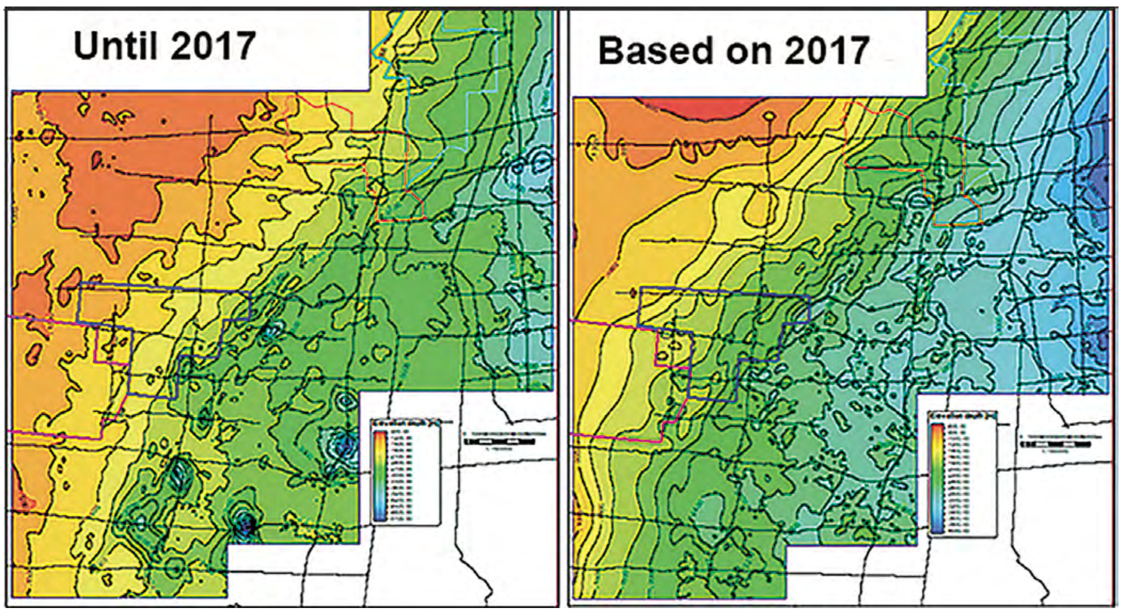

Fig. 6. Clarification of structural map OG "A", before and after considering buildings in Berezovo-Sergino area (20/2).

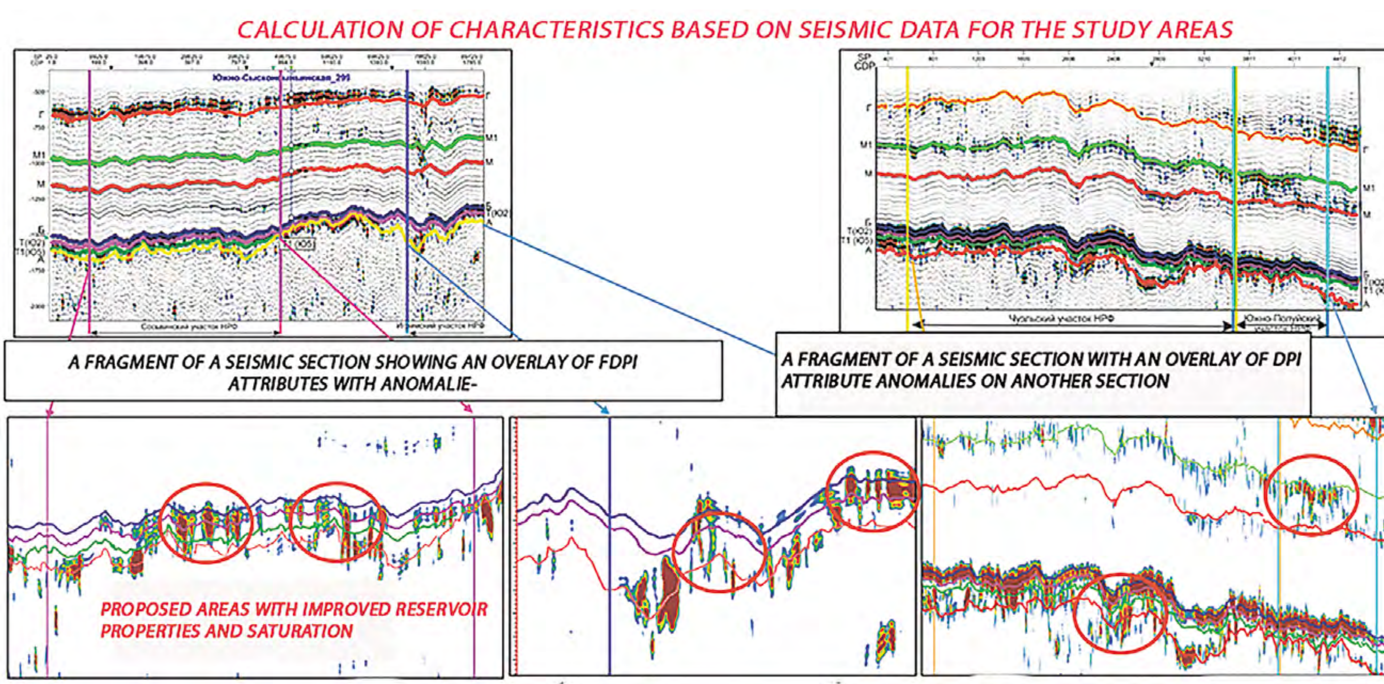

Fig. 7. Presence of FDPI anomalies associated with zones of improved reservoir saturation in Berezovsky-Serginsk area (02/0)

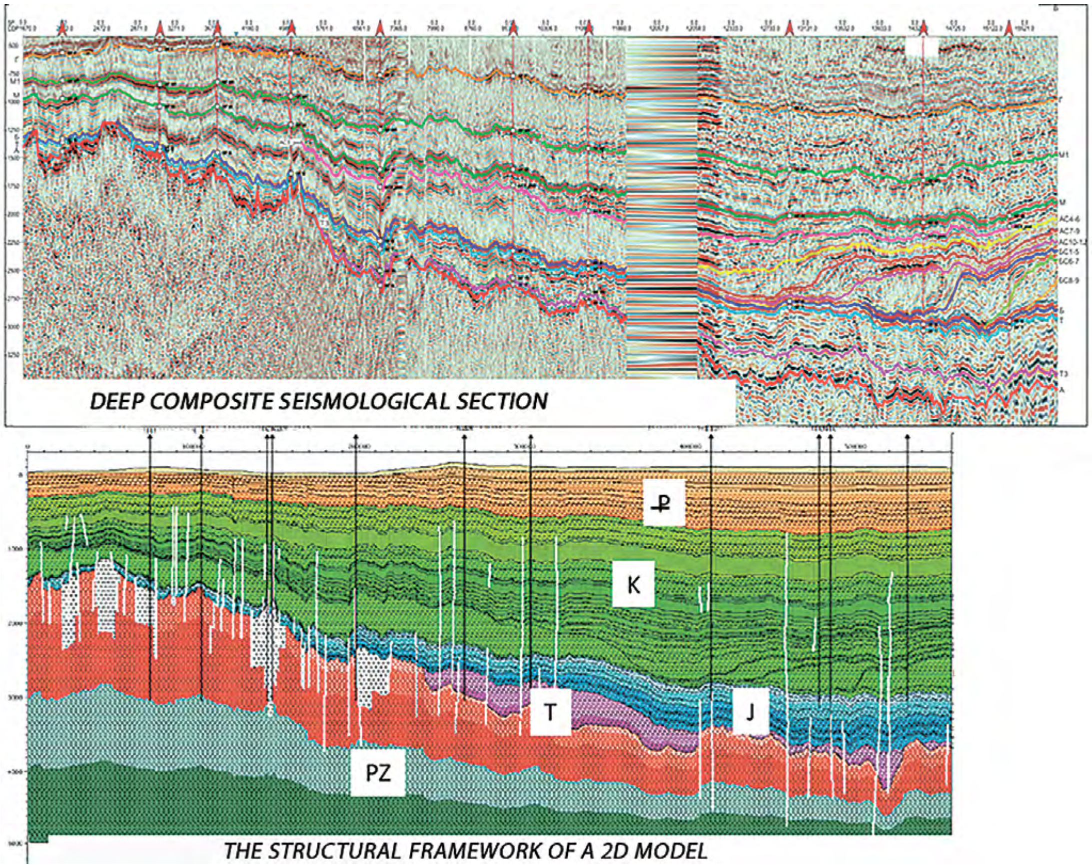

Fig. 8. Conceptual 2D model of the Berezovo-Serginsky zone along RP15

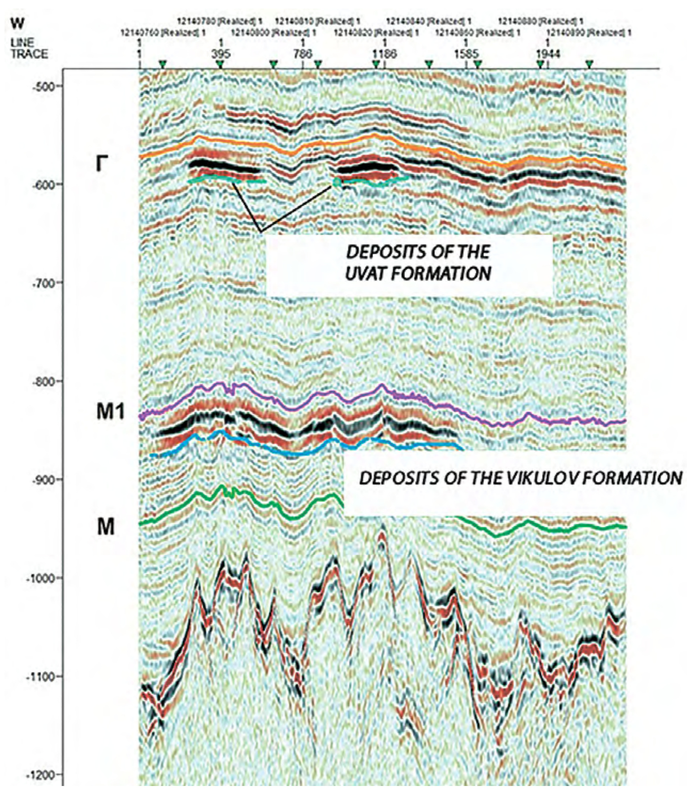

Fig. 9. Fragment of a seismic section along profile 12140250, illustrating prospective deposits of the Apt-Cenomanian complex in Ouryinsky-Evrin area

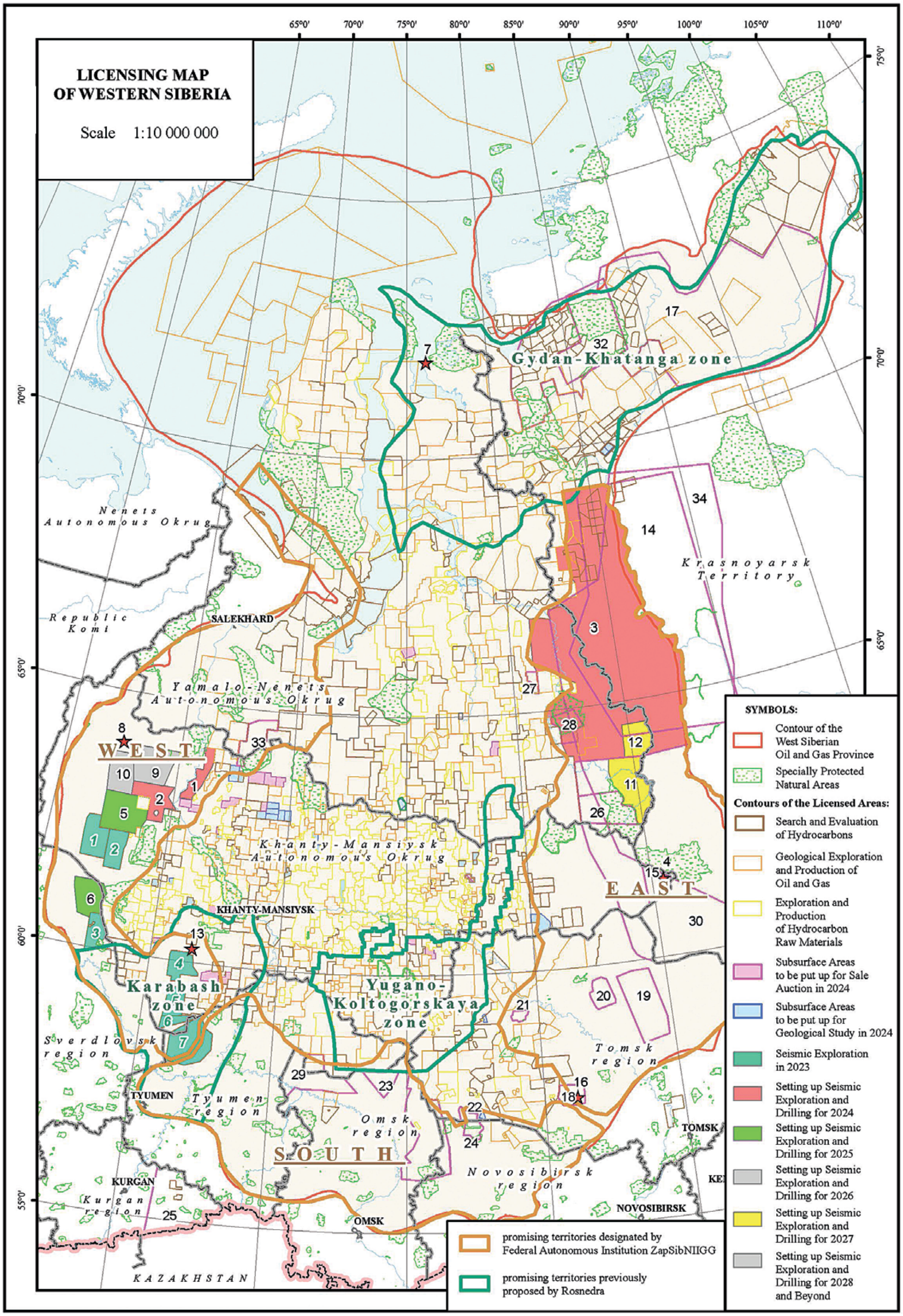

Fig. 10. Proposals for new geological exploration objects to be included in the federal list for geological study of subsurface areas

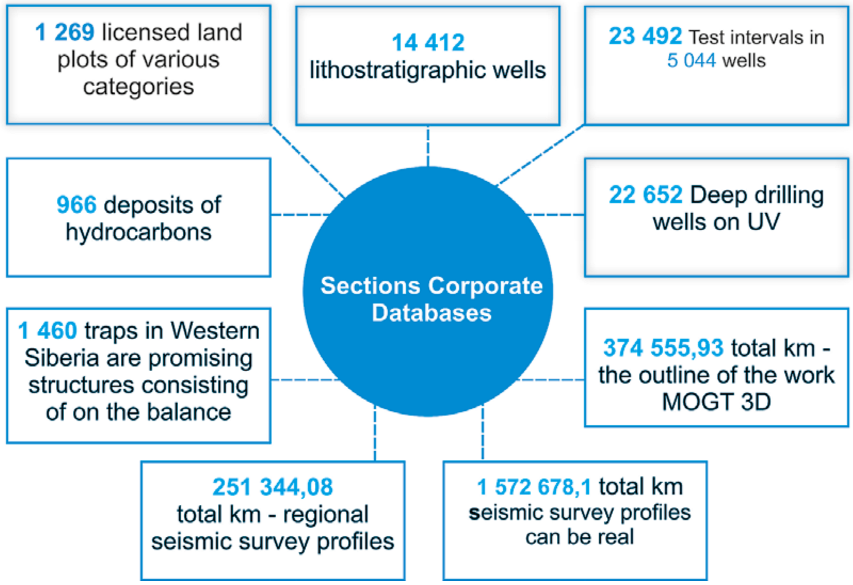

Fig. 11. Corporate database sections

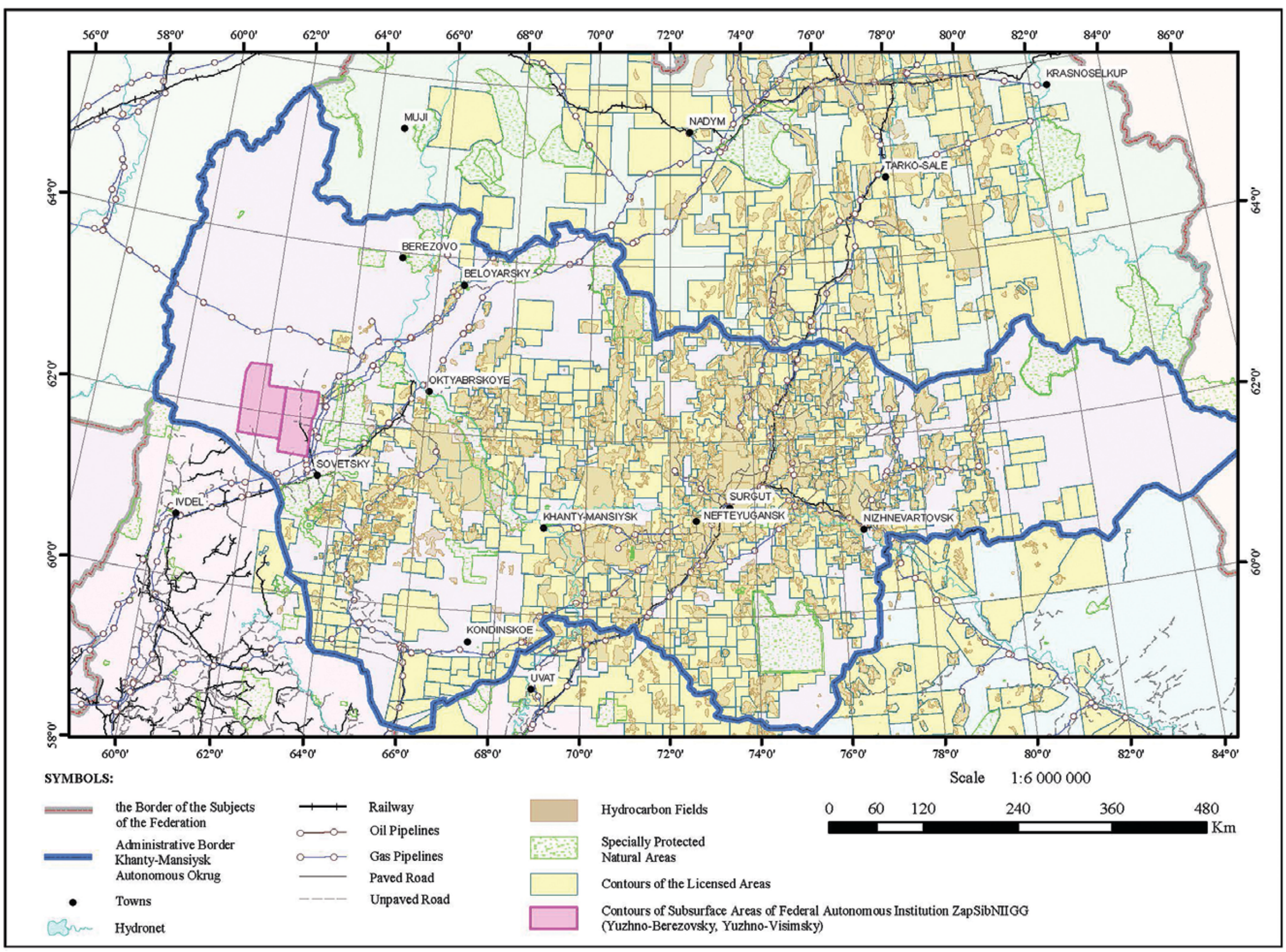

Fig 12. Overview map of regional seismic surveys conducted at Yuzhno-Visimsky, Yuzhno Berezovsky sites

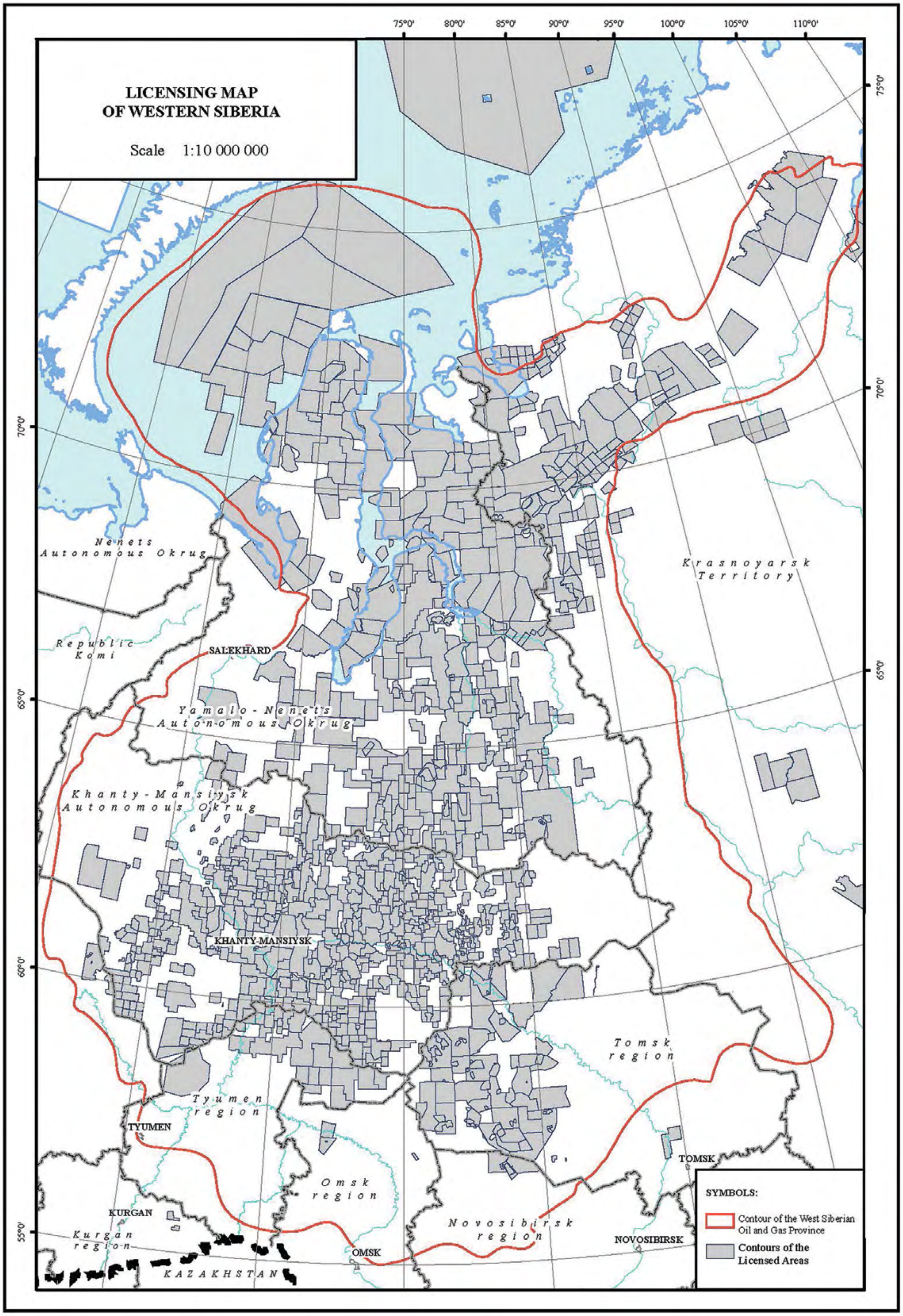

Fig. 13. License card for WSOGP dated 01/01/2024

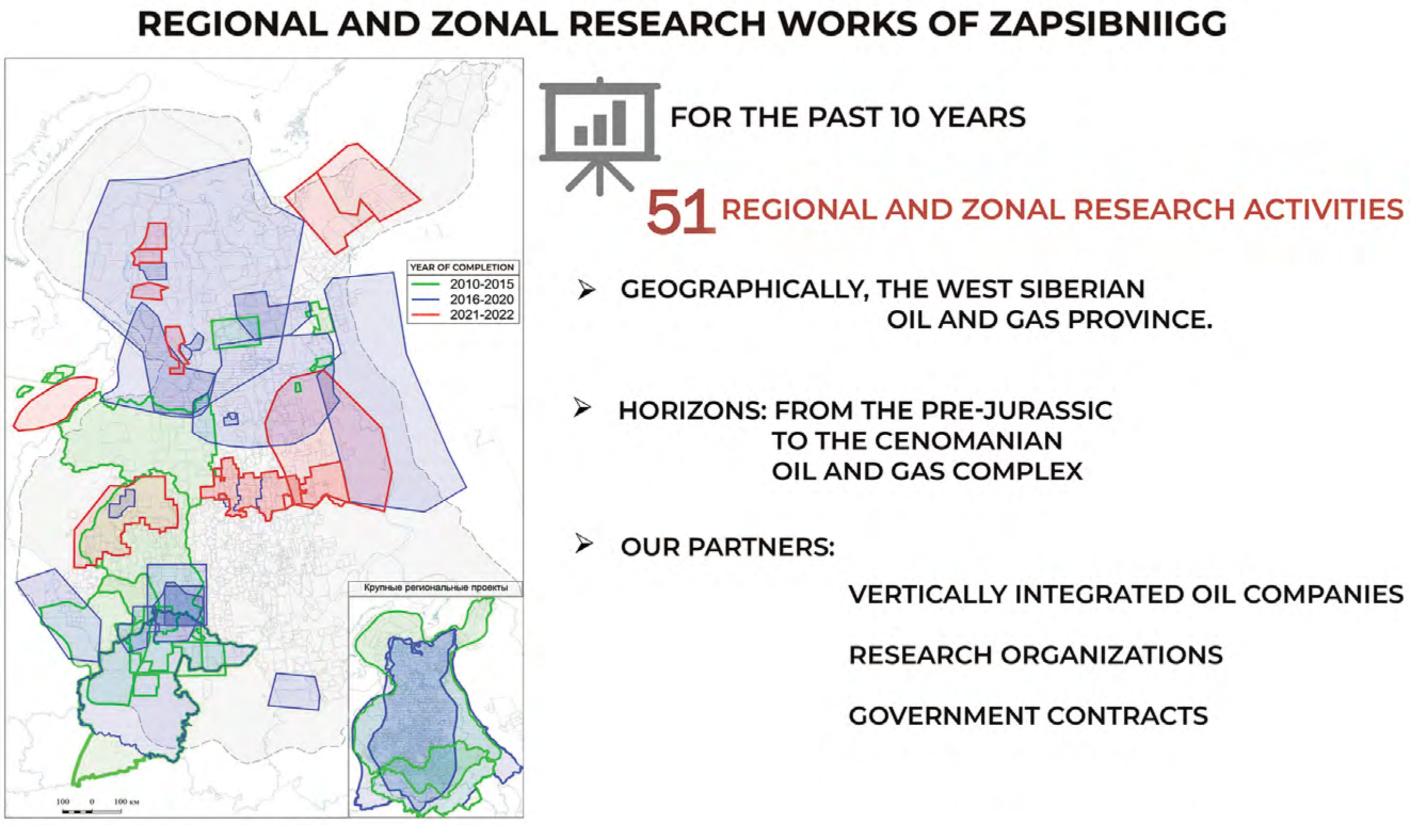

Fig14. Diagram of completed regional and zonal research works by ZapSibNIIGG during 2010–2022 period

quired for Rosnedra and territorial bodies to make decisions and control licensing activities in the region. The result of monitoring subsurface use is to keep up-to-date data on the structure and dynamics of changes in existing license agreements issued to subsurface users for carrying out activities in the province. A range of spatial data is required to construct cartographic materials necessary for solving problems related to licensing subsurface use (Fig. 13).

In addition, the highly qualified staff of the Institute have the competencies and extensive experience in drafting and protecting exploration projects, as well as all types of technical documentation for the development of hydrocarbon deposits. They also form programs for geological and technological measures, and methods for increasing oil recovery, in order to improve the efficiency of hydrocarbon development for subsurface users (Fig. 14).

Thus, a unique scientific school has been created at the ZapSibNIIGG FAI, which includes highly qualified specialists. This makes it possible to successfully work not only on tasks defined by the state but also to effectively solve tactical tasks in the exploration and development of oil and gas fields in other BRICS member states.

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