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## Mining-Geological and Economic Characteristics of Lead-Zinc Ore Deposits in the Russian Arctic *

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**Abstract.** The article analyzes the possibilities for prospecting, evaluation, exploration and extraction of zinc and lead deposits in the Arctic. The reserves and resources of zinc and lead deposits and ore occurrences on the Novaya Zemlya archipelago, on Vaygach Island, in the Polar Urals and in the Northern Timan are calculated on the territory of the Russian Arctic. The predominant reserves are represented by the Pavlovskoye deposit, which is being prepared for development by JSC First Mining Company of the Rosatom State Corporation. In 2019, the design of a mining enterprise was initiated, no lead and zinc mining has been carried out within the Arctic zone. A promising object is the Saureyskoye deposit in the Polar Urals. The problem is the remoteness of the site from transport highways. It is necessary to plan the construction of a dirt road from the deposit to the railway. Cargo can then be sent to the ports of the Gulf of Ob or to the port of Indiga when it is put into operation. Lead and zinc deposits on the island of Vaygach and on the Arctic coast near Amderma were previously developed. It is necessary to reassess their reserves and to determine possible development options. The extracted ore will be transported through the port of Amderma. In the Northern Timan, reassessment of non-ferrous metal ores should be carried out in a complex (lead, zinc, molybdenum, copper, nickel). Ore mining may be appropriate in connection with the construction of the deep-water seaport of Indiga. The purpose of this article is to study the mining, geological and economic characteristics of lead-zinc ore deposits and the spatial organization of marine communications for the development of the mineral resource complex of the Arctic zone of Russia. Mining facilities in the Arctic have an important strategic importance for strengthening national security of the country.
**Keywords:** *mining, geology, economics, deposit, lead, zinc, ore, Pavlovskoye, Samurayskoye, Amderminskoye, Novaya Zemlya, Vaygach, Northern Timan, Arctic*

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tion and Quarries" with training in the mining and geological information system Micromine at the Northern (Arctic) Federal University.

## *Introduction*

Mineral resource centers are decisive in the economy of the Arctic territories of all states in terms of solid mineral extraction. Russia's Arctic territories with their strategic metal deposits are the largest domestic and export suppliers of metals.

Deposits of solid minerals in the Arctic are of interest to the industry of all countries related to the Arctic [1, Bortnikov N.S., Lobanov K.V., Volkov A.V., Galyamov A.L., Lalomov A. V., Murashov K.Yu., Vikentiev I.V., Tarasov N.N., Distler V.V., Aristov V.V., Chizhova I.A.], [2, Dodin D.A., Ivanov V.L.], [3, Dodin D.A., Evdokimov A.N., Kaminskiy V.D.], [4, Goldfarb R.J., Ayuso R., Miller M.L.].

The article analyzes the possibilities of prospecting, evaluation, exploration and production of zinc and lead deposits in the Russian Arctic.

The total amount of zinc production in the Arctic territories is 4.64% of world production, the share of Arctic zinc ores in world reserves is 3.8% [1, Bortnikov N.S., Lobanov K.V., Volkov A. V., Galyamov A.L., Lalomov A.V., Murashov K.Yu., Vikentiev I.V., Tarasov N.N., Distler V.V., Aristov V.V., Chizhova I.A.].

According to the information compiled in the Solid Mineral Reserves Statement for the Arctic Territories of Russia as of 2021, the reserves of lead and zinc are distributed as indicated in the VSEGEI Statement [1].

The Pavlovskoe deposit is one of the largest in terms of zinc reserves; it is being prepared for development by JSC First Mining Company of the state corporation Rosatom. The total zinc reserves of category B+C1 are determined at 1325.3 thousand tons, category C2 is 1162.6, off-balance reserves are 531.1 thousand tons. In 2019, the design of a mining facility was started; no lead and zinc mining has been carried out within the Arctic zone of Russia.

The Saureyskoe deposit of lead and zinc is located in the Polar Urals within the Yamalo-Nenets Autonomous Okrug. The reserves of the deposit are estimated at more than 320 thousand tons of lead, 21 thousand tons of zinc, 300 tons of silver, 550 thousand tons of barite [5, Kontar E.S.]. The development of the deposit is not carried out yet.

The Amderminskoe lead-zinc-fluorite deposit is located on the coast of the Kara Sea in the Northern Pay-Khoy near the village of Amderma within the Nenets Autonomous Okrug. From 1932 to 1951, fluorite was mined at the deposit; it is currently under conservation. The ores of the deposit are represented by fluorite, sphalerite, galena and pyrite. The zinc content in the ores ranges from 0.33 to 1.11%, the lead content is 0.2%. At a depth of 100 m, the concentration of lead and

[1] Statement on the state and prospects of use of mineral resource base of the Arctic zone of the Russian Federation as of 15.03.2021. The statement was prepared by FSBI VSEGEI under the State Assignment of the Federal Agency for Subsoil Use dated 14.01.2021. No.049-00016-21-00. URL: https://www.rosnedra.gov.ru/data/Fast/Files/202104/45bb8bcc7b844220954744c0149a86f4.pdf (accessed 14 March 2022).

zinc in the ore increases in total to 1.5%. Lead-zinc resources have not been determined [5, Kontar E.S.].

Lead-zinc deposits and ore occurrences are known on Vaygach Island. Ore was mined at the Krasnoye and Razdelnoye deposits from 1931 to 1934. Ore occurrences of lead and zinc were discovered on the Northern Timan [6, Wittenburg P.V.]. In areas with the listed ore occurrences, additional exploration is required. These ore deposits will be of interest for industry in case of railway and motorways construction in the designed and reconstructed ports of Indiga, Amderma and Ust-Kara in the Nenets Autonomous Okrug.

## *Problem statement*

The information framework is based on the experience of prospecting, evaluation and exploration of lead-zinc ore deposits in the Arctic. The experience of field development in Alaska (USA) was used [4, Goldfarb R.J., Ayuso R., Miller M.L.].

The methodological and theoretical basis was the open-cut projects for the development of deposits of ores of solid minerals in the Arctic. Development of lead and zinc ore deposits in the Arctic territories is a new trend for Russian extractive industries. Transportation of cargoes and mined ore from the Pavlovskoe deposit on Novaya Zemlya, Saureyskoe and Amderminskoe deposits in the Polar Urals has not been started. One of the problems is ensuring the regional security of Russia in the context of the struggle for control over the mineral resources of the Arctic.

Lack of considerable researches of the analyzed region makes the study of the most rational approaches to the spatial organization of sea communications for the development of the mineral resource complex of the Arctic zone of Russia relevant.

## *Methodology*

The purpose of this work is to study the mining-geological and economic characteristics of lead-zinc ore deposits and the spatial organization of sea communications for the development of the mineral resource complex of the Arctic zone of Russia.

The tasks, which were solved to achieve the set goal, were as follows:

- to study the deposit design process using the example of the Pavlovskoe field on the Novaya Zemlya archipelago;
- to consider the geological and industrial characteristics of the deposit, to calculate the technological parameters of the development of the deposit;
- to carry out a calculation of open-cut transport with the parameters of transportation and the number of equipment used, as well as its performance;
- to describe drainage, power supply, water supply of the entire enterprise, including the open-cut;

- to consider environmental protection and to carry out calculations on emissions of harmful substances into the atmosphere from drilling and blasting operations and from the operation of equipment;
- to describe industrial safety and labor protection;
- to make economic calculations on the costs of starting the operation of an open-cut and to show an approximate annual costs calculation;
- to show the prospects for the development of the Saureyskoye and Amderminskoye lead-zinc deposits in the Polar Urals;
- to show the spatial organization of sea communications for the development of lead-zinc deposits in the Arctic.

## *Discussion*

The experience of studying lead-zinc deposits in the Arctic is given in the publications of many geologists, mining engineers and economists [2, Dodin D.A., Ivanov V.L.], [3, Dodin D.A., Evdokimov A.N., Kaminskiy V.D.], [4, Goldfarb R.J., Ayuso R., Miller M.L. et al.], [7, Evdokimov A.N., Kalenich A.P., Kryukov V.D., Lastochkin A.V., Semenov Yu.P.], [8, Lazhentsev V.N.], [9, Karpuzov A.F., Rundkvist D.V., Cherkasov S.V.], [10, Vartanyan S.S., Krivtsov A.I., Migachev I.F.], [11, Goverdovskaya T G., Dodin D.A., Evdokimov A.N.], [13, Mikhailov B.K., Petrov O.V., Kimelman S.A.], [14, Mikhaylov B.K., Vorobyov Yu. Yu., Kimelman S.A.], [15, Gusev G.S., Golovin A.A., Gushchin A.V.], [16, Karpuzov A.F., Lebedev A.V., Zhitnikov V.A., Korovkin V.A.], [17, Plyakin A.M.], [18, Dodin D.A., Ivanov V.L., Kaminskiy V.D.], [19, Kochnev-Pervukhov V.I., Migachev I.F., Zvezdov V.S.], [20, Badtiev B.P., Bibik S.D.], [21, Orlov V.P.], [22, Vercheba A.A.], [23, Lipina S.A., Cherepovitsyn A.E., Bocharova L.K.], [24, Cherepovitsyn A.E., Lipina S.A., Evseeva O.O.], [25, Kondratyev V.B.], [26, Kuznetsov S.K., Timonina N.N., Kuznetsov D.S.], [27, Tolvanen A., Eilu P., Juutinen A., Kangas K., Kivinen M., Markovaara-Koivisto M., Naskali A., Salo-kannel V., Tuulentie S., Similä J.].

The economic development of the mineral resource complex of the Arctic territories is based on the spatial organization of sea communications associated with the transportation of ores from mining and processing plants to consumers. The implementation of the goals of mineral resources development involves the formation of competitiveness clusters in the Arctic region in the field of spatial organization of sea communications, which will mobilize the resource of the network organization of the Arctic space, which becomes the basis of competition at the global level. Regional sea communications in the Western Arctic can be the basis of the country's national security, they must function in the form of clusters and guarantee free access to the markets for mined ores. Maritime systems must be competitive and have sufficient resources to upgrade the fleet during the development of the Arctic territories for the development of the mineral resource complex.

## *Mining and geological characteristics of Pavlovskoe silver-bearing lead-zinc deposit*

The Pavlovskoye deposit is located on Novaya Zemlya, Arkhangelsk Oblast, in the north-west of the Yuzhnyy Island of the archipelago, 16–17 km east of the mouth of the Bezymyannaya River within the Bezymyanskiy polymetallic mineragenic cluster.

In order to develop the Pavlovskoye deposit, JSC First Mining Company (FMC) was established in 1998. In 2000, it obtained a license to use the subsoil in the basin of the Bezymyannaya River for geological exploration. In 2001–2002, a set of prospecting and appraisal works resulted in obtaining a certificate confirming the deposit discovery. In 2013–2014, a project was drawn up and confirmed by the FSFI GKZ Rosnedra, which was approved by the Scientific and Technical Council of Subsurface Management Department of the Arkhangelsk Oblast. In 2014, a licence for lead-zinc ore exploration and mining was obtained. An exploration project at Pavlovskoe has been completed and approved by Rosgeoekspertiza. The work was approved by the Russian Ministry of Defense. A set of geological exploration works was carried out, and the environmental condition of the site was assessed.

In 2016, permanent exploration conditions and reserves of ores of zinc, lead and silver of industrial categories were approved for open-pit mining. FMC and Northern (Arctic) Federal University named after M.V. Lomonosov signed a cooperation agreement, which provides for the training and retraining of specialists, carrying out research work necessary for the development of the Pavlovskoe deposit. In 2018, the Pavlovskoe field development project received the status of a priority investment project in the Arkhangelsk Oblast. In 2019, engineering surveys were completed for the design of the port complex and the mining and processing plant.

In 2019, framework pre-off-take agreements and letters of intent were signed with a number of European traders, which are necessary for credit institutions as confirmation of the marketing and sales strategy.

In 2020, exploration work was carried out to assess the mineral resources in accordance with the JORC code, and engineering surveys were carried out as part of the Pre-Feasibility study. Repeated public hearings on the issue of environmental impact assessment were held. An agreement with a Finnish technology company to cooperate in the design, delivery and commissioning of a concentrator for the processing of lead-zinc ores was signed.

In 2021, the Northern (Arctic) Federal University opened a Mining and Pit Laboratory with training in the mining and geological information system Micromine, financed by the First Mining Company. The FMC performed the first JORC-compliant reserves assessment at the deposit and submitted the first estimate of ore reserves for open-pit mining.

In 2021, the Pavlovskoe project was included in the list of projects to be implemented in the Arctic zone of Russia. The conclusion of the ecological expertise of the project for the construction of the mining and processing plant and the port complex was received.

The silver-bearing lead-zinc deposit Pavlovskoe is divided into three blocks: Eastern, Central and Western.

Within the Eastern block, a network of boreholes and mine workings 150–200 x 100 m (6 profiles, 14 holes) was carried out.

The deposit structurally belongs to the Pay-Khoy–Novaya Zemlya fold system and is late Triassic – early Jurassic in age.

The Pavlovskoe ore field covers an area of more than 12 $km^2$ and is composed of Silurian–Devonian terrigenous, terrigenous-argillaceous and carbonate rocks. They are dislocated and form the Bezymyanskaya anticline with wings 3–4 km in size. The Pavlovskoye field is confined to the southeastern flank of the anticline, which is composed of carbonate formations of the Early Devonian Gribovskaya Formation (D1gr). The carbonate formations of the Gribovskaya are partially overlain by a sequence of carbonate-argillaceous deposits of the Taininskaya Formation (D1-2 tn).

About half of the ore intersections is associated with organogenic varieties, more than a third is associated with fine and microgranular varieties, 16% of ore intersections are attributed to sedimentary breccias, dolomite and clay varieties.

The degree of sulphide saturation in carbonate rocks varies from scattered sulphide (pyrite, sphalerite, galena) phenocrysts and isolated veins to breccia-like and massive ores.

### *Ore content and ore morphology of the deposit*

Three ore deposits have been established at Pavlovskoe — Tsentralnaya, Vostochnaya and Pravoberezhnaya. Tsentralnaya and Vostochnaya deposits are located on the left bank of the Bezymyannaya River, explored in detail and contain the main reserves of lead-zinc ores of the deposit of categories B, C1 and C2.

The ore bodies of the Tsentralnaya Deposit are partially exposed to the day surface in the west of the deposit, dipping to a depth of 300–450 m on the eastern flank within the adjacent tectonic block, where they overlap with the substantially argillaceous formation of the Taininskaya Formation, which composes the core of the graben-syncline forming this block.

The ore bodies isolated from the main mineralization and detected in the work are also attributed to the Tsentralnaya Deposit in its extreme northeastern and southwestern extensions.

The projection of the deposit on a horizontal plane (surface) has a complex configuration, the maximum dimensions are ~ 1500x1000 m, and it is oriented in the northeast (50–55°) direction. The Tsentralnaya and Vostochnaya deposits, expected to be joined at depth within the graben-syncline, have not been confirmed by exploration work; the deposits are separated by a north-east trending fault that forms the elevated Eastern tectonic block — the Eastern horst anticline.

The Vostochnaya Deposit is located within the Eastern and Diabase tectonic blocks. The mineralization of the deposit comes to the surface in the core of the horst anticline, also being exposed in the coastal cliff of the Bezymyannyi River in the north of the structure, and plunging to the south. In the west, the mineralization is limited by a northeast-trending discontinuity; in the

east, it is overlain by deposits of the Taininskaya suite and was traced by drilling to a depth of 290–310 m.

The deposit has a simpler horizontal projection configuration than the Tsentralnaya Deposit and extends in a northeaster direction. The maximum plan dimensions are 870x320 m.

In fact, it is a combination of one powerful (main) ore body that forms the core and wings of a horst — anticline and several thin and non-extended ore bodies that occur mainly above, less often — below the main ore body. The main ore body from the west and east is cut by north-east trending faults and traced behind them by a sparser network of boreholes. The thickness of the body decreases sharply behind the fault in the west and splits into 2–3 separate bodies ("branches") in some lines. On the contrary, to the east, behind the fault, its thickness either remains the same or increases. In resource estimation, the main ore body extensions beyond the faults have been separated into separate extraction blocks.

The right-bank deposit, which is a continuation of the Vostochnaya deposit on the right bank of the Bezymyannaya River, has dimensions of ~ 120x210 m and is also oriented in the northeast (25°) direction.

As a result of the appraisal and exploration work, the previously established mineralization patterns have generally been confirmed. The previously assumed local stratigraphic control of mineralisation by certain members or horizons within the Gribovskaya Formation has not been established.

The morphology of the main ore body for the Vostochnaya Deposit is confirmed, and the continuation of mineralization to a depth on the eastern flank of the deposit, several thin and non-extended ore bodies occurring mainly above, less often under the main ore body, has been established. An extension of the mineralization on the right bank of the Bezymyannaya River (Pravoberezhnaya deposit) has been identified.

Compared with the data of previous studies, the Tsentralnaya Deposit has a more complicated morphology of the deposit and its configuration due to increase of dissociation and number of ore bodies as well as ore bodies detached from the main mineralization and identified by 2014 works on its extreme northeastern and southwestern extensions (Table 1).

*Table 1*

*Average thickness of ore bodies of Vostochnaya and Tsentralnaya deposits by pit wall grades*

| Deposit | *Average thickness of ore bodies* | | | |
|---|---|---|---|---|
| | Pit wall 1.0% | Pit wall 1.5% | Pit wall 2% | Pit wall 2.5% |
| *Vostochnaya Deposit* | 32.25 | 29.8 | 28.2 | 28.3 |
| *Tsentralnaya Deposit* | 12.0 | 10.7 | 11.7 | 11.1 |

Pavlovskoe is classified as a geological-industrial stratiform lead-zinc deposit type in carbonate strata.

The genetic nature of stratiform (confined to lithological and stratigraphic levels) sulfide ore deposits is debatable. There are four prevailing points of view on the formation of ore deposits:

- from buried metal-bearing solutions-brines within the limits of carbonate strata with subsequent post-sedimentary redistribution with the implementation of solutions in the form of subconformable and concordant with the lamination of lenticular-stratal deposits;
- due to deep hydrothermal springs that supplied metal-containing solutions to the bottom of the paleobasin of carbonate accumulation with the subsequent transition of solutions into a gel-like and metacolloidal state with the formation of zoned ore deposits (along the normal to the ore deposit and the stratification of host rocks);
- due to reservoir migration of metal- and bitumen-containing solutions from oil source basins (with predominantly sandy-argillaceous facies) to their sides (with predominantly carbonate rock facies) with the implementation of metal-bearing solutions in the form of subconsistent ore deposits;
- due to hydrothermal metal-bearing solutions metasomatically replacing “favorable” rocks, while the source of such solutions, as a rule, is not established.

The first two points of view assume at least a two-stage formation of ore deposits. The first is at the stages of diagenesis and catagenesis (pre-folded). The second is the subsequent transformation and regeneration of the ore material into syn- and postfold plicative-disjunctive structural traps. In this case, near-ore metasomatic transformations are clearly manifested — dolomitization, calcitization, silicification, etc. Metasomatic changes in ore-bearing rocks are also characteristic of the formation of ore deposits according to elision-catagenetic and hydrothermal models. In addition, ore deposits formed according to these models have a symmetrical zoning along the normal of the ore body (from the axial part of the body to its hanging and recumbent sides).

Based on the studies of the sequence of ore mineral formation and its staging, structural and morphological features of ore minerals, the shape and position of ore deposits in the section, we can draw the following conclusions about its formation.

The ore deposits were probably formed synchronously with sedimentation due to the influx of hydrothermal solutions to the bottom of the paleobasin. Their formation took place in at least three stages.

At the first (sedimentary-diagenetic) stage, pyrite and galena-sphalerite-pyrite ores were formed in favorable facies settings.

Ores were formed from carbonaceous-sulfide-siliceous-carbonate gels. The origin of such gels is synchronous with sedimentation — from the solutions that came to the bottom along the system of consedimentary faults in the peripheral parts of organogenic structures.

The second stage is the repeated redistribution of the ore material during its diagenesis and catagenesis, accompanied by self-cracking of weakly diagenetic and diagenetic sulfide ores

with the formation of intraore breccias and the formation of sulfide minerals of several generations.

The third stage probably associated with ellision-hydrothermal processes during tectonic activation and fixed by “post-ore” fault tectonics and folding, leads to the formation of vein-nested and vein segregations (quartz-carbonate-sulfide, quartz-carbonate, quartz and carbonate compositions). In some cases, such formations compose reticulate-veinlet, stockwork, nested-disseminated and disseminated essentially galena-sphalerite aggregates on a carbonate and quartz-carbonate basis. At the same stage, partial linting and boudinage of ore bodies occur.

### *Qualitative characteristics of mineral resources*

Lead-zinc ores of the Pavlovskoe Deposit are localized mainly in the section of organogenic-riphogenic rocks of the Gribovskaya Formation of the early Devonian.

The Northern ore field includes the zinc occurrence of the Andreevskiy site and the lead of the Severnyy site, associated with mineralized faults.

The Bezymyanskiy ore cluster also includes the Perya, Promyslovoe, Pyritovoe, Daykovoe, and Perevalnaya ore prospective ore occurrences. According to the works of 2013, the prospects for the Perevalnaya area are assessed as negative.

The structure of the Tsentralnaya Deposit shows ore bodies located in clusters on several (from 2 to 5) levels. The length of ore bodies for the 1% slope is from 3.6 to 667 m down dip, 115.7 m on average; the minimum thickness is 0.5 m, maximum in swells — up to 54 m; average thickness (for slope variants from 1% to 2.5%, respectively) is 12.0 to 10.7 to 11.7 to 11.1 m.

For different options for the pit wall grade used for contouring, massive and breccia ores, according to block modeling, are 46% (cut-off 1%), 59% (cut-off 1.5%), 81% (cut-off 2%). The distribution of various morphological types of ores is unsystematic, massive and breccia ores are located both in the lying and in the hanging side, the change of disseminated ores to massive ones and vice versa is often noted along the fall of ore bodies. The average content of standard metal for the deposit for various options for the sides ranges from 3.78 to 6.51%.

The length of the ore bodies of the Eastern deposit for a wall of 1% is from 5.9 to 283.4 m in dip, 110.5 m on average; the minimum thickness is 1.4 m, the maximum is 69.5 m, the average thickness for the deposit is from 1% to 2.5%, respectively, 32.25 – 29.8 – 28.2 – 28.3 m.

For different options for pit wall grade used for contouring, massive and breccia ores, according to block modeling, account for 75% (cut-off 1%), 90% (cut-off 1.5%), 92% (cut-off 2%) of the total volume of ores of the deposit. In contrast to the ore bodies of the Tsentralnaya deposit, massive and breccia ores, which make up most of the ore bodies, are located mainly in the lying side of the bodies, alternating along the normal with vein-disseminated ores, or occupy the entire volume of the body.

The average content of useful components both for individual bodies and on average for the deposit is higher than in the Tsentralnaya deposit for pit wall grades 1%; 1.5%; 2% and practically coincide for the 2.5% bead option.

The right-bank deposit was identified by areal gravimetric works as an intense positive gravity anomaly and was discovered by wells in 2013. It is represented by one ore body that goes under the cover of Quaternary deposits, plunging to the east under the mudstones of the Taininskaya suite (dip angle 45°) according to the bedding and traced by dip 165 m to the horizon — 100 m from the surface. The thickness of the ore body is 11–12 m; from the north, south, and east, the body is bounded by faults. It is composed of massive and breccia ores.

As of February 2021, the resources of Pavlovskoe are estimated at 55 million tons with average zinc content of 4%, metal resources: zinc — 2 million tons, lead — 430 thousand tons, silver — 30.3 million ounces. Such an assessment of mineral resources confirms the status of Pavlovskoe as the country's largest zinc deposit among new projects [17]. The drilling program has provided a reasonable degree of confidence in the Mineral Resource estimate in the open pit zone. Geotechnical drilling with core orientation was carried out.

The resource estimate for the Pavlovskoe deposit is based on open pit contour optimization with a forecast price of $3.145/t for zinc, $2.176/t for lead, and $30/oz for silver. The extraction of zinc is planned to be 90%, the extraction of lead — 53%, the extraction into silver lead concentrate — 33%. Relative zinc (ZnConv) was calculated by the formula ZnConv% = Zn (%) + 0.408 * Pb (%) + 0.003 * Ag (g/t) based on metal prices and metal recovery into concentrate [18].

The average zinc content is 6.32%, lead — 1.26%, silver — 42.57 g/t, with a cut-off content of conventional zinc of 2%.

Table 2 shows the balance and off-balance reserves of minerals of the Pavlovskoe deposit by categories (according to the First Mining Company).

*Table 2*

*Mineral reserves of the Pavlovskoe Deposit*

| Reserve category | Ore reserves, thousand tons | Metal reserves | | | Average content | | |
|---|---|---|---|---|---|---|---|
| | | lead, thousand tons | zinc, thousand tons | silver, tons | lead, % | zinc, % | silver, g/t |
| Balance reserves | | | | | | | |
| B | 5234.68 | 56.92 | 234.40 | 122.04 | 1.09 | 4.48 | 23.31 |
| $C_1$ | 21653.05 | 246.14 | 1090.92 | 418.41 | 1.14 | 5.04 | 19.32 |
| $B+C_1$ | 26887.73 | 303.06 | 1325.32 | 540.45 | 1.13 | 4.93 | 20.10 |
| $C_2$ | 20830.05 | 246.31 | 1162.57 | 654.40 | 1.18 | 5.58 | 31.42 |
| Total | 47717.78 | 549.37 | 2487.89 | 1194.85 | 1.15 | 5.21 | 25.04 |
| Off-balance reserves | | | | | | | |
| $C_2$ | 13461.48 | 107.58 | 531.07 | 239.23 | 0.80 | 3.95 | 17.77 |

A draft was drawn up, including a business plan for the activities of the First Mining Company of the State Corporation Rosatom (based on materials from the First Mining Company).

The Pavlovskoe investment project is aimed at the effective development of a lead-zinc deposit. On the basis of the deposit, a mining enterprise will be created for the extraction and processing of ores with a capacity of 3.5 million tons of ore per year.

The production will consist of two types of concentrate: 1) lead concentrate with silver content; 2) zinc concentrate. Annual production of concentrates is estimated at 260.000 tons for zinc concentrate and 67.000 tons for lead concentrate with silver by-product.

It is planned to build berthing facilities 20 km from the processing plant for loading containers with concentrates onto container ships.

The mining enterprise includes an open pit, a processing plant, a tailing dump, a 30 MW liquefied natural gas power plant, a shift camp, storage facilities and other objects.

The deposit is supposed to be developed on a rotational basis year round. The number of personnel is 436 employees. The duration of development is up to 14 years.

The zinc concentrate is planned to be sold to the Swedish concern Boliden, which has subsidiaries in Norway, Finland and Sweden; lead concentrate — to Chinese state-owned company Chinalight Resources Imp.&Exp. Corp.

Alternatively, concentrates could be sold to commodity trader Glencore International AG.

Commodity trader Trafigura has proposed an option for pre-paid supplies, which may be considered after the start of construction of the Pavlovskiy Mining and Processing Plant.

The project's further implementation strategy includes design and survey work and construction and installation work on the deposit's facilities.

Design and survey work includes engineering investigations and the development of design documentation for the construction of a mining and processing plant; the necessary approvals and examinations of the design documentation; and the development of detailed design construction documentation.

The construction of port and its facilities is envisaged: backfilling of a highway and organization of a base in the construction area; arrangement of a temporary storage of fuel and lubricants with a total capacity of 2000 $m^3$ using flexible storage tanks; backfilling of the approach dam of the protective structure and the site of coastal structures; construction of a temporary floating berth for reloading construction and quarry equipment and oil products.

The purpose of the main construction phase is to commission the mining and processing facilities. An open pit diverter, a dam on the Bezymyannaya River and a drainage canal of the Bezymyannaya River should be built for mining facilities.

At the time of writing the business plan (March 2016), the main components of the project technology were identified for the basic option as one of the most cost-effective: open pit mining; processing of lead-zinc ores by the flotation method to obtain lead and zinc concentrates.

The deposit development system is transport, deepening, longitudinal, single-sided for the Central and Southern pits and double-sided for the Eastern pit, with the movement of overburden

by vehicles to dumps, with external and possible internal dumping in the worked-out area of the Central pit (on the gentle western side) and the Southern pit.

This system is the most suitable for the specific mining and geological conditions of the Pavlovskoe deposit.

The general direction of mining operations is taken in accordance with the direction of deepening, horizontal ledges, longitudinal penetrations when performing overburden and mining operations. Mining equipment for quarrying is adopted according to the scale of mining operations.

The technological scheme provides for mining in ledges 10 m high in overburden operations, and 5 m high in ore mining (in order to minimize losses and impoverishment). When approaching the limiting boundaries of the quarry, the working ledges are repaid — they are doubled or built with one 20 or 30-meter ledge, respectively, with a stable offset angle.

The structure of complex mechanization of mining processes is provided with the use of mining (drilling and excavation-loading) equipment with an electric drive.

The excavation of cover semi-rock overburden (to the level of bedrock) is planned to be carried out with a front loader with preliminary preparation of the rock mass for excavation by mechanical means — preliminary loosening with the help of a ripping-bulldozer unit, followed by stacking and loading by a loader into vehicles.

The rock mass (bedrock) is excavated by means of drilling and blasting preparation for extraction.

The mined ore is transported to the warehouse of the processing plant, located to the west of the Central pit (1.25 km).

Overburden rocks are transported to rock dumps. The stockpiles are bulldozed.

### *Mining processes*

The following drilling machines will be used for blast-hole drilling:

- overburden works (electric drive) — machine tool 4SBSH-200-40, bit diameter 215.9 mm;
- mining (electric drive) — machine tool SBU-100GA-50, pneumatic hammer P-110 (or P-130), drill bit diameter 110 mm.

Wells with a diameter of 216 mm are used in drilling and blasting operations on overburden with a ledge height of 10 m; wells with a diameter of 110 mm are used in the extraction of minerals. For the ores of the Pavlovskoe deposit, it is possible to use the Poremit emulsion explosive.

Rock mass loading after the explosion during the mining is carried out by a mining hydraulic excavator Komatsu PC750SE-7 “backhoe” with a bucket capacity of 2.8 m3 with the possibility of replacing it with a bucket of 4.5 m3 “front shovel”. Loading is planned in 30-ton BelAZ-7540 dump

trucks. On the overburden, a EKG-10 “straight shovel” mining excavator with a bucket capacity of 10 m3 will be used. Loading will be carried out in 90-ton BelAZ-7557 dump trucks.

### *Current state and mining technology*

It is planned to develop the reserves by open-pit mining method. Ore enrichment will be carried out at the concentrating plant, designed at the deposit, with the production of lead and zinc concentrates separately. The design capacity is at least 2000 thousand tons of ore per year.

As of February 2021, the reserves of the Pavlovskoe deposit are accounted for at 55 million tons (with a zinc concentration of 4%), metal reserves: zinc — 2 million tons, lead — 430 thousand tons, silver — 30.3 million ounces.

A mining and processing plant will be built to produce ore concentrate. In November 2020, the PKRK entered into a preliminary agreement with the Finnish company Metso Outotec for the design of a floating processing plant.

Estimated date for the mining and processing plant to reach industrial volumes is 2024.

One of the authors of this article Ushakova V.A. within the framework of the graduation project, defended on February 3, 2022 at the Northern (Arctic) Federal University, proposed the following option for the Pavlovskoe field development.

The deposit development system was determined by Sheshko E.F. The system is referred to group B with longitudinal (frontal) movement of rocks into disposal areas by means of vehicles; the B-5 system is provided with rock transportation to external disposal areas.

N.V. Melnikov’s mining system is defined as a transport mining system where overburden rocks are transported to external dumps by means of motor vehicles.

V.V. Rzhevskiy’s development system is a deepening longitudinal single-side system.

The development of the deposit will be carried out in two stages with ledges 20 m high and with preliminary loosening of minerals, overburden rocks using drilling and blasting.

The first four ledges have a height of 10 m, since the first 40 m are more subject to deformation displacement; there are interlayers of weaker rocks at this depth undergoing annual freeze-thaw cycles, which also reduces the strength characteristics of the rocks. In addition, once the field is completed, the first lower benches will be easier to reclaim (Fig. 1).

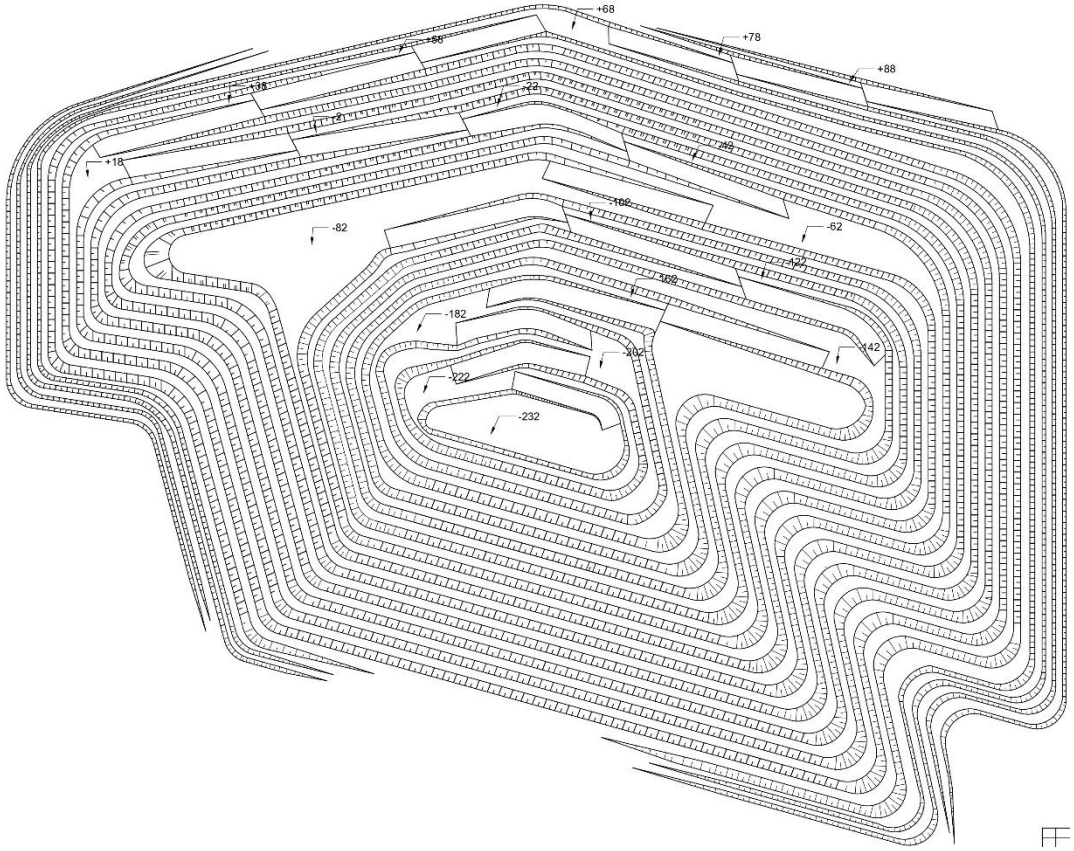


Fig. 1. The final contour of the open pit of the Tsentralnaya Deposit (executor Ushakova V.A.).

The projected concentrator is designed to process silver-bearing lead-zinc ores from the Pavlovskoe deposit to produce two types of commercial products — lead and zinc flotation concentrates. The processing plant will have a capacity of 3.5 million tons of raw ore per year.

To average the ore and to ensure its uninterrupted supply to the plant, it is planned to locate two stockpiles of commercial ore with a capacity of up to 150.000 tons each.

The initial ore is transported from the stockpile by a slatted feeder to a jaw crusher with a feeder opening.

Crushed ore with grain size of 0-250 mm (P80 — 152 mm), together with spills from the apron feeder, is delivered via a conveyor gallery to the intermediate ground stockpile of crushed ore. Ore from the intermediate storage of crushed ore through the conveyor gallery enters the grinding department.

The main lead flotation feed is the hydrocyclone overflow from the grinding section. Before the ore is fed into flotation, it enters the operation with reagents and with additional air supply to enhance pyrite depression. The tailings of the 1st and 2nd main lead flotation are sent to the check flotation, and the concentrate is fed to the sump, after that it is pumped to the 1st cleaning lead flotation. Lead control flotation tailings will be directed to the main zinc flotation.

The main zinc flotation is fed by the combined tailings of the lead flotation section. The main zinc flotation concentrate goes to the 1st cleaning zinc flotation, and the tailings are sent to the control zinc flotation.

The thickening section provides for the installation of two radial thickeners for the commercial concentrates of the lead and zinc flotation sections. Filtration of lead and zinc concentrates is carried out in chamber press filters.

To ensure stable, uniform and trouble-free operation of the concentrating plant, a system is provided for distributing automatic control over the technological parameters of equipment and automated control of technological processes based on logic controllers (DCS) with the output of all indicators and control actions to the central control room. The system is aimed at compliance with regime parameters and prevention of emergencies associated with equipment failure and violations of the technological regime.

The priority status of the Pavlovskoe project will provide further support and assistance to the Arkhangelsk Oblast authorities at all stages of its implementation. It provides for the granting of income tax and corporate property tax exemptions for JSC First Mining Company in the amount of about 500 million rubles. Successful implementation of the project, along with a contribution to the socio-economic development of the Arctic territories of the country, will increase the gross regional product of the region and create more than a thousand new jobs [7, Evdokimov A.N., Kalenich A.P., Kryukov V.D., Lastochkin A.V., Semenov Yu.P.].

### *Lead-zinc ore occurrences on Novaya Zemlya*

The Severnoe and Perevalnoe ore occurrences are located near the Pavlovskoe Deposit.

The northern ore field has not yet been studied enough, but it is promising for the extraction of lead-zinc ores. Average zinc content ranges from 32 to 58%, and lead — from 10 to 30%. The ore minerals sphalerite and galena do not form aggregates in the rock, but are located separately. Such a textural feature of ores can be used in the selective development of a deposit and subsequent enrichment of ores. The resources of the Severnoe ore field are taken into account in the amount of more than 5 million tons of zinc and about 1 million tons of lead.

The Perevalnoe ore field is located 20 km northeast of the Pavlovskoe Deposit. According to geophysical data, the ore bodies of the Perevalnoe field are similar in size to the deposits of massive lead-zinc ores of the Pavlovskoe Deposit. A two-tier ore deposit with a thickness of 25 to 50 m was identified on an area of 3 $km^2$.

JSC First Mining Company is going to continue exploration work on new areas. The discovery of zinc and lead deposits in the archipelago is quite likely. The Shumilikhinskiy mineralization is known on the Yuzhnyy Island, which covers an area of 1.2 $km^2$, where several ore deposits 1–3 m thick and tens of meters long have been found. The contents of zinc range from 1.2 to 24.89%, lead grades from 1.0 to 14.33% [6, Wittenburg P.V.].

### *Lead-zinc deposits and ore occurrences on Vaygach*

Lead-zinc deposits Krasnoe and Razdelnoe are known on the southwestern coast of Vaygach Island within the Lyamchinskiy ore cluster. In 1930s, ore was mined there by Gulag prisoners. The lead-zinc ore occurrences of Paygoto, Talata-Sale and Tsinkovyy Nos have been record-

ed. Zinc reserves at Vaygach are 9.0 thousand tons of C2 category, zinc resources: 22.8 thousand tons — P1, 705 thousand tons — P2, 3400 thousand tons — P3. Lead resources on Vaygach Island amounted to 0.5 thousand tons — P1, 68.0 thousand tons — P2, 260.0 thousand tons — P3. The ores contain impurities of silver, cadmium, germanium, gold. In total, the resources of various categories of zinc and lead on Vaygach Island reach 4 million tons.

### *Lead-zinc occurrences in the Northern Timan and Amderma areas of the Nenets Autonomous Okrug*

On the Northern Timan, small occurrences of lead and zinc are associated with greisenized pegmatites. Ore occurrences are disseminated galena, pyrite, chalcopyrite, molybdenite, pyrrhotite, sphalerite, pyrochlore and fluorite. The lead content ranges from 0.001 to 1.0%; zinc reaches up to 0.05%; copper — 0.005–0.01%. The total thickness of the mineralization zone is 16.5 m with an average lead content of 0.12%; zinc — 0.017%, cerium — 0.046% and lanthanum — 0.052%. Dense phenocrysts and nests of galena up to 5 cm in size are observed in mica at Malyy Rumyanichnyy Cape. Lead content is 0.61%, zinc — 0.18%, molybdenum — 0.02% with a thickness of the ore zone of 0.5 m. Mineralization confirmed by boreholes to a depth of 142 m [17, Plyakin A.M., Belyaev V.V.]. In Northern Timan, the zinc ore occurrence has been estimated to have a P2 resource of 700 thousand tonnes [6, Wittenburg P.V.].

Ore occurrences of copper-nickel ores are known in the Northern Timan [28, Danilov M.A., Ermolenko Yu.P., Skripnichenko V.A.], which were discovered by exploratory boreholes in gabbroid rocks. Copper resources in the Ruchievskaya area are estimated at 800 thousand tonnes in category P2. Nickel resources in the Bugrovskaya area are evaluated as 7.5 thousand tons P1, 23.7 thousand tons P2, 2000 thousand tons P3. Apatite-titanium-vanadium ores are discovered by wells within the layered gabbro-syenite complex of Northern Timan [29, Danilov M.A., Skripnichenko V.A.]; they can be mined in a complex with other minerals.

The **Amderminskoe** Deposit of fluorite, lead and zinc is known near the village of Amderma on the coast of the Kara Sea (Northern Pay-Khoy). Since 1932, ores have been mined at the deposit; the deposit has been mothballed since 1951. Ores are composed of fluorite and fluoritized limestones bearing sulfide (sphalerite, galena, pyrite) dissemination. The content of zinc is 0.33–1.11%, lead is 0.2%; at a depth of 100 m, the content of lead and zinc in total reaches 1.5%. Lead and zinc resources have not been estimated. Mining operations can be organized at the Amderminskoe field. Transportation of complex lead-zinc-fluorite ores will be carried out through the seaport of Amderma.

Employees of the Institute of Geology of the Komi Scientific Center of the Russian Academy of Sciences determined the value of reserves and resources of solid minerals in billion rubles: 1) in the subsoil of the Nenets Autonomous Okrug (Northern Timan), reserves + resources (P1 + P2) of zinc — 26 billion rubles; 2) in the subsoil of Vaygach Island, reserves + resources (P1 + P2) of zinc — 13 billion rubles, lead — 0.7 billion rubles [6, Wittenburg P.V.].

### *Lead-zinc deposits and ore occurrences in the Polar Urals*

The **Saureyskoe** lead-zinc deposit, discovered in 1967, is defined by its genesis as a stratiform telethermal regenerated deposit. The area is promising for the discovery of new ore deposits based on lead and zinc occurrences.

The Saureyskoe Deposit of lead ores is located in the Priuralskiy District in the upper reaches of the river Malaya Khuuta, 70 km northwest of the Obskaya-Bovanenkovo railway. The average copper-zinc-lead ore composition is 6.18% lead, 0.15% zinc, 0.059% copper. The reserves of the Saureyskoe Deposit are estimated at 2898 thousand tons of ore in category C1, (lead — 182.1 thousand tons, zinc — 9.0 thousand tons); 2578 thousand tons of ore in category C2, (lead — 144.6 thousand tons, zinc — 12.5 thousand tons).

A geological report was compiled by the Saureyskoe geological prospecting party (authors B.S. Kotelnikov, B.V. Malivanchuk, V.V. Donchak and others) was compiled based on the results of the works. Additional exploration work is required. The subsoil user of the Saureyskoe Deposit is CJSC Nefteresursy, which carries out exploration and mining of lead ores in the Saureyskoe ore field (License СЛХ 02276 ТЭ dated 10/11/2010). The mineralization zone of the deposit was traced for 1400 m, fixed at 200–700 m — along the dip with a width of about 100 m. There are 13 ore bodies in the Main and Eastern ore zones of the Saureyskoe Deposit.

The main ore minerals on the deposit are sulphides: galena, sphalerite, tetrahedrite, sulphate-baryte; pyrite, chalcopyrite, arsenopyrite, bournonite; copper green, cerusite, anglesite and smithsonite are found in the oxidation zone.

The reserves of the Saureyskoe Deposit are accounted for in categories C1+C2: ore in the amount of 6100.7 thousand tons, including lead — 357.6 thousand tons (content 5.86%), barite — 596.6 thousand tons (content 9.78%), zinc — 28.8 thousand tons (content 0.47%), silver — 183.6 tons (concentration 30.1 g/t), gold — 0.378 tons, copper — 1700 tons, cadmium — 278.6 tons, antimony — 236.4 tons [5, Kontar E.S.].

There are several ore occurrences on the flanks of the Saureyskoe Deposit: Novoe, Yuzhnoe (Tsinkovoe), Orangskoe, Spokoynoe, Pridorozhnoe, Svintsovoe.

The development of the Saureyskoe field is hampered by the lack of roads. The site is located on the banks of the Malaya Khuta River, which flows into the Baidaratskaya Bay, 70 km from the Obskaya-Bovanenkovo railway.

On the Taimyr Peninsula in the Krasnoyarsk Krai, the Partizanskoe deposit is represented by sphalerite-galena-siderite veins with a strike of 2–3 km. The average thickness of the veins ranges from 1.1 to 1.5 m, the content of zinc and lead in the ore reaches 4%; the admixture of silver is 800 g/t. The deposit is considered to be a promising ore-mining target, as it is located near the Nizhnyaya Taymyra River.

### *Conclusion*

The sites associated with mining in the Arctic are of strategic importance for strengthening the country's national security.

Lead-zinc deposits and ore occurrences in the Russian Arctic are located on the Novaya Zemlya archipelago, on Vaygach Island, in the Polar Urals and Northern Timan.

The Pavlovskoe Deposit on Novaya Zemlya is ready for development with an investment volume of 71 billion rubles. PGRK should receive 7 billion rubles from the budget as a subsidy for the construction of infrastructure facilities. Tax deductions will amount to at least 43 billion rubles for the development period. The company completed the calculation of ore reserves, carried out engineering surveys, and designed the mine and port complex.

Pavlovskoe mine will annually produce up to 47 thousand tons of lead and 223 thousand tons of zinc concentrates. Domestic and major foreign industrial groups have expressed interest in the production.

The deposit developers can achieve economic efficiency at the expense of open-pit mining with low stripping ratio, due to high metal content in ore (5.21% zinc, 1.15% lead), by using innovative technological solutions, for example , installation of an enrichment plant on a floating platform. The project is being implemented with the Finnish company Outotec.

The next most promising site is the Saureyskoe Deposit in the Polar Urals. The problem in developing the field is its remoteness from transportation routes. The field is located 70 km northwest of the Obskaya-Bovanenkovo railway line, so it is necessary to plan the construction of a road from the field to the railway. Cargo could then be shipped to the ports of the Gulf of Ob or Indiga, when it is put into operation.

Deposits of lead and zinc on Vaygach Island and on the shore near Amderma have been previously mined. It is necessary to re-evaluate their reserves and identify possible development options. Transportation of mined ore will be carried out through the port of Amderma.

In the Northern Timan, the reassessment of the reserves of non-ferrous metal ores should be carried out as a whole (lead, zinc, molybdenum, copper, nickel). Mining of ores may be feasible in connection with the construction of the deep sea port of Indiga, which is planned to be located several kilometers from non-ferrous metal ore occurrences.

Thus, the lead-zinc deposits of the Arctic territories of the Timan-Severouralsk region, including the Novaya Zemlya archipelago, Kolguev Island, the Polar Urals and Northern Timan, can be combined into a mineral resource center of great economic importance for Russia.

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