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ASSESSING THE RESOURCE POTENTIAL OF COBALT-NICKEL DEPOSITS DEVELOPMENT IN UKRAINE

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ОЦІНКА РЕСУРСНОГО ПОТЕНЦІАЛУ РОЗРОБКИ КОБАЛЬТ-НІКЕЛЕВИХ РОДОВИЩ В УКРАЇНІ

Purpose. Assessment of the current state and prospects for the development of cobalt-nickel ore deposits in Ukraine to supply the European Union countries and global industry with critical mineral raw materials.

Methodology. The work used a set of research methods: generalization – systematization of information about global production and demand for cobalt–nickel raw materials; analogy and comparison to determine the distribution of cobalt and nickel in deposits; analysis and synthesis to substantiate the feasibility of involving existing deposits of critical raw materials in development.

Findings. The dynamics of cobalt and nickel mining worldwide, as well as changes in their market value over the past fourteen years, have been established. The mining and geological characteristics of the largest cobalt–nickel deposits in Ukraine were studied, which makes it possible to focus attention on increasing the efficiency of technologies for extracting valuable components, since at present the mining of this raw material in the country is economically unprofitable due to its high cost. The main directions of global use of cobalt and nickel in high-tech sectors of the economy, including the production of alloy steels and batteries, were considered. Estimated reserves of cobalt and nickel in the most significant deposits of Ukraine were determined. The approximate content of cobalt and nickel in the ores of these deposits was established, which makes it possible to outline further prospects and the investment attractiveness of developing this critically important raw material in Ukraine.

The originality. The dependence of global nickel and cobalt production on the prices of these critical elements during the period from 2010 to 2023 has been established. For the first time, a classification of cobalt–nickel deposits has been carried out with the identification of the most significant deposits of critical mineral raw materials in Ukraine from which nickel and cobalt can be extracted. The necessity of further research into deposits in Ukraine has been substantiated in order to identify new occurrences of cobalt–nickel deposits and expand their existing list.

Practical implications. It has been determined that Ukraine has sufficient potential for the development of cobalt–nickel deposits by deposit types. At the same time, for their effective utilization, it is necessary to create a modern geological database, develop and implement advanced beneficiation technologies, attract investment under conditions of a transparent market, and organize a closed production cycle.

Keywords: *critical raw materials, cobalt-nickel deposits, assessment, mining, resource supply.*

Introduction. World nickel reserves are estimated at 210 million tons, while the US Geological Survey (USGS) estimates that ores with a content of more than 1% amount to 130 million tons of the metal. It is worth noting that significant reserves of nickel have been found at the bottom of the world ocean in iron-manganese formations, which, according to forecast estimates, amount more than 680 million tons with an average content of 0.5–1.3%.

According to the estimate of the USGS global nickel production in 2021 amounted to 2.7 million tons, which is 8% higher than the previous year. The first place in the world in terms of nickel production is held by Indonesia with an indicator of one million t/year, and in second place are the Philippines with an output of 370 thousand t/year [1]. The growth dynamics of the global volume of nickel development and its market price [2] is presented in fig. 1.

The main consumers of nickel in the world are countries with high-tech sectors of the economy, especially the USA, South Korea, Japan and China. Most of the nickel raw materials are used in mechanical engineering, construction, chemical industry, etc.

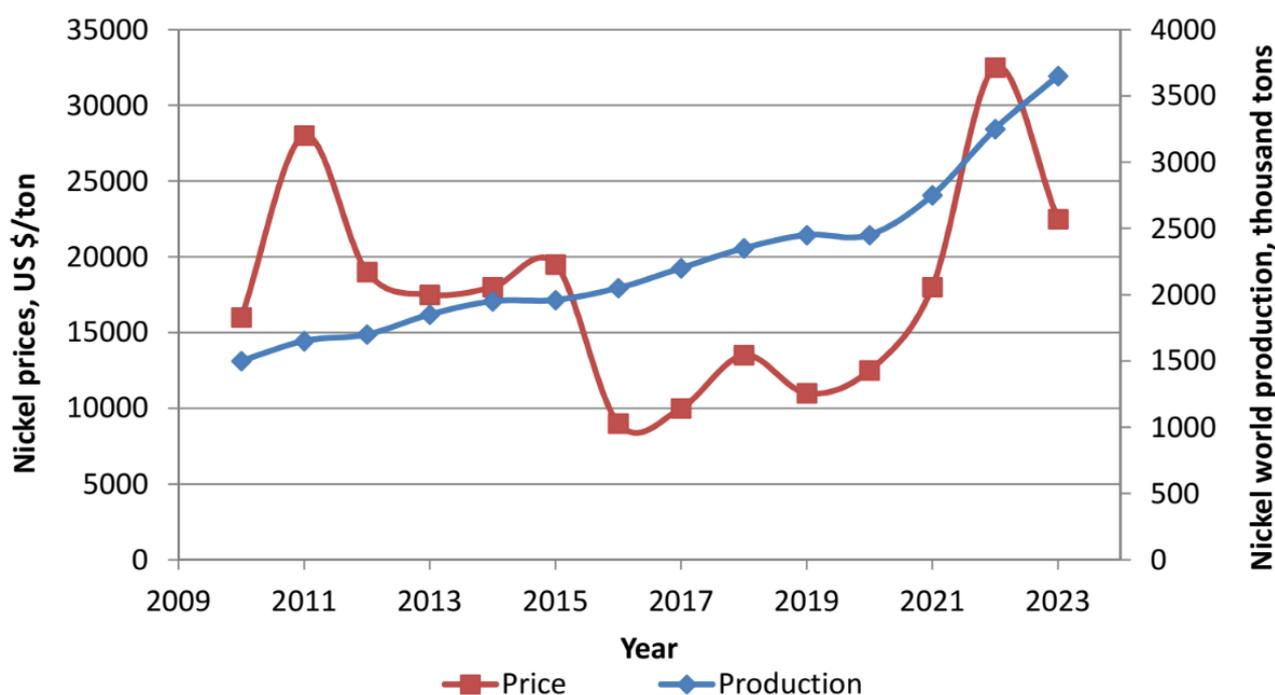


Fig. 1. World production and price of nickel in the period 2010–2023

The world experience of nickel deposits developing shows that development of the mineral is carried out by surface and underground mining methods [3]. Since nickel deposits are located in bedrock, preparation for excavation and loading works [4] is carried out by drilling and blasting. Underground mining [5] is carried out at a depth of more than 1,000 m and methane can be formed in mining operations [6].

The dynamics of changes in the value and indicators of global nickel production, shown in Fig. 1, allows asserting a constant increase in the production volume of this critical raw material. Over the past 14 years, nickel production has increased 2.4 times from 1,500 to 3,650 thousand tons. Despite the steady increase in demand, its value has undergone significant changes, and its maximum values were observed in 2011 and

2022 and exceeded 32,000 US \$/t, while in 2016 it decreased by 3 times to 9,000 US \$/t. The dynamics of nickel price changes in largely coincides with the cost of some critical materials used in the manufacture of lithium batteries [7], and is constantly changing despite the gradual increase in global production [8].

According to the USGS, global cobalt reserves amount to 7.1 million tons. The largest cobalt reserves have been explored in Australia – 1.2 million tons. Cuba is in second place with 490,000 tons. The top three is Congo with cobalt reserves of 310,000 tons. t. According to information from battery manufacturers, today the percentage of cobalt consumption by this industry is 42%. World practice shows that cobalt production depends on the copper and nickel market, as it is developed in 98% of cases as a secondary raw material of these deposits, which are developed by surface and underground mining methods [9].

Today, Congo is the world leader in cobalt mining with 70% of the total volume. Cobalt is mined as a secondary raw material at copper mines developed in various ways. It is worth noting that a significant part of cobalt (up to 14% of the World's) is mined in the artisanal mines of the Congo, where the work is performed without mechanization. This leads to significant casualties due to the collapse of unsecured mine workings. Up to 200,000 local residents work at such mines.

It is should be noting that Australia is the country with the greatest potential for growth in the volume of cobalt mining. To date, more than 70 projects for the development of this critical raw material have been approved and are awaiting implementation. This involvement will allow the country with the largest cobalt reserves to lead the ranking of producing countries.

The growth dynamics of the cobalt mining global production [10] and its market price [11] is presented in fig. 2.

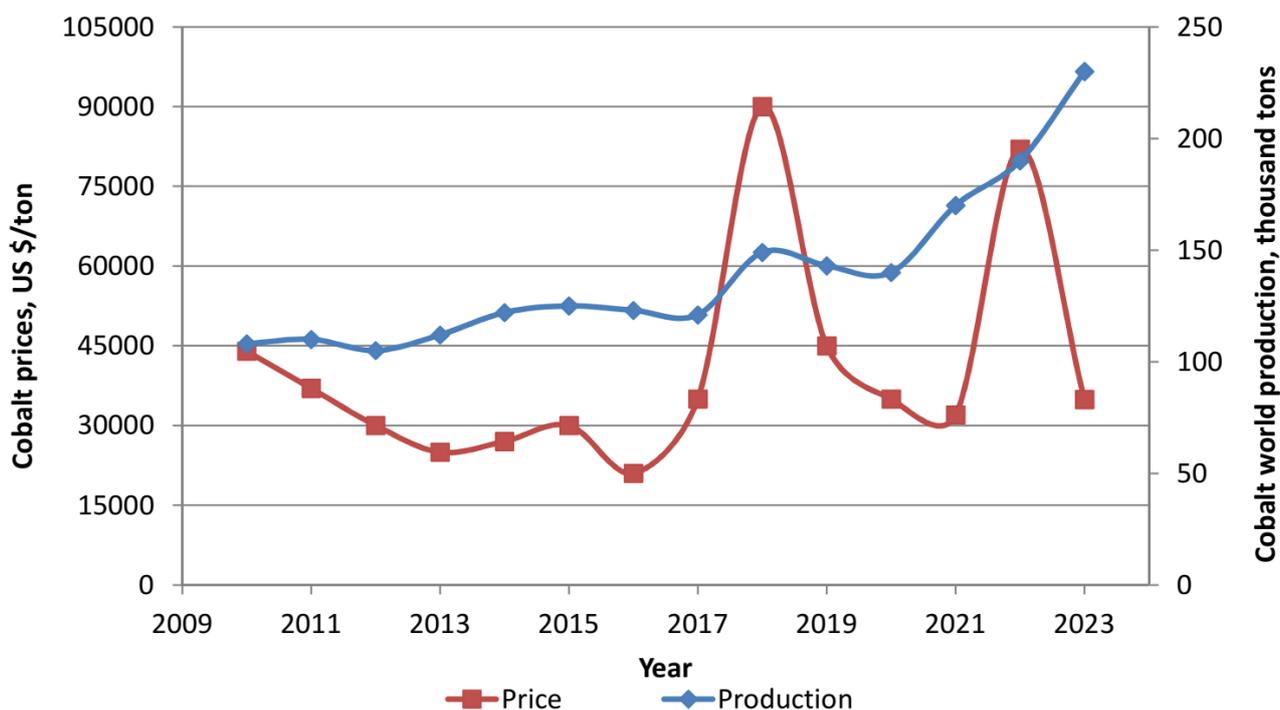


Fig. 2. World cobalt production and market price in the period 2010–2023

Analysis of the changes dynamics in the price and volumes of world cobalt production, shown in the graph (see. fig. 2), allows to state that the growth trend in production volumes is similar to that of nickel. Since 2010, this indicator has increased 2.1 times from 108 to 230 thousand tons. However, unlike nickel, the increase in the cobalt price is atypical for other critical minerals [12], since the maximum value of 90,000 US \$/t was reached in 2018 year, while the minimum recorded in 2016 was 21,000 US \$/t. The sharp increase in the price in 2018 is associated with problems with the supply of these critical raw materials from the DR Congo and a reaction to the growth of the electric vehicle market [8] and the corresponding risks. The increase in the cobalt cost in 2022 and fall in 2023 is typical of different critical mineral raw materials used in the production of electric vehicles.

Purpose. Assessment of the current state and prospects for the development of cobalt-nickel ore deposits in Ukraine to supply the European Union countries and global industry with critical mineral raw materials.

Methods. The work used a set of research methods: generalization – systematization of information about global production and demand for cobalt–nickel raw materials; analogy and comparison to determine the distribution of cobalt and nickel in deposits; analysis and synthesis to substantiate the feasibility of involving existing deposits of critical raw materials in development.

Analysis of mining and geological conditions of cobalt-nickel ore deposits and their development. Sulphide copper-nickel deposits have a fairly small distribution, which is determined by the conditions of their formation – on tectonically activated platforms in massifs of basic and ultrabasics rocks. The analysis of geological and localization structural features also indicates a certain endogenous and geodynamic regime of the massif in various structures of the earth's crust. The location of industrial deposits is determined by structural and tectonic conditions of two types: 1) regional deep faults in hard consolidated blocks of the earth's crust; 2) zones of high dynamic activity within cratons and ancient platforms with a tectonic regime characteristic of rift zones. Examples of sulfide deposits are Sedbury (Canada), Insizwa (South Africa), Kambalda (Australia) [13].

One of the important regularities of the localization of copper-nickel sulphide deposits is a clear evolutionary trend in the distribution of different types of mineralization and associated ore-bearing magmatic formations. This is reflected both in the general evolution of nickel-bearing intrusive-volcanic and intrusive-dyke belts from the Precambrian to the Mesozoic, and in the development of the belts themselves and their corresponding ore-bearing structures.

Based on the analysis of natural paragenesis, it can be asserted that in genetically uniform systems there is a wide range of the composition of sulphide solutions, which is the main factor in the location, zoning, and hidden layering of sulphide mineralization intrusive. For a number of deposits, the very significance of the regional metamorphism processes, which is manifested in the redistribution of magmatic ore raw materials and the averaging of the composition of sulphide associations, has been determined.

Accordingly, silicate (or laterite) nickel deposits of the weathering crust are distinguished, which develop during laterite weathering of basic and ultrabasic rocks (Pobuzhja and Dnieper deposits of Ukraine, a number of deposits in Cuba, Australia, Indonesia, Brazil). As a result of the analysis of their formation, geological structure and forms of occurrence, three main morphological types of weathering crust deposits are distinguished: square, linear, linear-square.

It should be noted that cobalt is considered as an accompanying raw material, because the intermediate position of cobalt between iron and nickel, under conditions of relatively small distribution, is not favourable for the formation of isolated accumulations of this metal. However, there are cases when the natural state can lead to a fairly complete separation of cobalt from nickel or a change in quantitative ratios to a sharp predominance of the former over the latter. To date, no independent cobalt deposits have been discovered in Ukraine.

In general, several stages are distinguished in the formation of nickel-bearing igneous rocks complexes [14]: multiple outpouring of lava and the formation of layers of volcanogenic and volcanogenic-sedimentary platform rocks; formation of interlayer ore-bearing intrusions; formation of dykes of the main composition [15].

Within the boundaries of the Ukrainian Crystalline Shield, ultramarphite-mafite formations are developed, which in terms of geodynamic modes of formation, geological-structural and geochemical characteristics are similar to nickel-bearing complexes known in the world. Due to the geological and structural analysis, a number of additional signs of similarity between the areas where komatiite content is developed and the known Archean nickel-bearing greenstone belts, including a wide distribution of volcanic-intrusive structures of ultramafic-mafic composition within the Middle Pobuzhie, significant capacities of metavolcanites komatiite series and detection of local sulphide copper-nickel mineralization, for example in the Demovyarivska area. This mineralization is attributed to the contact of pyroxenite and peridotite komatiites, which formed a rather powerful flow (up to 200 m). The ore body is formed by interspersed and interspersed perlandite-chalcopyrite-pyrrolite ores, with the corresponding content of nickel – 0.44%, copper – 0.15%, cobalt – 0.034%. In the same section, numerous occurrences of pyrite (pyrite-pyrrotine) in komatiitakh pyroxenitic ores were established.

Deposits of silicate nickel in Ukraine were explored by geologists as early as the 50s of the last century. At the same time, 2 main groups of deposits were distinguished: Pobuzka (Pushkivske, Lypovenkivske, Kapitanivske, Derenyuhinske, Hrushkivske, Ternuvatske) and Devladvivska (Devladvivske, Karnaukhivske, Sukhokhutirsk and Ternivska pack of ultrabasite).

According to open sources of information, a map of the most promising cobalt-nickel ore deposits of Ukraine for development was created (fig. 3).



Fig. 3. Prospective deposits of cobalt-nickel ores in Ukraine:
 1 – Devladvivsk; 2 – Karnaukhivsk; 3 – Sukhokhutirsk; 4 – Zhelezniaky site; 5 – Lyovenkivsk; 6 – Kapitaniivsk

Regarding the location and general characteristics of the Pobuzka group of deposits (which includes the Lypovenkivske, Derenyuhinske, Hrushkivske and Ternuvatske deposits) – ore bodies are presented with a thickness of 1 to 9 m, are square in shape, and can reach up to 1900-2000 m in length and width – up to 450–500 m. Ternuvatske is considered the most promising deposit of this group with an average nickel content of up to 0.91% in the ore-bearing weathering crust. Cobalt, as an accompanying component, is found in almost all nickel-bearing formations, in most of them with industrial concentrations [16].

The Devladiivka zone and adjacent areas are promising within the Ukrainian shield, where syngenetic perthlandite-chalcopyrite-pyrrhotite mineralization is recorded in weakly altered peridotites and gabroids. In addition to manifestations of sulfide-nickel mineralization, some intrusions of the Dnipro block under the Cenozoic sedimentary cover contain linear and linear-planar nickel-bearing weathering crusts with industrial concentration of the metal.

Accordingly, in the Middle Dnieper region there are deposits related to the weathering crust of serpentinites, for example, the Devladiivske, Karnaukhivske, Sukhohutirskе and Ternivske deposits. The Devladiivske and Sukhukhutirskе deposits are characterized by an average nickel content of 1.0-1.24%, which can reach 2% in some areas, and cobalt, respectively, up to 0.05%. On the contrary, the Karnaukhivske deposit has a lower percentage of nickel content (0.94%) and a higher percentage of cobalt [15]. There are also a number of ore occurrences in this area, classified as dykes archaean ultrabasics, for example, Varvarivskiyi, Vilkokhutirskiyi, etc. are potentially interesting for more detailed study for cobalt content.

When consider the overall nickel bearing of the Ukrainian Shield, it is also promising to consider sulphide mineralization in the gabbro-pyroxenites of the Azov region, belonging to the gabbro-werlite formation. Also, the north-western part of the Ukrainian shield (Zaliznyansky, Prutiv and Kamian massifs), represented by the Prutiv complex consisting of gabbro, gabbro-peridotites and other basite-ultrabasite formations, are promising for research on cobalt-nickel mineralization.

Use of cobalt and nickel in high-tech production processes. Nickel is quite widely used in various fields of industry due to its anti-corrosion and operational properties. Its strength increases at high temperature, plasticity allows to reduce destruction during impacts and mechanical loads [16] (fig. 4). It also has a shiny attractive appearance [17].

Electroforming should be singled out as one of the main areas of use. This technology combines the use of nickel chloride and nickel sulphate to produce with a high degree of protection stamps, postage stamps, banknotes, official documents, waveguides for radars, etc.

Strong and bright coins are quite often made of nickel-plated steel, which conveys high detail and clarity with intensive use for decades. Vending machines contain a magnetic nickel-plated signature in their design to determine the authenticity of currency units.

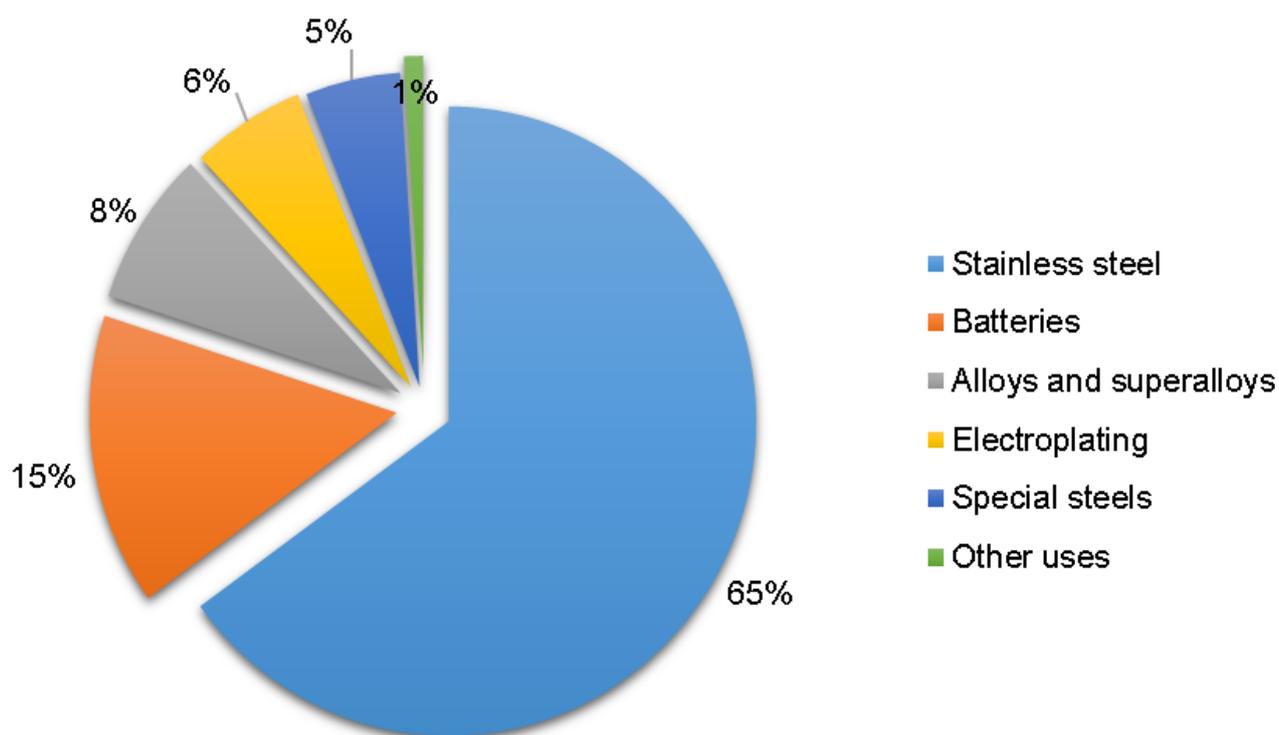


Fig. 4. Nickel demand by application in 2023

The automotive industry takes a leading place in the use of nickel-plated metal, namely plating and electroplating [17]. By covering such a non-ferrous metal as aluminium, it is possible to ensure durability and aesthetics. Equally important is the combination of zinc and nickel. Such a coating will protect fasteners, bolts and components from salt mist and corrosion. Nickel-plated metal is widely used in automatic car transmissions, hydraulics, brakes and various engine parts. The minimum thickness of zinc-nickel plating provides maximum thermal and corrosion resistance [18].

Nickel plating in the aerospace industry is extremely relevant, especially in the period of martial law, for increasing the state's defence capability. Strict standards for materials and coatings are the basis for ensuring high-quality maintenance and manufacturing of flying machines while maintaining high adhesion, wear resistance and hardness [19].

Plating also has found its use in electronics in the manufacture of microprocessors, integrated circuits, contacts and connectors to ensure the reliability and functionality of such products. When soldering metals, nickel creates a barrier layer to prevent metal migration and short circuits.

It should also be noted the use of nickel as a catalyst during hydrogenation in the petrochemical industry. Nickel-hydrogen and nickel-cadmium batteries are made of metallic nickel as a reliable chemical energy source that ensures efficient operation of phones, laptops, etc. Nickel is also found in the manufacture of water faucets, dishes and tableware. Construction and marine equipment, motorized vehicles and jet engines contain various combinations of metallic nickel [19].

Some nickel alloys are biologically compatible, that is, they are tolerated by the human body without harm to health, which allows it to be used in the manufacture of medical devices, implants and cardiovascular stents.

Cobalt is using in modern electric cars, smartphones and aircraft engines due to its wear-resistant and heat-resistant properties (fig. 5). Therefore, the main areas of its use are aviation, mechanical engineering and electronics. Traditionally, it is used for alloying steel or as a petrochemical catalyst. At the same time, the constantly growing demand for electric vehicles makes it one of the main elements of the periodic table [20].

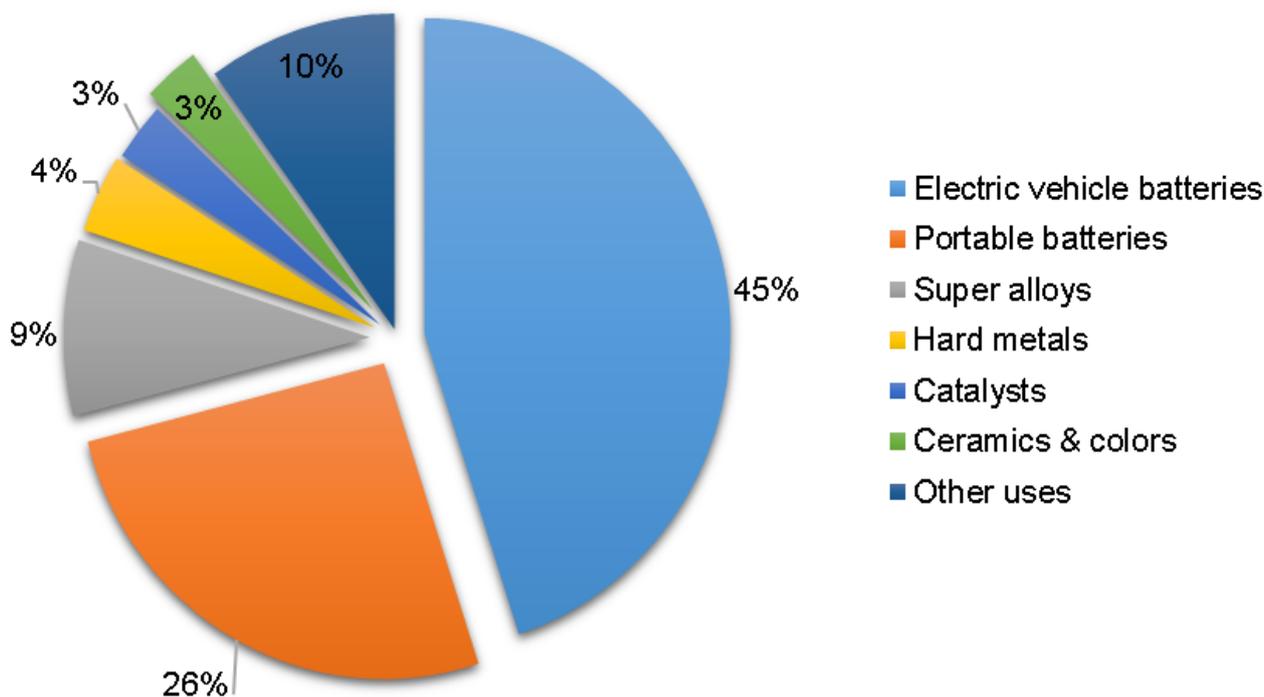


Fig. 5. Cobalt demand by application in 2023

Cobalt is used as an additive to steel in the form of a powder, which improves its mechanical properties, primarily hardness at elevated temperatures. Cobalt alloy can be used to protect the surfaces of parts from wear under heavy loads.

Noting the magnetic properties of cobalt, it is necessary to pay attention to their storage with a single magnetization. That is, magnetic alloys containing cobalt are used in the manufacture of transformers, cores of electric motors, etc. [20].

This metal is a serious competitor to nickel in the aerospace and aviation industries, namely in high-temperature engines and various aircraft turbine designs.

Cobalt alloys can often be found in the radio engineering industry in the manufacture of "printed circuits", as well as for the production of amplifiers and quantum generators. Thermoelectric generators with high efficiency are made on the basis of cobalt silicide. The attractive blue colour of glass products is achieved by the introduction of cobalt compounds during cooking [20].

Due to the regulation of temperature and stability that electric vehicles batteries containing cobalt are able to cover large distances of run [8].

Development of cobalt-nickel ore deposits of Ukraine. Confirmed nickel reserves in Ukraine amount to 340,000 tons, which is 0.4% of the total world reserves [21]. Ten nickel deposits located in Kirovohrad and Dnipropetrovsk regions with total reserves of 217.8 and 121.2 thousand tons have been explored.

Information about the average nickel content in ore for six deposits, established from open sources, is shown in (fig. 6). The low content of nickel in Ukrainian ore deposits [22], which were involved in exploitation, has led to unprofitable mining [23] and the need to import rich ores for the processing industry [24]. However, the latest studies show that additional profit from the accompanying mining [25], especially copper when designing the specified deposits, will increase investment attractiveness and involve it to the development.

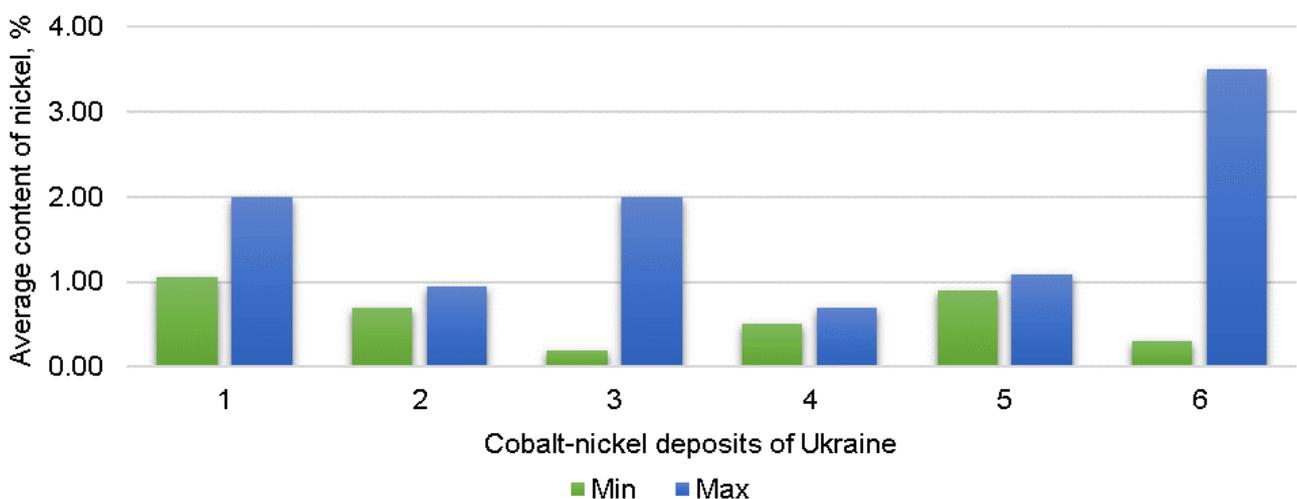


Fig. 6. The average content of nickel in ore by deposits:
1 – Devladivske; 2 – Karnaukhivske; 3 – Sukhokhutirskе; 4 – Zhelezniaky site;
5 – Lypovenkivske; 6 – Kapitanivske.

The analysis of previous studies [16] shows that there are no large cobalt deposits in the country. In subsoils, it is located as a concomitant component in cobalt-nickel ores. The total cobalt reserves that confirmed by the State Geoservice in Ukraine amount to 8,000 tons. Deposits and areas with balance reserves include: Lypovenkivske (Kirovohrad region), Zheleznyaki site (Zhytomyr region) and Sukhohutirskе (Dnipropetrovsk region). At the same time, the cobalt content in the ore is 0.04 - 0.14% (fig. 7).

Deposits of polymetallic ores of Ukraine, which contain cobalt, to a greater extent are ore occurrences and are promising for further scientific research [26], taking into account their insufficient geological exploration.

There are three potential deposits where cobalt-bearing ores can be mined [27] on an industrial scale: Karnaukhivske and Prutivske mining (Dnipropetrovsk region), as well as the Zheleznyaki site (Zhytomyr region). The State Geological Service highly valued the last deposit with the starting price of the lot at the auction of USD 0.1 million [16].

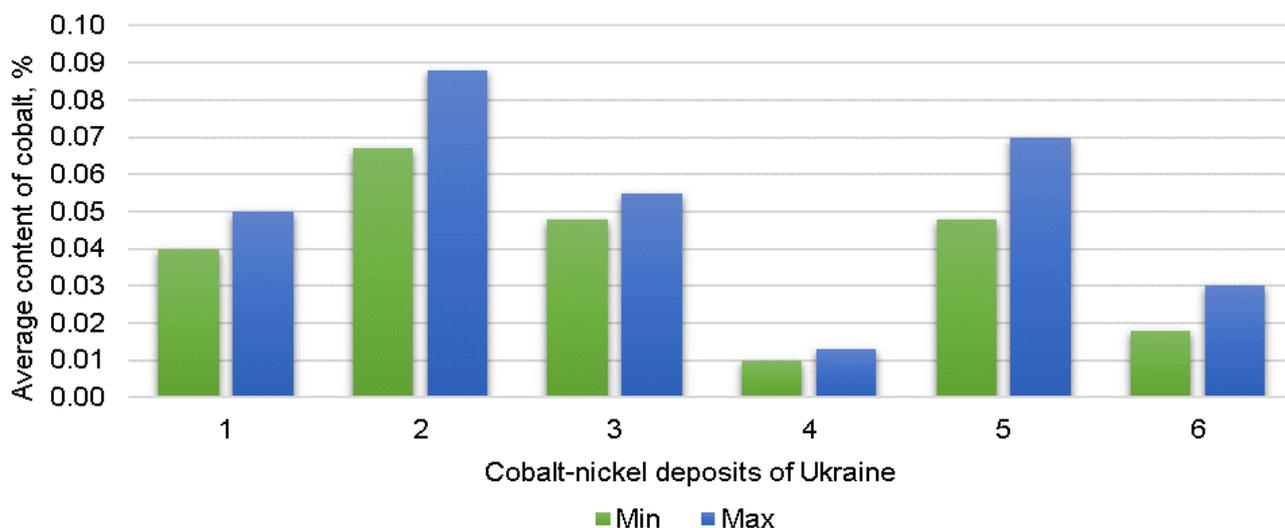


Fig. 7. The average content of cobalt in ore by deposits:
 1 – Devladivske; 2 – Karnaukhivske; 3 – Sukhokhutirskoe; 4 – Zhelezniaky site;
 5 – Lypovenkivske; 6 – Kapitanivske.

In addition to cobalt, there are also nickel and chromium in the Lypovenkiv deposit of polymetallic ores. The location of the deposit is the outskirts of the village of Lypovenke Golovaniv district. The thickness of the ore bodies is approximately 15 m and the length is 60-80 m. The State Geonadra proposes to develop the deposit by surface mining method [28] due to the possibility of joint extraction of cobalt-nickel and chromite ores, which are represented by a loose variety. The ores beneficiation [29] is recommended to be carried out according to a collective scheme due to the low percentage of nickel content in the ore (1.05%), and due to the difficulty of beneficiating nickel silicate ores, it is necessary to use a mechanical grinding method [30].

Zheleznyaki site with ore exposure covers an area of 290 hectares. The main minerals at this deposit are copper, cobalt and nickel, and platinum and palladium are associated minerals [31]. Reserves of critical raw materials are: nickel - 150.9 thousand tons; cobalt - 3.0 thousand tons. The depth of the deposits layer [32] in different parts of the site varies from relatively gentle (40-50 degrees) to steep (75 degrees) that significantly complicated mining process [33]. The thickness of the ore body is 5 m. The weighted average content of nickel is 0.66%, cobalt - 0.013%.

Processing of nickel ores in Ukraine is carried out at the Pobuzhsky Ferro-Nickel Plant, but now this enterprise is focused on imported raw materials of the Estonian company Bowrin Trading, which is imported from Guatemala. This is explained by the increased ore content [34] at the import to 1.7% compared to domestic 0.9%.

The production of metallic nickel is a rather complex technological line [35], which consists of extraction [36] and processing [37]. Nickel is mined [38] and beneficiated [39] from ore containing oxides, silicates and nickel-plated sulphides. After that, the ore is enriched to obtain a nickel concentrate, followed by conversion to nickel oxide. Due to the ore extraction in mine [40] and supply to benefaction plant where by the hydrogen, metallic nickel is already obtained, which is processed using the casting, forging, as well as separation from different impurities [17].

Conclusions. The conducted research made it possible to establish that over the past 14 years, nickel world production has increased 2.4 times to 3,650 thousand tons. Despite the steady increase in demand, its value has undergone significant changes, and its maximum values were observed in 2011 and 2022 and exceeded 32,000 US \$/t, while in 2016 it decreased by 3 times to 9,000 US \$/t. The dynamics of changes in the cost of nickel largely coincides with the cost of some critical materials used in the manufacture of lithium batteries and is constantly changing despite the gradual increase in global production.

It was determined that since 2010 cobalt production has increased 2.1 times from 230,000 tons. However, unlike nickel, the increase in the cobalt price is atypical for other critical minerals, since the maximum value of 90,000 US \$/t was reached in 2018 year, while the minimum recorded in 2016 was 21,000 US \$/t. The increase in the cost of cobalt from 2021 is typical of all critical mineral raw materials used in the production of electric vehicles.

The main geological characteristics of the nickel-bearing deposits of the Ukrainian shield have been determined, which allows establishing the most promising moderate-magnesian differentiated bodies of the Devladiiv zone and adjacent areas, where syngenetic perthlandite-chalcopyrite-pyrrotine mineralization is recorded in weakly altered peridotites and gabroids. The prospect of sulfide mineralization development in the gabbro-pyroxenites of the Azov region, belonging to the gabbro-wehrlite formation, was also confirmed.

The main areas of use of cobalt and nickel in industry are determined, which confirms their high level of importance for green transit and modern information technologies, namely electric cars, smartphones and superalloys.

The mining and geological characteristics of the largest cobalt-nickel deposits in Ukraine have been studied with an approximate total with a nickel content of 340,000 tons and cobalt of 8,000 tons. Obtained data allows to identify a number of promising deposits of cobalt-nickel ores for further research and development in Ukraine, which include Devladiivske, Karnaukhivske, Sukhokhutirskе, the Zheleznyaki site, Lypovenkivske, Kapitanivske.

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АНОТАЦІЯ

Мета. Оцінка сучасного стану та перспектив освоєння родовищ кобальт-нікелевих руд України для забезпечення країн Європейського Союзу та світової промисловості критичною мінеральною сировиною.

Методика. У роботі використано комплекс методів дослідження: узагальнення – систематизація інформації щодо світового виробництва та попиту на кобальт-нікелеву сировину; аналогії та порівняння – для визначення розподілу кобальту та нікелю у родовищах; аналіз і синтез – для обґрунтування доцільності залучення до освоєння наявних родовищ критичної сировини.

Результати дослідження. Встановлено динаміку видобутку кобальту та нікелю у світі, а також зміну їх ринкової вартості протягом останніх чотирнадцяти років. Досліджено гірничо-геологічні характеристики найбільших кобальт-нікелевих родовищ України, що дає змогу зосередити основну увагу на підвищенні ефективності технологій вилучення цінних компонентів, оскільки на сьогодні видобуток цієї сировини в країні є економічно нерентабельним через її високу собівартість. Розглянуто основні напрями світового використання кобальту та нікелю у високотехнологічних секторах економіки, зокрема у виробництві легованих сталей, акумуляторів. Встановлено оціночні запаси кобальту та нікелю в найбільш значущих родовищах України. Визначено орієнтовний вміст кобальту та нікелю в рудах родовищ, що дає змогу окреслити подальші перспективи та інвестиційну привабливість освоєння цієї критично важливої сировини в Україні.

Наукова новизна. Встановлено залежності світового виробництва нікелю та кобальту від вартості цих критичних елементів у період з 2010 по 2023 роки. Вперше здійснено розподіл кобальт-нікелевих покладів з виділенням найбільш значущих родовищ критичної мінеральної сировини України з яких можливе вилучення нікелю та кобальту. Обґрунтовано необхідність подальших досліджень родовищ України з метою виявлення нових проявів кобальт-нікелевих покладів та розширення їх наявного переліку.

Практичне значення. Встановлено, що Україна має достатній потенціал для освоєння кобальт-нікелевих покладів за типами родовищ. Водночас для їх ефективного використання необхідно створити сучасну геологічну базу даних, розробити та впровадити новітні технології збагачення, залучити інвестиції за умови формування прозорого ринку, а також організувати замкнений виробничий цикл.

Ключові слова: критична мінеральна сировина, кобальт-нікелеві родовища, оцінка, видобування, ресурсне забезпечення.

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