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Critical Mineral Deposits in the USA and Prospects for Their Development

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Abstract: *This article explores the key geological, economic, and strategic aspects of critical mineral development in the United States, focusing on rare earth elements, nickel, cobalt, and lithium. It analyzes the largest deposits, resource base characteristics, and prospects for expanding domestic extraction. Special attention is given to government policies aimed at reducing import dependency and ensuring supply chain resilience. The study also addresses environmental and technological challenges associated with resource development. The analysis is based on official data, expert assessments, and U.S. strategic policy documents.*

Keywords: critical minerals, USA, deposits, rare earth elements, strategic resources

I. INTRODUCTION

In the context of structural changes in high-tech industries, forced assimilation of renewable energy sources, and increasing geopolitical rivalry in the defense industry, critical metals are gaining fundamental strategic importance. They are becoming a technological independence and national security priority. In the United States, there is a growing demand for such materials as the rare earth minerals, nickel, cobalt, and lithium that comprise the majority of the batteries, electronics, and defense hardware material. Continued high dependence on imports of critical materials carries potential risks.

The primary objective of the current research is an assessment of the geologic, economic, and strategic significance of the developments of United States' most significant deposits of critical metals. Greater importance is given to the exploration of geologic characteristics, spatial distribution of the deposits, and an estimation of their impact on the industrial and military autonomy of the nation. The research aims to identify future trends in the field, assess their profitability, and evaluate their importance for the country's resource independence.

II. MAIN PART. CRITICAL METALS: DEFINITION AND SIGNIFICANCE

Critical metals are a group of chemical elements that are of particular strategic importance for the national economy and security, while being characterized by a high degree of risk in supply chains. The U.S. Department of the Interior lists rare earths, nickel, cobalt, and lithium among these metals in the updated list, based on their indispensability in priority sectors – from energy to the defense industry [1]. Their value is determined not only by the level of demand, but also by the limited availability of available sources in the United States, which makes it necessary to deploy its own production capacities (fig. 1).

Rare earth elements (REEs) play an important role in manufacturing magnetic materials, lasers, catalysts, and high-temperature alloys. Terbium and dysprosium, the heavy REEs, find their application in making permanent magnets, which are used in electric motors as well as wind turbines. Nickel is an important element, though, in battery systems, namely nickel-cobalt-aluminum (NCA) and nickel-manganese-cobalt (NMC) cathode production. Cobalt finds application in lithium-ion batteries to enhance their heat stability and lifespan, and lithium forms the foundation of battery technologies applied in the manufacture of electric vehicles and energy storage from renewable sources.

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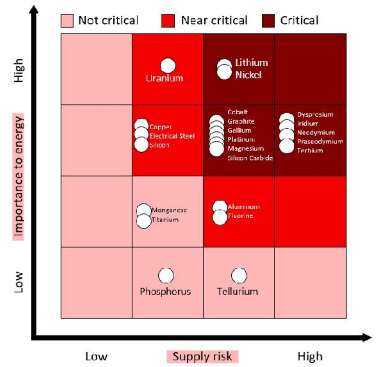

Figure 1. Medium-term (2025-2035) criticality matrix critical materials

It must be pointed out that the price of these metals is increasing as the world transitions to clean energy and decarbonization. Demand for nickel and lithium can be expected to increase many times by 2035, which means higher exploration and strategic interest in the resource security space [2]. In the face of tight international reserves and dependence on untrustworthy suppliers, resource sovereignty becomes more and more important to the United States, which concludes that it must seek out and create its own deposits.

III. GEOGRAPHY AND GEOLOGICAL CHARACTERISTICS OF THE LARGEST DEPOSITS IN THE UNITED STATES

The United States' critical metal resource base is extremely geological and spatially variable. The best deposits are found in the western and northern regions of the country, in the states of California, Nevada, Arizona, Minnesota and Alaska. They are characterized by the presence of ancient crystalline rocks, volcanogenic complexes, and metamorphosed formations that had formed accumulations of rare and strategically important elements.

One of the most well-known rare earth occurrences in the world is the Mountain Pass deposit in California, in the southeastern Mojave salient. It is an intrusion-type carbonatite-related deposit and is dominated mainly by light REEs such as neodymium, cerium, and lanthanum. Geologically, the field is bounded within the tectonic activation zone, and the reserves are estimated to be one of the greatest occurrences in the western hemisphere [3].

Another deposit is located in Nevada, the Clayton Valley deposit, which contains industrial concentrations of lithium in brines. It is geochemically related to dry salt lakes (pleia), in which lithium forms as a result of hydrothermal fluid migration and evaporation. Some technologies of evaporation are required in order to mine lithium from here, but stability and reserve of geochemical conditions make it an attractive target for long-term operation.

Northwest Michigan and Minnesota possess vast nickel and cobalt resources mainly in the form of sulfide ores. Paleoproterozoic magmatic intrusions with the accompanying Duluth Complex formation is considered the most favorable region. Platinum group metals' occurrence is also the greatest, mainly 95% of reserves in nickel and 88% in cobalt for the whole United States and manufactured in the provided complex. These resources are largely stored in sulfide mineral occurrences, which renders them strategically important for supply chain diversification [4].

Cobalt ore deposits and rare metal ore deposits that are related to them in ultramafic massifs and zones of contact metamorphic rocks have been found in Alaska. Geological conditions for their existence here involve great development costs, but in view of their inaccessibility, they are compensated by a high concentration of valuable components. Therefore, territorial occurrence and geodynamic development of the territories render each field singular in itself and the opportunity in this respect in securing the resource sovereignty of the United States.

IV. ECONOMIC ASSESSMENT OF FIELD DEVELOPMENT

The economic feasibility of developing critical metal deposits in the United States is determined by a complex of factors, including production costs, infrastructure availability, regulatory burden, and global market conditions. With high price volatility for strategic resources, the investment sustainability of projects in the long-term horizon becomes a

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key evaluation criterion. Additionally, the analysis of economic efficiency should take into account the level of geological exploration of the deposit, the depth of ore occurrence and the features of the extraction technologies used.
Comparative research identifies that lithium mining from brines, such as in Clayton Valley, is more labor-intensive compared to solid deposits, but requires longer production cycles and extremely high levels of processing the end product. Lithium production in the United States stands at an average of $5000 $ to $7000 per tonne of lithium carbonate, higher than that of South America's biggest producers. Simultaneously, focusing on domestic sources reduces logistic and geopolitical risks, an aspect that becomes especially important when constructing a national raw materials policy (table 1).

TABLE I: CAPITAL COSTS OF PROCESSING AND LITHIUM HYDROXIDE PLANTS [5]

Project name	Owners	Mining method	Processing plant cost ($m)	Share of initial capital cost (%)	Hydroxide conversion plant cost ($m)	Hydroxide plant capacity
Piedmont	Piedmont Lithium Inc. (Owner) 100%	Open pit	615	62	408	30,000 t/y LiOH
Karibib	Lepidico Ltd. (Venturer) 80%; Private Interest (Venturer) 20%	Open pit	112	72	85	5,600 t/y LiOH
Clayton Valley	Schlumberger Ltd. (Optionee) 100%; Pure Energy Minerals Ltd. (Optionor)	Brine extraction	100	34	27	6,563 t/y LiOH (11,500 t/y LHM)
Whabouchi	Investissement Québec (Venturer) 50%; Livent Corp. (Venturer) 50%	Open pit, underground	730	75	399	21,116 t/y LiOH (37,000 t/y LHM)
Zinnwald	Zinnwald Lithium PLC (Owner) 100%	Underground	238	71	116	6,855 t/y LiOH (12,011 t/y LHM)
South-West Arkansas	Standard Lithium Ltd. (Optionee) 100%; TETRA Technologies, Inc. (Optionor)	Brine extraction	433	50	91	17,121 t/y LiOH (30,000 t/y LHM)

From a nickel and cobalt point of view, economic interest in the Duluth Complex deposits is due to the by-production of copper and platinum group metals that enhances profitability due to the multi-element nature of ores. However, the development involves massive capital investments on infrastructure, including transport and processing, since the region does not have a well-established network of processing companies. In addition, the state's environmental regulations tightly restrict emissions and impacts on water resources [6].
In contrast to the international trend of localization of supply chains, economic analysis also considers strategic aspects. Irrespective of the increased expense of extraction, the development of internal resources is regarded as a long-term investment in autonomy of resources, which, with the appropriate assistance of the state, can pay back the initial cost and offer sustainable development of industry.

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V. RISK ANALYSIS AND STRATEGIC SUSTAINABILITY

Creation of critical metal deposits is associated with various risks which should be taken into account in the strategic planning. They comprise geological, economic, environmental and social risks that may significantly affect the implementation of projects. With the growing geopolitical tensions and changes in global value chains, investigation of strategic stability of the national mineral resource base is particularly pertinent.

Geological hazards imply uncertainty in estimating reserves and problems with forecasting the mineralogical structure of ores. Even after initial exploration, sharp deviations from the concentration of valuable components are possible, affecting the cost of treatment and output of finished products. Economic hazards are primarily connected with high price volatility in world markets. For example, in 2022-2023, lithium price dropped to $46000 per metric ton in 2023 from a peak of $68100 per metric ton in 2022, which exposed most projects to investment loss [7].

Environmental and social risks in the United States are particularly fierce due to the heavy regulation and active role of local communities. Nickel and cobalt mine projects typically need to meet lengthy environmental impact assessments, tribal land permits, and public hearings. Such factors can adversely slow down or even prevent the implementation of mining projects. Therefore, reputational costs are also coming forth as a considerable element of risk, especially for multinational businesses and private investors.

In order to ensure strategic sustainability, the U.S. Government is taking steps to diversify supplies by investing in exploration, processing, and development of metal recycling. Mechanisms of international cooperation with allies – Australia, Canada, and South Korea-aimed at creating sustainable supply chains are also considered. At the same time, the legal aspects of concluding and regulating international transactions, which determine the reliability of long-term agreements in the field of raw materials supply, are of particular importance [8]. However, priority remains given to the development of domestic production capacities with an emphasis on environmentally sound development methods, the introduction of advanced technologies and the creation of strategic reserves of critical resources. This approach helps to reduce external vulnerabilities and form a stable system for ensuring resource security in the long term.

VI. CONCLUSION

Rare earths, nickel, cobalt, and lithium are the most critical resources, as such, whose implications on the United States' level of technological and economic autonomy cannot be overstated. Their extraction and processing go hand in hand with delivering national security, especially given increasing competition in the arena of advanced technologies as well as defense. Though there is significant mineral potential, productive development of the resources has to overcome a whole range of obstacles-from complex geological conditions and environmental constraints to high capital intensity and infrastructure cost.

The realization of the potential of critical metal deposits in the United States is possible only with a comprehensive approach that includes not only the development of our own raw material bases, but also the introduction of innovative extraction and processing technologies. An important component of this strategy is environmental responsibility and the strengthening of internal infrastructure. Only with state support and international cooperation can we create a sustainable model for providing critical metals that will ensure long-term resource autonomy and minimize the risks associated with external supplies.

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