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CREATION OF MINERAL RESOURCE BASE OF STRATEGIC MATERIALS (BY EXAMPLE OF THE PRUTIVSKYI COPPER-NICKEL AND PRECIOUS METAL ORE DEPOSIT)

Introduction. *The growing interest in the possibility of obtaining certain types of strategic (critical) metals has prompted the intensification of research in this area.*

Problem Statement. *Many research works have dealt with creating a mineral resource base of strategic (critical) metals. However, this issue has not been systematically considered, and no respective industrial strategy has been developed so far. Insufficient attention is paid to modern investment requirements, especially during exploration and selection of ore processing schemes.*

Purpose. *The purpose of this research is to assess the available information on the prospects for the development of the Prutivskyi deposit of sulfide copper-nickel and precious metal ores and to outline the priority steps in order to prepare the deposit for integrated development.*

Materials and Methods. *Information from open (published) sources for the last 25 years, which concerns the ore-bearing capacity of Ukraine for precious and non-ferrous metals, in particular the potential platinum-bearing capacity, has been critically analyzed, given the authors' knowledge and experience.*

Results. *The authors have shown the insufficiency of the available information on the prospects of the Prutivskyi deposit of sulfide copper-nickel and precious metal ores and the inconsistency of some sources. At present, about 20% of ore-promising rocks of the Prutivka intrusive massif has been studied with varying level of detail. The authors have proven the necessity of changing approaches to the field preparation and development that should be based on modern schemes for integrated ore processing, given world investment requirements.*

Conclusions. *It has been shown that the final conclusion on the industrial significance and investment attractiveness of the Prutivskyi deposit can be made only after the implementation of a clearly defined set of works in compliance with modern world standards.*

Keywords: sulphide copper-nickel ores, platinum group metals, precious metal ores, Prutivskyi deposit, integrated ore processing, industrial deposits, and investment attractiveness.

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The exploration works related to the creation of Ukraine's own mineral base of non-ferrous metals started a long time (about 70 years) ago. In the course of these works, a special attention has been always paid to the search for copper and nickel deposits. However, in Soviet times, since the discovery of unique deposits of these metals in the Norilsk ore region (now the territory of the Russian Federation), systematic Ukraine-wide mineragenic studies, as well as prospecting and exploration works for copper, nickel, and related platinum group metals (PGM) had been almost suspended. Since Ukraine gained independence, the idea that for preserving this independence, Ukraine, like any other independent state, should have its own mineral resource base (MRB) became a fundamental truth. Since then, a special interest in the mineral raw materials that have never before been mined in our country, but are necessary for various production processes has revived. Among such important raw materials that are traditionally considered and called the strategic ones, there are copper, nickel, and platinum group metals [1]. Today, they may be certainly referred to the critical minerals [2].

Despite a high demand for these types of raw materials, there still have been no industrial deposits in our country, and no corresponding mining enterprises have been established. Why? Of course, one of the main reasons is the discovery and exploitation of Russian deposits of these metals in Soviet times. Another reason is the lack of a reliable analytical framework in Ukraine for determining the content of PGM in geological rocks. Unfortunately, Ukrainian geologists have not had modern laboratories in our country so far. Therefore, in the course of geological exploration activities, they have been focusing their efforts on the works associated with the discovery and development of copper-nickel deposits.

Summarizing the available geological information on these issues, it is necessary to emphasize the following facts. The study of geological structure and metallogenic features of the Volhynian megablock of the Ukrainian Shield (USh) has made it possible to identify several basite-ultrabasite intrusive massifs with signs of sulfide copper-nickel ore occurrences: Prutivskyi, Kamianskyi, Varvarivskyi, Zhelezniakivskyi, Sheikhivskyi, and Hodykivskyi. Based on this, the Volhynian nickel-bearing province or nickel-bearing district has been distinguished.

Proceeding form the analysis of the geological structure and the mineralogical, petrographic, and petrochemical properties of the basit-ultrabasites of this nickel-bearing region, the experts of *Pivnichgeologia* have identified the three magmatic formations with direct signs of nickel-bearing: peridotite-pyroxenite-gabronorite, gabbro-troctolite, and gabbro-dolerite. The latter two are sometimes combined into a gabbro-dolerite-troctolite formation with two corresponding subformations [3]. Having studied the geological, petrological, geochemical properties and prospects of ore-bearing basite dyke complexes of the USh Volhynian megablock, M. Kostenko has identified similar toleite gabbro-dolerite (prototropic) and toleite peridotite-troctolite gabbro-dolerite formations [4].

In our opinion, the conclusions of the well-known Ukrainian petrologist V. M. Skobelev [5, 6], which are based on the results of in-depth analysis of the history of geological development and determination of the absolute age of igneous rocks in the region are better substantiated. According to these data, all the mentioned intrusive massifs were formed at the stage of early Proterozoic tectonic magmatic activation, 2100—1960 million years ago. The earliest phases of intrusive activity were associated with the formation of mainly ultramafic massifs (peridotite-pyroxenite-gabronorite formation: Zhelezniakivskyi, Novoromanivskyi, Varvarovskyi, Hodykhivskyi, and Prydorozhnyi massifs); later, there were formed mainly gabroid massifs (troctolite-gabronorite-gabbro formation: Prutkivskyi and Kamenskyi massifs); and the formation of gabbro-monzonite-granite association of the Bukynskti massif is referred to the final phases of tectonic-magmatic activation [7]. Later, for the Prutivskyi and Kamianskyi massifs, the absolute age has been somewhat ad-

justed: up to 1780—1790 million years, and the Bukynskyi massif rocks have not been any longer considered potentially ore-bearing [8, 9]. Thus, intrusive massifs associated with the first two phases of intrusive activity during the Early Proterozoic activation in the region have been found to have the greatest ore-bearing potential.

A typical example of the peridotite-pyroxenite-gabronorite formation (essentially ultramafic) is the Zhelezniakivskyi basit-ultrabasite massif. Within its limits, a promising nickel ore occurrence associated with olivine-containing pyroxenites and peridotites (lercolites) has been discovered. Varvarivskyi, Prydorozhnyi, Hodykhivskyi, Sheykivskyi, Vidovskyi, and some other massifs are very similar to this massif in terms of geological and metallogenic parameters.

The formation of the Prutivskyi and Kamianskyi intrusive massifs belongs to the troctolite-gabronorite-gabbro (essentially, gabbroid) formation.

The results of a long study of the geological structure and metallogenic properties of the Prutivskyi intrusive massif have given some researchers reason to attribute the sulfide copper-nickel ore discovered here to medium-size fields with reserves of 44 million tons, according to the JORC standard [10]. Also, the researchers stress that based on the available analytical information, they have created a database that enables them to perform geological and mathematical modeling with the use of the *Micromine* software package and to determine activities to increase ore reserves in this deposit.

On the territory of the Kamianskyi basite-ultrabasite massif, in its lower part, a promising ore occurrence of sulfide copper-nickel ores has been discovered; the estimated projected nickel resources are about 3 million tons. The search results have given the same researchers an opportunity to make assumptions about the possibility of detecting rich sulfide ores and horizons with precious metal ore [10].

Of course, the available data are quite important for determining the types and scope of further exploration works. However, for a comprehensive assessment of the prospects of these metallogenic objects, it is necessary to take into consideration the results of the study and the estimation of the potential of platinum-, gold-, and silver-bearing sulfide-nickel basite-ultrabasite massifs of the Volhynian nickel-bearing area. Otherwise, any assessment will be incomplete and therefore erroneous.

Many publications have already dealt with this topic [1, 4, 7, 9, 11—16]. The research works described in them have helped to obtain data on the geological and metallogenic structure of the area and, above all, to emphasize the similarity of Ukrainian metallogenic objects to the well-known platinum-bearing objects of the Siberian platform and the Voronezh crystalline massif.

Why are they similar? Which common geological properties are of crucial importance? How promising are Ukrainian potentially platinum-bearing geological formations?

To answer these questions, we have used the hypothesis of the existence of the Eastern European submeridional metallogenic belt [17] that covers the PGM deposits and ore occurrences of one of the world largest platinum-bearing Kola province, in the north, and the Voronezh massif and, probably, the Ukrainian Shield, in the south. This belt is superimposed on a complex system of repeatedly reactivated rifts developed in the granite-greenstone areas of the Eastern European platform. The global properties of belts of this kind are polychronicity and polyformation not only of the belts themselves, but also of the platinum-bearing provinces. The confirmation of the correctness of this assumption is the conclusion of S. V. Nechaev that the Volhynian copper-nickel ore region is linked to the intersection of «B» lineament with the transverse Volhynia-Polissya depression [18]. Based on the geophysical data, S. V. Nechaev states that the increased content of precious metals in copper concentrate obtained after processing of sulfide copper-nickel ores are not accidental.

Finally, in the north-western part of the USh, the essentially ultramafic intrusions (peridotite-

pyroxenite-gabronorite formation: already mentioned Zhelezniakivskyi, Novoromanivskyj, Varvarivskyi, Hodykhinskyi, and Prydorozhnyi massifs) and essentially gabroide (troctolite-gabronorite-gabbro formation) Prutivskyi and Kamianskyi massifs are the most interesting from the standpoint of the presence of platinum mineralization. It is also important that the data on the age of the phases of intrusive activity of the mentioned above region are consistent with the sequence of classical platinoid oregenesis of the Kola province, where among the Early Proterozoic complexes of continental rifting there are distinguished the Monchegorsk sulfide platinoid-copper-nickel norite-orthopyroxeno-peridotite, the Fedorovsko-Panski low-sulfide platinometallic peridotite-pyroxenite-gabronorite, and other complexes.

Thus, the stratified rocks of the picrite-gabbrodolerite (prototropic) formation of the Prutivskyi intrusion with a high content of precious metals are formational analogs of intrusive formations of the Duluth-Norilsk genetic type (or, more precisely, the Norilsk-Talnakh-Prytrychophore subtype and, probably, the Monchegorsk subtype [19]. The presence of sulfide copper-nickel mineralization confirms the validity of such an analogy. It is known that the deposits associated with such intrusions belong to the actual magmatogenic (fluid-magmatogenic) group of endogenous deposits and, further, to the sulfide platinoid-copper-nickel subgroup (platinum-containing ore formation). The typical deposits (objects) associated with them are Talnakh, Norilsk, and Monchegorsk ones (Russia). It has been established that the first two have some of the world most promising platinum and PGM industrial deposits.

Unfortunately, the results of Prutivskyi intrusive massif rock tests for the content of precious metals have shown a modest content as the samples from the lower ore horizon contain 0.1—1.5 g/t platinum. In some places, in several sulfide sections, 0.35 g/t platinum, 0.23 g/t palladium, and 0.55 g/t gold have been found. The samples taken from the upper ore horizon contain 0.24—4.9 g/t platinum; the total content of platinum, palladium, and gold exceeds 5.0 g/t. The copper-nickel concentrate obtained from the technological sample contains platinum (0.096 g/t), palladium (0.24 g/t), gold (5.3 g/t), and silver (37 g/t) [16]. The results of the microprobe study at the Semenenko Institute of Geochemistry, Mineralogy, and Ore Formation of the NAS of Ukraine have shown that platinoids are present in the form of sulfides and solid solutions in tellurides and telluride-bismuthides [11]. In addition, at the same time, the possible presence of osmium and ruthenium in pyrrhotite has been suggested.

At the same time, almost all publications that deal with the geological study of the Prutivskyi intrusive massif, as well as with the search for deposits of sulfide copper-nickel ores in the Volhynian nickel-bearing region mention that no systematic precious metal mineralization tests of the promising ore layers have been made. Therefore, the available information is extremely incomplete and not always reliable (mainly because of unreliable analytical studies). However, it allows us to draw quite positive conclusions about the potential prospects of this object. This conclusion has been confirmed by preliminary estimates of PGM reserves in the Prutivskyi ore occurrence, which, according to K.Yu. Yesipchuk ([1]) account for 10.8 tons with an average content of platinum and palladium ore of 0.15 g/t each.

Regarding the mentioned Zheleznyakivskyi, Prydorozhnyi, Novoromanivskyi, Hodykhivskyi, Varvarivskyi and some other massifs, it may be assumed that they belong to the low-sulfide platinum-metal ore formation [19]. The typical representatives of this formation are Fedorovsko-Panske, Verkhnotalnashskoe (Russia), Reef J-M (Stillwater, USA), and Lac-les-Ile (Canada) deposits.

While summarizing the data obtained during the study of the geological structure and material composition of Prutivskyi and several other intrusions mentioned above, it should be noted that they differ from the known industrial deposits especially by a much smaller size and the lack of

high stratification that there has a rhythmic character, with consistent change of associations of formations from ultrabasic to basic. These regularities are directly related to the latinum-bearing capacity of the massifs, so commercial quantities of platinum and PGM are unlikely to be detected in these Ukrainian sites.

The prospects for industrial development of the Prutivskyi field should be considered only from the standpoint of integrated extraction of useful components. Previously, at the first stages of exploration works, the main attention was paid to the possibility of obtaining copper-nickel and cobalt concentrates. However, now the indispensable condition for ore processing should be the production of precious metal concentrates. Such an integrated object may definitely attract interest of industrial corporations.

However, according to [10], it may be concluded that at present, about 20% of ore-prospecting rocks of the Prutivskyi intrusive massif has been studied with varying level of detail. This study corresponds to modern generally accepted international principles of the evaluation with a certain degree of conventionality.

Therefore, in order to determine the industrial significance of the deposit it is necessary to continue geological surveys and to bring all available geological and economic data in line with international standards for classification and accounting of mineral assets.

The first practical measures in this direction should include as follows:

- new representative drilling and sampling;
- studying these samples at recognized international laboratories;
- volumetric geological modeling.

The development of such a model enables subsoil users to plan mining works for ore of a certain quality and to choose the optimal mining technology. The level of preparation of geological, ecological, technological, mining-related, and social aspects shall comply with modern international standards for the preparation of such projects.

After that, it will be possible to draw a final conclusion about the industrial significance and investment attractiveness of the Prutivskyi deposit. The conclusion on the feasibility of its industrial development will be confirmed if a technology for integrated ore processing is created.

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СТВОРЕННЯ МІНЕРАЛЬНО-СИРОВИННОЇ БАЗИ СТРАТЕГІЧНИХ (КРИТИЧНИХ) МЕТАЛІВ (НА ПРИКЛАДІ ПРУТІВСЬКОГО КОМПЛЕКСНОГО РОДОВИЩА МІДНО-НІКЕЛЕВИХ І БЛАГОРОДНОМЕТАЛЕВИХ РУД)

Вступ. Підвищення інтересу до питання щодо можливості отримання країною деяких видів стратегічних (критичних) металів спонукало до посилення досліджень цього спрямування.

Проблематика. Питанню створення власної мінерально-сировинної бази стратегічних (критичних) металів присвячено чимало праць та досліджень, проте системного розгляду з укладанням відповідної стратегії галузі так і не здійснено. Недостатньо уваги приділено урахуванню сучасних інвестиційних вимог, особливо під час проведення геологорозвідувальних робіт і вибору схем переробки руд.

Мета. Оцінити наявну інформацію щодо перспективності освоєння Прутівського комплексного родовища сульфідних мідно-нікелевих і благороднометалевих руд та окреслити необхідні першочергові кроки для підготовки родовища саме до комплексної розробки.

Матеріали й методи. Критично проаналізовано інформацію з відкритих (опублікованих) джерел за останні 25 років щодо перспектив рудоносності території України на благородні та кольорові метали, зокрема щодо потенційної платиноносності, з урахуванням власного доробку й досвіду авторів.

Результати. Показано недостатність наявної інформації про перспективність Прутівського комплексного родовища сульфідних мідно-нікелевих та благороднометалевих руд та суперечливість деяких джерел. Натепер із різним ступенем детальності вивчені близько 20 % рудоперспективних порід Прутівського інтрузивного масиву. Доведено необхідність зміни підходів до підготовки і розробки родовища, які повинні орієнтуватися на сучасні схеми комплексної переробки руд з урахуванням світових інвестиційних вимог.

Висновки. Показано, що остаточний висновок щодо промислового значення й інвестиційної привабливості Прутівського комплексного родовища можна буде зробити лише після виконання чітко визначеного комплексу робіт із дотриманням сучасних світових стандартів.

Ключові слова: сульфідні мідно-нікелеві руди, метали платинової групи, благороднометалеві руди, Прутівське комплексне родовище, комплексна переробка руд, промислові родовища, інвестиційна привабливість.