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ЕЩЕ РАЗ К ВОПРОСУ ОБ ЭКОНОМИЧЕСКОЙ ОЦЕНКЕ МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

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Ключевые слова: экономическая оценка, месторождения полезных ископаемых, методология, запасы полезных ископаемых.

Аннотация.
В настоящее время рынок минерально-сырьевых ресурсов находится в стадии реструктуризации, вызванной изменением в масштабах и пропорциях потребления сырья. В результате в течение ближайших лет возможна переоценка полезных ископаемых как общественно важного производственного ресурса, которая неизбежно приведет к росту их стоимости. Поэтому развитие научной экономической мысли в направлении совершенствования подходов к оценке минеральных ресурсов, с одной стороны, закладывает фундамент будущего национального богатства в условиях роста мирового потребления сырья. С другой стороны, совершенствование экономической оценки полезных ископаемых позволяет оценить возможности новой индустриализации – инновационного развития экономики за счет глубокой модернизации промышленности. В соответствии с данным постулатом, настоящая статья посвящена перспективным вопросам оценки полезных ископаемых, применительно к балансовым и забалансовым запасам.

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ONCE AGAIN ON THE QUESTION OF THE ECONOMIC ASSESSMENT OF MINERAL DEPOSITS

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Abstract.
Currently, the market of mineral resources is in the stage of restructuring, caused by changes in the scale and proportions of consumption of raw materials. As a result, over the next few years, a revaluation of minerals as a socially important production resource is possible, which will inevitably lead to an increase in their value. Therefore, the development of scientific economic thought in the direction of improving approaches to the assessment of mineral resources, on the one hand, lays the foundation for the future national wealth in the face of growing world consumption of raw materials. On the other hand, the improvement of the economic assessment of minerals makes it possible to assess the possibilities of new industrialization – the innovative development of the economy due to the deep modernization of industry. In accordance with this postulate, this article is devoted to promising issues of mineral valuation, in relation to balance and off-balance reserves.

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1 Introduction / Введение

With regard to the various understanding of notions – sources of mineral raw materials, deposits and mineral raw material reserves, mines, quarries, etc., it is worth defining the basic notions used in the deposit geology, mining and economy of mineral raw materials, i.e. in specializations that support the evaluation of mineral raw material resources.

Earth resources are abiotic resources from the lithosphere, hydrosphere and atmosphere that can be excavated or obtained by means of existing and available technologies with the aim of meeting the needs of human beings. Earth resources are also a reflection of the human approach as well as the development of civilization and technologies [1]. The development of inventions, technologies, trade, business, market requirements, investments, social and political events and institutions that control world trade as well as social relations within or between states may form a world-wide need that creates a required earth resource [2], e.g. from a raw material that either has not been used so far at all or has been used only locally, including using as a source of innovative development of the region [3].

A Mineral raw material (primary mineral raw material) is a mineral natural substance, which was, is or will be (under defined conditions) used in production or consumption processes due to the content of its industrial components.

A Source of mineral raw material is, at present (or under precisely defined conditions), an extractable part of a retrieved or explored deposit as well as a deposit reasonably anticipated on the basis of geological conditions. Sources of mineral raw materials also include the earth's atmosphere, seas, oceans and mineral water springs.

An Ore is a mineral raw material with a metal being its industrial component.

Other mineral raw materials belong to non-metallic raw materials or fossil kaustobiolites.

A Deposit of mineral raw materials is such an association of mineral bodies in the earth's crust, which, based on its position, quality and quantity of mineral raw materials, meets the condition of immediate industrial exploitability both from the technical and economic viewpoint. The term "deposit of mineral raw materials" is also used for each natural occurrence, which was exploited for production purposes in the past.

Occurrence (prospect) of mineral raw materials is a mineral raw material resource which has not been exploited so far, and the reserves of which could be verified by its further exploration. Thus the occurrence can become a deposit. This assumption is based on the physical presence of mineral raw materials verified by geological prospecting (in boreholes or exposures).

Reserves of mineral raw materials are parts of currently mineable mineral raw material resources, the quantity and quality of which has been calculated in their original state, "in the earth".

Calculation of mineral deposit reserves – it is a calculation (estimation) of the quantity and quality of reserves in a deposit or the estimation of quantity and quality of resources (prognosis resources) serving for the evaluation of mineral raw material deposits.

2 Materials and Methods / Материалы и методы

When calculating reserves it is extremely important to quantify an error (of both quantity and quality), which affects not only a category of reserves, but mainly the accuracy of subsequent technical and economic assessments. If output economic and financial information is required to maintain ± 5 - 10 % accuracy for a detailed feasibility study, also the accuracy of reserve calculation (both quantity and quality) must meet these requirements [4].

Another important requirement for the modern and comprehensive evaluation of mineral deposits is the implementation of alternative calculations of reserves for several cut off grades that cover the whole range interval of deposit quality parameters. The aim of alternative calculations of reserves is to define graphical and mathematical dependencies between reserves Z, the average quality x and limit value x_0, which subsequently enable alternative technical and economic assessments of reserves and an exact definition of optimum cut off grades x_0 for non-balancing x_{0N} and balancing x_{0B} reserves, and for the maximum deposit price $x_{0max.}$.

When calculating reserves it is necessary to distinguish between the following [5-6]:

- geological reserves Q_g, which are the result of alternative calculations of reserves, and make a basis for the calculation (estimate) of extractable reserves. Out of geological reserves, only free reserves are considered for the purpose of technical and economic assessment, while blocked reserves are excluded from this process [7]. The division of geological reserves to balancing (economic) a non-balancing (sub-economic) only results subsequently from alternative calculations of deposit reserves [8]. The division of geological reserves into balancing a non-balancing in accordance with the conditions of the feasibility of reserves set in advance cannot be considered suitable.
- extractable reserves Q_v, which consider recovery *v* and contamination *z* and are calculated by means of the Equation (1):

$$Q_v = \frac{Q_z \times v}{100 - z} \quad (1)$$

The basis of the price of an industrial mineral is its utility value. However, it is not related to the costs spent to gain it. A raw material price is given by natural properties. The difference between the raw material price and a production price is called the Differential Mining Rent (DMR), i.e. (2):

DMR = production costs + planned profit (2)

While this difference caused by natural conditions is a *DMR* of type „*I*“, and the one caused by technical equipment of mines and a following processing plant, which is a part of the mining company, is a *DMR* marked as *DMR* „*II*“. After the change in economic rules, geologists and economists used to consider the differential mining rent the mining industry an indicator evaluating the deposit price for which the deposits of industrial minerals should be rented to private companies [9]. The differential mining rent should be transferred to the government as unearned profit of a mining company conducting business on a deposit. Then a marginal deposit, i.e. a deposit from which only a planned profit is gained, has a zero value and the price of other deposits is equal to the differential mining rent [10].

However, the differential mining rent is neither a suitable nor useful tool for such a comprehensive issue such as the evaluation of deposits. The most frequently used methods evaluate deposits by means of a business project implemented on a deposit.

The following is an example that documents how an earth resource can be evaluated by a project [11]. Nobody doubts the existence of solar energy. It is difficult to evaluate this source differently than by means of a project focusing on the use of this energy [12]. The resource considered in this project is quantified by solar energy intensity and time of radiation, technologies used, for example, for the production of hot non-drinking water, distribution of energy, its use by end users, etc. The project also involves non quantifiable indicators such as the environmental “sense” of customers, the effort to use „clean“ and renewable energy resources, etc. Based on the project it determines whether the resource will or will not be used. This is a very simplified and suitable example of how to proceed with the evaluation of any earth resource. Thus the price of one and the same deposit of mineral raw materials may vary depending on the various factors accompanying the extraction, processing and sale of the raw material.

In accordance with their suitability for industrial purposes, the reserves can be classified as [13]:

a) balancing reserves,
b) non-balancing reserves.

Balancing reserves are reserves usable at present, which meet the current technical, technological and economic conditions for the use of a state owned deposit or its part.

Non-balancing reserves are reserves unusable at present, however in the future their efficiency can be assumed with regard to expected technical, technological and economic development.

In accordance with the possibilities of extraction conditioned by extracting technologies, safety of operation and defined protective pillars, the reserves are classified as blocked reserves and free reserves [14].

Blocked reserves are reserves in protective pillars of surface and underground structures, facilities and mining works and in pillars designed to ensure secure operation and preservation of protected interests. Other reserves are free.

The following indicators of conditions of usability of reserves are used for the classification of reserves of a state owned deposit or its part into balancing or non-balancing types, in accordance with mineral types and deposit character:

a) geological, , as deposit thickness, quality of the industrial component and its spatial changes, harmful and non-usable components and their spatial changes, quantity of reserves, tectonics, depth of deposit location, properties of an underwall and top wall, hydrogeological conditions, collecting properties at a productive level, etc.;

b) mining and technical, as stability of a deposit and surrounding rocks, the optimum mining method, occurrence of gases, treatability and yield, backfilling of mined areas, drainage of deposit, effects of mining on the environment and ways of dissolving these effects, water management, mounding, waste use and depositing, etc.;

c) economic, as mineral raw material prices, mining and processing costs, etc.

During the stage of a scouting exploration of deposits the geological work is carried out in accordance with the conditions of efficiency of expected reserves in state owned deposits set in advance. If geologic work is financed from the state budget of the Slovak Republic, it is specified by the Slovak Geological Office [15]. In other cases, it is specified by an organization that covers the costs of the geological work.

During the stage of a detailed and mining exploration of deposits and in the case of the excavation of state owned deposits, the conditions of the feasibility of reserves are set variably by an organisation, which either extracts or will extract the deposit, and on their basis calculates the reserves or has them calculated.

If changes of indicators of the reserve feasibility conditions occur that affect the quantity of balancing reserves, the organisation sets new conditions for the feasibility of reserves.

Features of the appraisal of deposits containing free reserves include the following:

1. Procedures for calculating reserves during the period of the geological exploration are specified by a special regulation. A similar course of action is taken also when calculating reserves during the period of designing and construction of mines and quarries and in case of the extraction of a state owned deposit.

2. In the calculation of reserves for the period of designing and construction of mines and quarries and in the case of the extraction of a state owned deposit the organisation also specifies the extractable reserves, i.e. balancing reserves reduced by the value of assumed mining losses resulting from the selected mining technology as well as geological, mining and technical conditions.

3. The calculation of reserves is approved by a geological office within a specified time period.

4. The organisation repeatedly submits the calculation of reserves, prepared in accordance with new conditions of the feasibility of reserves, for the approval to the geological office only in cases, when approved balancing reserves which are reduced by extracted reserves change by more than 15% [16].

Geological work stages are divided into:

- geological research (includes the stage of basic geological research and stage of the regional geology),
- geological exploration (deposit exploration, which is divided into prospecting exploration, detailed exploration and extraction exploration).

A stage of the prospecting deposit exploration includes a set of geological work focusing on the evaluation of the possible occurrence of deposits during prospecting and exploration of state owned mineral deposits, definition of approximate tonnage of an identified deposit, calculation of reserves in the category of expectant reserves at least in a part of the deposit, and stating inferred reserves or reconnaissance mineral resources in the rest of a deposit. During the prospecting and exploration of mineral deposits not owned by the state it is necessary to evaluate the territory from the viewpoint of possible occurrences of mineral deposits, identifying and verifying their approximate tonnage and calculating reserves at least in one part of a deposit.

A stage of the detailed deposit exploration includes a set of geological work with the aim of verifying whether the amount of assumed deposit reserves is sufficient for their excavation. As for state owned minerals in the category of verified reserves it aims at obtaining and the verifying of data needed for the development of the mine or quarry construction project as well as for the developing, preparation and extraction of a deposit, considering local conditions and environmental protection.

A stage of the extraction deposit exploration includes a set of geological work aimed at gaining more detailed knowledge of the quantity and quality of the deposit reserves during the extraction of the deposit, and on the geological, mining and technical conditions of the extraction with the purpose of transferring reserves in accordance to actual needs. It can also serve to explain peculiarities in the deposit development or conditions of its rational exploitation.

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3 Principles of Evaluation of Reconnaissance Mineral Resources / Принципы оценки разведанных минеральных ресурсов

1. Reconnaissance mineral resources are estimated to the depths accessible to the current or future mining in accordance with current economic, mining, technical, technological and other conditions, while considering possible changes of these conditions in the future. The estimation is carried out in units of mass or tonnage in a limited reconnaissance area.

2. The quantity of reconnaissance mineral resources is defined on the basis of expert estimations within the limits of large regions, basins or parts of deposit units.

3. Reconnaissance mineral resources are divided into:

a) Reconnaissance mineral resources *P1*, the presence of which, based on the positive evaluation of deposit indications and anomalies detected during geological mapping and geophysical, geochemical and other work, is assumed in basins, mining properties or geological regions, where deposits of identical formation and genetic type are known. The estimation of reconnaissance mineral resources in assumed deposits and the idea of the shape and size of deposit bodies, their composition and quality are based on the analogy with these known mineral deposits.

b) Reconnaissance mineral resources *P2*, the presence of which, based on favourable stratigraphic, litologic, tectonic and paleographic assumptions identified in the evaluated area during geological mapping and by the analysis of geophysical and geochemical data, is assumed in the evaluated area. The estimation of quantity and quality of reconnaissance mineral resources is based on analogy with other areas examined in more detail, in which deposits of the identical genetic and formation type have been found and verified.

A geological study is divided into four gradual classes of geological research and exploration, which are grouped in the upcoming order, in accordance with the degree of details contained within: reconnaissance exploration, prospecting, general exploration and detailed exploration. These levels reflect the increasing degree of the geological assurance.

The feasibility estimation is divided into three stages according to the increased level of details contained within: initial feasibility study, pre-feasibility study, detailed feasibility study/mining report. These stages reflect the economic viability. A mining report and a detailed feasibility study have the highest degree of assurance and form one category; as for the pre-feasibility study, it is usually carried out before a detailed feasibility study and provides data on the economic viability at a lower level of assurance. An initial feasibility study does not aim at providing information on the state of economic implementation.

Economic effectiveness, corresponding to the state of reserves/resources, as it results from the evaluation of effectiveness, is understood as the third dimension in the UN system of classification. Two categories of economic effectiveness can be distinguished: economic and potentially economic, as quoted in the levels of the mining report/detailed feasibility study. If needed, each of these categories can be divided into two groups at the national level, called normal and conditioned in the case of economic categories, and marginal and sub-marginal in the case of categories of potentially economic resources.

In the initial feasibility study, compared with the detailed feasibility study/mining report and pre-feasibility study, the economic evaluation is only roughly estimated using estimated data and/or by the comparison with mining activities in similar deposits. Data estimated this way is quoted in the area of economic to potentially economic, and therefore is outside the limits of economic interests. Due to these reasons forms of “in situ” reserves/resources are quoted in the geological study, while the mining report/detailed feasibility study and pre-feasibility study mention two quantities: “in situ” and “workable”. In all cases it must be stated clearly, whether reserves/resources are “in situ” or “workable”.

The definitions of the above mentioned terms from the UN framework classification system are listed in the Definitions of terms, used in the English version of the UN framework classification system of reserves/resources [17]. These definitions have been formulated on the basis of all comments raised at meetings of the working commission (Tables 1-3).

As follows from the terminology of mineral deposit feasibility assessment, the stages of this process are considered from the point of view of ensuring the economic efficiency of extracting a mineral under given economic, mining and geological, ecological conditions. All terms presented in Tab. 1, provide an accessible understanding of the importance and economic value of the mineral, the deposit of which is subject to assessment. Once a decision has been made on the suitability of a field to current conditions and strategic importance, it is important to provide a general understanding of the terms of its geological assessment (Table 2).

Table 1. Definitions of Stages of Mineral Deposit Feasibility Assessment.

Definition	Explanation
Mining report	A mining report is understood as the current documentation of the state of development and exploitation of a deposit during its economic life including current mining maps. It is generally kept by the mine operator. The study records the quantity and quality of the minerals extracted during the monitored period of time, changes in economic conditions resulting from changes in prices of technologies, changes connected with amended environmental legislation or other regulations and data on mining. It presents the current status of the deposit, provided in detailed and accurate manner and updates volumes of reserves and the remaining resources.
Detailed feasibility study	A detailed feasibility study assesses in detail the technical soundness and economic Viability of a mining project, and serves as the basis for the investment decision as well as a bank document for a financial project. The study represents an audit of geological, environmental, legal and economic information accumulated in the project. Price data must be reasonably accurate (usually within 10 %) in order to provide a basis for the investment decision without further investigations. The information basis associated with this level of accuracy expresses the shape of a deposit based on the results of detailed exploration, results of technological tests and quotations of necessary equipment. A detailed list of the items provided in the detailed feasibility study is given in List of the most important feasibility items.
Pre-feasibility study	A pre-feasibility study provides a preliminary assessment of the economic viability of deposits for the justification of further investigations. It usually follows after a successful exploration campaign, and summarizes geological, environmental, legal and economic information gained until the date of the project. In a project that has reached a relatively advantageous stage, the pre-feasibility study can be made with the error of 25 %. In less successful projects higher errors can be expected. Various terms are used in a pre-feasibility study to reflect the reached accuracy level. The data required to achieve this stage of accuracy are tonnages of reserves/resources based on general and detailed exploration, technological tests at laboratory scale and price estimates from catalogues, based on comparable mining operations. The prefeasibility study deals with items provided by the detailed feasibility study, although not with so many details.
Initial feasibility study	An initial feasibility study is an initial evaluation of economic viability. This is obtained by the application of meaningful cut-off values for grade, thickness, depth, and costs estimated on the basis of comparisons with other mining operations. A category of economic viability generally cannot be defined from the initial feasibility study because of the lack of details necessary for an economic viability evaluation. The defined resources are indicated as the deposit outside economic interests, i.e. in the range of economic to potentially economic. An initial feasibility study is generally carried out in the following stages: reconnaissance, prospecting, general exploration and detailed exploration. The purpose of the initial feasibility study is to identify mineralization, to establish form, quantity, and quality of a mineral deposit, and define conditions for the deposit effective use.

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Table 2. Definition of Stages of Geological Work on a Mineral Deposit

Definition	**Explanation**
Reconnaissance	A reconnaissance serves to identify areas of enhanced mineral content on a regional scale based mainly on results of regional mapping, airborne and indirect measurements, preliminary field inspection, as well as geological comparisons and extrapolation. Its objective is to identify mineralised areas for further deposit identification. Estimates of the quality are possible only if sufficient data are available, and when an analogy with known deposits of similar geological character is possible.
Prospecting	Prospecting is the systematic process of searching for a mineral deposit of promising enhanced mineral potential in narrowly limited areas. The methods utilized are outcrop identification, geological mapping, and indirect methods such as geophysical and geochemical studies. Limited trenching, drilling, and sampling may be used. The objective of prospecting is to identify a deposit as a target for further exploration. Estimates of quality are based on geological, geophysical and geochemical results.
General exploration	General Exploration involves the initial delineation of an identified deposit. Methods used include surface mapping, sampling, trenching and drilling for evaluation of quantity and quality (laboratory tests are also required), and limited interpolation based on indirect methods of investigation. The objective is to establish the main geological features of a deposit, and indication of their shape, size, structure and grade. The degree of accuracy must be sufficient for deciding whether a prefeasibility study and detailed exploration recommended.
Detailed exploration	Detailed exploration involves the three-dimensional delineation of a known deposit achieved through sampling of trenches, boreholes, shafts and tunnels. Sampling is made so that size, shape, structure, and other relevant characteristics of the deposit are identified with a high degree of accuracy. Detailed exploration information results in a decision whether a detailed feasibility study is conducted.

As follows from the description of the stages of geological study of mineral deposits presented in Tab. 2, understanding the detailed conditions for their development precedes the economic assessment of this process (Table 3).

The estimation of quantity and quality of reconnaissance resources is based on an analogy with other similar areas explored in detail, in which deposits of the identical genetic and formation type have been verified. The new classification of reserves and resources (ECE - UN) proposes to divide the degree of exploration depending on the stage of deposit geological work to detailed exploration, general exploration, prospecting, reconnaissance.

The new system proposes to list the degree of exploration to the last, third place, after classification of the economic viability category and classification stage evaluation feasibility.

Deposits of various origin, different geological structure and variability require different density of the exploration network for a certain degree of exploration. The exploration network density is conditioned by the required accuracy of exploration (required category of reserves) and the character of the explored deposit.

In accordance with V.M. Krejter [18] the exploration network density is understood as a deposit area S_0 which belongs to one exploration corridor can be defined as (3):

$$S_0 = \frac{S}{n} \quad (3)$$

where: S – the area of the ore body (deposit);

n – the number of exploration works that intersect the ore body (deposit).

In exploration practice the exploration network density is expressed either by the size of the area S_o or by the distance between exploration works.

The classification of exploration stages in accordance with the relative accuracy *p* of calculated reserves and their quality has been proposed as follows [19]:

- for p < 10% – the detailed exploration;
- for p 10-25% – the general exploration;
- for p 25-80% – the for prospecting;
- for p > 80% – the for reconnaissance.

The main factor, which determines the exploration network density is the degree of variability of individual deposit parameters. The more variable the deposit, the higher the density of the exploration network required.

Table 3. Definitions of Mineral Deposit Economic Viability Categories.

Definition	**Explanation**
Economic	Reserves expressed in tonnes/volume with a certain grade/quality, demonstrated by means of a prefeasibility study, detailed feasibility study or mining report, in order to justify extraction under the technological, economic, environmental and other relevant conditions, valid at the time of the determination. The term "economic" comprises two subcategories applicable at a national level - normal economic and conditional economic.
Normal economic	Normal economic reserves are reserves that justify extraction under competitive market conditions. The average value of the mined commodity must be sufficient to ensure the required return on investment.
Conditional economic	Conditional economic reserves are reserves which at present are not economic under competitive market conditions. Their exploitation is possible through government subsidies and/or other supportive measures.
Potentially economic	Reserves expressed in tonnes/volume with a certain grade/quality, demonstrated by means of a prefeasibility study, detailed feasibility study or mining report, not justifying extraction under the technological, economic, environmental and other relevant conditions, valid at the time of the determination, but with a possibility of extraction in the future. The term "potentially economic" comprises terms "marginal" and "sub-marginal" used at a national level.
Marginal economic	Marginal economic resources are resources which at the time of determination are not economic, but on the border of being economic. They may become economic in the near future as a result of changes in technological, economic, environmental and/or other relevant conditions.
Sub-marginal economic	Sub-marginal economic resources are resources that would require a substantially higher commodity price or a significant cost-reducing advance in technology to re-classify them to economic.
Economic to potentially economic	Reserves expressed in tonnes/volume with a certain grade/quality, marked by initial feasibility studies as economically interest. Although initial feasibility studies include a preliminary evaluation of economic viability, they are not classified as economic and potentially economic. These resources are marked as resources belonging to the range of economic to potentially economic.

4 Classification of Reserves in Accordance with their Economic Importance / Классификация запасов по их экономическому значению

The definition of dependencies between reserves of the deposit *Z*, average grade *x* and cut off grade x_o is of crucial importance for the optimum classification of proved reserves to balancing (economic) reserves and non-balancing (potentially economic) reserves. As a rule, the dependencies between *Z*, *x* and x_o are obtained by means of alternative calculations of reserves at various cut off grades x_o. In the majority of mineral deposits the quantity of geological reserves *Z* and their average grade *x* depend on the accepted cut off grade x_o value. When the cut off grade x_o values are low, the estimation (calculation)

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of reserves results in a large quantity of geological reserves *Z* with a low average grade *x*. With the increase of the cut off grade x_o the quantity of geological reserves *Z* decreases and the average grade *x* increases.

Depending on the variability of mineralization and industrial component distribution type (lognormal, normal, left asymmetric, right asymmetric, bimodal, complex, etc.) the curve of reserve dependency *Z* on the cut off grade x_o also changes (Fig. 1).

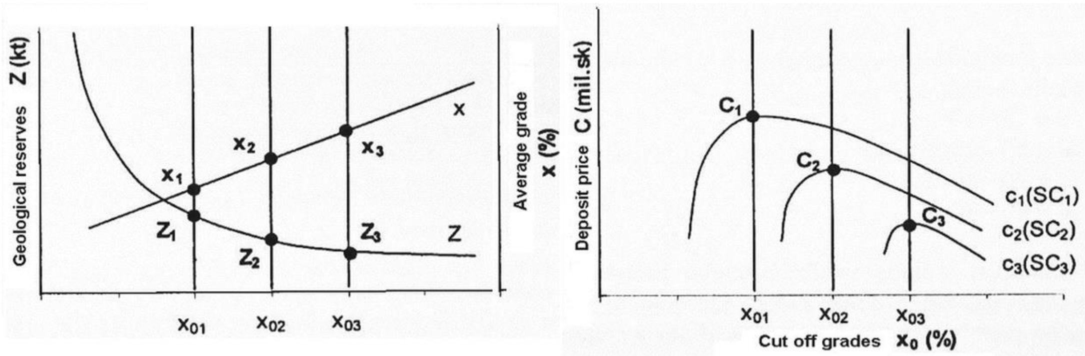

Fig. 1. Dependency between maximum deposit price *C* and geological deposit parameters *Z*, *x*, x_0 at changed prices of mineral commodities *SC*.

From the above stated it results, that each mineral deposit, being a unique natural object, has its specific properties, which it is possible to express by means of dependencies Z, x a x_o which can be graphically and mathematically described on the basis of alternative estimations (calculations) of reserves with various cut off grades of industrial components at each studied deposit.

The suitability of this procedure which defines dependencies between Z, x and x_o results from the need to define contours of balancing and non-balancing reserves and also from the possibility to use this method for the definition of optimum Z, x and x_o**,** which correspond to the maximum deposit price at variable economic, technical and technological parameters (price, production costs, contamination, recovery, yield, etc.).

The relationship between the deposit price and "static" geological-deposit parameters (Z, x, x_o) is illustrated in Fig. 2.

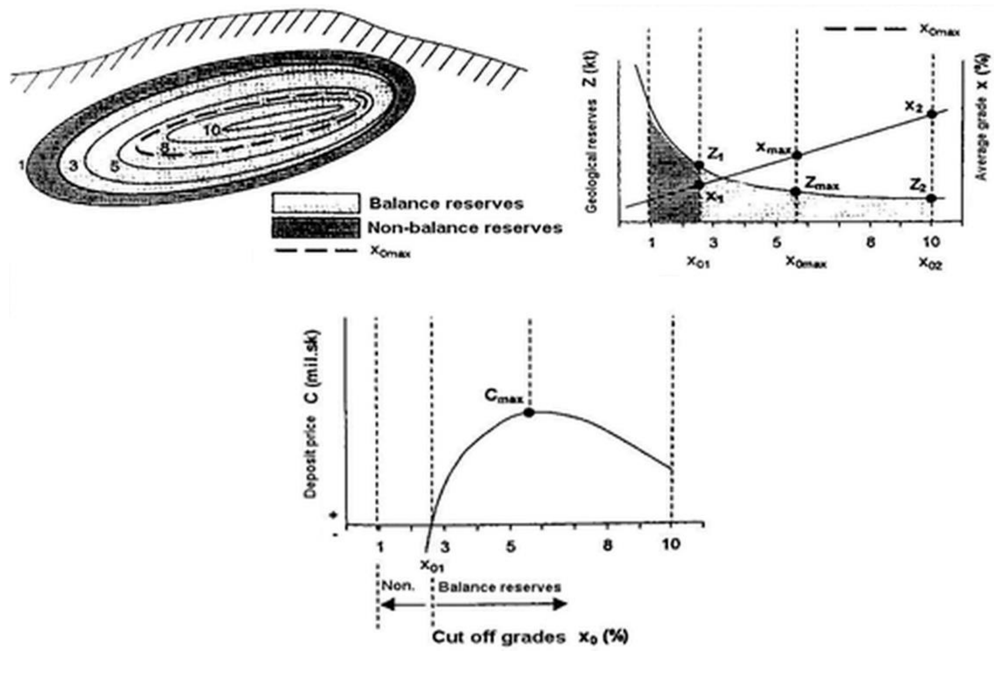

Fig. 2. Methodology of defining balancing and non-balancing reserves for state owned deposits.

From Fig. 1 it results that with the growth of global prices of mineral commodities ($SC_1 \geq SC_2 \geq SC_3$) and constant production costs, technical and technological parameters, not only the increase of deposit prices ($C_1 \geq C_2 \geq C_3$), but simultaneously the change of optimum geological-deposit parameters Z, x a x_o corresponding to the maximum deposit prices occur:

– at the world price SC_1 reserves of the deposit Z_1 with the average grade x_1 above the cut off grade x_{o1} correspond to the maximum deposit price C_1;
– at the world price SC_2 reserves of the deposit Z_2 with the average grade x_2 above the cut off grade x_{o2} correspond to the maximum deposit price C_2;
– after further drops in the global price to the level SC_3, reserves of the deposit Z_3 with the average grade x_3 above the cut off grade x_{o3} corresponding to the maximum deposit price C_3;
– a further drop in the global prices of the given commodity would result in a negative value of the deposit price, i.e., no reserves would be listed as economic, and all deposit reserves would be classified only as potentially economic.

Similar dependencies between the deposit price and "static" geological-deposit characteristics (Z, x, x_o) also apply in cases of more significant changes in production costs and technical and technological parameters. From the above it can be assumed that the deposit price C (economic value of its proved reserves – Equation (4)) depends not only on the price of raw materials c, production costs n and technical and technological parameters t_p, but also on geological-deposit parameters (Z, x, x_o), which principally affect "dynamic" economic and technical and technological parameter.

$$C \rightarrow f(Z, x, x_0, n, c, t_p) \quad (4)$$

From mutual dependencies between the so called "static" (geological-deposit) and "dynamic" (technical, technological and economic) parameter mineral deposits it results that:

1. Only an accurately specified quantity of reserves, defined by means of the cut off grade x_o value, average grade x value and geological reserves Z correspond to the maximum deposit price at a constant price of raw materials, constant production costs and technical and technological parameters. Significant changes in raw material prices, production costs and technical and technological parameters result in changes of cut off grades x_o, average grades x and geological reserves Z that define the maximum deposit price.

2. With a certain ratio between raw material prices and production costs the balancing (economic) reserves are "lost" ($Z_B = 0$), and only non-balancing reserves (potentially economic resources), the quantity Z_N and average grade x_N of which correspond to reserves above the contour of the cut off grade for non-balancing reserves x_{oN}, remain in the deposit.

Despite the fact that mineral deposits have different origins, age, morphology, composition, etc., the use of the above stated methodology for the economic viability evaluation of reserves and resources (balancing - non-balancing) is likely to become generally applicable for the majority of mineral deposits, with certain modifications for various morphological and geological-technological types.

In accordance with our valid legal standards balancing reserves are reserves that are usable at present, and meet current technical, technological and economic conditions of the use of the state owned deposit or its part. Non-balancing reserves are reserves unusable at present, however, with regard to the technical, technological and economic development, their use in the future is assumed.

Internationally, balancing reserves are reserves that ensure profitable extraction at defined investment assumptions with a reasonable degree of assurance. From this definition it results that these are reserves that must ensure profitable extraction. The issue that arises is the definition of the optimum profit-cost ratio (profitability), at which contours of balancing reserves are defined. The previous chapter implies that in some deposits with a high average grade (with a high value of differential mining rent), it is possible to also define contours of reserves with a value lower than x_{omax} that meet the standards of balancing reserves along with contours of reserves defining the maximum deposit price (cut off grade x_{omax}). For example, it is possible to define contours with the following cut off grade:

• x_{o1}, which ensures profitability R = 10%;
• x_{o2}, which ensures profitability R = 20%;
• x_{o3}, which ensures profitability R = 30%.

Current understanding of "Conditions for Feasibility of Reserves" (CFR) (conditions), along with the requirement to direct geological work during the prospecting stage in accordance with conditions

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for feasibility of expected reserves in a state owned deposit set in advance, leads to disputable methodological procedures, which in some cases may have a negative impact on the deposit evaluation.

First of all, each deposit is understood as a unique object with a natural accumulation of industrially usable minerals, for which it is neither possible nor reasonable to define the CFR, which serves for the division of reserves to balancing and non-balancing, in advance. In advance, e.g. before starting the prospecting stage it is only possible to state generally that the goal is to search for and verify the biggest and highest grade deposit, e.g. of gold, or other minerals. Parameters (like reserves, quality, etc.) of a deposit, which is verified after completing work at the given stage, e.g. prospecting stages are not known in advance, and it is possible to start the economic evaluation of the deposit only subsequently, when its "static" geological-deposit parameter Z, x, x_o as well as other mining, technical, technological, environmental and other parameters are defined in alternative calculations.

The philosophy of the CFR set in advance does not consider the existence of dependencies between deposit price and "static" geological-deposit parameters, hence it does not allow the definition of the optimum contour of balancing reserves x_B, $x_{Bmax.}$, as stated above.

The second significant drawback in the methodology of defining the CFR for ore and selected non-metallic raw materials is the defining of one value of the "marginal sample" (cut off grade x_o) for balancing and non-balancing reserves of the deposit (as a rule in accordance with a 50 % value of treatment costs). This approach results in the increase of the reserve quantity in many ore deposits, however their average grade decreases. Naturally this fact has a negative impact on the deposit price and the ratio between balancing and non-balancing reserves. As reasoned in the previous chapters, and as also results from the definition of balancing and non-balancing reserves, cut off grades should be defined individually for balancing non-balancing reserves x_{oB}, x_{oN}.

The third drawback of methodologies of defining the CFR for ore and some non-metallic deposits that are frequently used nowadays consists in the possibility of assigning "low grade blocks of reserves" to higher grade blocks of reserves up to the value of the defined minimal average grade for balancing reserves of the entire deposit. This can eventually reduce the deposit price by reducing the average grade of balancing reserves x_B.

In case of some non-metallic raw materials, the balancing of which is evaluated in accordance with general conditions of non-metallic minerals in the prospecting stage, it is worth emphasising that in the case of absence of economic (cost and price) CFR parameters, the objective definition of balancing and non-balancing reserves is purely illusory.

The requirements of these conditions with regard to the minimum quantity of balancing and non-balancing reserves can be considered economically proofless. As in the case of many non-metallic raw materials the changes of technological requirements have also been made, we consider further application of these conditions for the evaluation of the balancing and non-balancing of proved reserves unsuitable.

The evaluation of the balancing and non-balancing state of proved reserves of brown coal and lignite having completed the stage of prospecting is problematic, similarly to the group of non-metallic raw materials. Doubts on the objectiveness of evaluating the coal deposit reserves balancing is caused by the absence of economic parameters (price, production costs) in the conditions.

Also in the case of non-metallic raw material and coal deposits it is possible to consider the CFR (conditions) only as a set of geological-deposit, technological and technical requirements, which when lacking economic requirements and the optimum methodological approach documented in the previous chapters, enable neither the objective classification of proved reserves to balancing and non-balancing nor the quantification of the deposit price.

4 Conclusion / Заключение

Despite the significant volumes of minerals extracted from the subsoil over the last one and a half centuries, mineral resources remain an important factor in the competitiveness of the national economy. Changes in the resource intensity of production and an increase in consumption on a global scale, raw material super-cycles and an increase in energy demand in the era of total digitalization, an explosive growth in demand for raw materials for the production of batteries, electric machines - these and other factors of overestimation of mineral resources cause the need for its improvement. Different categories of raw materials reserves require a unified approach to their economic assessment, taking into account, at the same time, current investment, financial, and technological variables. The economic justification of the prospects of deposits for development should be guided not only by current, but also by future demand, which is formed under the influence of the spread of Industry 4.0. In accordance with this, the principles for evaluating mineral deposits should include taking into account the prospects for demand when determining the final depth of development, anticipating geological exploration, establishing the relationship between the price of raw materials and the geological parameters of the deposit.

References

1. Dotsenko E., Ezdina N. Sustainable Subsoil Use as a Factor of Innovative Development of Mining Region. E3S Web of Conferences. 2018. Vol. 41. pp. 04048. DOI: 10.1051/e3sconf/20184104048

2. Dotsenko E., Ezdina N., Mudrova S. Zero Waste Technologies and Solution of Economic and Environmental Problems of Sustainable Development. E3S Web of Conferences. 2019. Vol. 105. pp. 02008. DOI: 10.1051/e3sconf/201910502008

3. Khasanova A., Dotsenko E., Ezdina N., Khasanov M. Multi-aspect impact of eco-innovations ("sustainable goods") as a form of development of innovative potential of the region. E3S Web of Conferences. 2020. Vol. 220. pp. 01004. DOI: 10.1051/e3sconf/202022001004

4. Cehlar M., Engel J., Mihok J., Rybar, R. Povrchové dobývanie, Edicne stredisko. Kosice: AMS, F.BERG TUKE, 2005. 366 p.

5. Rybar P. Cehlar M. Economic Evaluations of Mining Projects. Szkola Ekonomiki i zarzadzania w Gornictwie. 1997. 97. pp. 461-475.

6. Rybar P. Zemské zdroje. Acta Montanistica Slovaca. 1997. Vol. 2 No.1. pp.1-53.

7. Armstrong M., Dowed P.A. Geostatistical simulations. Proceedings of the Geostatistical Simulation Workshop, Fontainebleau, France. 27-28 May, 1993. Boston, London: Kluwer academic publishers, 1994. 255 p.

8. Coube P. Mining microeconomics in Slovakia. Paris: Centre de Geotechnique d'Exploitation du Sous-sol. Ecole Nationale Superieure des Mines, 1993. 102 p.

9. Gentry D.W., O'Neil T.J. Mine Investment analysis. Society of Mining Engineers of America. New York: Institute of Mining, Metallurgy, and Petroleum Engineers, 1984. 502 p.

10. Duchene M. Economie de l'enterprise miniere. Lectures, Centre de Geotechnique d'Exploitation du Sous-sol. Paris: Ecole Nationale Superieure des Mines, 1990. 88 p.

11. Cavender B. Determination of the optimum lifetime of a mining project using discounted cash-flow and option pricing techniques. New York: Mining Engineering, 1992. 405 p.

12. Rybar R., Kudelas D., Fischer G. Alternatívne zdroje energie 3, 1. vyd. - Kosice: Edičné stredisko/AMS, 2004. 99 p.

13. Torries Th.F. Evaluating Mineral Projects: Applications and Misconceptions. Littleton: Society for Mining, Metallurgy and Exploration, 1997. 153 p.

14. Kudelas D. Rybar, R. Technicka analyza vhodnosti vyuzitia roznych typov veternych rotorov pre pohon kompresora akumulacneho systému umoznujuceho využitie nízkopotencialnej veternej energie. Acta Montanistica Slovaca. 2005. Vol. 10 No. 1. pp. 38-42.

15. Kudelas D., Rybar R., Taus P. Realne moznosti vyuzitie veternej energie na Slovensku. Casopis Elektroenergetika. 2005. No. 2. pp. 34-45.

16. Wackernagel H. Multivaiate geostatistics. Springer Verlag. Berlin: Heidelberg, 1995, 232 p.

17. OSN. Ekonomicka komisia pre Europu: Systém medzinarodnej klasifikacie zasob a zdrojov. 1997. 20. Pp.36-42.

18. Krejter V.M. Poisky i razvedka mestoroždenij poleznych iskopajemych. Moskva: NEDRA. 1961. 356 p.

19. Sejak J. Ocenovani pozemku a prirodnich zdroju. Grada: Publishing, 1999. 233 p.

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