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# METHODS FOR PREDICTION OF THE CONDITIONS OF DIP FORMATION ON THE GROUND SURFACE DURING UNDERGROUND DEVELOPMENT ORE DEPOSITS

**Abstract.** The article deals with the issues of predicting the conditions for the formation of dips on the earth's surface under the influence of underground mining in relation to the ore deposits of Kyrgyzstan. The analysis of existing methods for calculating the stability of the earth's surface is carried out, and calculation methods for predicting the conditions for the formation of dips are presented. The main factors influencing the shape and nature of the displacement of the overburden and the surface of the mines of antimony and mercury deposits have been identified. As a result of the research and analysis of the data obtained, the nature of the development of displacement in the undermined massif over time was revealed and empirical dependences of the change in the development depth on the strength of the rocks were established.

***Key words:*** *underground mining, rock movement, earth surface failure, forecasting methods, subsidence, curvature, displacement trough, horizontal displacements, tension, compression, goaf, development depth.*

## Рудалы кен орындарын жер астында игеру кезінде жер бетінде опырылымдардың пайда болу жағдайларын болжау әдістері

**Аңдатпа.** Мақалада Қырғызстанның рудалы кен орындарына қатысты жер асты жұмыстардың әсерінен жер бетіндегі опырылмдардың пайда болу жағдайларын болжау мәселелері қарастырылған. Жер бетінің тұрақтылығын есептеудің қолданыстағы әдістеріне талдау жасалды, шөгінділердің пайда болу жағдайларын болжаудың есептеу әдістері ұсынылды. Сурмя және сынап кен орындары кеніштерінің беті мен жабушы жыныстардың жылжу түрі мен сипатына әсер ететін негізгі факторлар анықталды. Жүргізілген зерттеулер мен алынған деректерді талдау нәтижесінде уақыт өте келе алынған массивте жылжудың даму сипаты анықталды және даму тереңдігінің өзгеруі тау жыныстарының беріктігіне эмпирикалық тәуелділіктер анықталды.

***Түйінді сөздер:*** *жер асты жұмыстары, тау жыныстарының жылжуы, жер бетінің опырылуы, болжау әдістері, шөгу, қисықтық, сырғу мульдалары, көлденең сырғу, созылу, сығылу, игерілген кеңістік, игеру тереңдігі.*

## Методы прогнозирования условий образования провалов на поверхности земли при подземной разработке рудных месторождений

**Аңдатпа.** В статье рассматриваются вопросы прогнозирования условий образования провалов на поверхности земли под воздействием подземной разработки применительно к рудным месторождениям Кыргызстана. Проведен анализ существующих методов расчета устойчивости земной поверхности, а также представлены методы расчета для прогнозирования условий образования провалов. Выявлены основные факторы, влияющие на форму и характер смещения вскрышных пород и поверхности шахт месторождений сурьмы и ртути. В результате исследования и анализа полученных данных был выявлен характер развития смещений в подорванном массиве с течением времени и установлены эмпирические зависимости изменения глубины разработки от прочности горных пород.

***Ключевые слова:*** *подземные работы, сдвиг горных пород, обвал земной поверхности, методы прогнозирования, усадка, кривизна, скольжение, поперечное скольжение, растяжение, сжатие, освоенное пространство, глубина освоения.*

## Introduction and relevance of the study

Underground mining of mineral deposits is accompanied by a mandatory imbalance in the rock mass, which, depending on the parameters and development technology, can either be localized inside the rock mass or manifest itself on the earth's surface in the form of dips, terraces, cracks and zones of smooth deformations. The whole complex of phenomena associated with the deformation of a rock mass and disturbance of the earth's surface in the area of influence of mining operations is united in mining by a common concept – the process of displacement of rocks.

The urgency of the problems of rock displacement has been preserved throughout the history of mining and is due to the danger of destruction from the impact of the displacement process of both the structures of mining enterprises and the surrounding industrial, residential and public buildings and structures, as well as natural objects falling into the zone of influence of underground mining. Along with the destruction of undermined objects, the displacement process often creates a danger for the mining operations themselves, in particular, the formation of collapse zones and water-conducting cracks during the extraction of minerals under rivers, lakes and reservoirs or in the presence of karsts, flooded rocks, quicksand, etc. can lead to water breakthrough and flooding of mine workings.

An exact description of the role and place of rock movement in the development of underground mining is given by I.M. Bakhurin, the founder of research work on rock movement in the former Soviet Union: «Rock movement in a mine is one of the main difficulties in mining. It is also one of the main threats to the safe conduct of mining: it breaks the fastening, reduces the useful section of the workings, and sometimes completely fills them up. We will not be mistaken if we say that the whole history of finding the best mining systems is the history of the struggle against the displacement of rocks»[1].

Thus, the problems in the field of rock movement, which have been acute throughout the history of underground mining and have

[1]*Kuznetsov M.A., Akimov A.G., Kuzmin V.I. and others. Displacement of rocks in ore deposits. – M.:Nedra, 1971. – 224 p. (in Russian)*

become increasingly important in modern mining in connection with the expansion of mining and the development of deep deposits with complex mining conditions, are among the most important. The fulfillment of the main goal of mining science «...to create the most advanced technical means and technological methods and techniques for achieving the safest and most economic development of minerals while facilitating the work of miners in every way...» [1] depends on their solution to a large extent.

In modern scientific and technical literature, the displacement of rocks and the earth's surface [2] in a broad sense is understood as displacements and deformations caused by an imbalance in a rock mass under the influence of anthropogenic activities for the extraction of various types of minerals or the development of natural processes and phenomena[2]. The main modern ideas about the process of rock movement at ore deposits (figure 1) are set out in a generalizing collective work, the current rules for the protection of structures for mining regions, in instructions for monitoring movements at ore deposits, and in extensive scientific and industrial literature.

In the theory and practice of the protection of structures, more than a dozen parameters are used to characterize various aspects of the displacement process [3], which can be conditionally divided into the following groups [4]:

- angular parameters (boundary angles, angles of displacement, breaks, collapse and funneling);
- deformations and displacements of rocks and the earth's surface (subsidence, slope, curvature, horizontal displacements, tension and compression);
- time parameters (duration of the displacement process, the rate of deformations and displacements, the period of dangerous deformations).

The angular parameters characterize the relative position of the boundaries of underground mining with the boundaries of the characteristic zones of the shear trough on the Earth's surface. All angular parameters are conditional indicators applicable only for constructing the boundaries of safety pillars and corresponding zones on the surface, and the inclined lines and planes constructed with their help do not reflect the actual boundaries in the rock mass.

Displacement and deformation parameters characterize vertical and horizontal displacements and deformations of the earth's surface and host rocks. Unlike the previous group, these parameters characterize the actual mechanical phenomena occurring in the rock mass as a result of a violation during the underground mining of the deposit.

The third group of parameters characterizes the development of the shear process in time and, in addition to shear rates and deformations, include such important indicators as the total duration of the shear process and the period of dangerous deformations.

In the general provisions of the «Rules» and «Instructions» and in the scientific and technical literature, a different number of factors influencing the nature and parameters of rock movement are considered. Most of them have been studied very poorly, and it is not possible to quantify their effect on the displacement parameters. It is all the more difficult to establish the influence of a complex of factors. The rules quantitatively take into account only those factors that change within a significant range and cause significant changes in the rock displacement parameters.

**Research methodology**

Modern methods for predicting deformations and displacements for designing measures to protect structures and natural objects from the influence of underground mining in ore deposits, by analogy with coal mines, according to the main assumptions and used for forecasting, can also be divided into empirical, based on distribution functions, and based on theoretical models . Empirical methods of forecasting the displacement process based on the results of instrumental observations are the most common in modern practice in the development of ore deposits. They are adopted in all the «Rules» and «Instructions» in force at the enterprises of Krivoy Rog (Ukraine), the Urals, Mountain Shoria and Siberia (Russia), Kazakhstan[3].

Along with basin or regional rules on newly developed deposits of ferrous and non-ferrous metals, temporary rules for the protection of objects at deposits with an unexplored shear process are widely used.

**Figure 1. Quarry ledges of ore deposits.**
**Сурет 1. Кен орындарының карьерлік кемерлері.**
**Рис. 1. Карьерные уступы рудных месторождений.**

*[2]Sashurin A.D. Displacement of rocks in the mines of ferrous metallurgy. – Yekaterinburg: Institute of Mining of the Ural Branch of the Russian Academy of Sciences, 1999. – 268 p. (in Russian)*
*[3]Kratch G. Displacement of rocks and protection of workable structures. – M.: Nedra, 1978. – 494 p. (in Russian)*

*Table 1*

***Calculation methods for predicting the conditions of failure formation***

*Кесте 1*

***Сәтсіздіктердің пайда болу жағдайларын болжау үшін есептеу әдістері***

*Таблица 1*

***Методы расчета для прогнозирования условий образования провалов***

| Author | Deposit | Formula |
|---|---|---|
| ***Limit depth*** | | |
| VNIMI | | $H_1 = k \times l_э, l_э = (L \times l) / \sqrt{L + l^2}$ |
| Unipromed | Ural | $H = k\sqrt{m \times l}, l = (L^1 \times n) / (L^1 + n)$ |
| Kuznetsov M.A., Akimov A.G. and etc | Kazakhstan, Siberia, Ural, Krivoy Rog | $H > H_P = (300 \times M_3 \times L^1) / (L^1 + 74M_3)$ |
| VNIMI | Krivoy Rog | $H = [L \times (20 - f)] / [3,3 \times (1 + 0,1f)$ |
| Yalymov N.G., Beglyakov V.E. | Khaidarkan | $H = L / [2 \times tg(\delta - 90°)$ |
| ***Collapse zone height*** | | |
| Akimov A.G. | | $h = A\sqrt{(L \times n \times \gamma \times m/k_M)}$ |
| VNIMI | Sovetskoe | $h = (a \times L^1 \times S) / [b \times (L^1)^2 + c \times S)$ |
| Skozobtsev B.S.,<br>Efimov E.P. and etc. | Mirgalimsay | $h = 0,37L$ – average disturbed array<br>$h = 0,48L + 8$ – heavily disturbed array |
| Kravets V.S. | Krivoy Rog | $h = L \times (0,7 + 0,0042H);$<br>$h = (0,9 + 0,0095H + 0,000001H^2)m;$ |
| Borisov A.A. | | $h = 3/2 \times [(\gamma \times H + q)l^2] / \sigma \times h_1$ |

At developed fields with a studied shear process, the normative parameters for drawing up rules or designing measures for the protection of objects in practice are predicted by extrapolating the results of instrumental observations to subsequent periods of development. At newly developed deposits or at new areas of developed deposits that differ in mining and geological conditions, the displacement process is predicted by analogy with the studied deposits, which have approximately the same development conditions. This approach was called the analogy method and, as applied to coal deposits, was first developed by D.A. Kazakovsky. For ore deposits, the analogy method was substantiated in the development of temporary rules for deposits with an unexplored shear process and was further developed by M.A. Kuznetsov. The effectiveness of applying the analogy method depends on the correct choice of analogue deposits, which is based on the classification features of deposits[4].

The stability of the earth's surface during the development of ore bodies is determined by the mining system and depends on many mining and geological factors. Currently, as a criterion for assessing the safe depth of development, it is accepted that the deformations of the earth's surface do not exceed the following critical values[5]:

- slope of the shift trough: $i = 4 \times 10^{-3}$ (4 мм/м);
- curvature: $k = 0,2 \times 10^{-3}$ (0,2 мм/м$^2$);
- horizontal stretching: $\varepsilon = 2 \times 10^{-3}$ (2 мм/м).

In general, the calculation methods for predicting the conditions for the formation of dips can be represented as follows (table 1).

Thus, from the analysis of existing methods for calculating the stability of the earth's surface, it follows that the value of the safe depth of development is determined by the development systems used, their parameters, and the physical and mechanical properties of the host rocks. But, as you know, the process of displacement of a rock mass is temporary, and therefore, in order to justify and apply one or another method in specific mining and geological conditions, it is necessary to analyze the actual state of underground voids and the surface, comparative calculations and establish the possibility of formation of surface dips in time.

## Discussion of the research results

The process of rock displacement in ore deposits, having a commonality with similar phenomena in deposits of other types of mineral raw materials, has a number of features, mainly due to the parameters of the ore bodies, the properties and condition of the host rocks, and the mining technology. In the practice of solving the problems of rock displacement, in most cases, issues are considered in relation to mines,

[4] *Turchaninov I.A., Iofis M.A., Kaspar'jan Je.V. Fundamentals of rock mechanics. – L.: Nedra, 1989. – 488 p. (in Russian)*

[5] *Temporary rules for the protection of structures and natural objects from the harmful effects of underground mining of non-ferrous metal deposits with an unexplored process of rock movement. / Approved by the Ministry of non-ferrous metals 30.06.86. – L.:VNIMI, 1986. – 74 p. (in Russian)*

where systems with the collapse of host rocks are used[1, 2].

As is known, the underground mining of ore deposits in Kyrgyzstan is carried out by systems with natural maintenance of the mined-out space. Under these conditions, the development, as a rule, is accompanied by the formation of underground voids of considerable size. If timely appropriate measures are not taken to extinguish them, then under certain conditions, over time, the process of shifting the overlying strata may begin. Developing in the array, this process reaches the earth's surface with the formation of dangerous deformations and dips. So, for example, at the Khaidarkan mine, dips formed under the main roads to the plant and quarry and under a residential village. At the Chauvai mine, dips formed under a residential area. The largest number of sinkholes (more than 40) took place at the Kadamzhai mine.

To assess the stability and identify the main factors affecting the shape and nature of the displacement of the earth's surface, we have studied and processed the geological and surveying documentation for the Kadamzhai and Khaidarkan mines. At the same time, the depth of development, the parameters of chambers and stores, the characteristics of the roof rocks, the time of working out the chambers and the formation of dips were recorded.

Based on these data and the calculation formulas given in the above table, we carried out comparative calculations of the development depth, at which dangerous deformations and dips may form on the surface, and according to the data obtained, graphs were constructed to assess the stability of the surface depending on the geometric parameters of the voids and physical and mechanical properties rocks [5] of the overlying massif [6].

As a result of the research and analysis of the data obtained, the nature of the development of displacement in the undermined massif over time was revealed and empirical dependences of the change in the development depth on the strength of the rocks were established.

The time of formation of surface dips during the development of ore bodies by systems with an open mining area without forced filling of underground voids significantly depends on the stability of the roof of the chambers in time and the duration of the process of self-collapse of overlying rocks. At the same time, the influence of the time factor on the depth of formation of dips is recommended to be taken into account by the coefficient kt, the values of which, depending on the strength of the overlying rocks, are given in [7].

Comparative calculations and evaluation of the obtained results showed that, along with the geometric parameters of the voids and the physical and mechanical properties of the rocks, the value of the safe depth is significantly affected by structural weakening in the rock mass and the time factor.

**Conclusion**

1. The result of the research and analysis of the data obtained showed that the conditions for the formation of sinkholes in the ore deposits of Kyrgyzstan depend on a number of factors: the geometric parameters of the voids, the physical and mechanical properties of the rocks, the structural features of the massif, and the time factor.

2. The value of the safe depth according to the normative document is determined depending on the physical and mechanical properties of the rocks and the geometric parameters of the voids: $H_l > k_l l_з$.

3. Comparative calculations and evaluation of the obtained results showed that along with the geometric parameters of the voids and the physical and mechanical properties of the rocks, the value of the safe depth is also significantly affected by structural weakening in the rock mass and the time factor. Taking into account these factors, we recommend that the safe depth be determined by the formula [7]:

$$H_l > k_l l_з k_t / k_c,$$

where:
$k_c$ – structural weakening factor;
$k_t$ – coefficient taking into account the influence of the time factor.

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