ABSTRACT

dissertation in candidacy for a degree of doctorate in philosophy (PhD) in the specialty 6D070600 - " Geology and exploration of mineral deposits»

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CREATION OF A GEOLOGICAL AND GEOPHYSICAL MODEL FOR THE ROOF STABILITY FORECAST OF COAL BEDS TOP ROCKS OF THE KARAGANDA BASIN

The history of the development of mining and geological work of the Karaganda coal basin is reduced to an increase in the deep mining. In the twentieth century, the average depth of development was about 300 m vertically from the surface, currently the depth of development by underground mining is 600-700 m.

In the future, it is planned to increase the operating depth due to the need for coking coal, since Karaganda coals are currently used as coking in metallurgy, energy, and also as sources of natural associated gas (methane) [4, 5].

Coals of the Karaganda basin provide not only domestic needs, but also the export of Kazakhstan. To increase production capacities, the introduction of modern technological schemes and high-performance mining, transport and auxiliary equipment at coal enterprises is required. The Karaganda coking coal basin is developed by underground mining; therefore, rational and safe mining is relevant for improving the technical and economic indicators of production. Improving the methods of mine geology will make it possible to apply methods of actively combating adverse engineering and geological phenomena.With the increasing introduction of resource-saving technologies in the mining industry, is one of the main prerequisites for the successful operation of a modern mining enterprise.

The main problem in the operation of a coal deposit underground method is the prevention of coal beds top rocks collapse. Scientifically-based forecasting of the stability of coal beds top rocks of the Karaganda coal basin contributes not only to the full development of reserves, but also ensures rational and safe mining operations. Which, in turn, is necessary when building new mines and increasing the number of employees [6-8].

A number of works for predicting the stability of coal beds top rocks methods by Kobilev A.G., Pogromsky D.V., Voronin I.N., Glushko T.V., Zingel I.P., Shirokov Z.A., Skvortsov G.G. and Fromm V., Kolegov A.A., Chulkov A.D., Isakov P.P., Radko B.V., Malinin S.I., Smirnov V.B., Alferov O.S., Zubenko E.N., Nenasheva R.N., Aksenenko M.I., Kulikov B.B., Lazarev V.S. and others.

The physical and mechanical properties of carbon-bearing rocks and coals of the Karaganda coal basin were studied by Serikbaev T.R., Kosenko I.M., Pudov M.S., Boldyrev V.E., Baibatsha A.B. However, it is necessary to develop a unified methodology for studying the physicomechanical properties of top rocks and the stability forecast for the Karaganda basin.

The basis and initial data for the development of the topic. The basis for the development of the dissertation topic is engineering-geological support for the stability of coal beds top rocks with an increase in the power of lavas. Initial data are data from field and laboratory experiments to study the engineering and geological conditions of mine fields in the Karaganda coal basin - the most important coal base in Kazakhstan. The work is based on the study and analysis of database materials from previous years and a literature review, field observations in mines, core and stone material from a section of exploration wells and mine workings, and of experiments results during the author's research work from 2010 to 2019. Core material was selected for laboratory tests. Sections were made from the main types of carbon-bearing rocks. A total of 55 core samples and 10 monolithic rock samples were studied, well logs of 92 exploratory wells were analyzed, and 22 thin sections were described under a microscope. The author carried out observations top of mine workings behavior to identify mining and geological factors and experiments to determine the petrographic (material composition, structure and texture, vitrinite reflectivity) features and physical and mechanical properties (density, compressive and tensile strength limits, dynamic constants) in laboratories during training and internships at the State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology (Beijing) in Beijing (China).

Justification of the need for research work. With the development of mining operations at great depths, the complication of geological conditions, as well as in connection with the part-time workings of the built-up territories, the need arose for a more complete study of the engineering-geological state of the coal mass. With an increase in mining depth by the mine method, maintaining the top of the worked-out space and its stability are an important indicator for the safe and rational conduct of mining operations. The issues of coal beds top rocks stability are problems of economic importance for coal enterprises, since the downtime in the work of treatment lavas equipped with mechanized supports is associated with the sudden collapse of mine workings top rocks and the breakdown of parts support located in areas of high rock pressure. Therefore, the justification of carbon-bearing rocks stability in the mine workings will ensure high rates of mining operations development, elimination of emergency situations and maintenance of preparatory mine workings during coal mining and without the need for repair work for parts of the mechanized complex [9].

Information about the planned scientific and technical level of development, patent research and conclusions from them are determined by the completeness study of the engineering and geological conditions of the mine fields basin. On the issue of sustainability, a literature and patent review of domestic and foreign scientists was carried out. Modern methods of study in laboratories equipped with equipment that meets the requirements of science and technology of the present are selected. Mine observations of the roofing of mine workings have been carried out.

The scientific and technical level of the dissertation is determined by the novelty of the results obtained, the prospects of using the results and the completeness of the researches. The developed methodology for assessing physical and mechanical

properties includes an integrated approach to solving the problem of mine workings top rocks stability.

Information about metrological dissertation support. The reliability of the results is confirmed by the use of modern instruments that have undergone metrological testing for engineering and geological research at modern certified laboratories of the "Innovation Geological and Mineralogical Laboratory" KazNRTU named after K.I. Satpayev, State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology (Beijing) in Beijing (China), Tsentrgeolanalit LLP (Karaganda).

The physical and mechanical properties of carbon-bearing rocks are determined by the GCTS testing system: Rapid Triaxial Rock Testing System (RTR-1000), Direct Rock Digital Shear System (RDS-100) and a porosity determination machine built by SKL; To determine the petrological features of coal and carbon-bearing rocks, a Leitz 307-107.002 microphotometer and Leica DM2700 microscopes, POLAM L-213M were used; the results were generated by VMware Workstation Pro in the Linux system, numerical models based on the MATLAB 2018 program were built.

The degree of coal metamorphism and coal classification were determined in accordance with GOST 12113-94, GOST 25543-88, ASTM D388, ASTM D2798.

The units of measure in the thesis correspond to the metrological rules and norms of the SI International System of Units.

Relevance of the topic. Adverse mining and geological factors complicating the operation of the working faces have a significant impact on reducing costs in coal mining. Evaluation of these factors, the prevention of complications depends on the reliability of the identification of mining and geological factors that affect the development of coal reserves. The mine fields of the Karaganda coal basin are characterized by a complex geological structure, variability in the quality indicators of coal and the physical and mechanical properties of carbon-bearing rocks in area and lateral. Therefore, the composition and physical and mechanical properties of carbon-bearing rocks should be studied in more detail.

The scientific basis for identifying the geological foundations of the formation of the structure, lithological composition and physical and mechanical properties, the general condition of the rock mass, and the post-diagenetic changes in coal and carbon-bearing rocks become relevant for the development and improvement of mining technology. Based on the above analysis, a quantitative assessment of the physical and mechanical properties can be made, which makes it possible to predict the stability of coal beds top rocks in treatment workings.

The novelty of the topic.

- for the first time, the dependence of the composition and properties of the carbon-bearing rocks of the Karaganda basin on the sediment basin petrofund, the conditions of formation and morphology of coal bedding, lithogenetic and facies types of rocks that affect the state of rocks in the top of underground mine workings was established;

- Apex-Shifted Radon Transform method (ASRT - Diffraction extraction method using a modified radon transform vertex), which determines the location of diffraction

points and Double-Branch Radon Transform (a method with preserving the polarity of two-vector radon transform), which preserves the diffraction polarity. These methods are used to identify geological blocks of rocks in the coal bed tops [10].

- multivariate correlation equations are derived for assessing the physical and mechanical properties of carbon-bearing rocks according to the logging data of exploratory wells using apparent resistance and caliper methods and studies of petrographic features in laboratories;

- for the first time, a geological and geophysical model for assessing physical and mechanical properties was created and the scientific basis for predicting the stability of coal bed top rocks of the Karaganda coal basin with the allocation of their classes in the mine workings was developed.

The relationship of this work with other research projects. The author takes an active part in the implementation of program-targeted financing projects No. BR05233713 "Integrated geological exploration of mineral resources for the development of the resource base and the development of new sources of crude ore in Kazakhstan" (for 2018-2020) and No. U1261203 "Combined coal project of the National Natural Science Foundation" (PRC) for 2018-2020.

The purpose of the work is to create a geological and geophysical model of physical and mechanical properties and to predict the stability of coal beds top rocks of the Karaganda coal basin using a complex of geological and geophysical methods and taking into account the peculiarities of the geological structure of the carbon-bearing massif.

The idea of the work is to use the reflectivity of vitrinite (R_0) coals to determine the physical and mechanical properties and predict the top stability of mine workings, the geophysical parameter $\rho_к$ - the apparent electrical resistance of rocks reflecting the geophysical field; d is the diameter of the well, reflecting the state of the well walls from the moment of rebuilding to the removal of the caliper log.

The object of research is the Karaganda coal basin, developed by underground mining.

The subject of the study is engineering and geological conditions affecting the stability of coal beds top rocks in the mine workings.

Research objectives, their place in the implementation of research work as a whole:

1. The study of engineering and geological conditions of the Karaganda coal basin. Identification of adverse mining and geological factors in predicting the top stability of mine workings.

2. Analysis of methods, principles and means of assessing the physical and mechanical properties of rocks from previous studies.

3. Studies of physical and mechanical properties, the study of petrographic features of carbon-bearing rocks in laboratories.

4. Creation of a methodology for assessing the physical and mechanical properties of typical coal beds top rocks of a sedimentation basin using geophysical methods for exploring wells.

5. Development of a geological and geophysical model of the stability of coal beds top rocks according to exploration data.

6. To develop recommendations for managing rock pressure, cost-effective and safe mining technology, and the choice of mechanized supports types that ensure the maintenance of the top during cleaning work in lavas.

The methodological base of research consists of the following main methods and analyzes:

- determination of the composition, structure, structural and texture features of carbon-bearing rocks on polarizing microscopes POLAM L-213M, Leica DM2700;
- determination of coal metamorphism degree from the reflectivity of vitrinite on a Leitz 307-107.002 microphotometer;
- testing samples of carbon-bearing rocks for triaxial compression and tension by the GCTS testing system: Rapid Triaxial Rock Testing System (RTR-1000), Digital Rock direct shear system (RDS-100)
- determination of porosity on an instrument constructed by SKL;
- geological and seismic modeling according to experimental data using P-wave and S-wave velocities based on VMware Workstation Pro software in the Linux system, building a numerical model based on MATLAB 2018;
- interpretation of geophysical diagrams of the electrical method of apparent resistance to determine the physical and mechanical properties;
- based on mathematical statistics, deriving a multidimensional mathematical geological and geophysical model of physical and mechanical properties for claystones, siltstones, sandstones;

Based on the geological and geophysical model, a predictive map of the top rocks stability of mine workings was developed and recommendations for rational mining operations were developed.

Defense Provisions

1. The geological conditions for the formation of the composition, properties and condition of the carbon-bearing rocks are associated with the petroleum fund of the feeding provinces, the facies feature of the sedimentation basin and the degree of post-diagenetic transformation of sediments. The degree of postdiagenetic changes in rocks can be quantified by the reflectivity of vitrinite coals. The dependence between coal metamorphism, petrographic features, physical and mechanical properties and stability of carbon-bearing rocks is established.

2. A geological and geophysical model of the physical and mechanical properties and stability of carbon-bearing rocks has been created according to geophysical methods for researching boreholes (logging). The relationship of the physical and mechanical properties of coal beds top rocks with geophysical parameters is described by multidimensional mathematical equations that take into account the genetic and epigenetic factors in the formation of the coal mass.

3. The developed geological and geophysical model of the properties and condition of carbon-bearing rocks serves as the scientific basis for predicting the stability of top rocks and choosing the type of mechanized support in lavas. A map of top rocks stability, based on geological exploration data with the allocation of the

corresponding classes of top for stability in the pre-design stage, provides rational and safe mining operations in lavas.

The practical significance of the thesis is that the research results allow:

- promptly assess the physical and mechanical properties of carbon-bearing rocks using the geological and geophysical model, which is created on the basis of geophysical logging diagrams by lithotypes of rocks;

- the use of this model provides an assessment of the properties of rocks continuously throughout the section of an exploratory well in their natural occurrence and to cover a sufficient number of wells in the mine field. Such a method is economically viable and the reliability of the method is confirmed by the use of representative logs.

- using the developed technique, it is possible to model properties on graphic programs for any part of the Karaganda basin.

- to recommend the management of lavas top, taking into account the geological structure and physical and mechanical properties of carbon-bearing rocks for the selection of mechanized supports.

Publications and approbation of the work. According to the results of the conducted scientific research published 17 articles and reports, including 4 international scientific publication within the company database Clarivate Analytics, Scopus and having a non-zero impact factor and 5 articles in scientific journals recommended by Ministry of Education and Science. The results are widely tested at international and national scientific conferences.

The structure and scope of the dissertation. The dissertation consists of introduction, six chapters, conclusion, list of sources and applications. The total volume of the dissertation is 136 pages of text and includes 19 tables, 24 figures, a list of references from 100 titles and 6 appendices.

The introduction presents a general description of the dissertation**.** The goal is determined, the tasks are set to achieve the goal, the relevance of the topic is formulated, the scientific provisions put forward for defense and the practical significance of the dissertation are stated.

The first chapter sets out the current state of the study of the problem of the stability of underground mine workings top with an increase in the depth of mining, the causes and consequences of the collapse of the mine workings top rocks, identifies factors affecting the stability of top mine workings rocks.

The second chapter presents the features of the geological structure of the mine fields “named after Kostenko”, “named after Kuzembaev T.”, “Saranskaya” of the Karaganda coal-bearing region, “Shakhtinskaya” and “Abayskaya” of the Cherubaynurinsky coal-bearing region, “named after Lenin V.I.", "Kazakhstan", "Tentek" Tentek district of the Karaganda coal basin. Breeds of various age and origin take part in the structure.

Engineering and geological conditions for mining the Karaganda basin are complex, this is due to the structure of the basin, tectonics and physical and mechanical properties of carbon-bearing rocks. The modern development of mining in the Karaganda basin is characterized by an increase in mining depth. The main condition

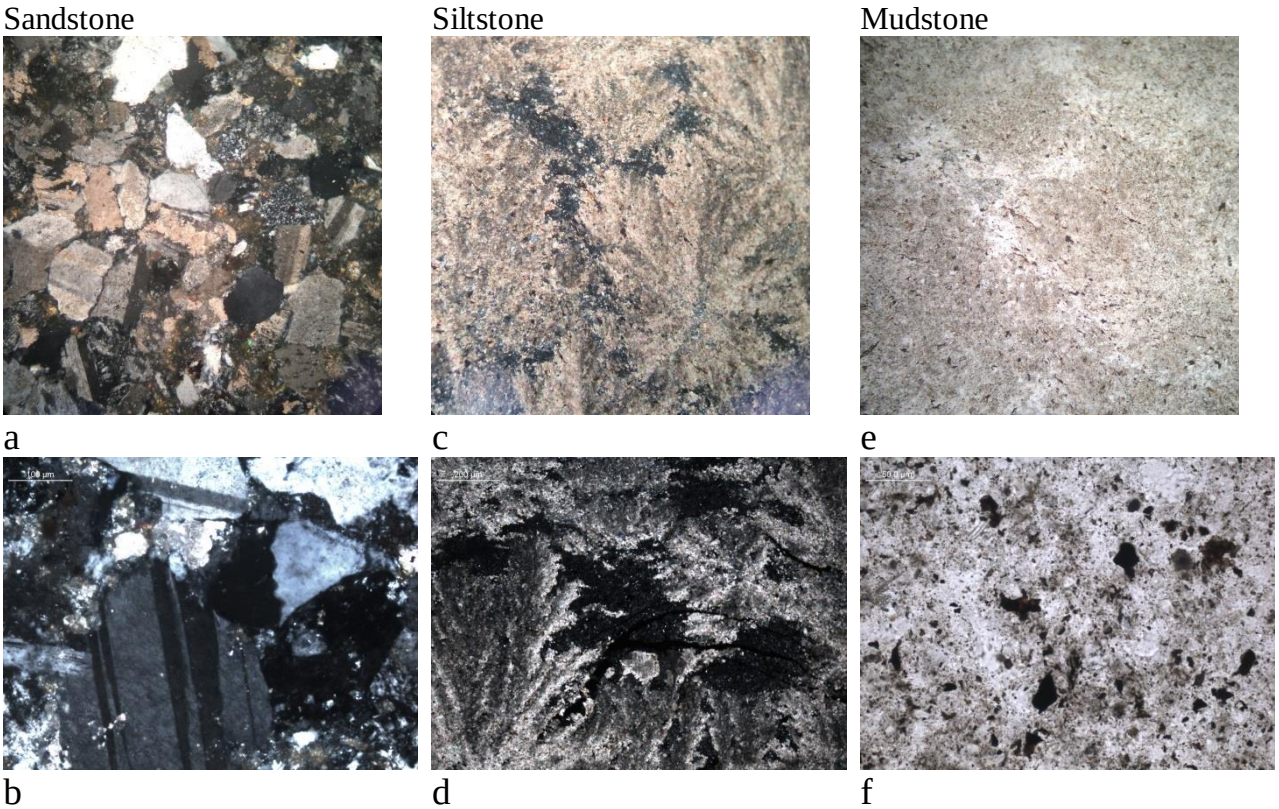
for moving to the deep horizons of the basin, along with the geological and tectonic structure of the basin, is knowledge of the physical and mechanical properties of carbon-bearing rocks.

The third chapter presents the methodology of engineering and geological research in order to determine the main indicators that affect the stability of mine workings top rocks.

To determine the main indicators affecting the stability of the coal beds top rocks of the Karaganda basin, comprehensive studies were carried out [25, 26]. The purpose of the research was:

- monitoring the behavior of coal beds top rocks in the mine workings;
- microscopic studies of coal beds top rocks;
- study of the physical and mechanical properties of carbon-bearing rocks;
- study of the variability of the top rocks strength properties of developed coal beds.

Figure 3.2 below shows microscopic images of rocks. Polymictic sandstones (Figure 3.2 a, b) have a gray, light gray color, the composition revealed clastic material of effusive, sedimentary, and less commonly metamorphic rocks. The mineral composition of sandstones is feldspars (plagioclases), quartz. Siltstone rocks (Figure 3.2 c, d) are ubiquitous and are found in all strata. In composition, they are similar with sandy rocks. Pelitic rocks (Figure 3.2 e, f) contain kaolinite, hydromica, and montmorillonite. In siltstones and mudstones, carbonaceous matter is often found (in the pictures as black spots).



a, c, e - images obtained in the Inter-Cathedral Laboratory of IGML KazNRTU;
b, d, f - images taken in SKL (PRC, Beijing)

Figure 1 - Microscopic examination of carbon-bearing rocks

Determination of metamorphism degree using the petrographic components of the vitren coal macrocomponents using a Leitz 307-107.002 microphotometer in the "Department of Microscopic Research" (Figure 3.3, Appendix C) in accordance with international standards SAUS 25543-88, SAUS 12113-94, ASTM D388, ASTM D2798, ISO 11760. A certain reflectivity of vitrinite Rmax = 1.48, corresponds to coal.

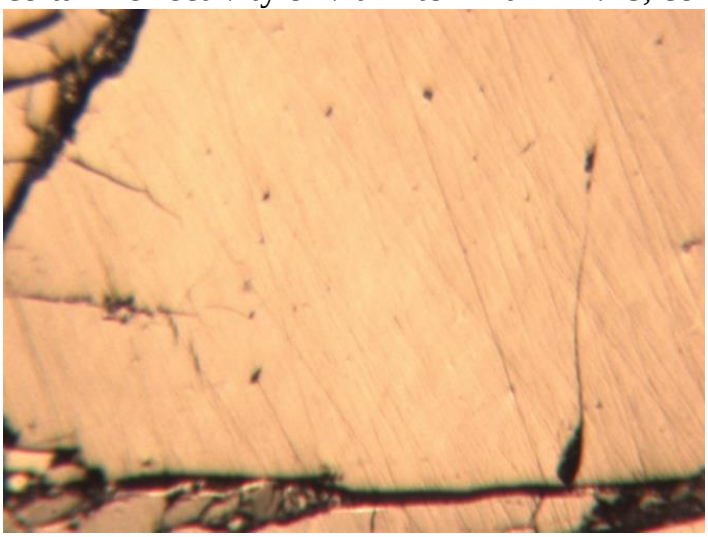


Figure 3.3 - Vitrinitis under a Leitz 307-107.002 microphotometer

Results of physical and mechanical properties: density, g/cm3 (mudstones 2.2-2.55, siltstones 2.25-2.58, sandstones 2.1-2.60), porosity, % (mudstones 9-19, siltstones 9-20, sandstones 6-17), compressive strength, MPa (mudstones 11-40, siltstones 15-52, sandstones 21-85) and tension strength, MPa (mudstones 0.7-3.0, siltstones 0.9 -4.0, sandstones 1.9-6.3). The moisture content of the rocks at intervals varies from 2.3-8.6%.

Geophysical studies were performed for lithological separation of rocks, mapping and extraction of synonymics of coal beds, determination of unstable zones, depth and thickness of rocks in order to use these data to create a geological and geophysical model. From the complex of geophysical methods for researching wells, diagrams of the apparent electrical resistance method and caliper logging were used. Altogether, well logs of 92 wells were interpreted.

The fourth chapter defines the logical relationship between the physical and mechanical properties of rocks and their composition, which has a geological nature. Products of various types of parent rocks weathering of the surrounding land, i.e. feeding provinces are the primary factors determining the composition and physical and mechanical properties of a terrigenous formation rocks.

Based on the performed petrographic studies, a diagram of terrigenous rocks composition formation of the coal-bearing strata of the Karaganda basin from the sources of the feeding provinces, which are complex terrigenous-mineral complexes (figure 4.3), is constructed.

Figure 4.3 - Diagram of the terrigenous rock's formation of coal-bearing strata of the Karaganda basin from feeding provinces sources (Baibatsha A., Satibekova S., 2018)

The litho-facies composition of the Karaganda coal basin is comprised of typical rocks such as sandstones (36%), siltstones (30%) and mudstones (27%). The remaining rocks (coals, conglomerates, carbonate rocks, tuffs) are no more than 7-10%.

It can be concluded that the physical and mechanical properties of rocks are determined by the geological nature of the formation and their change in subsequent stages. The change in the facies type in area and lateral clearly presents a picture of the restoration of the development geological history in the form of lithological maps.

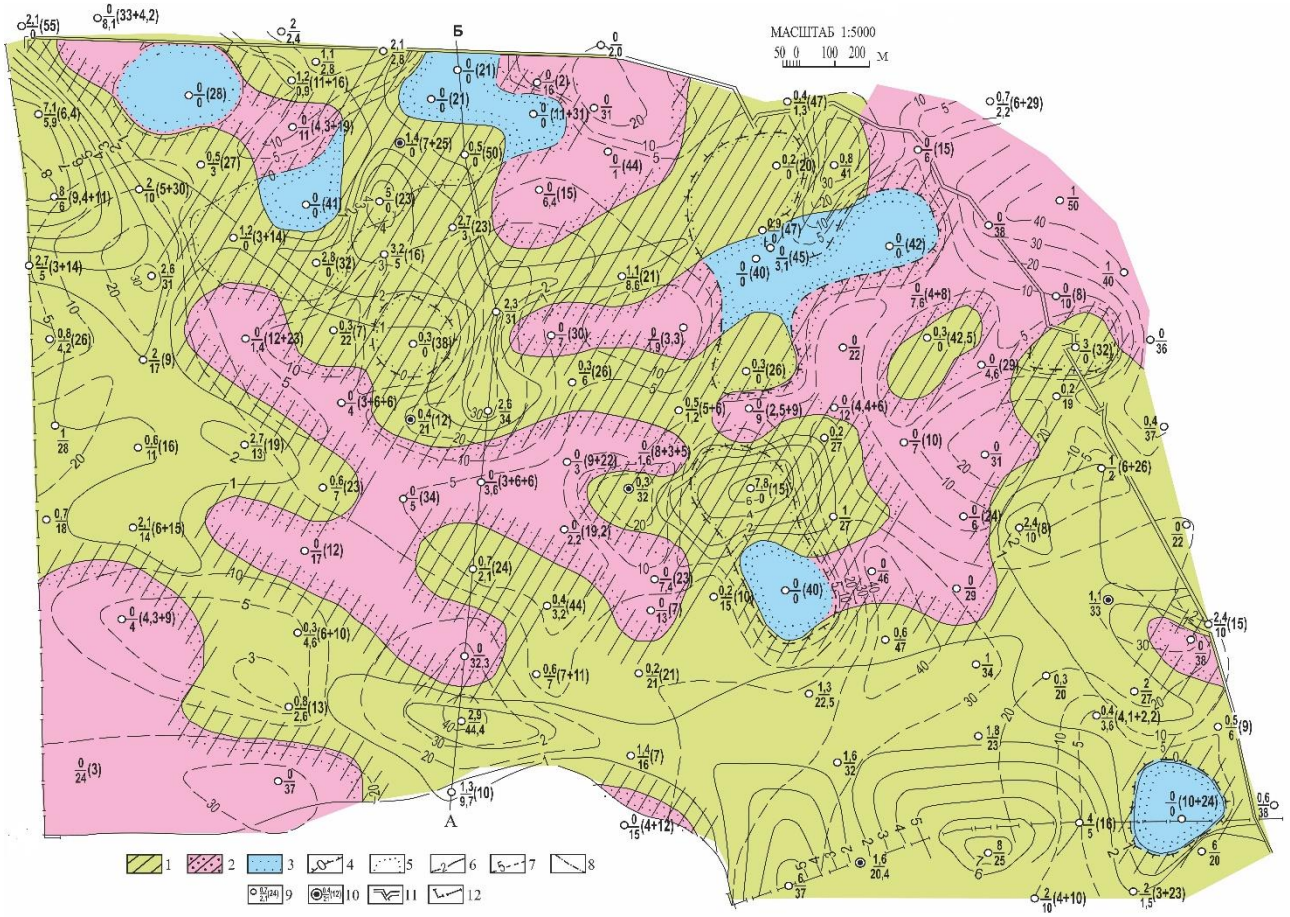


Figure 4.7- Lithological map of top formation d_6

The physical properties of the host rocks are indicators of coal and metamorphism brand composition [76], which is determined by the metamorphism model of Professor Ermekov M. A. (1990) using the reflectivity of vitrinite in coals. This is due to the stratigraphic patterns in changing the physical properties of coals and host rocks are due to one and the same reason - the maximum depth of their immersion in the period of progressive epigenesis.

In the fifth chapter, a geological and geophysical model is created to assess the physical and mechanical properties and stability of carbon-bearing rocks according to the data of geophysical well research methods (logging).

For this, a complex of geophysical methods is analyzed, namely, methods of natural gamma radiation (gamma method), scattered gamma radiation (gamma-gamma method) and the apparent resistance method. The method of apparent resistance and caliper was chosen from all the methods as the most suitable for determining the physical and mechanical properties of rocks.

On each exploration section of the Karaganda basin, lateral current logging with a set of probes from 0.3 to 4.0 m in length was performed. Based on the Resistivity logging materials, the true electrical resistivity was determined, which are compared with the AR diagrams. In the course of experimental and methodical work, the curves were compared with the true values of electrical resistivity determined by the RL method. The curves of the standard gradient probe A1,2M0,1N almost completely

coincided with the true electrical resistivity. The small gradient probe A0.3M0.03N gives a large spread and small tightness of communication, due to the significant influence of downhole conditions on the recording results, the small size of the probe and the small depth research.

Empirical formulas have been obtained for the simplified determination of the physical and mechanical properties of rocks by the RC method and caliper separately. The relationship between the rocks mechanical strength (σc) that make the well section with cavernousness (d, mm), taking into account the exposure influence of the exposed well walls from the time of re-drilling to caliper (t, days) and the depth (N, m), is characterized, respectively for mudstones, siltstones and sandstones by equations [90, p. 53]:

$$\sigma_{\text{c}}^{\text{apr}} = 0{,}4018 \cdot 10^{6} d^{-2.362} t^{0.346} H^{0.209} \qquad \text{R} = 0{,}80; \qquad (5.27)$$

$$\sigma_{\text{c}}^{\text{ал}} = 3118{,}0 d^{-1.374} t^{0.088} H^{0.357} \qquad \text{R} = 0{,}61; \qquad (5.28)$$

$$\sigma_{\text{c}}^{\text{п}} = 5058.7 d^{-1.196} t^{0.188} H^{0.148} \qquad \text{R} = 0{,}63. \qquad (5.29)$$

The relationship of the physical and mechanical properties of coal beds top rocks with geophysical parameters is described by multidimensional correlation equations that take into account genetic and epigenetic factors in the formation of the coal mass.

In the sixth chapter, the scientific basis for predicting the stability of top rocks and choosing the type of mechanized support in lavas is developed. A classification of coal beds top rocks stability of the Karaganda coal basin based on exploration data is made and recommendations for mining are developed.

The presented map of coal beds top rocks stability d_6 of the Lenin mine (Figure 6.3) can solve issues related to the planning of mining, the choice of top management method and development technology. When constructing the stability map [100], the following features of the Karaganda basin mine field were taken into account: lithological and strength characteristics of rocks, hydrogeological conditions, fracturing, and discontinuous disturbances. Carbonaceous rocks, mudstones, siltstones, intercalation of sandstones with siltstones with a strength of less than 15 MPa, which are in the interval of the substandard part of the formation, false and direct top, are classified as easily collapsible rocks.

Strengths of more than 60 MPa are characterized by hard-to-break sandstones, interlayer of sandstones with siltstones and sandy siltstones of the main top. Interlayers of strong sandstones with a thickness of less than 3.0 m are classified as easily fractured. The main top is represented by sandstones (60%), siltstones (19%) and interbedding (21%). The average rock strength is 64 MPa. The immediate top of the reservoir is composed of siltstones (80%), interbedded sand and clay rocks (20%). The strength of the rock's ranges from 22-48 MPa. False top was determined only in a few wells, which is represented by mudstones with an average thickness of 0.20 m. Strength is 16 MPa. Hard-fractured rocks of the main top of the formation have a strength of 69 MPa, easily fractured of the direct top, respectively 17 MPa.

Table 6.1 - Classification of the stability of coal beds top rocks of the Karaganda coal basin according to exploration data (Baibatsha A.B., Satibekova S.B., 2018)

Top class	Lithological type of rocks	Strength, MPa		lamination		Cleavage		Δd, mm / day	Top explosure		fracturing and secondary precipitation cycle
		σ^c	σ^p	m,	K_p, шт/м	n, шт	l, m		S, $м^2$	t, ч.	
1. Sustainable	Carbonaceous mudstones and siltstones, carbon rich up to 20-58%	<15	<1,2	<0,1	>10	>6	<0,5	>20	<3	<0,5	Fracturing after coal mining
2. Few-sustainable	Mudstones and siltstones, carbon rich up to 10-30%	15-25	1,2-2,0	0,1-0,25	4-10	4-8	0,3-1,0	10-20	3-10	To 2 h	Fracturing when removing the lining
3. mmedium-sustainable	Massive mudstones, thin-layered siltstones and sandstones	20-40	2-3	0,25-0,6	1,6-4	2-4	0,5-1,5	5-10	10-50	To 1 day.	5-10
4.Sustainable	Massive siltstones, layered fine-grained sandstones	40-60	3-4	0,6-1,5	0,6-1,6	1-2	1-5		50-300	To 10 days	10-20
5.hard fracturing	Monolithic coarse-grained siltstones and fine-grained sandstones	>60	>4	>1,5	<0,6	0-1	>3	<5	300-15 ths.	From 10 days to 1 month	20-40 and more

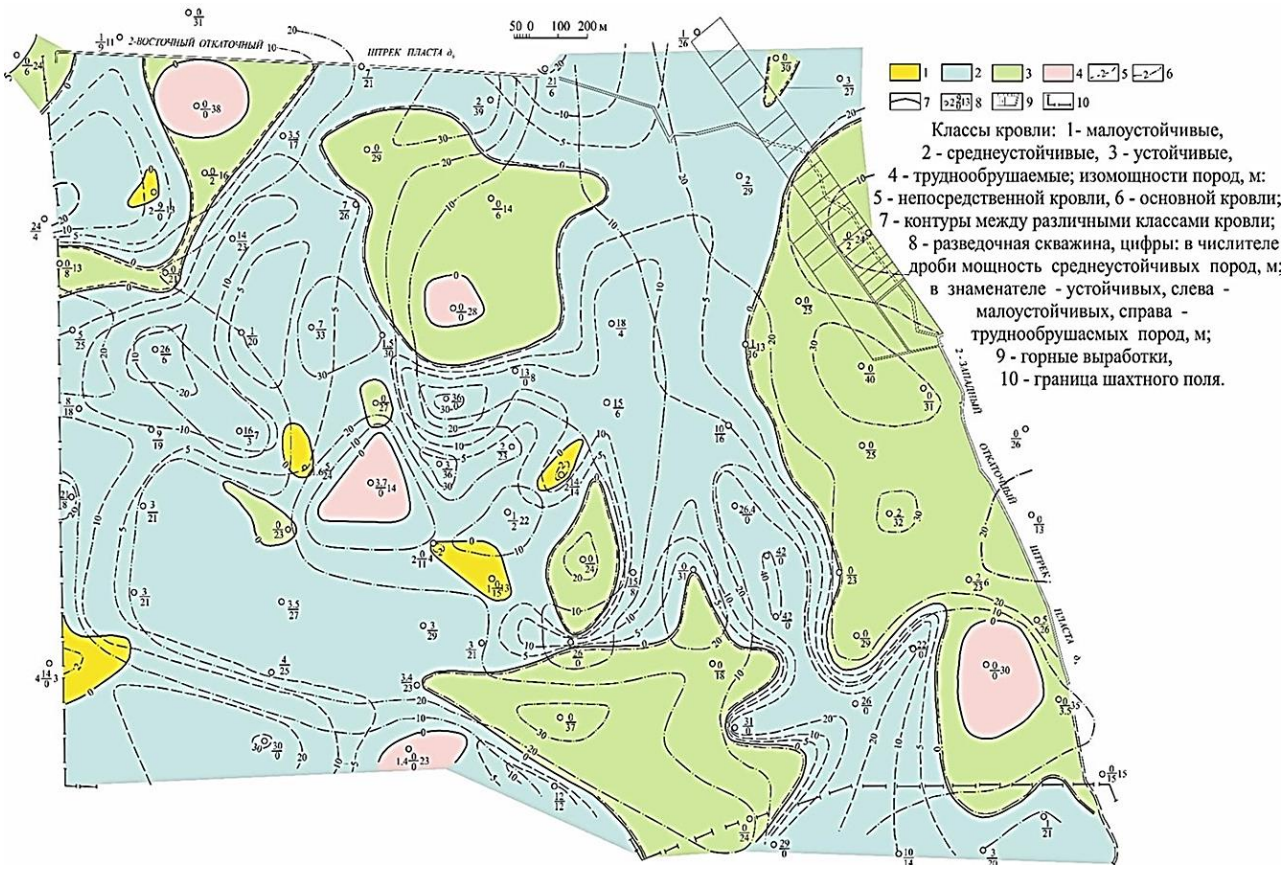


Figure 6.3 - Map of the stability of formation top rocks d_6

List of published works on dissertation topic

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2 Baibatsha A. Sup P., Satibekova S. Estimation of the physical-mechanical properties of the rocks on the degree of coal metamorphism // News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences. Volume 1, Number 433. – P. 187-194. DOI: 10.32014/2019.2518-170X.23

3 Li, C., Peng, S., Zhao, J., Cui, X., Du, W., S. Satibekova Polarity-preserved diffraction extracting method using the modified apex-shifted Radon transform and double-branch Radon transform electronic Journal of Geophysics and Engineering, Volume 15. – P. 1991-2000. DOI: 10.1088/1742-2140/aabd8f

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5 Baibatsha A., Sadybekova S. About feeding the provinces coal-bearing strata of the Karaganda basin // Vestnik of KBTU, volume 15, issue 2 (45) June 2018 – S. 94-101.

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7 Baibatsha A., Sadybekova S. Facies types and lithogenetic composition of coal formations of the Karaganda basin // Vestnik KazNTU them. K. I. Satpaev, №2 (126), 2018 – S. 24-30.

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