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Қ. И. Сәтпаев атындағы Қазақ ұлттық техникалық зерттеу университеті

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ИЗВЕСТИЯ

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Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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A. B. Baibatsha[1], Suping Peng[2], S. B. Satibekova[1]

[1]Kazakh National Research Technical University named after K. I. Satbayev, Almaty, Kazakhstan,
[2]State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology (Beijing), Beijing, People's Republic of China.
E-mail: baibatsha48@mail.ru, psp@cumtb.edu.cn, s.satibekova@bk.ru

ESTIMATION OF THE PHYSICAL-MECHANICAL PROPERTIES OF THE ROCKS ON THE DEGREE OF COAL METAMORPHISM

Abstract. This article discusses the physical-mechanical properties of Karaganda basin coal seam wall rock, depending on the degree of metamorphism, which is determined by a maturity parameter of the reflectivity of organic matter - vitrinite. This method is significant in connection with the increase of geological exploration for coal, as well as methane, in connection with the preparation of new minefields at deep depths, when the coal core is the only substance to determine the properties of coal and their rocks. The determination of the physical and mechanical properties of coal seam wall rock, taking into account the stage of coal metamorphism, is great practical importance in the mining industry. Based on previous years' materials and laboratory data, which we conducted together with our Chinese colleagues in the State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology (Beijing, China), and based on M.A. Ermekov (1990) mathematical model of metamorphism describes the degree change of coal metamorphism and physical-mechanical properties of coal seam wall rock by a depth. This research contributes to the solution of problems related to the roof stability of coal seams in mines since the physical and mechanical properties of rocks are one of the main criteria for mining and technical works.

Keywords: vitrinite reflectivity, coal metamorphism, physical and mechanical properties of rocks, coal seam, roof stability, methane.

Introduction. Karagandy coal basin is located in Central Kazakhstan. In terms of coal reserves and quality, it occupies a leading position among the largest coal-bearing basins in the world. In the basin extended in the latitudinal direction for 120 km with an average width of 60 km, four coal-bearing areas are distinguished: Tentek, Sherubajnura, Karagandy, and Verhnesokur (figure 1).

Carboniferous coal-bearing sediments with a total thickness of about 4,000 m are divided into seven formations according to coal saturation, lithological composition, fauna, flora, and other characteristics: akkuduk, ashhylyajryk, karagandy, nadkaragandy, dolinka, tentek, shahan.

The karagandy, dolinka and partly ashhylyajryk and tentek formations are productive in the Carboniferous sediments. In this series, there are up to 80 layers and seams of coal with a total thickness of up to 110 m. The thickness of coal seams increases in the basin from west to east, and within each region from north to south [1].

Accounting for the coal metamorphism in solving mining and geological problems is of paramount importance. Metamorphism in the Karagandy basin is manifested in an increase in its degree: 1) with stratigraphic depth of formation according to the Hilt-Skok law; 2) with increases ofthe coal-bearing strata thicknesses; 3) in a section through the dip of layers with an increase in the modern depth of their occurrence [2].

In the Karagandy basin, taking into account the influence of the post-inversion component of metamorphism, it was possible to refine the predictions of the distribution of coal by grades to its deep horizons.

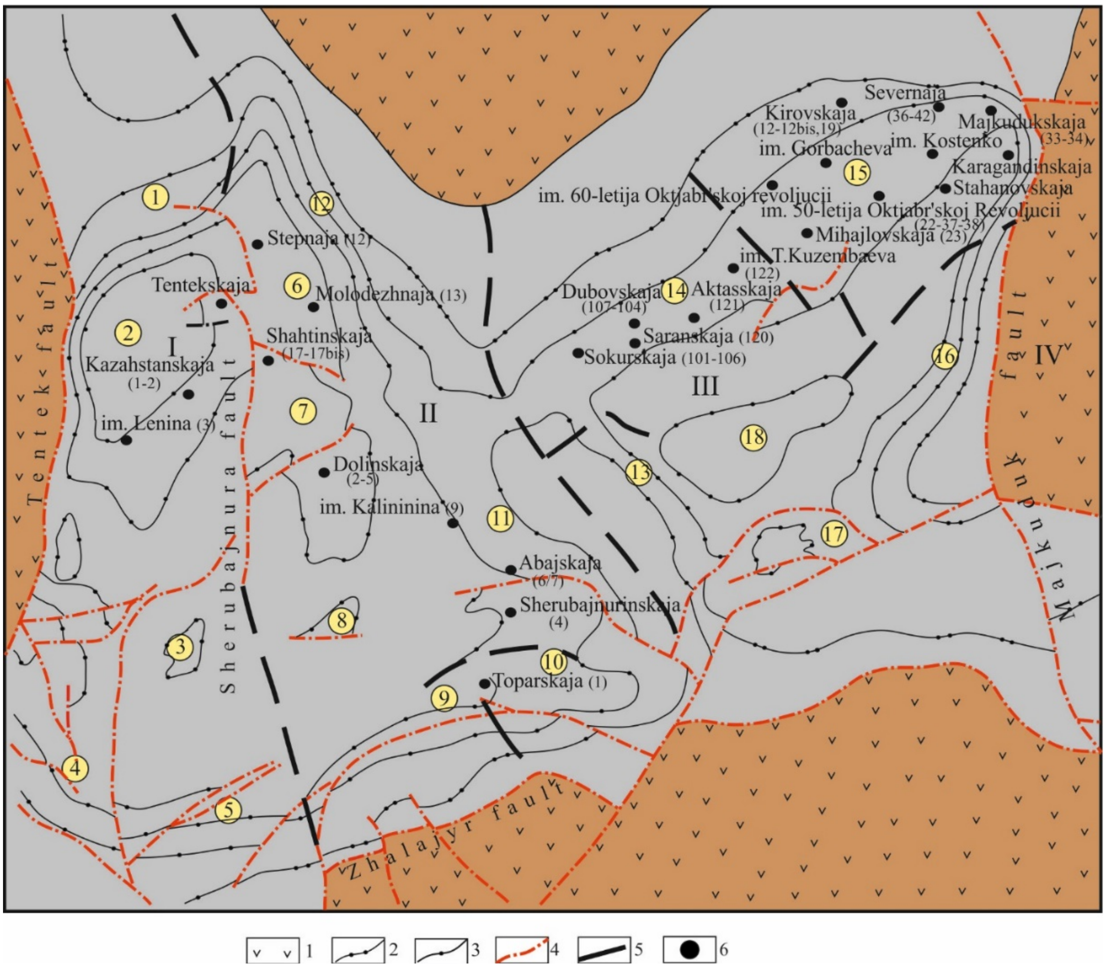

Figure 1 – Schematic geological map of the Karagandy basin:
1 – pre-Carboniferous deposits; 2 – lower border of the ashhylyajryksuite; 3 – boundaries of the karagandy suite;
4 – faults; 5 – borders of coal-bearing areas and sites; 6 – operating mines, in numbers – old name.
Coal-bearing areas: I – Tentek; II – Sherubaynura; III – Karagandy, IV – Verkhnesokur.
Basin areas (numbers in circles): 1 – Manzhin; 2 – Tentek; 3 – Karagok; 4 – Sasykkol; 5 – Taskamys;
6 – Karazhar-Shahan; 7 – Dolinka; 8 – Kolpak; 9 – Kishkenekol; 10 – Southern; 11 – Central;
11 – Northern; 13 – Alabas; 14 – Saran; 15 – Promyshlennyi; 16 – Maykudyk; 17 – Taldykudyk; 18 – Dubovka

Studying the degree of coal metamorphism allows solving problems related to predicting the roof stability of coal seams in mining, which in turn depends on the physical and mechanical properties of rocks.

Research methods. The task of the study is to assess changes in organic matter, in this case, vitrinite, to establish relationships between quantitative petrographic features, properties of coal and the physico-mechanical properties of coal seam wall rock. To quantify the degree of metamorphism of coal seam wall rock, on which their physicomechanical properties depend, we used the indices of reflectivity of vitrinite and its refractive indices, measured in immersions. We carried out such studies together with our Chinese colleagues in the State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology (Beijing, China).

As noted by J.T. McCartney, M. Teichmuller (1972), M.A. Ermekov (1990), the degree of coal metamorphism, estimated by the reflectivity of vitrinite, serves as a "geological thermometer" and allows recovering the geological history of evolution, in particular, the depth of the rocks and the duration of their stay at the maximum depth [3-5]. A mathematical model of coal metamorphism, created by Professor M.A. Ermekov (1990) based on the topokinetic Kolmogorov-Erofeev equation, has the form:

$$I = 100\left[1 - e^{-\sum t \exp(B - A/T)}\right] \quad (1)$$

here I – the impulse of metamorphism according to M.V. Golitsyn (1975), °C/billion years; t – the duration of the stay of coal (coal seam wall rock) at a given depth, billion years; T – an absolute temperature of coal in the depths, °K.

For the process of regional coal metamorphism in the Karagandy coal basin, the coefficients of equation (1) take the following values: A=7300, B=21,6. The results of Professor M.A. Ermekov's calculation of (1990) lead to the following conclusions: coal metamorphism began at the beginning of the Upper Carboniferous after 30-35 million years from the beginning of the ashhylyajryk formation, i.e. after deposition of the completely coal-bearing stratum. At the same time, immersion of the lower part of the sequence was accompanied by an increase in temperature to 70°C. The process of further metamorphism was intense and was completed by the beginning of the Upper Permian when the depression exceeded 5 km, and the temperature reached 135-140°C. After inversion at the end of the Upper Permian, the lower boundary of the coal-bearing strata rises to a value of 3 km and the decrease in its temperature to 80-85°C sharply slowed down the process of metamorphism. The impulse of metamorphism was at the same time 85 %.

Adopted by M.V. Golicyn (1975) the correspondence of temperatures of regional and contact-thermal metamorphism to the stages of metamorphism of Carboniferous coals of Central Kazakhstan is preserved [6]and according to calculated impulses of metamorphism for the duration of regional metamorphism, taken equal to 10 million years, and thermal – 5 thousandyears (table1).

Table1 – Temperature and impulse values at regional and thermal metamorphism

Stage of coal metamorphism	Rank of coal	Regional		Thermal	
		Average temperature, °C (Golicyn, 1975)	Estimated impulse, % (Ermekov, 1990)	Average temperature, °C(Golicyn, 1975)	Estimated impulse,% (Ermekov, 1990)
I	LF	60	0,7	–	–
II	G	85	3,3	up to 300	3,3
III	Ft	110	11,9	325	5,3
IV	C	130	27,9	412	24,6
V	Fg	148	50,7	475	50,0
VI	Cc	163	72,4	525	72,2
VII-VIII	A	185	94,4	575	88,8
IX-X	A	250	100	695	99,8
LF - long-flame coal, G - gas coal, Ft - fat coal, C - coking coal, Fg - forge coal, Cc - carbonaceous coal, A - anthracite.					

According to the proposed model, a change in the reflectivity index of vitrinite (*R*□) from the metamorphism stage was established (*I*) (table 2).

Table 2 – Indicators of coal metamorphism

Stage of coal metamorphism	$V^{d.a.f.}_{av}$, %	*R*□ , %	$10R_0$, unit.	*I*, %
L	–	0,58	73,5	0,72
G	32	0,79	80,5	3,3
Fat	25	1,07	88,5	11,9
C	17	1,40	96,5	27,9
F	12,5	1,80	104,0	50,7
CC	9	2,37	114	72,4
A	–	2,77	121	94,40

As a result of research, it was established that with the depth of the coal seams the volatile yield decreases, the reflectivity of vitrinite increases, and rank composition of coal changes from lignite to anthracite accordingly (figure 2) [3, 4].

According to ISO 11760 the physical and chemical properties of coal are determined by its geological maturity (rank), petrographic composition and quantity (as well as the nature and form of association) of

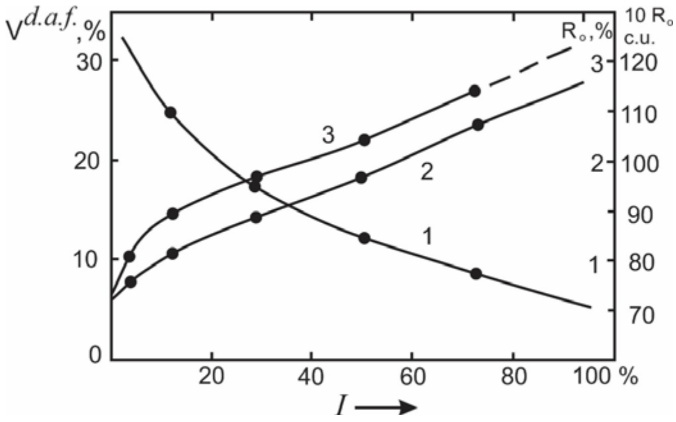

Figure 2 – Dependence of volatile yield, reflectivity indicators on the "impulse" of metamorphism (after *M.A. Ermekov, 1990*): 1 – $V^{d.a.f.}$, 2 – R_o, 3 – $10R_o$ conditional units (c.u.).

the mineral substance present. Thus, for simplicity, this classification for coal is based on the following properties of coal: vitrinite reflectance, expressed as a percentage: mean random reflection, R_r, which is directly determined or calculated from R_{max}.

According to this standard, the coals are divided into three ranks: low (lignite and sub-bituminous coals), medium (bituminous coals) and high (anthracites) [7, 8]. According to GOST 25543-88 based on the vitrinite reflectivity indicators, coals are also divided into three types: lignite, bituminous coals, and anthracites or, which, depending on their genetic characteristics, are divided into 50 classes according to the average vitrinite reflectivity R_o, determined according to GOST12113-94. Lignite coals are characterized by an average vitrinite reflectivity R_o less than 0.60 %, bituminous coals – R_o=0,40-2,59 %, anthracites – 2,20 and more [9, 10]. Dedicated 50 classes of coal characterize the degree of post-sedimentation transformation of their host rocks from the stage of initial catagenesis to the stage of metagenesis, inclusive [5, 11, 12]. The H_{str}, parameter, which shows the stratigraphic levels of the occurrence of terrigenous rocks according to the degree of their post-sedimentation transformation, in this case, increases from late metagenesis to initial catagenesis, acquiring values accordingly H_{str} = 1…10.

Mathematical processing of field and laboratory research results, taking into account the cumulative effect of all selected petrographic and geological [2, 13, 14] features, allowed the creation of universal geological and mathematical models of the physical-mechanical properties of rocks in terrigenous formations. So, multidimensional geological and mathematical models of ultimate strength under uniaxial compression (σ_c) for the main lithological types of terrigenous rocks expressed as follows:

for fine and medium grained sandstones:

$$\sigma_c = 166{,}46 - 0{,}37X_3 + 0{,}06X_4 + 0{,}123X_5 + 0{,}652X_6 - 0{,}42X_7 + 0{,}23CM_1 + 0{,}45CM_2 + 0{,}52CM_3 - 0{,}01C_1 - 0{,}16C_2 + 0{,}26C_3 + 0{,}017H - 2{,}99H_{str}, \quad R = 0{,}99; \quad (2)$$

for fine grained sandstones:

$$\sigma_c = 65{,}75 - 0{,}06X_1 + 0{,}156X_2 + 0{,}7X_3 + 0{,}24CM_1 + 0{,}2CM_2 + 0{,}41CM_3 - 0{,}027C_1 - 0{,}033C_2 + 0{,}69C_3 + 0{,}032H - 2{,}24H_{str}, \quad R = 0{,}98; \quad (3)$$

for siltstone:

$$\sigma_c = 47{,}74 + 0{,}1X_1 + 0{,}286X_2 + 0{,}012CM_1 + 0{,}0470M_2 + 0{,}067CM_3 - 0{,}06C_1 + 0{,}034C_2 + 0{,}32C_3 + 0{,}05H - 1{,}28H_{str}, \quad R = 0{,}96; \quad (4)$$

for argillite:

$$\sigma_c = 35{,}4 + 0{,}29X_1 + 0{,}157C_2 + 0{,}515C_3 + 0{,}004H - 0{,}52H_{str}, \quad R = 0{,}92. \quad (5)$$

where fractions, mm: X_1 – 0,01-0,05, X_2 – 0,05-0,1, X_3 – 0,1-0,2, X_4 – 0,2-0,3, X_5 – 0,3-0,4, X_6 – 0,4-0,5, X_7 – 0,5-1,0; clastic material: CM_1 – quartz, CM_2 – amount of feldspar, CM_3 – the amount of rocks; cement: C_1 – clayey, C_2 – carbonate, C_3 – siliceous; H, м – depth of terrigenous rocks.

The coefficients of multiple correlations, which is a measure of the cumulative effect of all the geologic-petrographic factors cited, have values from 0.92 to 0.99, i.e. their connection with the strength properties of rocks approaches functional. Often, the layers of rocks of the same lithological composition, occurring in different geological and structural parts of the field, due to the difference in thermodynamic conditions of formation characterized by variability of physical and mechanical properties. An example of this is the drastic changes in the properties of rocks and the coal metamorphism in the zone of deep faults and in various modern geological and structural areas that were at the same level in the pre-inversion period of the basin development. For example, along the southern border of the Karagandy coal basin in the zone of influence of the sub latitudinal Zhalajyr deep fault (thrust), the coal metamorphism degree corresponds to CC rank, whereas these same stratigraphic horizons outside the zone of influence of the deep faults include layers of coal of Fat and C ranks.

The results of a wide-scale study of rockphysical-mechanical properties of the basin minefields located in various geological and industrial areas, coal-bearing formations and depths of occurrence are summarized in the research. The averaged values of the physical-mechanical properties of the main lithological types of the coal-bearing formations of the basin, obtained as a result of generalization and analysis of previous studies and new data on deep horizons (depth up to 900-1000 m), are given in table2 [2, 15, 16].

Table 2 – Physical-mechanical properties of rocks in the Karagandy coal basin

Structural block	Lithological types	Depth, m	ρ, g/cm^3	P, %	W, %	σ_c, MPa	σ_t, MPa	Softening		
								difficult	medium	easy
Ashhylyajryk and karagandy formations										
The north wing of the Karagandy and east wing of the Sherubainura syncline	sandstones fine- and medium-grained	Up to 50	2,49	14	5	33	2,7	64	15	21
		50-100	2,51	11	3	48	3,7	71	19	10
		100-300	2,55	9	3	63	5,0	94	4	2
		300-600	2,58	8	2	78	6,0	96	4	–
		More than 600	2,60	7	2	85	6,3	100	–	–
	siltstones	Up to 50	2,35	20	6	23	1,5	30	27	43
		50-100	2,47	13	4	32	1,8	33	27	40
		100-300	2,52	11	3	45	2,6	46	18	36
		300-600	2,55	10	3	50	3,4	54	26	20
		More than 600	2,58	9	3	52	4,0	60	30	10
	mudstones	Up to 50	2,25	19	7	15	1,0	13	5	82
		50-100	2,41	13	4	32	1,8	33	27	40
		100-300	2,52	11	3	45	2,6	46	18	36
		300-600	2,55	10	3	50	3,4	54	26	20
		More than 600	2,55	9	3	40	3,0	40	30	30
Dolinka and tentek formations										
The northern half of Sherubainura syncline (Tentek region)	sandstones fine- and medium-grained	Up to 50	2,31	17	6	21	1,9	47	20	33
		50-100	2,47	11	4	38	3,2	69	18	13
		100-300	2,51	9	3	58	4,3	85	8	7
		300-600	2,55	8	3	72	5,5	93	6	1
		More than 600	2,58	8	2	78	5,8	96	4	–
	siltstone	Up to50	2,25	20	8	15	0,9	23	17	60
		50-100	2,45	12	4	28	1,9	33	14	53
		100-300	2,5	10	4	42	2,5	46	14	40
		300-600	2,54	9	3	47	3,1	54	20	26
		More than600	2,56	9	3	50	3,8	60	24	16
	mudstone	Up to50	2,22	23	11	11	0,7	13	5	82
		50-100	2,40	17	6	17	1,5	18	12	70
		100-300	2,46	14	5	30	1,8	28	18	54
		300-600	2,52	11	4	36	2,3	33	22	45
		More than600	2,55	10	3	38	2,6	40	30	30

As can be seen from table 2, the physical-mechanical properties of coal seam wall rock naturally change depending on their lithological types, depth and stratigraphic level of occurrence. The most stable rocks are medium-grained sandstones of lower coal-bearing formations, lying on deep horizons, for example, they have values of compressive strength σ_c=90-140 MPa and tensile strength σ_t=5-10 MPa at depths of more than 600 m. With a decrease in grain size, the content of a clastic material, an increase in clay material in cement and a deterioration in the degree of lithification, the strength of sandstones decreases. Of all lithological types of coal seam wall rocks, mudstones have the lowest strength.

The sharp decrease in strength and density, the increase in porosity and the natural moisture of rocks at depths of up to 100 m are associated with the evolution of a weathered zone of coalstrata. The water resistance of rocks also naturally increases with depth. At depths of more than 600 m, sandstones of all coal-bearing formations are practically non-softable, non-softable also up to 60% of siltstones and up to 40% of mudstones. The geological nature of the regular variability of the physical-mechanical properties of rocks allows them to be estimated from geological studies of the coal-bearing strata [16].

Discussion of the results. Different paleotectonic and paleogeographic conditions at different stages of the tectonic evolution of the Karaganda basin led to a change in the character of coal content and the quality of coal. At depths of more than 1000 m, the metamorphism of coals is greatly enhanced and fat coals practically disappear, the areas with coking coals are sharply reduced. Forge coal hasmain distribution. Coals of the ashhylyajryk formation and the bottom of the karaganda formation are high-ash, hard-cleaning, belong to theC, Fg, Ft ranks. These coals are used for coking. Coals of the dolinka and the bottom of the tentek formation are fat, partially coking stage of metamorphism, are characterized by easy washability of coal and serve as valuable coking chemical raw materials. Coals of the upper horizons of the tentek formation mainly relate to G rank, difficult washability of coal, energetic.

In the basin, predominantly carbon-coking coals are being developed, representing 82.2% of the total production in the basin. Karagandy basin explored to a depth of 500-700 m. The mining industry has developed the depth of 400-500 m.

Conclusions. The ability to assess the properties of coal by the vitrinite reflectivityis an important factor in the petrographic analysis since it can be used not only for coals but also for their host clay and sandy rocks. This method of evaluation is also important in connection with the increase of a volume of geological exploration for associated methane, with a preparation of new minefields at deep depths, when a coal core will be only coal substance for judging the properties of coal.

Therefore, the determination of the physical-mechanical properties of coal seam wall rock, taking into account the stage of coal metamorphism in terms of the vitrinite reflectivity, is of great practical importance in geological prospecting and mining.

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А. Б. Байбатша[1], Супин Пен[2], С. Б. Сатибекова[1]

[1]Қ. И. Сәтбаев атындағы Қазақ ұлттық зерттеу техникалық университеті,
Алматы, Қазақстан,
[2]State Key Laboratory of Coal Resources and Safe Mining,
China University of Mining and Technology (Beijing), Beijing, China

ТАУЖЫНЫСТАРДЫҢ ФИЗИКАЛЫҚ-МЕХАНИКАЛЫҚ ҚАСИЕТТЕРІН КӨМІР МЕТАМОРФИЗМІНІҢ ДӘРЕЖЕСІ БОЙЫНША БАҒАЛАУ

Аннотация. Мақалада Қарағанды таскөмір алабының көмір сыйыстырушы таужыныстардың физика-механикалық қасиеттерінің органикалық зат – витриниттің шағылысу қабілеті көрсеткіші арқылы анықталатын көмір метаморфизмі дәрежесіне тәуелділігі қарастырылған. Мұндай әдіс көміргежәнеілеспе метанға геологиялық барлау жұмыстары көлемінің артуында, тереңдегі жаңа шахта алаңдарын дайындауда көмір және сыйыстырушы таужыныстар қасиеттері бойынша көмір керні жалғыз ғана ақпарат көзі болған жағдайда маңызды болып саналады. Көмір метаморфизмі кезеңдерін ескере отырып, көмір сыйыстырушы таужыныстардың физикалық-механикалық қасиеттерін анықтау кен-техникалық жұмыстарды жүргізу кезінде аса зор практикалық мәнге ие. Бұрынғы жүргізілген жұмыстар мен State Key Laboratoryof Coal Resources and Safe Mining, China University of Mining and Technology (Бейжің, Қытай) зертханасында қытай әріптестермен жүргізілген зерттеулер, сонымен қоса М.А. Ермековтың (1990) метаморфизмнің математикалық моделі негізінде көмір метаморфизмі дәрежесі мен көмір сыйыстырушы таужыныстардың физикалық-механикалық қасиеттерінің тереңдік бойынша өзгеруі келтірілген. Мұндай зерттеулер түрі кен-техникалық жұмыстардағы негізгі көрсеткіштердің бірі болып табылатын таужыныстардың физикалық-механикалық қасиеттері болғандықтан, кен үңгімелеріндегі көмір қабаттары жабыны таужыныстарының орнықтылығымен байланысты мәселелерді шешуге мүмкіндік береді.

Түйін сөздер: витриниттің шағылыстыру қабілеті, көмір метаморфизмі, таужыныстардың физикалық-механикалық қасиеттері, көмір қабаты, жабын орнықтылығы, метан.

А. Б. Байбатша[1], Супин Пен[2], С. Б. Сатибекова[1]

[1]Казахский национальный исследовательский технический университет им. К. И. Сатбаева,
Алматы, Казахстан,
[2]State Key Laboratory of Coal Resources and Safe Mining,
China University of Mining and Technology (Beijing), Beijing, China

ОЦЕНКА ФИЗИКО-МЕХАНИЧЕСКИХ СВОЙСТВ ГОРНЫХ ПОРОД ПО СТЕПЕНИ МЕТАМОРФИЗМА УГЛЕЙ

Аннотация. В статье рассмотрены физико-механическиесвойства углевмещающих пород Карагандинского каменноугольногобассейна в зависимости от степени метаморфизма, которая определяется по показателю отражательной способности органического вещества – витринита. Данный способ является значимым в связи с увеличением объемагеологоразведочных работ на уголь, а также на попутный метан, в связи сподготовкой новых шахтных полей на больших глубинах, когда керн углябудет единственным веществом для суждения о свойствах угля и ихвмещающих пород. Определение физико-механических свойств углевмещающих пород с учетом стадии метаморфизма углей имеет большоепрактическое значение при горнотехнических работах. Основываясь на материалах прежних лет и лабораторных данных, проведенных нами совместно с китайскими коллегами в лаборатории State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology (Пекин, Қытай), а также на основе математической модели метаморфизмаМ.А. Ермекова (1990) приводится изменение степени метаморфизма углей ифизико-механических свойств углевмещающих пород с глубинойпогружения. Такой вид исследований способствует решению задач,связанных с устойчивостью пород кровли угольных пластов в горныхвыработках, так как физико-механические свойства пород являются одним изглавных критериев при горнотехнических работах.

Ключевые слова: отражательная способность витринита, метаморфизмугля, физико-механические свойства горных пород, угольный пласт,устойчивость кровли, метан.

Information about authors:

Baibatsha A.B., Kazakh National Research Technical University named after K. I. Satbayev, Almaty, Kazakhstan; baibatsha48@mail.ru; https://orcid.org/0000-0002-9521-7872

Suping Peng, State Key Laboratory of Coal Resources and Safe Mining, China University of Mining and Technology (Beijing), Beijing, China; psp@cumtb.edu.cn; https://orcid.org/0000-0001-9644-3495

Satibekova S.B., Kazakh National Research Technical University named after K. I. Satbayev, Almaty, Kazakhstan; s.satibekova@bk.ru; https://orcid.org/0000-0002-7445-1395

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