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Satbayev University

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ИЗВЕСТИЯ

НАЦИОНАЛЬНОЙ АКАДЕМИИ НАУК
РЕСПУБЛИКИ КАЗАХСТАН
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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.

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CHANGES IN THE COMPOSITION AND PROPERTIES OF THE HOST ROCKS OF COAL DEPOSITS IN YAKUTIA UNDER THE INFLUENCE OF CRYOGENESIS

Abstract. The results of laboratory tests carried out on rock samples of the Kharbalakhskoye coalfield located in Central Yakutia revealed significant secondary changes having taken place in the host rocks containing the coal. Evidently, under transformation processes, it is not only the composition of the rocks that had changed, but also the nature of structural bonds that have a great influence on their physical and mechanical properties. Thus, the ultimate strength values of coal-containing sandstone and siltstone samples under uniaxial compression vary from 20 to 30 MPa, while under uniaxial tension, the ultimate strength values range from 6 to 10 MPa. These relatively low numerical values pertaining to the physicomechanical properties of rocks, which are generally atypical for long-flame coal deposits, are almost 50% lower than those of analogous rocks hosting other coal deposits in Russia. It is considered that the mechanical strength properties of the rocks of the Kharbalakhskoye field are due to significant cryogenic processes. A comparative analysis of the properties of core samples obtained from boreholes drilled in 2019 with samples from a quarry obtained several decades ago reveals signs of transformation of rocks in the Kharbalakhskoye field due to phase transitions of freezing and thawing water.

Key words: coal, Yakutia, cryogenesis, physical and mechanical properties, Harbalakhskoye deposit, host rocks, material composition.

Introduction. In the mining industry, ensuring the stability of pit walls is a very important issue. In turn, the stability of inclined technogenic landforms largely depends on the cryogenic predisposition of constituent rock strata [1] (in this work, cryogenesis is understood as a set of processes associated with phase transitions of water resulting from freezing and thawing [2]). Insufficient attention paid to factors determining the nature and intensity of cryogenesis in the design of mining facilities leads to the development of undesirable processes that complicate mining operations and reduce their safety level [3-8].

In order to obtain quantitative characteristics of the influence of cryogenesis on the technological elements of the open pit mine, taking the timing of its impact into account, studies were carried out on the physicomechanical properties (PMS) of carbon-bearing rocks of the Lensky coal basin. The object of the study was the pit wall of the Kharbalakhsky open pit mine, which has played a significant role in the mining activities of Central Yakutia in its more than 55 years of operation since the discover of the deposit in 1962.

The Kharbalakhskoye coal deposit is located in the central part of the Lower Aldan coal-bearing region of the Lena basin in the Sakha Republic (Yakutia) (figures 1, 2, 3). In orographic terms, the deposit area is confined to the flat plain of the Lena-Amginsky interfluve and characterised by a weak dissection of the relief.

Figure 1 – Main coal basins of the Russian Federation (infographic with vip.karelia.pro)

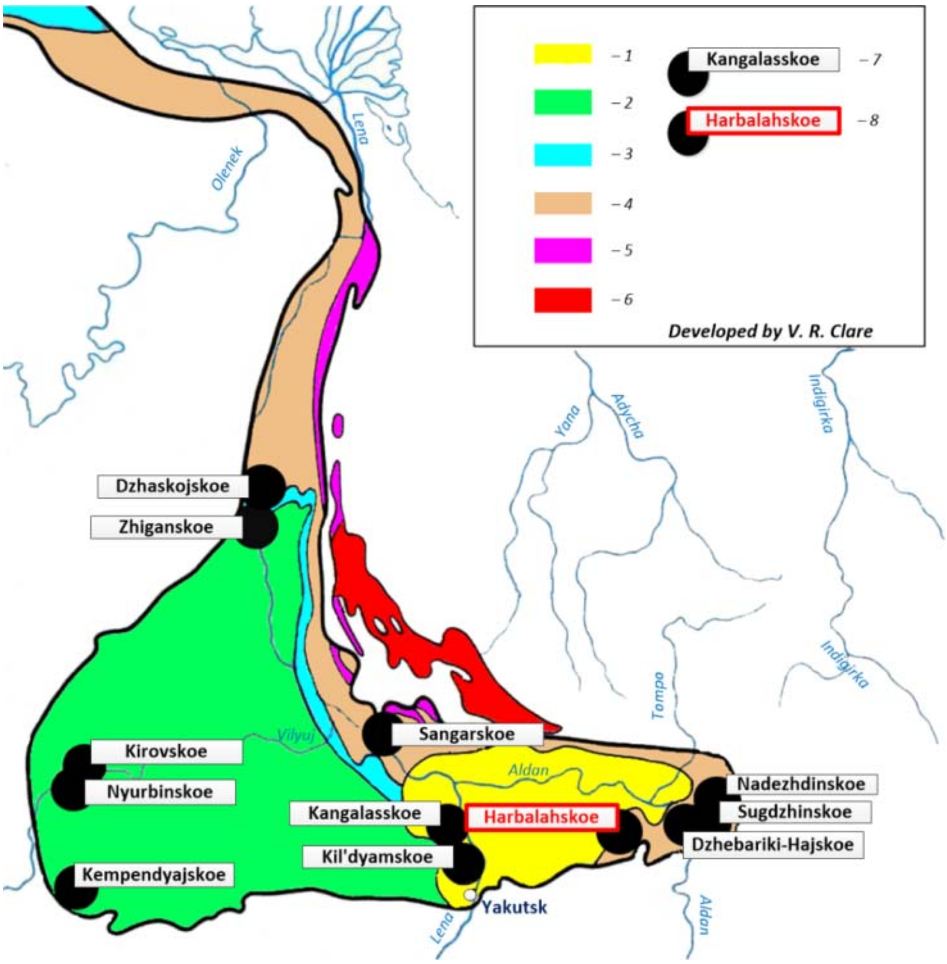

Figure 2 – Area of distribution of coal deposits of the Lensky basin showing coals of various technological groups. Legend. Brown coal: 1 – grade B_1; 2 – grade B_2; 3 – grade B_3. Coal: 4 – grade D – G; 5 – grade G–OS; 6 - grade T. 7 – coal mining enterprises; 8 – *Harbalakh* open-pit mine.

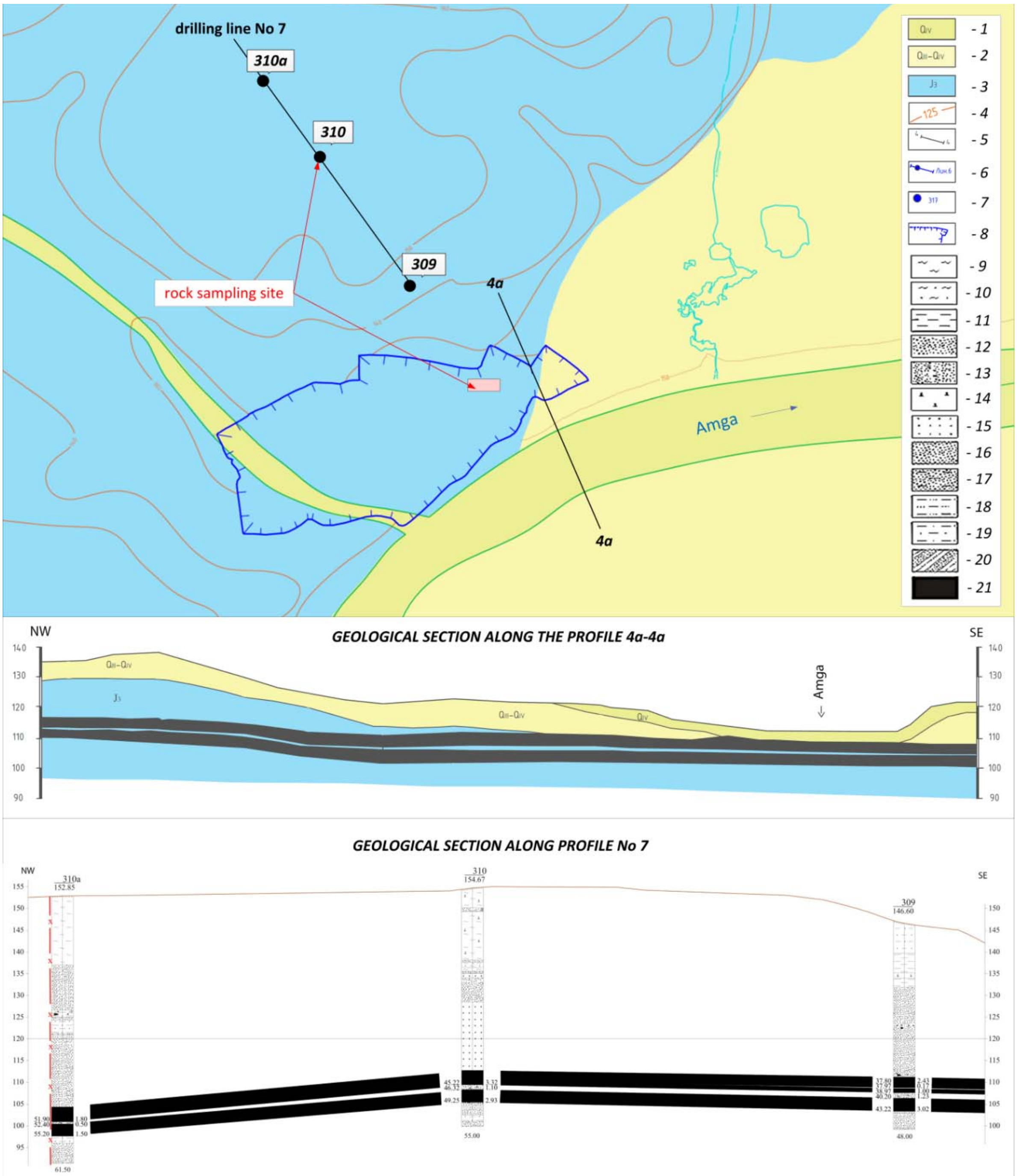

Figure 3 – Geological scheme of the site. Legend: 1 – alluvial floodplain and riverbed – sand, pebble; 2 - Sartang horizon – alluvium of the I-floodplain terrace – pebbles, sands, sandy loam, loam; 3 – Upper Jurassic deposits – sandstones, siltstones; 4 – contour; 5 – line of geological section; 6 – line of geological section of the works of 2019; 7 – wells drilled in 2019; 8 – boundaries of the investigated quarry; 9 – loam; 10 – sandy loam; 11 – clay; 12 – sand; 13 – sand-gravel mixture; 14 – ice; 15 – medium-grained sandstone; 16 – fine-grained sandstone; 17 – fine-grained sandstone; 18 – coarse siltstone; 19 – siltstone; 20 – intercalation of lithological differences; 21 – coal.

Absolute elevations range from 110 to 147 m. The climate of the deposit area is characterised as extremely continental. The average annual air temperature is minus 10 °C. The absolute minimum air temperature is minus 66 °C, while the absolute maximum is plus 38 °C.

The average number of days with frost is 240, while the frost-free period falls within the range of 120-125 days. The last frosts are observed at the end of May, with negative temperatures starting to appear at the end of August.

The geological structure of the region is characterised by terrigenous Jurassic deposits, which are represented by the alternation of sandstones, siltstones (aleurolites) and mudstones (argillites) (see figure 3). The total thickness of the deposits is 225-270 m. The deposits are overlain by loose Quaternary formations. One coal seam, extending to 10.4 m, was identified in the sediments of the Upper Jurassic upper sub-formation within the Kharbalakhskoye deposit. This coal seam is divided into two bands, with the thickness of the upper band varying between 1.45 m and 5.40 m, while the lower band has a thickness of between 1.66 m and 5.56 m. The rocky intercalation separating the seam into bands is typically composed of sandstone or, less frequently, coarse siltstone. The depth of the intercalation varies from 0.15-0.20 to 3.5-5.21 m. The top of the seam is overlain by medium- and fine-grained sandstones. This soil is composed of fine-grained sandstones and coarse siltstone. Fault tectonics in the area of work are represented by infrequent nonsinusoidal in-situ shear zones. In general, the deposit is characterised by a fairly uncomplicated geological structure [9].

Research methods. In 2019, in order to clarify the PMS and the material composition of the host rocks, as well as to study the main mining-geological and engineering-geological conditions, boreholes up to 62.0 m deep were drilled at the Kharbalakhskoye coal deposit (see Figure 3). In the process of carrying out work on the boreholes, carbon-bearing rocks represented by Jurassic deposits comprising heterogeneous sandstones and siltstones were tested.

Laboratory tests were performed on a recently-obtained rock core in order to determine the following characteristics: density; porosity; humidity; tensile strength under uniaxial compression and uniaxial tension; acoustic properties (propagation velocity of longitudinal and transverse waves in a rock sample); Poisson's ratio; and Young's modulus of elasticity. The determination of these rock indicators was carried out in accordance with the requirements established by state standards of the Russian Federation (GOSTs: 12071-2014; 21153.7-75; 21153.2-84; 21153.3-85; 24941-81; 5180-2015; 1248-2010, etc.).

When examining the specificity of material transformations of rocks during cryogenesis, chemical-analytical studies are typically carried out [10-13]. However, the analysis of changes in the chemical composition of rocks does not fully characterise the conversion of their mineral composition and fails to completely take into account the effect of structural transforming processes, which are of great importance for sedimentary rocks [14]. A satisfactory understanding of the relationship between changes in the composition and PMS of rocks informs their mineralogical and petrographic study. According to the authors, this approach gives the most accurate results by identifying the most complete range of possible reasons for their change as well as providing a forecast of further possible changes in the rocks. Thus, in addition to defining the PMS, laboratory work included mineralogical and petrographic studies.

The effect of cryogenesis on rocks was estimated from sandstone samples taken from borehole No. 310, which was drilled in 2019, as well as from the pit wall (opening date 1962), located 750 m from the borehole. Samples from the borehole were correlated with the corresponding section of the pit wall.

Results. The main results for determining the PMS of rocks from the borehole core and the pit wall of the Kharbalakhskoye field are shown in table.

The density of rocks from borehole cores at natural humidity is in the range from 1.99 to 2.37 g/cm^3; the tensile strength of siltstone under uniaxial compression is about 20 MPa, while for sandstone it varies from 21.2 MPa to 31.4 MPa. The uniaxial tensile strength of the host rocks of the considered field typically does not exceed 10 MPa. At the same time, sandstone samples taken from the quarry showed a 20–27% decrease in uniaxial compression strength, a 16% decrease in density and an increase in porosity coefficient of 25-32% as compared to fresh samples from borehole 310.

The results of mineralogical and petrographic studies of sandstones from the bore hole and pit wall allowed the following main transformational mechanisms to be identified (figure 4):

1) hydromicasation, which is caused by the decomposition of feldspars, fragments of aluminosilicate rocks and clay cement, and is accompanied by a general softening of the rock mass;

2) carbonation, accompanied by the formation of ankerite with grain sizes <0.01 mm and calcite;

3) ironisation due to surface oxidation of carbonates containing iron (ankerite and siderite) and layered silicates (chlorite and biotites).

PMS of rock samples taken from a borehole core of (2019) and the pit wall (opened 1962) of the Kharbalakhskoye field

No. in order	Borehole number	Rock stratum	Sampling interval, m		ρ	K_P	Vp	Vs	μ	E	$\sigma_{compress}$	σ_p
			from	to								
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
1	310A	Sandstone, fine-grained	40.0	45.0	2.15	3.10	3.66	2.03	0.27	2268.3	27.2	9.5
2	310A	Siltstone	55.2	56.8	2.17	1.39	3.42	1.95	0.26	2084.6	21.6	6.5
3	310A	Sandstone, fine-grained	56.8	60.2	1.99	3.16	3.76	2.12	0.27	2283.1	26.1	8.4
4	310	Sandstone, very fine-grained	22.0	23.5	2.07	2.28	3.47	1.96	0.27	2032.6	29.5	8.6
5	310	Sandstone, medium-grained	34.8	36.5	2.12	2.75	3.68	2.04	0.28	2291.6	24.9	8.9
6	309	Sandstone, fine-grained	14.5	30.3	2.37	3.50	3.78	2.09	0.28	2654.6	31.4	14.3
7	309	Sandstone, fine-grained	44.0	16.5	2.10	7.26	3.09	1.75	0.26	1671.3	21.2	9.8
8	open pit mine	Sandstone, very fine-grained	22.0	23.5	1.87	5.1	–	–	–	–	20.3	6.1
9	open pit mine	Sandstone, medium-grained	34.8	36.5	1.82	6.3	–	–	–	–	18.2	5.5

Table legend: ρ – rock density at natural humidity, g / cm³; K_P – porosity,%; V_P – propagation velocity of elastic longitudinal waves in a rock sample, km / s; V_S – propagation velocity of elastic transverse waves in a rock sample, km/s; μ – Poisson's ratio; E – Young's modulus, MPa; $\sigma_{compress}$ – ultimate strength under uniaxial compression, MPa; σ_p – ultimate strength under uniaxial tension, MPa; f/g – fine-grained; vf/g – very fine-grained; m/g – medium-grained.

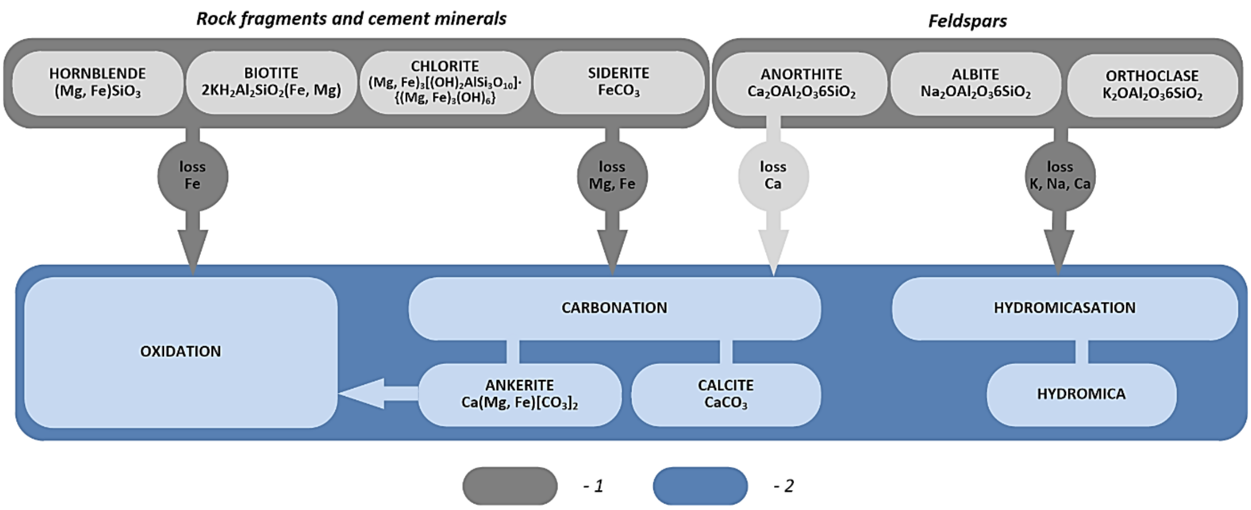

Figure 4 – Scheme of mineralogical-petrographic transformations of sandstones of the Kharbalakhsky coal deposit.
1 – composition of sandstones from borehole 310; *2* – composition of sandstones from the quarry after 57 years of exposure to cryogenesis

In the mineralogical and petrographic study of sandstone samples taken from the pit wall, deformations of individual fragments of quartz grains and feldspars (crushing, fracturing), as well as plastic damage to materials were identified taking the form of clastic defectiveness and recrystallisation of carbonate grains. All of these deformational distortions are evidently the result not only of lithostatic pressure, temperature and hydration mechanisms of weathering, but are also due to cryohydration during the phase transition of water into ice at the stage of seasonal freezing of rocks.

The influence of cryogenesis on sandstones in the natural mass revealed by the borehole is broadly similar to the effects observed in the same rocks that make up the pit walls.

Common signs are the staged nature of weathering and uneven nature of its manifestation, as well as the mineralogical identity of the neoplasms, including the formation of hydromica with an admixture of ancherite, kaolinite, calcite and iron hydroxides. The main difference between the transformations of sandstones from the quarry consists in their greater intensity, especially in terms of carbonation, as well as the completeness of the manifested processes of the selected mechanisms.

We note that similar mechanisms for the transformation of host rocks subjected to cryogenesis have been established for other coal deposits in Yakutia. In particular, studies of the mineralogical and petrographic composition of the Jurassic sandstones of the Neryungri coal deposit in South Yakutia led to the conclusion that the transformation of the mineral part of sandstones during cryogenesis is expressed in a change in the PMS of the rocks composing the massif, whose nature depends on the leading role of one of the above mechanisms [14].

Conclusions. The high intensity of changes in the initial properties of sandstones in the studied region over a relatively short period of time appears to be due to processes of cryogenesis. Moreover, the degree of change in the properties of coal-bearing rocks is determined by the duration of cryogenic impact. Thus, no forecast of the stability of manmade gradients, cut slopes and pit walls can be sufficiently substantiated without a detailed study of cryogenesis processes. To date, there is still a significant lag in the study of the theory of weathering processes on which basis methods for their assessment can be developed. Although the processes of cryogenesis in temperate climates have been studied for several decades, methods and approaches for areas of permafrost distribution are under development. Hardly any work has been carried out to describe the mechanisms (mineralogical, structural, including the nature of water migration and ice formation) and material transformations that occur during phase transitions of water, i.e. freezing and thawing.

According to the authors, the establishment of features of regional cryogenesis is universal in nature and can be applicable to solving a wide range of tasks in assessing and predicting the degree of cryogenic transformation of rocks having various structural components.

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КРИОГЕНЕЗ ӘСЕРІНЕН ЯКУТИЯ КӨМІР КЕН ОРЫНДАРЫНЫҢ СЫЙЫМДЫ ЖЫНЫСТАРЫНЫҢ ҚҰРАМЫ МЕН ҚАСИЕТТЕРІНІҢ ӨЗГЕРУІ

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ИЗМЕНЕНИЕ СОСТАВА И СВОЙСТВ ВМЕЩАЮЩИХ ПОРОД УГОЛЬНЫХ МЕСТОРОЖДЕНИЙ ЯКУТИИ ПОД ВОЗДЕЙСТВИЕМ КРИОГЕНЕЗА

Аннотация. По результатам лабораторных испытаний проб горных пород месторождения угля «Харбалахское», расположенного в Центральной Якутии, установлено, что вторичные изменения в горных породах, вмещающих угли, являются весьма существенными. В процессе преобразования изменился не только состав пород, но и характер структурных связей, оказавших большое влияние на их физико-механи-

ческие свойства. Так, значения предела прочности при одноосном сжатии образцов песчаника и алевролита, вмещающих угли, изменяются от 20 до 30 МПа, при одноосном растяжении – от 6 до 10 МПа. Данные числовые значения физико-механических свойств пород относительно низки и, в целом, не типичны для месторождений длиннопламенных углей. Прочностные свойства вмещающих пород почти наполовину ниже по сравнению с аналогичными породами других месторождений угля в России. Вероятно, на прочностные свойства пород Харбалахского месторождения существенное влияние оказали процессы криогенеза. Проведенный сравнительный анализ свойств керна из скважин, пробуренных в 2019 г., с пробами из карьера, вскрытого несколько десятилетий назад, обнаруживает признаки преобразования пород Харбалахского месторождения, обусловленного фазовыми переходами воды, промерзанием и оттаиванием.

Петрографо-минералогические исследования позволили выделить следующие основные механизмы изменения пород: 1) гидрослютизация, которая обусловлена разложением полевых шпатов, обломков алюмосиликатных пород и глинистого цемента, данный механизм сопровождается общим разупрочнением скального массива; 2) карбонатизация, сопровождающаяся образованием анкерита и кальцита; 3) ожелезнение, обусловленное поверхностным окислением карбонатов содержащих железо (анкерита и сидерита) и слоистых силикатов (хлорита и биотитов). Аналогичные механизмы преобразования вмещающих пород, подвергшихся криогенезу, установлены и для других угольных месторождений Якутии, в частности, Южной Якутии.

При минералого-петрографическом исследовании образцов горных пород, отобранных с борта карьера, идентифицировались деформации отдельных обломков зерен кварца и полевых шпатов (дробление, трещинноватость), а также признаки обломочной дефектности и перекристаллизации зерен карбонатов. Все эти деформационные «искажения», по-видимому, являются результатом литостатического давления, температурного и гидратного механизмов выветривания, а также обусловлены криогидратной природой в процессе фазового перехода воды в лед на стадии сезонного промерзания пород.

Во влиянии криогенеза на песчаники в естественном массиве, вскрытого скважиной, и таких же породах, слагающих стенки карьерного уступа, обнаружилось много сходного. Общими признаками являются стадийный характер выветривания, неравномерный характер его проявления, минералогическая индивидуальность новообразований. Отличие преобразований песчаников из карьера выражается в большей их интенсивности, особенно карбонатизации, и полноте проявлений выделенных механизмов.

Таким образом, высокая интенсивность изменения первоначальных свойств песчаников в исследуемом регионе за относительно короткий период времени обусловлена процессами криогенеза. Причем степень изменения свойств углевмещающих пород определяется сроком его воздействия. В связи с чем, прогноз устойчивости искусственных склонов, откосов выемок и бортов карьеров не может быть достаточно обоснован без детального изучения процессов криогенеза. На сегодняшний день все еще имеется существенное отставание в изучении теории процессов выветривания и в разработке методик их оценки. Если процессы криогенеза в условиях умеренного климата изучаются несколько десятилетий, то для районов распространения многолетней мерзлоты методы и подходы находятся в стадии разработки. Практически никогда не проводятся работы по описанию механизмов (минералогических, структурных, в том числе характер миграции воды и льдообразования) и вещественных преобразований, возникающих при фазовых переходах воды, промерзании и оттаиванием. По мнению авторов, установление особенностей регионального криогенеза имеет универсальный характер и может быть применимо для решения широкого спектра задач при оценке и прогнозе степени криогенной трансформации пород с различными структурными связями.

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Ключевые слова: уголь, Якутия, криогенез, физико-механические свойства, месторождение Харбалахское, вмещающие горные породы, вещественный состав.

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