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Substantiation of the specific energy intensity of drilling as a criterion characterizing the explosive destruction of rocks on the example of the Koktaszhal deposit

Ozhigin S.G. [1], **Chunuev I.K.** [2], **Musin R.A.** [1], **Tyan S.G.** [1*]

[1] Karaganda Technical University, Karaganda, Kazakhstan
[2] Kyrgyz State University of Geology, Mining and Natural Resources Development named after Academician U.A. Asanaliev, Kyrgyzstan.

** Corresponding author email: info@geo-in.kz*

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ABSTRACT
Drilling and blasting operations are one of the most important components of the mining industry. Currently, further improvement and optimization of technological processes at mining enterprises are possible mainly due to the determination and constant monitoring of the mining and technological properties of the rock mass – their drillability, explosivity and exaviability. A prospective assessment of the explosivity of rocks in the massif, which is the basis for designing and calculating the parameters of the DBO, is currently possible only using the energy parameters of technological work. The article provides information on methods for studying the strength and elastic characteristics of rocks in natural occurrence. The results of the study of the relationship between the specific energy intensity of drilling and explosive destruction of rocks are presented. The correlation between the specific energy intensity of drilling and the propagation velocity of elastic longitudinal waves is also considered. A comparative analysis is carried out between the traditional calculation of the explosive index using the results of laboratory studies on the physical and mechanical properties of the rocks of the Koktaszhal deposit and the calculation of the explosive destruction index taking into account the energy parameters of drilling. The validity of the use of the specific energy intensity of drilling as a criterion characterizing the explosive destruction of rocks in the design of drilling and blasting operations is shown.
Keywords: Drillability, energy intensity of drilling, explosiveness, rock strength.

Information about authors:

Ozhigin Sergey Georgievich
Doctor of Technical Sciences, Professor. Karaganda Technical University, Karaganda, Kazakhstan. ORCID ID: 0000-0003-2432-3851. Email: osg62@mail.ru

Chunuev Ishimbay Karybayevich
Doctor of Technical Sciences, Professor. Kyrgyz State University of Geology, Mining and Natural Resources Development named after Academician U.A. Asanaliev, Bishkek, Kyrgyzstan. Email: ichunuev@gmail.com

Musin Ravil Altavovich
PhD, senior lecturer. Karaganda Technical University, Karaganda, Kazakhstan. ORCID ID: 0000-0002-1206-6889. Email: r.a.mussin@mail.ru

Tyan Stanislav Georgievich
Doctoral student, Karaganda Technical University, Karaganda, Kazakhstan. . ORCID ID: 0000-0002-3566-1437. Email: info@geo-in.kz

Introduction

Drilling and blasting operations are one of the most important components of the mining industry. Every year, the volume of exploding rocks is only growing, which increases the demand for technologies that accelerate the design process and calculate the efficiency of the work performed. Currently, further improvement and optimization of technological processes at mining enterprises are possible mainly due to the determination and constant monitoring of the mining and technological properties of the rock mass – their drillability, explosivity and exaviability. A prospective assessment of the explosivity of rocks in the massif, which is the basis for designing and calculating the parameters of the DBO, is currently possible only using the energy parameters of technological work.

According to morphostructural features, physical and geographical conditions and technical and economic parameters, the Koktaszhal copper-porphyry deposit is planned to be worked out in an open-pit manner with a depth of 300 m.

As shown in [1], the surface of the industrial areas of the Koktaszhal mining and Processing Plant is represented by a rocky base covered in areas with covers with low power within 10-30 cm of delvial-proluvial deposits. The rocks are represented by strong silica tuffs, plagiogranitic porphyry and porphyry, silicic acid-invasive rocks, monochrome and quartz-shimmering chlorite rocks.

Components included in the mineral composition:

1. Quartz 43-45%,
2. Sour plagioclase 31 - 33 %,
3. Chloride 9 - 11 %,
4. Hydrosluda 8-10 %,
5. Dolomite 2 – 3 %.

Zones of tectonic disturbances are mostly filled with differently oriented quartz veins, which has a positive effect on the stability of rocks. Ores and host rocks of the deposit have the same strength properties due to the fact that mineralization has no pronounced boundaries and the mineral grains of the rocks have a dense structural-crystallization relationship between them. Groundwater within the mountain drainage in the weathering crust does not spread. In rock formations they are deep enough (10 - 30 m) and do not affect the change of engineering and geological properties of rocks. That is why the category of complexity of engineering and geological criteria for the development of the Koktaszhal site, according to the "Methodological guidelines for the study of mining and geological conditions of deposits of solid minerals" belongs to the simple. The contract area is characterized by strong differences. Ores and rocks are not sensitive to spontaneous combustion and swelling, are not radioactive [1].

The experimental part

For blasting a rock mass under ideal conditions, the main physical and mechanical characteristics of rocks are: strength ($\sigma_{сж}$, $\sigma_{раст.}$,$\sigma_{сд}$), strength coefficient - f, elastic wave velocity - V_p, density - γ. Tests on the strength and elastic properties of rocks were carried out on the cores of six geotechnical wells drilled along the contour of the quarry to its design depth.

The determination of the tensile strength under uniaxial compression was carried out according to Gost 21153.2 -84.

Figure 1 shows the essence of the main method for determining the maximum destructive force ($P_{сж}$), which is applied to the ends of the sample of the correct shape through steel flat plates.

Figure 1 - Testing of rocks for tensile strength under uniaxial compression on a press

The compressive strength of the rock ($\sigma_{сж}$) for each test sample was calculated by the formula:

$$\sigma_{сж} = k_в \cdot \frac{P_{сж}}{F_0} \cdot 10, \qquad (1)$$

where - $P_{сж}$ is the total maximum load on the sample at the time of its destruction, kN;

$F_0=(\pi/4)*d^2$ - initial cross-sectional area of the sample, cm^2;

d – sample diameter, cm;

$k_в$ – the dimensionless height coefficient of the sample, equal to 1.00 with the ratio of height to diameter m = 2 ± 0.5. For other values of the ratio m, the coefficient $k_в$ was set according to Table 1.

Table 1 - Determination of the dimensionless coefficient $k_в$

m	0,7	0,80	0,90	1,00	1,20	1,40	1,60	1,80	2,00
kв	0,68	0,72	0,76	0,80	0,86	0,90	0,94	0,97	1,00

Determination of the rock strength limit under uniaxial tension was carried out according to GOST 21153.3 – 85.

Figure 2 shows the essence of the method, which consists in determining the maximum destructive force ($P_{рас}$) applied perpendicular to the generatrix of a cylindrical rock sample, as a result of which tensile stresses arise in the sample, leading to its destruction in the plane of the longitudinal section.

Figure 2 - Testing of rocks for tensile strength under uniaxial tension

The tensile strength of the rock (σ_p) was calculated by the formula:

$$\sigma_p = \frac{P_{pac}}{d \cdot h} \cdot 10 , \qquad (2)$$

where – (P_{pac}) is the maximum load on the sample at which the sample ruptured, kN;

d - is the diameter of the sample, cm;

h - is the height of the sample.

The coefficient of rock strength on the scale of M.M. Protodyakonov and is determined on pieces of rock with a size of 20-40 mm in the POK device by dropping weights weighing 2.5 kg from a height of 60 cm. The number of drops varies from 5 to 15. After crushing, the material is sieved through a 0.5 mm sieve and the volume of the crushed material is measured in a volume meter.

$$f = \frac{20 \times n}{h} \qquad (3)$$

where n – the number of kettlebell drops during the test of one hitch;

h – the height of the column of the fine fraction (after sieving on a sieve of 0.5 mm) in the volume meter after testing five attachments, mm;

20 - an empirical numerical coefficient that provides the generally accepted values of the strength coefficient and takes into account the work spent on crushing [2].

In preparation for measurements of elastic parameters of rocks, the end surfaces of the core were carefully sanded, their length strictly corresponded to 100 mm, diameter 48 mm, the ratio l/d ≥ 2 was observed, where d - is the diameter of the sample.

For laboratory studies of the propagation velocity of longitudinal and transverse waves, the measurement equipment and methods described in the literature [[4], [5], [6]] were used. A MATRIX Corp. high-frequency generator was used as instruments. MFG-8216 and digital storage oscilloscope (DSO) from ACUTE Tecn. DS 1002. Piezoelectric converters PRIZ-12 [3], (Figure 3) are used as converters.

«The main measurement parameter in determining the elastic properties of rocks is the acoustic delay time Δt of the front of the first half-period of the received signal pulse, which, at a constant value of the rock sample L = 100mm, allows us to determine the propagation velocity of

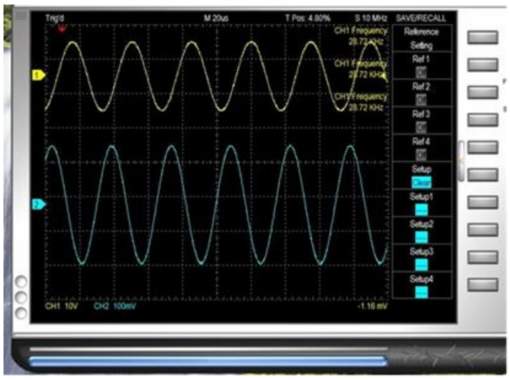


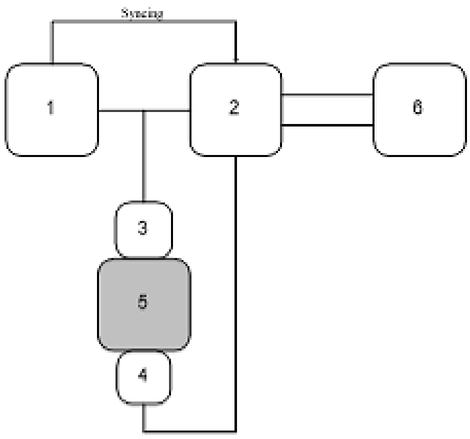
Figure 3 - Ultrasound examination method

the longitudinal wave Vp = L/ Δt. To determine the velocity of propagation of a transverse wave, a signal reception sensor (piezoelectric transducer - emitting or receiving) was located on the sample at an angle

$$90^\circ Vs = L(90^\circ)/ \Delta t, \qquad (4)$$

where L (90) - is the length of the sample, taking into account the displacement of sensors on the sample surface.

Figure 4 shows a block diagram of the measurement of elastic parameters by the pulse method».



1 - generator; 2 - oscilloscope; 3 - radiating piezoelectric converter; 4 - receiving piezoelectric converter; 5 - acoustic load - rock sample made of core or reference; 6 - computer for data input and pulse observation.

Figure 4 - Block diagram of elastic parameters measurement by pulse method

«Laboratory tests for determining the density of rocks were carried out according to Gost 8269.0-97.

Also, the basic density in the framework of the experiment was determined by measuring the mass

Table 2 - Strength properties of rocks along the horizons

Horizon, m		γ, g/cm³	Ultimate strength			f	Wave speed	
from	to		($\sigma_{сж}$), MPa	($\sigma_{рс}$), MPa	($\sigma_{сд}$), MPa		(V_p), m/sec	(V_s), m/sec
720	705	2,75	82,1	8,0	20,2	12	4548	2697
705	690	2,75	82,1	8,0	20,2	12	4548	2697
690	675	2,78	79,8	7,9	27,5	12	4552	2686
675	660	2,78	79,8	7,9	27,5	12	4552	2686
660	645	2,76	72,8	7,0	27,6	11	4139	2536
645	630	2,76	72,8	7,0	27,6	11	4139	2536
630	615	2,80	65,1	6,8	33,6	11	4212	2576
615	600	2,80	65,1	6,8	33,6	11	4212	2576

of a unit volume of solid pieces of rock using hydrostatic weighing scales.

The measurement of the average density (γ) of the test rock was carried out according to the formula:

$$\gamma = q / V, \ g/cm^3 \quad (5)$$

where q – the mass of the sample, determined on technical scales with an accuracy of 0.01, g;

V – sample volume determined by hydrostatic weighing, cm^3».

«3-5 parallel volume density determinations were performed for each sample. The arithmetic mean of all definitions was taken as the final test result.

The true (specific) density (γ_y) was determined by measuring the mass of a unit volume of crushed dried rock according to the formula:

$$\gamma_y = q_u / V_u, \ g/cm^3 \quad (6)$$

where q_u – mass of the crushed sample (mineral part of the rock), g;

V_u – volume of crushed rock (mineral part of the rock), cm^3.

Two parallel determinations of the true density were made for each rock, then the average value was calculated with an accuracy of 0.01 [2].

The results of the research are spread across the horizons and summarized in summary table 2.

To destroy the rock mass in the quarry, a drilling and blasting method is used, the main task of which is to ensure the necessary lumpiness of the rock mass (65% - dk ≤ 300 mm). Primary crushing is carried out by the method of borehole charges (mass explosions). Blast wells with a diameter of 215 mm are drilled using high-performance ball drilling rigs of the DML LPE 1600/110 brand. The development of the deposit is planned in an open way, with 15-meter ledges. Cutting of oversized items is carried out by the shpurov method, overhead and cumulative charges. The calculation of the design specific consumption of explosives was adopted according to the methodology proposed by Academician V.V. Rzhevsky [7]:

$$q_п = q_э К_т К_д К_{о.п.} К_з К_v К_{вв}, \quad (7)$$

where $q_э$ - reference consumption of explosives [8]:

$$q_э = К_1(\sigma_{сж} + \sigma_{рс} + \sigma_{сд}) + К_2 \gamma g, \quad (8)$$

$К_т$ - coefficient that takes into account the effect of fracturing of the mountain range,

$К_д$ - coefficient that takes into account the degree of crushing,

$К_{о.п.}$ - correction factor that takes into account the number of open surfaces,

$К_з$ - correction factor for the degree of charge concentration in the array,

$К_у$ - correction factor for the height of the ledge,

$К_{вв}$ - correction factor for the consumption of explosives, taking into account the required degree of crushing,

$К_1$ и $К_2$ – empirical coefficients [7].

Table 3 - Calculated values of the design specific consumption of explosives

Horizon, m		$q_э$	$К_т$	$К_д$	$К_{о.п.}$	$К_з$	$К_у$	$К_{вв}$	$q_п$ (g/cm^3)
from	to								
720	705	0,124	0,45	1,667	4,750	1,026	1,000	1,533	**0,69**
705	690	0,124							**0,69**
690	675	0,124							**0,69**
675	660	0,124							**0,69**
660	645	0,120							**0,67**
645	630	0,120							**0,67**
630	615	0,106							**0,62**
615	600	0,106							**0,62**

It follows from the data obtained that the rocks forming horizons of 720-600 m at the Koktaszhal deposit belong to the average degree of explosivity and to the category of explosivity - II [9].

Discussion of the results

To substantiate the specific energy intensity of drilling as a universal criterion for the strength of rocks and massifs, it is necessary to compare it with the specific energy intensity of explosive destruction [10].

Comprehensive research in this direction in production conditions in the 70-80-ies of the 20th century was conducted by Professor I.A. Tangaev, as a result, the following was noted:

1. the specific consumption of BB- q (kg/m^3) of energy q_e (Mcal /m^3) is the coefficient of proportionality between the energy of the charge and its load, reflecting the strength properties of the medium:

$$Q=qV \qquad (9)$$

2. the relationship between the specific energy intensity of drilling - e (kW·h/m^3) and explosive destruction - q_e (Mcal/m^3) is approximated by the linear equation:

$$q_e=0,15+0,011e \qquad (10)$$

3. in accordance with the value e, kW·h/m, the value of the specific consumption of explosive q, kg/m^3, can be calculated by the formula:

$$q_n=0,24e+0,16 \qquad (11)$$

There is an unambiguous dependence of the explosivity on the velocity of propagation of longitudinal waves in rocks.

This is due to the close correlation with such characteristics of the medium as density, fracturing, anisotropy, etc. [[10], [11]].

Applying data on the velocity of longitudinal waves of rocks of the Koktaszhal deposit and indicators of the specific energy intensity of drilling of rocks similar in lithological, strength and elastic properties, we determine the relationship between them. (Figure 5).

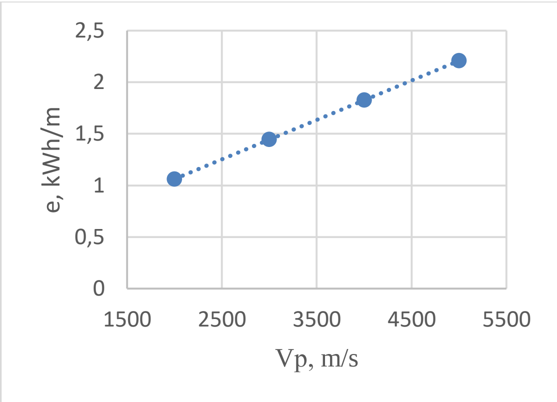


Figure 5 - The relationship between the specific energy intensity of drilling and the propagation velocity of elastic waves.

This dependence can be represented by the following linear function:

$$e=0.0004V_p+0,2967 \qquad (12)$$

Solving equations (12) and (11) together, we obtain the value of the specific explosive consumption q, kg/m^3, taking into account the specific energy intensity of drilling. Table 4.

Table 4 - Calculated values of the design specific consumption of explosives

Horizon, m from	Horizon, m to	Velocity of longitudinal waves (V_p), m/sec	Specific energy intensity of drilling, e, (kW·h/m)	Design specific consumption of explosive q_n according to the Rzhevsky method (kg/m3)	Design specific consumption of explosive q_n by drilling energy intensity, (kg/m^3)	Difference, %
720	705	4547,69	2,116	**0,69**	**0,68**	**-1,5**
705	690	4547,69	2,116	**0,69**	**0,68**	**-1,5**
690	675	4552,46	2,118	**0,69**	**0,67**	**-2,9**
675	660	4552,46	2,118	**0,69**	**0,67**	**-2,9**
660	645	4139,51	1,952	**0,67**	**0,63**	**-6,0**
645	630	4139,51	1,952	**0,67**	**0,63**	**-6,0**
630	615	4211,92	1,981	**0,62**	**0,64**	**3,2**
615	600	4211,92	1,981	**0,62**	**0,64**	**3,2**

Conclusions

Comparative analysis shows good convergence of the results and suggests the legitimacy of using the specific energy intensity of drilling as a criterion characterizing the explosive destruction of rocks.

It should be noted that the data under consideration on the strength and elastic properties of rocks were obtained by laboratory means in samples, which does not guarantee their identity in the array.

The use of specific energy capacities of drilling and blasting makes it possible to obtain information for each well directly on the block and, in accordance with the characteristics of the array, set or adjust the energy and detonation parameters of charges and geometric parameters of the location of wells.

Conflict of interest

On behalf of all the authors, the correspondent author declares that there is no conflict of interest.

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Көктасжал кен орны мысалында тау жыныстарының жарылғыш бұзылуын сипаттайтын өлшем ретінде бұрғылаудың меншікті энергия сыйымдылығын негіздеу

Ожигин С.Г. [1], Чунуев И.К. [2], Мусин Р.А. [1], Тян С.Г. [1]

[1] *Қарағанды Техникалық Университеті, Қарағанды, Қазақстан*
[2] *Қырғыз мемлекеттік Геология, тау-кен ісі және табиғи ресурстарды игеру университеті. академик Ө. А. Асаналиева, Қырғызстан.*

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ТҮЙІНДЕМЕ

Бұрғылау-жару жұмыстары Тау-кен өнеркәсібінің маңызды құрамдас бөлігі болып табылады. Қазіргі уақытта тау-кен кәсіпорындарындағы технологиялық процестерді одан әрі жетілдіру және оңтайландыру, негізінен, тау жыныстары массивінің тау – технологиялық қасиеттерін-олардың бұрғылануын, жарылғыштығын және эксавацияланауын анықтау және үнемі бақылау есебінен мүмкін болады. БВР параметрлерін жобалау мен есептеудің негізі болып табылатын массивтегі жыныстардың жарылғыштығын перспективалық бағалау қазіргі уақытта технологиялық жұмыстардың энергетикалық параметрлерін пайдалану арқылы ғана мүмкін болады. Мақалада тау жыныстарының табиғи жатыс кезіндегі беріктік және серпімділік сипаттамаларын зерттеу әдістері туралы мәліметтер келтірілген. Бұрғылаудың нақты энергия сыйымдылығы мен тау жыныстарының жарылғыш бұзылуы арасындағы байланысты зерттеу нәтижелері келтірілген. Бұрғылаудың нақты энергия сыйымдылығы мен серпімді бойлық толқындардың таралу жылдамдығы арасындағы корреляциялық байланыс қарастырылған. "Көктасжал" кен орны жыныстарының физикалық-механикалық қасиеттері бойынша зертханалық зерттеулердің нәтижелерін пайдалана отырып, жарылғыштық көрсеткішінің дәстүрлі есебі мен бұрғылаудың энергетикалық параметрлерін ескере отырып, жарылғыштық көрсеткішінің есебі арасында салыстырмалы талдау жүргізілді. Бұрғылау-жару жұмыстарын жобалау кезінде тау жыныстарының жарылғыш бұзылуын сипаттайтын өлшем ретінде бұрғылаудың меншікті энергия сыйымдылығын пайдаланудың негізділігі көрсетілген.

Түйін сөздер: Бұрғылау, бұрғылаудың энергия сыйымдылығы, жарылғыштық, тау жыныстарының беріктігі.

Авторлар туралы ақпарат:

Ожигин Сергей Георгиевич — *Техника ғылымдарының докторы, профессор. Қарағанды Техникалық Университеті, Қарағанды, Қазақстан. ORCID ID: 0000-0003-2432-3851. Email: osg62@mail.ru*

Чунуев Ишимбай Карыбаевич — *Техника ғылымдарының докторы, профессор. Қырғыз мемлекеттік Геология, тау-кен ісі және табиғи ресурстарды игеру университеті. академик Ө. а. Асаналиева, Бішкек, Қырғызстан. Email: ichuniev@gmail.com*

Мусин Равиль Альтавович — *PhD, аға оқытушы. Қарағанды Техникалық Университеті, Қарағанды, Қазақстан. ORCID ID: 0000-0002-1206-6889. Email: r.a.mussin@mail.ru*

Тян Станислав Георгиевич — *Докторант, Қарағанды Техникалық Университеті, Қарағанды, Қазақстан. ORCID ID: 0000-0002-3566-1437. Email: info@geo-in.kz*

Обоснование удельной энергоемкости бурения как критерия, характеризующего взрывное разрушение горных пород на примере месторождения Коктасжал

Ожигин С.Г. [1], Чунуев И.К. [2], Мусин Р.А. [1], Тян С.Г. [1]

[1] Карагандинский Технический Университет, Караганда, Казахстан
[2] Кыргызский государственный университет геологии, горного дела и освоения природных ресурсов им. академика У.А. Асаналиева, Кыргыстан

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АННОТАЦИЯ

Буровзрывные работы являются одной из важнейших составляющих горнодобывающей промышленности. В настоящее время дальнейшее совершенствование и оптимизация технологических процессов на горных предприятиях возможны преимущественно за счет определения и постоянного контроля горно-технологических свойств массива горных пород – их буримости, взрываемости и эксавируемости. Перспективная оценка взрываемости пород в массиве, являющаяся основой проектирования и расчетов параметров БВР, на данный момент возможна только с использованием энергетических параметров технологических работ. В статье приведены сведения о методах изучения прочностных и упругих характеристик горных пород в естественном залегании. Приведены результаты исследования взаимосвязи между удельной энергоемкостью бурения и взрывного разрушения горных пород. Также рассмотрена корреляционная зависимость между удельной энергоемкостью бурения и скоростью распространения упругих продольных волн. Проведен сравнительный анализ между традиционным расчетом показателя взрываемости с использованием результатов лабораторных исследований по физико-механическим свойствам пород месторождения «Коктасжал» и расчетом показателя взрывного разрушения с учетом энергетических параметров бурения. Показана обоснованность использования удельной энергоемкости бурения как критерия, характеризующего взрывное разрушение горных пород при проектировании буровзрывных работ.

Ключевые слова: Буримость, энергоемкость бурения, взрываемость, прочность пород.

Информация об авторах:

Ожигин Сергей Георгиевич — *Доктор технических наук, профессор. Карагандинский Технический Университет, Караганда, Казахстан. ORCID ID: 0000-0003-2432-3851. Email: osg62@mail.ru*

Чунуев Ишимбай Карыбаевич — *Доктор технических наук, профессор. Кыргызский государственный университет геологии, горного дела и освоения природных ресурсов им. академика У.А. Асаналиева, Бишкек, Кыргыстан. Email: ichuniev@gmail.com*

Мусин Равиль Альтавович — *PhD, старший преподаватель. Карагандинский Технический Университет, Караганда,*

	Казахстан. ORCID ID: 0000-0002-1206-6889. Email: r.a.mussin@mail.ru
Тян Станислав Георгиевич	*Докторант, Карагандинский Технический Университет, Караганда, Казахстан. ORCID ID: 0000-0002-3566-1437. Email: info@geo-in.kz*

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