ГЕОМЕХАНИКА. РАЗРУШЕНИЕ ГОРНЫХ ПОРОД. ФИЗИЧЕСКИЕ И ХИМИЧЕСКИЕ ПРОЦЕССЫ ГОРНОГО ПРОИЗВОДСТВА

DOI: 10.21440/0536-1028-2021-7-16-24

Determination of horizontal stress orientation in the areas of the Tomsk region

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Abstract
Introduction. *The World Stress Map project proves that horizontal stress orientation determination is a global task essential for the majority of geomechanical calculations. However, there is scant data on stress orientations in the territory of Russia at the moment. The task is therefore highly relevant.*
Research objective *is to determine the orientations of maximum and minimum horizontal stresses by separate areas of the Tomsk region and build a map of horizontal stresses.*
Method of research. *The basis for determining the orientations of horizontal stresses is the theory of drilling-induced fracture and borehole breakouts occurrence. The maximum stress orientation coincides with the drilling-induced fracture orientation, whereas the minimum stress orientation coincides with the borehole breakouts orientation or is perpendicular to the maximum stresses.*
Results. *Research results are compiled in a summary table containing mean orientations of horizontal stresses by areas and a map of horizontal stress orientations.*
Conclusions. *A summary map of maximum horizontal stress strike azimuths has been constructed. The stresses are of similar orientation in every well under consideration, except for a well in the North-Shingin area. The average value of maximum horizontal stress orientation has made up 337° northwest and 157° southeast.*

Keywords: *drilling-induced fracture; stress orientation; geomechanics; borehole breakout; microimager.*

Introduction. To carry out several tasks, namely hydraulic fracturing design development, predicting complications when drilling, designing wellbores, predicting sand production, and building geomechanical models, it is necessary to determine horizontal stresses in the areas of the Tomsk region. The obtained data will also add new information to the World Stress Map (WSM) [1].

Open-source information analysis makes it possible to conclude that data on horizontal stresses in the Tomsk region territory is scant. Most often there is information on separate wellbores in different areas and considered as a quality value for various tasks execution.

General data collation on horizontal stress orientation from open sources is presented in paper [2]. According to [2], the average value of horizontal stresses orientation is 330° for West Siberia. Up to 30° deviation of horizontal stress orientation was also recorded in several areas.

Other papers that use data on horizontal stress orientation prove the orientation from 310° to 350°. Paper [3] accepts from 320° to 350° when calculating multistage hydraulic fracturing at the Em-Egovsky field; paper [4] uses orientations within the range of 310° to 350° to analyse the stability of Palianovsky fieldTs wellbore; paper [5] accepts 340° horizontal stress orientation to select hydraulic fracturing parameters at the West-Salymsky field; paper [6] accepts 330° horizontal stress orientation for 3D geomechanical modelling at the Middle-Nazymsky field; paper [7] accepts 330° when exploring hard-to-recover reserves of the Bazhenov formation by the example of the Bittemsky field; paper [8] defines horizontal stress orientation within the range of 350°–10° when describing the experience of employing horizontal wells for hard-to-recover reserves in West Siberia. Some papers have data on separate wells, maximum horizontal stress orientation of which is from 10° to 40°, for example, in paper [9], within the framework of the geomechanical simulation at the East-Messoyakhsky field, maximum horizontal stress orientation is set 10°–20°.

In this research, the determination of horizontal stress orientation is based on the theory of drilling-induced fracture and borehole breakouts in the course of drilling [10–13].

To determine the orientation of drilling-induced fracture and breakouts, microimages data from 5 fields was analysed, namely Archinsky, West-Luginetsky, Kulginsky, Urmansky, and North-Shinginsky.

As part of the study the following key data have been obtained: horizontal stress orientation variability in the area under investigation, horizontal stress orientations comparison in the pre-Jurassic assemblage and the sedimentary mantle.

Research method and results. In the course of drilling, drilling-induced fractures and borehole breakouts develop in the well. Determination of the drilling-induced fracture with a high degree of accuracy can be carried out based on the data from the microimagers. At the microimages, drilling-induced fractures are of a distinctive form: vertical stripes or inclined lines (dashed lines) extended along orientation.

The presence of the drilling-induced fracture or borehole breakouts makes it possible to estimate the orientation of maximum and minimum horizontal stress in a vertical well. Drilling-induced fractures develop parallel to maximum horizontal stress, while borehole breakouts develop in the transverse orientation [14]. In the course of this research, the orientations of drilling-induced fracture and breakouts in each area taken separately have been distinguished.

Statistical processing has been carried out by formulae from [14]. To calculate the mean orientation $\overline{\theta}$ and standard deviation *SD*, the Fisher statistics have been applied. Mean orientation is determined as the angular mean of all sample vectors. For this purpose, C_i and S_i are determined as the coordinates of the unit vector end, the orientation of which is set by angle θ_i:

$$C_i = \cos\theta_i; \qquad S_i = \sin\theta_i,$$

where $i = 1, \dots, N$ – drilling-induced fractures found.

Mean orientation is determined by the formula:

$$\overline{\theta} = \text{arctg}\left(S/C\right),$$

where $S = \sum_{i=1}^{n} S_i$ and $C = \sum_{i=1}^{n} C_i$.

By sines and cosines summation, the resultant vector is obtained:

$$R^2 = \left(\sum_{i=1}^{n} C_i\right)^2 + \left(\sum_{i=1}^{n} S_i\right)^2.$$

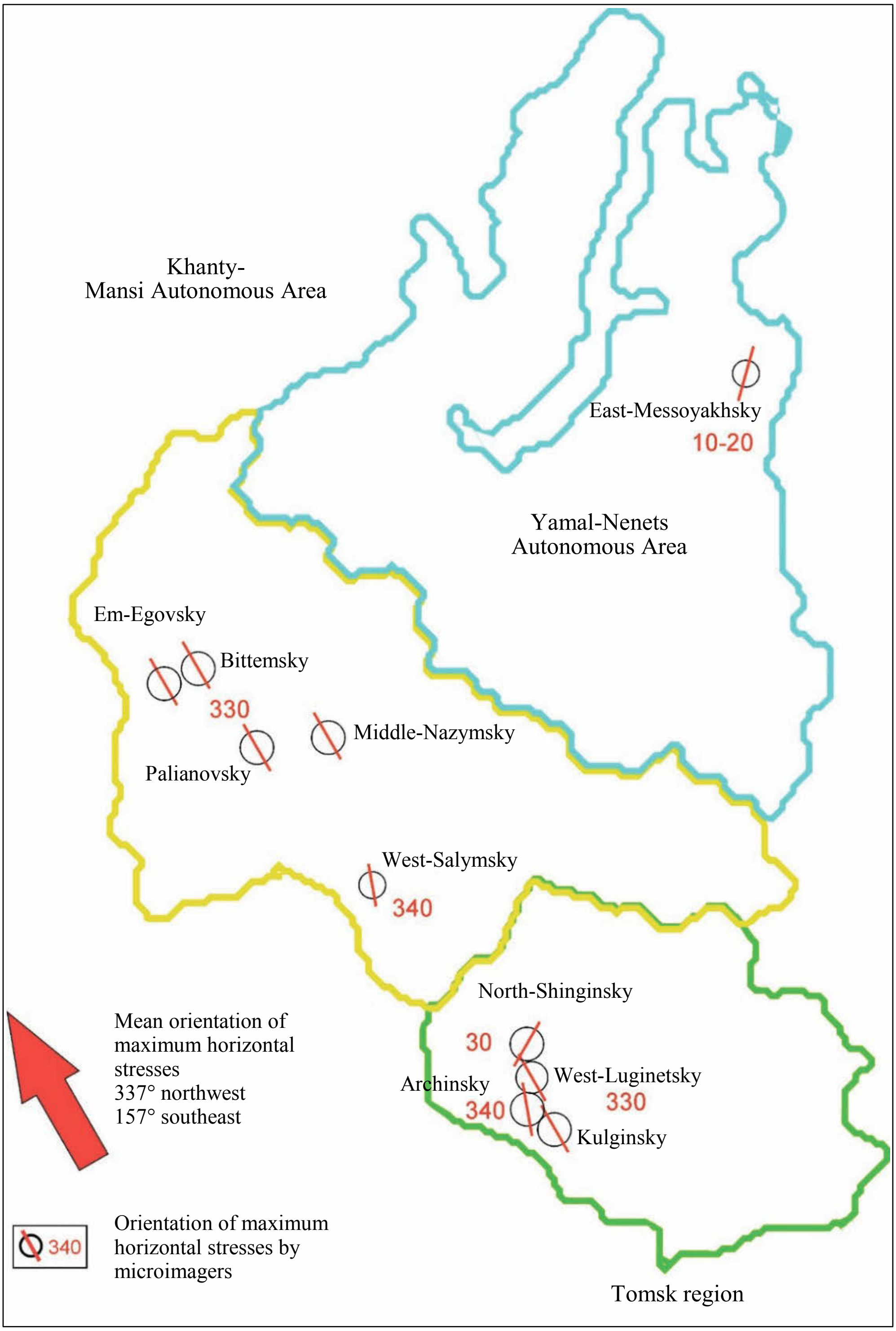

Figure 1. A map of horizontal stress mean orientations
Рисунок 1. Карта средних направлений горизонтальных напряжений

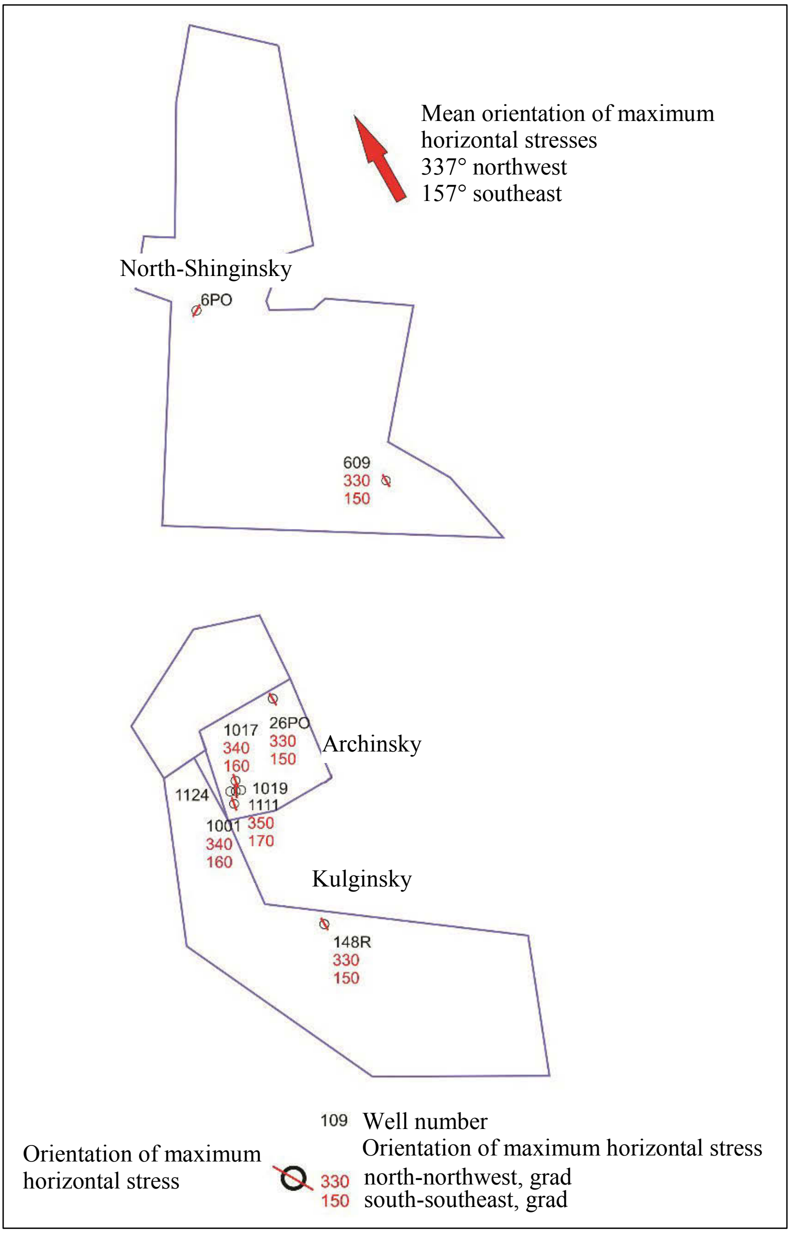

Figure 2. A map of horizontal stress mean orientations by areas
Рисунок 2. Карта средних направлений горизонтальных напряжений по площадям

Standard deviation is determined as

$$SD = 81^\circ \left(\sqrt{\frac{N-1}{N-R}} \right)^{-1}.$$

Mean orientation and standard deviations have been determined for all wells.

The Kulginsky area is represented by one well; mean orientation of the drilling-induced fractures, therefore maximum horizontal stresses, makes up 330° northwest

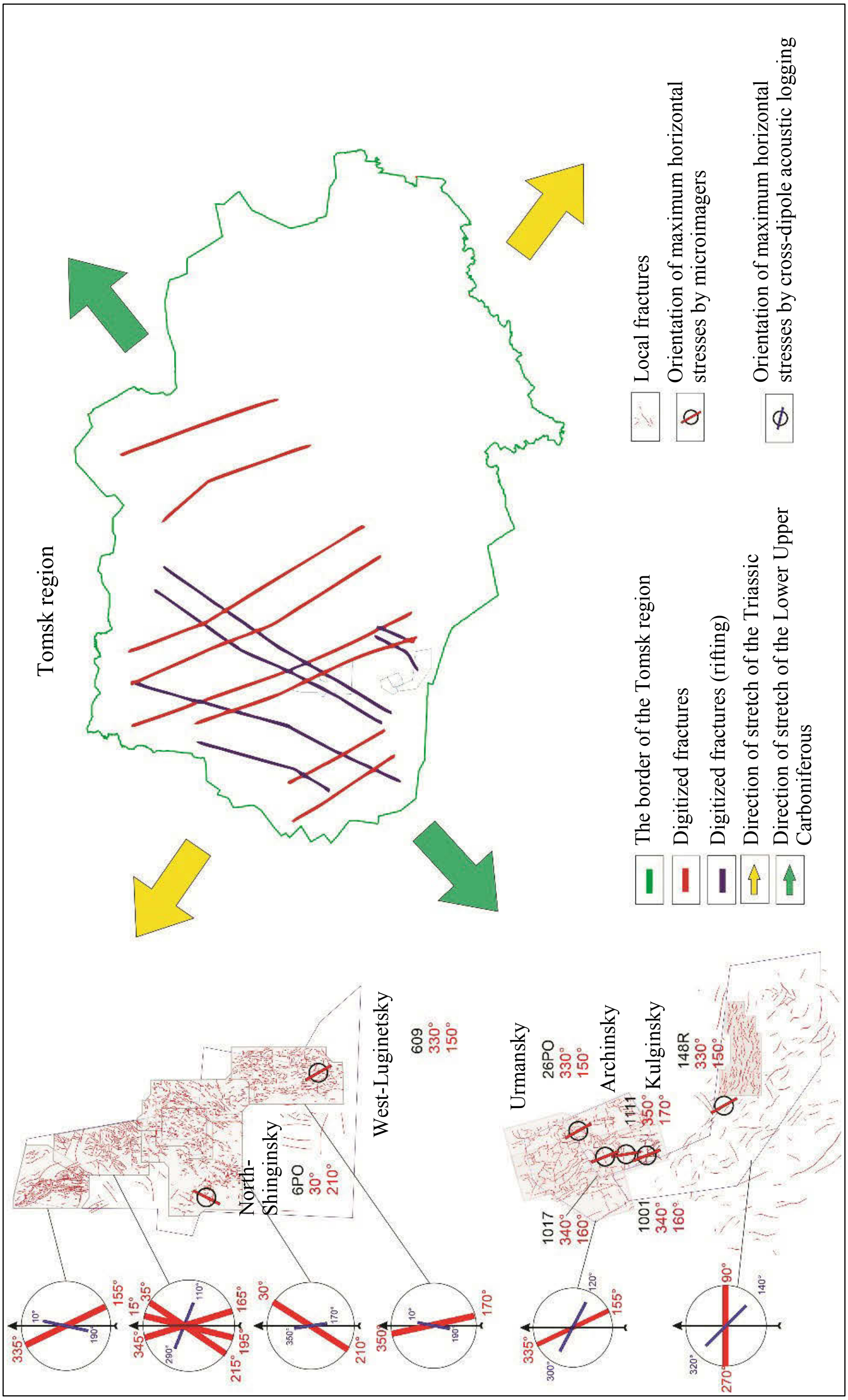

Figure 3. The orientation of horizontal stresses in the Tomsk region and a map of fractures the Tomsk region
Рисунок 3. Направление горизонтальных напряжений по Томской области и карта разломов Томской области

and 150° southeast with a standard deviation equal to 23° which is rank C of the WSM quality ranking scheme [14].

The Archinsky area is represented by three wells, mean orientation of maximum horizontal stresses makes up 340°–350° northwest and 160°–170° southeast, with a standard deviation of not more than 25°, which is rank C of the WSM quality ranking scheme.

The Urmansky area is represented by one well, the mean orientation of maximum horizontal stresses makes up 330° northwest and 150° southeast, with a standard deviation of 18°, which is rank B of the WSM quality ranking scheme.

Table 1. Summary table of S_{Hmax} azimuth values, standard deviations, and stress indicator ranks by area

Таблица 1. Сводная таблица значений азимута S_{Hmax}, стандартных отклонений *SD*, рангов индикаторов напряжений по площадям

Area	Orientation S_{Hmax}	*SD*	Rank
West-Luginetsky	150°	20°	B
Urmansky	150°	18°	B
Archinsky	160°	25°	C
Kulginsky	150°	23°	C
North-Shinginsky	15°	24°	C

The West-Luginetsky area is represented by one well, the mean orientation of maximum horizontal stresses makes up 330° northwest and 150° southeast, with a standard deviation of 20°, which is rank B of the WSM quality ranking scheme.

In the North-Shinginsky field, a deviation from the mean value of the horizontal stresses orientation is recorded in the previously studied areas. Drilling-induced fractures strike azimuth in this well makes up 30° northeast – 210° southwest, with a standard deviation of 24°, which is rank C of the WSM quality ranking scheme. This orientation does not correspond to the neighboring wells. Presumably, the deviation may be caused by the local variation of stresses as a result of the lithological variation: the well of the North-Shingin area opened up the igneous type of log, while the logs of the remaining wells are represented mainly by the carbonate sediments.

The stress orientations have also been compared with the data on the North-Ostaninsky field with both microscanners and the cross-dipole acoustic instruments. It has been found that the orientations of maximum stresses according to FMI data of the North-Ostaninsky area correspond to the orientation in the North-Shingin area's well; the orientations according to the cross-dipole acoustic logging correspond to the mean orientation in the remaining wells.

After that, the values have been plotted on maps allowing to get an idea of horizontal stress orientations variation (Figures 1 and 2).

As a whole, stress orientation is rather consistent, the minimum value of azimuth is recorded in four wells and makes up 330° northwest, the maximum value of 350° northwest is recorded in one well. So, the spread of values is not more than 20°.

When comparing the obtained data with the map of fractures of the Tomsk region, it has been found that the direction of maximum stress in wells of the West-Luginetsky, Urmansky, Archinsky, and Kulginsky areas as a whole is similar to the orientation of the local fractures (Figure 3) and corresponds to the general orientation of regional fractures of the Tomsk region and was presumably formed in the lower Upper Carboniferous. Local variation of stress orientation in the well of the North-Shingin area is similar to the variation of the orientation of the local fractures and corresponds to Tomsk regional fracture general orientation, which was presumably formed in the Triassic [15, 16].

Conclusions. The mean value of maximum horizontal stress is 157°–337°. It follows from the constructed map of horizontal stress orientations that the variability of horizontal stress orientations in the area under investigation is low.

The values of the horizontal stress orientations keep their direction from well to well in the area under investigation, except for a well in the North-Shingin area.

For each area, the following maximum horizontal stress orientations have been determined (Table 1).

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Received 16 July 2021

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УДК 622.831.3:622.24(571.16) DOI: 10.21440/0536-1028-2021-7-16-24

Определение направлений горизонтальных напряжений по площадям Томской области

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Реферат

Введение. *Определение направления горизонтальных напряжений необходимо для большинства геомеханических расчетов и представляет собой глобальную задачу, что подтверждает проект по построению мировой карты напряжений. С другой стороны, в настоящее время на карте практически отсутствуют данные о направлениях напряжений на территории России, поэтому задача определения направления горизонтальных напряжений является весьма актуальной.*
Цель работы. *Определить направления максимальных и минимальных горизонтальных напряжений по отдельным площадям Томской области, составить карту горизонтальных напряжений.*
Методология. *В основу определения направлений горизонтальных напряжений положена теория возникновения техногенной трещиноватости и вывалов стенок скважины. Направление максимальных напряжений совпадает с направлением техногенных трещин, направление минимальных напряжений совпадает с направлением вывалов стенок скважины или перпендикулярно максимальным напряжениям.*
Результаты. *Результатом проделанной работы являются сводная таблица средних направлений горизонтальных напряжений по площадям, а также карта направлений горизонтальных напряжений.*
Выводы. *Составлена сводная карта, на которую вынесены азимуты простирания максимального горизонтального напряжения. Напряжения имеют схожую направленность во всех рассматриваемых скважинах, кроме скважины Северо-Шингинской площади. Среднее значение направления максимальных горизонтальных напряжений составило 337° на северо-запад, 157° на юго-восток.*

Ключевые слова: *техногенная трещина; направление напряжений; геомеханика; вывал стенок скважины; микроимиджер.*

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Поступила в редакцию 16 июля 2021 года

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Для цитирования: Антонов А. Е., Шадрин А. С., Коношонкин Д. В., Рукавишников В. С., Петрова Д. С. Определение направлений горизонтальных напряжений по площадям Томской области // Известия вузов. Горный журнал. 2021. № 7. С. 16–24 (In Eng.). DOI: 10.21440/0536-1028-2021-7-16-24
For citation: Antonov A. E., Shadrin A. S., Konoshonkin D. V., Rukavishnikov V. S., Petrova D. S. Determination of horizontal stresses orientation in the area of the Tomsk region. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal*. 2021; 7: 16–24. DOI: 10.21440/0536-1028-2021-7-16-24