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Assessing a natural field of rock mass stress by means of in-situ measurements within Vostochnaya Sary-Oba deposit in Kazakhstan

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Abstract

Purpose is to assess a natural field of rock mass stress within Vostochnaya Sary-Oba deposit using in-situ measurements. It will help identify stress distribution as well as high-stress areas that may be dangerous for mining operations.

Methods. The research has applied a technique of well hydraulic fracturing to study parameters of the initial stress field within the deposit. For the purpose, two metering points in two measuring (horizontal and vertical) wells were used. Hydraulic fracturing has been tested at each installation location.

Findings. The in-situ measurement results have helped obtain quantitative parameters of stress-strain state of the rock mass. It has been understood that the available tectonic disturbances may result from the shape of structural folds as well as from tectonic fissility. Operating azimuth of the maximum horizontal stress within the points coincides, it is equal to 70° ± 10.

Originality is the use of a new approach to assess the stress rock mass state within Vostochnaya Sary-Oba deposit while applying in-situ measurements and well hydraulic fracturing. The abovementioned favours more accurate and reliable assessment of rock stress state at the field being quite important for mining safety and for the development of the efficient supporting procedures and ore extraction procedures.

Practical implications. The research results are applicable to adapt project documents for the deposit mining, a supporting technique selection, and ore extracting. Moreover, they will help make the substantiated choice of a structure and geotechnical parameters taking into consideration safety of operations as well as quality of ore mining. In addition, the results help develop measures to prevent rock mass outburst and fall in mine workings.

Keywords: *rocks, ore, rock stability, mine working support, outburst, rock mass fissility*

1. Introduction

The mining industry in Kazakhstan is characterized by a diverse range of minerals and metals, making it one of the world's leading mining destinations. Abundant reserves of various resources, including coal, oil, gas, uranium, copper, gold, zinc, and other rare earth elements, have positioned Kazakhstan as a key player in the global mining landscape [1]-[5]. The country's favorable geology and vast territory have allowed for extensive exploration and exploitation of its mineral wealth. This has led to the discovery of substantial deposits, many of which are considered world-class, attracting attention from major mining companies and investors seeking to capitalize on the potential of Kazakhstan's mineral resources [5]-[11].

Currently, support of workings in mines can be characterized as a step-by-step process being a body of activities to construct a support (and its move, maintenance etc.) for underground mineral extraction and subsurface facility construction. Selection of a reasoning support type as well as development of measures preventing from bursts, outbursts and delaminations is among the key measures to build a system controlling technological risks in ore mines [12], [13].

Safe mining operations and efficient ore extraction should involve natural field of the rock mass stress state. The field understanding helps identify stress distribution as well as high-stress zones, which may be dangerous for mine working stability, and safety of miners [14]-[16]. As the most important condition for correct design solutions, diagnostics of an initial stress field of rock masses is required while selecting and substantiating rational mineral mining procedure providing mining safety [17]; and while constructing and operating of hydraulic engineering structures as well as other technical objects interacting with neighbouring (enclosing) rock mass [18], [19].

Numerous studies have been pursued to analyze natural field of the stressed rock mass as well as its impact on the mining safety [20]-[23]. Some of them were intended to assess stress state in the context of the specific deposits [24]-[26]. Other studies were of more general nature; they concerned different deposits and regions [27] as well as substantiated backfilling technologies at ore mining [28].

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The current techniques make it possible to perform more accurate and detailed stress measurements in rocks. New measuring and testing approaches are added inclusive of well hydraulic fracturing, use of indicators and auxiliary elements, remote sensing etc. [29]-[31]. Consideration of geological and structural characteristics places a particular emphasis upon the impact by such geological features as folds, fissures, and faults on the stressed rock mass state. Analysis of the properties helps understand stress distribution, and identify high-risk areas [32]. Numerical models and computer simulation enable forecasting rock behaviour under different loading conditions, and optimizing of techniques to support mine workings as well as ore extraction which reduces the risk of accidents and improves mining safety [33]-[34].

Development of new support procedures and techniques deserves special attention. In this vein, studies are aimed at the design of more efficient and reliable methods of mine working timbering taking into consideration the stressed rock mass state [35]. Earlier studies have made it possible to develop new materials, structures, and technologies promoting an increase in rock stability as well as outburst and failure prevention [36]-[37]. Identifying complex industrial control objects through their accelerating characteristics and control information space allows for a deeper understanding of the underlying processes [38]-[40]. Study of the stressed rock mass state needs collection and analysis of various big data. Recently, it has become more and more popular to apply a multidisciplinary approach combining geological, geophysical, hydrogeological, and other scientific data for better understanding of the stressed rock state [41], [42].

The carried out studies speak for constant progress and improvement of techniques and approaches to the analysis of the natural field of the stressed rock mass state as well as its impact on the mining safety. Hence, they help make mining operations safer while reducing accident risks [43], [44].

Vostochnaya Sary-Oba field of Zhilandy deposit group has become a pilot research object. Reserves of the group have been certified by the State Commission on Mineral Resources of the USSR in 1965 (Karashoshak field); Western Saryoba, Vostochnaya Sary-Oba, Kipshakpay mine) in 1975; and Itauyz mine in 1988. After 1975, mining and geological operations were mainly intended to increase the reserves on the wings as well as within deep levels; and the detailed study of reserves applicable for open-pit mining. Geomechanical conditions of the deposits have not been analyzed thoroughly. Owing to similarity of the fields with Zhezkazgan mines, the conditions were assumed as identical; however, it is not entirely true. Ore deposits are represented by intrusive, ribbon-like, and lens-like bodies varying in their thickness and distribution of useful components. Mainly, they occur in a parallel with enclosing rocks.

Vostochnaya Sary-Oba field is represented by southerly dipping low-angle (10-20°) deposits with medium thickness seams and thin ones. In south, dipping angle of deep levels increases up to 50-60°. The deposit has been developed through access ramps from surface. It is being mined using room-and-pillar system.

Analysis of the available information on Zhylandy group of fields lists following disadvantages:

1. Lack of data concerning the ore and rock characteristics that can complicate assessment of their economic value, mining efficiency, and possible preparation techniques. The data may involve chemical composition, physical properties, impurity content, and other relevant information.

2. No information on the rock mass fissility that is quite an important factor while ore extraction scheduling and assessing. Formation fractures may influence both permeability and leak-off capacity being essential while identifying the draining and mining efficiency.

3. No information concerning natural stress state of the rock mass helping understand its stability, mining optimization and planning. The data make it possible to forecast possible deformations, falls, and other engineering problems.

On the whole, non-availability of the information prevents from understanding of the potential of Zhylandy group of fields; moreover, it can influence the decisions made concerning their development and operation. Additional studies are recommended to collect missing information and perform more complete analysis of capacity of the deposits.

The preliminary conclusion that Zhylandy mine conditions are similar with the Zhezkazgan ones turned out to be mistaken. Statistical analysis has shown that ore from Zhezkazgan is harder than ore from Zhylandy fields [45].

According to the data by geomechanical department of the mine, excavation conditions within Vostochnaya Sary-Oba field are complicated by the following:

– differently oriented cross fractures split the rock mass and faults are available;

– large inclined empty fractures as well as those filled with gangue minerals or slickensides with clay gouge (calcite, and gray sand) occur;

– presence of the watered areas;

– availability of flexural zones.

Such fissures and faults may complicate ore discovering, extracting, and preparating. In addition, they may complicate processes of draining, rock caving, and making mine working stable. Large empty fractures as well as those filled with minerals may result in deformations and instability of mine workings [46], [47]. Slickensides with clay gouge may also influence mechanical characteristics of rocks and the formation behaviour while mining. Deposit inundation may initiate drainage problems and impact the rock mass stability. The watered areas need specific measures controlling their draining to provide both security and efficient mining. Flexural zones are those ones within which rock mass perform its bending; that can cause fissures and deformations in addition to instability requiring specific measures for mining safety [48].

The listed complicating factors speak for the necessity of more detailed geomechanical analysis and development of relevant strategies and procedures to mine ore within Vostochnaya Sary-Oba field both efficiently and safely. Moreover, the abovementioned emphasizes the importance of extra data collection concerning geological and geomechanical characteristics of the deposit to perform more accurate mining scheduling and controlling.

Visual examination of the development workings and stopes in Zhylandy mines demonstrated unsatisfactory state of them and their timbering. Based upon the generalized Vostochnaya Sary-Oba mine data, locations of tectonic faults and large fissures have been identified. Figure 1 shows a frequency diagram of various support disturbances in the mine.

As the diagram explains, exposed bolts (27%), deep fissures in rock mass resulting from its displacement (23%), and intervals in steel polymer roof bolting (12%) are the most common violations as for mine working timbering. Roof bolt is a critical element in ensuring the safety and stability of underground mine workings.

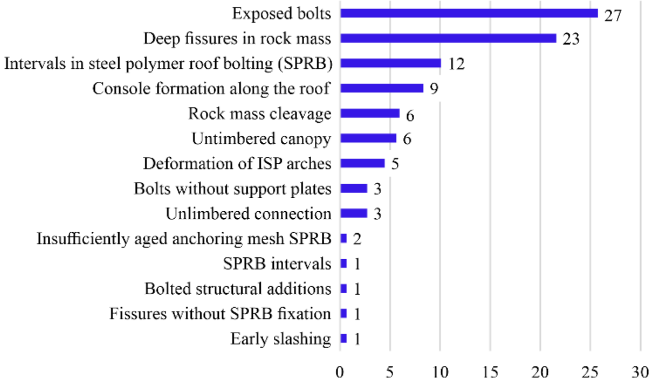


Figure 1. Frequency diagram of the support disturbance types

It is a specialized type of anchoring system used to support the roof and walls of underground excavations, helping to prevent rockfalls, collapses, and other hazards that can endanger miners' lives [49], [50].

Rather often, violations, depended upon either nonavailability of the combined timbering or complexity of its mounting took place in the mine; among other things, it concerns shotcrete with $\delta = 3\text{-}5$ cm thickness since heavily fissured roof was assessed as the semi-solid one (i.e. III).

To reinforce workings, the mine applies shotcrete for:

– developing a coverage connected closely with rock and preventing it from weathering and exfoliation;

– developing damp-proof, rust-proof, antiseptic, fire-proof, and air-tight coverage;

– reinforcement and repair of concrete supports;

– decrease in surface roughness of uncoated air gates.

Findings of the research in the mine have shown that high quality and reliability of the coating are among advantages of the shotcrete.

The following is among disadvantages of the material ant its application technique:

– necessity to use only fine-grade fillers causing excess cement consumption to compare with the standard concrete;

– dust formation while working;

– low efficiency of the applied facilities, their complex design, and significant parts wear;

– necessity to dry the washed fillers up to the predetermined moisture content.

Visual observations in mines of Zhylandy group have identified insufficiency of the available timbering to support stability of mine workings and provide their safe operation. Such accidents results in frequent rock mass falls while being quite risky for stuff and equipment:

– risk of injury to miners operating in stopes and drifting faces;

– risk of rock mass defoliation from roof and mine working walls while blasthole drilling, casing, and charging.

Moreover, they need revision of attitude towards rock mass state.

Improvement of the present quality of drilling-and-blasting operations as well as the applied casing may increase stability of the mine workings since the available character of the rock mass makes it possible to support mine workings using the combined timbering as well as adjusting the support parameters [51], [52].

Following studies should be carried out in the field of geomechanical substantiation for mining of the group deposits:

1) to assess critically all available geological and geomechanical data collected during previous stages of the mine analysis and development inclusive of investigation materials concerning accidents and incidents resulting from rock mass fall as well as enclosing rock displacement and failure;

2) to assess stress-strain state of the rock mass through field measurements;

3) to evaluate the current geomechanical situation in the mine while:

– analyzing engineering geological and surveying documentation to identify location regularities of the areas where rock pressure is manifested;

– inspecting visually both development workings and stopes to find the areas of rock pressure manifestation;

– determining forms and shapes as well as extension, falls, exfoliation, and damage of pillars in the development workings and stopes with the data collecting being sufficient for reverse calculation of rock mass strength characteristics or its stress state;

– assessing visually a loading degree of the erected support, i.e. its expediency and efficiency;

4) to make a simplified geomechanical model of the mine inclusive of the rock mass stress-strain state analysis while mining.

2. Mining and geological characteristic of Vostochnaya Sary-Oba field

Latitudinal expansion of the deposit ore field is as follows: more than 3.5 km on the strike of ore bodies and up to 3.0 km to the dip. Dip directions of the ore bodies are as follows: almost 215° southwest along the azimuth; 0 up 25° inclination angles in the central and northwestern shares of the deposit with up to 430 m occurrence depth; and up to 40-80° within the southwest and southern shares of the deposit with 786 m occurrence depth. In the flexural zones, dip of the ore bodies may achieve 70-80°.

Mineralization is characterized by heavy variety in thickness and content as well as complex shape in the plan. The copper mineralization is associated with conglomerates, and gray and colour sandstone; rarely, it is associated with greenish-gray aleurites. Series of cross intrastratal and interformational fractures divide the rocks having a tendency to exfoliation. The fissures are filled with calcite and/or fragmentation material. They also may be empty.

There are three main orebody shapes within Vostochnaya Sary-Oba field: blanket-like, roundish-prolate, and ribbon-like ones. Blanket-like orebodies, differing in large sizes, are typical for those deposits occurring in the central share of ore-bearing levels. Being associated with the most tectonized sandstone seam, they involve anticlines, sinclinals, and their wings. The key copper ore reserves are in the blanket-like deposits. The highest copper concentration as well as orebody thickness is observed in the domes of flat folds, and within wings of flexural zones. In this context, the major part of orebodies within such structural areas is oriented as a long axis towards enclosing rock dip (Fig. 2).

Roundish-prolate and ribbon-like orebodies are small; usually, they occur closer to a floor and roof of ore-bearing levels as well as within the wings of blanket-like deposits where tectonic dislocation is manifested to a lesser degree. Material composition of ore-bearing rocks within the field is rather uniform.

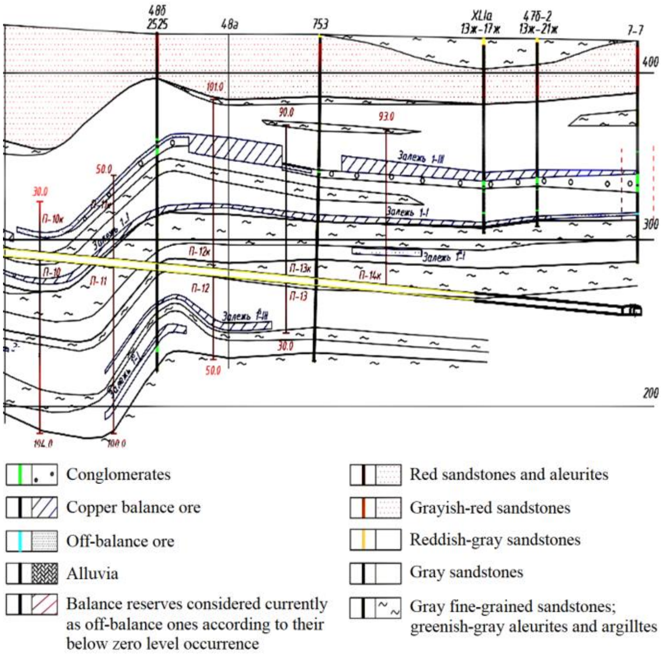


Figure 2. Geological section of Vostochnaya Sary-Oba deposit

Their structure contains red aleurites and argillites, and gray and red sandstones. According to composition of fragments, they are polymictic and fall into fine-grained with 0.10-0.55 mm grains; medium-grained with 0.25-0.50 mm grains; and conglomerates. The listed ore-bearing rocks are almost similar in terms of their composition and genesis.

Gray sandstones are the basic ore-bearing formations. The rocks are homogeneous with an uneven fragmentation surface; they are gray, ash-gray, greenish-gray, and dark-gray in colour. Gray sandstones have many common features with red ones. Feldspars and quartz are the basic minerals as well. Mainly, feldspar is represented by oligoclase, and rarely by microcline. Its content varies from 5 up to 15%. Within oreless sandstones, feldspars are of rather fresh look; they are slightly caolinitized and sericitizatized. Within ore sandstones, feldspars are turbid; they are heavily caolinitized and sericitizatized. Quartz content varies from 5 up to 30%. It depends upon the secondary silicatization processes. Quartz grains are also displaced by ore minerals. Zircon, sphene, rutile, tourmalin, and apatite are accessory minerals.

Intensive sericitization, manifested poorly in oreless sandstone, is the feature of ore-bearing gray sandstones. Gangue minerals in the sandstones are represented by quartz and calcite. The stratified structure, associated with layer-by-layer changes in the material composition and grains of fragments, is the most typical for sandstones.

To compare with the sandstones, aleurites and argillites are of significantly subordinate importance. Aleurites are rather dense rock with continuous homogeneous structure and shell-like fracture. They are greenish-gray in colour owing to chlorite presence in the cement. Martite is the only ore mineral represented in the aleurite composition.

Red sandstones are fine-, small-, and middle-grained rocks. Quartz and feldspars are dominating minerals. Zircon, tourmalin, sphene, rutile, and garnet are accessory minerals. They differ from the gray ones in colour owing to presence of hydrous ferric oxides forming films and clots around grains. Intraformational conglomerates are associated with gray sandstones. They are composed by poorly rounded pebbles, being mostly of carbonate nature, and red and green aleurite.

Interformational conglomerates are characterized by diverse composition, and good roundness of a pebble material. The pebbles contain quartzites, silica, limestones, tuffs, and porphyrites.

Geological structure of the deposit is complicated by a series of tectonic disturbances. The Central Sary-Oba lateral fault, located between Zapadnaya Sary-Oba and Vostochnaya Sary-Oba deposits, is the largest among them. In addition, small faults have been logged within the field. Orebodies occur subhorizontally with enclosing rocks; they are of sheet-like, lensoid, and ribbon-like shape. Their bearing is lateral.

Geological engineering conditions of the deposits were studied in the course of the detailed exploration in 1968-1975. Physicomechanical characteristics of the rocks were identified while exploring. For the purpose, six specific wells (with the capacity of 1929.7 l.m. and 171 down to 918 m depths) were drilled within the fields. To analyze physicomechanical properties of enclosing rocks, 305 samples have been taken which shown their significant strength. The studies also helped identify hardness of the rocks (f) using a scale by Professor M.M. Protodyakonov: f = 8-16 for gray sandstones; f = 8-16 for red sandstones; f = 6-8 for aleurites and argillites; and f = 4-18 for conglomerates.

Increase in depth adds somewhat rock strength. Despite lithological composition, the least strength is typical for rocks in the upper share of the section; it depends upon the development of weathering fissuring within a near-surface area. The area thickness is 70-90 m; deeper, the fissuring is mainly developed in the neighbourhood of tectonic zones. It dies down with depth. Mostly, fine-grained red rocks are subject to weathering processes. The matter is that within a near-surface zone the rocks are loose mass consisting of small fragments where native rock structure has been preserved. Ore-bearing gray sandstones are more resistant to weathering.

3. The research methods

Currently, the three basic methods are the most popular while studying parameters of the initial stress field [53]-[55]:

– a method of well hydraulic fracturing;

– a method of parallel wells;

– a method of partial central well unloading with the help of pairs of survey marks following the principle of rectangular tensometric rosette etc.

Combination of the methods helps get an insight into the stress state of rocks. To obtain more reliable information for the conditions of Zhylandy field, a method of well hydraulic fracturing was taken.

The following is the equipment for underground experiments (Fig. 3): measuring and computing complex (MCC) Gidrorazryv; video probe to monitor measuring well; and devices to cut both circular and longitudinal slots on the well walls. Gidrorazryv MCC contains: two-packer probe, hand pump, manometer, pressure pipelines, commutating facilities, and a system of pressure recording consisting of pressure meter with pressure sensor, PC, connecting cables, and charger. The equipment configuration is portable; it is intended to be used underground. Under subsurface conditions, a pressure meter applies wireless communication to transfer experimental data to PC where they are stored and processed automatically [56]-[59].

The experiment identified minimum value and calculated maximum value of a horizontal component of effective stresses.

Figure 3. The equipment determining natural stress field at a measuring point

The calculations apply values of indices of rock mass physicomechanical characteristics within the experiment area. It should be mentioned that material content of rocks characterize qualitative rather than quantitative idea of physicomechanical properties. Hence, if physicomechanical characteristics of rock mass within the experimental area are not measured then stress identification by means of well hydraulic fracturing method may be of approximate nature.

To monitor stresses within the rock mass, sites were selected as well as metering points (hereinafter referred to as MSs) distancing maximally from mining operations. MS facility applied to forecast well construction relying upon following parameters: 76-mm diameter and no more than 12-m depth. In such a way, inner sides of wells were studied. A gauging probe was in the end zone of a well; then the experiment was carried out.

First, critical fluid pressure was identified followed by the determination of its stabilization pressure after the fluid stopped to be delivered. The stabilization pressure was recorded and documented properly. Injection pressure was decreased down to a zero level; the well surface was loaded several times; every time the result was recorded. The gauging probe repositioning towards the wellhead was performed through its placement in two-three areas along with the well length; 1.0-1.5 m interval was applied. The experiment was performed at each location of the device. The findings helped identify both minimum and maximum values of horizontal component of the effective stress. After that, the gauging probe was extracted.

Two measuring points were involved in the procedure. The points to apply WH for stress field monitoring by means of hydraulic fracturing were selected depending upon the state of mining; possibilities of diamond well drilling; experimental place remoteness from mining areas; and nonavailability of overmining or undermining. Experimental place remoteness from mining areas, nonavailability of overmining or undermining, and drilling equipment arrangement were taken into consideration while WH place selecting. The places were selected at 123.5 and 42.1 m marks.

Due to heavy rock mass fissuring, the basic stresses were defined through a method of the repeated natural fissure opening. Within the areas, where rock tensile strength is mentioned, the calculations were performed using the classical scheme.

The experiment registered following parameters: P_c being hydraulic fracturing pressure; $P_s^{/}$ being blocking pressure during hydraulic fracturing; P_r being opening pressure of a fracturing fissure during the second loading; $P_s^{//}$ being bloc-king pressure during the second loading; $P_r^{/}$ being opening pressure during the third loading; and $P_s^{///}$ being blocking pressure.

Metering point 1 is near a reloading chamber at the junction with haulage and transportation slope (100-m level; 123.5-m mark); distance from the surface is about 310 m (Fig. 4).

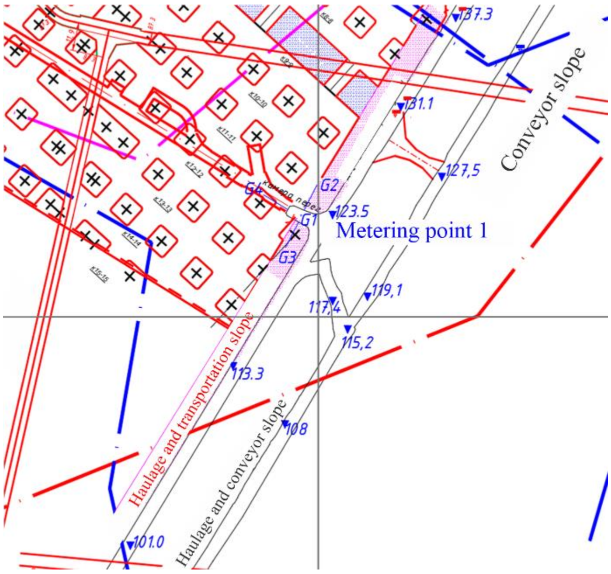


Figure 4. Plan of the metering point 1

Arrangement of wells within the metering point 1 is as follows (Fig. 5):

– G1 being a vertical well;

– G2 being a well with 27° azimuth located at a 1.3-m height from the mine working floor;

– G3 being a well with 207° azimuth located at a 1.4-m height from the mine working floor;

– G4 being a well with 301°azimuth located at a 1.25-m height from the mine working floor.

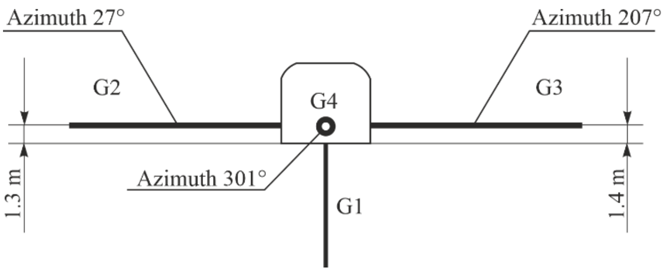


Figure 5. Arrangement of G1-G4 wells (123.5-m level)

The experiments took place within a reloading chamber. Vehicles were broken down and lowered into the vertical well; hence, it turned out to be impossible to make measurements inside. Metering point 2 is in the niche of a haulage and transportation slope (42.1-m level; almost 290-m distance from the surface (Fig. 6).

Arrangement of wells within the metering point 2 is as follows (Fig. 7):

– G5 being a vertical well;

– G6 being a well with 27° azimuth located at a 1.35-m height from the mine working floor;

– G7 being a well with 207° azimuth located at a 1.3-m height from the mine working floor;

– G8 being a well with 301° azimuth located at a 1.25-m height from the mine working floor.

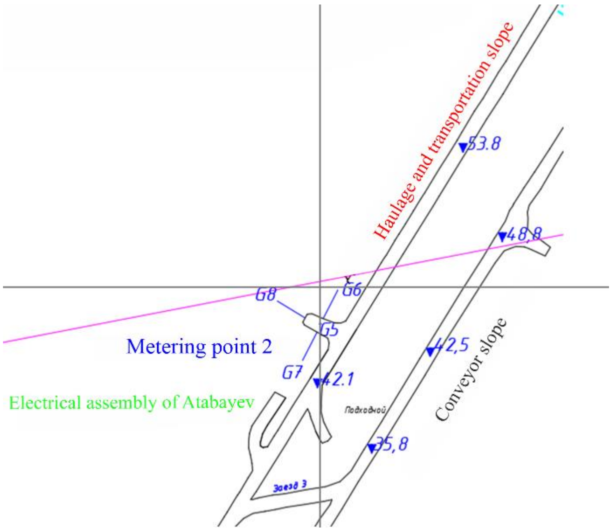


Figure 6. Plan of the metering point 2

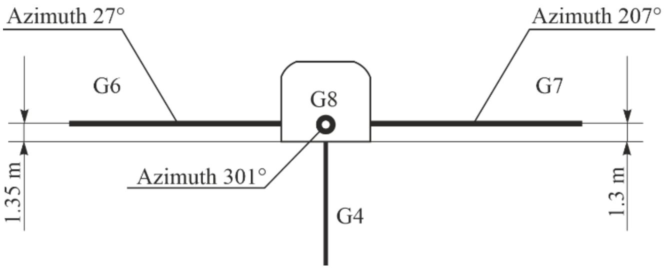


Figure 7. Arrangement of G5-G8 wells (42.1-m level)

The well walls were examined within its end part where a gauging probe is installed and hydraulic fracturing is tested. Critical fluid pressure is registered during the hydraulic fracturing; its stabilization pressure is registered after the fluid is not delivered any more. Stabilization pressure is registered during five minutes. Injection pressure is released down to zero. The process of well wall loading is repeated 2-3 times; in either case recording took place. The gauging probe repositioning towards the wellhead was performed through its placement in two-three areas along with the well length; 1.0-1.5 m interval was applied. Within each area of the procedure, hydraulic fracturing was tested. Parameters of the tests help identify the value of a lesser and calculate value of a greater horizontal components of effective stresses. After that, the gauging probe is removed from the well.

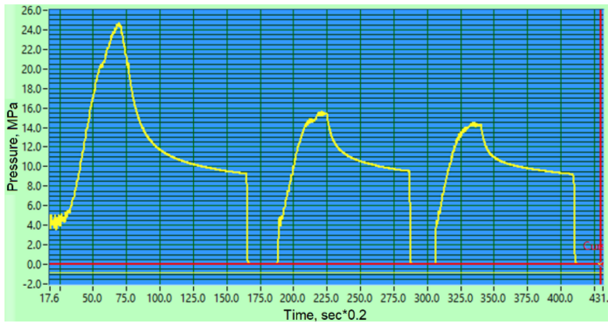
4. Results and discussion

The chapter represents findings of experiments within Vostochnaya Sary-Oba field carried out to identify stresses. The research applied a method hydraulic fracturing of wells; specific attention has been paid to the reloading chamber area at the junction with haulage and transportation slope. Geographic coordinates of the region are as follows: 100-m horizontal distance and 123.5-m vertical location above sea level. The experiment also involved study of a niche of a haulage and transportation slope located at a 42.1-m height. The findings make it possible to draw conclusions on the stress nature within the specified areas of the deposit.

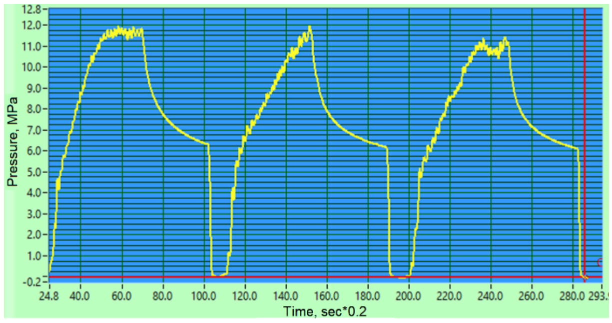
Specific nature of the experiment concerning stress state of rock mass is as follows. It is impossible technically to identify stresses, acting in a solid medium whether it is a material being a part of any rock mass or artificial structure made of metal, concrete etc. Their qualitative and quantitative assessment (being of the particular importance for practice) can be performed according to stress manifestations during various mechanical and geophysical processes, i.e. deformability, disintegration etc. A method of rock hydraulic fracturing in a well belongs to the universal procedures. On the one hand, it is efficient when stress fields are being analyzed thoroughly within the areas of subsurface and surface structure influence; on the other hand, it is among those not numerous ones which can be applied for stress state diagnosis in deep wells.

Tensile strength of geomedium $P(t)$ is a difference between hydraulic fracturing pressure (P_c) and pressure of failure fissure opening during the repeated loading (P_r). Below, you can find records of the tensile strength of geomedium $P(t)$ (Figs. 8-11).

(a)



(b)



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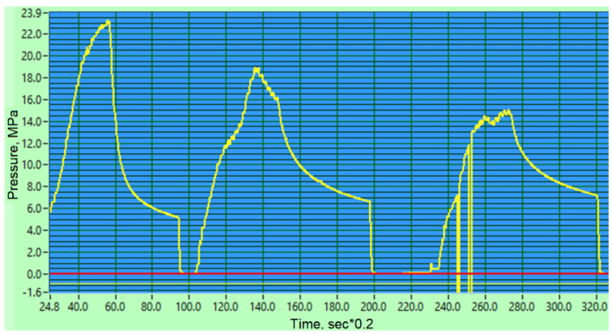
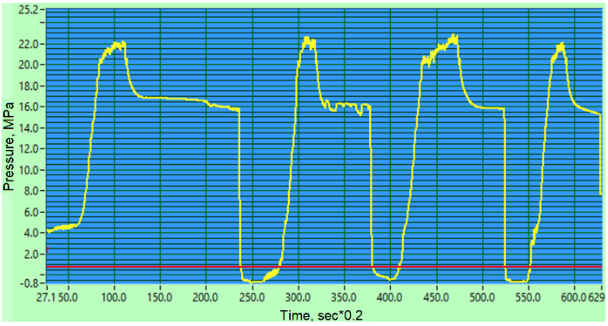


Figure 8. Graphs of P(t) dependence within the metering point 1 in a 1-1 well: (a) h = 10 m; (b) h = 9 m; (c) h = 10 m

In such a way, while well wall loading, a logger was recording $P(t)$ diagrams. Critical fluid pressure at the time of hydraulic fracturing as well as its stabilization pressure after the fluid stopped to be supplied was registered. In addition, following parameters were also reported: hydraulic fracturing pressure in terms of initial loading; pressure of fissure edges connecting; and pressure of a fissure opening in terms of the repeated loads, which may be several.

(a)



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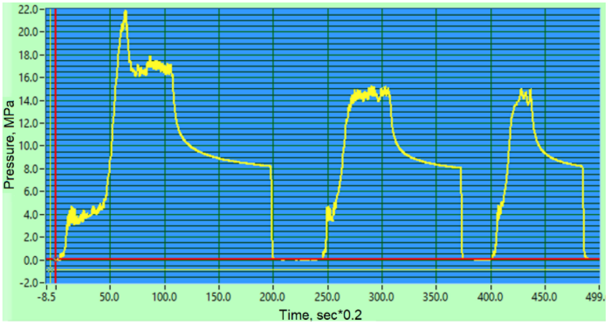
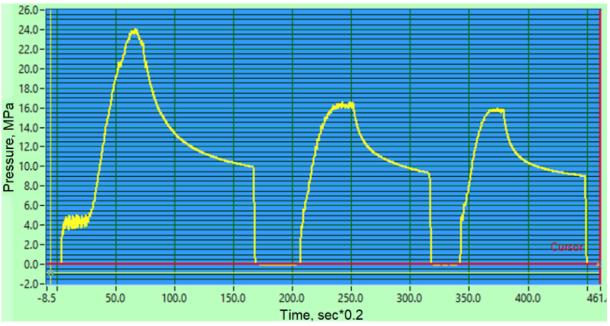


Figure 9. Graphs of P(t) dependence within the metering point 1 in a 1-2 well: (a) h = 10 m; (b) h = 9m

(a)



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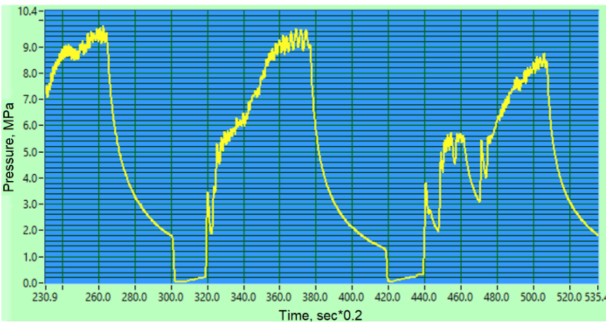


(c)

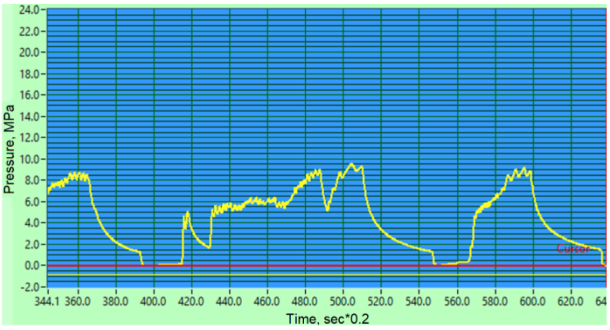
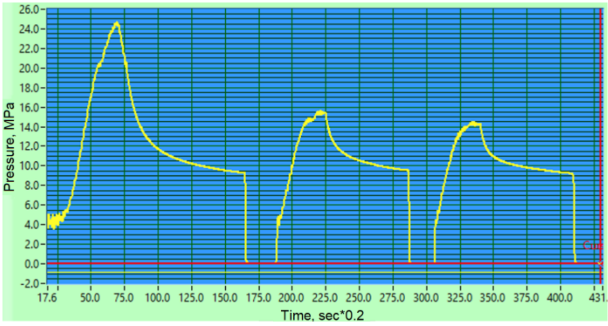
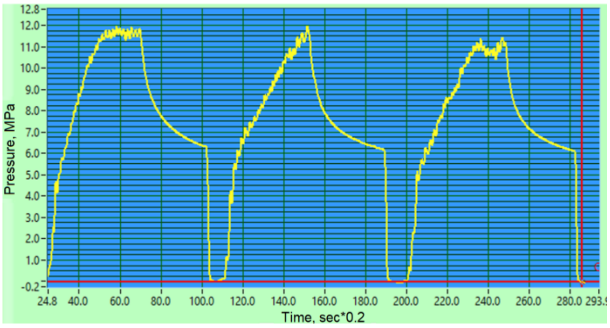


Figure 10. Graphs of P(t) dependence within the metering point 2 in a 2-1 well: (a) h = 10 m; (b) h = 9 m; (c) h = 10 m

(a)



(b)



(c)

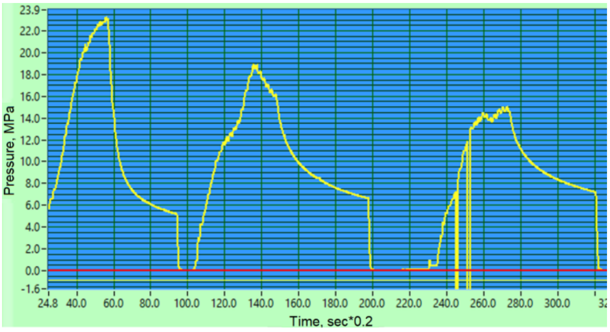


Figure 11. Graphs of P(t) dependence within the metering point 2 in a 2-2 well: (a) h = 10 m; (b) h = 9 m; (c) h = 10 m

Two-packer probe was installed on a well section. Then, loading was performed through a liquid injection into the interpacker space until critical tension stresses are achieved on the wall; as a result, rock fracturing takes place. The measuring hydraulic fracturing is based upon the fact that critical pressures depend on rock strength as well as on the level of stresses acting within the rock. In this vein, control of injection mode and the possibility to load repeatedly the selected well interval make it possible to identify typical pressure values within the pressure-time diagrams. Later, the values are interpreted in terms of stresses acting within the rock mass. Such values are: rock fracturing pressure during the first loading; pressure of a fissure opening during the repeated loading cycles; and pressure of a fissure closure. Since pressure and stress are of similar dimension, there is no necessity to identify straining characteristics of rocks while assessing the unknown stresses.

Hydraulic test parameters have helped define a value of lesser and calculate value of a greater horizontal components of effective stresses. The calculation procedure uses indicators of physicomechanical characteristics of rocks within the experiment. It should be mentioned that material content of rocks characterizes rather qualitative than quantitative idea of physicomechanical properties.

Visual inspection of horizontal wells within the metering point 1 has helped understand that a well, drilled around a left side, contains water flowing out under pressure. An attempt to place a gauging probe within the wall resulted in its squeezing from the wall. The matter is that 3-mm gap between a well wall and the device case prevents the probe from its free motion through the well. Measurements were performed in G2 well (right side of the mine workings) and G4 well (a stope). Table 1 demonstrates the results of observations during hydraulic fracturing tests within the metering point 1 (influence by a mine working is ignored); and Table 2 shows processing results of $P(t)$ diagrams.

While the experiment recording, zero at 10-m depth was at 1.6 MPa mark inside G2 well (right side). Within the point, a fissure was seen passing along the well axis and ongoing beyond the packer elements. Relying upon the laboratory-based experiments, pressure of the fissure opening is equal to the upper peak.

Inside G2 well (right side), the initial fissure developed towards the minimum stress; nevertheless, during the repeated openings, it varied its direction towards the maximum one (the fact explains difference in indications during repetitive measurements). While the experiment recording, zero at 10-m depth was at 0.7 MPa mark inside G2 well (a stope).

Table 1. Observation results obtained while hydraulic fracturing testing within the metering point 1 at Vostochnaya Sary-Oba deposit (influence by a mine working is ignored)

Coordinates of the experiment		1st loading		2nd loading		3rd loading		Rock tensile strength (T_c), MPa
Index of a measuring well	Distance between a mine working boundary and hydraulic fracturing place, m	Pressure, MPa						
		P_c	$P_s^{/}$	P_r	$P_s^{//}$	$P_r^{/}$	$P_r^{///}$	
G2	10	–	11.30	–	15.80	–	9.8	fissure
G2	9	24.8	20.76	23.0	11.28	14.4	8.8	8.6
G2	9	–	–	13.5	9.09	–	–	–
G2	8	23.1	12.75	16.9	11.80	14.0	10.5	6.2-9.1
G4	10	22.5	19.27	22.8	17.80	22.9	18.3	fissure
G4	10	–	–	22.6	18.10	–	–	–
G4	9	21.6	9.50	14.2	9.32	13.8	9.1	6.7-7.1

Table 2. Averaged values of the derived experimental stress components obtained within the metering point 1

Index of a measuring well	Distance from a mine working boundary, m	Σ_{ver}, MPa	σ_{min}, MPa	σ_{max}, MPa
G2	10	–	10.55	–
G2	9	8.95	11.28	20.76
G2	8	–	11.68	18.00
G4	10	–	–	18.36
G4	9	9.30	–	–

Lithostatic pressure ($\sigma_h = \gamma h$) for the metering point was almost 9 MPa at 123.5 m mark. 17 hydraulic fracturing tests were taken at the metering point 1. Processing results of $P(t)$ diagrams have made it possible to identify following values of stresses acting within the rock mass:

– σ_{min} = 10.55-11.68 MPa ≈ 1.2 γh;

– σ_{max} = 18.36-20.76 MPa ≈ 2.14 γh;

– σ_{ver} = 9.125 MPa.

The maximum horizontal stress is oriented along 70° ± 10 azimuth. γh is an average value of the obtained σ_{ver} (σ_{ver} may differ from γh because of rock mass overmining or undermining). The measurements can be considered as the natural stress field at the given depth (in this context, distance from the surface is about 310 m).

Visual inspection of horizontal wells within the metering point 2 has helped understand that the well drilled around a left side, contains water flowing out under pressure. An attempt to place a gauging probe within the wall resulted in its squeezing from the wall. Measurements were performed in G6 well (right side of the mine workings) and G8 well (a stope). Table 3 demonstrates results of the observations during hydraulic fracturing tests within the metering point 1 (influence by a mine working is ignored); and Table 4 shows processing results of $P(t)$ diagrams.

In this context, filtration is a fluid passing through a fissure connected mainly with other fissures or that one going beyond the pressurized space, and getting to a well. In such a way, closing pressure is defined according to the maximum value under the constant consumption.

Lithostatic pressure ($\sigma_h = \gamma h$) for the metering point at a 42-m mark within a filling ort (block 27; level 0) is about 8.5 MPa. 18 hydraulic fracturing tests have been performed within the metering point 2. Processing results of $P(t)$ diagrams have made it possible to identify following values of stresses acting within the rock mass:

– σ_{min} = 11.63-13.5 MPa ≈ 1.35-1.56 γh;

– σ_{max} = 15.0-17.2 MPa ≈ 1.74-2.0 γh;

– σ_{ver} = 8.08-9.0 MPa.

The maximum horizontal stress is oriented along 70° ± 10 azimuth. γh is an average value of the obtained σ_{ver} = 8.61 MPa. In the future, the authors set themselves the task to analyze correlation between stresses and geological structures. More detailed study of interaction between the stresses and such geological structures as folds, fissures, and faults will provide better understanding of high stress state within the certain zones. Moreover, it will help forecast dangerous areas, and develop more accurate supporting methods as well as ore mining techniques. In addition, one of the key prospects for further research is a multidisciplinary approach uniting knowledge from different fields of science and engineering. Combination of geological, geophysical, engineering, and mathematical methods will make it possible to get more complete idea of the stress rock mass state and formulate more reliable and safe procedures for mining operations.

Generally, further research will be aimed at a deeper understanding of the natural field of rock mass which will help develop innovative supporting and mining techniques, optimize design of workings, and avoid accidents while promoting sustainable and safe progress of a mining sector.

Table 3. Observation results obtained while hydraulic fracturing testing within the metering point 1 at Vostochnaya Sary-Oba deposit (influence by a mine working is ignored)

Coordinates of the experiment		1st loading		2nd loading		3rd loading		Rock tensile strength (T_c), MPa
Index of a measuring well	Distance between a mine working boundary and hydraulic fracturing place, m	Pressure, MPa						
		P_c	$P_s^{/}$	P_r	$P_s^{//}$	$P_r^{/}$	$P_r^{///}$	
G6	10	23.9	15.0	16.0	12.07	15.8	11.2	7.9-8.1
G6	9	–	9.5	–	9.00	–	8.5	filtered fissure
G6	8	–	8.1	–	8.80	–	8.4	filtered fissure
G8	10	24.3	13.2	15.5	12.00	14.2	11.6	8.8-10.1
G8	9	11.7	8.4	11.9	8.01	11.2	7.84	fissure
G8	8	23.2	8.96	18.6	10.16	14.6	10.6	–

Table 4. Averaged values of the derived experimental stress components obtained within the metering point 2

Index of a measuring well	Distance from a mine working boundary, m	Σ_{ver}, MPa	$\sigma_{\min}$, MPa	$\sigma_{\max}$, MPa
G6	10	–	11.63	15.0
G6	9	9.00	–	–
G6	8	8.43	–	–
G8	10	–	12.20	–
G8	9	8.08	13.50	–
G8	8	8.96	11.88	17.2

5. Conclusions

The obtained findings of field measurement, and performed hydraulic fracturing fields have made it possible to identify quantitative parameters of stress-strain state of rock mass within Vostochnaya Sary-Oba field.

As a result of the studies, 35 hydraulic fracturing tests have been performed within the two metering points (MP 1 and 2), at 123.5-m and 42-m marks respectively. 17 hydraulic fracturing tests have been performed within MP 1; lithostatic pressure is about 9 MPa. 18 hydraulic fracturing tests have been performed within MP 2; lithostatic pressure is about 8.5 MPa. Processing of dependence graphs $P(t)$ at both MPs has identified values of stresses acting within the rock mass $\sigma_{\min}$, $\sigma_{\max}$, and σ_{ver}.

There is tectonic stress at the field; the stress may depend upon the shape of structural folds as well as tectonic fissuring. It has been defined that azimuth of the maximum horizontal stress within the points coincides; it is equal to 70° ± 10.

The findings may be applied to correct design documentation for the deposit development; select optimum supporting and ore mining techniques; and design activities avoiding rock mass inrush and failure in workings. The abovementioned promotes operational safety and increase in ore extraction quality.

Generally, the research has helped obtain more accurate and reliable idea of the stress state of rocks within Vostochnaya Sary-Oba field, which contributes to the development of more safe and efficient methods to control rock pressure, and helps make sound decisions while ore deposit planning and mining.

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Оцінка природного поля напруженого стану масиву за допомогою натурних вимірів на родовищі “Східна Сари-Оба”, Казахстан

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Мета. Оцінка природного поля напруженого стану масиву на родовищі “Східна Сари-Оба” за допомогою натурних вимірювань, що дозволить визначити розподіл напружень і виявити зони з підвищеними напруженнями, які можуть становити небезпеку для безпеки гірничих робіт.

Методика. У рамках дослідження було використано метод гідророзриву свердловин для вивчення параметрів вихідного поля напружень на родовищі. Виміри були зроблені на двох замірних станціях за допомогою вимірних свердловин, що прокладалися горизонтально і вертикально. У кожному місці установки було виконано тести гідророзриву.

Результати. В результаті проведення натурних вимірювань отримано кількісні параметри напружено-деформованого стану масиву на двох замірних станціях. Виявлено, що на родовищі присутні тектонічні порушення, які можуть бути обумовлені формою структурних складок та тектонічною тріщинуватістю. Азимут дії максимального горизонтального напруження на всіх станціях збігається і дорівнює 70° ± 10.

Наукова новизна полягає у застосуванні нової методики оцінки напруженого стану масиву на родовищі “Східна Сари-Оба” з використанням натурних вимірювань та гідророзриву свердловин. Це сприяє більш точній та надійній оцінці напруженого стану гірських порід на родовищі, що має важливе значення для безпеки гірничих робіт та розробки ефективних технологій кріплення й виймання запасів руд.

Практична значимість. Отримані результати дослідження можуть бути використані для коригування проєктної документації на відпрацювання родовища та вибору технології кріплення й вилучення запасів руд, що дозволить здійснювати обґрунтований вибір конструкції і параметрів геотехнології з урахуванням безпеки робіт та якості вилучення запасів руд. Також ці результати сприяють розробці заходів щодо запобігання вивалам та обваленням гірничої маси у виробках.

Ключові слова: *гірські породи, руда, стійкість порід, кріплення гірських виробок, вивали, тріщинуватість масиву*