GEOPHYSICAL STUDIES OF ROCK DISTORTION IN MINING OPERATIONS IN COMPLEX GEOLOGICAL CONDITIONS

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KEY WORDS: Geophysical methods, Fracturing, Rock Mass, Seismic survey, Fields, Model.

ABSTRACT:

Geophysical methods of rock mass survey are one of the most effective ways of solving various problems in mining and are widely used in mining, gas and oil industries, as well as in science. They allow carrying out prospecting and evaluation works remotely, to reveal structural heterogeneities, cavities, contact zones of different media in rock mass with rather high accuracy. At the stage of designing a mining enterprise and making major decisions, it is necessary to have reliable information about the tectonic structure of the undermined and adjacent massif and parameters of its geodynamic activity. For this purpose, special studies of the tectonic structure of the rock massif must be carried out and the parameters of modern geodynamic movements must be determined. The most complete information about tectonic disturbances, identification of gliding surfaces, zones of macrofracturing are provided by geophysical methods of rock mass survey.
In the article analysis of study of structural-tectonic structure of ore areas, separation and specification of ore-controlling structures, detection and depth mapping of ore-controlling faults, volume mapping of intrusive massifs based on previously conducted geophysical research in Zhezkazgan syncline area carried out. Geological and geophysical conditions of the central ore field (presence of rich bodies with high electric conductivity, considerable thicknesses of ore bodies, etc.) were favorable for application of various geophysical methods to search and trace rich ore bodies occurring at low depths.
Moreover, possibilities of application of seismic works are considered at the solution of problems of ore geology in difficult mining-geological conditions of Kazakhstan.

1. INTRODUCTION

At the design stage of a deposit of minerals occurring at great depths, in order to assess the condition of the rock mass, it is rational to use geophysical survey methods for optimal design decisions on the development of these mineral deposits (Nurpeissova et al., 2020). During field development, the geomechanical processes taking place in the rock massif as a result of the technogenic impact of mining can be investigated not only by instrumental geodetic methods, which provide only quantitative estimates of the shifts that have already occurred, but their initial origin can be monitored by geophysical methods (Bazaluk et al., 2022).

One of the geophysical methods is seismic surveys. It is the most powerful and informative geophysical method for prospecting and exploring for ore deposits. The success of the seismic method has proven itself in oil and gas prospecting and exploration.

The difficulties of studying deep and buried ore deposits using other geophysical methods and the lower cost compared to drilling have fundamentally changed the place of seismic surveying in the complex of ore geophysics methods in recent years. This has shown the need to develop special technology for 3D seismic surveying at all stages of rock mass disturbance surveying for prospecting and exploration of solid minerals in complex geological conditions (Sirazhev et al., 2021).

The seismic technique can detect and trace the tectonic disturbances that often play an important role in the formation of ore deposits at depth. Seismic surveys can clarify the contours of ore-bearing intrusions, determine the position of their apical parts, and trace the contact lateral surfaces and lower edges. This increases the efficiency of prospecting for contact-metasomatic, skarn, stockwork and other deposits.

In the early days, seismic exploration was used in ore areas in the refracted-wave modification, but now the reflected-wave method takes the lead (Kieush et al., 2022). Seismic surveys using this method have been effective in studying the flat-lying boundaries of sedimentary and metamorphic complexes, complex structures of effusive-sedimentary complexes, morphology and internal structure of intrusions, mapping of faults, upthrusts and large tectonic zones to considerable depths.

2. GEOPHYSICAL STUDY

In order to determine the disturbance of the rock massif during prospecting and exploration for deep mineralisation in the Zhilandinskaya cluster of cuprous sandstones, pilot field seismic surveys were carried out to build 3D models to visualise the continuous spatial characteristics of the targets under investigation. The objective is to prepare and submit them for exploration drilling or in-mine exploration of the targets during exploration and production drilling (Aidarbekov et al., 2023).

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The research was carried out in three stages: field seismic survey (Figure 1), processing and interpretation of 3D field seismic information, and construction of a 3D field model of the Zhilandinskaya copper sandstone group experimental plots.

2.1 Field seismic surveys

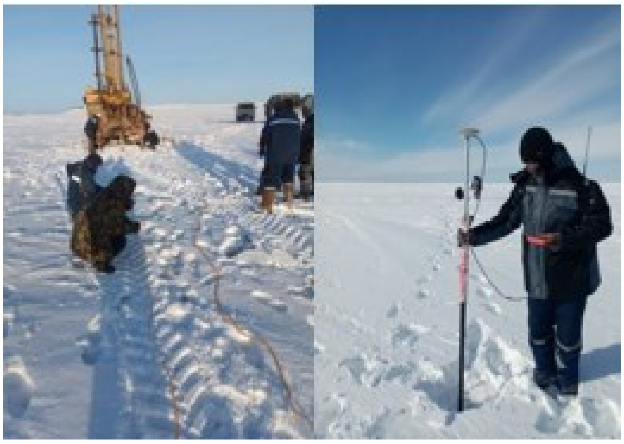


Figure 1. Field 3D seismic survey.

The 3D field seismic survey was carried out using area survey systems using the multiple overlap methodology, where the required survey multiplicity, bin dimensions, allowable offsets of blast point, receiving point are determined. (Aidarbekov at al., 2018).

Based on the simulation of the blast and reception point schemes, the optimal observation scheme and its parameters are selected: distances between initiation and reception lines; orientation of initiation and reception lines; number of initiation and reception lines; number of active channels and their distribution over reception lines; and overlap.

For 3D seismic surveys a modern cableless SCOUT seismic system was used (Figure 2).

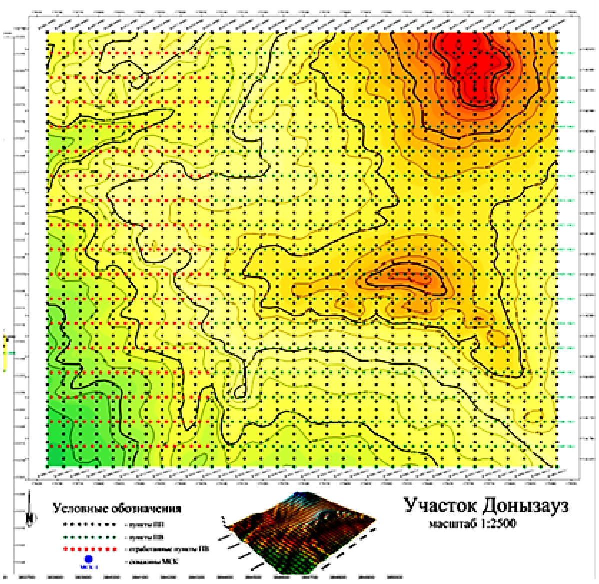


Figure 2. Point excavation diagram for experiment area of the copper sandstones group of the Zhilandy deposits.

The field seismic survey was carried out using field seismic survey complexes, which include equipment and equipment for initiating, receiving and registering wave fields, as well as auxiliary equipment.

It is recommended that initiation points be placed in the middle between the centres of two neighbouring groups of seismic receivers. The step of the shot point can be determined by the given multiplicity of observations; when the multiplicity is 24 or greater on one of the travel time curve branches at the shallowest target horizon it is advisable to combine the shot point and receiver point in the arrangement, with the shot point moved out to a distance multiple of one receiver point step.

For operational quality control and assessment of the parameters of the recorded seismic oscillations, it was envisaged to process seismic data in the conditions of the field-computing centre. The scope of work in the field-computing centre included: processing of microseismic logging data and output of results; processing of experimental work and output of optimal excitation conditions for solving the problem of mapping of copper sandstone beds with a thickness from 1.5 to 4.5 m; and quality control of production seismograms.

2.2 Processing and interpretation of 3D seismic field data

Seismograms obtained in the field transferred to a stationary processing centre for in-depth processing with preserved amplitudes (Figure 3).

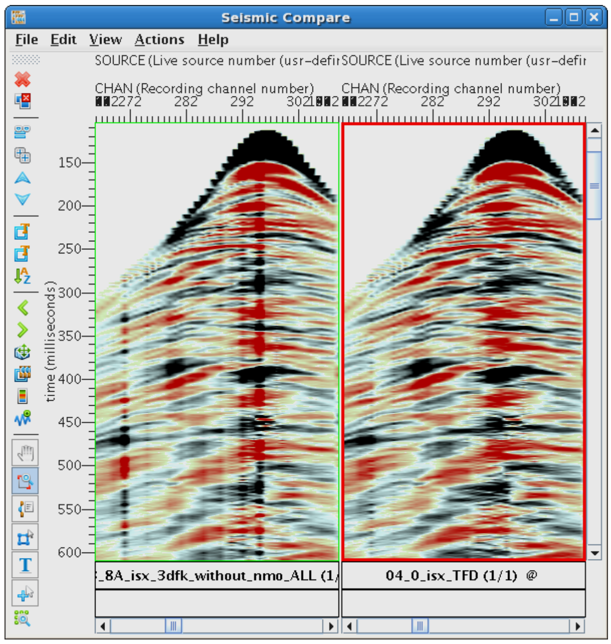


Figure 3. Seismogram before and after noise suppression.

The processing of the seismic data revealed extraneous noise. The use of adaptive signal-to-noise processing was tested on the original data to suppress surface-wave-induced noise. In the signal to noise procedure, noise is suppressed adaptively and only in places where it is required, without affecting good parts of the data.

The resulting seismic cubes at the field processing centre were interpreted using Geographix Discovery software (Halliburton) and additional dynamic attribute calculation modules (Alireza et al., 2010).

The data interpretation divided into two stages: structural interpretation and dynamic interpretation. The structural and dynamic interpretation resulted in the construction of structural maps and contours of geological bodies; picking of faults and fractures by inphase axis discontinuities on vertical and horizontal time slices as well as by cube of tectonic disturbances derived from coherence attribute; tracing of productive horizons by inline and crossline profiles network with 100x100 m step; analysis of dynamic parameters for detailed study of section lithology. The isochron and structural maps of the selected horizons shown in Figure 4.

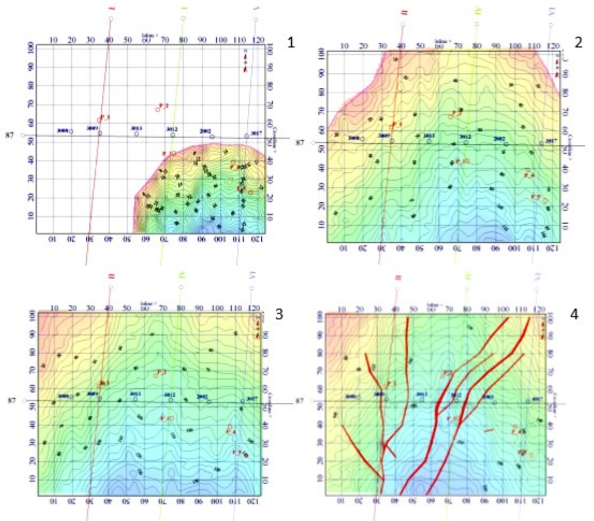


Figure 4. Isochron map by horizon: 1 - top of Zlatoust horizon, 2 - top of Tuskuduk horizon, 3 - top of Zhilandy horizon, 4 - top of Kopkuduk horizon.

The interpretation process combines two interdependent approaches: geophysical, which consists of determining structural models and seismo-geological parameters from seismic data; geological, which consists of predicting lithological, petrophysical, genetic and other geological characteristics from seismic data (David et al., 2010). Correlation carried out in automatic mode by extremums of oscillations based on a set of such attributes as repeatability of form and apparent period, smooth change of arrival times and amplitude of the wave, regular behaviour of the correlated in-phase axis in relation to the adjacent axes.

At various stages of interpretation, maps created to determine the configuration of boundaries and reveal the distribution patterns of seismic parameters and attributes over the study area, which objectively reflect the peculiarity of the medium structure (Bekbergenov et al., 2020).

To show the most significant features of the geological structure of the entire area of the Zhilandy group of cupper sandstone deposits, structural maps constructed based on seismic and geological boundaries. The position of faults, contacts, areas of attenuation and other localised structural features on the maps was consistent with the results of wave correlation. The cross section of the structural maps was chosen to be equal to the error in depth determination. Additional isolines were carried out to provide a more relief representation of low-amplitude structures. Areas with lower accuracy were plotted with dotted contour lines. For better visual perception of the structural maps, colour shading was used in addition to contour lines. The isochron maps were converted to structural maps using the averaged time-depth relation obtained from the velocity model of pre-stack temporal migration (Figure 5).

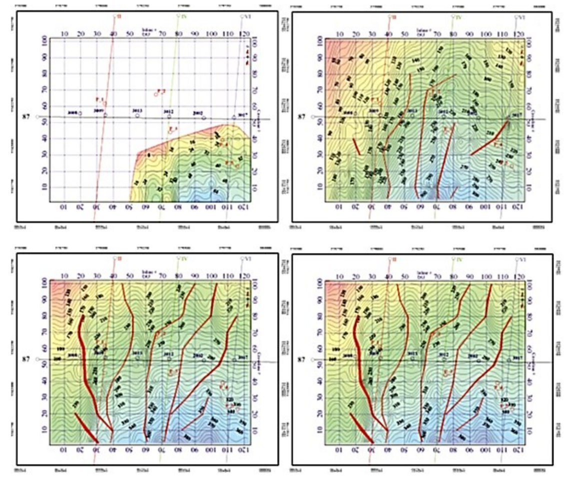
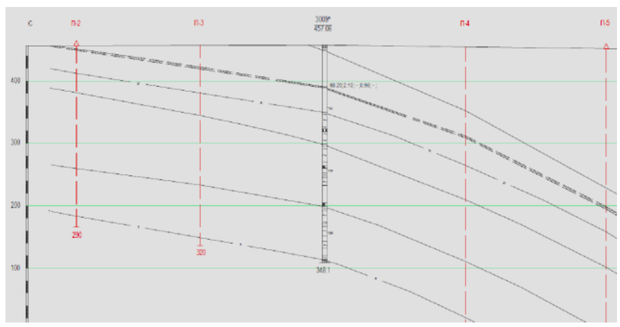


Figure 5. Structure maps.

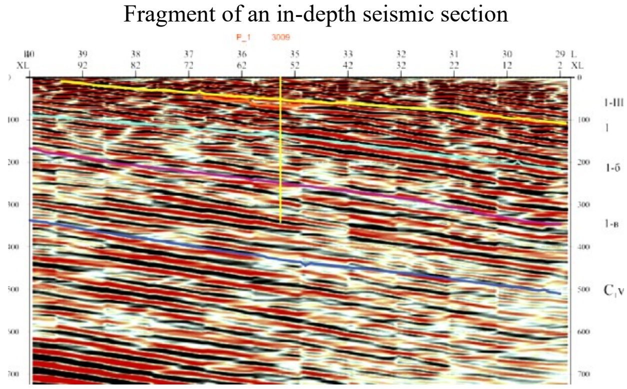
The configuration and position of the boundaries, for objective reasons due to differences in velocity migration models, differ slightly from the pre-stack temporal migration data.

Figure 6 compares geological sections from drilling data, seismic depth sections and geological sections constructed from 3D seismic data.

Fragment of a geological section



Fragment of an in-depth seismic section



Geological cross-section based on seismic data

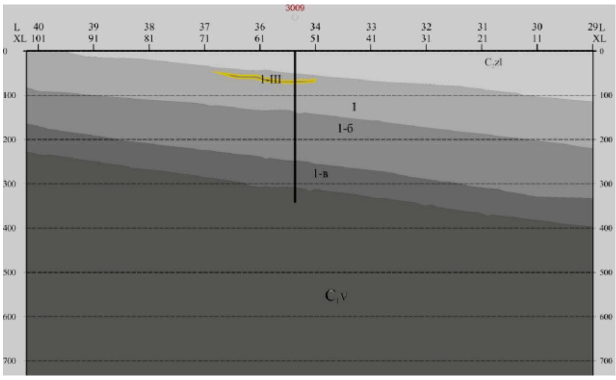


Figure 6. Interpretation of Profile II seismic data.

The resulting structural maps do not contradict the model obtained from geological mapping and drilling data. Multiple micro-tectonic faults are observed along the seismic sections, but because of the large number of such fractures and the loss of information content of the seismic section images, we show only the main faults on the structural maps, which are shown in Figure 5.

As a result of the interpretation of 3D seismic data, seismic cubes were obtained, velocity models were built using seismic data, and the spatial extent of tectonic faults of ore-bearing horizons in the Upper Beleutin and Taskuduk Formation layers of the Lower Carboniferous system was determined. To build a 3D model, seismic profiles coinciding with the coordinates of geological sections constructed by exploration drilling were extracted from seismic cubes. For each profile, we tied reflecting boundaries to stratigraphic complexes, their lithological heterogeneity along strike and depth, taking into account velocity changes obtained during seismic data processing.

As a result of correlating and linking temporal sections with actual geological data, three-dimensional models of traced horizons were built, from which seismic sections can be selected at 10 m increments, as well as profiles through any points on the seismic data cube. The temporal and depth sections show all target reflecting horizons, the nature of their alteration, individual rock blocks, major tectonic faults, etc.

In the process of comprehensive geological and geophysical modelling of productive horizons in the pilot areas of the Zhilandy group of cupper sandstone deposits, seismic and geological models of the study sites were built for structural mapping of ore-bearing areas and subsequent design of exploration drilling; tectonic faults, decompaction and fracture zones were identified, contours of ore-bearing rocks, boundaries of ore deposits were determined, and digital geological models of the study areas with the actual values of the predicted parameters and the possibility of restoring the values of the specified parameters at any point in the model.

The main ore-bearing horizon is the Tuskuduk horizon of the Tuskuduk Formation, which is the most saturated with commercial ore mineralisation. This is followed by the Zhilandinskiy horizon, which lies on the sediments of the Lower Carboniferous Beleutin strata. Commercial ores have been identified in grey sandstones with limestone interlayers with fauna.

The ore bodies are confined to the vaulted parts of box-type anticlines, are characterized by a low bedding and are typical bedding plane deposits. In steeply dipping faults and flexures, the ore bodies occur as steeply dipping lenses and veins. The mineralisation of the deposit is irregular, vein-disseminated and closely associated with fault zones of various ranks. In the Taskuduk and Zhilandy horizons described above, fine cracks filled with calcite and disseminated ore minerals are quite numerous. In areas of significant development of filamentous fractures, the mineralization has a vein-disseminated character.

2.3 Building a 3D field model

Seams and ore deposits were modelled using Petrel software (Schlumberger). The initial stage involved a review of historical materials within the study area and documentation relating to the technical parameters and geological conditions of the exploration activities. Information from previous survey reports and other sources was entered into the databases. All source data was divided into two types - tabular and graphical.

Tabular data: catalogues of coordinates of wells; sampling logs of wells and mine workings; sampling tables on graphical annexes; block passports.

Graphic information - geological sections; horizon sampling plans; borehole and geological section coordinates, etc.

The data was georeferenced to the study area and, if necessary, well inclinometry results were taken from the geological sections. Necessary data were entered into the modelling software and the numerical data and graphics were compared with each other to improve the accuracy of the model. A three-dimensional model at the start of the simulation was created by preparing a "blank" model (Figure 7).

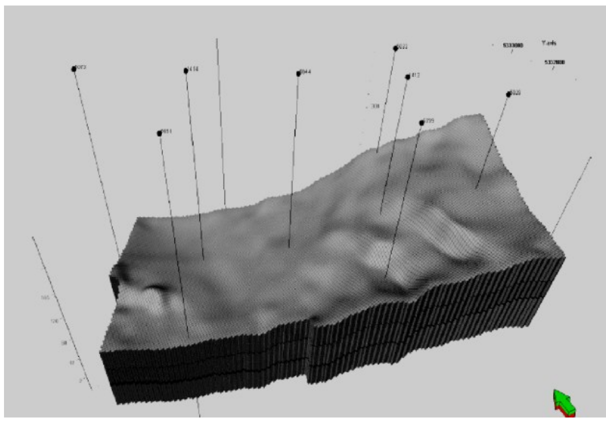


Figure 7. Three-dimensional wireframe model of the study area.

During the modelling process, a three-dimensional wireframe model of one of the study areas in the Zhilanda Group of cupper sandstone deposits was populated with data and was ultimately used as an estimation and visualisation tool. This enabled the identification of areas with higher mineral content and allowed the estimation of reserves with its correct construction. A grid consisting of cells on three coordinate axes x, y, z was created to generate the initial model (Figure 8).

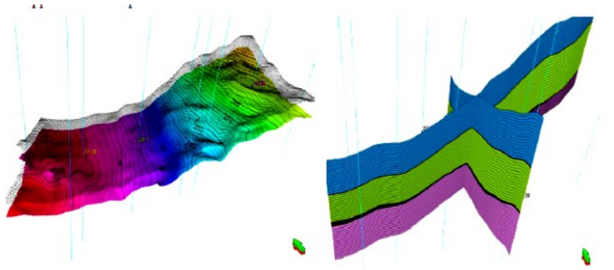


Figure 8. Creating an initial block model along the three x, y, z coordinate axes.

The initial block model can be subdivided into smaller blocks or cells, if required, to reveal detailed fracture tectonics with a certain accuracy.

The next modelling step is to import data on the commercial component content into an "empty" block model (Figure 9), followed by interpolation of fracture and component content values over the study area.

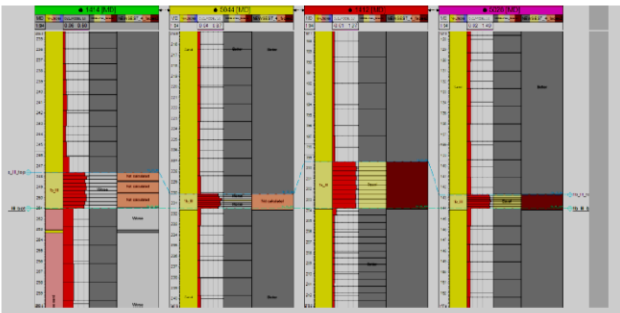


Figure 9. Importing raw data into the trajectories of wells drilled within the area.

This block model was used to interpolate the fracture and component contents in the study area of the Zhilandy group of fields. The interpolation and extrapolation of the mineral content was carried out using variogram analysis procedures (Figure 10).

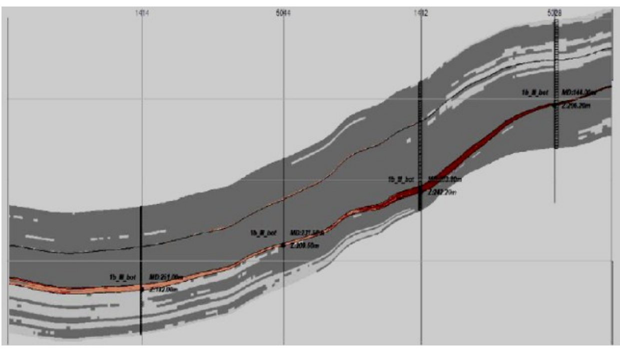


Figure 10. Input of raw data and interpolation of commercial component content.

After interpolation of grades, the block model was verified by comparing the distribution of grades in samples with the distribution of grades in model blocks on plans by horizons and sections. The result of this work was a volumetric geological model of the study area, which we plan to use in assessing the geomechanical and geodynamic state of the rock massif during the development of mineral deposits in complex mining and geological conditions.

3. CONCLUSIONS

The article considers the possibilities of applying seismic surveys when solving the problems of ore geology in the complex mining and geological conditions of Kazakhstan.

The use of high-density, wide-azimuth 3D seismic survey for structural mapping of ore-prospective areas and detailed study of ore-controlling complexes in the selected area is considered. The evaluation and possibility of modern processing and interpretation complexes at ore sites for obtaining materials of high quality is given. The efficiency of ore seismic survey is shown in solving the following geological problems: study of structural-tectonic structure of ore areas, separation and specification of ore-controlling structures in sedimentary and effusive-sedimentary folded rock complexes, detection and deep mapping of ore-controlling faults, volume mapping of intrusions, etc.

3D modelling of geological environments based on the use of 3D seismic surveys will ensure optimal development of complex structured ore objects. In general, increase the sustainability of the development of mining and closely related processing and other industries in the Republic of Kazakhstan.

ACKNOWLEDGEMENTS

The research has been performed under the financial support of the Committee of Science of the MES of the RK "Study and development of a high-efficiency methods for monitoring a geotechnical rock mass state to assess and predict deformation processes during mineral development (grant No. AP14871828)" and a commercialization project "Threedimensional seismic exploration to model ore deposits under complex mining and geological conditions of Kazakhstan".

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