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INTEGRATED MONITORING OF THE AREA OF ZHILANDY DEPOSITS

The industrial and environmental safety of mining at the Zhilandy group of deposits is ensured via identification and prediction of hazardous geodynamic processes and phenomena.

This study used and integrated approach including: geological engineering of the structure and tectonics of rock mass with mapping of disturbed, displaced and crushed rock zones, instrumental surveying using electronic tachometer, surface monitoring of pit wall using ground scanning and UAV, examination of displacements at the points of a geodynamic testing area (GTA) points and assessment of the stress strain behavior changes in rock mass using satellite geodesy technologies.

The methodology for integrated geodynamic monitoring is developed. The new method for GTA creation is proposed. The study results were implemented at existing mine within the R&D projects, namely, "Comprehensive monitoring of slow deformation processes of the earth's surface during large-scale ore mining in Central Kazakhstan" and "Highly effective methodology for monitoring geotechnical conditions in rock mass to assess and predict deformation processes during mineral mining", and also in the educational process at the Satbayev University.

The implemented R&D resulted in creation and commissioning of:

– the geodynamic testing area in the region;

– the designs of permanent (ground and underground) forced centering points (FCP) allowing an increase in observation efficiency and accuracy;

– the pit wall reinforcement method and the method of the stress–strain behavior prediction in rock mass;

– the composition of the mine waste solution to reinforce the disturbed pit wall areas.

The novelty of the developed methods and means is confirmed by the patents of invention of the Republic of Kazakhstan.

The GTA creation at mineral deposits in Central Kazakhstan is a reliable framework for the long-term monitoring of the earth's surface deformation during large-scale mineral mining, allowing the enhanced efficiency and accuracy of observations. The results obtained can be used to improve the level of industrial safety at mines and minimize the environmental risks caused by subsoil development.

Keywords: *mineral deposits, fracturing, rocks, physical and mechanical properties of rocks, rock mass stress state, monitoring, geodynamic testing area, geodetic surveys, satellite systems, accuracy assessment*

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Introduction

Kazakhstan occupies a prominent place in the world copper trade and is among the top ten countries in in copper production in the world. The largest volume of copper in Kazakhstan was produced in 1988 (462 thousand tons). In terms of proven copper reserves, Kazakhstan ranks fifth in the world, and in terms of the average copper content in ores (0.44%), it is in 75th place out of 88 countries. Intensive development of mineral deposits in Central Kazakhstan has been ongoing for more than 80 years. During this time, more than 60 deposits of solid minerals were discovered in the area of Central Kazakhstan, of which 36 deposits are actively being developed. Central Kazakhstan is the main supplier of copper and manganese in the Republic. Dozens of large cities and urban settlements were built here, such as Zhezkazgan, Satpayev, Balkhash, Akzhal, Aksu, Akshatau and some others [1].

Mineral extraction which usually occurs in difficult mining and geological conditions causes changes in the geodynamic regime of geological environment. If rock mass is composed of strong rocks, then during its intensive development, significant geomechanical and geodynamic processes are observed, since its stress state changes, and deformations and displacements take place. Manmade changes in the bowels of the Earth usually occur slowly and, as a rule, have long-term consequences and are difficult to eliminate.

Comparative analysis

Induced earthquakes are recorded all over the world where mineral extraction is carried out (Germany, USA, Poland, Czech Republic) [1, 2]. In Russia, this problem is acute in the North Ural bauxite mine, the mines of the Upper Kama potassium salt deposit, and in the Khibiny apatite–nepheline mines [3, 4].

Changes in the geodynamic regime of geological environment during large-scale mining confirm the results of scientific research that were and are being carried out in the Zhezkazgan natural-technical system which includes mines, processing plants with tailings, copper smelters in Balkhash and Zhezkazgan. The mining industry infrastructure in Central Kazakhstan is a powerful subject of anthropogenic impact on the environment, presenting great opportunities for studying a wide range of environmental problems [5–7].

Due to the depletion of mineral reserves, mineral deposits located in difficult mining and geological conditions and at great depths are being more actively developed, which involves special facilities for the development of these objects. Kazakh scientist-geologist K. I. Satpayev raised this problem in his work "Dzhezkazgan copper ore region and its mineral resources", as well as during creation of metallogenic forecast map of Kazakhstan [8]. Currently, the domestic copper industry is represented by Kazakhmys Corporation LLP, Balkhash Non-Ferrous Metals Processing Plant JSC and several smaller enterprises specializing in scrap remelting.

The Corporation includes 12 underground and open-pit mines with annual ore production volume of more than 38 million tons, 8 processing plants producing copper, lead and zinc concentrates, 2 copper smelters, copper wire rods plant with productivity of about 50 thousand tons per year and precious metals refineries. To date, copper reserves of the unique Zhezkazgan deposit, which has been developed since 1929, are gradually fading out. Meanwhile, in this area there are a number of other explored copper deposits that are being developed and replenish the diminishing resources of the Zhezkazgan mines — these are deposits of the Zhilandy group: Eastern and Western Saryoba, Kipshakpai, Karashoshak, Itauz, located along the northern side of the Dzhezkazgan syncline, which are being developed by Zhilandy mine of Kazakhmys Corporation LLP [9–11] (**Fig. 1**).

Since the explored reserves of copper ore of the Zhezkazgan deposit are gradually being depleted, at the present stage there is a need to detect new ore reserves to extend life of this deposit for another 40–50 years, as well

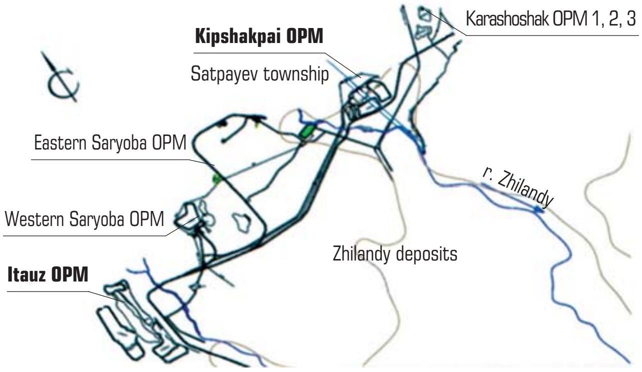

Fig. 1. Zhilandy group of mineral deposits (OPM — open pit mine)

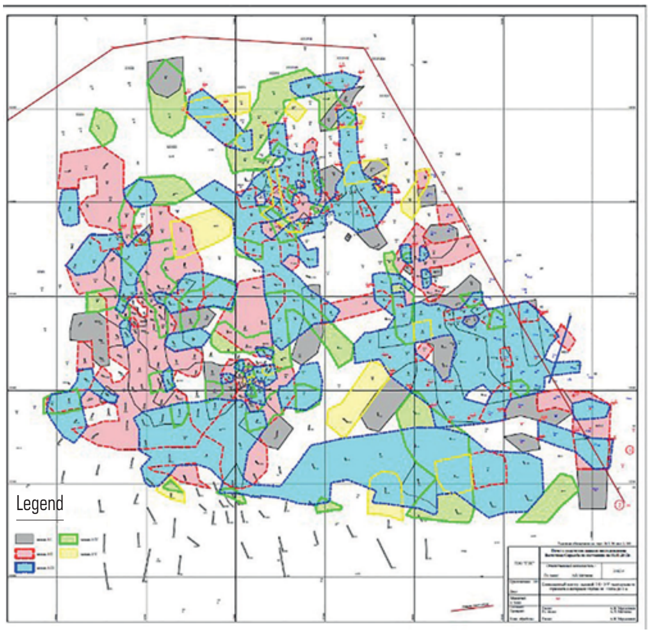

Fig. 2. Co-located contour map of ore deposits in the depth range from +340 m to 0 m

as to develop new deposits near the townships of Zhezkazgan and Satpayev. Currently, conditions are being created for expanding mineral resources base of Central Kazakhstan.

Recently, satellite radar interferometry data from space sensing of the Earth are widely used in monitoring induced processes. The main advantage of this method is the ability to cover large areas. Despite a large number of research works [12–14], the issue of predicting and managing the risk of induced disasters due to complexity and wide variety of mining and geological features of deposits has not yet been completely resolved. The purpose of this work is to carry out geomonitoring of rock mass, including the comprehensive review and analysis of all natural and man-made factors, as well as the use of the control methods and means developed by the authors.

Research methods

The scientific school of the Department of Surveying and Geodesy at the Satbayev University has been performing a long-term research aimed to ensure industrial safety in the mines of Kazakhstan. The main role is given to the introduction of modern technologies and means of rock mass monitoring into actual practice. Evidence of this is the research implemented by the authors under the projects “Development of innovative methods for evaluation and prediction of rock mass behavior to prevent induced emergencies” and “Comprehensive monitoring of slow deformation processes on the earth’s surface during large-scale ore mining in Central Kazakhstan”.

The analysis of geodetic observations in the area mineral deposits being mined point at the lack of effective methods for determining magnitude of deformations, which necessitates improvement of observation methods using modern instruments. Geodetic observations make it possible to identify rock mass deformations, which is essential for assessing geomechanical situation in the mining area, but are unable to offer a complete picture of deformation processes in time.

Research methodology

In the world, the leading role in the rational and safe use of subsoil is given to surveying services of mines. Currently, the tasks of surveying service have become significantly more complicated due to expansion of mineral deposits and greater depths of mining operations, which requires surveyors to carry out thorough, high-precision and timely monitoring work. Solving problems of monitoring and predicting geodynamic processes in the areas of intensive mineral mining in Central Kazakhstan is possible using the integrated monitoring approach developed by the Department of Mine Surveying and Geodesy at the Satbayev University using the data on geological and tectonic structure of the area, modern instruments, as well as the observation tools developed by the authors [15, 16].

According to the elaborated methodology, geology, tectonics and structural features of the test deposit were studied.

Geological and geotechnical conditions

The thickness of commercial ore for all deposits of the Zhilandy group ranges from 0.1 to 20 m and on average is 3–8 m for the Eastern Saryoba deposit (as well as Western Saryoba and Kipshakpai). The sizes of ore bodies range from 200×100 m to 3200×1400 m (Western Saryoba field) and 3000×750 m (Itauz field). In the ore field, 11 ore deposits were identified, of which 109 ore bodies were explored. The largest deposits adjoin the Taskuduk horizon [17, 18]. Their strike is northeast, the length is up to 3200 m, the thickness is from 0.5 to 17 m, and the on-dip size is up to 1400 m (**Fig. 2**).

The rock mass is complicated by tectonic faulting, rock interfaces and various shape and size mine workings, which makes mining greatly difficult.

The structural features of the outcrops and the physical and mechanical properties of rock mass were studied, and the results made it possible to determine graphical-analytical dependences of strength of rocks on their occurrence depth, and to promptly adjust calculated level-by-level stability of mine workings [19]. The most important geomechanical characteristic of rock mass is its stress–strain behavior. To date, various methods and methods for the stress–strain control in rock mass have been developed. The main methods are the VNIMI destressing, core disking, etc. To study stress state of rock masses in Central Kazakhstan area, the authors developed the seismoacoustic method of the stress–strain behavior prediction in rock mass [20].

Geomonitoring procedure

Monitoring of rock masses during development of mineral deposits that occupy a large area and occur at various depths requires creation of a high-precision geodetic justification. The classic option of geodetic networking in the listed fields is quite labor-intensive and financially unprofitable. Therefore, the authors proposed and implemented a new approach to creating a geodynamic testing area (GTA). For the Zhilandy group of deposits, “nodal” branches with control points and deformation benchmarks [19]. All GTA nodes are located in accordance with ore veins and are tied to triangulation points of the State Geodetic Network (SGN): Taskuduk, Aslanbek, Burovaya and Poselkovaya (**Fig. 3**).

In practice of monitoring deformation of ground surface and structures during mineral mining, various types of benchmarks and control points are used. Long-term instrumental observations have exhibited the work complexity, especially relocation of a set of instruments (device itself, a tripod, slats) from one point to another. In this regard, to install instruments and increase speed of measurement, the authors developed a *permanent forced*

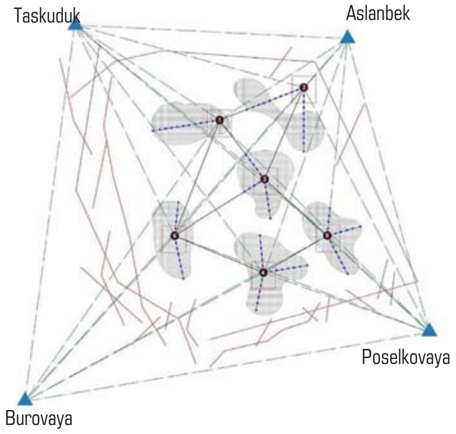

Fig. 3. Layout of GTA points with SGN tie

centering point to be installed at a control point during geomonitoring [21]. The device is a geodetic station for instrument centering signalling. The purpose of the invention is to improve the centering accuracy and measurement efficiency in the absence of tripods at observation points. Its advantages: simplicity and high accuracy of installation and orientation (without a tripod); the point is a clearly visible and prominent landmark for monitoring large areas.

Comparison with the 1st cycle of measurements

Name of points (ground benchmarks)	1st measurement cycle			4th measurement cycle			Deviation from 1st cycle measurement		
	Rectangular coordinates		Marks in Baltic. height system	Rectangular coordinates		Marks in Baltic. height system			
	East c.p.	North c.p.		East c.p.	North c.p.		r	r	r
Rp-1	57 082.981	113 967.788	448.980	57 082.981	113 967.803	448.962	0.001	0.015	–0.019
Rp-2	57 834.074	114 050.073	436.717	57 834.074	114 050.749	436.708	–0.002	0.006	–0.009
Rp-3	57 449.053	113 395.256	431.823	57 449.053	113 395.266	431.800	–0.007	0.010	–0.022
Rp-4	57 075.569	112 714.886	430.963	57 075.569	112 714.896	430.949	–0.005	0.010	–0.014
Rp-5	58 091.770	113 520.328	428.583	58 091.770	113 520.369	428.568	0.049	0.040	–0.015
Rp-6	56 891.610	113 541.914	432.034	56 891.610	113 541.916	432.000	–0.002	0.002	–0.035

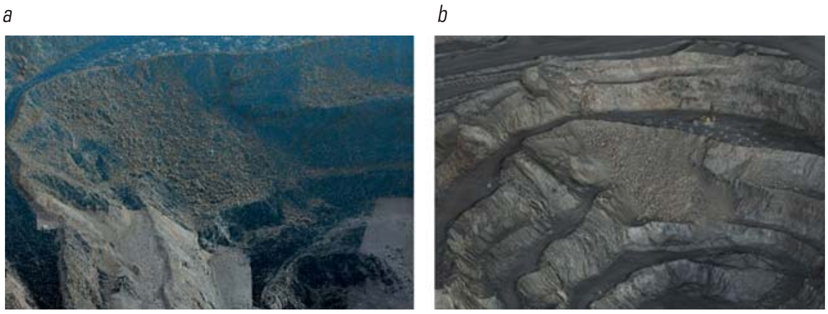

Fig. 4. Landslides on the eastern (*a*) and southern (*b*) pit wall

GPS observations

All coordinates and heights of ground benchmarks were determined using GNSS equipment, by measurements from starting points for the distances no more than 5 km.

Satellite observations were carried out using modern geodetic instruments GS16, in static mode, using the network method, with 4 cycles of observations. Based on the results of four seasonal observations, a comparative analysis was developed (**Table**).

During the work, the following necessary observation conditions were met: the maximum distance between receivers was 5 km; the minimum number of satellites for processing was 8; the recording interval was 5 s; the accuracy of obtained coordinates: 0.002 m horizontally and 0.002 m vertically; GDOP (satellite geometry) was less than 5; the duration of observations at the point was 70 minutes.

Elevations of working benchmarks along profile lines were determined by trigonometric levelling using a Leica TS06 5" electronic total station, by the method of double measurement at point with obtaining an arithmetic mean [22, 23].

Monitoring at open pit mine

To achieve efficient and safe operation during open-pit mining, monitoring is carried out with involvement of specialists from various fields. The role of a surveyor in this system is invaluable, since the surveyor must provide information on the open pit parameters, as well as the rock mass displacements and deformations being observed. It is necessary to control geomechanical processes in the pit wall rock mass, with regard to such important factors as the geology-based regional geodynamics in the mine field area, tectonic faults and structural features of rocks, etc.

The characteristic features of tectonic movements show up in the pit wall rock mass in the Eastern Saryoba OPM. In this open pit, large areas of screeы and rock falls are observed along the whole pit wall due saturation of clay rocks with water and owing to discrepancy between the actual and recommended pit wall parameters by the criterion of stability. At the Eastern Saryoba OPM, instrumental survey was carried out using a Stonex 300 laser scanner and an industrial flight platform MATRICE 300 RTK. As a result, a 3D model of landslides was obtained using MICROMINE program (**Fig. 4**).

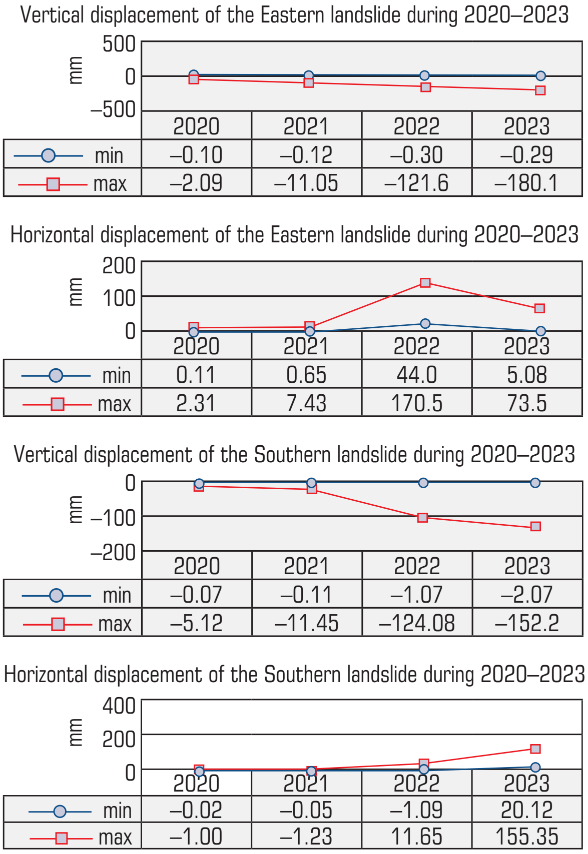

Fig. 5. Displacement curves for Eastern and Southern landslides from 2020 to 2023

The monitoring data on the landslide areas in the test open pit from 2020 to 2023 and the found displacement values in space and time are shown in **Fig. 5**.

Since the ultimate goal of all geomechanical studies is to ensure industrial safety, to prevent further collapse of the test pit wall, the authors have developed a pit wall reinforcement method, the technical novelty of which is confirmed by the patent of the Republic of Kazakhstan [24].

Currently, the pilot tests of the proposed method are being carried out at the mine, and the method has shown sufficient ability to serve as additional support to maintain stability of pit wall.

Conclusions

The integrated monitoring in the area of the Zhilandy deposits and the interpretation of 2021–2023 monitoring results makes it possible to formulate the following conclusions:

1. The preliminary analysis of geological and faulting structure of the earth's crust indicates unevenness of geodynamic processes in space, with identifiable active faults and tectonically stressed zones;

2. Based on the review of domestic and foreign scientific and technical literature, work experience in the field of studying geomechanical and geodynamic processes, as well as means of deformation observation, the detailed methodology of geomonitoring using modern high-precision geodetic instruments is recommended. The approach to setting up and performing observations over geodynamic and geomechanical at in solid mineral deposits is analyzed. The new "nodal" method for constructing geodetic observation systems in geodynamic test areas is presented, which allows monitoring ongoing seismic surveys, increasing efficiency of observations and reducing capital costs of their implementation.

3. The monitoring results allow concluding us to conclude that current mineral mining in the test field using various methods induces no significant change to existing natural–manmade and geodynamic behavior of the subsoil. The recorded minor displacements are associated with tectonic disturbances.

4. In such conditions, it is required to continue development of methods and means for the geodynamic testing area, to install of additional geomonitoring devices in weak areas of open pit mines and to substantiate reliable precursors of weakening. To do this, it is necessary to carry out special research to improve methodological and technical framework for the geodynamic test area.

5. For preventing deformation of ultimate pit wall in the Eastern Saryoba mine, the reinforcement method has been developed. The method is implemented at the present time ensures additional support toward the pit wall stability. The results of the activities are estimated using continuous instrumental surveying of landsliding areas.

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