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UDK 622.832

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HIGHLY EFFICIENT MONITORING PROCEDURE FOR DEFORMATION PREDICTION IN COPPER ORE MINING

The new highly effective rock mass behavior monitoring procedure ensures environmental and industrial safety in the area of Central Kazakhstan. The implemented integrated research includes the analysis of the geology, structure and physical and mechanical properties of rocks mass, as well as in-situ monitoring using the authorial methods and means. The accomplished research results are: the geodynamic test ground; the designs of the permanent (surface and underground) forced centering points of enhanced capacity and accuracy, the method of 3D laser scanning of rock mass structure, which allows a comprehensive study of fractures and faults in rock mass, the stress–strain behavior prediction method, as well as the composition of a reinforcement solution made of mining waste to enhance stability of dislocated pitwall slopes.

The geodynamic test ground created for mineral deposits in Central Kazakhstan is a reliable framework for the long-term ground deformation monitoring in large-scale mineral mining at the enhanced capacity and accuracy of observation. The results are applicable in operating safety improvement and ecological risk minimization in underground mineral mining.

Keywords: *deposits, fracturing, rocks, physical and mechanical properties, stress state, mining, monitoring, geodynamic test ground, geodetic network, geodetic surveys, satellite systems, accuracy assessment Introduction*

DOI: *10.17580/em.2023.01.04*

The Earth population grows yearly and is going to face the lack of mineral resources very soon. Mineral mining will be carried out in difficult geological conditions, at great depths, and with drastic environmental consequences [1].

In Kazakhstan, the mining sector is one of the most advanced job-offering industries. For the complete extraction of mineral raw materials, mining activities extensively involve mineral deposits at great depths in difficult ground. Naturally, major complications are expected due to geomechanics and geodynamics in this case. The geomechanical and geodynamic processes entail not only catastrophic technical and economic consequences, but sometimes lead to human casualties. Induced earthquakes occur in Germany, USA, Poland, Czech Republic. In Russia, this problem is critical in the mines of the Upper Kama potash salt deposit and the Khibiny apatite nepheline massif [2, 3]. All this is a direct consequence of geodynamic alteration of geological environment under the impact of large-scale mining, which is convincingly confirmed by the results of long-term scientific research of the Zhezkazgan nature-and-technology system, which is formed by mines, concentration factories with tailings and, copper smelters in Karaganda, Balkhash, Zhezkazgan and Satpaev. The mining infrastructure in Central Kazakhstan also exerts a powerful anthropogenic impact on the environment and offers comprehensive facilities to study a wide range of environmental problems [4–6].

Literature review

The geomechanical studies were carried out in individual mines and promoted gain of experience in this area. The mining industry dynamics in Kazakhstan and in the world over the past century has led to a qualitatively new situation, when the 'local' geomechanical fields induced by anthropogenic activities are no longer small in comparison with the global geodynamic processes and tectonic activity of the Earth [7–9]. Consequently, it is necessary to consider mines as unique natural laboratories, where it is possible to study in detail the relationship of the geomechanical and geodynamic processes using geophysical and satellite geodetic methods [10, 11].

One of such deposits in Central Kazakhstan is a giant copper ore province Saryoba, (East and West sites) located in the Ulytau area 30–35 km north of the Zhezkazgan Mine. The deposit was discovered in 1938–1940, and the first geological exploration headed by K. I. Satpayev revealed 11 ore deposits including 109 proved ore bodies. The ore bodies contained many faults which greatly hindered development.

Reliable information about structural features and deformations of rocks can only be obtained using innovative methods and means (high-precision strain gauges) for recording of stresses and strains, and using modern GIS technologies that enable 3D geological modeling and optimization of mining of structurally complex ore bodies. This problem is of particular relevance for hard-to-recover deep-seated objects [12, 13].

Monitoring of geomechanical and geodynamic changes of rock mass is currently carried out by various agencies using different methods and at different accuracy, which makes the comparison of monitoring data, their generalization and use practically impossible. It is necessary to elaborate special geomonitoring of induced geo-processes using the generalized deformation monitoring methods, reference point measurement of rock displacements, GPS technologies, as well as assessment techniques of stresses and groundwater flow. Such geomonitoring should be all-inclusive and inter-disciplinary to embrace and analyze very many different data using IT.

The technical level of traditional geodetic observations in geomechanical monitoring not always meets the requirements of mines as the work takes much time and it is impossible to obtain necessary and real-time information on deformation of rock mass. Therefore, we believe that use of modern geodetic instruments (electronic tacheometers, GPS technologies and laser scanners) in geomonitoring and the improvement of geodetic survey is closely related with innovation [14]. This confirms the importance of geomechanical geomonitoring procedure perfection using modern geodetic instruments as the basis of effective solution to the set problem of science and technology.

Modern methods of geomechanical monitoring in open pit mines are highly varied. Laser scanning, electric tacheometers and GPS technologies are the most common equipment in safety monitoring in pen pit mines [15, 16].

Methodology

The methodological analysis of geodetic observations with a mine field suffers from the lack of effective ways to determine deformation values, which calls for improvement of methodology of geodetic observations over deformations in rocks using modern facilities. Geodetic observations reveal deformations in rock mass, which is essential for assessing the geomechanical situation in the field development area. **Figure 1** describes a procedure proposed for the rock mass behavior monitoring.

This procedure allows defining, formulating and validating the goal, idea and structure of the integrated geo-monitoring in Central Kazakhstan [17–19].

Results and discussion

According to block 1 of the recommended procedure (Fig. 1), the geological and geotechnical conditions of giant copper deposit Saryoba located in Central Kazakhstan are carfully studied.

According to block 2 of the procedure, the structural features are inspected on rock exposures, and physical and mechanical properties (PMP) of rocks are tested on core samples from geological exploration wells. The analysis of the PMP test data allows the graph-analytical correlation of the rock strength and occurrence depth and prompt updating of layer-by-layer calculations of pitwall slope stability (**Fig. 2**).

The curves of the rock properties are plotted by the averaged indicators by depth at a step of 50 m. Reliability of the curves is evaluated using

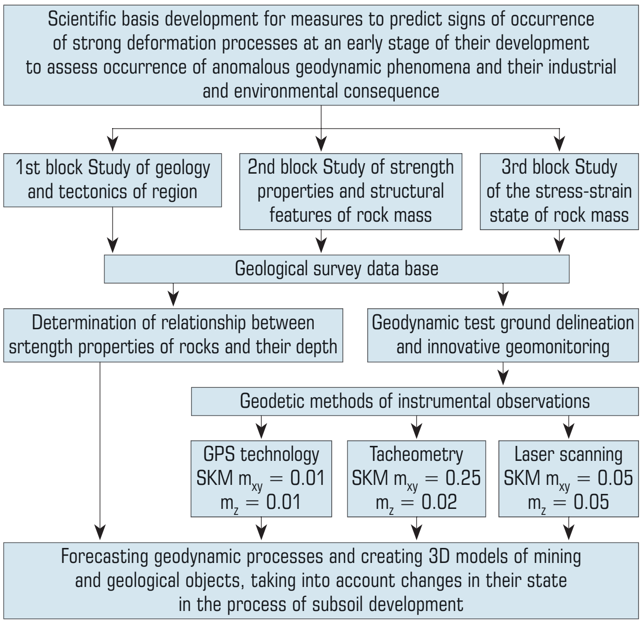


Fig. 1. Integrated geomonitoring procedure architecture

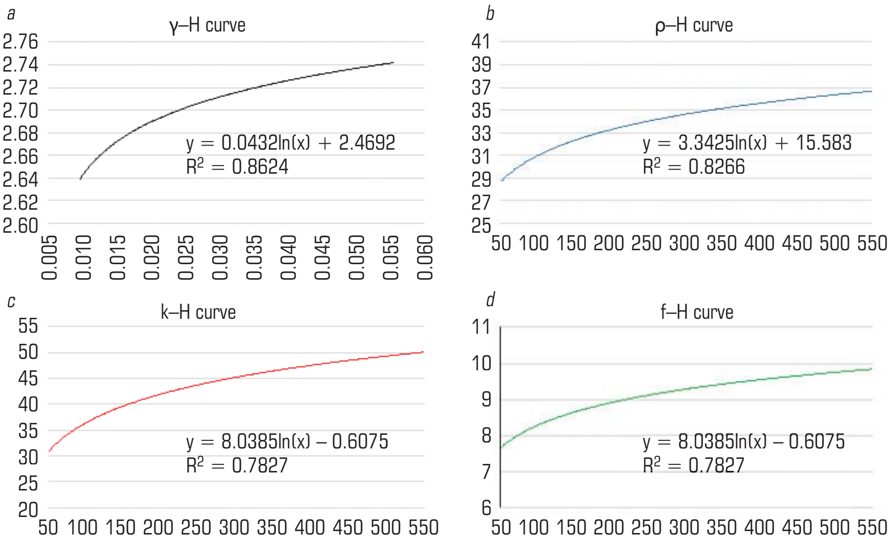


Fig. 2. Strength properties versus occurrence depth occurrences H for massive limestone:
(*a*) density γ; (*b*) internal friction angle ρ; (*c*) cohesion k; (*d*) rock hardness f

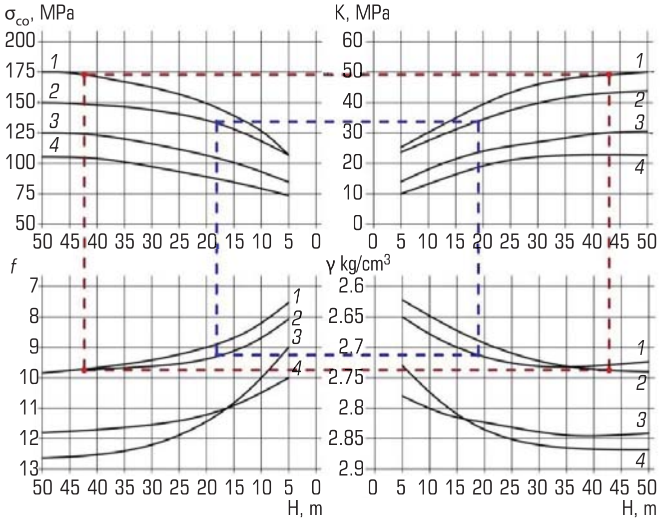
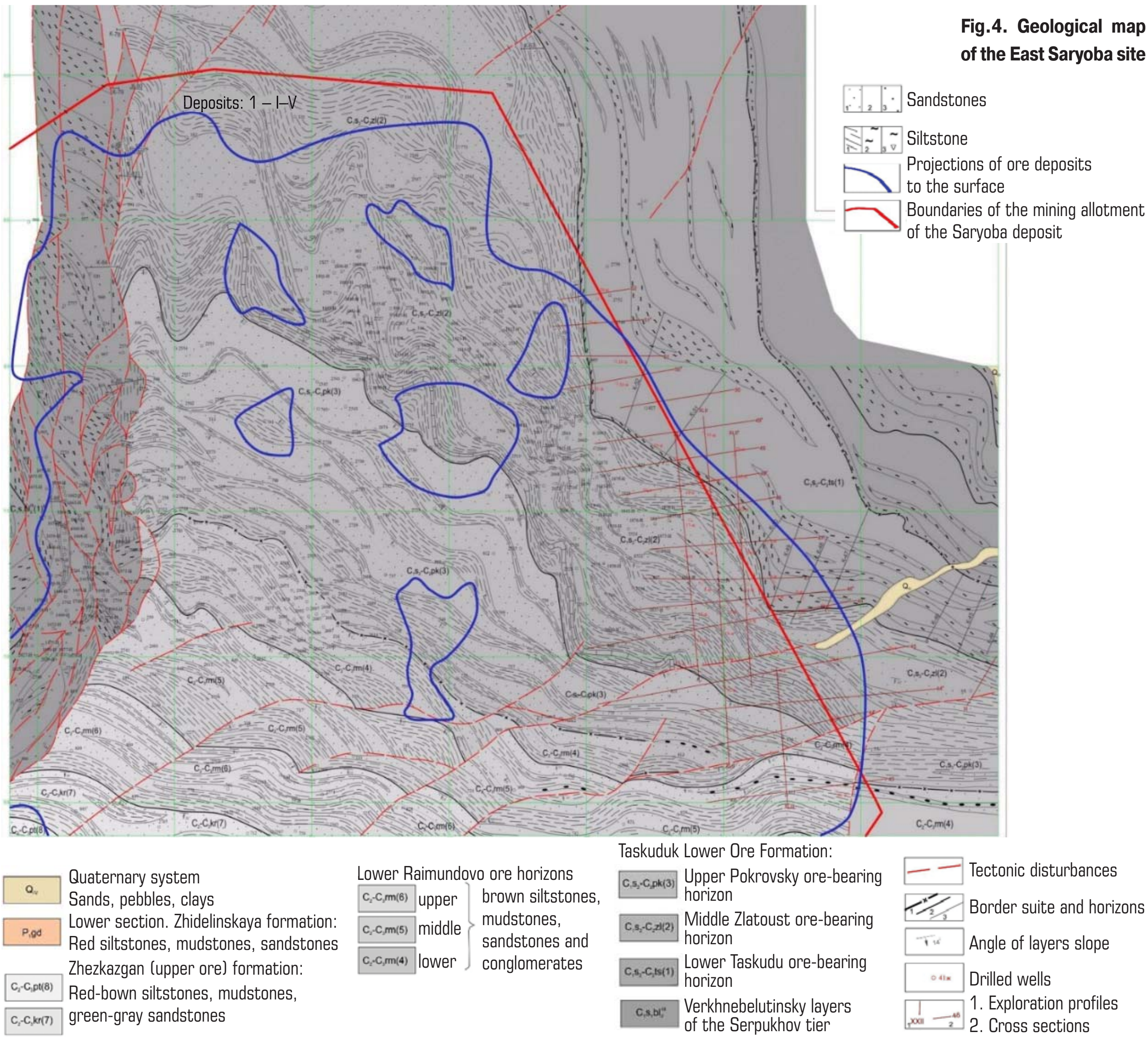


Fig. 3. Properties of rocks versus rock occurrence depth:
1–Saryoba deposit; *2*–Akzhal deposit, *3*–Sayak deposit, *4*–Akbakai deposit (σ_{co}–compressive strength of rocks, MPa; K–cohesion, MPa; f–rock hardness; γ–density)

formulas of mathematical statistics. The deviation of the calculated and empirical relations fluctuates in within 5–8%, and the curves mostly coincide. The data analysis also shows that the strength properties of rocks noticeably changes with depth [20, 21].

The similar dependencies were also obtained for a number of fields in Kazakhstan, namely, the fields of Akzhal, Akbakai, Sayak etc. To find general variability patterns of rock mass strength and structure, data on a number of deposits are generalized and the graphic-analytical relationships between the average density, cohesion, compression, strength of rocks and their depth are obtained. The depth intervals for averaging the strength data for plotting was

Fig.4. Geological map of the East Saryoba site



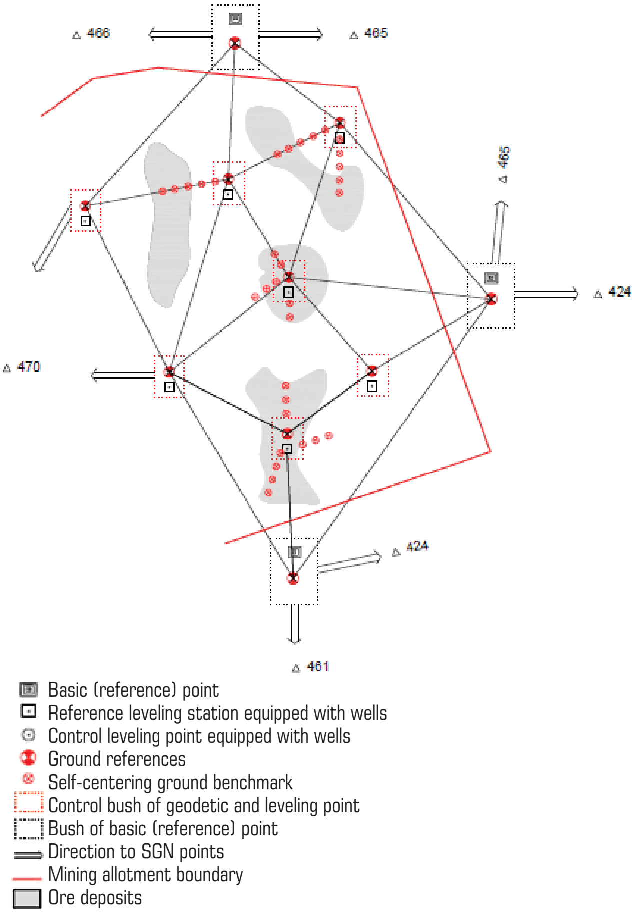


Fig. 5. Layout of observational network within geodynamic test ground

Fig. 6. Monitoring by GPS receivers and electronic tacheometers installed at permanent forced centering points

5 m. To compare the preset test results with the data from other mines [22–24], the integrated graph of relationship of rock properties was plotted (**Fig. 3**).

To date, various methods and techniques are available for the stress–strain monitoring in rock mass, including VNIMI's method of stress relaxation, core disking, etc. The present authors have developed the acoustic method of the stress–strain prediction in rock mass [25]. In this method, sensors are installed in rock mass to receive noise from natural sources in rock mass and to determine parameters of these signals later on.

According to block 3 of the procedure, the monitoring of a vast area of the giant copper deposit composed of a few ore bodies at various depths requires high-precision geodetic justification.

In the ore province of Saryoba, 11 ore deposits are identified, including 109 proved ore bodies. Moreover, the Saryoba province contains pre-mineral and post-mineral disjunctives which greatly complicate detailed exploration and mining (**Fig. 4**).

The traditional geodetic networking over a vast area of a mine field takes much labor and money. The authors propose to replace long leveling lines with local geodetic imaging in the form of geodynamic profiles, profile lines and control clusters of geodetic and leveling points. The integrated application of the ground and space geodetic methods will make it possible to cover the entire mine field area with monitoring observations, as well as to increase efficiency of observations and to reduce a large area and designed for deep seams, the authors suggest covering a mine field with *chief* branches of *base* (reference), support (initial) and check points of ground control and leveling [26, 21].

All key points are located in accordance with the layout of ore veins (see Fig. 4) and are tied to the points of the State Geodetic Network (**Fig. 5**).

Instrumental observations showed complexity of the field work, especially transferal of the equipment (the tool, tripod, rails, etc.) from one point to another. In this regard, in order to speed up the installation and measurement operations, the permanent forced centering points (FCP) have been developed to be set at the reference point during geomechanical monitoring. The FCP belongs to the geodetic centers for new instruments and signals [26].

Purpose of this invention is to improve accuracy of centering and to enhance efficiency of measurement at observation points unequipped with tripods. The new device allows fast and accurate centering, and also eliminates using tripods.

The plane coordinates and the preliminary heights of these points were determined by the satellite method using Leica GS16 3.75G geodetic satellite receiver. The final heights of the points were determined by class II geometric leveling method using Trimble Dini03 digital level and barcode rails (**Fig. 6**).

Upon completion of field satellite measurements, the data were converted in office conditions into the universal Rinex exchange format. The office post-processing of the data was performed in Giodis software from Javad GNSS. Giodis is a program for high-precision geodetic processing of GNSS-measurements. To obtain the accurate coordinates and heights, the post-processing included initial data points of the global IGS network. This network is a permanent basis of the data processing and adjustment. Linking our pints to the above network provides high accuracy and consistency of the obtained coordinates and heights with the ITRF2008 world coordinate base and the WGS84 coordinate system. To improve accuracy of the final results, before processing, the project was

Table 1. Satellite measurement processing results

	ITRF2008			WGS84			UTM 42N		
Point	X, m	Y, m	Z, m	B	L	h, m	X	Y	h, m
RP02	1632200.5571	3937264.7502	4729578.8152	48°10'01.00481"N	067°29'00.44123"E	404.6638	5335967.857	387239.534	404.664
RP03	1632741.9030	3937565.5219	4729137.8417	48°09'39.78017"N	067°28'41.81649"E	399.7218	5335320.178	386841.903	399.722
RP04	1633280.7021	3937890.2852	4728683.2077	48°09'17.74768"N	067°28'23.75454"E	398.8271	5334647.385	386455.317	398.827
RP05	1632111.4814	3937723.5393	4729218.9788	48°09'43.83469"N	067°29'12.92478"E	396.4978	5335432.674	387486.927	396.498
RP06	1633215.0023	3937251.3304	4729235.7251	48°09'44.52246"N	067°29'14.84566"E	399.9548	5335477.642	386287.716	399.955
RP01	1632921.1178	3937041.9195	4729532.5184	48°09'58.31277"N	067°29'24.09944"E	416.9637	5335899.6	386487.308	416.964
RP02.10	1632391.6424	3937148.8425	4729615.0502	48°10'02.60468"N	067°28'49.75059"E	409.0589	5336021.61	387019.714	409.059
RP05.10	1632288.9604	3937600.6683	4729268.3701	48°09'45.99982"N	067°29'02.71440"E	402.9158	5335503.674	387277.348	402.916

Table 2. Static GNSS measurement results

Temporary benchmarks	Adjusted coordinates by the method of static measurements, first session, August 2021			Adjusted coordinates by the method of static measurements, second session, May 2022			Difference, m		
	E (Easting)	N (Northing)	H (Reduced height)	E (Easting)	N (Northing)	H (Reduced height)	dE	dN	dH
RP01	388487.308	5338999.600	416.964	386487.317	5335899.609	416.960	0.009	0.009	–0.004
RP02	387239.534	5335967.857	404.664	387239.541	5335967.868	ref.coordinates	0.007	0.011	–
RP03	388841.903	5335320.178	399.722	reference coordinates		399.711	–	–	–0.011
RP04	388455.317	5334647.385	398.827	386455.324	5334647.395	398.825	0.007	0.010	–0.002
RP05	387486.927	5335432.674	396.498	387486.936	5335432.684	396.494	0.009	0.010	–0.004
RP06	386287.716	5335477.642	399.955	386287.728	5335477.651	399.958	0.012	0.009	0.003

Notes: RP3 coordinates and RP2 elevations were used for adjustment
Measurement method : Static measurements
Coordinate system : Coordinate system WGS-84 UTM Zone 42
Elevation Datum : Height system Baltic 1977
All dimensions are in meters

added with the data of accurate satellite ephemeris, ionospheric charts, condition cards troposphere and updated satellite hours for the period of field work (**Table 1**).

The use of these data in post-processing made it possible to eliminate the main sources of errors that occur when performing satellite measurements, and to increase accuracy of the final results, i.e. the plane coordinates and heights of the test points. Position of initial benchmarks in the created observation system is determined by linear–angular point position fixing on the reference mine surveying geodetic network. Guided by the high-precision satellite measurements, the profile lines were drawn and the geodetic measurements carried out at the main geodetic points using the TS15 Plus tacheometer [27].

In this manner, the integrated geodetic measurements were implemented in the Saryoba field, namely, coordination of 6 GFCPs using GPS technologies. Satellite observations were implemented using modern geodetic instruments GS16, in static mode, and the network method. All in all, 4 observation sessions were performed on 6 GFCPs, and duration of a session was 4–6 hours. Displacements were revealed from the in-situ instrumental observations along profile lines of 6 GFCPs by the method of trigonometric levelling: the tool was positioned and the datum point was assumed as the point of the GFCP shoe. Two season observation data were used to compare the initial and second observation cycles (**Table 2**). The comparison revealed the difference of heights in profile lines 1 2 and 5 of FCP, which enabled detecting the sites of displacements on ground surface at the Saryoba deposit.

Conclusions

The database of geospatial data on ore deposits in Central Kazakhstan was created. The strength properties, structural features and the stress–strain behavior of rock mass on the lower levels of the test mine were studied to create three-dimensional models of geological objects with regard to their changes in the process of subsoil development.

The modern approach to setting up and performing observations of geodynamic and geomechanical processes during development of ore deposits was analyzed, the geodynamic test ground (GTG) was created, consisting of 6 permanent reference ground points of forced centering and 72 deformation benchmarks, and the reliable framework was formed for organizing long-term monitoring of slow deformation processes of the earth's surface during large-scale ore mining in Central Kazakhstan.

The permanent ground point of forced centering is designed to improve productivity and accuracy of observations. The zero and second cycles of monitoring of the Earth's surface using the GS16 GPS device were accomplished, and a catalog of coordinates of the points and benchmarks within GTG was compiled.

Acknowledgment

The study was supported by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, Grant No. AP14871694828.

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