ANNOTATION

Of the work of Kozhayev Zhenis Tursunalievich on the theme: "Investigations of the processes of displacement in the weakened zones of the deposit on the basis of geodetic and space technologies", submitted for the Ph.D. degree in the specialty 6D071100 - "Geodesy"

The relevance of the research theme. The increase in the intensity of development of mineral deposits is accompanied by manifestations of deformation processes that do not fit into modern concepts of the rock mass shift. So, for example, at present in Kazakhstan and Russia (the Krasnoyarsk mine of SUEK-Kuzbass OJSC, Kazakhmys JSC, etc.), there are gaps on the earth's surface that are not predicted by normative methods. In addition, the rates of excavation of minerals have dramatically increased, which also raises questions about the assessment of the reaction of the earth's surface to these impacts. This trend is global in nature, accompanied by an increase in the intensity of negative manifestations on the earth's surface in the territories of mining mineral deposits. A good example is the Zhezkazgan ore deposit. For many decades, as a result of the mining of mineral deposits, a dense network of various underground mine workings was formed. To increase the volume of copper production, with the excavation of deposits, it is necessary to develop ever deeper horizons in unfavorable and difficult mining and geological conditions. In a number of cases, this leads to the destruction of the pillars and the collapse of the overlying strata, down to the earth's surface. In these zones, further mining of mineral resources is prohibited, in accordance with the rules of industrial safety of mining. However, under the zones of collapse, there are significant reserves of minerals that can not be lost, provided reliable prediction of the process of displacement of the earth's surface on the basis of geomechanical monitoring.

In this connection, the actual task is to increase the reliability of the determination of the displacement of the earth's surface with the help of fundamentally new measuring instruments that improve the geomechanical methods of observation, by definition and forecasting of the deformation processes of the mountain massif.

The thesis was carried out on the basis of the project studies: No. 1059 / GF4 "Mineral development in weakened zones with support for geomechanical monitoring based on innovative surveying, topographic and geodesic and aerospace technologies" at the Annensk deposit of Kazakhmys JSC.

The purpose of the work is to develop an integrated system for observing geomechanical processes of earth surface displacement in weakened zones of the field on the basis of geodetic and space technologies "

The idea of the work lies in the technology of building situational maps based on geomechanical monitoring of the earth's surface in the weakened zones of the field with the use of geodetic and space technologies.

The main objectives of the study:

- analysis of existing methods of geomechanical monitoring in the study of faulty zones of the earth's surface in the development of mineral deposits;

- the development of a rational method for constructing displacement maps of the earth's surface in the weakened zones of the field using the results of space-based radar interferometry.

- creation of a three-dimensional model of the geomechanical state of a mountain massif taking into account the conditions for the formation of dips on the earth's surface;

- the development of a method for zonal zoning of the earth's surface of the field by the degree of danger to collapse.

- practical implementation of the developed methods and recommendations for forecasting areas of possible man-made violations and measures for their timely prevention in mining operations.

Object of study. Annenskoye copper ore deposit LLP Corporation Kazakhmys.

The research methodology consists of a literature review and practical experience in the study of geomechanical processes, the methodology of geomechanical monitoring, the use of modern geodetic instruments, complex analysis and mathematical methods of processing results and the use of GIS technologies.

The scientific novelty of the thesis is as follows:

- The method for constructing a digital map of the displacement of the earth's surface on run-in areas, the integrated use of aerospace images, differential radar interferometry, and topographic and geodetic observations;

- Graph-analytical dependence is obtained on the basis of measurement results of deformation processes, which allows to obtain the expected maximum permissible deformations depending on the depth and thickness of ore bodies, allowing to choose rational parameters of mine workings for increasing the efficiency and safety of mining operations;

The scientific significance of the work lies in the prospects and the creation of a new approach and management solution for the use of innovative technologies for the collection and processing of geospatial data for the management of mining operations in weakened zones of rocks. In improving the methodology for developing displacement maps of the earth's surface at mining sites based on the results of the CWI and geodetic observations.

Practical significance. It consists in the development and integrated application of innovative methods of surveying and geodetic observations and space radar interferometry based on the use of radar probing systems of a new generation (TerraSarX, CosmoScyMed) as well as ground-based topographic and geodetic measurements in the geoinformation environment for constructing a situational (continuous) map.

The following basic provisions are made for defense:

- method of constructing a digital map of the displacement of the earth's surface in the mining areas of mining operations using the results of aerospace imagery, differential radar interferometry and topographic and geodetic observations;

- graph-analytical dependence on the basis of measurement results of deformation processes to obtain the expected maximum permissible deformation values depending on the depth and development power.

Realization of the results of work. The main provisions of the thesis are recommended for use in mine planning at the Annenskoye mine, geomonitoring for possible processes, displacement of the earth's surface in faulty areas, for forecasting and preventing dangerous situations during the introduction of mining operations.

Approbation of work. The results of the work were reported and discussed at:

International scientific and technical conference of young scientists "Problems of subsoil development in the XXI century through the eyes of the young" (Moscow, IPKON RAS, 2014); 15th international Multidisciplinary Scientific Geoconference and EXPO, SGM 2015, (Albena Resort, Bulgaria, 2015); International scientific and technical conference "Problems and perspectives of integrated development and conservation of the Earth's interior" (Moscow, 2016); scientific and technical council of the Annensk mine (Satpaev, 2016); International scientific and technical conference "Modern scientific potential and perspective directions of theoretical and practical aspects" (St. Petersburg, 2017); International Scientific and Practical Conference "Scientific and Personnel Support of Innovative Development of the Mining and Metallurgical Complex" (Almaty, 2017); International Satpayev Readings "Scientific Heritage of Shahmardan Yesenov" (2017), scientific seminar of the Department "Mine Surveying and Geodesy" (2017).

Publications. On the topic of the thesis 16 publications were published, including 6 articles in scientific publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan; 1 article - in the log, included in the Scopus database, 9 articles at international conferences near and far abroad.

Scope and structure of the work. The thesis consists of an introduction, four chapters, 125 pages of typewritten text, 85 drawings, 17 tables, a conclusion, 111 lists of literary sources and 5 applications.

The first chapter is devoted to the current state of monitoring of deformation processes and a literature review on improving methods of geomechanical monitoring.

At mining enterprises, the mining and geological conditions of the field become more complex, and ore is mined in less favorable fields. With the depth of field development, as a rule, the content of useful components decreases and the stress-strain state of the mountain mass increases. In many fields of the CIS and Kazakhstan, during the development of deposits by the underground method, waste spaces have been created for many years, which lead to the destruction of safety pillars, collapse of the roof and displacement of the earth's surface. Factors such as the complication of mining and geological conditions, the reduction of the content of useful components, the increase in ore losses and the extensive rock shifts, subsidence and collapse of the terrestrial as a whole lead to an increase in production costs.

Such an extensive list of the main factors that determine the process of deformation of the day surface in the development of deposits has been sufficiently studied and a number of measures have been taken to eliminate them.

A great contribution to the study of geomechanical processes was made by the miners of the CIS and Kazakhstan-Trubetskoi K.N., Mashanov A.Zh., Rakishev B.R., Iofis M.A., Turchaninov, Fisenko G.L., Popov I.I., , Borsch-Komponietz I.A., Popov V.N., Makarov A.B., Erzhanov Zh.S., Buktukov N.S., Nurpeisova M.B., Nizametdinov F.K., Kasymkhanova H.M., Shamganova L.S., Bekbergenov D.K. and many others.

The reviewed scientific research describes the results of the current state of the problem being solved in the field of geomechanical monitoring, related to the movement of rocks and the subsidence of the earth's surface in conditions of underground and open mining. They recommend methods for assessing deformation processes that provide the most rational methods for managing the stress-strain state of a mountain massif in the development of deposits.

In the "EPON RK" st.424. It is noted that when developing deposits, it is necessary to systematically monitor the state of subsurface resources, mine workings, slopes of ledges and dumps, ceilings, soils and springs in order to detect deformations in them in time, to ensure the safety of mining operations.

In the process of developing deposits, mining operations must necessarily be accompanied by geological and mine survey observations, i.e.:

- to carry out in full and on a qualitative level the established geological and mine surveying documentation;
- perform mine survey work to ensure rational and comprehensive use of minerals, efficient and safe mining, protection of buildings and structures from the impact of mining;
- constantly monitor the movement of the earth's surface, the stability of the mining mountain range of the quarry to ensure industrial safety while conducting mining operations.

Thus, according to the results of joint research by the geomechanical and geological survey services of the mining enterprise, special observations were made on the deformation processes of the earth's surface and the mountain massif. An example of mining of the Anne deposit, where the depth of mining of ore deposits exceeds 450 m, recommended a number of developments to reduce NDS in order to ensure the safety of mining operations and the extraction of mineral resources. In particular, when mining reserves were mined by the chamber-pillar system, rational schemes were developed for working off the safety pillars, which allowed obtaining additional reserves of copper mining.

The second chapter provides methods for conducting geomechanical monitoring of the deformation of the earth's surface at the Annenskoye field.

The main methods of carrying out geomechanical observations at the Annenskoye deposit were carried out in three ways:

1. Geomechanical monitoring;
2. Space interferometric monitoring;
3. Instrumental monitoring.

Recently, the methods of space-based radar interferometry (CWR), which fixes the amplitude and phase reflected from the surface of a radio signal, are becoming increasingly widespread for determining the vertical and horizontal displacements of the earth's surface.

The principal advantage of the SRI over other methods of monitoring vertical and planned deformations of the earth's surface is the direct measurement of the differences in the relief that occurred during the period between two (three, four) different-time space surveys. The displacement file obtained as a result of the interferometric processing reflects the changes in the relief of the studied earth's surface that occurred as a result of various natural and anthropogenic processes.

The interferometric technique for monitoring earth surface movements presupposes the presence of a pair of SAR images taken from two close, but spaced apart, locally parallel orbits of the spacecraft.

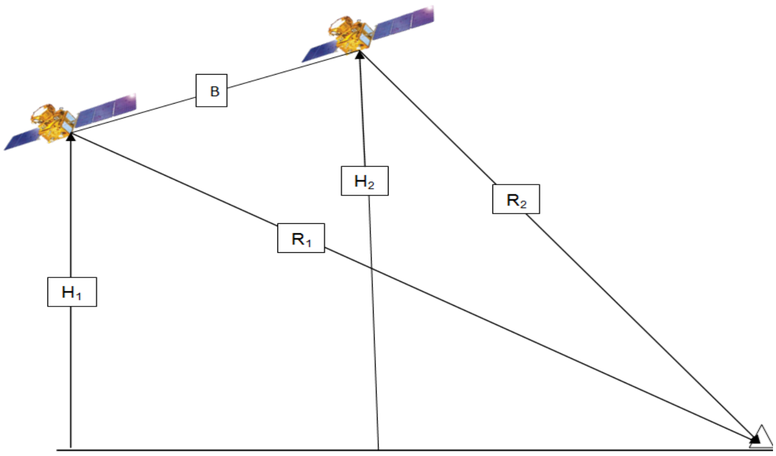

Figure 1-Spatial position of radar, images from which form an interferometric pair

Each radar image of an interferometric pair (or chain) contains an amplitude and phase layer. The amplitude layer is more suitable for visual analysis. The resulting phase Φ obtained during the interferometric processing of the phase layers of the images of the interferometric pair consists of the following components:

$$\Phi = \Phi_{topo} + \Phi_{def} + \Phi_{atm} + \Phi_{n}, \quad (1)$$

There: Φ_{topo} — phase foray due to survey of topography at two different angles;

Φ_{def}— phase invasion due to the displacement of the surface in the period between surveys;

Φ_{atm}— phase incursion due to the difference in optical path lengths due to refraction in the propagation medium of the signal;

Φ_{n}— phase variations due to electromagnetic noise.

This property of the interferometric phase difference makes it possible to measure the movements of the earth's surface by quantities comparable to the radar wavelength, that is, by centimeters or even millimeters.

To create an interferogram for a pair of radar satellite imagery, licensed software products (Gamma, D-InSAR (ERDAS), PhotomodRadar, SARscape (Envi), etc.) are used, which, among other things, enable the creation of high-precision and multi-scale digital terrain models, and a number of specialized maps showing quantitative and qualitative information on the stability of the earth's surface.

As a result of the work carried out, a map of the displacements of the earth's surface of the territory of the Annenskoye mine was constructed, on which soil and soil displacements were recorded in the tundish melt down to 5 cm.

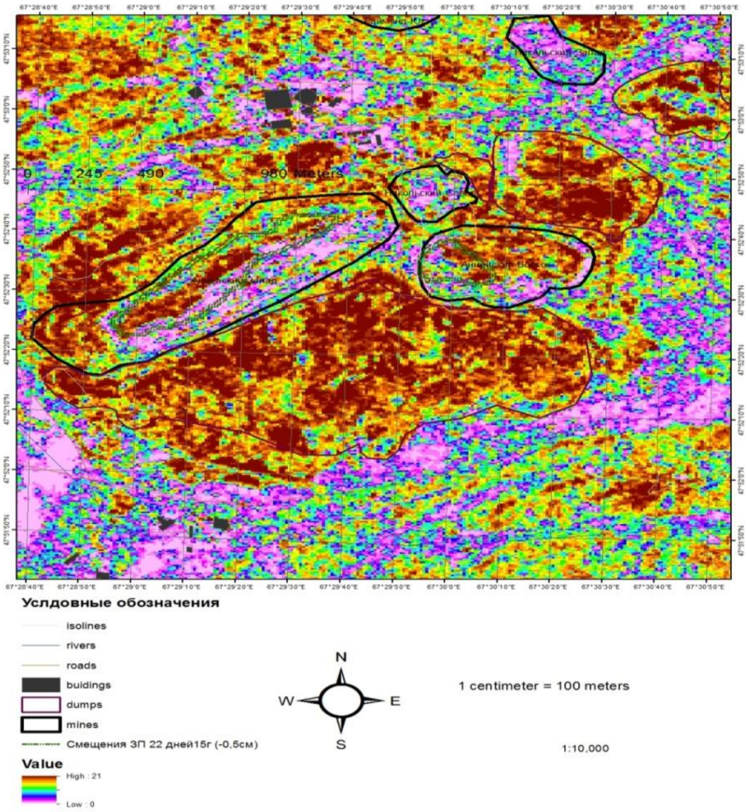

Figure 2 - Results of coherent analysis of a tandem pair of radar images (September 17 and October 9, 2015).

Thus, it is established that the space radar interferometry is one of the most important solutions of the complex monitoring system for the state and construction of a continuous situational map of deformations of the earth's surface.

In the third chapter, the methods of differential radar interferometry are used to determine the deformation of attenuated zones based on the use of aerospace imagery.

The geoinformation technology of constructing a map of earth surface displacements of differential interferometry (DI) for the territory of the Annenskoye mine of the Zhezkazgan deposit is considered. Interferometry combines complex images recorded by antennas at different viewing angles or at different times. Based on the results of comparison of two images of the same section of the terrain, an interferogram is obtained, representing a network of colored bands whose width corresponds to the phase difference for both exposures. Due to the high frequency of the radiation, the movements are recorded with an accuracy of millimeters-the first centimeters. All survey data are presented in digital form, which ensures the objectivity and unambiguous interpretation.

Each point of the complex image can be described in general form as

$$Z(x, y) = I(x, y)e^{i\varphi(x,y)}, \quad (2)$$

there I – the intensity attributable to it, φ - phase of the point and coordinates x and y .

As a result, the definition of complex image points allows us to determine the key value in constructing the difference-phase pattern of interferometric coherence, which shows the degree of decorrelation of the images:

$$\gamma = \frac{[\sum S_1(x) * S_2(x)]}{\sqrt{\sum[S_1(x)]^2 * \sum[S_2(x)]^2}}, \tag{3}$$

there S_1 and S_2 the phase values of the corresponding pixels of the two images.

Interferometric coherence takes values from 0 to 1, it approaches zero in the case of complete decorrelation of images, when information from the interference pattern can not be extracted, and equal to unity in the case of ideal correlation., The higher the value γ , the more reliable the phase measurements read on the interferogram.

For better visualization, interferograms are usually encoded in color. One color cycle corresponds to the phase cycle π to + π.

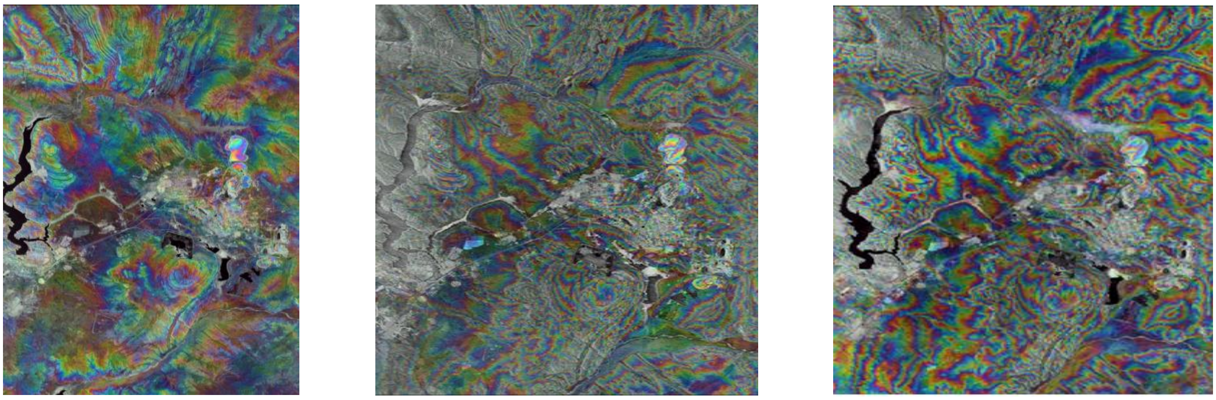

Figure 3 - Examples of interferograms built on pairs of radar satellite images of a spacecraft
TerraSAR-X and COSMO-SkyMed

Figure 3 shows examples of interferograms built on pairs of TerraSAR-X radar satellite imagery with a time base of 351 days (A), COSMO-SkyMed with a 16-day time base (B) and COSMO-SkyMed with a 16-day time base (C) . Three different interferograms illustrate the dependence of the brightness and continuity of the interferometric bands on the survey parameters.

To obtain the displacement map, differential interferometry was used. This helped to identify displacements of the earth's surface, which was carried out using radar images from the TerraSAR-X spacecraft with a time base of nine months.

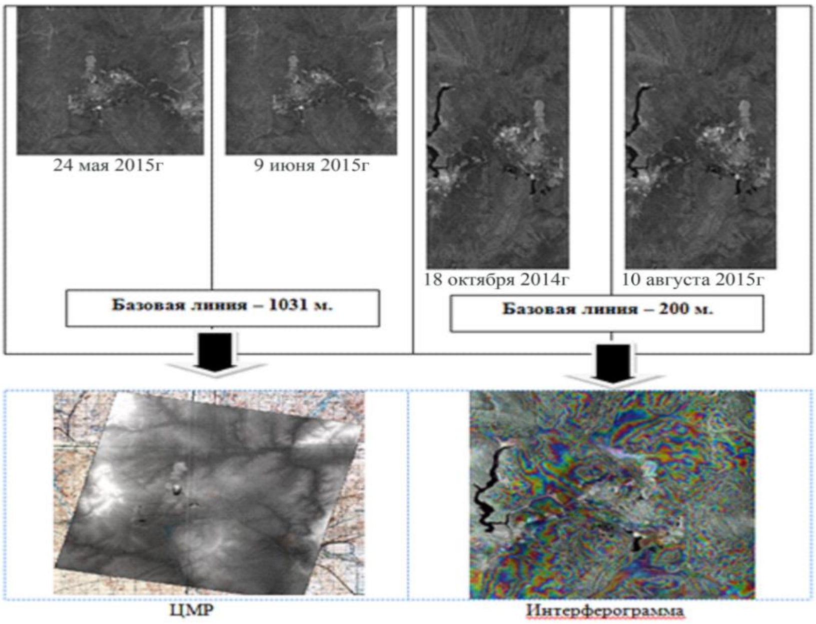

Figure 4 - DEM generation and interferograms

The contours show the values of the vertical displacements of the earth's surface in centimeters.

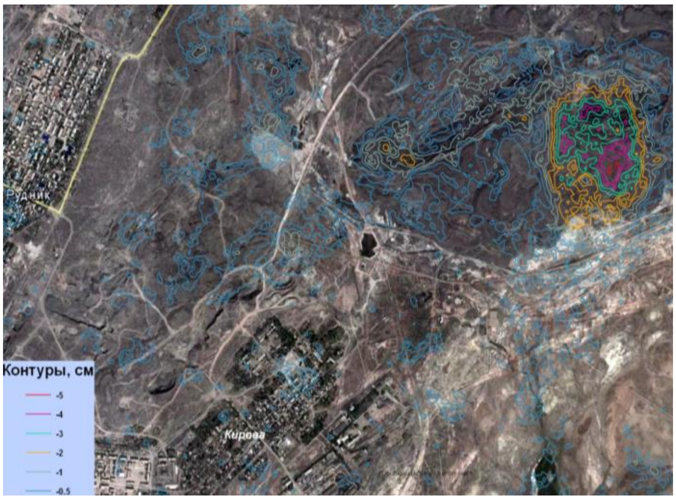

Figure 5. - Map of earth displacements on the Annenskoye deposits

The maximum absolute value of the subsidence of the Earth's surface within the tundra of the Annenskoye mine from October 2014 to August 2015 was 0.8 cm.

Comparative analysis of the results of differential interferometry and comparison of the results of subsidence of the earth's surface, obtained by differential interferometry with the data of surveying measurements for the period 2011-2016. on the profile, showed a fairly high correlation. Figure 6 shows the layout of the profile on the resulting displacement map obtained from interferometric measurements and the magnitude of the displacements along this profile. According to the data of interferometric measurements at the point of reference 27, the absolute value of the subsidence of the earth's surface from October 2014 to August 2015 was 0.8 cm, and by ground measurements this value is 1 cm.

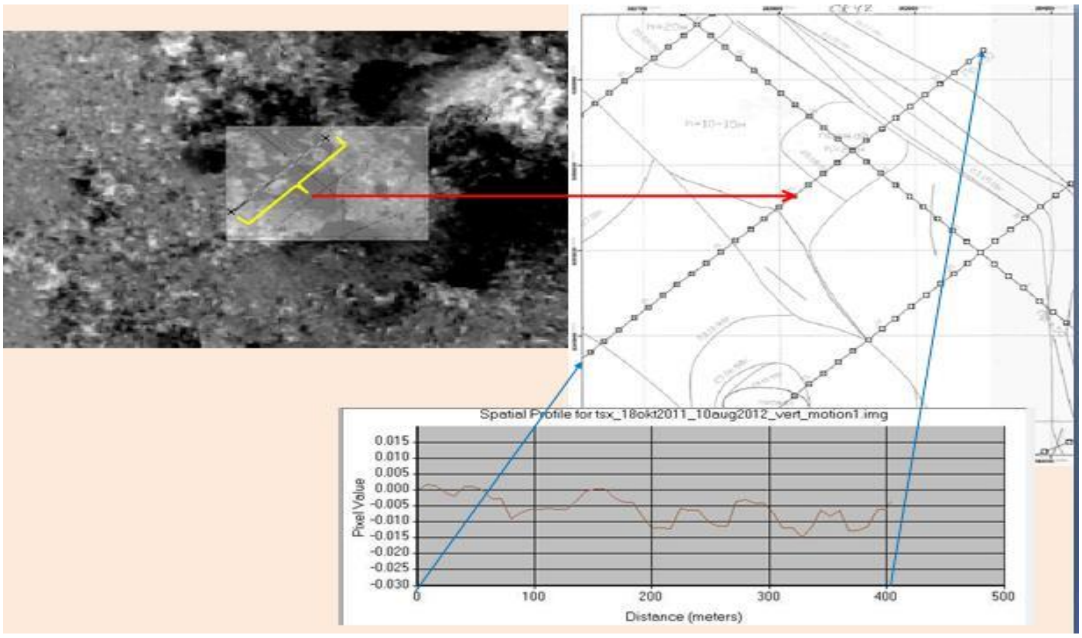

Figure 6 - Comparison of the results of subsidence of the Earth's surface, obtained by differential interferometry and ground-based measurements.

It is established that the application of the interferometry method combines complex images fixed by antennas at different viewing angles or at different times. Based on the results of the comparison of two images of the same section of the terrain, an interferogram is obtained that allowed the two exposures to be recorded with millimeters, the first centimeters are presented in digital form and provides an objective and unambiguous interpretation. The recorded displacements of the earth's surface on the territory of the Annenskoye mine using radar and differential interferometry methods are spatially timed to the tundish of the Annenskoye mine.

The Earth's surface displacement zone obtained from the technology using the data of the TerraSAR-X radar satellite, which has a higher spatial resolution (up to 1 meter), has a more detailed detail and more accurately displays the contours of the intensive-shift trough obtained by ground surveying measurements.

In the fourth chapter, an innovative method for zone zoning of the deposit surface is proposed.

Previously proposed methods by the geomechanical service of Kazakhmys corporation LLP consider that the main drawback of the considered method is that the obtained criterion H / m< 10 is determined only by geometric parameters: the depth of the worked out space H and the output power m. At the same time, it is known that the parameters of the geodynamic event mainly depend on the pressure P on the work area on the side of the overlapping rocks extending from the upper boundary of the worked out space to the surface of the deposit in proportion to their weight, that is, the density distribution in this volume:

$$P = \boldsymbol{k} \int_{\boldsymbol{0}}^{\boldsymbol{H}} \boldsymbol{\rho}(x, y, \boldsymbol{z}) g \boldsymbol{dz}, \tag{4}$$

there к – coefficient of proportionality, g – acceleration of gravity, H – depth of worked space.

The use of the case of the collapse in the Zhezkazgan field of the criterion H/m< 10, based on a retrospective analysis, with the replacement of $H\ by\ H_{pr}$, makes it possible to significantly improve the accuracy of zone zoning, especially in the boundary region.

For example, obtained from consideration of the causes and consequences of the collapses that occurred, it was possible to reveal the correlation dependence of the maximum allowable sedimentation amount η_{ad} on the multiplicity of the working H_{pr}/m

$$\eta = 3.95\ (H_{pr}/m)^2 - 21.28\ (H_{pr}/m) + 55.17, \text{ мм} \tag{5}$$

there η - maximum permissible value of settling, mm;

$H_{пр}/m$ – the multiplicity of work.

Further for convenience we use in the formulas and graphs H as $H_{пр}$.

The correlation dependence describing the parameters of the depleted space and the displacement of the earth's surface is shown in Fig. 7. This dependence can be used for an approximate estimation of the maximum permissible values in those areas where there are no instrumental observations of surface deformations (profile lines of displacement).

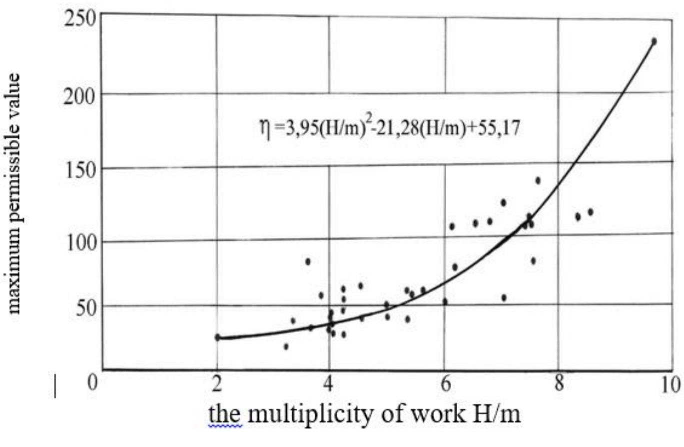

Figure 7 - Graph of dependence of subsidence of the earth's surface from the multiplicity of work

The criterion H / m <10, with the conditional assumption that the supportive crooked space of the cispa has lost its bearing capacity, makes it possible to diagnose the final state of the run-in mountain massif.

The established dependence (7) allows to take into account such factors as the excavation power m and the reduced depth H of the deposit development, the permissible settling velocity η, which determine the conditions and the location of the funnels on the earth's surface. The reliability is confirmed by the fact that all the realized cracks are in the zones identified by the specified criteria (Figure 8).

The obtained correlation dependence makes it possible to obtain the expected maximum permissible deformations depending on the depth and power of the development, and also to solve inverse problems, i.e. choose such dimensions of voids, under which the deformations of the earth's surface will not exceed the maximum allowable for work items. This will significantly increase the extraction ratio of minerals under the built-up objects.

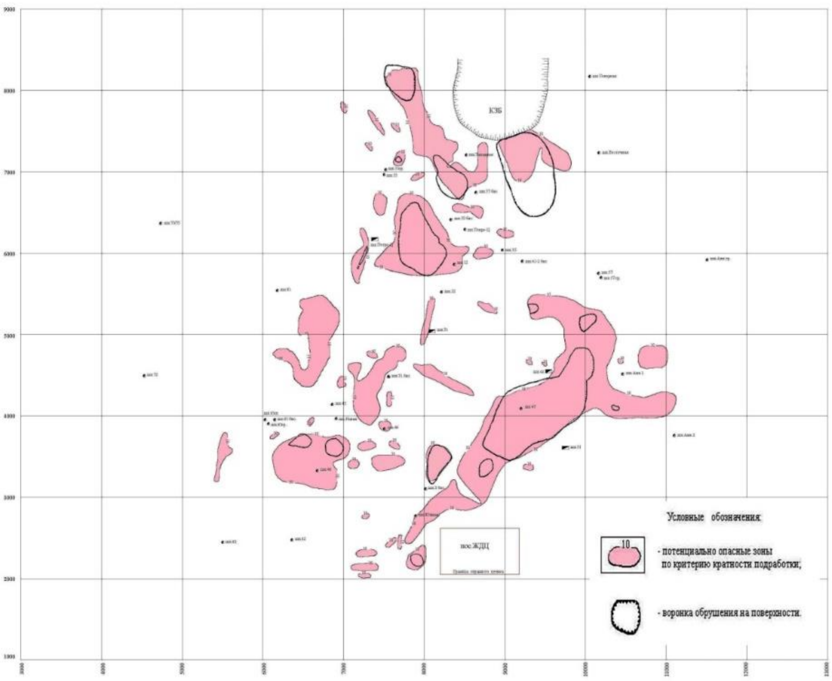

Figure 8 - Scheme of the forecast plan for the multiplicity of processing of the Zhezkazgan deposit

In another method proposed by us, such quantities as the height of the worked area and the overlapping rocks from the boundary of the worked out space to the surface (H), the power (m) are replaced by the vertical component (Zc) coordinate of the center of gravity of the column of the array extending vertically up to the surface of the deposit.

For a discrete mass distribution (the density remains constant in a certain interval), the vertical coordinate of the center of mass of the column Z_c is equal to:

$$Z_c = \frac{\frac{1}{2}\sum_{i=1}^{n}(Z_i^2 - Z_{i-1}^2)\rho_{i},_{i-1}}{\sum_{i=1}^{n}(Z_i - Z_{i-1})\rho_{i,i-1}}, \tag{6}$$

there $Z_{i,}Z_{i-1}$ - coordinates of the boundaries of an interval with a constant density on this interval $\rho_{i,i-1}$, n is the number of intervals.

It should be noted that the position of the center of gravity is determined by the distribution of the mass in depth, and not just in depth, and therefore its change is most sensitive to processes occurring in the mountain massif.

The change in position is characterized by a relative displacement of the center of gravity ε equal to:

$$\varepsilon = \frac{Z_{c0} - Z_c}{Z_{c0}} = 1 - \frac{Z_c}{Z_{co}}, \tag{7}$$

there Z_{c0} and Z_c– vertical components of the coordinate of the center of gravity, respectively, in the initial and current state.

On the plan, using extrapolation method connecting points with the same values of ε, isolines are constructed, dividing the surface of the deposit into certain zones (by analogy with ΔZ).

The most dangerous are the zones with an increased value of ε, which correspond to the largest volumes of excavations and the depth of occurrence. The degree of danger of the zone depends on its area and the difference ε of adjacent zones (from the gradient ε). The zonal surface of the deposit covered by the isolines can be characterized by an effective radius R_{eff} - the radius of a circle whose area is equal to the area of the zone. Accordingly, the value of the gradient ε is determined by the ratio of the difference in the values of the neighboring bands ε to the difference in their effective radii:

$$\gamma = \frac{\varepsilon_i - \varepsilon_{i-1}}{R} \tag{8}$$

For the Annenskoye mine, which is part of the Zhezkazgan deposit, the relative displacement of the vertical component of the center of gravity of the column ε is shown in Table 1.

Table 1. Relative displacement of the vertical component of the center of gravity of the column ε

Zone	safe	danger	High danger
ε, %	ε < 7	7≤ ε	ε >12
Colour of zone	green	yellow	red

Thus, the proposed forecasting method, provided that the criteria can be quickly determined, can provide a sufficiently high level of prediction of geodynamic events. This is evidenced by a sufficiently high convergence of monitoring data with technological situations in actual conditions.

In 2016, field and experimental survey work was carried out to monitor the state of the earth's surface on the territory of the Annenskoye field using an unmanned aerial vehicle (UAV 101).

To process the primary data of the AFS, software products (AgisoftPhotoScan) were used. The tasks of the survey work performed on the dump site of the pilot site were to study the possibility of constructing a large-scale digital bulk model of the quarry surface and assess its accuracy with a view to their further use in other mining and geological systems (Fig. 9).

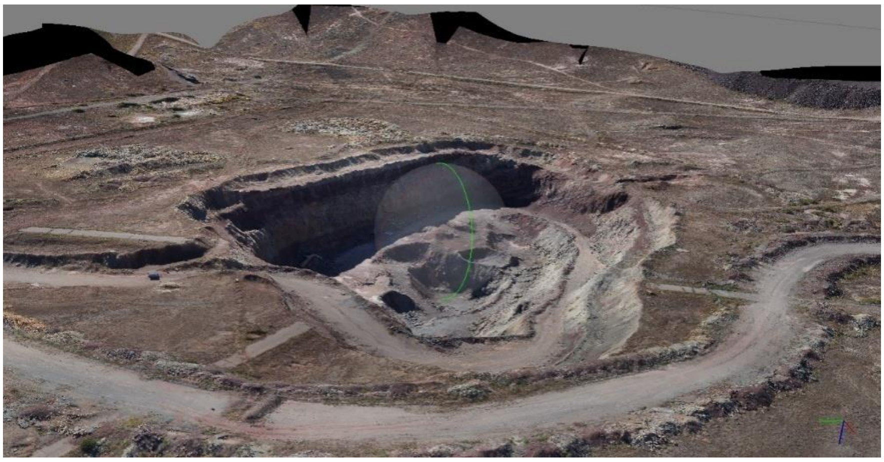

Figure 9. - Map of the survey (orthophotomaps) of the territory of the Annenskoye deposit

One of the basic basic methods for surveying and geodetic control over processes of vertical displacements of a mountain massif and deformations of engineering structures is the high-precision leveling of the profile lines (observation stations), each of which consists of a certain number of benchmarks. On the territory of the Annenskoye mine, high-precision leveling along the 126 bis line was carried out, passing by rail in the area above the deposits of PS-3-II and PS-3-Ihorizontov 260, 360.

Thus, the system of complex geotechnical monitoring carried out during the studies of deformation processes, their control and prediction on the example of the Annenskoye deposit made it possible to determine the rational direction of mining operations to extract the remaining balance reserves in the zones of possible collapse or subsidence of the earth's surface.

Based on the methods of mine surveying and geodetic observations on the earth's surface of the Annenskoye deposit, it was possible to identify weakened zones on the surface of the deposit and rationally concentrate the geomonitoring technology, increasing its intensity, continuity and accuracy.

CONCLUSION

In the dissertation work on the basis of the complex geomechanical monitoring a new solution of the actual problem on the study of geomechanical processes of the earth surface displacement in the weakened zones of the field on the basis of geodetic and space technologies was obtained and allowed to obtain the following results:

1. The analysis of the current state and the study of geomechanical monitoring of the processes of earth surface displacement for the development of ore bodies in the weakened zones of the deposit is carried out.

2. It was suggested that during the period of increasing intensity of development of mineral deposits in complex mining and geological conditions, in particular, in weakened areas of the field, the introduction of innovative methods of geodetic observations for more effective control and prediction of the development of the process of destruction in a rock massif.

3. As a result of the work carried out with the help of differential interferometry, a map of the displacements of the earth's surface of the territory of the Annenskoye mine was constructed, on which soil and ground shifts in the tundish meltdown were recorded up to 5 cm.

4. A comparative analysis of the results of differential interferometry with geodetic observations for the period 2011-2016 was carried out. on the profile lines and showed a fairly high correlation. According to interferometric observations on the bench 27, the absolute value of the subsidence of the earth's surface was 0.8 cm, and by geodetic measurements it was 1 cm, which allows obtaining a high measurement accuracy (± 0.2 cm) that meets the requirement of geodetic measurements.

5. The method of zone zoning of the earth's surface of the deposit is developed and the method of Hpr / m criterion, the relative coefficient of displacement of the center of gravity ε and the gradient of the difference in their effective radii, taking into account the anisotropy of the density of the array, the accuracy of the control and the degree of reliability of prediction of deformation processes are proposed.

6. Geodetic methods of observation with the help of an unmanned aerial vehicle (UAV 101) and high-precision leveling over the condition of the earth's surface in the weakened zones of the territory of the Annenskoye deposit are proposed. A map of the displacements of faulty zones on the earth's surface is created. It ensures the survey of the entire territory with an accuracy of 1-2 mm and significantly reducing the cost of observation compared with space imagery.

7. On the basis of mathematical processing of measurement results, the graph-analytical dependence of the parameters of deformation processes is obtained, which allows obtaining the expected maximum permissible deformation values depending on the depth and development power and allowing to choose rational sizes of voids in order to increase the efficiency and safety of mining operations.