Estimation of Geodynamic Activity and Its Effect on Mining-Geological Conditions And Flooding of Potassium Mines

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Abstract.

The problem of forecasting of geodynamic dangerous zones at early stage of potash deposits development is very important for providing safe mining operation. In result of insufficient geological studies and /or improper mine planning more than 80 potash mines have been flooded over the past 150 years in the world. The author and others have developed special techniques for assessing geodynamic (neotectonic) activity of territories - morphoneotectonic, lineament-geodynamic and landscape-geodynamic analyzes based on remote sensing, which allow to reliably establish geoactive zones of various levels - from regional (with areas of hundreds and thousands km^2) to local (with areas less than 1 km^2). The used methodology includes analysis of the remote sensing data at different scale and defining the spatial distribution of the neotectonic indicators, the most important of which is a density of lineaments. The results of the analysis of modern tectonics and geodynamics in the area of the Verkhnekamskoye potassium salt deposit (Russia, Perm Territory) - the largest in the world and best studied by various geological and geophysical methods, as well as Zhilyanskoe (Kazakhstan) and Tyubegatanskoye (Uzbekistan, Turkmenistan) potassium salt deposits.

Keywords: neotectonics, geodynamic active zones, potash mines, remote sensing, photo-interpretation.

Introduction

Evaluation of the geodynamic activity of the of mine lands in the development of any mineral deposits, including - potassium salts is an essential element of their geological safety.

The problem of forecasting geodynamic hazardous zones at an early stage of potash mining is very important to ensure the safe mining of mineral resources. As a result of insufficient geological research and / or inadequate mine planning in the world over the past 150 years, more than 80 potash mines have been flooded (of which over 30 in Germany, 6 in Canada, 2 in Russia). It was established that the overwhelming majority of accidents in mines occur under conditions of high geodynamic activity of mountain ranges, complicated by high fracturing of rocks [1, 3, 5].

The newest tectonics and modern geodynamics, pronounced geodynamic active zones, discontinuous dislocations and other structures, objects, manifestations, together with the salt karst, determine the main factors of engineering-geological and mining-geological conditions (especially the strength properties of the water-resistant strata of rocks, due to the increased degree of fracture) conducting mining operations in the potash mines. Most accidents at potash mines occur at the boundaries of neotectonic blocks of different levels, where, under conditions of high geodynamic activity, areas with a high degree of fracture of rocks are formed.

In recent years, remote sensing methods, interpretation of satellite images for studying regional interblock faults [2], environmental problems of mining in karst areas [1] and geodynamic zoning of mine lands [5, 6, 7 have been widely used to assess the geodynamic activity of territories of various objects.]. In this article, we present an example of successful use of remote sensing data to solve the problems of the geological safety of mines.

Methodology for assessing geodynamic activity

Geodynamic active zones (or simply geo-active zones) are areas of the earth's crust that are active at the present stage of neotectonic development, characterized by increased fracturing, permeability, manifestations of discontinuous tectonics, seismicity and other processes. They are a powerful factor in the formation and alteration of the ecological, hydrogeological, and geological conditions of the territories of the development of mineral resources, and often lead to accidents in mines.

The basis of the methodology for studying and evaluating geodynamic hazards (geodynamic active zones) in areas of existing and projected potash mines can be a systemic lineament-geodynamic analysis based on remote aerospace geological methods in combination with geophysical, structural geomorphological, hydrogeological and geochemical methods.

The author and others have developed special methods for assessing the geodynamic (neotectonic) activity of territories - morphoneotectonic, lineament-geodynamic and landscape-geodynamic analyzes based on remote sensing, which allow to reliably establish geoactive zones of various levels - from regional (with areas of hundreds and thousands km2) to local (with areas less than 1 km2). Lineament analysis based on remote sensing studies in combination with geological and geophysical data proved to be a useful tool for characterizing the regional and local geodynamic field [5, 6, 7].

Criteria for assessing geodynamic (neotectonic) activity are various calculated indicators. One of the most important indicators of geoactive zones is the increased density of tectonic disturbances (lineaments), expressed in their total length per unit area. The ranking of geodynamic activity by this indicator is carried out according to the gradations, taking into account the classes of statistical distribution according to their intensity (usually 6 grades are distinguished taking into account the arithmetic mean – «x» and the standard deviation – «s»): 1 class <(x-s); 2 class (x-s) ÷ x; 3 class x ÷ (x + s); 4 class (x + s) ÷ (x + 2s); 5 class (x + 2s) ÷ (x + 3s); 6 class > (x + 3s). It is quite confident that they reflect, respectively, various degrees of geodynamic activity (from conditionally stable to conditionally extremely high activity). In this case, geoactive zones include areas with very high and extremely high fracturing, and in some cases - areas with high fracturing, characterized by high contrast relative to the background. The author identifies 9 ranks of geoactive zones by dimension: 1 - planetary zones (several hundred thousand km^2), 2 - subplanetary zones (tens of thousand km^2), 3 - geozones (first tens of thousand km^2), 4 - megazones (first thousand). km^2), 5 - macrozones (several hundreds of km^2), 6 - mezozones (up to 100 km^2), 7 - local I order zones (several tens of km^2), 8 - local II order zones (several km^2), 9 - local III order zones (shares and units km^2). As a rule, large geo-active zones have a complex mosaic structure and upon more detailed study, they are divided into lower-level zones with different degrees of activity. The analysis consists in obtaining a lineament-block model by interpreting satellite images, ranking the territory according to the degree of geodynamic activity and building its cartographic evaluation models, comparing it with geophysical fields. Decoding of digital space images, data processing, geographic information cartographic modeling is carried out using GIS technologies in Arc GIS and ArcView GIS.

Below are some examples of identifying geodynamic active zones based on the analysis of modern tectonics and geodynamics based on aerospace research in various salt-bearing regions: in the Verkhnekamskoye potassium salt deposit (Russia, Perm region), the largest and best studied in the world by various geological and geophysical methods and also Zhilyansky (Kazakhstan) and Tubegatansky (Uzbekistan and Turkmenistan) deposits of potassium salts. In areas poorly studied by aerospace methods, deciphering was carried out over several (5-8) levels of generalization, ranging from survey and regional 1:10 000 000-1: 1 000 000 over large areas (hundreds of thousands of km^2) to detailed work 1:50 000 and 1:25 000 in the mining allotment areas.

Research results and discussion

The Verkhnekamskoye potassium-magnesium salt deposit (VPMSD) is the world's largest deposit of potassium and potassium-magnesium salts. After its discovery in 1925, over 1000 works were published, highlighting its geological structure and genesis, several large monographs were published, a large number of maps and schemes of discontinuous tectonics and faults were compiled (e.g. R.N Valeev, 1974; M.I. Denisov, 1980; G.G. Kassin, 1985, 1991; N.M. Dzhinoridze, 1987; V.P. Belyaev, 1989; L. Noyaksova, 1990; T.V. Kharitonov, 1992; I.A. Sanfirov, G.G. Kassin, 1993; B.M. Golubev, 1998; A.I. Kudryashov, 2001, 2004, 2013; I.A. Sanfirov, S.G. Bychkov, 2009; V.P. Kolesnikov, 2010; V V. Belkin, 2010; G.G Kassin, V.V. Filatov, 2011).

The Verkhnekamskoye field is characterized by increased seismicity, anomalously high values of the velocities of modern vertical movements of the surface, and is limited by deep faults active at the present stage of tectogenesis. The newest tectonics and geodynamics (geodynamic active zones, discontinuous dislocations and structures) together with salt karst determine the main factors of engineering-geological and mining-geological conditions (especially the strength properties of the water-resistant strata of rocks, due to the increased degree of fracturing) of mining operations in potash mines VPMSD [6, 8]. Powerful complex technogenesis leads to the technogenic transformation of the geological environment of the Verkhnekamskoye field.

Within the limits of the geodynamic active zones, earthquake-prone sites are located, the main anomalies coincide with the regional zone of the north-west strike of the possible occurrence of earthquakes. Within their limits, the epicenters of earthquakes were recorded with an intensity of 3-6 points of the MSK-64 scale. All of them are potentially dangerous with the possible presence of weakened sections of water protection strata. Known catastrophic failures at the Berezniki mines – №. 3 (1986) and №. 1 (2006), which led to their complete flooding, as well as failure on the railway tracks in the city of Berezniki in 2010, failure at the Solikamsky mine No. 2 (2014) occurred precisely in the geodynamic active zones.

In 2010, special work was carried out to compile a map of the geodynamic active zones of the Perm Territory at a scale of 1: 500,000 and at the Verkhnekamskoye field at a scale of 1: 100,000 (I.S. Kopylov, V.Z. Khursik). According to the results of the interpretation of digital spectral space images on the territory of VPMSD, more than 1,800 straight lineaments identified with tectonic basement and sedimentary cover disturbances were identified.

According to the regional geodynamic estimate of a scale of 1: 500,000, it was established that the territory of VPMSD is within geo-active zones of the regional level with an area of more than 1,000 km^2. According to the zoning scale of 1: 100,000, over 50 geoactive zones ranging in size from 1-2 to 5-15 km are allocated within its limits. Detailed aerospace geological studies of a scale of 1:25 000, in which the interpretation of digital satellite images was applied, data processing using GIS technologies made it possible to further detail the geodynamic structure – geo-active zones with sizes up to 1 km were identified. Some of them had good spatial convergence with decompression zones by gravimetry (Sanfirov, 2009) and with strong permeability zones for electrical exploration (Kolesnikov, 2010), as well as for GPR studies [4]. Based on a set of geodynamic assessment criteria, geoinformation modeling was conducted and a map of the geodynamic state anomaly was compiled, the data of which were taken into account later when designing mining operations at new sites (for example, Talitsky section) [6].

Zhilyanskoe deposit of potassium and polyhalite salts, located in the Aktyubinsk region of the Republic of Kazakhstan, 10 km east southeast of Aktobe; represented by deposits of polyhalite and sylvinite. It is characterized by a large extent, disunity in plans of and heights of ore bodies, sharp fluctuations in the conditions of occurrence, capacities of ore bodies and the content of useful components. By geodynamic conditions, the Zhilyanskoe deposit area is located in difficult tectonic conditions, being at the junction of the Caspian syneclise (from

the west and directly on the square), the Pre-Urals regional (from the north) trough and the Ural folded system (from the east). The block-thrust interaction of these large tectonic structures is complicated by the salt-dome tectonics, forming a complex modern geodynamic setting. The main geodynamic activity is associated with the system of meridional tectonic disturbance, passing through the field from south to north. It is crossed by numerous local sublatitudinal and diagonal lineaments, which in turn are fledged with short lineaments.

According to the results of aerospace geological research at the Zhilyanskoe deposit, its geological and neotectonic structure was specified. Lineamental-geodynamic analysis and geodynamic zoning were carried out at the level of detail of 1:50 000 and 1:25 000 scale [7]. In the contours of the mining allotment of the deposit, 8 local geoactive zones with very high lineament density are established, their dimensions are 0.7-4.0 km long, 0.3-0.8 km wide. Within their boundaries, 13 sections (with an extremely high density of lineaments), with sizes ranging from 0.1 × 0.2 to 0.6 × 1.5 km, are set. They must be taken into account in the design, construction of the mining and processing plant and in the further development of the field.

Tyubegatanskoye potash salt deposit, located: the northern part - in the Dekhkanabad district of the Kashkadarya region of the Republic of Uzbekistan; the southern part - within the Republic of Turkmenistan. The length of the field from the southwest to the northeast is 24 km with a width of up to 7 km (within the Uzbek part, respectively, 14 and 1.5-3 km). In the contour of the calculation of reserves the area is 69.6 km2. By geodynamic conditions, the region is located in complex tectonic and seismic conditions, being at the junction of the planetary (Eurasian and Indian plates) and subplanetary (Turan plate and Tien Shan orogen) tectonic structures. The block-thrust interaction of these large tectonic structures is complicated by local shear and salt-dome tectonics and karst (Figure 1).

Figure 1. *Landscapes and Geodynamic Manifestations in the Tyubegatanskoye potash salt deposit: a - tectonic fractures, b - karst, c - temporary watercourses, d - brine inflow in the mine*

The main geodynamic activity is associated with the system of the northeastern tectonic disturbance, which passes through the Tyubegatan structure from south-west to northeast. It is crossed by numerous local sublatitudinal and diagonal lineaments, which in turn are fledged with short lineaments. For the field under development, the study of modern tectonics and modern geodynamics is particularly important, since at the end of 2012 there was a strong emergency inflow of brines into the mine shafts at the mine, which with great difficulty was eliminated. It was necessary to establish unfavorable and more favorable areas for the penetration of the shaft.

Remote sensing and interpretation of satellite images were carried out on 8 levels of study - from a survey within the whole of Southern Uzbekistan and Northern Turkmenistan, to a large-scale on the Tyubegatan field and a detailed one - on a section of mine fields with analysis of the latest tectonics and modern geodynamics. According to the results of regional aerospace geological studies of 1: 1 000 000 - 1: 100 000 scales, large lineament zones of alleged tectonic basement and sedimentary cover disturbances were identified. More than 2,150 rectilinear tectonic lineaments of various ranks with prevailing northeastern and northwestern directions, as well as arc-shaped lineaments and ring structures were distinguished in large-scale decoding of satellite images of 1:50 000 - 1: 10 000 scales in the field and the adjacent territory.

Neotectonic zoning was carried out on the basis of lineament-block analysis with the allocation of neotectonic block structures. In

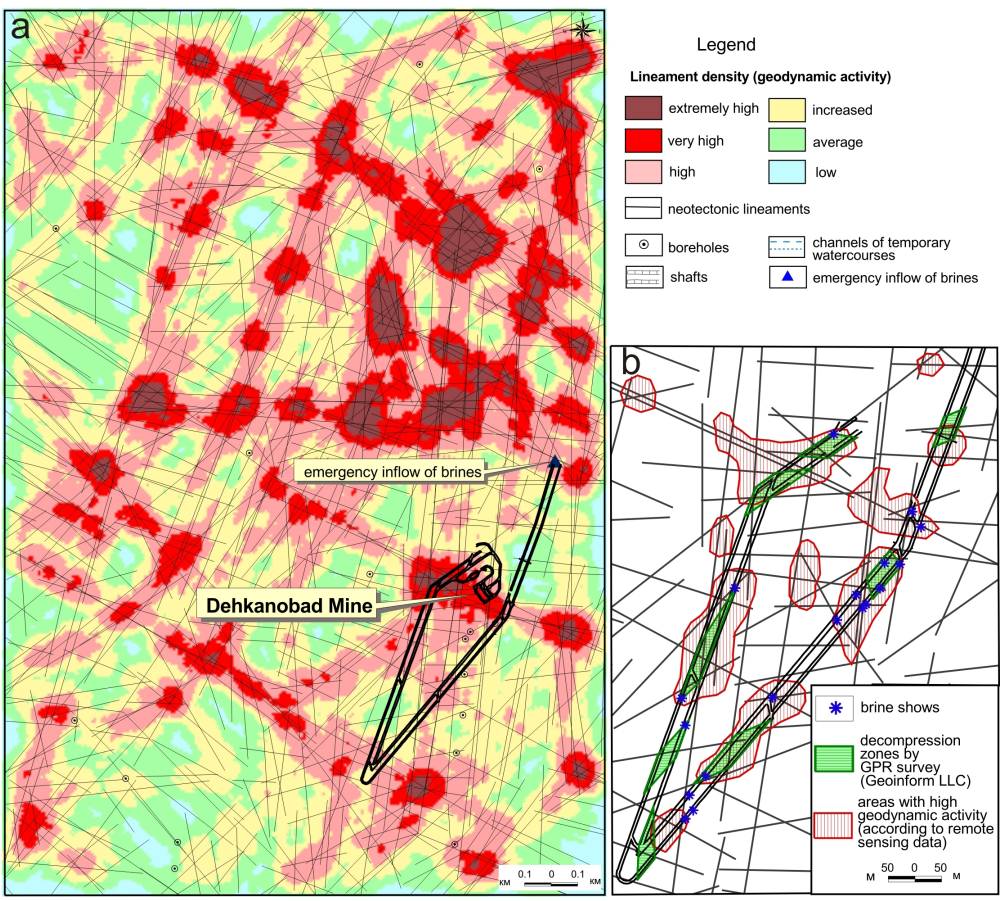

Figure 2. Maps of geodynamic activity of the Dekhkanabad mine territory in scales of 1:10 000 (A) and 1: 5 000 (B)

the central part of the field, 2 mesoblocks, 6 local blocks of the first order and 22 local blocks of the second order, characterized by varying degrees of neotectonic activity, are distinguished. Lineamental-geodynamic analysis and geodynamic zoning were performed at the level of detail scales of 1:50 000, 1:25 000 and 1:10 000. 10 geoactive zones were identified in the area of the field (Figure 2).

The largest of them is the Tulesh geoactive zone in the northern part of the central part of the field, isometric in shape, with an area of 4.3 km^2; in detailing, it is differentiated into 11 zones with areas of 0.01-0.06 km^2 [5]. Taking into account the available geological material in the mine area of the mine, a comprehensive analysis of geological and aerospace geological materials was carried out with the construction of a comprehensive analysis map and methodological recommendations were made for conducting geological and geophysical studies for the safe conduct of mining and industrial development.

Conclusion

Detailed remote sensing studies conducted at the operating mines of the Verkhnekamsk and Tyubegatang deposits show that the results of various remote sensing and geophysics methods are well convergent. This ensures the reliability of prediction of areas of increased fracturing of rocks and brines in mining, knowledge of which is necessary for making operational decisions on the sinking of shafts. In these areas, the most active geodynamic zones are predicted, which represent the greatest danger to mining. In the areas of the mine fields of the Dekhkanobad mine, they were confirmed by field observations and geophysical survey data.

The established anomalous geodynamic active zones (zones of very high and extremely high geodynamic risk) must be taken into account when mining and industrial development of potash deposits. Probably, local areas within geodynamic active zones with an extremely high degree of fracturing should be excluded from the field development, leaving the pillars. So, in the Tyubegatang field, it is necessary to assign reserves in the area of 2, 4, 6 panels to the temporarily preserved ones, which will be worked out at the final stage of mining operations.

According to the results of aerospace geological studies in all the regions we studied, high spatial and correlation convergence of geodynamic active zones with geophysical, geochemical and hydrogeological anomalies with areas of unfavorable geological processes and phenomena and soil conditions, increasing the intensity of dangerous natural and man-made processes was established. The provision on the leading role of geodynamic active zones in the formation of geological, hydrogeological, engineering-geological and geoecological conditions is confirmed.

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