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GEOMECHANICAL STATE OF THE ROCK MASS AT THE TASHTAGOL MINE IN THE COURSE OF NUCLEATION AND MANIFESTATION OF ROCK BURSTS

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Integrated research data are presented for the earth motion and rock mass displacement at the Tashtagol Mine under general intensification of the dynamic geomedium activity, including periods of rock burst developments, by using conventional and satellite geodesy procedures.

Rock burst, tectonic disturbances, geodynamic movements of rocks, tectonic stresses, technogenic impact

INTRODUCTION

The iron-ore deposits in Gornaya Shoria and Khakasia are developed under abnormal seismic and rockburst hazard. Rock shocks, rock bursts and micro-bursts are typical of the local Tashtagol and Sheregesh deposits. The Kaz and Abakan deposits are distinguished for rock spalling, exfoliation and loosening, and for seldom low energy shocks [1]. The Tashtagol deposit is known as the most hazardous by both the number of seismic events and their energy.

The analysis of features of the dynamic events at the Tashtagol deposit makes it possible to reveal that a majority of them occur in wall rocks. It is typical that a dynamic event develops on a sudden, with no relation to blasting operations, for example, rock bursts registered on April 30, 1982; November 27, 1984; November 28, 1987; August 31, 1992. In the most cases, the form of the fracture, e.g., buckle of rail tracks, arching of walls in mine workings, points at the tectonic stresses being crucial in these processes.

Since early 1980s, rockbursts started capturing larger areas at the Tashtagol deposit. Sometimes a number of stopes at two or more mining levels including wall rocks, failed under dynamic impacts. Rock bursts being confine to tectonic disturbances and dikes, the rise of appreciable wall rock movements along with a variety of epigenetic fracture foci refers them to the tectonic events (December 25, 1982; November 28, 1987; January 4, 1990; February 19, 1992; March 29, 1998; October 24, 1999). It is important to outline that the Rockburst Prediction and Prevention Service at the Mine monitors regularly the rock mass state by employing the electrometry procedure. Nevertheless, the hazard of a dynamic event development is not detected, as a rule, the rockburst hazard is not revealed in mine workings because the prime fracture focus is usually deep in the rock mass and is formed under large-scale blasting and additional dynamic loading exerted by moving wall rocks. Considering high rock burst energy accumulated during geodynamic processes, the present studies were focused on the behavior of large rock mass sections braced by complex geodetic chains underground and on the surface (Fig. 1).

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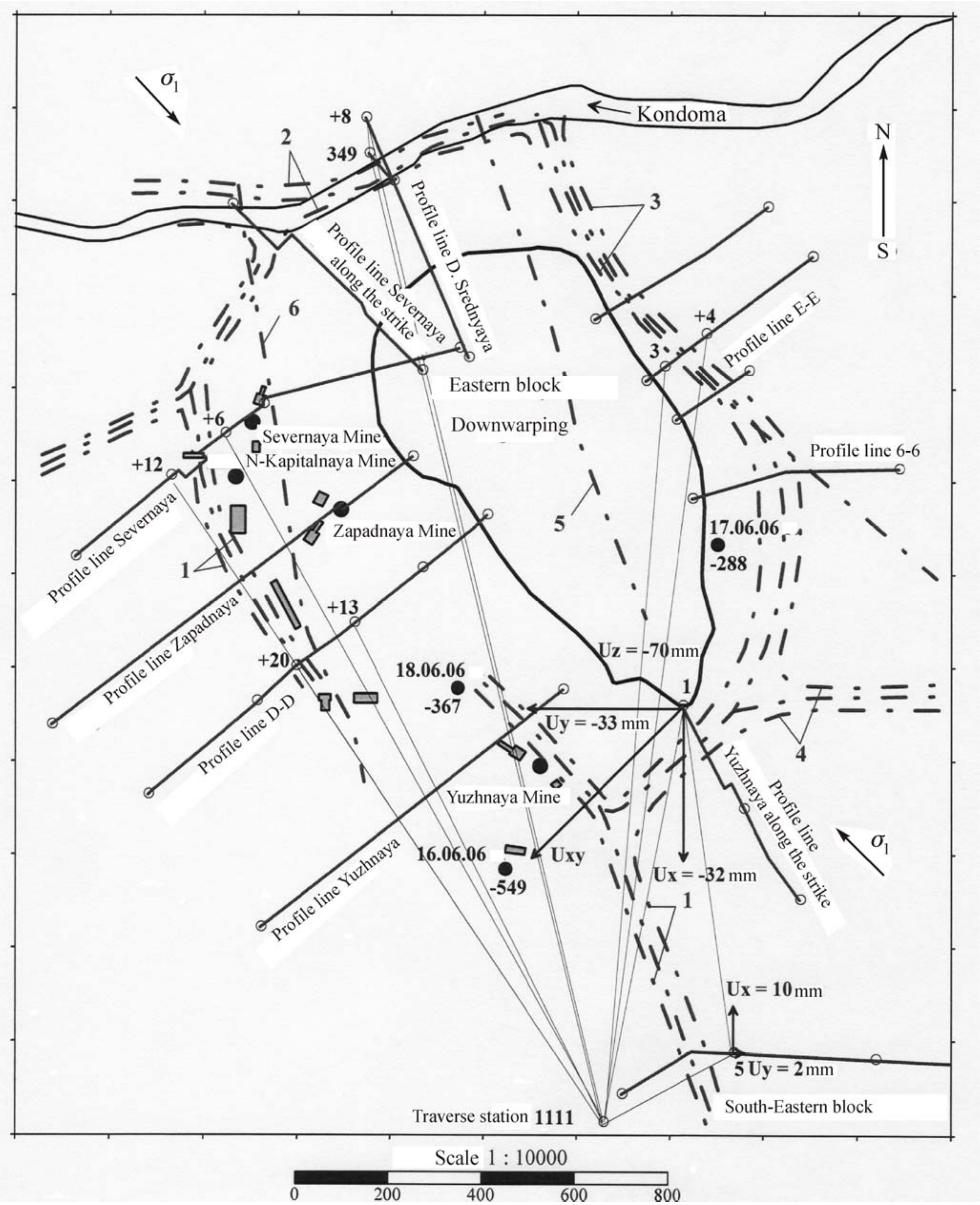

Fig. 1. Scheme of geodynamic ground for observation of fault activity at the Tashtagol deposit, GPS-observation data of June 16, 2006 are cited: 1, 2, 3, 4, 5 — faults “Kholodny,” “Kondomsky,” “Nagorny,” “Shakhtyorsky,” “Diagonalny,” respectively, 6 — submeridian tectonic disturbance; ● June 17, 2006 – 288 — shock hypocentre in a rock mass, date of its manifestation and depth from the zero level

ROCK MASS MOVEMENT MONITORING — CONVENTIONAL GEODESY PROCEDURES

The most representative data on development and manifestation of rock bursts in rock mass at the Tashtagol Mine were obtained at deep reference point stations installed at five levels of the mine in the areas of Diagonalny and Nagorny (Vostochny) faults [2].

The large-scale rock mass weakenings in rock crumpling zones are responsive to variations of the stress-strain state. The block movements condition the state of the rockburst hazard in the rock mass. Spallings develop along disturbance planes in areas of maximal compression of tectonic structures. The compression accumulation starts 2 – 3 months before a dynamic event manifestation. The contractive strain of fault edges ranges within $(0.3-0.9)\cdot10^{-3}$, or $(1.4-2.1)\cdot10^{-3}$ in particular cases. Boundaries of structural weakenings converge at velocity of 7 – 36 mm/s and up to 280 mm/month at some stations. By automated recordings of displacements of the deep reference points, loading – unloading of the rock mass occurs instantly [3], thereby the registered scattering of the displacement parameters is due to the discrete character of observations.

The intermittent direct and reverse movements of the rock mass are a vivid indication of increasing activity of faulting. The alternating-sign displacements and strains in the fault area are conditioned by spalling developed within it. The concurrent rise of reverse displacements at a number of reference point stations in the lying and hanging wall, and appreciably long compressions in the disturbance areas imply that the total stressed state of a mining field tends to grow and the rockburst hazard increases in the rock mass. After a rock burst, the rock mass undergoes unloading in the form of the rock mass tension and exposure of tectonic structure edges.

The role of deep faults in the formation of the rockburst-hazardous situation can be demonstrated on the example of nucleation and manifestation of the tectonic rock bursts. By the recordings of deep reference points in the center of the mined block at levels – 210 m and –280 m in 1992, none of appreciable displacements and deformations of the rock mass were observed. The things changed after the rock burst on August 31, 1992, when the compression along the ore body strike rose at level – 210 m, ort No. 10 (Fig. 2). The excess loading of the rock mass gradually grew in the intermediate section between fringe drifts, the localized compression zones remaining stable for a long time.

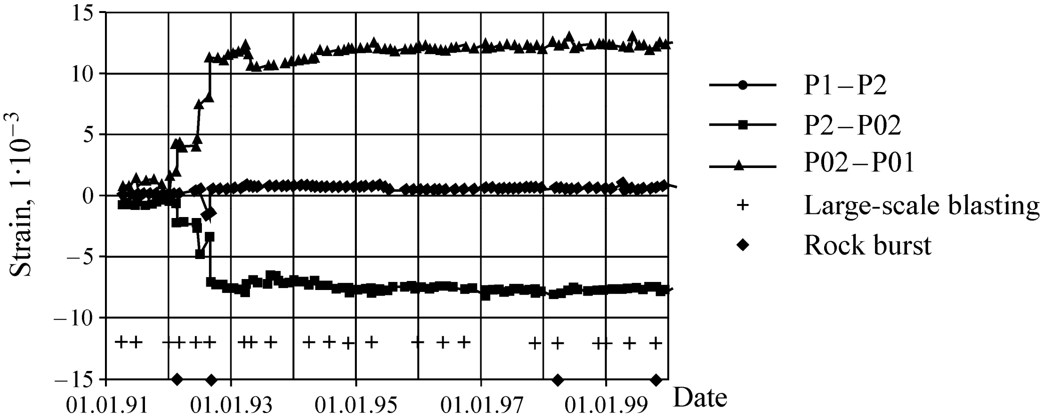

Fig. 2. Time variations in strain of ore at level – 210 m along the ore body strike: reference points R1 and R2 are oriented towards the stoping face and RO1 and RO2 towards the intact rock mass

Since 1994 the further excess wall rock loading in 400–600 m long lying wall sections was registered in cross-cuts at levels –140 m and –280 m (Fig. 3). By early 1998 the total compression of the area from shafts to fringe drifts was more than 100 mm. The tectonic rock burst initiated by large-scale blasting in March, resulted only in partial unloading of the rock mass with more than 40 mm jump-wise displacement of rocks towards mine workings. The balance of accumulated energy released with the next tectonic rock burst on October 24, 1999. An opportunity for the development of a large-scale dynamic event at level (–280) ÷ (–210) m, orts Nos. 9 ÷ –13 was forecasted by indirect estimates of host rocks and by the character of deformation development. The new wave of extra loading was registered in long sections nearby the ore body. The dynamic event of $2.3\cdot10^9$ J took place at 830 m depth in 26 s after the large-scale blasting of a block at level (–280) ÷ (–210) m. The mining area is specified by crossing of steeply-dipping diagonal fault and thick flat-dipping fault at the block bottom. The rock shock caused failure of mine workings at level –210 m, orts Nos. 6–10 and level –280 m, orts Nos. 8–18, namely, upheaval of railways by 0.6 m, fracturing and cleaving in concrete roof and wall supports, rock outbursts, the total volume of ore falls at underlying level exceeded 900 m^3.

The recorded jump-wise displacement of deep reference points ranged within 60–100 mm towards the worked-out area at level –210 m and 13–20 mm towards the ore mass at orts Nos. 11–12, level –210 m and orts Nos. 16–17, level –280 m, thus indicating appreciable dynamic loading in the area of the block under extraction. There are the stations where, judging from the character and values of displacements of the reference points, the process ran more intensively, along with the stations where no displacement of the rock mass was registered. Diagonalny and flat-dipping faults served as interfaces.

The dynamic events in 1999 were intensified by active surface displacements at the deposit location. The rates of strains and rock displacements towards the downwarping increased 2–3-fold as compared to the previous observation periods, the maximum increment of horizontal displacements (surface extension up to 37 m) occurred at the boundary of tectonic structures (submeridianal fault, Kondoma fault), being the feature of this event. The production mining area appeared under an impact of tectonic stresses, higher by both components: along and across the ore body strike. It is important to mention that in previous period (1996–1998), the reverse displacements and upheaval of reference points were observed, and, moreover, the most loaded areas were at a large distance from mine workings, beyond the boundaries of the tectonic faults. The large-scale blasting in a highly compressed rock mass distinguished for the complicated structure and tectonic faulting of steep and flat dipping, involved extra loading of the rock mass adjacent to the blasted block and resulted in the breakdown of contacts of large blocks between Diagonalny fault and the flat-dipping fault at level (–280) ÷ (–210) m.

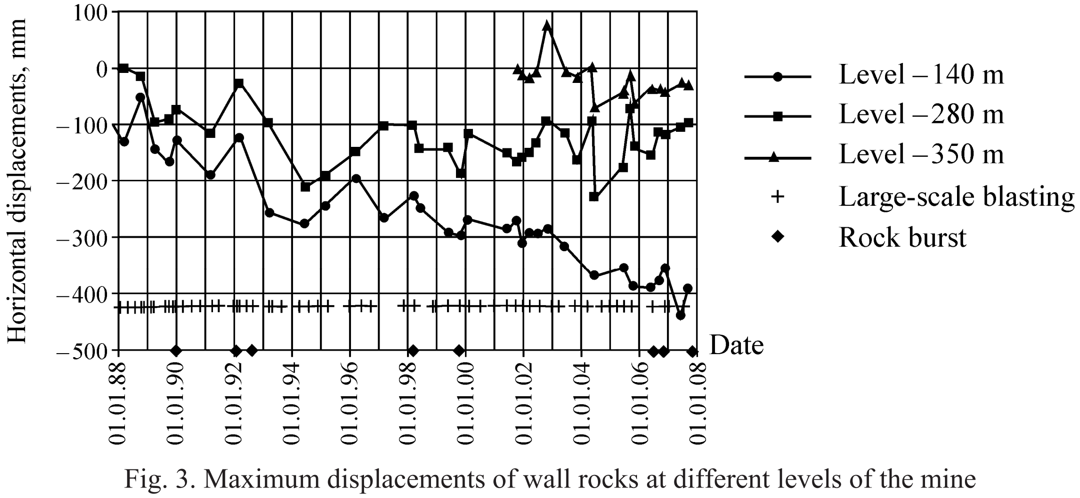

Fig. 3. Maximum displacements of wall rocks at different levels of the mine

Thus, it has been proved that the stress state of the Tashtagol deposit area is induced by local tectonic forces and is prone to variations in the course of extraction of stoping panels. The displacements at boundaries of large structural blocks contribute to the stress and strain concentration, thus conditioning the subsequent displacement of large rock masses at the ore deposit location.

Under consideration was the problem on the stress distribution nearby the worked-out areas in the cross-section across the ore body strike with a tectonic disturbance in its center, with taking into account specific conditions of the Tashtagol Mine. The size of the rock shock area and its energy can be calculated based on the problem solution [4]. It was established that energy of a dynamic event does not undergo sharp variations if the tectonic stress component continuously acting across the ore body strike is 1.3 times higher than the component of the weight of overlying rocks (γH). The energy jump is observed under external load exceeding $2.1\gamma H$. As the external load grows, the angle of the disturbance inclination increases, thus contributing to a dynamic event with the maximum energy release. In this way, at stresses $(1.9-2.4)\gamma H$ disturbances inclined at $5-10^\circ$ pose the greatest hazard. The obtained data are in good compliance with the shock distribution in classes and trajectories of flat and inclined disturbances.

The appreciable increase in horizontal displacements towards the downwarping area was registered before the rock burst of October 24, 1999, at Kondoma fault and the submeridianal tectonic disturbance in sections far from the downwarping. Using obtained data, increments of the lateral thrust coefficients in the intact rock mass across the ore body strike were calculated. By the calculation data, the lateral thrust coefficients increase by 0.3 and 0.5, respectively, for the increments of horizontal displacements at boundaries of structural blocks up to 37 mm along the strike and up to 16 mm across the strike.

Therefore, the level of tectonic stresses in the intact rock mass substantially rose and got comparable to the level, at which disturbances with the dip angle within $5 - 10^{\circ}$ are of the greatest hazard according to the latest research data, the latter statement was proved by the rock burst on October 24, 1999.

Similar evaluations of the natural stress field were also made in the Ural [5, 6], based on the instrument observation data obtained at specially-equipped underground and surface stations.

ROCK MASS MOVEMENT MONITORING — SATELLITE GEODESY PROCEDURES

The mobility of tectonic structures in the Tashtagol deposit area, being the greatest one as compared to the surrounding rock masses, was established by experts from the Eastern Scientific-Research Mining Institute by means of conventional instrument observations of rock movements in the course of geodynamic zoning [7, 8] and geomorphological studies in the 90s [9, 10, 11]. Since 2005 the stress-strain state of the deposit is controlled by employing the satellite geodesy techniques.

To date, two series of GPS observations of the earth movements were performed in the tectonically faulted areas. The survey was carried out in ten directions, comprising the following faults: Kholodny, Kondoma, Nagorny, Shakhtersky, Diagonalny and submeridianal tectonic fault (Fig. 1). The instrument set consists of four Trimble single-frequency receivers, series 4600 LS. Traverse station 1111 situated beyond the influence zone of mining operations in the South-Eastern geodynamic block, was taken as the reference for observations. Mobile receivers moved between observation points (in the fault areas) at the base line lengths from 70 m to 2200 m.

TABLE 1. Observations of Short-Term Displacements in Tectonic Fault Areas at the Tashtagol Ore Deposit

Region of observations	Maximum absolute displacements, mm			
	horizontal		vertical	
	2005	2006	2005	2006
Kholodny fault				
— Administration and on-site facilities (profile line D–D)	22	34	30	39
— Severny shaft (profile line Severnaya)	9	7	17	17
— a winder route (South-East)	3	10	7	25
Nagorny fault (profile line D–D)	18	37	20	108
Kondoma fault (profile line D Srednyaya)	35	50	28	36
Shakhtersky fault (profile line Yuzhnaya along the strike)	17	34	22	74

At each point the satellite geodetic data were accumulated during 3 – 9 hours with 15 s recording interval. The data obtained were processed by the conventional procedure Trimble Geomatics Office. Then coordinates X, Y, Z, distances and increments between reference points were calculated. The evaluation error for the reference point location did not exceed, as a rule, 2 mm in plan and 3 mm in height.

Comparison of the survey data for two last years (Table 1) shows that both horizontal and vertical displacements at faults rose appreciably from 3 – 35 mm in 2005 to 10 – 108 mm in 2006, thus verifying the actuation of geodynamic processes in the rock mass, and their manifestation was registered by the Rockburst Prediction and Prevention Service as a series of micro-bursts in the mine.

The maximum variations of the displacement amplitude were recorded in Nagorny fault area within the reference point interval $(3) \div (+4)$ of the profile line D – D in the hanging wall. Moreover, magnitudes of the horizontal displacements appeared comparable during two years, magnitudes of the vertical displacements increased 5-fold from 20 mm in 2005 to 100 mm. It is specific that the strong shocks and micro-bursts occurred in 2006 were registered exactly in the hanging wall of the ore body.

A high level of short-term displacements in 2006 was detected at Shakhtersky fault on the south of the downwarping, at the boundary between the Eastern and South-Eastern blocks. Hereto, the dominating vertical displacements reached 74 mm, that is they were two-three times higher than in 2005. Jump-wise variations of the displacement magnitudes vividly showed up on June 16, 2006, in Shakhtersky fault area and on September 22, 2006, at Nagorny fault [12].

The surface deformation in the faulted areas can be easily related to rock burst manifestation in the mine field. So, movement of reference point 1, Yuzhnaya profile line along the strike in the Eastern block and reference point 5 in the South-Eastern block showed that within 11:40 – 12:00 Shakhtersky fault was compressed, the Eastern block lifted relative to the South-Eastern block as a result of its displacement along the fault plane in the direction from east to west (Fig. 4). It is characteristic that the resultant vector of the horizontal movements is parallel-directed to the fault (Fig. 3) towards the region of the 2.1-class shock occurred the day before at 0:59:54 at mark of – 549 m. During the following 20 min the rock mass nearby reference point 1 practically returned to the initial position, thus revealing the elastic recovery of the rock mass state. This short-term jumping movement of the earth in the areas of tectonic faults separating geodynamic blocks is perhaps not accidental as two other shocks occurred in the influence zone of Nagorny fault on June 17, 2006, and in the area of Kholodny fault at the southern end of the Eastern block on June 18, 2006. The similar short-term jump-wise displacements were recorded at Kondoma fault on September 26, 2006, and Nagorny fault on September 27, 2006, when the 4 – 5-class shocks were recorded in the northern wing of the deposit.

The separate periods of heterodirectional rock mass movements along the fault plane were established in vertical and horizontal directions when observing the short-term displacements in the areas of tectonic faults at the Tashtagol deposit. We think, the displacement character observed more than once in 2006 indicates the activation of geodynamic situation at the deposit [13]. It is important to mention that the heterodirectional displacement character is related to the short-term jump-wise displacements and spontaneous extra loading of the rock mass in line of the motion. The registered rock mass movement proves the mechanism of nucleation and manifestation of strong shocks and tectonic rock bursts, established earlier by the data of discrete measurements at the stations of deep, contour and soil reference points [14].

The modeling of the stress-strain state of the rock mass under conditions when the component of the horizontal stresses reaches $3\gamma H$ (in compliance with the data on the Gornaya Shoria and Khakasia) and when the faults strike to a depth of 500 – 1000 m made it possible to establish that the horizontal rock displacements along the faults can range within 9 - 92 mm and the vertical ones can reach 16 - 77 mm [15]. These values are in good match with the data obtained during short-term GPS-observations at the Tashtagol deposit.

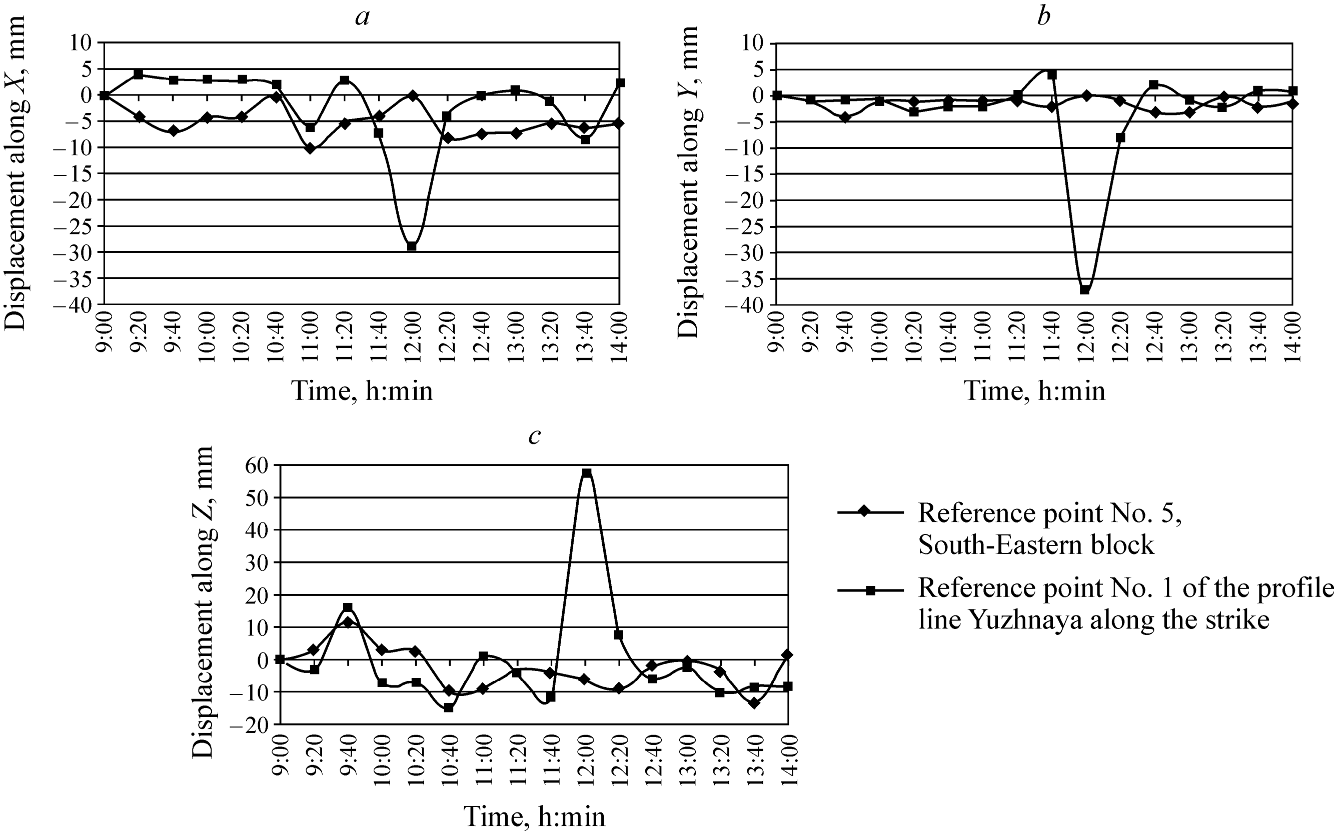

Fig. 4. Time variations of movements in the area of Shakhtersky fault, GPS survey, June 16, 2006

CONCLUSIONS

1. The rockburst hazard is conditioned by the character of interaction between blocks at their interfaces. The indicators of the increased rockburst hazard in a geomedium can be reverse displacements of reference points and convergence rates of fault edges.

2. At the Tashtagol deposit the accumulation of compression at faults becomes apparent $2-3$ months before a rock burst. The compressive strain of fault edges amounts to $(0.3-0.9)\cdot 10^{-3}$, or $(1.4-2.1)\cdot 10^{-3}$ in some cases. Thereto, the convergence velocities of boundaries of structure weakenings vary within $(7-36)$ mm/month and can reach 280 mm/month at separate stations.

3. The combination of three factors is compulsory for the tectonic rock burst manifestation: availability of heterodirectional (for example, vertical and flat) disturbances inducing displacements of wall rocks along them; extra loading of the deposit due to variations of natural (tectonic) stresses and technogenic effect of stoping and large-scale blasting.

4. Hetrodirectional height-wise movements of deep-fault edges and compression/tension alteration in their separate sections indicate nucleation of the conditions for rock burst manifestation. By the data of satellite observations, these geodynamic phenomena are short-term, and periods of compressions and and upheavals of the rock mass coincide with the periods of dynamic activity of the deposit.

5. At the Tashtagol Mine the strains recorded at interfaces of the tectonic blocks is the evidence of the increase in compression in the horizontal plane along and across to the strike of the deposit by 0.3 and $0.5\,\gamma H$, respectively.

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