General and regional geology

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The assessment of strained massif state aimed to improve mining safety

The trouble geodynamic situation in a number of mines of the North Uralian Bauxite Basin that manifests itself in frequent rock bumps in the zones of tectonic disturbances necessitated structural tectonophysic investigations in a number of excavations and natural exposures. Various deformations of the massif enabled one to reconstruct the parameters of tectonic stresses that had occurred. The method of kinematic analysis of fractured tensile structure elaborated by O.I. Gushchenko and refined by V.A. Korchemagin was used for that. As basic parameters of tectonic movements the method has the pointing vectors of shifts and the spatialisation of shear fractures. It makes it possible to make use of the entire of faults and relaxed surfaces caused by displacements to reconstruct the parameters of stressed fields. As a result, compression stresses have been found to take place in the massif, whose magnitude considerably exceeds a theoretical value calculated for the corresponding depth without regard for tectonic forces. The orientation of maximal compression stresses is sublatitudinal that is perpendicular to the strike of the Ural structures. The minimal compression has been registered along the strike of the structures.

Key words: strain elements, stress fields, kinematic analysis, dynamic effects, fault zone.

Dynamic effects in mines such as rock bursts, coal and gas inrushes are known for 200 years in many mining regions throughout the world. These effects complicate mining exploration as they are cause of material losses and human victims. Now there can be no doubt that the reason of the effects is stresses existing in massif. It can clearly be seen during the rock bursts. That fact becomes apparent more distinctly by rock bursts. Rock burst is brittle in the most compressed part of the massif in zone of openings influence. The strength features of the effect – prone rocks such as bituminous and brown coals, salts, bauxites and different sedimentary and crystalline host rocks vary on a large scale. In particular, there are some main factors which are necessary and sufficient for occurrence of rock bursts in massif and openings of NUBR mines [3]:

- high initial level of stress maximal component;
- transformation of stress field to most field heterogeneity;
- wide range of orientation of faults and massif slackening;
- sufficient length of tectonic sutures.

Immediate measurements of stresses in openings in many regions show that massif compressed state is different from normal isostatic one. Measured horizontal compression stresses considerably exceed (in 2–3 times) value of estimated side stresses. Reconstruction of spatial orientation of stresses ellipsoid main axes for many consolidated crust parts also indicates a deviation of from vertical and horizontal position on angle up to 300 and maximal main normal stress is more often oriented more horizontally than vertically. It shows that stresses in Earth's crust generated by tectonic forces are prevail and massif compressed state is the result of isostatic and tectonic stresses summing up.

In this case the next mechanism of the dynamic effects can be suggested. Additional tectonic stresses increase rocks strength that leads to accumulation of additional potential rocks energy without destruction. As a result parts of heightened stresses are formed in the massif. There is a possibility of burst-like accumulated energy release on similar massif parts when breaking steady equilibrium state during the mining works. Because of if rocks destruction happens and accumulated energy releases in the way of seismic waves.

Heightened tangential stresses in tectonic stresses field were registered by instrumental methods in the certain areas around existing disjunctives. Configuration of these zones and its dimensions depends on fault type, its spatial orientation and position relative to the traces of main normal stresses axes. There is a large probability of instantaneous failure of massif part when overlapping abutment pressure from openings on these areas. On account of it localization of rock bursts and inrushes is closely connected with fault zones.

Taking into account the above, it should be noted that development of forecast and dynamic occurrences is difficult without stress tectonic fields study (the massif local level within mine fields and mine field level as a whole).

Thus development of methods of forecast and dynamic effects control is impossible without research of stresses tectonic fields.

Active stresses fields in massif and previously active ones can be explored with the instrumental of different methods. Some of them make it possible to determine parameters of whole stresses tensor and other ones determine certain of the parameters only. Instrumental methods are used to characterize total stresses fields which are active in the massif on the moment of determination. Structural methods are based on interconnection of main stresses values with micro- and macrostrain structures (mineral grains straining direction, fractures, slickensides, folds and etc.) and they make it possible to reconstruct stresses fields which were realized in different deformations. Instrumental methods characterize stresses fields of lowest structural level which are active in local massif volumes and structural ones allow to reconstruct stresses tectonic fields on different levels.

There are some structural methods for reconstruction of parameters of stresses tectonic fields which were active in the massif on it different deformation elements. The simplest and versatile method is method of kinematic analysis of fractured structures [4, 5]. The orientations of shift displacement vectors and spatial orientation of shear fractures are used as the principal parameters of tectonic movements of the method. Kinematic analysis makes it possible to use the whole set of faults and relaxed surfaces on which displacements were happened at tectonic processes for stresses fields parameters. The main parameters of reconstructed stresses tectonic fields are: spatial orientation of main normal stresses axes (σ_1 – maximum stretching, σ_3 – maximum compressing and σ_2 – intermediate), and also coefficient μ_σ showing compressed state condition on which tectonic deformations happened on. Absolute values of stresses can't be determined by the method.

Coefficient μ_σ varies from +1 (uniaxial compression) to -1 (uniaxial stretching).

Process of solution and searching of spatial orientations of main normal stresses axes ($\sigma_1 \geq \sigma_2 \geq \sigma_3$) and ratio of values of tensor deviatoric part (coefficient μ_σ) can be realized by analytic or graphic (plotting on stereographic projections net) ways. There are three structural levels of reconstruction:

- local (within definite rock exposures, openings);
- mesoregional (mine field, group of mines);
- regional (a whole region).

The results adduced in an article were obtained in the course of structural and tectonophysical researches carried out on NUBR mines. Most part of observations was made on openings (mines no. 13, 14, 15) and rock exposures along the banks of Vagran and Kalya rivers.

The mine fields are formed by the Upper Silurian and Devonian deposits [1]. The Silurian deposits are represented by andesite and basalt porphyrites (pokrovskaya suite) overlapping massive and stratified limestones (voskresenskaya and kolginskaya suites) and volcanic and sedimentary rocks of sosvinskaya suite. Ore level with thickness under 20 m occurs on uneven water-worn surface of petropavlovskaya suite (S_2^2-D_1) and overlapped by limestones of vagronskaya suite (Eifelian age, D_1^2). Limestone levels have quite variational thickness and often replaced by gritstones, sandstones, argillaceous and tufogene slates. Mine fields are allocated on the western limb of large syncline with axe meridional strike. Ore level occurrence is quite persistent with the next averaged occurrence elements: direction of dip – 80–90°, angle of dip – 20–30°. Mine fields are allocated in laying side of the large thrust with the northeastern strike (5–20°) and east-oriented dip of fault fissure (40–50°). Fault fissure of the thrust was mapped on the surface eastward of the mine fields. It moves away from ore level outcrops on 2–3 km along the strike from south to north.

Prevailed less large level structures are relatively subvertical northeastern strike faults (sinistral strike-slip faults) which are technical boundaries of mine fields.

Horizontal amplitude of the largest faults reaches 750 m and vertical component of apparent relative movement of similar stratigraphic levels reaches 500. Such faults are bounded mine fields along the strike and it seems that they are most recent faults shifting different-oriented ones. Longitudinal to rock strike faults bounded mine fields by dip. For example mine fields no. 14 and 15 are separated by submeridional fault (dip azimuth 250–260°∠50°). Displacement stratigraphic amplitude of ore level reaches 300–500 m (Fig. 1). Apparently to sliding grooves orientation it is a strike-slip fault.

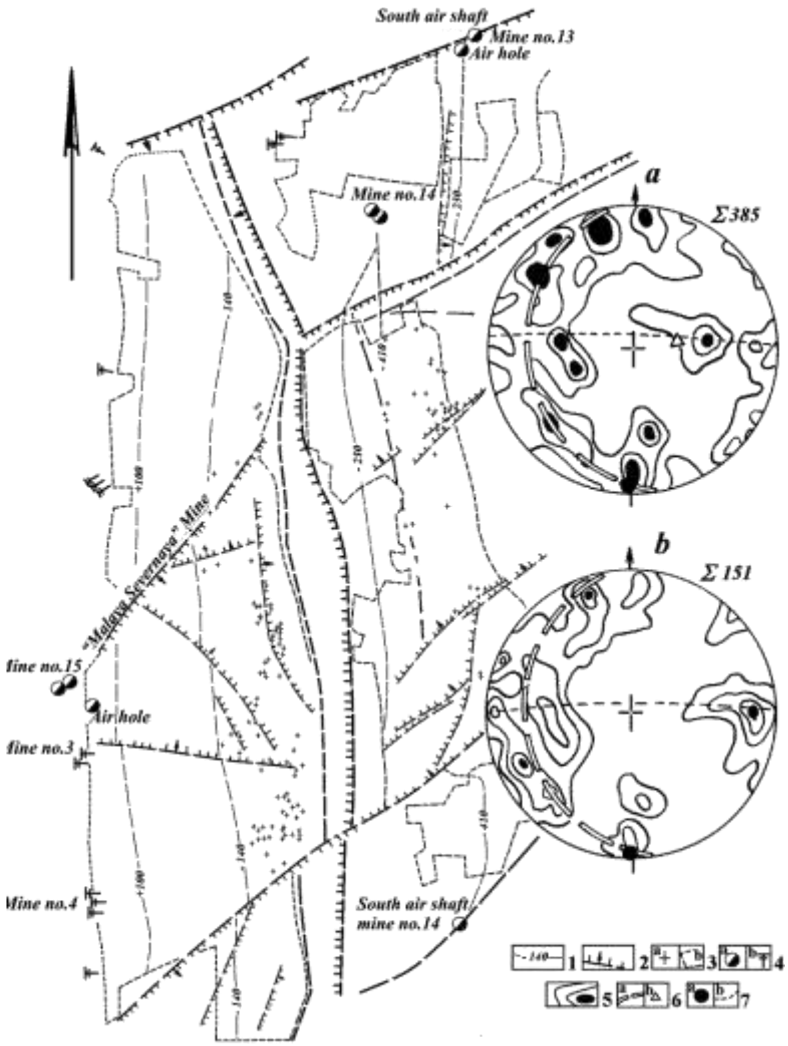

Fig. 1. Schematic plan of mining works of mines no. 14 and 15 and orientation of tectonic shear joints of the region (a) and field of mine no. 15 (b). 1 – ground ore level contour lines; 2 – tectonic faults; 3 – mining works outlines (b) and mining shocks places (a); 4 – mine shafts: vertical (a), inclined (b); on stereograms: 5 – contour lines of distribution density of fault axes; 6 – trace (a) and pole (b) of bedding plane; 7 – axe (a) and belt (b) of symmetry

Besides above-mentioned faults there are many small-amplitude (up to tens meters) faults of northeastern, meridional and sublatitudinal fault fissure orientations which were revealed during mining exploration (Fig. 1). It was registered slips with different vertical component on many of them. In result of that fact some mine fields have small-block structure. Majority of blocks has trigonal and trapezoidal forms. Average linear dimensions of such blocks reach 300–500 m. They are often characterized by different tectonic faulting intensity and different type of massif compressed state.

Fissure tectonics of certain blocks is determined by spatial position and fault kinematics. Most intensive tectonic jointing observes on areas bordering to the faults and it decreases as faults influence zones move away. Small faults and slickensides in limbs of such faults are usually subparallel to main fault fissure or form acute angle with it. Poles of the fractures forms different intensity maximum around main fault fissure pole on stereograms (Fig. 2, a).

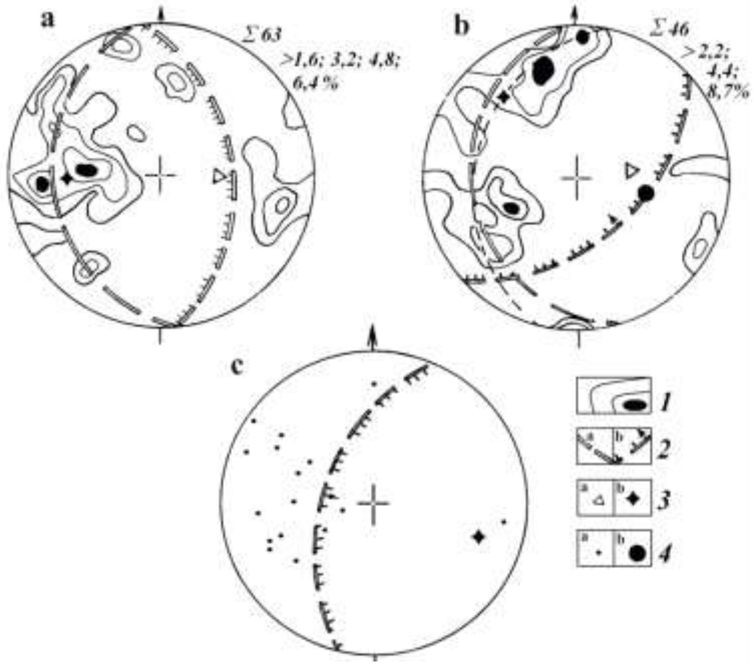

Fig. 2. Tectonic shear joints distribution in limbs of large faults (mining works mine no. 15). 1 – contour lines of distribution density of joints poles; 2 – planes: bedding (a), large faults (b); 3 – poles: bedding (a), main fault (b); 4 – poles of certain joints (a) and symmetry belt axe (b)

Sometimes slickensides poles are localized along large cycles forming persistent or fragmented (composed of certain maximum) belts. These belts are usually matched with large fault kinematic plane or bedding plane (Fig. 2, b). In some cases small faults poles scatters along main fault plane trace (Fig. 2, c). Summary stereograms show coincidence of the clearly defined belts of feather joints poles and averaged bedding plane trace and also less defined belts orthogonal him (Fig. 1, a, b). Thus double symmetry is peculiar to most of small faults: symmetry relative to rock bedding and to more large faults planes. The similar symmetry suggests genetic relationship all of these structural elements. Most of small faults were formed as the result of displacements on large disjunctives planes and activated by already existing primary nonuniformities such as normal-cutting fractures and interstratal stripping planes.

Method of kinematic analysis of fractured structures was applied for reconstruction of stresses tectonic fields parameters on more than 400 measured shears. It was observed quite significant changes of massif compressed state parameters on local level which is quite full characterized to mine fields no. 13 and 15 (Fig. 3). Values of main normal stresses traces and coefficient μ_σ are unusually distinctly changed when crossing faults bounded certain mine fields. Stresses axe orientation is more or less stable within mine no. 15. Main normal stretching stresses axe (σ_1) in local volumes takes mainly subhorizontal position and has northeastern orientation. Main compression stresses axe (σ_3) changes own position from subvertical to horizontal and has sublatitudinal orientation.

Total stresses field is characterized by the next main normal stresses axes parameters for mine field: σ_1 – dip azimuth 188°∠7°, σ_3 – dip azimuth 284°∠63°. Spatial orientation of σ_3 axe is more persistent than σ_1 axe within mine field no. 13. Stresses tectonic field is characterized by the next parameters on mesoregional structural level here: σ_1 – dip azimuth 8°∠6°, σ_3 – dip azimuth 265° ∠58°. Stresses tectonic field reconstructed on base of Kalya River valley outcrops measurements is characterized by the next parameters: σ_1 – dip azimuth 358°∠20°, σ_3 – dip azimuth 262°∠22°. As a whole, reconstructed tectonic stresses field are defined by horizontal submeridional stretching (strike azimuth 360–10°) and latitudinal compression (strike azimuth 265–275°). Values of coefficient μ_σ of tectonic stresses total field are close to 0 (μ_σ=+0,1–0,2). It means that massif compressed state is close to simple shear with small additional compression.

At the same time there are zones close to large faults where massif stress state assume a special type changing from uniaxial compression to uniaxial tension states (μ_σ=±1).

It should be noted that it was determined the same natural connection of the certain parameters of tectonic stress and deformation fields of mine fields of Donetsk–Makeevka and Central coal regions with outburst-hazardous zones [2]. Heightened outburst hazard is characteristic for zones with shear or changeable (transitional: normal and strike-slip fault) field type. There are most hazardous local volumes of the massif within the zones where deformations were happened in conditions when massif stress state changed from uniaxial compression to uniaxial tension states (pulsating type of stress field).

It should be observed that tectonic stresses field reconstructed by structural methods is agree with the field which is active at present and registered by instrumental methods. It was established values of active compression stresses are exceed the theoretical ones determined for appropriate depth without of tectonic forces accounts. Orientation of maximal compression stresses is sublatitudinal that is perpendicularly to Ural structures strike. Minimal compression or even stretching was registered along the strike of the structures.

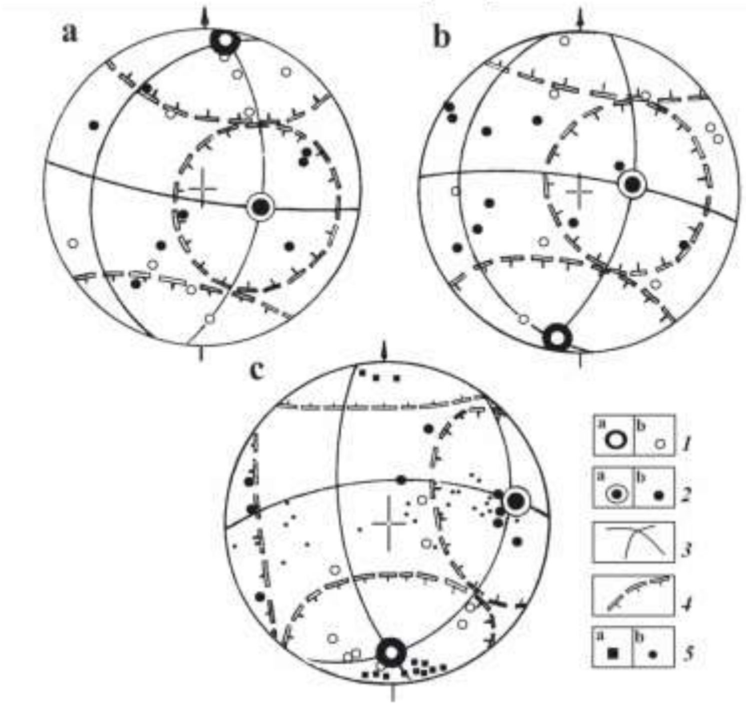

Fig. 3. Tectonic stresses fields reconstructions: a – mine no. 13, b – mine no. 15, c – Kalya River valley. 1 – stretching axe σ_1 of mesoregional (a) and local (b) levels; 2 – compression axe σ_3 of mesoregional (a) and local (b) levels; 3 – planes of main normal stresses effects; 4 – conic surfaces bounded regions with similar axes; 5 – small folds hinges (a), bedding planes poles (b)

The summary is:

1. Field of paleotectonic stresses which is characterized by latitudinal compression and submeridional stretching was reconstructed in the massif. The same stresses tectonic field is active now.
2. Most of small faults were formed as a result of displacements on large disjunctives planes and activated by already existed primary nonuniformities such as normal-cutting fractures and interstratal stripping planes.
3. Pulsating type of stress field is setting for rock burst zones while stress state of massif is changing from uniaxial compression to uniaxial tension (μ_σ coefficient value changes from +1 to –1).

Thus, it can be concluded that zones of rock burst occurrence are characterized by specific tectonic stress fields. These zones can be recognized by structural and tectonophysical survey for local and mesoregional forecast.

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Общая и региональная геология

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ЧЕРНЫШ ОЛЬГА ГЕННАДИЕВНА – кандидат геологических наук, доцент кафедры безопасности в чрезвычайных ситуациях и защиты окружающей среды Инженерной школы (Дальневосточный федеральный университет, Владивосток). Суханова ул., 8, Владивосток, 690950. E-mail: xanfia@yandex.ru

Оценка напряженного состояния породного массива с целью повышения безопасности горных работ

В связи с напряженной геодинамической обстановкой на ряде шахт Североуральского бокситоносного района, выраженной частыми горными ударами в зонах тектонических нарушений, в ряде горных выработок и естественных обнажений были проведены структурно-тектонофизические исследования. По различным деформационным элементам горного массива были реконструированы параметры действовавших тектонических полей напряжений по методике кинематического анализа трещинно-разрывных структур, разработанной О.И. Гущенко и усовершенствованной В.А. Корчемагиным. В качестве основных параметров тектонических движений в этой методике используются ориентировки векторов сдвиговых смещений и ориентация в пространстве самих сместителей сколовых трещин. Это позволяет использовать для реконструкции параметров полей напряжений всю совокупность разрывов и ослабленных поверхностей, по которым происходили подвижки при тектонических процессах. В результате было установлено, что в горном массиве действуют сжимающие напряжения, по величине существенно превышающие теоретические значения, вычисленные для соответствующей глубины без учета тектонических сил. Максимальные сжимающие напряжения ориентированы в субширотном направлении, перпендикулярно простиранию уральских структур. Минимальное сжатие фиксировалось по простиранию последних.

Ключевые слова: деформационные элементы, поля напряжений, кинематический анализ, динамические эффекты, тектоническое нарушение.

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