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# **Dynamical Model for Evolution of Rock Massive State as a Response on a Changing of Stress-Deformed State**

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Additional information is available at the end of the chapter

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## **1. Introduction**

Geological medium is an open dynamical system, which is influenced on different scales by natural and man-made impacts, which change the medium state and lead as a result to a complicated many ranked hierarchic evolution. That is the subject of geo synergetics. Paradigm of physical mesomechanics, which was advanced by academician Panin V. E. and his scientific school, which includes the synergetic approach is a constructive method for research and changing the state of heterogenic materials [1]. That result had been obtained on specimens of different materials. In our results of research of no stationary geological medium in a frame of natural experiments in real rock massifs, which are under high man-made influence it was shown, that the state dynamics can be revealed with use synergetics in hierarchic medium. Active and passive geophysical monitoring plays a very important role for research of the state of dynamical geological systems. It can be achieved by use electromagnetic and seismic fields. Our experience of that research showed the changing of the system state reveals on the space scales and times in the parameters, which are linked with the peculiarities of the medium of the second or higher ranks [2 – 5].

It is known that the most geological systems are open and non equilibrium, which can long exist only in the regime of energy through circulation. The closing of the energy flow leads to the system transfer to a conservation stage, when the duration of its existence depends on its energy potential due to accumulated energy on the previous stage [4]. On a certain stage of open dynamical system evolution, exchanging by matter and energy with the surrounding medium, decays on a set of subsystems, which in their turn can decay on smaller systems. The criterion of defining boundaries of these systems is one of synergetic law: macroscopic processes in the systems, which exist in a non linear area with a self organization processes, are

performed cooperative, coordinated and coherent. The base of the processes of self organization in the open non equilibrium geological systems is the energetic origin. If the energy potential does not achieve its threshold value, the processes of self organization do not begin, if it is sufficient for compensate losses to the outer medium, in the system will begin the processes of self organization and form space-time or time structures. The transition from chaos to a structure is performed by a jump. If the income of the energy is too much, the structurization of the medium finishes and the transition to the chaos begins.

In arbitrary open dissipative and nonlinear systems are generated self-oscillating processes, which are sustained by outer energy sources, due to self organization exists [4]. The research of the state dynamics, its structure and effects of self organization in the massif we can provide with geophysical methods, set on a many ranked hierarchic non stationary medium model.

## 2. Physical models and mathematical methods of research

From the mathematical point of view dynamical system is an object or process, for which the concept of a state is defined as a set of values in a given time and an operator, which defines the evolution of the initial state in time [6]. If for the description of system state evolution it is sufficient to know its state in a given moments of time, that system is denoted as a system with discrete time. Let the set of numbers is defined as  $\mathbf{x}=\{x_1, x_2,.. x_N\}$  in a some time moment describes the state of a dynamical system and to different sets  $\{x_1, x_2,.. x_N\}$  correspond different states. Let us define the evolution operator, indicating the velocity of changing of each system state as:

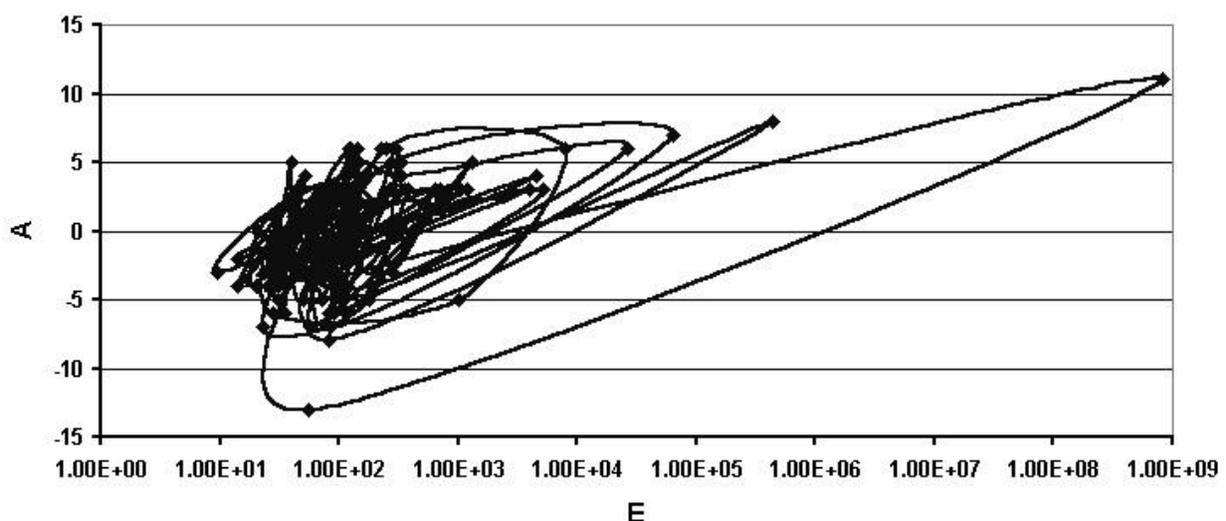
$$\frac{\partial x_i}{\partial t} = F_i(t, x_1, x_2, \dots, x_N), i = 1, \dots, N \quad (1)$$

$\mathbf{x}$  – point of Euclid space  $\mathcal{R}_N$ , which is named as phase space,  $\mathbf{x}$  – phase point. The system (1), for which the right part does not depend from time, is named autonomous. By research of dynamical system, which describes the change of oil layer state by vibration action, the right parts of equations (1) will depend from time, and the system will not be autonomous. If the system (1) complete with initial conditions  $\mathbf{x}(0) = \mathbf{x}_0$ , we shall obtain an initial conditions problem (problem Koshi) for (1). The solution  $\{\mathbf{x}(t), t > 0\}$ , which belongs to a set of points of phase space  $\mathcal{R}_N$ , which forms a phase trajectory; vector-function  $F(\mathbf{x})$  specifies the vector field of velocities. The phase trajectories and vector field of velocities give a descriptive representation about the system behavior character during time. The set of phase trajectories, which correspond to different origin conditions, form a phase portrait of the dynamical system.

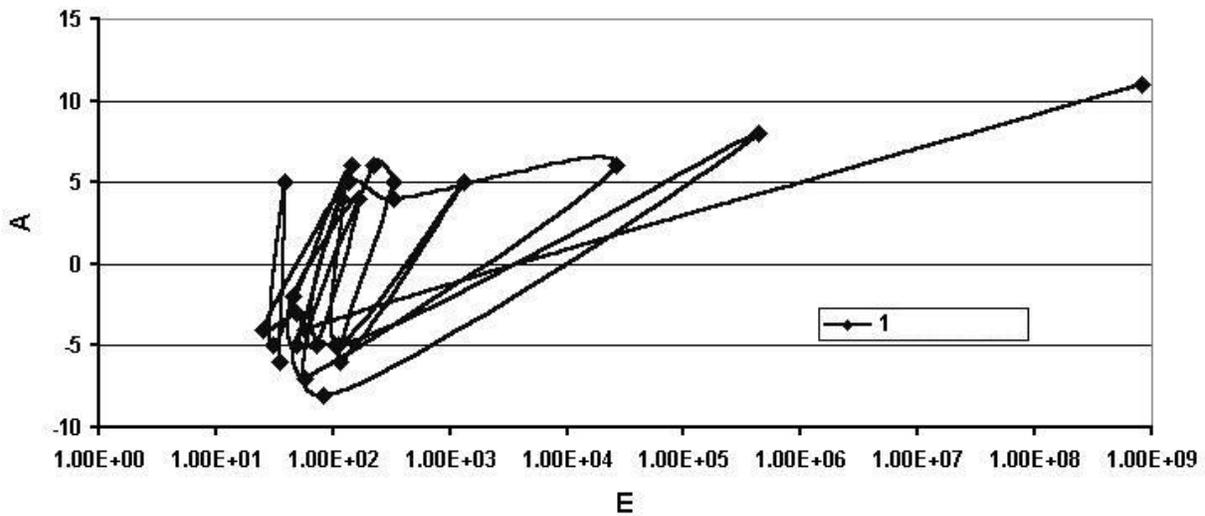
The dynamical systems can be divided on conservative and dissipative systems. For the first type the whole energy of the system is conserved, for the second type can be energy losses. As concerns to our problem of research of massif state, which is in a state of oil recovery, the best model is such: heterogeneous, no stationary dissipative system. Nevertheless there can occur in the massif such local places, which will be described by a conservative dynamical model that is by a model of energetic equilibrium.

The analyses of the phase portrait of dynamical system allow us to make a conclusion about the system state during the period of observation. So, in conservative systems attracting sets do not exist. The set of phase space  $\mathcal{R}_N$  is named attracting; to which trajectories tend with time, which begin in some its neighborhood. If in conservative system a periodical movement exists, thus such movements are infinitely many and they are defined by the initial value of energy. In dissipative systems the attracting sets can exist. Stationary oscillations for dissipative dynamical systems are not typical one. But in nonlinear systems a periodic asymptotic stable movement can exist, for which we have a mathematical image as a limited cycle, which is represented in the phase space as a closed line, to which all trajectories from some neighborhood of that line tend in time. We can conclude about the characteristic behavior of the system analyzing the form of phase portrait, by the way the "smooth" deformations of the phase space do not lead to quality changes of the system dynamics. That property is named as topologic equivalence of phase portraits. It allows analyzing the behavior of different dynamical systems from the unique point of view: on that base the set of dynamical systems can be divided on classes, inside of which the systems show an identical behavior. Mathematically "smooth deformation" of phase portrait is homeomorphous transformation of phase coordinates, for which new singular points can not occur, from the other hand – singular points can not vanish.

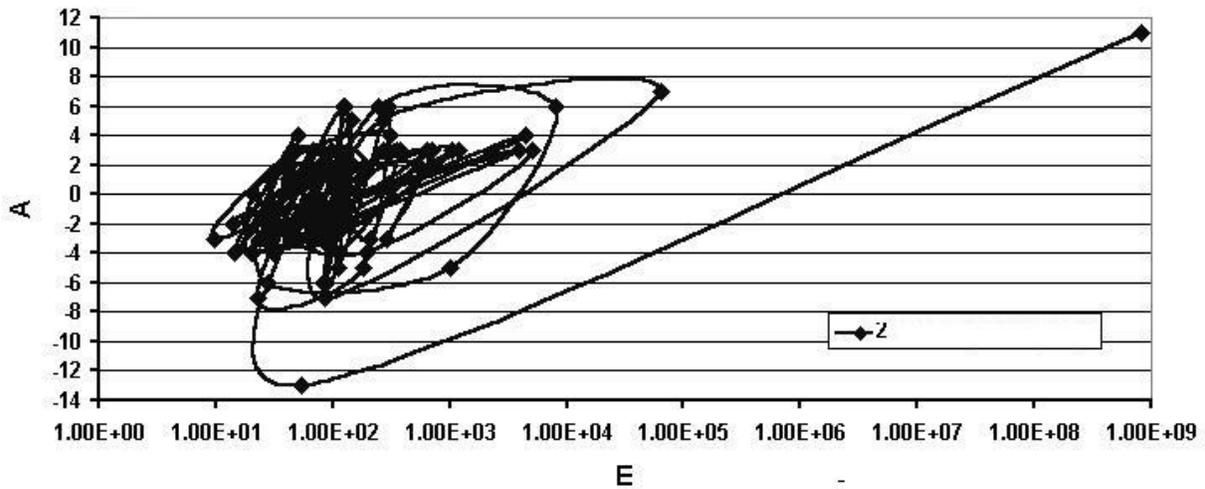
We had analyzed the seismological detailed information of space-time oscillations of state features of rock massif from the point of the theory of open dynamical systems [7 – 8]. We had revealed some synergetic features of the massif response on heavy man-made influences before a very intensive rock shock in the mine [9]. We defined a typical morphology of response phase trajectories of the massif, which is in the current time in stable state: on the phase plane we see a local area as a clew of twisted trajectories and small overshots from that clew with energies not more, than  $10^5$  joules. In some periods of time these overshots can be larger, than  $10^6$  joules up to  $10^9$  joules (see Figure1).



**Figure 1.** Phase portrait of the energies of massif responses during one of the most rock bursts on Tashtagol mine. Legend: E-energy in joules. A –  $d(LgE)/dt$ .



**Figure 2.** Phase portrait of the energies of massif responses before the one of the most rock bursts on Tashtagol mine. The legend of Figure 2. is identical to the legend of Figure 1.



**Figure 3.** Phase portrait of the energies of massif responses after the same rock burst on Tashtagol mine. The legend of Figure 3. is identical to the legend of Figure 1.

Since the massif volume under investigation is the same and we research the process of it's activation and dissipation, we obviously see two mutual depending processes: the energy accumulation when phase point is near phase trajectories attracting area and resonant releasing of the accumulated energy. It is interesting to notice, that after the releasing the system returns to the same phase trajectory attracting area (see Figure 2 and 3).

In the book [8] is developed a new mathematical method for modeling of processes in local active continuum, which are energetically influenced from an outer energy source. The common causes of chaotization and stochastization of dynamical system movements are its losing of stability and exponential recession of near located phase trajectories together with its common boundedness and its common compression. The mathematical result coincides as a whole with the practical result (see Figure 2, 3): in the phase area the smaller attracting

phase trajectories area exists where may occur an exponential recession of them (see Figure 2), then the movement character changes and the further movement of phase points lead to return to the same attracting area (see Figure 3.). These movements can occur in resonance or spontaneous cases.

The received results are of great significance because firstly we could find the coincidences between the mathematical theory of open systems and experimental results for natural objects with very complicated structure. On that base we developed a new processing method for the seismological information which can be used real-time for estimation of the disaster danger degree changing in mine massif.

The second feature of the state evolution is: the local massif volume does not immediately respond on the changing in environment stress state. Therefore it stores energy and then releases it with a high energy dynamical effect. It is very significant to define the time of reaction lagging, in spite of the influence on the massif can be assumed as elastic. The unique model which can explain that effect is a model of the massif with a hierarchic structure. We developed a mathematical algorithm using integral and integral-differential equations for 2D model for two problems in a frequency domain: diffraction of a sound wave and linear polarized transverse wave through an arbitrary hierarchy rank inclusion located in an N-layered medium. That algorithm differs from the fractal model approach by a freer selecting of heterogeneities position of each rank. And the second problem is solved in the dynamical approach. As higher amount of the hierarchic ranks as greater is the degree of nonlinearity of massif response and as longer can be the time of massif reaction lag of the influence [10].

In that paper integral equations and integral differential equations of 2D direct problem for the seismic field in the dynamical variant are derived and the joint analysis of the integral equations for 2D problems for electromagnetic and seismic fields had been provided. The received results can be used for definition of the complex criterions of achievement the research of high-complicated medium both with seismic and electromagnetic methods.

For the problem of sound diffraction on the 2D elastic heterogeneity, located in the  $j$ -th layer of the  $n$ -layered medium, using the approach from the papers [11, 12], we can derive the integral differential equation for the distribution of the potential for the vector of elastic displacements inside the heterogeneity. Using the second integral-differential presentation we can define the potential of the elastic displacements in the arbitrary layer, and then we can calculate the distribution of the vector of elastic displacements in the arbitrary layer. Let us compare the derived expressions with the solution of the diffraction problem for electromagnetic field in the frame of the same geometrical model. That case corresponds to the problem of exciting by a plane wave H – polarization, the solution of which is done in the paper [11]. Let us transform it to the form similarly to (1) and let us compare the derived equations for the solution of the inner 2D seismic and electromagnetic problem:

$$\begin{aligned}
& \frac{(k_{1ji}^2 - k_{1j}^2)}{2\pi} \iint_{S_C} \varphi(M) G_{S_j}(M, M^0) d\tau_M + \frac{\sigma_{ja}}{\sigma_{ji}} \varphi^0(M^0) - \\
& - \frac{(\sigma_{ja} - \sigma_{ji})}{\sigma_{ji} 2\pi} \oint_C G_{S_j} \frac{\partial \varphi}{\partial n} dc = \varphi(M^0) \text{ by } M^0 \in S_C \\
& \frac{\sigma_{ji}(k_{1ji}^2 - k_{1j}^2)}{\sigma(M^0) 2\pi} \iint_{S_C} \varphi(M) G_{S_j}(M, M^0) d\tau_M + \varphi^0(M^0) - \\
& - \frac{(\sigma_{ja} - \sigma_{ji})}{\sigma(M^0) 2\pi} \oint_C G_{S_j} \frac{\partial \varphi}{\partial n} dc = \varphi(M^0) \text{ by } M^0 \notin S_C
\end{aligned} \tag{2}$$

$G_{S_j}(M, M^0)$  - the source function of seismic field for involved problem,  $k_{1ji}^2 = \omega^2(\sigma_{ji} / \lambda_{ji})$ ; - index  $ji$  signs the membership to the features of the medium into the heterogeneity,  $\lambda$  - is a const of Lamoux,  $\sigma$  - the density of the medium,  $\omega$  - the round frequency,  $\vec{u}_i = \text{grad}\varphi_i$ ;  $i=1, \dots, j, ji, \dots, n$ .  $k^2(M^0) = i\omega\mu_0\sigma(M^0)$ ,  $\mu_0 = 4\pi 10^{-7} \frac{2H}{M}$ ,  $\sigma(M^0)$  - conductivity in the point  $M^0$ ,  $i$  - the imaginary unit,  $H_x(M^0)$  - the summarized component of magnetic field,  $H_x^0(M^0)$  - the component of magnetic field in the layered medium without heterogeneity,  $k_{ji}^2 = i\omega\mu_0\sigma_{ji}$ ,  $k_i^2 = i\omega\mu_0\sigma_i$ ,  $\sigma_{ji}$  - conductivity into the heterogeneity, located into the  $j$ -the layer,  $\sigma_i$  - conductivity of the  $i$ -th layer of the  $n$ -layered medium,  $G_m(M, M^0)$  - the Green function of the 2 - D problem for the case of H-polarization [18]. The difference in the boundary conditions for the seismic and electromagnetic problems lead to different types of equations: in the seismic case - to the integral-differential equation, in the electromagnetic cases to the load integral equation of Fredholm of the second type.

$$\begin{aligned}
\varphi(M^0) &= \frac{(k_{1ji}^2 - k_{1j}^2)}{2\pi} \iint_{S_C} \varphi(M) G_{S_{p,j}}(M, M^0) d\tau_M + \\
&+ \frac{(\sigma_{ji} - \sigma_{ja})}{\sigma_{ji} 2\pi} \oint_C G_{S_{p,j}} \frac{\partial \varphi}{\partial n} dc + \frac{\sigma_{ja}}{\sigma_{ji}} \varphi^0(M^0) \text{ by } M^0 \in S_C \\
H_x(M^0) &= \frac{k_{ji}^2 - k_j^2}{2\pi} \iint_{S_C} H_x(M) G_m(M, M^0) d\tau_M + \\
&+ \frac{k_{ji}^2 - k_j^2}{k_j^2 2\pi} \oint_C H_x(M) \frac{\partial G_m}{\partial n} dc + \frac{k_{ji}^2}{k_j^2} H_x^0(M^0) \text{ by } M^0 \in S_C
\end{aligned} \tag{3}$$

If for the solutions of the direct electromagnetic and seismic in dynamical variant problems we can establish the similarity in the explicit expressions for the components of electromagnetic and seismic fields by definite types of excitation then with complicating of the medium structure as can we see from the obtained result by the case of the seismic field

linked with longitudinal waves the similarity vanishes. That means that the seismic information is additional to the electromagnetic information about the structure and state of the medium. For the problem of diffraction of a linearly polarized elastic transverse wave on the 2D heterogeneity located in the  $j$ -th layer of the  $n$ -layered medium, using the approach described in the paper [11] for the electromagnetic wave 2D problem (case H – polarization), (the geometric model is similar to a that described higher in the previous problem) we obtain the expressions as follows for the components of the displacement vector:

$$\begin{aligned}
 & \frac{(k_{2ji}^2 - k_{2j}^2)}{2\pi} \iint_{S_C} u_x(M) G_{Ss,j}(M, M^0) d\tau_M + \frac{\mu_{ja}}{\mu_{ji}} u_x^0(M^0) + \\
 & + \frac{(\mu_{ja} - \mu_{ji})}{\mu_{ji} 2\pi} \oint_C u_x(M) \frac{\partial G_{Ss,j}}{\partial n} dc = u_x(M^0) \quad \text{by } M^0 \in S_C \\
 & \frac{\mu_{ji}(k_{2ji}^2 - k_{2j}^2)}{\mu(M^0) 2\pi} \iint_{S_C} u_x(M) G_{Ss,j}(M, M^0) d\tau_M + u_x^0(M^0) + \\
 & + \frac{(\mu_{ja} - \mu_{ji})}{\mu(M^0) 2\pi} \oint_C u_x(M) \frac{\partial G_{Ss,j}}{\partial n} dc = u_x(M^0) \quad \text{by } M^0 \notin S_C
 \end{aligned} \tag{4}$$

The expressions (3) content the algorithm of seismic field simulation for distribution of transversal waves in the  $n$ -layered medium, which contain a 2D heterogeneity. The first expression is a Fredholm load integral equation of the second type the solution of which gives the distribution of the components of the elastic displacements vector inside the heterogeneity. The second of them is an integral expression for calculation of the elastic displacements vector in the arbitrary layer of the  $n$ -layered medium.

Comparing the expressions (3) with correspondingly for the electromagnetic field (H-polarization) (2) we see that there is a similarity of the integral structure of these expressions. The difference is only for the coefficients of corresponding terms in the expressions (2) and (3). That we can account by choosing the system of observation with one or another field. We must also account the difference of the medium response frequency dependence from seismic or electromagnetic excitation. But keeping within the similarity of the coefficients the seismic field, excited by transversal waves, and the electromagnetic field will contain the similar information about the structure of the heterogeneous medium and state, linked with it. Those results are confirmed by the natural experiments described in the papers [13 – 17]. Thus, it is showed that for more complicated, than horizontal-layered structures of the geological medium the similarity between the electromagnetic and seismic problems for longitudinal waves get broken. Therefore, these observations with two fields allow getting reciprocally additional information about the structure and especially about the state of the medium. These fields will differently reflect the peculiarities of the heterogeneous structures and response on the changing their state. If we can arrange seismic observations only with the transversal waves together with the magnetic component of electromagnetic one (H-polarization) in the 2D medium, it will be establish the similarity,

which can be used by construction of mutual systems of observation for magneto-telluric soundings and deep seismic soundings on exchanged waves. For research of hierarchic medium we had developed an iterative algorithm for electromagnetic and seismic fields in the problem setting similar to analyzed higher for layered-block models with homogeneous inclusions [19].

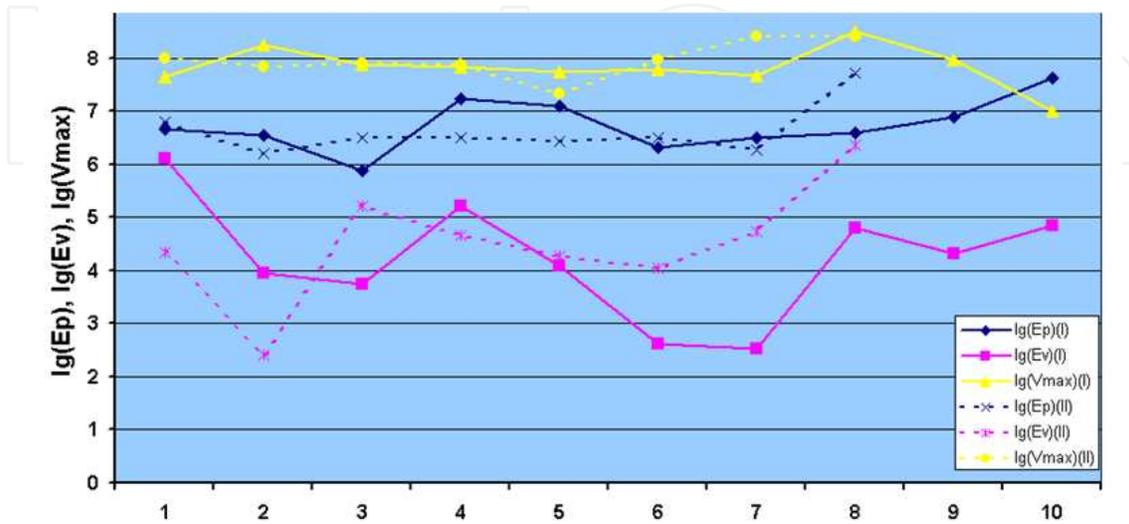
### **3. Investigation of non-linear dynamics of rock massive, using seismological catalogue data and induction electromagnetic monitoring data in a rock burst mine**

During the research of massif response on heavy explosions in some blocks of a rock burst hazard mine it had been derived some peculiarities of the rock massif behavior on different scale levels (Figures 4, 5). By exploitation of a concrete block the whole massif, mine field experiences the change of the stressed-deformed and phase state from explosion to explosion. The amounts of absorbed and dissipated by the massif energy are not equal to each other and therefore energy accumulation occurs inside the massif. The process of energy dissipating occurs with time delay and it strongly depends on the gradient of absorbing energy from mass explosions. Zones of dynamical calmness appear inside the massif. It is needed to trace such zones with use of seismological monitoring data and parameters described in [5]. After leaving out of the minimum of calmness it is needed during one or two weeks up to the moment of the technological crushing arrange the space-time active electromagnetic or seismic monitoring for revealing zones of potential non stability of the second rank. Such zones may appear after the mass crash explosion or after strong dynamical events.

These conclusions had been made using analysis of seismology data which is linked with the massif of concrete block mining. But the analysis of seismological data of the mine show that powerful dynamical events (rock bursts) can occur in more wide area than near of the block of mining and can be initiated in time delay. In the papers [5, 20] for the first time it had been analyzed the seismological detailed information from the synergetic position and the theory of open dynamical systems. Using the quality analysis of phase trajectories [21] the repeating regularities had been shown, consist of transitions in the massif state from chaotic to ordered and reverse.

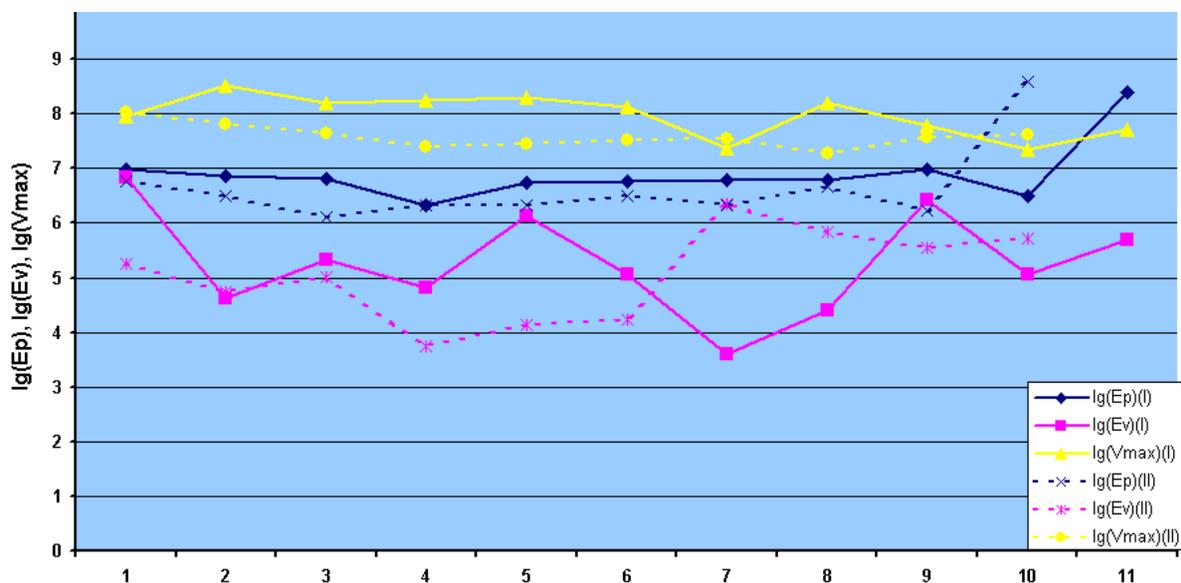
For realization of that research data of the seismic catalogue of Tashtagol mine during two years from June 2006 to June 2008 had been used. As a data set we used the space-time coordinates for all dynamical events-responses of the massif occur in that time period inside the mine field and also explosions, which had been developed for massif outworking and values of energy which had been fixed by the seismological station. In our analysis we divided the whole mine field in two parts (figures 6, 7). The events-responses had been taken into account from horizons – 140 m, – 210 m, – 280 m, – 350 m. According to the catalogue, explosions had been provided on the south-east place – on horizons + 70 m, 0 m, – 70 m, on other places – on all listed higher horizons. The whole catalogue had been

divided on two parts: north and south – for response events and for explosions occur in the south and north parts of the mine’s field correspondingly. Between the explosions we summarized the precipitated energy of dynamical massif responses correspondently of the northern and southern parts.



Ep – absorbed energy (joules), Ev-dissipated energy (joules), Vmax – the maximum dimension of the volume, where had been observed dynamical events.

**Figure 4.** The response of the massif by the man-made influence: 07. 10 – 23. 12 2001, block23, horizon(- 280/ - 210) (I) 19. 01 – 20. 03 2003, block24, horizon (- 280/ - 210)(II) X-axis– number of explosions



**Figure 5.** The response of the massif by the man-made influence: 27. 02 – 09. 07. 2000, block7, horizon (- 210/ - 240) (I), 21. 12 – 21. 03 2003 – 2004, block6, horizon (- 210/ - 140)(II). X-axis – number of explosions The legend of Figure 5 is the same as in Figure 4.

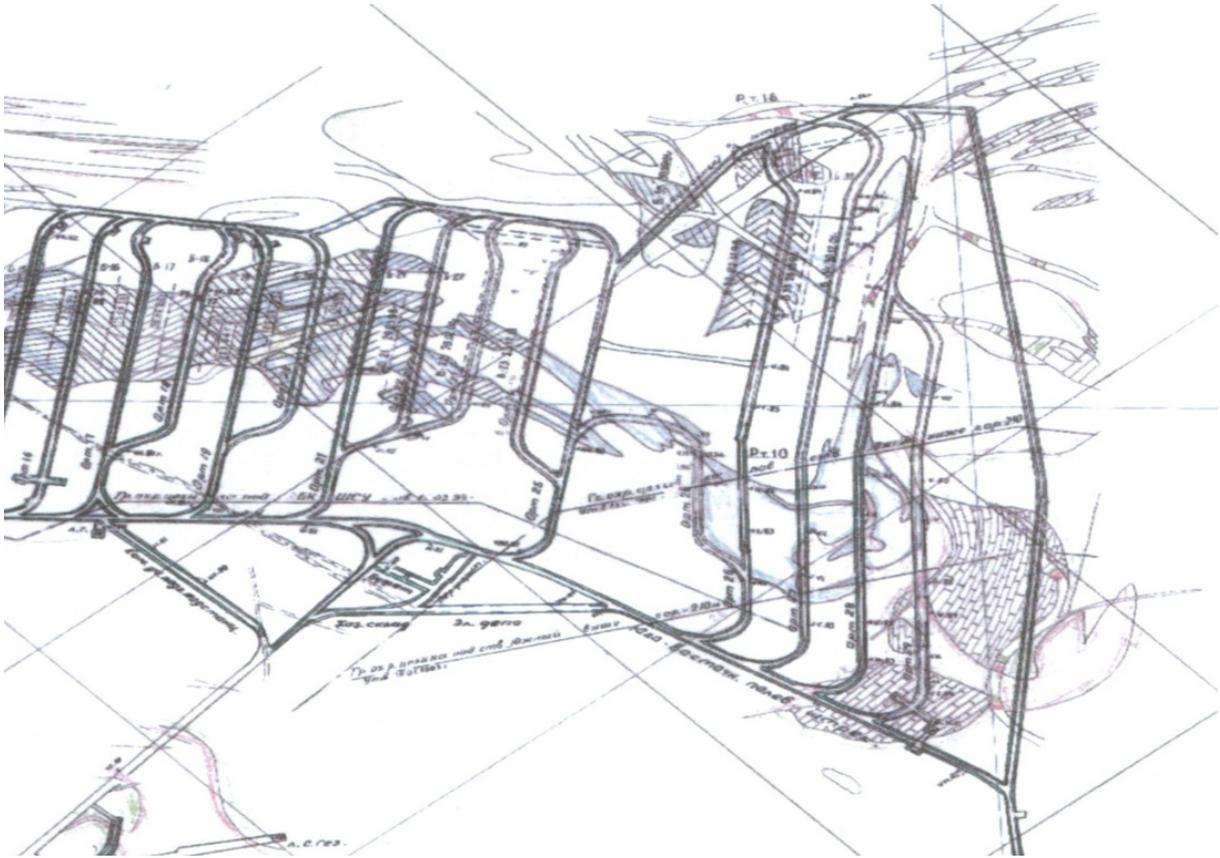


Figure 6. Plan of horizon – 210, southern place.

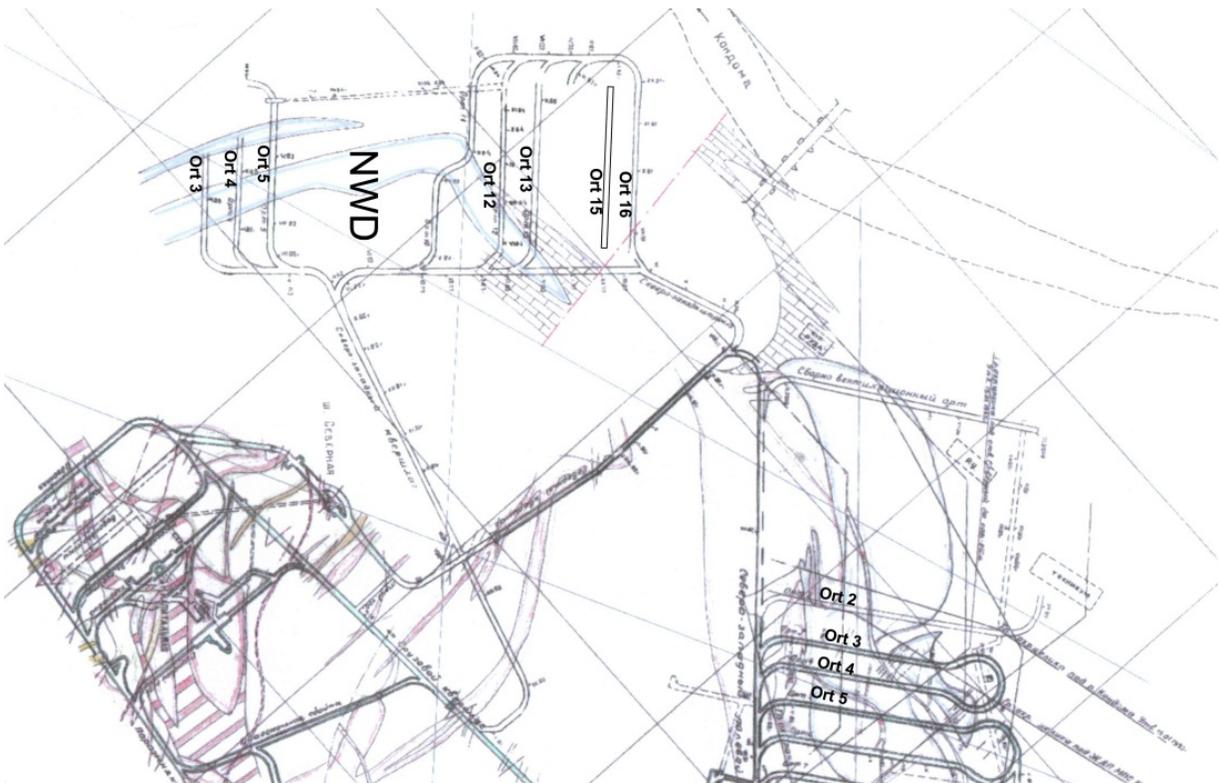
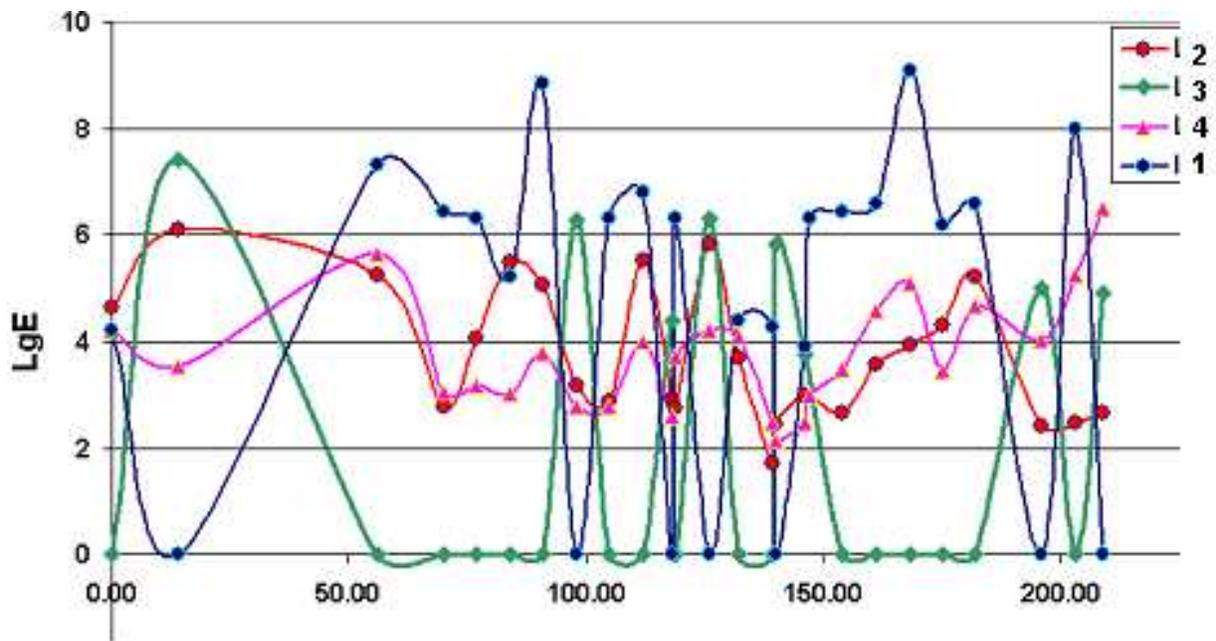
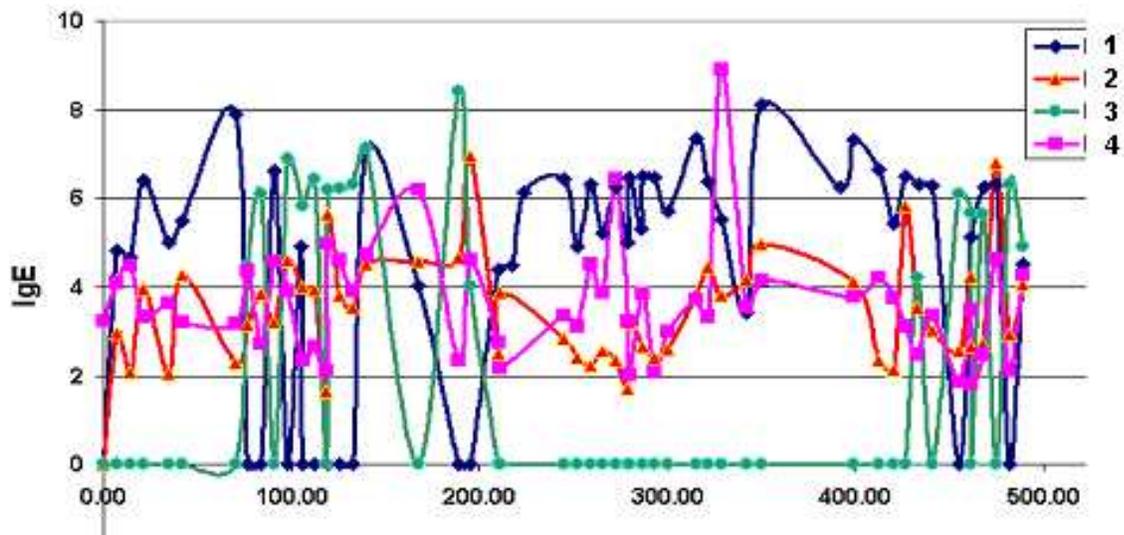


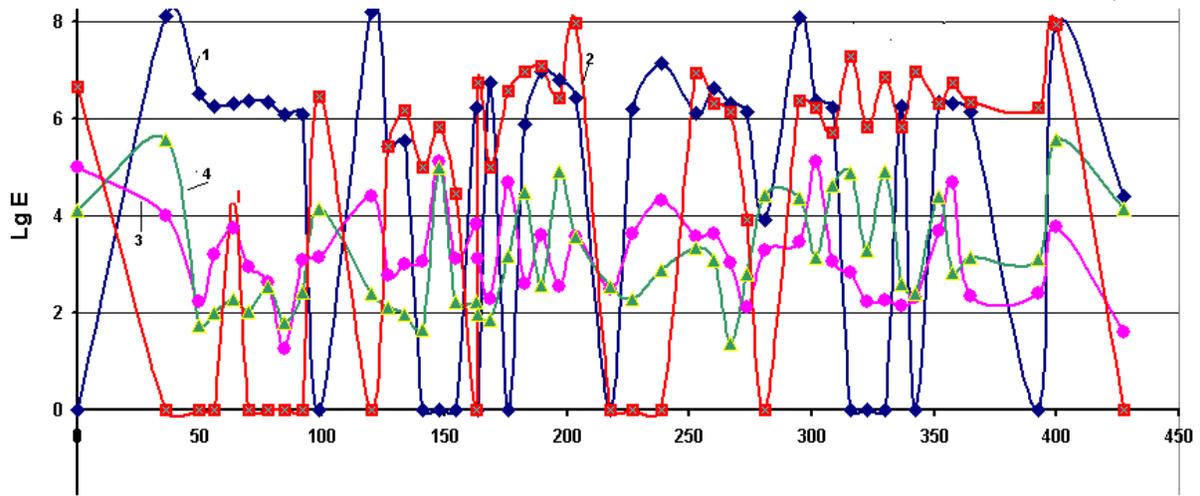
Figure 7. Plan of horizon – 210, northern place.



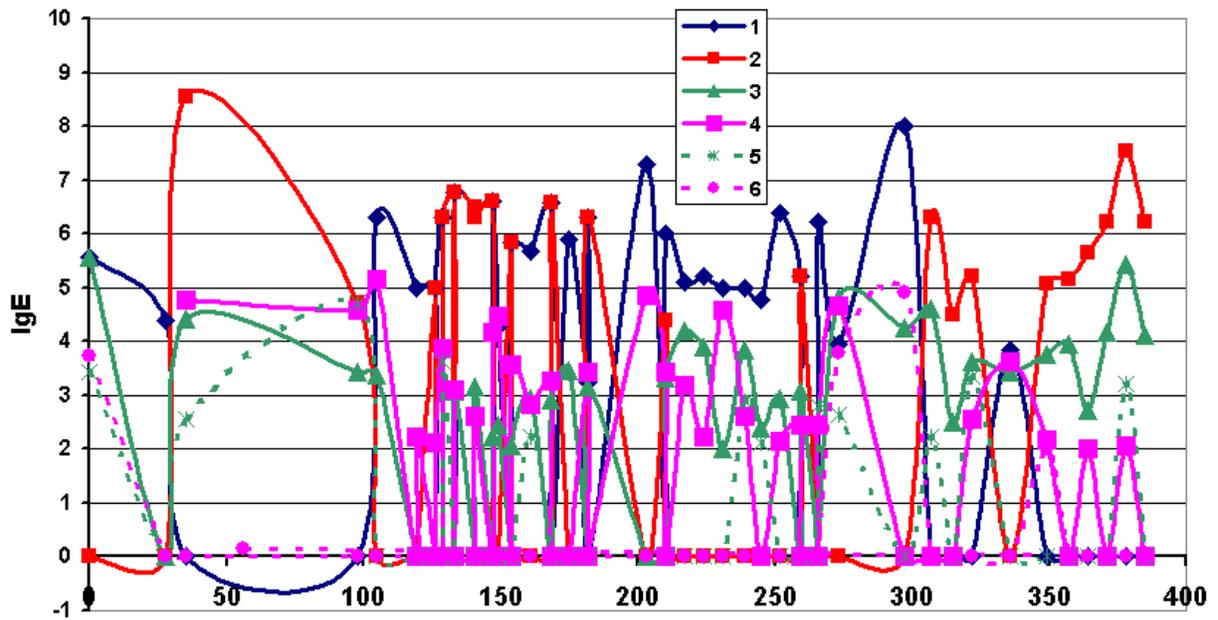
**Figure 8.** Distribution of absorbed (1 – 2) and dissipated (3 – 4) energy of the whole mine field during the period I 03. 06. 2006 – 13. 01. 2007. The horizontal axes is time per days



**Figure 9.** Distribution of absorbed (1 – 2) and dissipated (3 – 4) energy of the whole mine field during the period II 13. 01. 2007 – 17. 05. 2008. The horizontal axes is time per days.



**Figure 10.** Distribution of absorbed (1 – 2) and dissipated (3 – 4) energy of the whole mine field during the period III 24. 05. 2008 – 26. 07. 2009. The horizontal axes is time per days



**Figure 11.** Distribution of absorbed (1 – 2) and extracted (3 – 6) energy of the whole mine field during the period IV 28. 06. 2009 – 18. 07. 2010. The horizontal axes is time per days

The whole interval of research had been divided into four periods: from 03. 06. 2006 – 13. 01. 2007 (period I), from 14. 01. 2007 – 17. 05. 2008 (period II), from 24. 05. 2008 – 26. 07. 2009 (period III), from 28. 06. 2009 – 18. 07. 2010 (period IV). (Figures 8 – 11).

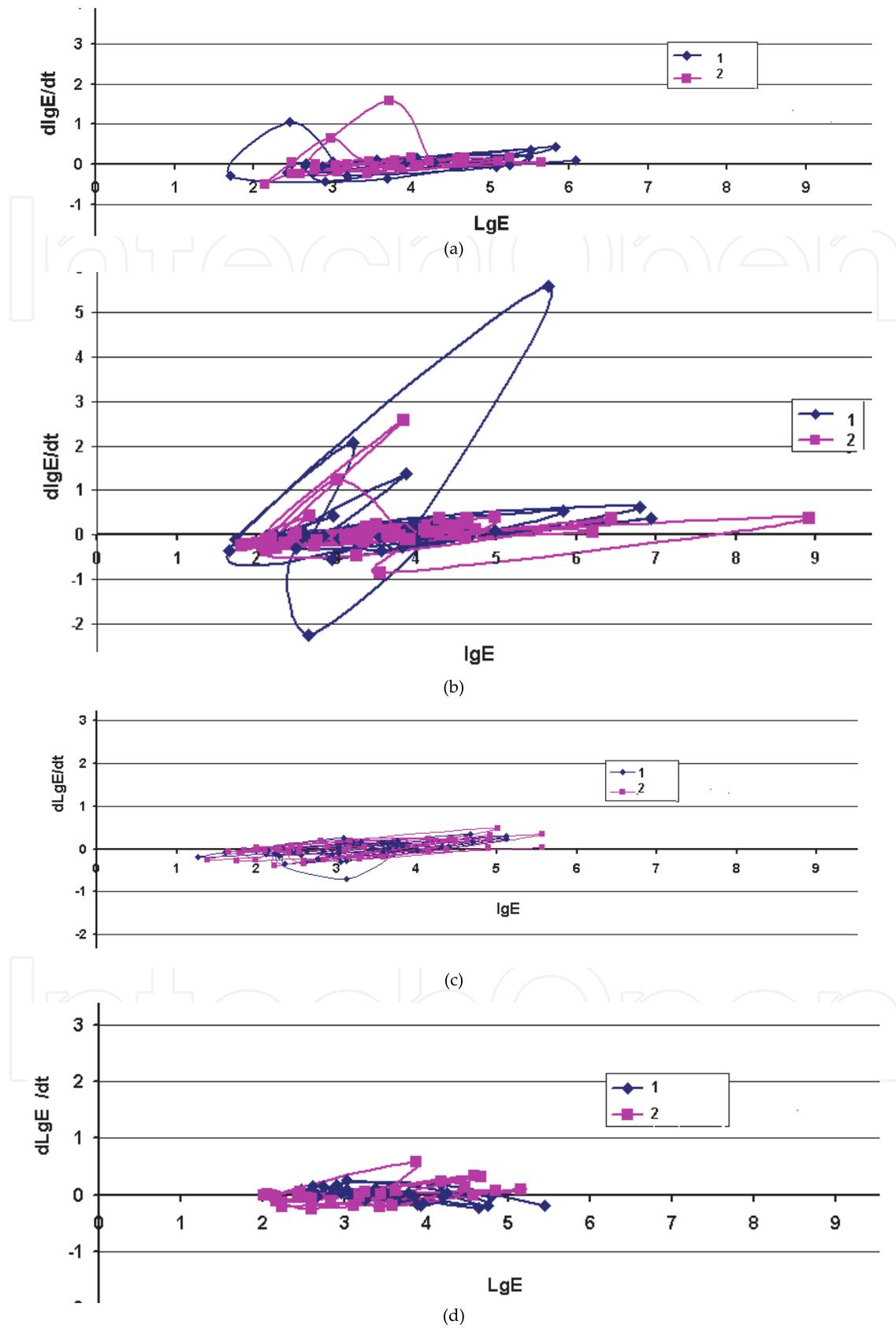
We would like to note such peculiarities for the fourth period (Figure 11): during the period 100 days, beginning from 100 days from the beginning of the analyzed period and finishing by 200 days, the explosions had been provided in the northern and in the southern part of the mine field approximately of equal intensity, however the energy of massif response in the southern part is significantly larger, than from the northern part. During next 50 days the explosions had been provided in the southern part, but the energy of the massif response in the northern part and in the southern part are approximately equal. During the period from 300 days to 400 days the explosions had been provided mainly in the northern part of the mine field, the distribution of the massif response energy in the northern part practically corresponds to the distribution of the absorbed energy.

Period I						
Northern part(A)		Southern part (B)		Correlation coefficients		
Ep(joule)	Ev(joule)	Ep(joule)	Ev(joule)	R(Ep, Ev)(A)	R(Ep, Ev)(B)	R(Ev, Ev)(A, B)
3. 1·10 <sup>7</sup>	3. 1·10 <sup>6</sup>	2. 04·10 <sup>9</sup>	4. 11·10 <sup>6</sup>	0	0. 3	0. 34
Period II.						
2. 98·10 <sup>8</sup>	1. 67·10 <sup>7</sup>	3. 02·10 <sup>8</sup>	8. 2·10 <sup>8</sup>	– 0. 03	– 0. 12	– 0. 03
Period III						
2. 91·10 <sup>8</sup>	1. 3·10 <sup>6</sup>	5. 72·10 <sup>8</sup>	5. 81·10 <sup>5</sup>	0. 3	– 0. 005	0. 21

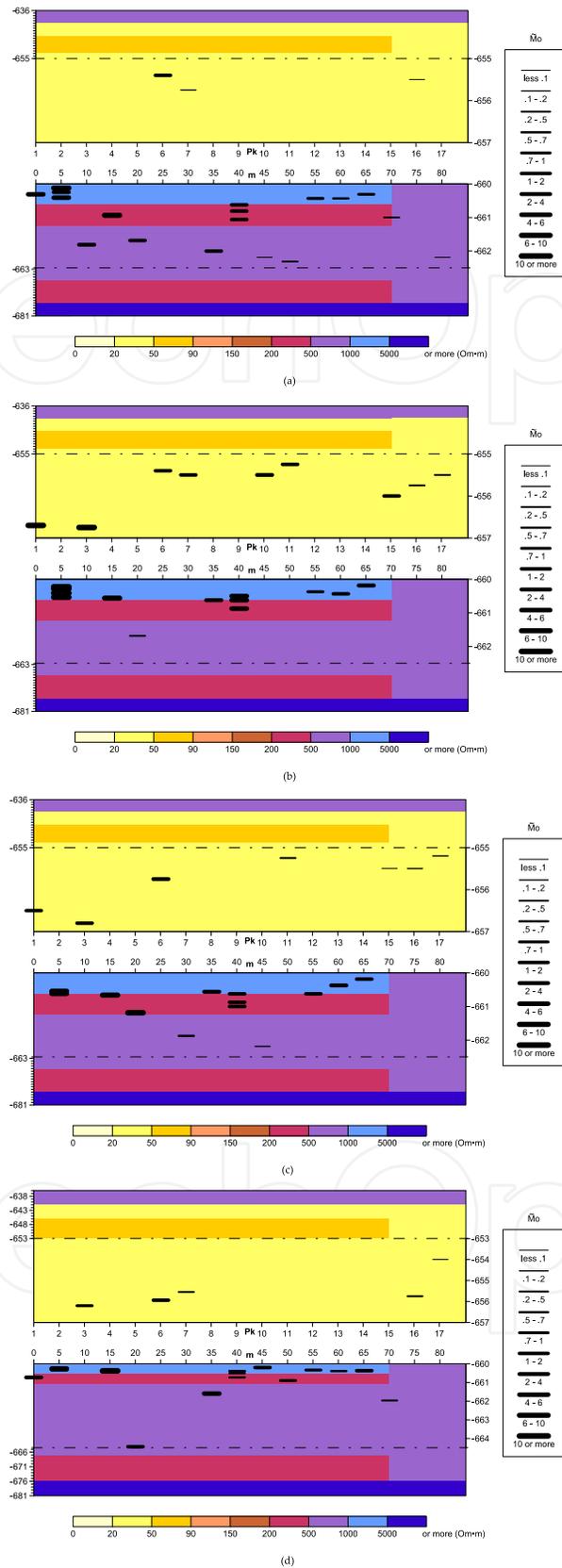
**Table 1.** Distribution of correlation coefficients during the 1 – III periods during the determined time intervals.

Days	Period 129 – 182	Period 203 – 259	Period 307 – 385
Northern part	R(Ea, Ed)=0. 02		R(Ea, Ed)=0. 52
Southern part	R(Ea, Ed)=0. 68	R(Ea, Ed)=0. 24	

**Table 2.** Distribution of correlation coefficients during the IV period during the determined time intervals.



**Figure 12.** Phase diagrams: a) period 1, b) period 2, c) period 3, d) period 4., 1 – southern part, 2 – northern part.



**Figure 13.** Geoelectrical sections along the profile horizon – 210, NWP, ort 3, frequency 10. 16 kHz. a) 9-th of July 2010, b) 16-th of July 2010, c) 23-th of July 2010, d) 26-th of July 2010,  $\tilde{M}_0$  -intensity of discrete zones .

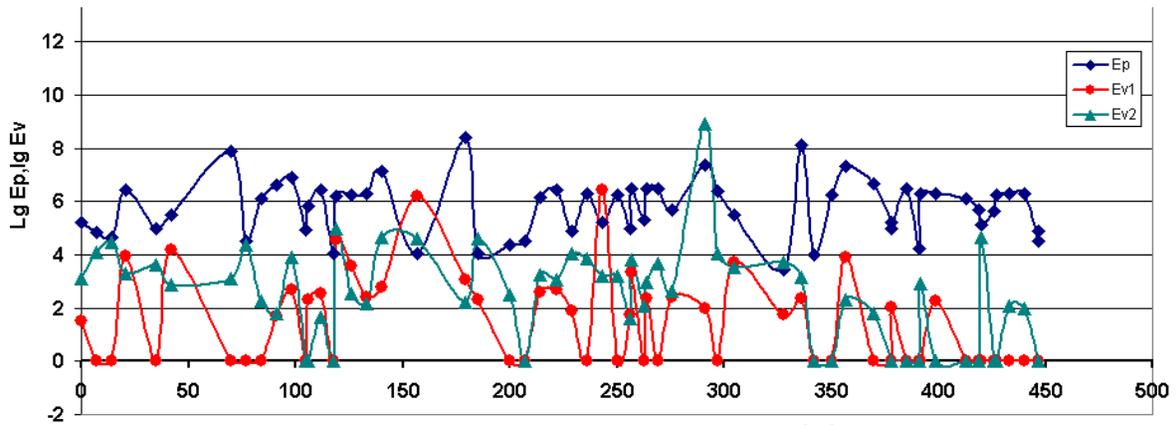
Here, looking the table 1, we can see the changing of nonlinearity in time of the massif state by its active blast effects. The practical massif state situation cannot be described by a linear model. Phase diagrams reflect the dependence of massif energy dissipation velocity from the irregularity in time active man-caused influence. So during the first period 03. 06. 2006 – 13. 01. 2007 the influence of that irregularity leads to dynamical events for the southern part 27. 08 2006. и 17. 09. 2006., in the northern part 10. 09. 2006, however the intensity of the dynamical events during that period did not exceed, than  $5 \cdot 10^6$  joules. During the second period 14. 01. 2007 – 17. 05. 2008 the influence of the irregularity significantly increases compared to the first period, especially in the northern part of the mine and there occurred some dynamical events on 13. 05, 12. 08 and on 21. 10. 2007 in the southern part the most powerful rock burst occurred with energy amplitude –  $10^9$  joules.

The phase diagrams of the massif state during the two last periods show the identity of the massif state of the southern and northern parts during the last two years. The energy of responses and the velocity of its changing's has an identical character.

The successive cycle of induction active electromagnetic monitoring was provided in 2010 from 9-th of July to 26-th of July in the holes of the northern –west department and in some holes of the southern part of the mine's field. During the same time the man-caused works had been arranged in the block 4 – 5 of the northern part of the mine. The explosions had been achieved 04. 07 – Energy of the explosion  $1.7E+06$  joules, 11. 07 – Energy of the explosion  $3.50E+07$  joules, 18. 07 – Energy of the explosion  $1.7E+06$  joules, 25. 07 – Energy of the explosion  $1.7E+06$  joules, 01. 08 – Energy of the explosion  $1.4E+05$  joules. The repeated electromagnetic observations had been achieved in the ort 3 NWD 9. 07, 16. 07, 23. 07 and 26. 07. (figure 10, (a-d)) The analyze of electromagnetic data during the 4 cycles of observation from 2007 to 2010 showed that the massif of the 3-d ort is more sensitive to the change of the stress-deformed state in the northern-west part of the mine field, which is caused by the influence outside it.

#### **4. Geosynergetics approach for analyze of rock state – Theoretical and experimental results**

The research of rock burst hazard massif of the mine Tashtagol was arranged using the approaches of the theory of open dynamical systems [6, 8, 20]. We would like to search the criterions of changing the regimes of dissipation for the real rock massif, which are under heavy man-caused influence. We used the data from the seismic catalogue from June 2006 to June 2008, used the space-time coordinates of whole dynamical events-responses of the massif, which occurred during that period and also explosions, which are fixed by the seismic station using the energy parameter [20]. The phase portraits of the massif state of the northern and southern places had been developed in the coordinates  $E_v(t)$  and  $d(E_v(t))/dt$ ,  $t$ -time in the parts of days,  $E_v$ -seismic energy dissipated by the massif in joules.



**Figure 14.** The distribution of absorbed ( $E_p$ ) and dissipated energy ( $E_v$ ) by the first and second part of the southern part of the massif during the second period of observation time 14. 01. 2007 – 17. 05. 2008. The horizontal ax is time per days.

Intervals	$R(\lg E_p, \lg E_{v2})$		
1 – 21 0 – 179	- 0. 0062		
21 – 60 179 – 450	0. 240683		
23 – 42 200 – 342	0535269		
Intervals	$R(\lg E_p, \lg E_{v1})$	$R(\lg E_p, \lg E_{v2})$	$R(\lg E_{v2}, \lg E_{v1})$
24 – 41 207 – 336	- 0. 00881		0. 12652
12 – 24 105 – 207	0. 30794	0. 13077	0. 70973
1 – 23 0 – 200			0. 26314

**Table 3.** Coefficients of correlation  $R$  for processes between absorption energy ( $E_p$ ) and dissipation energy ( $E_v$ ) in the massif for different time intervals ( $N_i$ ), for the second period.

Here we divided the southern part of the mine's field on two parts: orts 13 – 16 – block (1) and 23 – 31 – block (2), horizons – 280, – 350 and used the data from the mines catalogue from 14-th January 2007 to 17-th of May 2008 (period 2).. From the results of the table 3 we see that the process of energy adsorption and dissipation in the researched blocks 1 and 2 as a rule is nonlinear, but the degree of nonlinearity changes in time. In the interval 23 – 42, which corresponds to the interval DT (200 – 342), the correlation coefficient between  $\lg(E_p)(DT)$  and  $\lg(E_{v2})(DT)$  has the maximum value. That interval includes the process of

preparation of the resonance release energy by the massif as a rock burst of the 9-th class. From the other side for the interval 12 – 42 we see the changing of the type of the correlation dependence between the functions  $R(\lg(Ev2), \lg(Ev1))$ : for the interval 12 – 24 the correlation coefficient corresponds to a linear correlation function, which reflects the elastic interaction between two blocks (orts 15 – 16) and (orts 27 – 29). By the way the relation between  $\lg(Ep)$  and  $\lg(Ev2)$  and  $\lg(Ev1)$  is practically nonlinear. For the interval 24 – 41 the type of correlation function  $R(\lg(Ep2), \lg(Ep1))$  changes nonlinear and the dependence between  $\lg(Ep)$  and  $\lg(Ev1)$  is practically absent (table 3). However before 48 days a rock burst of 6.4-th class occurs in the block 1 after the explosion of 5.2 classes in the block 2. Can we think that this rock burst was a foreshock for the rock shock of the 9-th class in the block 2? On that question we can answer only after providing detailed every day observations of electromagnetic active induction and deformation monitoring in the whole space of the 1-st and second blocks.

There is a deep principal difference between the mechanics of linear and nonlinear oscillations, which still persists by research weak nonlinear oscillations, which can be described by differential equations, which differ from linear equations only by presence of small terms, which begin to influence especially on the time intervals larger, than the period of oscillations. In the system there can be energy sources and absorbers, which produce and absorb very small work for one period of oscillations, but by prolonged actions their produced effect can be summarized and provide a sufficient influence on the oscillatory processing: decay, increase, stability. The small nonlinear terms can provide cumulative influence and damage the superposition principle, apart harmonics begin to influence on each other, and therefore the individual research of the behavior each harmonic oscillation apart cannot be done. The continuous waves can practically exist only in the case, if the system contains an energy source, which can compensate the energy decay, which appears as a result of existence of dissipative forces. Such source plays a role of negative friction. The oscillations which occur owing to a source, which influence has not constant period, are known as auto oscillations and any auto oscillatory system is described by a non linear differential equation.

Relaxation oscillations are widely distributed in the nature, for them oscillatory process has two stages: slow energy accumulation by the system and then energy relaxation, which take place almost immediately after the moment when potential threshold is over reached for that system.

## 5. Conclusions

One of the mathematical ideas about the common causes of chaotization and stochastization of dynamical system movements are its losses of stability and exponential recession of near located phase trajectories together with its common boundedness and its common compression [8]. The mathematical result coincides as a whole with the practical result: in the phase area the smaller attracting phase trajectories area exists where may occur an exponential recession of them, then the movement character changes and the

further movement of phase points lead to return to the same attracting area. These movements may take place in resonance or spontaneous cases. The received practical results are significant because firstly we could find the coincidences with the mathematical theory between open systems and results of experiments in natural medium with very complicated structure. On this base we developed a new processing method for the seismological information which can be used real-time for estimation of the disaster danger degree changing in mine massif.

On the base of the constructed algorithm for calculation of the distribution of seismic waves into a medium with hierarchic inclusions located in an arbitrary layer of a horizontal layered elastic medium we can compute the stress components on each hierarchic level. This information we use to estimate the medium state analyzing the hierarchic structure and its changing. From the other side as higher the degree of hierarchic structure as larger becomes the degree of space nonlinearity of seismic field components distribution. This feature should be taken into account by interpretation to minimize linearization negative effects. From the received theoretical results we did a conclusion, that as higher is rank of hierarchy of the medium as less the similarity between seismic and electromagnetic results, and the obtained information has a independent sense, which underlines the complexity of the researched medium.

The analysis of experimental seismological and electromagnetic information showed the common additional information on different space-time scale levels of the state of rock massif, which is under energetic influence of mining explosions. It has revealed the change of nonlinearity in time of the massif state. The description of the massif behavior in the frame of the linear dynamical model does not correspond to the real practical situation. As it follows from the received results, the changing of the massif state: decreasing and increasing of its activization, does not depend on the space location of the explosion and on delay in time. It is needed to determine that delay function of its activization to be able to forecast the massif behavior. For that it is needed to continue obtaining and analyzing the complex information from passive and active seismic and electromagnetic detailed monitoring. For quantitative research of the behavior of different types of nonlinear dynamical systems we shall use the asymptotical methods for nonlinear mechanics, developed by N. M. Krilov, N. N. Bogolubov and Yu. A. Mitropolsky [bibliography in [23]]. However if we want to use the data from the seismic catalogue, we must convert energetic characteristics to forces and displacements. For that we need additional information about deformations, which occur in the massif by the explosions influence. The mathematical method, which had been developed by academician N. N. Bogolubov, allows us to get on with quantitative description of the causes of self excitation of the nonlinear mechanical system and the occurrence of the space-time local resonance in the system as a response to the outer influence. Using of common theoretical approaches [8, 23] and complex data: seismic catalogue data, deformation and induction electromagnetic monitoring data [20, 22] will allow us to formulate and solve the problem of forecasting the critical state of activated local place in rock massif.

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## 6. References

- [1] Physical mesomechanics and computer construction of materials. Novosibirsk: Nauka, SIFR; 1995. V. 1.
- [2] Hachay O. A. The problem of the research of redistribution of stress and phase states of massif between high man-made influences. Mining information and analytic bulletin 2006; 5 109 – 115.
- [3] Hachay O. A., Khachay O. Yu. Theoretical approaches for system of geophysical state control validation of geological medium by man-made influence. Mining information and analytic bulletin 2008; 1 161 – 169.
- [4] Hachay O. A., Khachay O. Yu. Results of electromagnetic and seismic monitoring of the state of rock massif by use the approach of the open dynamical systems. Geophysical research abstracts 2009; 11 EGU2009 – 137.
- [5] Hachay O. A. Synergetic events in geological medium and nonlinear features of wave propagation. Geophysical research abstracts 2009; 11 EGU2009 – 3684.
- [6] Chulichkov A. I. Mathematical models of nonlinear dynamics. Moscow: Phismatlit; 2003.
- [7] Malineckiy G. G. Mathematical base of synergetics. Moscow; LKI; 2007.
- [8] Naimark Yu. I., Landa P. S. Stochastic and chaotic oscillations. Moscow; Kniginy dom "LIBROKOM"; 2009.
- [9] Hachay O. A. Geosynergetics: theory, methods, experiments. In: Spichak V. V. (ed.) Electromagnetic research of the Earth. Moscow: Krasand; 2009. p. 138 – 153.
- [10] Hachay O. A., Khachay A. Yu. Theory of integrating seismic and electromagnetic active methods for mapping and monitoring the state of 2D heterogeneities with hierarchic structure in a N-layered medium. In: Shkuratnik V. L., Fokin A. V., Mironov A. V., Didenkulov I. N. (eds) Physical acoustics, nonlinear acoustics, distribution and wave diffraction, geoacoustics : proceedings of the XX-th session of the Russian acoustic society 27 – 31 October 2008, Moscow. Russia. VI. Moscow: GEOS; 2008.

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- [11] Dmitriev V. I. The diffraction of the plane electromagnetic field on cylindrical bodies, located in layered medium. In: Voevodin V. V. Methods of calculation and programming in layered medium. Moscow: MSU, 1965. V. 3. p. 307 – 316.
- [12] Kupradze V. D. The boundary problems of the theory of waves and integral equations. Moscow-Leningrad: TTL. 1950,
- [13] Khachay A. Yu. Algorithm of direct problem solution of dynamical seismic research by excitation with a vertical point force source, located in an arbitrary layer of n-layered isotropic elastic medium. In: Mazurov V. D., A. I. Smirnov (eds) Informatics and mathematical modeling. Yekaterinburg: USU; 2006. p. 279 – 310.
- [14] Hachay O. A., Novgorodova E. N., Khachay A. Yu. Research of resolution of planshet electromagnetic method for active mapping and monitoring of heterogeneous geoelectrics medium. *Fizika Zemli* 2003; 1 30 – 41.
- [15] Hachay O. A., Hinkina T. A., Bodin V. V. Preconditions of seismic and electromagnetic monitoring of nonstationary medium. *Russian geophysical journal* 2000; 17 – 18 83 – 89.
- [16] Hachay O. A., Hinkina T. A., Bodin V. V. Research of the criterion of similarity for seismic and electromagnetic research in frequency-geometrical variant. In: Holshevnikov K. V., Shustov B. M. Zacharova P. E. (eds) Astronomical and geodetic research. Yekaterinburg: USU; 2001. p. 30 – 35.
- [17] Hachay O. A., Druginin V. S., Karetin Yu. S., Bodin V. V., Novgorodova E. N., Khachay A. Yu., Zacharov I. B., Groznieh M. V. The use of complex planshet seismic and electromagnetic method for solution of mapping subsurface heterogeneities problems. In: Solodilov L. N., Kostuchenko S. L., Yasuleyitch N. N. (eds.): Geophysics of the 21 – st century: proceedings of the third geophysical symposium, 22 – 24 February 2001,. Moscow, Russia. Moscow: Nauchniy Mir; 2001.
- [18] Hachay. O. A. Mathematical modeling and interpretation of alternative electromagnetic field for heterogeneous crust and upper mantle of the Earth. Prof. thesis. Yekaterinburg: IGF UB RAS; 1994.
- [19] Hachay O. A., Khachay O. Yu. Simulation of seismic and electromagnetic field in hierarchic heterogeneous structures. In: Martyshko P. S. (Ed): Geophysical research of the Ural and adjacent regions: proceedings of the international conference, 4 – 8 February 2008, Yekaterinburg, Russia. Yekaterinburg: OOO"IRA UTK", 2008.
- [20] Hachay O. A., Khachay O. Yu., Klimko V. K., Shipeev O. V. Reflection of synergetic features of rock massif state under man-made influence in the data of seismological catalogue. *Mining information and analytical bulletin* 2010; 6 259 – 271.
- [21] Hachay O. A., Khachay A. Yu. Construction of dynamical Model for Evolution of Rock Massive State as a Response on a Changing of stress-deformed State. *Geophysical Research abstracts* 2010; 12. EGU2010 – 2662.
- [22] Hachay O. A., Khachay O. Yu, Klimko V. K., Shipeev O. Yu. The reflection of synergetic features in the response of geological medium on outer force actions. In: Jinghong F., Junqian Z., Haibo C., Zhaohui J.: *Advances in heterogeneous Material Mechanics:*

proceedings of the third international conference on heterogeneous material mechanics  
22 – 26 May 2011, Shanghai, China. Lancaster, USA: DEStech Publications, Inc. 2011.

[23] Bogolubov N. N. Mathematics and nonlinear mechanics. Moscow: Nauka; 2005.

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