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Modelling of Seismic-Electromagnetic Processes in Hierarchic Structures, Linked with Seismic-Tectonic Activity

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Summary

That chapter is devoted to discuss the key ideas of new structural models of a rock massif and new approaches to research the nonlinear effects which can be measured as a reflection on different types of natural and man-caused actions. Here are demonstrated the results, which are developed in theory and practical use of seismic and electromagnetic monitoring. All these approaches are used for different rock massif of different contents. They are effective and can reflect more precisely the real state of the rock massif, therefore we can obtain a more effective management of the oil or of rock deposits outworking.

10.1 Introduction

The last decades are characterized by an active development of Earth's sciences. We shall use the materials, published in the book (Dmitrievsky, 2009) by the Russian academician Dmitrievsky A.N., who suggested the conception about the development of oil-gas geology in Russian Federation. The modern research methods and technologies give the opportunity to obtain new data about the Earth's structure and processes, which occur in its interior. The conception development of the nonlinear geodynamics practically coincides with research of nonlinear processes in different parts of physics. In geology soliton, wave and auto wave conceptions are developed, and principles of synergetic and self-organization are used, whereas in geodynamics, the macro quantum behavior of large mass matter, which are in critical state, and in geophysics, the auto wave nature of geophysical fields is researched. A new direction of quantum geodynamics appeared. In contrast with traditional approaches in geodynamics, which are based on classical models of continuum, quantum geodynamics allows analyzing the Earth's energetic structure, which evolves in time and penetrates in all natural phenomena and possesses macro quantum time features.

Analogies of the oil gas formation and oil gas accumulation processes with processes of the formation of ore and ore magmatic deposits, in which are sharply appeared its endogen nature, also indicates the essential role of endogen factors in the processes of forming oil gas clusters. It becomes a sharp need for the solution of the generation problem of hydrocarbons not only in a system of an organic matter but in a more widely systems, which include combustible deposits and ore deposits. The development of possible methods and approaches must be based on the considering energy of dynamical processes.

For understanding and analyzing the state of oil gas geology and geophysics on the border of centuries it is needed to compare the key ideas of geophysics, which give the main ideas to research hydrocarbon deposits.

"Geophysics of XX century" is the understanding of such features:

- geophysical fields are indicators of the processes, which occur in lithosphere; geophysical parameters, which are registered distantly can have a functional or correlation relation with the matter-structural characteristics of a geological medium (on macro- and micro levels);

- analysis of space-time and energetic distribution of geophysical field can give information about space-time distribution of geological medium properties;
- registration and analysis of geophysical field in the monitoring regime can give information about the geodynamical processes in near borehole space, in Earth's crust and lithosphere in more deep Earth's layers.

Practical problems of geophysics of XX century had been vigorous stimulus of the evolution of theoretical and experimental physics of thin layered, porous and crack media. That allowed to derive new classes of mathematical models describing fluid saturated of heterogeneous media, to research anisotropic effects of geological media, and to reveal different physical and physical-chemical effects which occur on the boundaries "solid skeleton-fluid". Geophysics for the first time set a question about the possibility of constructing physical-geological and mathematical models of geological objects and processes. Applied geophysics of XX century had realized the possibility of research one and the same geological objects on micro level (nuclear geophysics), meso level (electrical, heat, magnetic, acoustic fields) and macro level (fields of elastic waves and low frequency electromagnetic fields).

Geophysics allowed answering some of these geological questions:

- what is the value of the depth down and the geometry (sometimes morphology) of researched object?
- what is the matter-structure content of the geological object?
- where and how sub vertical and sub horizontal heterogeneities are located and first of all the zones of micro cracks?
- how are the conditions of filtration in fluid porous aggregate?

- what are the thermal dynamical conditions of a researched object location?

We can approve that the modern geophysicists, depending on geological-geophysical conditions, complex of using methods and the level of soft ware can solve these problems.

Key ideas in XXI century in geophysics.

Geophysics of the XXI century is- the understanding of that: the Earth is a self evolutionary, self conditioned geo cybernetic system for which the role of a driving mechanism fulfills gradients of geophysical fields. The use in geophysics principles of hierarchic and quantum features of geophysical space, nonlinear effects, effects of re-emission of geophysical fields allow us to create a new geophysics.

New aspects in the methods:

A wide use of interaction and transformation geophysical fields effects.

A wide use of joined measuring systems with use of control influence (type "borehole logging-influence-borehole logging")

Realization by using new investigation methods has recently discovered principles of an organization of a geological and a geophysical space (quantum and hierarchic features).

New aspects in theory and mathematical modelling of geophysical fields and new systems of data interpretation.

Development of new equation classes, which describes the distribution of elastic and electromagnetic fields in heterogeneous media with account of various effects of nonlinearity of geological media and irreversibility of geophysical processes. It will developed new theories of inverse problems solution with account of the hierarchic structure of inclusions imbedded into the layered medium.

Now we shall investigate and study some results which are into the key direction of geophysics of XXI century, noted by Dmitrievsky, 2009.

10.2 Research of Nonlinear Effects in an Energy Saturated Medium

The important role of developing new methods for managing of oil deposit by its outworking plays the account of the influence of nonlinear effects in an energy saturated medium.

For that, we need to use the theoretical results of nonlinear oscillation processes research. The founders of research methods of such processes are Puancare, Lapunov, Van-der-Pole, Strett. Their results had been used and developed by Andronov and Witt. The basement of nonlinear mechanics was developed by Krilov and Bogolubov (Bogolubov, 2005). They had developed new integration methods of nonlinear equations, which describe nonlinear oscillation processes and new methods of a general theory of no conservative dynamical systems.

It is a deep principal difference between the mechanics of linear and nonlinear oscillations, which persists even by considering weak nonlinear oscillations, which are described by differential equations, that differ from the linear equations by small terms whose influence will be significant on the intervals larger, than the oscillation period. In the system, there can be energy sources and absorbers, which produce and absorb very small work during one oscillation period, but by, long-term their influence the developed effect can be accumulated and achieve a cumulative influence on the behavior of the oscillation process: attenuation, swinging, and stability. The small nonlinear terms can cumulative influence and destroy the principle of superposition, some particular harmonics begin to interact with each other; as a result we cannot consider the behavior of each harmonic apart.

Non damping oscillations can practically exist only in the case, when an energy source exists in the system, which can set off the energy decay, occurring as a result of dissipative forces existence. Such a source plays a role of a negative friction. The oscillations, which are supported by a source, and it does not periodically influence, are known as auto oscillations and an arbitrary auto oscillator system can be described only by a nonlinear differential equation. A wide distribution in the nature has relaxation oscillations, for which the oscillation process is divided into two stages: slow energy accumulation by the system and after that the energy discharge, which results almost immediately, after the critical potential level is achieved by the value of the accumulated energy.

The mathematical new method, which had been developed by N.N. Bogolubov (2005) and the whole series of model nonlinear problems allow us to understand on the quantitative level the causes of self excitation of the nonlinear mechanical system and occurring of the space-time resonance of the system as a response on the outer influence.

As an example we shall consider some model problems with the use of the algorithm of asymptotical solution.

If the force f, which perturbs the oscillation system, does not depend on time explicitly, they depend only on the dynamical state from that system. That behavior of oscillations can be described by the differential equation of that type:

$$\frac{d^2x}{dt^2}+\omega^2 x=\varepsilon f\left(x,\frac{dx}{dt}\right), \tag{1}$$

ε is a small positive parameter. By ε=0, the oscillations will be pure harmonically:

$x=a\cos\psi$, a is a constant amplitude and uniformly changing phase angle.

$$\frac{da}{dt}=0,\ \frac{d\psi}{dt}=\omega\ \ (\psi=\omega t+\theta) \tag{2}$$

(amplitude a and phase of oscillations θ will be constant in time and depend on the initial conditions).

The solution of the equation (1), following (2) we shall search as:

$$x=a\cos\psi+\varepsilon u_1(a,\psi)+\varepsilon^2 u_2(a,\psi)+\varepsilon^3 u_3(a,\psi)+... \tag{3}$$

in which $u_1(a,\psi),u_2(a,\psi).....$ are periodic functions of the angle ψ with a period 2π, functions from time a,ψ can be determined from differential equations:

$$\begin{aligned}\frac{da}{dt}&=\varepsilon A_1(a)+\varepsilon^2 A_2(a)+....\\ \frac{d\psi}{dt}&=\omega+\varepsilon B_1(a)+\varepsilon^2 B_2(a)+....\end{aligned} \tag{4}$$

The solution algorithm of the problem consists of finding an explicit type for functions:

$u_1(a,\psi), u_2(a,\psi),..., A_1(a), B_1(a), A_2(a), B_2(a),...$ in such a way in order to the expression (3) will be a solution of the equation (1), and a,ψ will satisfy the system (2). By that the problem of integration of the equation (1) is reduced to a simpler problem of integration the system (4) with separate variables.

But the procedure of an explicit definition of the expansion coefficients (3) and (4) very quickly become complicated, practically effective we can find two-three first terms of the expansion, therefore the solution method (1) has a content of an asymptotic method for fixed m=1, 2, 3… by $\varepsilon \to 0$. Thus the problem formulates as follows: we need to find functions $u_1(a,\psi), u_2(a,\psi),..., A_1(a), B_1(a), A_2(a), B_2(a),...$, in order to valid such an expression.

$$x = a\cos\psi + \varepsilon u_1(a,\psi) + \varepsilon^2 u_2(a,\psi) + ...\varepsilon^m u_m(a,\psi) + ...(m=1,2,...) \tag{5}$$

Where the functions a,ψ, which depend from time can be defined from the" equations of the m-th approximation":

$$\begin{aligned} \frac{da}{dt} &= \varepsilon A_1(a) + \varepsilon^2 A_2(a) + ...\varepsilon^m A_m(a) \\ \frac{d\psi}{dt} &= \omega + \varepsilon B_1(a) + \varepsilon^2 B_2(a) + ...\varepsilon^m B_m(a) \end{aligned} \tag{6}$$

will satisfy the equation (1) with the accuracy up to values of ε^{m+1} order infinitesimal. The definition of parameters a,ψ is achieved by additional conditions of absence of the first harmonic in the expressions $u_1(a,\psi), u_2(a,\psi),...$, that is by conditions:

$$\begin{aligned} &\int_0^{2\pi} u_1(a,\psi)\cos\psi d\psi = 0, \int_0^{2\pi} u_2(a,\psi)\cos\psi d\psi = 0,..., \\ &\int_0^{2\pi} u_1(a,\psi)\sin\psi d\psi = 0, \int_0^{2\pi} u_2(a,\psi)\sin\psi d\psi = 0,..., \end{aligned} \tag{7}$$

By using the expressions (4) and (5) let us introduce the left part of the equation (1) as such:

$$\frac{d^2x}{dt^2}+\omega^2 x=\varepsilon\left\{-2\omega A_1\sin\psi-2\omega aB_1\cos\psi+\omega^2\frac{\partial^2 u_1}{\partial\psi^2}+\omega^2 u_1\right\}+$$
$$+\varepsilon^2\left\{\begin{array}{l}\left(A_1\frac{dA_1}{da}-aB_1^2-2\omega aB_2\right)\cos\psi-\left(A_1\frac{dB_1}{da}a-+2A_1B_1+2\omega aA_2\right)\sin\psi+\\+\left(2\omega A_1\frac{\partial^2 u_1}{\partial a\partial\psi}+2\omega B_1\frac{\partial^2 u_1}{\partial\psi^2}+\omega^2\frac{\partial^2 u_2}{\partial\psi^2}+\omega^2 u_2\right)\end{array}\right\}+\varepsilon^3\ldots \tag{8}$$

The right part of the equation (1) we can write, taking into account (3) and the expressions of the first and the second derivative *x* on *t* as such:

$$\varepsilon f(x,\frac{dx}{dt})=\varepsilon f\left(a\cos\psi,-a\omega\sin\psi\right)+$$
$$+\varepsilon^2\left\{\begin{array}{l}u_1 f_x'\left(a\cos\psi,-a\omega\sin\psi\right)+\\+\left(A_1\cos\psi-aB_1\sin\psi+\omega\frac{\partial u_1}{\partial\psi}\right)\times f_{x'}'\left(a\cos\psi,-a\omega\sin\psi\right)\end{array}\right\}+\varepsilon^3\ldots \tag{9}$$

Furthermore, we must compare coefficients with an equal degree of ε in the right parts of expressions (8 - 9). As a result we shall receive such equations:

$$\begin{aligned}
&\omega^2\left(\frac{\partial^2 u_1}{\partial\psi^2}+u_1\right)=f_0(a,\psi)+2\omega A_1\sin\psi+2\omega aB_1\cos\psi,\\
&\omega^2\left(\frac{\partial^2 u_2}{\partial\psi^2}+u_2\right)=f_1(a,\psi)+2\omega A_2\sin\psi+2\omega aB_2\cos\psi,\\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\\
&\omega^2\left(\frac{\partial^2 u_m}{\partial\psi^2}+u_m\right)=f_{m-1}(a,\psi)+2\omega A_m\sin\psi+2\omega aB_m\cos\psi,
\end{aligned} \tag{10}$$

where for m=0, 1:

$$
\begin{aligned}
& f_0(a,\psi) = f\left(a\cos\psi, -a\omega\sin\psi\right), \\
& f_1(a,\psi) = u_1 f_x'\left(a\cos\psi, -a\omega\sin\psi\right) + \\
& + \left[A_1\cos\psi - aB_1\sin\psi + \omega\frac{\partial u_1}{\partial\psi}\right] f_x'\left(a\cos\psi, -a\omega\sin\psi\right) + \\
& + \left(aB_1^2 - A_1\frac{dA_1}{da}\right)\cos\psi + \left(2A_1B_1 - A_1\frac{dB_1}{da}a\right)\sin\psi - \\
& -2\omega A_1\frac{\partial^2 u_1}{\partial a\partial\psi} - 2\omega B_1\frac{\partial^2 u_1}{\partial\psi^2},
\end{aligned}
\tag{11}
$$

From the expression (11) follows, that $f_k(a,\psi)$ - are periodical functions of variable ψ, therefore for these, as also for functions $u_l(a,\psi)$ it is valid the Fourier transformation. For defining $A_1(a), B_1(a), u_1(a,\psi)$ from the first equation of the system (10) we introduce $f_0(a,\psi), u_1(a,\psi)$ as follows:

$$
\begin{aligned}
& f_0(a,\psi) = g_0(a) + \sum_{n=1}^{\infty}\left\{g_n(a)\cos n\psi + h_n(a)\sin n\psi\right\} \\
& u_1(a,\psi) = v_0(a) + \sum_{n=1}^{\infty}\left\{v_n(a)\cos n\psi + w_n(a)\sin n\psi\right\}
\end{aligned}
\tag{12}
$$

Let us substitute the right parts of (12) in the first equation of the system (10), equating the coefficients by equal harmonics, then we receive:

$$
\begin{aligned}
& g_1(a) + 2\omega aB_1 = 0, \quad h_1(a) + 2\omega aA_1 = 0, \\
& v_0(a) = \frac{g_0(a)}{\omega^2},\ v_n(a) = \frac{g_n(a)}{\omega^2(1-n^2)},\ w_n(a) = \frac{h_n(a)}{\omega^2(1-n^2)},\ n = 2,3...
\end{aligned}
\tag{13}
$$

In the expressions (13) all harmonic components of the function $u_1(a,\psi)$ are defined, besides the first, which according the condition (6) are equal to zero and we can write $u_1(a,\psi)$ as follows:

$$u_1(a,\psi) = \frac{g_0(a)}{\omega^2} + \frac{1}{\omega^2} \sum_{n=2}^{\infty} \frac{g_n(a)\cos n\psi + h_n(a)\sin n\psi}{1-n^2} \tag{14}$$

Thus we have an explicit expression for $f_1(a,\psi)$ and we can expand that function into Fourier set and analogously (12):

$$f_1(a,\psi) = g_0^{(1)}(a) + \sum_{n=1}^{\infty} \left\{ g_n^{(1)}(a)\cos n\psi + h_n^{(1)}(a)\sin n\psi \right\} \tag{15}$$

Let us recycle the procedure, which we did on the previous step, then we shall receive analogously (13):

$$g_1^{(1)}(a) + 2\omega a B_2 = 0, \quad h_1^{(1)}(a) + 2\omega a A_2 = 0,$$

$$u_2(a,\psi) = \frac{g_0^{(1)}(a)}{\omega^2} + \frac{1}{\omega^2} \sum_{n=2}^{\infty} \frac{g_n^{(1)}(a)\cos n\psi + h_n^{(1)}(a)\sin n\psi}{1-n^2} \tag{16}$$

The derived algorithm allows us to determine $u_n(a,\psi), A_n(a), B_n(a)$ $(n = 1,2,3,...)$ for arbitrary large n and therefore we can construct approximate solutions, which satisfy equation (1) with accuracy up to values to ε of arbitrary high degree infinitesimal.

Let us consider some private examples by using that approach.

First example: free pseudo harmonic oscillations without damping. Let us assume that the relation between the elastic field and displacement is nonlinear but sufficient "weak". Following the algorithm, which is written higher, for the first approximation the oscillation amplitude will not depend on time, the searched oscillation for the first approximation will be harmonic, but the frequency of system oscillations will depend on the amplitude, the loss of isochronisms will be less, depending on the nonlinear part of the force will be less than the linear part. Analyzing the second approximation, using the written algorithm we also can constitute that the oscillation amplitude will not depend on time. That feature is valid for conservative systems for arbitrary approximation. In the expression for the frequency arrive terms, which will depend on the harmonic of the active force, which are more less if the parameter ε is less by the nonlinear part of the active force.

Second example: let us consider the case of system oscillations under the influence of a linear elastic force and nonlinear weak friction, which depends on velocity. That case is a private case of the considered algorithm of the nonlinear problem solution. In the first approximation the amplitude of oscillations damps in relation of frequency and parameter ε, at the same time the system oscillations are harmonic with a constant frequency, that is for the first approximation the system remains isochronous. In the second approximation, the damping law remains the same, as for the first approximation, but the oscillation frequency varies proportionally to the square of parameter ε, which may show small variations under the influence of the nonlinear friction.

Third example: let us consider an oscillatory system, which is described by the equation as follows:

$$\frac{d^2x}{dt^2} + \omega^2 x = \varepsilon f(x)\frac{dx}{dt} \qquad (17),$$

This is also a private case of the equation (1). Comparing the obtained approximate solutions with the solutions of the case II we can testify their identity for the first and second approximations. If we consider $f(x) = 1 - x^2 \ \ \omega = 1$, the equation (17) will be written as such:

$\frac{d^2x}{dt^2} - \varepsilon(1 - x^2)\frac{dx}{dt} + x = 0$, it is known as the equation of Van der Pole, which describes the auto oscillation systems (Bogolubov, 2005). Using the algorithm, which is written higher, we can obtain for the first approximation for that equation an expression as such:

$$x = \frac{a_0 e^{\varepsilon t/2}}{\sqrt{1 + a_0^2 \left(e^{\varepsilon t} - 1\right) / 4}} \cos(\omega t + \theta) \tag{18}$$

As we can see from the expression (18), if the initial value of the amplitude is equal to zero, the amplitude will be equal to zero for arbitrary t, that confirms the static regime that is the absence of oscillations in the system. But that regime is not stable. Since small shocks always exist in the system, the oscillations excite automatically with growing amplitude, approaching to its limiting value.

Let us consider the main difference between auto oscillation systems and conservative oscillation systems. In the second systems oscillations are possible with arbitrary constant amplitude; in the first systems oscillations with constant amplitude are possible only by their some definite value. In conservative systems there is not dissipation and not an energy source, therefore if the oscillations were once excited, they cannot either grow, no damp and its amplitude equals its initial value. In self exciting systems energy dissipation and a source exist. Therefore the oscillation amplitude will grow and the energy amount, which the system obtains from the source will override the energy amount, which is dissipated by the forces. If the energy amount, becoming from the source is less, than the amount of dissipated energy, the oscillations become decay. If the energy amounts in the system are equal to each other, the amplitude will save its constant value.

Fourth example: let us consider a nonlinear oscillation system, for which the physical parameters, which define its features m, k slow relatively to the period of its self oscillations vary with time. For that case the equation (1) will be written as follows:

$$\frac{d}{dt}\left[m(\tau)\frac{dx}{dt}\right]+k(\tau)x=\varepsilon f\left(\tau,x,\frac{dx}{dt}\right),\ \tau=\varepsilon t \tag{19}$$

ε, - small positive parameter, *τ* - "slow time". Formula (3 - 4) will vary as follows:

$$x=a\cos\psi+\varepsilon u_1(\tau,a,\psi)+\varepsilon^2 u_2(\tau,a,\psi)+\varepsilon^3 u_3(\tau,a,\psi)+\ldots \tag{20}$$

$u_1(\tau,a,\psi),u_2(\tau,a,\psi)$..... , are periodical functions of the angle ψ with a period 2π, functions a,ψ as functions on time can be defined by differential equations:

$$\begin{aligned}&\frac{da}{dt}=\varepsilon A_1(\tau,a)+\varepsilon^2 A_2(\tau,a)+....\\&\frac{d\psi}{dt}=\omega(\tau)+\varepsilon B_1(\tau,a)+\varepsilon^2 B_2(\tau,a)+....\quad \omega(\tau)=\sqrt{k(\tau)/m(\tau)}\end{aligned} \tag{21}$$

ω(τ) - "self frequency" of the considered oscillation system.

The scheme described above can be used for obtaining asymptotic solutions for first and second approximations, as a result in the case of the first approximation of the solution, besides the inharmonic an additional term occurs, which depends from physical parameters of the system.

Apart it is interesting to consider the use of the method of obtaining the asymptotic solution by influence an outer force, which depends explicitly from time. As it was shown in the book (Bogolubov, 2005) that method is effective to consider the occurring resonances in the oscillatory system with self set of frequencies.

Thus as you can see the considered set of nonlinear mechanics solutions (Bogolubov, 2005) can be used as approximation constructions for local space-time modeling of the state of high complicated no stationary medium, which is the geological elastic and oil saturated medium (Hachay et al., 2011; Hachay and Khachay, 2012). Using the joined theoretical approaches

(Tshulichkov, 2003; Bogolubov, 2005; Naimark and Landa, 2009) will allow us to formulate and solve these problems.

10.3 New Paradigm of Mesomechanics

In present days, for a more adequate understanding of the dynamics of processes, which occur in the geological medium on deep levels by the action of natural and man caused factors Academician V.E.Panin using the results, which had been derived by his colleagues (Panin, 2005, chapter 9) had introduced a new paradigm on the junction between physics and mechanics of a deformed solid body, which is the base of physical mesomechanics.

- Identification of mechanisms of plastic flow on different structural deformation levels, which lead to a fundamental change of the initial inner structure of the solid body and forming into it dissipative substructures as a mesoscopic plastic deformation support.
- Fixing a relation between the outer action, changing of the initial inner structure, forming a hierarchy of mesoscopic self matched structural levels of deformation and occurring as a result of its mechanical fields.
- A synergetic approach in the methodology of describing the deformed solid body as a non equilibrium many leveled medium, which in the points of bifurcation loses its shift stability on different structural levels and becomes to be destroyed in the conditions of global losses of its shift stability on a macro scale level.

For experimental research of deformation mechanisms of specimens on meso level it had been developed new methods with use of speckle interferometry and optical television devices of technical vision, measuring of fractal dimension of deformed solid body. It turns out, that on the meso level 3-D structural elements (meso volumes) move as a whole. In that case it is sufficient to consider a representative volume, which consists of some tens meso volumes, for writing the equations of mesomechanics, taking into account the inner structure of the deforming solid body

For realizing the second point of the new paradigm Panin with his colleagues had written a system of equations, which describes the mechanical field in the deforming solid body on one level (Panin, 2005, chapter 9). It turned out, that it is similarly the Maxwell system of equations for alternating electromagnetic fields. Similarly electromagnetic field, where alternating electric and magnetic fields are mutually linked, the common mechanical field occurs in the deforming solid body, which contains organic mutual linked the translational and rotating modes (Panin, 2005, chapter 9).

That result was very significant for the choice of geophysical methods, using for monitoring of structure and state of rock massif, which is under strong man based action, which is a component of the geological medium in seismic-tectonically areas.

For the research of processes, linked with a change of the structure and the state of a rock massif, which are under a strong man-based action, for the first time, in the Institute of Geophysics UB RAS, with the use of the the planshet electromagnetic method, it had been realized in a natural research the idea of revealing disintegration zones and organizing the monitoring of its morphology (previous chapter) (Hachay, 2004, chapter 9; Hachay and Khachay, 2006). That method is related to geophysical methods of no destroying control. It differs from other earlier knowing methods of transmission or tomography by systems of observation and interpretation method, based on the three stage conception of interpretation.

10.4 Comparison of Results of an Electromagnetic and a Seismic Monitoring

It is of interest the comparison of results of electromagnetic active induction rock massif monitoring with energetic data of mass explosions and dynamical events in the same volume. The interval of averaging is equal to one year that is the interval between the cycles of an electromagnetic monitoring.

On the fig, 1 are presented data of absorbed E_1 and released E_2 energy in the rock massif before each cycle of electromagnetic monitoring for the time interval of one year.

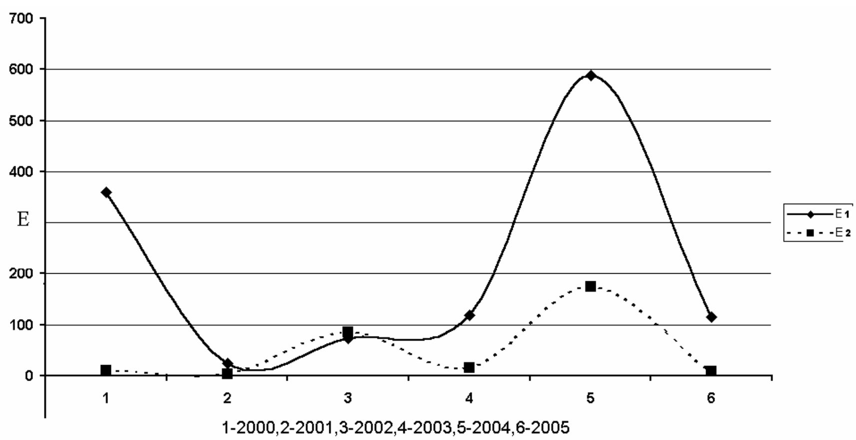

Figure 1. *Distribution of absorbed and released energy during 6 years of seismic monitoring.*

From these data it follows, that the excess release of the massif energy and, therefore, intense formation of cracks had been during the interval between the second and third cycles of electromagnetic monitoring. Let us analyze the parameter of sum intensity of disintegration zones, located down the hole: $Sp = \sum_N Sp\,\mathrm{int}(N,T)$ (previous chapter) for different orts and horizons during 6 cycles of observation (fig. 2a-2f) and develop a space-time massif classification using the degree of the most relation "action-response".

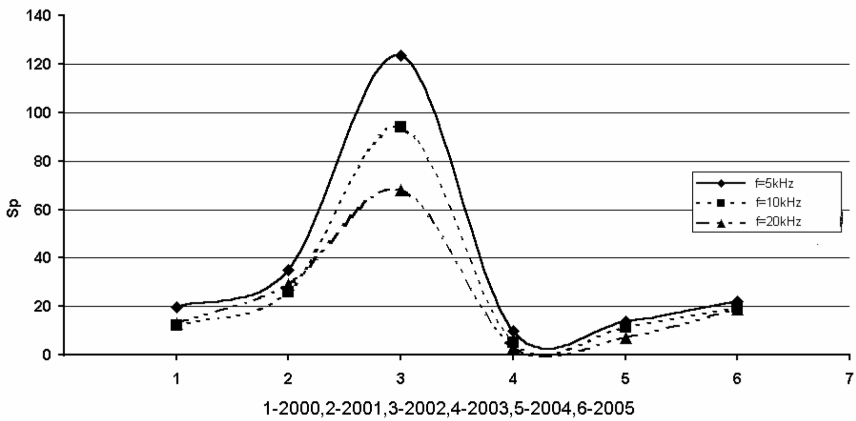

Fig.2a

As seen from the distribution in time of the parameter *Sp* for the massif of the orts 7-8, horizon -210 (fig. 2a), it is in the best conforming with the geomechanical situation of progressive cracks formation and energy release in a frame of dynamical events as bumps and rock shocks during the second and third cycles of observation (fig. 1). By that we can see also a frequency similarity of that distribution (fig. 2a) and the largest values of that parameter are for the frequency 5 kHz, what testifies that the process of structure change does include not only the nearest massif part down the hole, but also its deeper parts and the reconstruction takes place similarly.

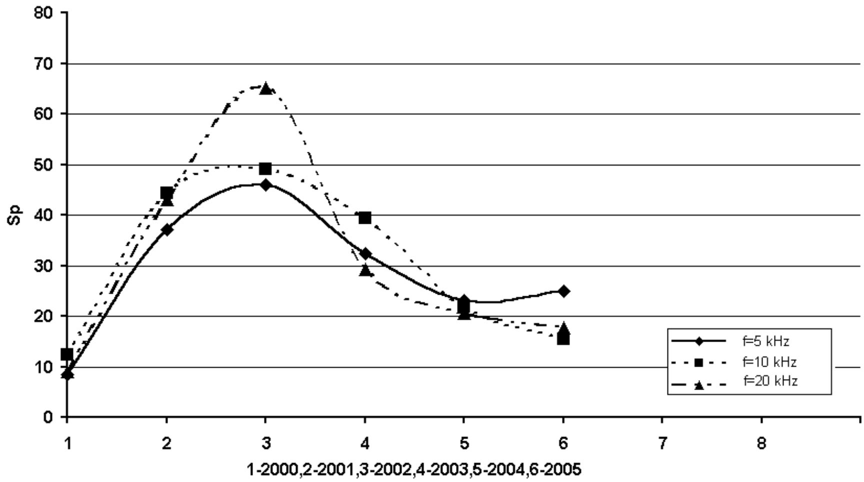

Fig.2b

For the massif of ort 18 horizon -350 (fig.2b) the values of the parameter Sp are less by amplitudes, but morphological coincide with the distribution of the parameter Sp for orts 7-8, horizon -210. At the same time the amplitude maximum for the third cycle of observation had been fixed for the frequency 20 kHz and the minimum for the frequency 5 kHz.

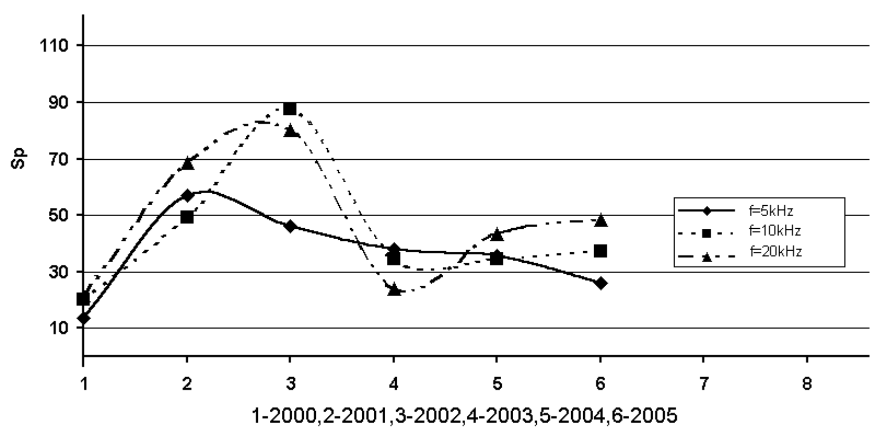

Fig.2c

It means, that the reconstruction of the massif structure occurs similarly in the near and the deeper part of the down part of the hole, but stronger it develops near the contour of the hole.

The same effect we can see for the massif, ort 2, horizon -210, (fig. 2c). At the same time, it intensifies the difference of the distribution of the parameter *Sp* between frequency 5 kHz and frequencies 10, 20 kHz for the third cycle of observations.

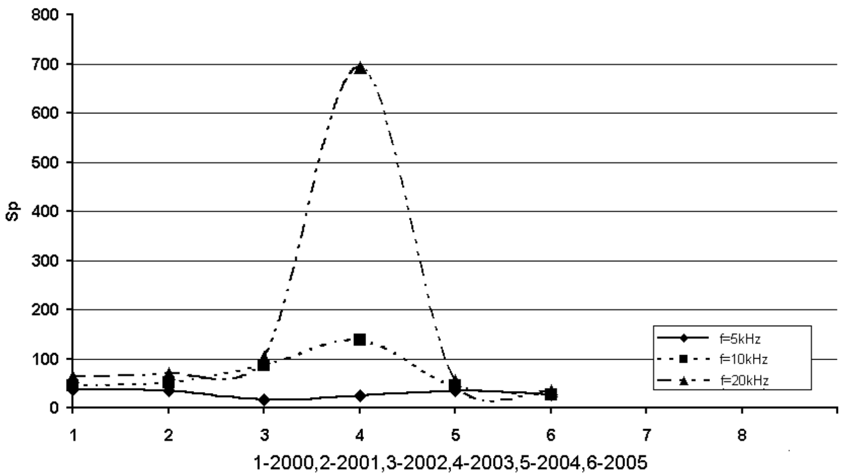

Fig. 2d

Furthermore, we can consider the massif, which respond with a lag on the man-caused action intensify, especially that effect appeared for the massif ort 19, horizon -350 (fig.2d) with very strong frequency dispersion. The maximum distribution of the parameter *Sp* is fixed for the frequency 20 kHz and for the fourth cycle of observation 2003 year, not for the third cycle 2002 year, as it was for the previous three massifs.

The values of the parameter distribution *Sp* for the massif ort 20, horizon -350 (Fig. 2e) is significantly less, then for other previous places. But for the sixth cycle of monitoring we can see the sharp intense of the parameter *Sp* for the frequency 20 kHz, that can testify the growing of massif activization in the down near hole part in the hole space of the ort 20.

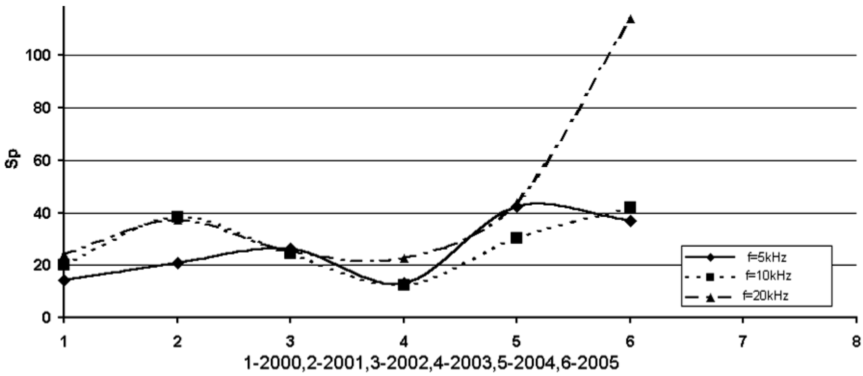

Fig.2e

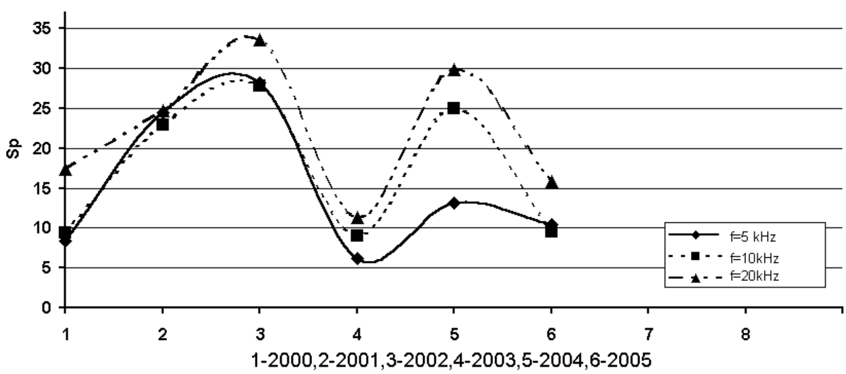

Fig.2f

Figure 2. *Distribution of the integral parameter Sp, defined from the results of the interpretation of electromagnetic monitoring data during 6 years for three frequencies.*

2a-ort 7-8 , horizon -210, 2b-ort ort 18 horizon -350, 2c - ort 2, horizon -210, 2d- ort 19, horizon -350, 2e- ort 20, horizon -350, 2f- ort 4 horizon -210

The distribution of the parameter *Sp* (previous chapter) for the massif ort 4 horizon -210 (fig.2f) testifies about its high sensitivity to geodynamical reconstructions in the massif, which belongs to the area of developing electromagnetic monitoring (fig. 1) and its capacity of turning to its change. So, for instance, after seismological data (fig.1) we can see two maximums of the released energy by the massif, which correspond to 2002 year and 2005 year. However in the year 2002 the integral value of released energy during the period 2001-2002 years exceeded correspondingly the value of absorbed energy, but in the year 2005 it is significantly less. According to data of the parameter distribution *Sp* we can see, that the first maximum occurs on the third cycle of observations, that is on the year 2002 and the distribution has been matched by a frequency character, the second maximum occurs on the fifth cycle of observations, that is on the 2005 year, but at that time its values for the frequency 5 kHz significantly differ from the values 10 and 20 kHz, that is to say that the process of structural massif reconstruction for the fifth cycle has a near contour down hole. And the absolute value of the amplitude *Sp* is minimum, comparing with previous places of observation. Such properties have stable massif. That conclusion coincides with an earlier done conclusion (previous chapter), linked with the massif classification with the use of the parameter *Sp int*: massif of the ort 4, horizon -210 was classified as stable massif.

Table 1 presents data selected from the seismological monitoring, an arranged on the Tashtagol mine by our colleagues V.K. Klimko and O.V. Shipeev. The results of the electromagnetic natural research had been developed together with E.N. Novgorodova and T.A. Hinkina to whom the authors are thankful.

Table 1. *Dynamical events in the areas of orts, where electromagnetic monitoring research had been provided during 2000-2005 years.*

Data, time (hour)	**Absorbed energy as a result of mass explosion E1 (joules)**	**Vertical mark H(m) +450m**	**Released energy as a result of rock shocks E2(joules)**	**Place of dynamical event**
27.02.2000 1:00	9.5 e+07	-181	6.3 e+06	ort 7, west
		-305	1.6 e+05	ort 11-12, east
02.04.2000 0:00	6.4 e+07	-292	2.1 e+05	ort 10-11, center
15.04.2000 7:00	5.6 e+07	-139	1.3 e+06	ort 6, west
21.05.2000 0:08	9.5 e+07	-165	2.1e+06	ort 9 center
09.07.2000 4:00	2.5 e+08	-233	1.6 e+05	орт 5-6,center
The first cycle of active electromagnetic monitoring				
11.02.2001 1:00	2.1 e+06	-156	1.5 e+06	ort 3-4, west
18.02.2001 1:56	5.6 e+06	-217	1.3 e+06	ort 2, center
08.04.2001 0:00	2.1 e+06	-284	1.6 e+05	ort 20-21,west
30.04.2001 7:12	1.4 e+07	-336	3.1 e+05	ort 13, center
The second cycle of active electromagnetic monitoring				
28.10.2001 1:00	1.7 e+07	-228	1.6 e+05	ort 5, center
13.01.2002 1:00	6.6 e+06	-153	1.3 e+05	ort 2, center
03.02.2002 1:00	4.6 e+06	-394	7.5 e+07	ort 22, east
28.07.2002 4:00	4.4 e+08	-312	1.2 e+06	ort 12-13, center
		-206	4.6 e+06	ort 12, west
		-290	3.1 e+05	ort 8, center
		-231	3.2 e+06	ort 2, center
The third cycle of active electromagnetic monitoring				
08.12.2002 15:01	2.9 e+06	-379	1.6 e+05	ort 11, east
02.02.2003 8:00	3.2 e+06	-236	1.6 e+05	ort 28-29, east
15.06.2003 7:59	4.0 e+06	-213	2.5 e+06	ort 5, west
13.07.2003 8:00	1.5 e+04	-213	2.5 e+06	ort 5, west
The fourth cycle of active electromagnetic monitoring				
24.08.2003 8:00	5.8 e+07	-350	3.2 e+06	ort 6, east
		-293	6.8 e+05	ort 12
		-349	1.4 e+07	ort YuSVSh east
14.09.2003 8:01	6.5 e+06	-240	1.1 e+08	ort 11 west
12.10.2003 14:29	3.5e +08	-235	1.3 e+06	ort 19, west

Data, time (hour)	Absorbed energy as a result of mass explosion E1 (joules)	Vertical mark H(m) +450m	Released energy as a result of rock shocks E2(joules)	Place of dynamical event
23.11.2003 8:00	6.4 e+06	-360	1.e+05	ort 17-18, center
21.12.2003 16:48	6.0 e+06	-133	1.e+05	ort 1-2, center
11.01.2004 8:00	1.2 e+06	-230	1.e+05	ort 4-5, east
25.01.2004 8:01	2.1 e+06	-141	1.e+05	ort 4-5, west
15.02.2004 8:00	3.1 e+05	-146	2.1e+06	ort 2, center
21.02.2004 8:00	3.2 e+06	-160	6.8 e+05	ort 5, west
22.02.2004 8:00	4.6 e+06	-243	1.2 e+06	ort 5, east
29.02.2004 8:00	1.7 e+06	-401	3.1 e+05	ort 11, east
		-141	1. e+05	ort 5-6, west
21.03.2004 12:45	3.9 e+08	-215	3.1 e+05	ort 3, east
		-362	8.5 e+06	ort 17-18, east
		-285	2.1 e+05	ort 16-17, east
		-334	2.5 e+06	ort 17, center
28.04.2004 5:06	4.4E+05	-116	1. e+05	ort 2, west
08.05.2004 7:00	7.8E+04	-367	1. e+05	ort 15, center
30.05.2004 4:00	1.3E+08	-367	1. e+05	ort 15, center
The fifth cycle of active electromagnetic monitoring				
19.09.2004 4:00	1.E+08	-310	3.1E+05	ort 24, west
		-201	5.8E+06	ort 3, east
05.12.2004 1:00	3.4E+06	-213	2.5E+05	ort 4, east
		-231	1.E+05	ort 8-9, center
30.01.2005 1:00	3.2E+06	-211	6.8E+05	орт 9-10, center
06.02.2005 2:58	1.2E+06	-170	6.8E+05	ort 13 west
08.05.2005 0:19	3.2E+06	-228	1.4E+05	ort 10-11 west
22.05.2005 0:00	4.7E+04	-228	1.4E+05	ort 10-11west
The sixth cycle of active electromagnetic monitoring				

10.5 Conclusion

The obtained results allow us to make such conclusions. The principles of the physical mesomechanics paradigm are a very constructive idea for research of the non-stationary geological medium. Natural experiments in real rock massif, which are under strong man-based action, allow us to reveal the peculiarities of the geological medium behavior, which can be fixed in geophysical fields. The significant role for research of these dynamical systems plays the active geophysical monitoring, which can be arranged with the use of electromagnetic and seismic fields. As it had shown in our results the change of the system state occurs on used space arrays and time intervals, which are linked with structural medium peculiarities periods of the second rank. Thus the research of the massif state dynamics, of its structure and of self-organization events in it, we can develop by using geophysical methods, which are settled on a ranked hierarchic medium model. The use of planshet many leveled induction electromagnetic method with a controlled source and corresponding method of processing and interpretation allows us to reveal the zones of disintegration, which are the indicators of a massif stability. The introduction a new integral parameter-interval distribution of the intensity of the disintegration zones allows us to develop a detailed massif classification by its degree of stability, introduce for that quantitative criterions and characterize the massif stability from the point of view as going out on a stationary cycling of the location of the maximum of the parameter $Sp\,int$ (previous chapter) in relation of the depth from the holes contour. Comparison with data of seismological monitoring allows us to the geodynamical classification of the massif with the use of integral parameter *Sp*.

10.6 Mathematical Modeling and Comparison of a Seismic and an Electromagnetic Response for a Block Model

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 2-D model for two problems in a frequency domain: diffraction a sound wave and linear polarized transverse wave through an arbitrary hierarchy rank inclusion plunged 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. The higher the amount of the hierarchic ranks the more is the degree of nonlinearity of the massif response and the longer can be the time of massif reaction lag of the influence. In that paper, integral equations and integral differential equations of 2-D direct problem for the seismic field in the dynamical variant had been derived and they had provided the joint analysis of the integral equations for 2-D problems for electromagnetic and seismic fields. The received results can be used for the definition of the complex criterions to achieve the research of high complicated medium both with seismic and electromagnetic methods. For the problem of sound diffraction on the 2-D elastic heterogeneity, located in the j-th layer of the n-layered medium. Using the approach from V.I. Dmitriev and V.D. Kupradze (Kupradze, 1950, chapter 9; Dmitriev, 1965), we had derived the integral differential equation for the distribution of the potential of the elastic displacements vector inside the heterogeneity.

$$\begin{aligned}
&\frac{(k_{1ji}^2-k_{1j}^2)}{2\pi}\iint_{S_C}\varphi(M)G_{Spj}(M,M^0)d\tau_M+\frac{\sigma_{ja}}{\sigma_{ji}}\varphi^0(M^0)-\\
&-\frac{(\sigma_{ja}-\sigma_{ji})}{\sigma_{ji}2\pi}\oint_C G_{Spj}\frac{\partial\varphi}{\partial n}dc=\varphi(M^0)\quad by\, M^0\in S_C\\
&\frac{\sigma_{ji}(k_{1ji}^2-k_{1j}^2)}{\sigma(M^0)2\pi}\iint_{S_C}\varphi(M)G_{Spj}(M,M^0)d\tau_M+\varphi^0(M^0)-\\
&-\frac{(\sigma_{ja}-\sigma_{ji})}{\sigma(M^0)2\pi}\oint_C G_{Spj}\frac{\partial\varphi}{\partial n}dc=\varphi(M^0)\quad by\, M^0\notin S_C
\end{aligned}\tag{22}$$

Using the second integral-differential presentation we can define the potential of the elastic displacements in the arbitrary layer outside the heterogeneity, and then we can calculate the distribution of the vector of elastic displacements in the arbitrary layer.

$G_{Spj}(M, M^0)$ - 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, λ, μ - are the constants of Lame, σ -the density of the medium, ω- the cycle frequency, $\vec{u}_i = grad\varphi_i;$ i=1,…j, $ji,…n$. 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, whose solution is presented in our prvious papers (Hachay and Khachay, 2007; Hachay, 2008). Let us transform it to the form similarly to (22) and let us compare the derived equations for the solution of the inner 2-D seismic and electromagnetic problem.

$$\begin{aligned}
&\varphi(M^0) = \frac{(k_{1ji}^2 - k_{1j}^2)}{2\pi} \iint_{S_C} \varphi(M) G_{Sp,j}(M, M^0) d\tau_M + \\
&+ \frac{(\sigma_{ji} - \sigma_{ja})}{\sigma_{ji} 2\pi} \oint_C G_{Sp,j} \frac{\partial \varphi}{\partial n} dc + \frac{\sigma_{ja}}{\sigma_{ji}} \varphi^0(M^0) \; by \, M^0 \in S_C \\
&H_x(M^0) = \frac{k_{ji}^2 - k_j^2}{2\pi} \iint_{S_C} H_x(M) G_m(M, M^0) d\tau_M + \\
&+ \frac{k_{ji}^2 - k_j^2}{k_j^2 2\pi} \oint_C H_x(M) \frac{\partial G_m}{\partial n} dc + \frac{k_{ji}^2}{k_j^2} H_x^0(M^0) \; by \, M^0 \in S_C
\end{aligned} \tag{23}$$

$k^2(M^0) = i\omega\mu_0\sigma(M^0), \mu_0 = 4\pi 10^{-7} \frac{hn}{m}, \sigma(M^0)$ - conductivity in the point $M^{0.}$., i-the imaginary unit, $H_x(M^0)$ - the total component of magnetic field,

$H_x^0(M^0)$ - the component of magnetic field in the layered medium without heterogeneity, $k_{ji}^2 = i\omega\mu_0\sigma_{ji}, k_i^2 = i\omega\mu_0\sigma_i$, σ_{ji} -conductivity into the heterogeneity, located into the *j*-th layer, σ_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 (Hachay, 2007, chapter 9). 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 case to the load integral equation of Fredholm of the second type. 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.

$$
\begin{aligned}
&\frac{(k_{2ji}^2 - k_{2j}^2)}{2\pi} \iint_{S_C} u_x(M) G_{Ssj}(M, M^0) d\tau_M + \frac{\mu_{ja}}{\mu_{ji}} u_x^0(M^0) + \\
&+ \frac{(\mu_{ja} - \mu_{ji})}{\mu_{ji} 2\pi} \oint_C u_x(M) \frac{\partial G_{Ssj}}{\partial n} dc = u_x(M^0) \quad by\, M^0 \in S_C \\
&\frac{\mu_{ji}(k_{2ji}^2 - k_{2j}^2)}{\mu(M^0) 2\pi} \iint_{S_C} u_x M) G_{Ssj}(M, M^0) d\tau_M + u_x^0(M^0) + \\
&+ \frac{(\mu_{ja} - \mu_{ji})}{\mu(M^0) 2\pi} \oint_C u_x(M) \frac{\partial G_{Ssj}}{\partial n} dc = u_x(M^0) \quad by\, M^0 \notin S_C
\end{aligned}
\tag{24}
$$

$G_{Ssj}(M, M^0)$ - the source function of seismic field for involved problem, $k_{2ji}^2 = \omega^2 (\sigma_{ji} / \mu_{ji})$.

For the problem of diffraction of a linearly polarized elastic transverse wave on the 2-*D* heterogeneity located in the *j*-th layer of the n-layered medium, using the approach described in the papers (Hachay and Khachay, 2007; Hachay, 2008) for the electromagnetic wave 2-*D* problem (case *H*- polarization), (the geometric model is similar to that described higher for the previous problem) we obtain the expressions as follow for the components of the displacement vector. The expressions (24) content the algorithm of seismic field simulation for distribution of transversal waves in the n-layered medium, which contain a 2-*D* heterogeneity. The first expression is a Fredholm load integral equation of the second type whose solution gives the distribution of the components of the elastic displacements vector inside the heterogeneity. The second of them is an integral expression for the calculation of the elastic displacements vector in the arbitrary layer of the n-layered medium. Comparing the expressions (24) with correspondingly for the electromagnetic field (H-polarization) (23) 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 (23) and (24). Thus, 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 a seismic or an 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 paper (Hachay, 2007, chapter 9). 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 got 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 of 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 2-D medium, it will establish the similarity, which can be used by construction of joined systems of observation for magnetotellurics soundings and deep seismic soundings on exchanged waves.

10.7 Modelling Seismic-Electromagnetic Processes in Hierarchic Structures

10.7.1 Introduction

Rock massifs can be described by four functions: structure, physical features, content and state. The last feature plays the most important role by forecasting the dynamical events which can occur in it. The energy and intensity of the dynamical events depend from the structure of the massif and the space-time changes of the influence on it. The influence can be man-caused or of natural origin. Thus, we need to construct a physical and mathematical model of the dynamical state evolution of the massif, using the theory of open dynamical systems and the paradigm of physical mesomechanics (Panin, 2005, chapter 9). For that we used the detailed seismological information of a mining seismological catalogue, which contained information of the energy of explosions, provided in the massif, and the energy of its response and the results of active electromagnetic induction monitoring.

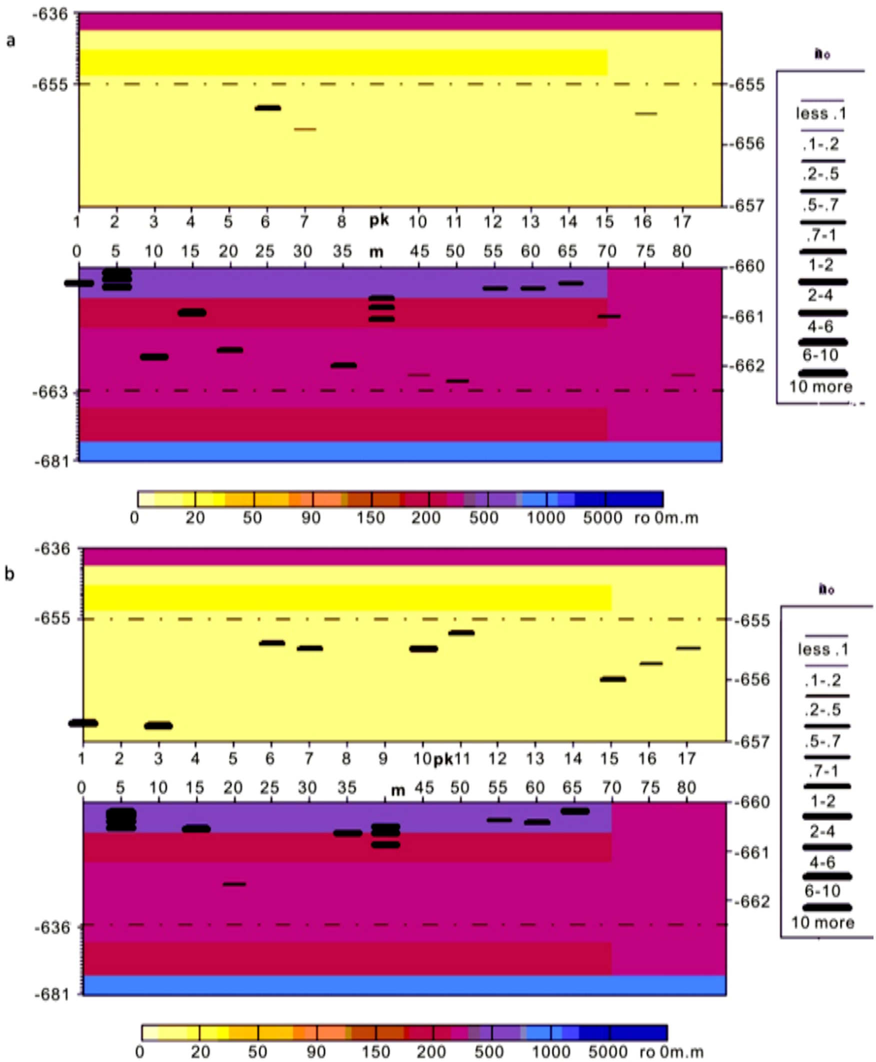

Figure 3. *Geoelectrical sections along the profile in the Tashtagol mine for the depth 660m for two cycles of active electromagnetic monitoring during one week between the two cycles, the frequency was 10.15 kHz; a-data of the first cycle the 9-th of July 2010, b-data of the second cycle the 16-th of July 2010.*

Here you can see some examples of massif structure changing in heterogeneities of the second rank: figure 3, (a, b).

Using the qualitative analysis of phase trajectories, constructed on the plane with coordinates *lgE* and *A= d/dt (lgE)*, where *E* is the total energy of the massif response between the influences on it by explosions we had observed some repeating regularities, which consist on transitions from the chaotic state to an ordered and backward returning to the same state, figure2 t is time in 24 hours units. The second feature of the state evolution is: the local volume massif does not immediately respond to the changing of the surrounding stress state. Therefore it stores the response energy and then extracts it through a high energy dynamical effect.

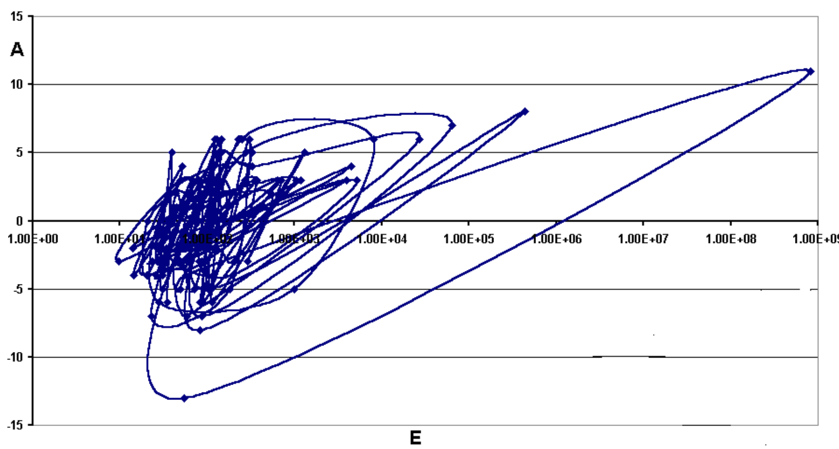

Figure 4. *The phase diagram of the massif state before and after the high energy rock burst.*

10.7.2 Mathematical Modeling of Seismic Response for a Hierarchic Model

From the point of view of the paradigm of physical mesomechanics, which includes the synergetic approach to the change of rock massif state of different matter content, that problem can be solved with the use of monitoring methods, which are settled on the research of hierarchic structured media (Panin., 2005, chapter 9). For the description of these effects it is needed to consider the wave process in the hierarchic blocked medium. Let us consider an algorithm of sound diffraction on 2-D elastic heterogeneity with hierarchic structure, located in the j-th layer of n-layered medium (Hachay, 2007, chapter 9; Hachay and Khachay, 2008; Hachay and Khachay, 2011, chapter 9). If by transition on the next hierarchic level the axis of two-dimensionality does not change and only the geometry of the section of embedded structures change, then we can write the iteration process of modeling of the seismic field (case generation only longitudinal wave).

$$\begin{aligned}
&\frac{(k_{1jil}^2-k_{1j}^2)}{2\pi}\iint_{S_{Cl}}\varphi_l(M)G_{Sp,j}(M,M^0)d\tau_M+\frac{\sigma_{ja}}{\sigma_{jil}}\varphi_{l-1}^0(M^0)-\\
&-\frac{(\sigma_{ja}-\sigma_{jil})}{\sigma_{jil}2\pi}\oint_{Cl}G_{Sp,j}\frac{\partial\varphi_l}{\partial n}dc=\varphi_l(M^0)\quad by\,M^0\in S_{Cl}\\
&\frac{\sigma_{jil}(k_{1jil}^2-k_{1j}^2)}{\sigma(M^0)2\pi}\iint_{S_{Cl}}\varphi_l(M)G_{Sp,j}(M,M^0)d\tau_M+\varphi_{l-1}^0(M^0)-\\
&-\frac{(\sigma_{ja}-\sigma_{jil})}{\sigma(M^0)2\pi}\oint_{Cl}G_{Sp,j}\frac{\partial\varphi_l}{\partial n}dc=\varphi_l(M^0)\quad by\,M^0\notin S_C
\end{aligned}\tag{25}$$

$$\begin{aligned}
&\frac{(k_{2jil}^2-k_{2j}^2)}{2\pi}\iint_{S_{Cl}}u_{xl}(M)G_{Ss,j}(M,M^0)d\tau_M+\frac{\mu_{ja}}{\mu_{jil}}u_{x(l-1)}^0(M^0)+\\
&+\frac{(\mu_{ja}-\mu_{jil})}{\mu_{jil}2\pi}\oint_{Cl}u_{xl}(M)\frac{\partial G_{Ss,j}}{\partial n}dc=u_{xl}(M^0)\quad by\,M^0\in S_{Cl}\\
&\frac{\mu_{jil}(k_{2jil}^2-k_{2j}^2)}{\mu(M^0)2\pi}\iint_{S_{Cl}}u_{xl}M)G_{Ss,j}(M,M^0)d\tau_M+u_{x(l-1)}^0(M^0)+\\
&+\frac{(\mu_{ja}-\mu_{jil})}{\mu(M^0)2\pi}\oint_{Cl}u_{xl}(M)\frac{\partial G_{Ss,j}}{\partial n}dc=u_{xl}(M^0)\quad by\,M^0\notin S_{Cl}
\end{aligned}\tag{26}$$

The iteration process covers to modeling of the response of transition from the previous hierarchic level on the next level. Inside each hierarchic level the integral-differential equation and the integral-differential representation are calculated as it is written in (Hachay and Khachay, 2013, chapter 9).

10.8 Conclusions

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 of 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 2-D medium, this will establish the similarity, which can be used by the construction of mutual systems of observation for magneto-telluric soundings and deep seismic soundings on exchanged waves. For a research of a 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.

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