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Review Article

New Monitoring Geophysical Systems by Oil Deposits Extraction

Olga Hachay[1]*, Andrey Khachay[2] and Oleg Khachay[2]

[1]*Ural Branch of RAS, Institute of Geophysics, Russia*

[2]*Ural Federal University, Russia*

***Corresponding author:** Hachay OA, Institute of Geophysics, Ural Branch of RAS, Ekaterinburg, 620016, Russia

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Abstract

The processes of oil deposit development are linked with the movement of multi-phase multi-component media, which are characterized by non-equilibrium and non-linear rheological features. The real behavior of layered systems is defined by the complexity of the rheology of moving fluids and the morphology structure of the porous medium, and also by the great variety of interactions between the fluid and the porous medium [1]. It is necessary to take into account these features in order to informatively describe the filtration processes due to the non-linearity, non-equilibrium and heterogeneity that are features of real systems. In this way, new synergetic events can be revealed (namely, a loss of stability when oscillations occur, and the formation of ordered structures). This allows us to suggest new methods for the control and management of complicated natural systems that are constructed on account of these phenomena. Thus the layered system, from which it is necessary to extract the oil, is a complicated dynamical hierarchical system. To construct the mathematical model of a real object, as a priori information it is necessary to use data from active and passive monitoring, which we can obtain during exploitation of the object. The solution of inverse problems has great significance for the oil industry, because the oil layer refers to a number of natural systems that cannot be observed as a whole by direct measurements. The results of last year's research showed that in the evolution of dynamic systems, non-stabilities and their origin play a role in the theory of self organization or synergetic studies. Information about their manifestation in the oil reservoir from its extraction can only be obtained using monitoring data, which is sensitive to its hierarchical structure. It should be noted that, to study the thin structure of the discrete hierarchical media, geophysical fields are more sensitive, depending on spatial, time or frequency parameters–namely, electromagnetic and seismic fields. In addition, these fields, excited by local sources due to the geometry of the normal field, have a focusing or localization property that allows the given resolution to be distinguished. For the new methods of wave monitoring is constructed a new theory of distribution wave fields in a medium of hierarchical structure with different physical features.

Account of Rock Massif Hierarchic Heterogeneity by Oil Deposits Extraction

For the first time the phenomenon of zonal rocks disintegration around the underground holes had been described in the paper of Shemjakin et al. [2], which was later registered as a discovery [2]. The questions of structures formation related to the fundamental problems of the natural sciences, and the study of the structure of occurrence is one of the major purposes of scientific knowledge. In real systems, considered in physics, the spatial and temporal structures can be founded. The temporal structure is inseparable from the systems dynamics; there are particularly important reasons and principles of pointedness and causality. Formation of structures by irreversible processes is associated with a qualitative jump when the system reaches the threshold (critical) parameters. Self-organization is a supercritical phenomenon when the system parameters exceed their critical values. When the system deviates greatly from its equilibrium state their variables satisfy nonlinear equations.

Nonlinearity is an important and common feature of the processes taking place far from the system equilibrium. This supercritical output of entropy is only possible if there is an unusual, special internal structure of the system [3]. This means that self organization is not a universal property of matter; it exists in certain internal and external conditions and is not associated with a particular class of substances. So, there are two classes of irreversible processes: destruction of the structure near the equilibrium position, this is a universal property of systems under arbitrary conditions. The structures away from the equilibrium position under the conditions, that the system is open and has a non-linear internal dynamics and its external parameters contain supercritical parameters I. Prigogine called: dissipative structures [4]. The study of the morphology and dynamics of the migration of these zones is of particular importance when developing deep located deposits mining, complicated by dynamically events as rock bursts. Important tools for this study are the geophysical methods of mapping and monitoring. Because of the information about the structure and state of the massif can be obtained from geophysical data by interpreting them in terms of the model, which is an approximation to the real massif, it is needed to select the model from the class of physically and geologically reasonable. As it is shown in the book Sadovskiy et al. [5], for the description of the geological environment in the form of a rock massif with its natural and technogenic heterogeneity it should use its more adequate description of what is a discrete model of the environment in the form of a piecewise heterogeneous block media with embedded heterogeneities of lower rank than the block size. This nesting can be traced back several times, i. e, changing the scale of the study, we see that the heterogeneity of lower rank now serve as blocks for the irregularities of the next rank. The simple averaging of the measured geophysical parameters can lead to a distorted view of the structure of the environment and its evolution. In the Institute of Geophysics, UB RAS it was developed the hardware-methodical and interpretation complex to study structure and state of complex geological environment, which has the potential no stability and ability to re-building of the hierarchical structure by a significant external influence. The base of this complex is the developed 3-D planshet technique for electromagnetic induction studies in frequency geometric variant, based from one side on program realized interpretation system for 3-D alternating electromagnetic fields, and on the other hand on developed by prof. A.I.Chelovechkov set of devices for realizing the induction studies [6,7].

Development of a Mathematical Model Using the Results of Active and Passive Geophysical Monitoring

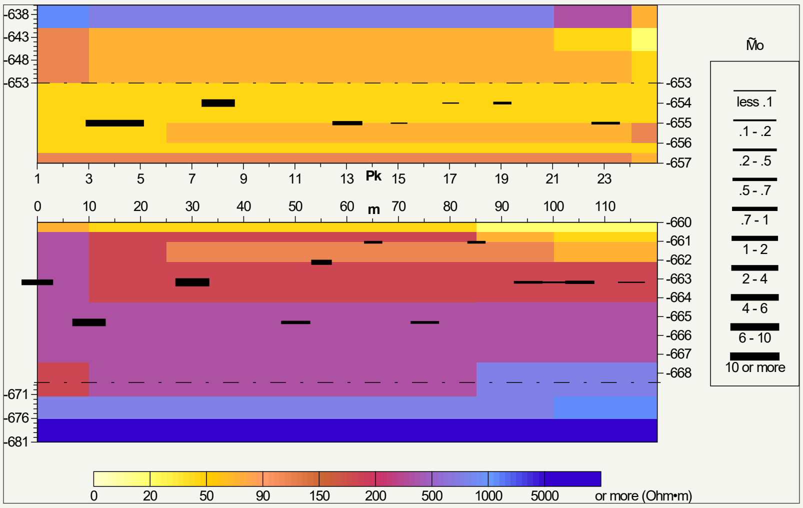

Figure 1a

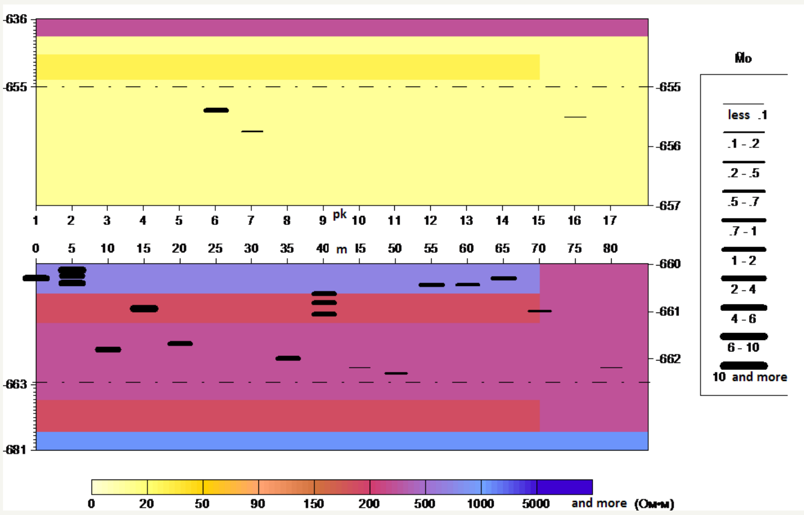

Figure 1a

Figure 1: Geoelectrical sections of the 4-th ort, horizon -210, Tashtagol mine, 2002, frequency 5 kHz, a,b-two cycles of observation, each cycle after the explosion.

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To construct the mathematical model of a real object, as a priori information it is necessary to use data from active and passive monitoring, which we can obtain during exploitation of the object. The solution of inverse problems has great significance for the oil industry, because the oil layer refers to a number of natural systems that cannot be observed as a whole by direct measurements. The results of last year's research Hachay et al. [8] showed that in the evolution of dynamic systems, non-stabilities and their origin play a role in the theory of self-organization or synergetic studies. Information about their manifestation in the oil reservoir from its extraction can only be obtained using monitoring data, which is sensitive to its hierarchic structure. It should be noted that, to study the thin structure of the discrete hierarchic media, geophysical fields are more sensitive, depending on spatial, time or frequency parameters-namely, electromagnetic and seismic fields. In addition, these fields, excited by local sources due to the geometry of the normal field, have a focusing or localization property that allows the given resolution to be distinguished. A new complex volume method of electromagnetic induction and seismic (in the dynamic variant) research allows the construction of a volume geo electrical and elastic model of the rock massif structure. In mining conditions for deposits of different material content, by using this method, zones of rock massif heterogeneities were revealed. The formulated criteria allowed the grading of these zones into zones of hidden fracture and contact (between different modules) zones, which were confirmed by geological and geo mechanical data Hachay et al. [8], and the staged detection of these zones by seismic and electromagnetic data was researched. Analysis of the results of electromagnetic induction monitoring in natural conditions allows the following conclusions to be formulated: the rock massif structure of different material content corresponds to the model of the hierarchic structure of the discrete medium; we could use our system of observation to deduce two hierarchic levels. The disintegration zones, revealed by the electromagnetic monitoring data in the surrounding hole space, are located non-symmetrically in the roof and in the bottom and are discrete: that is, there are intervals in which the maximum change in the massif, which occurs directly under man-made influence in the morphology of the spatial location of these zones, depending on time, is absent as a whole [9,10]. For example you can see the geo electrical sections, you can see the changing of the geo electrical parameters of the block layered structure in the medium of top and bottom inside the massif on the horizon with the depth 660m during two cycles of observations using the developed method of electromagnetic induction monitoring Hachay et al. [11] and the parameters of inclusions, named zones of disintegration, that have hierarchic structure. The changing occurs because of the influence of explosions on the massif. The data had been developed in a rock burst iron mine. In the presented sections (Figure 1), we can see that even during a short period of time (1 week) the most significant change of location of the heterogeneity zones occurs under the influence of explosions. Thus, the results of the active electromagnetic induction monitoring allow drawing such conclusions: Solid rock represents a hierarchical structure, the study of the state and dynamics of that structure can be carried out only by means of geophysical methods that are configured on a hierarchical model of the environment. Use planshet multilevel induction electromagnetic method with controlled source and corresponding methods of processing and interpretation make possible to trace the two hierarchical levels and identify areas of disintegration that are indicators of the stability of the massif. The zones of disintegration in the around the hole space are located asymmetrically in the soil and the roof and discrete: ie, there are intervals of the hole space without the zones. Maximum changes in the massif, which is under the man-made influence occur in the morphology of spatial position of these zones as a function of time. The use of a new integral parameter of intensity distribution of disintegration zones allow to obtain the detailed classification of the massif for the degree of stability and to introduce these quantitative criteria (Figure 2).

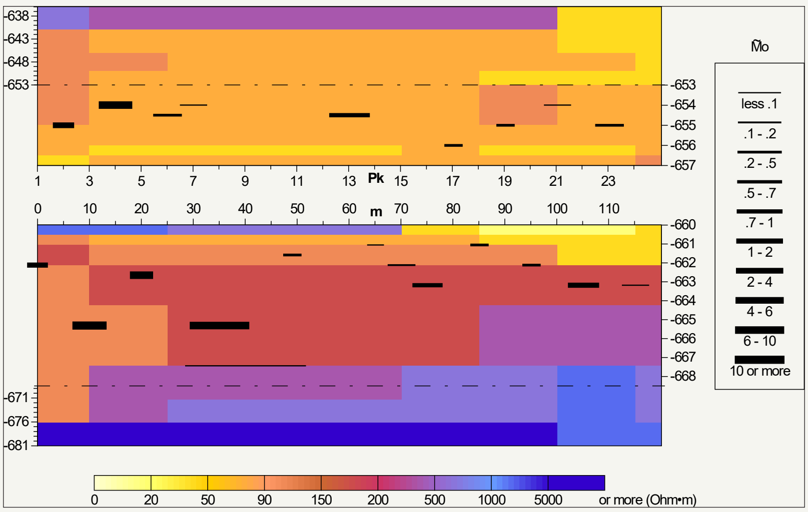

Figure 2: Geoelectrical section of a block-layered section of rock massif with inclusions of the second rank in a rock burst mine Tashtagol (the upper half of the section corresponds to the roof structure, the lower – to the floor) Morphology of anomaly stressed objects.

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To consider the behavior of the two-phase rock massif in the frame of the model of a hierarchical medium of arbitrary rank, we developed an algorithm for solution of the direct 2-D problem for the seismic field in the dynamic variant. In this way, the model of the local hierarchical heterogeneity of the Lth rank is presented as a porous fluid-saturated inclusion. The hierarchical inclusions of other ranks are presented as elastic heterogeneities in the frame of an approximation, when the parameter Lame μ=0, either in the inclusions or in the imbedded medium. For that case, the seismic dynamic problem can be considered independently for the cases of the distribution of longitudinal and transversal waves. Here we will consider the first case for the suggested model. The obtained results can be used to determine the joining criteria of seismic research methods for highly complicated media.

Algorithm of Modeling for Longitudinal Wave Propagation in the Medium with Hierarchic Fluid-Saturated Inclusions

A concept was suggested in the paper Hachay et al. [12] for solution of the direct problem for the 2-D case of longitudinal wave propagation through a local elastic heterogeneity with a hierarchical structure, located in the J-th layer of an N-layered medium.

$$\frac{(k_{1jil}^2 - k_{1j}^2)}{2\pi} \int_{S_b} \varphi_l(M) G_{Sp,j}(M, M^0) d\tau + \frac{\sigma_{ja}}{\sigma_{jil}} \varphi_{l-1}^0(M^0) -$$

$$\frac{(\sigma_{ja} - \sigma_{jil})}{\sigma_{jil} 2\pi} \oint_{C_l} G_{Sp,j} \frac{\partial \varphi_l}{\partial n} d = \varphi_l(M^0),\ M^0 \in S_C ,$$

$$\frac{\sigma_{jil}(k_{1jil}^2 - k_{1j}^2)}{\sigma(M^0) 2\pi} \int_{S_b} \varphi_l(M) G_{Sp,j}(M, M^0) d\tau + \varphi_{l-1}^0(M^0) -$$

$$\frac{(\sigma_{ja} - \sigma_{jil})}{\sigma(M^0) 2\pi} \oint_{C_l} G_{Sp,j} \frac{\partial \varphi_l}{\partial n} d = \varphi_l(M^0),\ M^0 \notin S_C ,$$

$G_{Sp,j}(M, M^0)$ - is the source function of the seismic field, the boundary value problem for which was formulated in the paper Hachay et al. [12], $k_{1ji}^2 = \omega^2(\sigma_{ji} / \lambda_{ji})$ is the wave number for the longitudinal wave; in the above expression, the index ji denotes the property of the medium inside the heterogeneity, ja is outside the heterogeneity, λ is the Lamé constant, σ-density of medium, ω - circular frequency, $\vec{u} = grad\varphi$ - vector of displacements, φ^0 - potential of normal seismic field in layered medium in the absence of heterogeneity: $\varphi_{ji}^0 = \varphi_{ja}^0$. φ_l^0 is the potential of a normal seismic field in a layered medium in the absence of an heterogeneity of the previous rank l, if l = 2 … L, $\varphi_l^0 = \varphi_{l-1}$, if l = 1 $\varphi_l^0 = \varphi^0$, which coincides with the corresponding expression in the paper Hachay et al. [12]. Let us extend this to the case, on the Lth hierarchical level, of the occurrence of a porous fluid-saturated inclusion.

$$\frac{(k_{1jil}^2 - k_{1j}^2)}{2\pi} \int_{S_b} \varphi_l(M) G_{Sp,j}(M, M^0) d\tau + \frac{\sigma_{ja}}{\sigma_{jil}} \varphi_{l-1}^0(M^0) -$$

$$\frac{(\sigma_{ja} - \sigma_{jil})}{\sigma_{jil} 2\pi} \oint_{C_l} G_{Sp,j} \frac{\partial \varphi_l}{\partial n} d = (\varphi_l(M^0) + \alpha p_2),\ M^0 \in S_{0l}, l = L$$

$$\frac{\sigma_{jil}(k_{1jil}^2 - k_{1j}^2)}{\sigma(M^0) 2\pi} \int_{S_b} \varphi_l(M) G_{Sp,j}(M, M^0) d\tau + \varphi_{l-1}^0(M^0) -$$

$$\frac{(\sigma_{ja} - \sigma_{jil})}{\sigma(M^0) 2\pi} \oint_{C_l} G_{Sp,j} \frac{\partial \varphi_l}{\partial n} d = \varphi_l(M^0),\ M^0 \in S_{0l}, l = L$$

where, $\alpha = 1 - \chi - \frac{K}{K_0}$, $K = \lambda$ -complete compression module, χ -porosity, K_0 -the true modulus of phase compressibility, p_2- pore hydrostatic pressure.

Conclusion

We considered the problem of modeling the distribution of seismic field in a two component layered medium with inclusions of hierarchic structure. We had developed algorithms of modeling in acoustic case for 2D plastic heterogeneities with hierarchical structure with account of the case of oil or fluid saturation of these heterogeneities. These algorithms allow studying the resonant processes in the two component medium and on each level study the possible deviation from the generalized Hooke's law of the stress and deformation tensors. The algorithm developed for modeling, and the method of mapping and monitoring a heterogenic highly complicated two-phase medium can be used for managing viscous oil extraction in mining conditions and light oil in sub-horizontal boreholes. The demand for effective economic parameters and fuller extraction of oil and gas from deposits dictates the necessity of developing new geo technology based on the fundamental achievements in the area of geophysics and geo mechanics [13,14].

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