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ELECTRODYNAMICS OF TECTONICS PROCESSES AND ELECTROMAGNETIC PROFILING OF THE EARTH CRUST IN ANTARCTIC REGION

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Abstract. This paper discusses the problems of the natural Earth pulse electromagnetic radiation occurrence and it's usage for the Earth interior exploration. The main attention is paid to radiation of the radiowave diapason (from ~1 kHz to ~1 MHz) which sources is located inside the Earth lithosphere. The nonlinear aspect of mechanic – electromagnetic interaction and electromagnetic wave propagation is discussed. The different models of such a radiation generation and propagation are considered. We have proposed the model of such radiation generation based on the initiation of optical vibrations of complex crystal lattice and therefore associated electromagnetic oscillations that appear due to formation and movement of point, linear (dislocation) and volume (microcracks, pores) defects of crystals. In solid state physics the electromagnetic radiation associated with inherent (optical) lattice vibrations is called polariton radiation. As long as intensity of defect creation is in direct proportion to deformation of the crystal, the intensity of the signal generated will be maximal in maximal deformation zones of the Earth crust. This fact allows the application of this radiation for the Earth crust structure study.
Referring to polariton emission, the strained rock is active medium, i.e. the existence of radiation stimulates creation and vanishing of defects leading to radiation amplification. Such mechanism of non-linear amplification of electromagnetic waves together with “transparency windows” existence may explain the observed ultraweak attenuation of such electromagnetic waves in the Earth crust.
In this work, we gave the examples of geopolariton radiation usage for investigations of the glaciers in Antarctic region.
Key words: spontaneous electromagnetic emission, litosphere, mantle, glasier, Antarctica

Аннотация. В статье обсуждаются вопросы возникновения естественного импульсного электромагнитного излучения Земли и его использования для исследования земных недр. Основное внимание уделяется радиоизлучению в диапазоне 1кГц – 1 МГц, источники которого расположены в литосфере. Обсуждаются нелинейные аспекты механо-электромагнитных трансформаций и распространения электромагнитных волн. Рассмотрены различные модели генерации и распространения этих волн. Нами предложена модель генерации излучения, основанная на возбуждении оптических колебаний сложных кристаллических решеток, а значит и связанных с ними электромагнитных колебаний, при возникновении и движении точечных, линейных (дислокации) и объемных (микротрещины, поры) дефектов кристаллов. В физике твердого тела электромагнитное излучение, связанное с собственными (оптическими) колебаниями решетки, называют поляритонным излучением. Поскольку интенсивность рождения дефектов пропорциональна деформации кристалла, то интенсивность генерируемого сигнала будет максимальной в местах максимальной деформации коры. Этот факт позволяет применять спонтанное излучение для изучения структуры земной коры.
По отношению к испусканию поляритонов напряженные горные породы являются активной средой, т.е. существование излучения способствует рождению и уничтожению дефектов, что приводит к усилению излучения. Этот механизм нелинейного усиления электромагнитных волн совместно с существованием «окон прозрачности» может объяснить сверхслабое затухание электромагнитных волн в земной коре.
В работе приведены примеры использования геополяритонного излучения для исследования структуры ледников в Антарктике.
Ключевые слова: спонтанная электромагнитная эмиссия, литосфера, мантия, ледник, Антарктика

1. Introduction

As experiment shows, there are the electromagnetic perturbation of the naturale sources in the Earth crust, oceans, atmosphere, ionosphere and magnetosphere in the broad range of frequencies. [Surkov, 2000; Gulielmi, 2007]. The most known and investigated are the electromagnetic waves with periods 0,2 – 600 s – ultra low frequency (ULF) electromagnetic waves of different sources. While it was shown experimentally that the lithosphere is emitted sufficiently high frequency (up to 1 MHz) electromagnetic wave, interest to which is increased visibly in last years. This is due to new possibilities in lithosphere structure study, investigation of physical processes inside the Earth, earthquake prediction ets, which arise on the base of intensity and frequency analysis of such radiation. The study of such phenomenon has the wide experimental and theoretical basis, although there is some uncertainty of physical mechanisms of its generation and propagation. In particular, the list of references on these questions consists hundreds of papers and tens of monographies, even brief survey of which is of great difficulty. Therefore below we will refer mainly the review articles and first of all the reviews by [Surkov, 2000; Gershenzon and Bambakidis, 2001; Gulielmy, 2006; 2007; 2008; Bogdanov, 2007; Nenovsky, Boichev, 2004] should be mentioned.

It is known that the generation of the lithosphere electromagnetic signals can occurs spontaneously (without direct dependence on seismic activity) and forcedly due to movement of rocks during earthquakes [Levshenko, 1995]. Such a terminology conflicts with usual physical terminology because, even in the absence of seismicity, there are the stresses in the Earth crust due to reciprocal movement of the mantle and crust and different blocks of the crust. Just those stresses leads to spontaneous emission origin. The frequency range of perturbations generating by the geological medium is quite wide – from 10^{-4} to 10^{6} Hz [Gogberg et al., 1985; Levsyenko, 1995; Surkov, 2000]. But traditionally only ultra low frequency (ULF) electromagnetic perturbations of lithosphere origin with periods 0.2 – 600 s were studied extensively [Surkov, 2000; Gulielmy, 2007; 2008]. In this frequency range the width of skin-layer can exceed tens of kilometres, therefore the perturbations of this type leave the generation area without sufficient absorption. Concerning the electromagnetic radiation with frequencies of tens and hundreds of kHz, its skin-layer width is only tens – hundreds of meters. Seemingly, the radio radiation of high frequency range (3 kHz –300 kHz) can not leave the deep generation area due to strong absorption, and this is a reason of some authors scepticism concerning such radiation utilisation in the study of deep located objects.

The conception of low frequency electromagnetic wave generation mechanism plurality is widely dispersed [Surkov, 2000; Gulielmy, 2007]. But if the questions of forced (by seismic events) electromagnetic radiation generation are studied sufficiently, the theoretical approaches to analysis of spontaneous radiation are schematic and not definite [Shuman, 2007; 2008]. Let us note the main difficulties emergent solving these questions. First, this is incompatibility of the scale of electromagnetic radiation with a wave length of the order of tens meters and local character of its excitation. Second, this is the explanation of the physical mechanism of its super long-distance propagation from the places of origin to the points of registration at day surface or upper.

First difficulty has probably psychological "geophysical" base. Why nobody ask the question when the atom of size ~1 A emits the light with wavelength ~10^3 A at electronic transitions and ~10^5 A at vibration transitions. The second difficulty needs the well-founded physical explanation.

Before the further analysis, let us clarify the definitions. We will denote the mechanical vibration of the medium as seismic vibration if its frequency is <1Hz. The mechanical vibrations with frequencies between 1 Hz and 20 Hz is infrasound vibrations, between 20 Hz and 20 khz is sound vibration, > 20 kHz is ultrasound. The last three types of vibrations are called acoustic vibrations. Often in geophysical literature the concept of seismic vibrations is extended to lowfrequency acoustic vibrations not defining frequency range, but only taking into account the source of its generation. In long wave acoustic and seismic vibrations the neighbour atoms of medium vibrate practically in-phase, besides phase shift is increased with frequency increasing.

There is any more type of mechanical vibrations of crystal lattice, this is the optical vibrations. They arise in crystals unit cell of which has more then one atom (geological medium is, as a rule, polycrystalline medium with complex crystal lattice). They show themselves most vividly in ionic crystals or in crystals with a great part of ionic bonds. The most materials of geological medium are just such crystals. The neighbor atoms in the longwave optical vibration move in antiphase, so these vibrations lead to crystal dipole moment change and therefore to the electromagnetic wave generation. The vibrations of both types (acoustical and optical) excite during the mechanical impact to the crystals. Therefore the expediency and necessity of mutual consideration of mechanical vibration field and electromagnetic radiation becomes evident because they are connected together in geological medium.

The mutual optical and electromagnetic vibrations in insulating crystals are called polariton vibrations. This term is commonly accepted, included in all physical handbooks, and its non-acceptance by many of geophysicists is surprising. Any electromagnetic wave in insulator in the range of crystall eigenfrequency excites the optical vibration (and vice versa), and therefore the polariton vibration appears in the crystal. Term "polariton" is compact, and its utilization for high frequency electromagnetic wave indication in geological medium is well-taken from our point of view.

2. The geological medium models

One can suppose that at least two main factors can be considered as the fundamental base of analysis of spontaneous lithosphere perturbation generation processes – these are the model of geological medium and the type of possible mechanic – electromagnetic transformations. It is clear that the medium which can generate seismic and electromagnetic waves can not be considered as a continuum –the inner self-similarity prove to be peculiar to geological medium [Stakhovsky, 2007]. It consists of plurality of blocks of different size, which move as a single whole and interact one with another during the movement. This interaction, mainly along the block boundaries, includes the processes of crushing, volume and shift deformation and plastic yielding of individuals, linkage of mechanical and physical nature and so on [Sadovsky, 1982; Danilenko, 1992; Dubrovsky, Sergeev, 2006; Starostenko et al., 2001].

The physical self-similarity (fractality [Mundelbrot, 2002]) always has the limits in the ranges both of small and big scales, in contrast to mathematical fractals. The self-similarity of geological medium is limited from the big scale side by the sizes of the Earth crust plates. These limits from the small scale side are probably the sizes of crystal grains, of which polycrystalline Earth rocks consist. The crystalline grains itself are not perfect crystals, they contain point, linear (dislocations) and volume (pores, micro cracks) defects. It was supposed in the work [Stakhovsky, 2007, see also the references in this work] that just the micro cracks in the rocks forms the fractal multitude, along which the main rupture (earthquake) is developed. The quantity of defects of all types is increased due to dynamical interaction between blocks comparing to the equilibrium crystals.

Geological medium is the thermodynamically nonequilibrium system. This nonequilibrium is caused first of all by the relative movement of the mantle and the Earth crust and also by the relative movement of different crust blocks. These movements lead to appearance of heterogeneous mechanical stresses located mainly in the boundary layers of the blocks. These stresses very frequently exceed the elastic limit what leads to new defect creation. As usual, the times of relaxation are sufficiently large, so the stresses have no time to relax what cause the general nonequilibrium of the system. In addition, the nonequilibrium arises due to existence of other physical fields, in particular temperature field. As it is known (see for example [Glensdorf, Prigozhin, 1980]), the different time and space structures can appear in strongly nonequilibrium system (dissipative structures) which can impact and define to the processes of wave generation and propagation. Just such a creation of dissipative structure is called self-organization, and it is quite possible that the formation of the fractal structure of the Earth crust is the manifestation of such a self-organization. The last assumption should be proved at least at model level.

The presence inside the Earth crust of the energy active regions, which can lead to nonlinear wave propagation effects, is frequently supposed in literature (see for example [Dmitrievsky et al., 2006 – 2008]). The proposed mechanisms of the energy accumulation in such zones are, generally speaking, insufficiently developed and sometimes are unphysical. But now nobody has doubts, probably, that geological medium is nonlinear, and nonlinear waves can propagate in it. The physical nature of nonlinearity can be different in every particular case in dependence on wave type and frequency range.

The sufficient feature of geological medium is the existence of fluids. The term fluid itself assumes the presence of fluid liquids. In many cases the fluid is simple mineralized water, frequently in mixture with hydrocarbons saturated by gases and salts, which particular content is defined by the content of surrounding rocks, temperature and pressure. In any case, the fluid is the conductive liquid (or gas) which can move along the block boundaries (faults, cracks, grain boundaries and so on, in general along the topologically connected regions). Just one connect with moving liquids the existence of so called electrokinetic effects, i.e. the excitation of electromagnetic vibration due to charged liquid movement. In the absence of catastrophic changes (earthquakes) such movement is slow, caused by the gradient of different fields and can lead to excitation of the low frequency electromagnetic vibrations in the ULF range only.

Thus the geological medium is nonequilibrium nonlinear heterogeneous fractal medium, which complex geometry influences to all the processes occurring in this medium. It is known, for example [Fractals in Physics, 1988], that the processes of diffusion, electroconductivity, wave propagation and scattering proceed in such a medium in a way which differ from those in traditional continuous medium. The geophysical application of such questions are now in embryo.

3. The mechanisms of the wave generation and propagation

The processes of the wave generation and propagation are closely connected in the nonlinear systems (the geological medium is probably such a system). Many of the particular questions related to the mechanisms of mechanical – electromagnetic transformation (transformation of the rock movement energy to the energy of electromagnetic radiation) in the wide range of frequency, connection of intensity and frequency of radiation with the peculiarities of geological structure, are still open and need further study. We will discuss below in more detail these processes concentrating our attention on the physical aspects of problem of generation and possibilities to use obtained regularities in geological applications, particularly in Antarctic region.

Let us consider first the linear models of generation. Gulielmi and Levshenko proposed in the works [Gulielmi, 1995, 2007, 2008; Levshenko, 1995] the general linear equation of the seismo-magnetic signal generation considering the Earth crust as porous water containing medium having magnetic structure and lying in constant magnetic field of the Earth core. This equation describes the excitation of the low frequency magnetic field

$$\frac{\partial \mathbf{B}(\mathbf{x},t)}{\partial t} - \frac{c^2}{4\pi\sigma}\nabla^2 \mathbf{B}(\mathbf{x},t) = \nabla \times \mathbf{C}(\mathbf{x},t) \quad (1)$$

where ? the rock conductivity; c is the light velocity in vacuum;

$\mathbf{C} = \alpha\,\mathbf{A} + \mathbf{v}\times\mathbf{B}_0 + \beta\,\theta\,\mathbf{E}_0 + \nabla\times M$; $\mathbf{A} = \dfrac{\partial \mathbf{v}}{\partial t}$ is the acceleration of the rocks; $\mathbf{v}$ is their velocity; α is the coefficient of mechanic-magnetic transformation; $\mathbf{B}_0$ is the main geomagnetic field;

$\beta = \frac{\partial \ln \sigma}{\partial \theta}$, $\theta = \nabla \mathbf{U}$, $\mathbf{U}$ is the field of displacements; $\mathbf{M}$ is the unit volume magnetic moment; $M_i = (\gamma_1 P_{II} \delta_{ij} + \gamma_2 P_{ij}) B_{0j}$, P_{II} is the pressure parallel to axial load.

It was assumed that the rock conductivity σ, parameters of mechanic – magnetic transformation $\alpha, \beta, \gamma_1, \gamma_2$, external electric $\mathbf{E}_0$ and magnetic $\mathbf{B}_0$ fields are homogeneous and time independent. But these parameters really change in a broad range of values, are measurable with difficulties, and the knowledge of all of them is necessary concerning the given region of investigation during the quantitative evaluations.

The equation of generation (1) should be obviously solved with definite parameters of medium movement and definite boundary conditions. But this solution has the doubtful value for interpretation of a given event until the phenomenlogical parameters of propagation medium are not define. It is important that due to linearity of equation (1) it is possible to study different mechanisms of generation independently adding then the obtained results.

Using equation (1), one can make the comparative analysis of relative effectiveness of different generation mechanisms [Gulielny, 2007, 2008], in particular inductive mechanism connected with a movement of conductive elements of the crust and inertial one due to which the generation of magnetic field caused by the shift stream of fluids in pores and cracks relative rock matrix. It was founded that critical frequency exists at which both mechanisms are effective equally, but inductive mechanism is prevailed at low frequencies and inertial one prevailed at high frequencies.

It should be mentioned that the equation (1) is obtained at quasi stable approximation when the change in system state is negligibly small during the time of signal propagation from the source to the observation point (distance R). The condition of this approximation adaptability for a vacuum propagation of the signal is $\frac{R}{c} << T$, where T is the character period. For example, the condition of quasi stationarity is fulfilled for frequency 100 Hz at the distance not exceeding 100 km, for frequency 100 kHz at the distance no more then 1 km from the source.

If the signal is propagated in the geological medium, these results are valid for the frequency range for which the depth of skin layer is sufficiently large, so the radiation of such a type can go away from the zone of generation. Concerning the radio radiation with the frequencies of tens, hundreds of kHz and even MHz, it can not go away the deep source seemingly. In surface layers of 10 – 150 m in contrary, it is quite problematic to find the sufficient quantity of radio radiation sources, and it is hard to connect this radiation with seismic source or dynamical processes leading to its emission [Surkov, 2000]. Therefore the explanation of the superlong radio wave propagation mechanism and of it coming out the day surface has great difficulties in the frame of classic linear electromagnetic theory.

Let us remember that from the point of view of classic electrodynamics, the possibility of superlong propagation at distances much exceeding the skin layer power can be resulting from two causes [Shuman, Bogdanov, 2008]. First, this is the existence in the medium of propagation of the dependence of wave phase velocity on the transverse to the direction of propagation coordinates. This means the waveguides or surface waves. Second, this is the possibility of existence of the intermediate "dispersion" window in the frequency range of which the electromagnetic pulses can propagate to a long distances practically without distortions. At that, the pulse amplitude depends relatively weak on the medium conductivity, if the spectral width of the pulse does not exceed the width of "intermediate window". The existence of this window in the dispersive medium is connected to the anomaly increase of the relative dielectric constant value, which was revealed experimentally on some rock samples at the frequencies below 25 MHz [Shuman, Prychepiy, 2007]. This increase change the ratio between the conductivity currents and polarization currents which play the role of biasing current in dispersive medium at this frequencies. The existence of the " dispersion windows" does not proved at real propagation lines in geological medium. It should be noted that the appearing of the “dispersion window” is an experimental results and its physical cause not obligatory lies in the frame of classic linear electrodynamics.

The several models of generation and propagation were suggested in order to overcome the noted difficulties. In particular, the hypothesis was presented in the frame of classic approach which connects the ULF noise with both the creation of tensile cracks and dilatansion effect [Surkov, 2000]. It is important that the effective magnetic moments of all opening cracks are paralleled and directed oppositely to the vector of geomagnetic field induction $\mathbf{B}_0$, what leades to the coherent amplification of the ULF field of crack assembly. The obtained estimation gives that the time and spectral characteristics of the electromagnetic radiation are defined by the dynamics of crack growth and their concentration in the zone of medium destruction. The evaluation of the ULF noise amplitude in the frame of this model is in agreement with experimental data obtained before some earthquakes. It should be noted that the high frequency electromagnetic signals up to Roentgen frequencies are generated during the crack opening. The high frequency acoustic vibrations are generated also.

Basing on the above consideration it is evident that one should solve the problem of radio radiation generation and its super long-distance propagation leaning on the nonlinear theory of transformation of the rock movement energy to the energy of electromagnetic field taking into account the empirical regularities about its connection with the structure and dynamics of geological systems. The several models were proposed in the frame of nonlinear theory.

One of them is based on the appearing of the optical vibrations of the complex lattices and connected with them electromagnetic perturbations due to creation and movement of point, linear (dislocations) and volume (pores, microcracks) defects of the crystals [Bogdanov, Pavlovych, 2008]. Since the intensity of defect creation is proportional to crystal deformation, then the intensity of generated waves is maximal in the regions of greatest deformation of the Earth crust. At the same time, the main question of superlong propagation of the electromagnetic perturbations can be solved on the base of nonlinear mechanism of amplification of electromagnetic waves during their interaction with defects of crystal lattice of the Earth crust substance which is in a thermodynamically nonequilibrium state. In essence this mechanism is very close to mechanism of Dicke superradiation (see for example [Men'shikov, 1999]), moreover microscopic consideration of this question leads to the Hamiltonian very close to Dicke Hamiltonian.

The Dicke superradiation is the collective emission of the excited medium, and was first discovered experimentally in astrophysics as radiation of Crab-like nebula which is the remains of Supernova Star. In 1954 Dicke [Dicke, 1954] first have proposed the theory of superradiation, after that this phenomenon was revealed in plasma, inverted solids, caesium vapour, and other excited objects [Men'shikov, 1999]. Since the interior of the Earth is continuously in excited state due to tectonic motion, especially in the fault zones, then the conditions for superradiation generation as a source of natural electromagnetic field of the Earth are appeared.

The essence of the superradiation mechanism is the correlated interaction of the oscillators with field leading to the cophased vibration of the oscillators and radiation appearing along the direction of medium spread.

The linear dependence of the active medium size and intensity of radiation is peculiar for spontaneous radiation of excited medium known as luminescence:

$$I \approx I_0 n L, \; I_0 = \frac{h\omega}{\tau_0};$$

where I_0 is the intensity of a single oscillator, n is the linear oscillator density, L is the spread of the excited medium, $\omega = \frac{E_2 - E_1}{h}$ is the frequency of radiation, τ_0 is the character time of the spontaneous transition $E_2 \rightarrow E_1$.

In contrary, the peculiar feature of the superradation is the pulse anisotropic radiation with duration τ_s and intensity I which is proportional to the square of the body size and quantity

$$\tau_s = \frac{\tau_0 k^2}{3\pi nL}, \; I \approx I_0 \; L^2 n^2 \; ;$$

The characteristic of superradiation is the existence of critical size of the sample which follows from the condition of superradiation occurrence in extensive bodies:

$$3\pi\alpha L/k^2 >> 1;$$

Here α is the mean distance between the oscillators, L is the body size, $k = \omega/c$, $= 2\pi/k$.

In the last years the questions of nonlinear wave (soliton, autosoliton, autowave) propagation in the geological medium are widely discussed in literature (see for example [Dmitrievskii et al, 2006 – 2008]). In order to apply these conceptions in geophysics, it is necessary to understand clear the area of their definition. Soliton (solitary wave) is the wave which keeps its shape and velocity during the propagation and after collision with another solitary wave [Solitons. Ed.Bullaf, Codry, 1983]. The solitons are the solutions of nonlinear equations, which describe the behavior of the conservative Hamilton systems. The soliton shape is kept due to concurrence between nonlinearity and dispersion – the nonlinearity leads to the increase of the wave slope, and dispersion leads to the wave smearing. It is clear that the dissipation does not take into account in conservative Hamilton systems, where the processes of wave energy scattering in the medium are negligibly small, for example, the propagation of light in insulators just in which the phenomenon of self-induced transparency connected with solitons was observed. From this point of view, the geological medium is doubtfully the object for solitone propagation.

On the other hand, the autosolitons [Kerner and Osipov, 1991] is formatted and propagated in dissipative noneqilibrium media, such is geological medium itself, and they are one of the types of the system self-organization. Autosoliton is the solitary eigenstate of the system, and its parameters are completely determined by the medium parameters and do not depend on the initial condition with minor reservation. The initial perturbation should be sufficiently power (with great amplitude) and prolonged to excite autosoliton in the medium, i.e. small perturbation decays in the medium and great one is transformed to autosoliton. Therefore the natural electromagnetic radiation of the Earth with sufficiently small amplitudes probably does not consist of autosolitons. But seismic, acoustic and electromagnetic waves generated by the earthquake are most likely autosolitons. These waves are not the subject of the given paper.

The moving autosoliton is one of the types of wider concept of autowave, and the name derives from its shape in the form of solitary wave. Autowaves can have different shape, in particular the form of front when the system converts from some initial state to final one. There are plurality of autowave appearing in different systems – physical, technical, chemical, biological (see for example [Vasiliev et al., 1987]). The theory of autowaves and autosolitons is now developed in details, so there is the possibility to analyse the creation of such structures in geological medium on this base.

4. Autowave mechanisms of the Earth degassing, dynamics of fluids and radionoise generation

As it was noted above, the state of geosystem is self-regulating and self-developing under the influence of continuously changing in time abyssal energy flow forming the space – time dissipative structures at great level of nonequilibrium. The concept of energy flow should be detailed. The main part of energy flow, which passes on from the Earth interior to day surface, is a heat flow due to temperature gradient. The relative motion of the mantle and crust creates the gradients of stress, deformation and pressure in the crust. The acoustic and electromagnetic waves are generated during the plastic and brittle deformation of the rocks which also transfer the energy from interior the day surface. The existence of the gradients of different fields originates the conditions for substance transfer. This is transfer of gases and liquids in normal not catastrophic conditions. Thus the energy transfers from interior to surface in the form of heat, electromagnetic, acoustic energy and energy of moving substances of gases and liquids (fluids).

The main cause of fluid movement is the existence of physical field gradients. But other transfer mechanisms are possible in noneqilibrium nonlinear media, for example, the effect of Stepanov – the enhanced movement of liquids through the capillary at the presence of ultrasound.

In general, the energy pumping into the geological medium promotes the forming of active systems, characterizing by the nonlinear dynamics of physical field in common. In usual algorithm, the equation system of macroscopic kinetics, which describe the fluid movement through the medium in some field (temperature, electromagnetic, acoustic), allows the autowave solution in the form of propagating front of fluid concentration. Additional energy pumping into the medium can lead to appearing of the static, pulsed and running areas of fluid concentration, out of which the local energy and fluid concentration keep practically constant. The electromagnetic and seismoacoustic fields (pulses) generated and emitted from these local areas – solitary states or autosolitons – get the day surface and can be detected by geophysics methods. Generally speaking, these considerations should be illustrated by specific mathematical models accounting for the geophysical peculiarities.

Taking into account the above consideration, one can clearly understand the presented earlier nonlinear equation of electromagnetic noise generation in excitable geological medium (system of lithosphere blocks separated by weakened transition zones), which has localized immovable or mobile solutions [Shuman, 2007; Shuman, Bogdanov, 2008a; Shuman, Bogdanov, 2008b]. This equation generalize the known quasi stationary Maxwell equation. The concept of “trapped waves” (generalized Rayleigh wave), propagating along the contact zones of lithosphere blocks (localized nonequilibrium areas or volume deformation perturbations), is accepted as a starting “mechanical” component of the model, which has the experimental grounds [Dubrovskii, Sergeev, 2006; Li et al., 1990].

The generalized Rayleigh waves exponentially decay in direction perpendicular to the fault plane and canalized by this plane, therefore they are called “trapped”. These waves can accept the energy of the volume seismic waves. According to [Dubrovskii, Sergeev, 2006], this means the increase of trapped wave amplitude and instability of the ground state of relative block slip. The instability of slip along the faults in turn leads to solid deformation instability with sufficient decrease of shift characteristics [Dubrovskii, Sergeev, 2006].

The trapped wave propagating along the fault formats the changes in complex dielectric permittivity, and this wave of complex permittivity can be the source of transient radiation or scattering [Ginzburg, Tsitovich, 1984]. This is a base of mechanic-electromagnetic transformation concept accepted in the work [Shuman, Bogdanov, 2008b].

In general, the solution of the delivered problem is sufficiently complex. One should solve the Maxwell equation system together with equation of trapped wave propagation along the boundary between two media, at that it is necessary to insert the explicit form of permittivity dependence on the trapped wave parameters to the Maxwell equations. If one takes into account that the solution, corresponding to the observed in experiment [Li et al., 1990] random jump-like sliding of the interface, was not obtained in explicit form, and the continuous sliding is instable, then the problem becomes insoluble. But one can try to solve the problem with model dependence of permittivity in the form of some time dependent random function, i.e. the problem of vibration parametric excitation by random force.

In general, there is any more possibility of permittivity autowave change due to movement of fluids. In geological medium with complex structure, there is the plurality of nonlinear interaction between different physical fields. The static, pulse or propagating regions of fluid concentration can appear in such systems, out of which the energy and concentration are relatively constant. Generating and emitting from these regions electromagnetic and acoustic waves could be detected at day surface, what in principle gives the possibility to study the processes of Earth fluid nonlinear dynamics [Dmitrievskii, Volodin, 2008]. Therefore the fluid transfer processes can be noticeably determined by the autosoliton nonlinear dynamics, what permits to consider the mechanisms of space-time pulse Earth degassing and pulse electromagnetic emission from new point of view.

Taking into account the above consideration and generally accepted description of the active media in the form of parabolic equation system of "diffusion-reaction" type [Davydov et al., 1991], one can clearer understand the presented earlier nonlinear generalized equation of the geomagnetic noise generation [Shuman, 2007; 2008; Shuman, Bogdanov, 2008]:

$$\frac{\partial B_i}{\partial t} = \alpha_{ij}\nabla^2 B_j + F_i(\mathbf{B}), \qquad (2)$$

where α_{ij} is the diffusion matrix, B_i is the generalized induction; F_i (**B**) is some nonlinear function which presents the intensity of mechanic – electromagnetic transformation and determines by dynamics of deformation processes of geological medium.

As it is known, the nonlinear system of type (2) has in general both the localized and propagating solutions, and the main rules of autowave structure formation could be demonstrated in the frame of two component system:

$$\frac{\partial B_i}{\partial t} = \alpha_{ij}\nabla^2 B_j + F_i(\mathbf{B},\mathbf{G}),$$

$$\frac{\partial G_i}{\partial t} = \beta_{ij}\nabla^2 G_i + \varepsilon P_i(\mathbf{B},\mathbf{G}),$$

where function G determines the intensity and scale of dynamical sources of geomagnetic perturbations. In particular, G can be the concentration of fluid or one of the fluid components. At that, the excitation characteristics of such systems are determine by the peculiar N-like form of nonlinear function F_i (**B, G**). The case $\varepsilon = 0$ corresponds to one-component system which has two stable states [Davydov et al., 1991].

Note that one can obtain quite full information about the autowave structure evolution describing the time change of wave front only. This idea sufficiently simplifying the autowave process consideration lies in the base of kinematical approach of autowave structures [Davydov et al., 1991]. It can be important from the point of view that the seismic-electromagnetic radiation becomes apparent most actively at the propagating fronts of fluid concentration where the formation of the wave of complex permittivity becomes possible. And therefore the transient radiation and scattering can appear at these regions.

Commonly the solution of the seismic-electromagnetic noise generation problem should be seek possibly in close relation with the autowave mechanisms of the Earth degassing accounting for the plurality of mechanic-electromagnetic transformations and empirical rules of this radiation connection with the structure and dynamics of geological medium.

5. Experimental data

It is quite surprising that the simple geometrical proportions between space parameters of radiowave noise, registered at the day surface or over it, and location depth of "point" emitter exist in condition of many phase hierarchic geological medium of complex structure [Shuman, Bogdanov, 2008b]. These proportions do not depend practically on the electrical characteristic of profile but define by the sinking depth of emitting element, and the signal amplitude gives the information about physical properties of rocks along the way of it propagation.

It is experimentally revealed that the intensity of spontaneous electromagnetic radiation in radiowave diapason (the number of pulses per unit time which amplitudes exceed the given threshold) is characterized by the sufficient space inhomogeneous. The space size and shape of its anomaly can serve as a base for the recovery of geophysical cross section geometry [Bogdanov et al, 2007; Shuman, Bogdanov, 2008]. Besides, the radiation characteristics from the similar structures have the close parameters independently on their location. One can use for recovery purpose both the change of intensity along the profile of observation and the spectral components or wavelet transformations. As it is known, the wavelet transformation permits to pick out the boundary of anomaly radiation zones, to define their spacial sizes and to obtain the information about sinking depth of emitting object.

Let us illustrate the above consideration by examples of glacier structure in Antarctic region. The investigations were held by "Tezey" device in 2005, 2007 on Galindez Island glacier during season parts of Ukrainian Antarctic expeditions. The device is an analyzer of geopolariton field activity (number of pulses with amplitude over 5mkV/m) with broadband frame antenna (the magnetic component of electromagnetic field is detected perpendicular to the frame).

The coordinates and the height of the points were determined by GPS technology. The data was written in DGPS controller constantly during measurements by profiling the Galindez Island glacier. The profiles location (2005) is shown in fig.1.

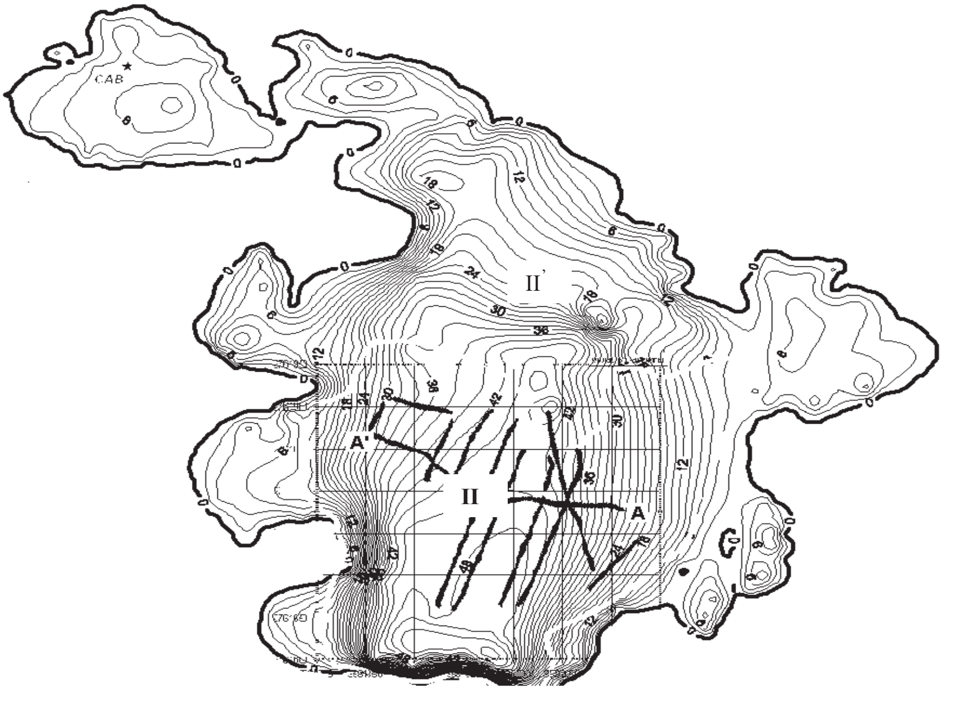
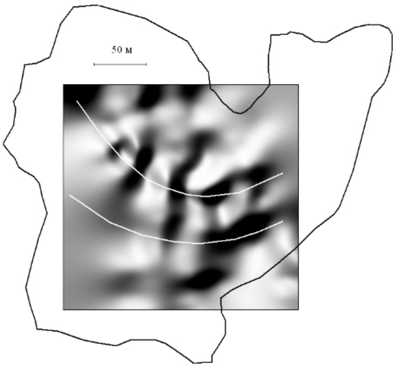


Fig.1. Geopolariton sounding profiles.

The results are given as geopolariton radiation intensity maps (fig.2) and geological section by A'-A line (fig.3, 4). The map (fig.2) shows structure failures of submeredional extent and sublatitude arc-like failures that may be caused by glacier movement.



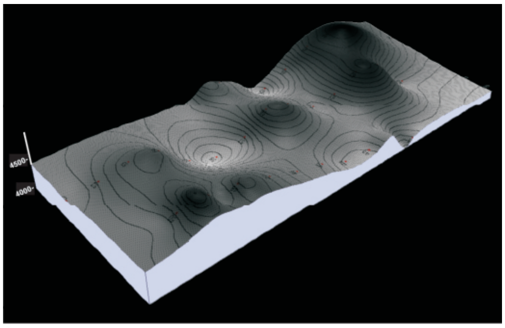


Fig. 2. The geopolariton radiation intensity map on Galindez Island glacier. The contours show glacier borders. The white lines on the left – arc-like failures. On the left there is a fragment of watered part of rock surface on depth of 22m from the glacier surface (shown in white).

As known, the line of maximal velocities of glacier movement is usually located in its middle. Across the glacier from the axis the velocity decreases due to friction on bottom and walls of the valley. In our case the arc-like failures may origin due to such velocities variations. The maximal convexity zone of the failures detected (or perpendicular to arcs) shows on the glacier movement direction in south-south-west.

A profile is constructed along the A'-A line (fig. 3) – from the north-north-west through central glacier part to the east.

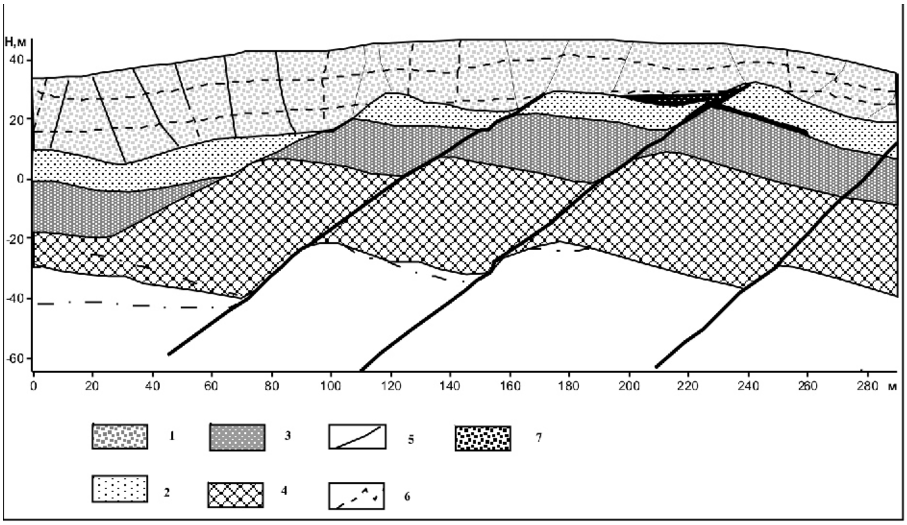


Fig. 3. Geophysical section through central glacier part by A'-A profile.
Here: 1-glacier cover, 2,3,4-lithologic borders, 5-rupture faults, 6-firn, 7-water-saturated floor.

The glacier lower border and a complex fault system both in glacier (cracks) and the Earth crust are visible in the section. There are also two borders stand out in the glacier at depths of 10 and 20 m from the glacier surface. Both borders quiet accurately repeat the glacier surface form and partially – the underlying surface.

It seems that they represent phases of glacier formation as snow turned to ice i.e. firn surface. Presence of more than one firn may be associated with nonuniform glacier formation.

The cracks in the glacier partially inherited structural faults in the floor, partially formed by ground relief and glacier movement. Some of the faults detected may be the strain zones and correspondingly – forming cracks.

There are signs of caves or broad cracks detected in majority on the glacier border and confined to intersection of cracks and detected layers inside ice.

The sub-vertical cracks with the slope corresponding to the floor slope dominate in case of the ice thickness is large. The slope increases in the case of glacier thickness is small. We may guess that both movement types are characteristic for the given glacier: the viscous-plastic flow and the lump sliding on glacier bed. The first movement type dominates in eastern glacier part (see right part of fig.3), where the glacier thickness is small and the cracks and strain zones are strongly inclined. Determining from the crack slopes, the upper ice layers speed is greater than that of near-bottom. Such velocity change is characteristic for viscous-plastic flow. Subvertical cracks in thick ice layer (south glacier part) reveal that velocity of the ice movement is approximately constant across the all its thickness that is more characteristic for the lump sliding.

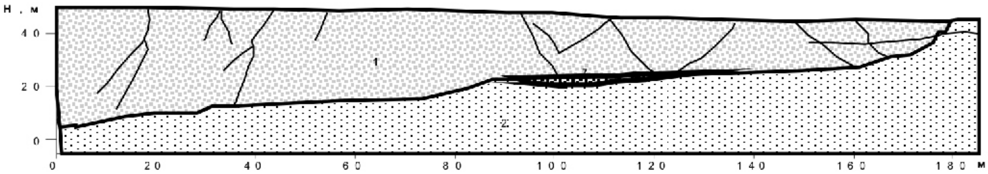


Fig.4. Geophysical section through the glacier central part according to II profile (see the legend on fig.3)

At lower glacier border in some places the liquid water is found. The most confident tracks of water were noted in the south-eastern part of the glacier (fig.3-4) where the water is found both under the glacier and in the soil along the geological layer slope that reaches the ocean at the island border.

The most probable water source is the ice melting. From the glacier bed it flows to the sea. But it is also possible that the water weeps from the sea along crumbly border of geological layers. The water saturated soil and correspondingly lowered stress areas are shown as dark spots on the map (fig.2. right).

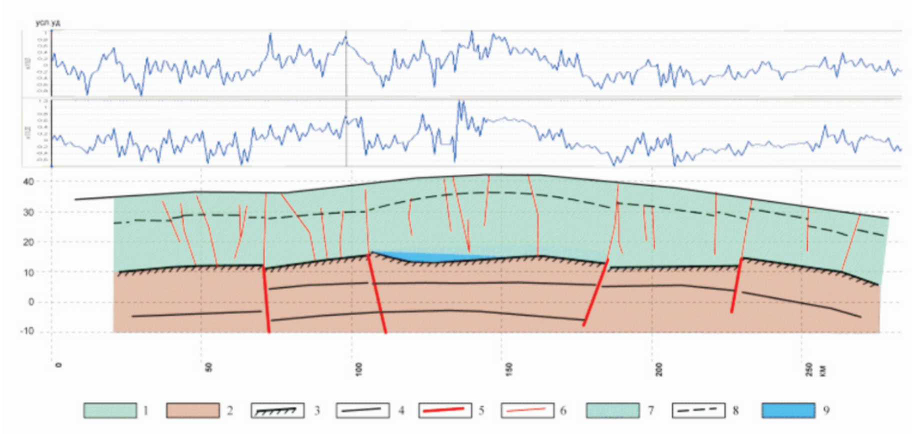


Fig.5.Geology-geophysical section through central glacier part by A'-A profile (data of 2007) with the wavelet components of the signal (above).

Here: 1-glacier cover, 2,3,4-lithologic borders, 5-tectonic faults, 6 - glacier faults, 7,8-firn, 9-water-saturated floor.

Practically the same profile was investigated in 2007 by “Astrogon” device which is improved variant of “Tezey”. The result is shown at Fig.5 together with the wavelet components of the signal (above). The comparison of the same profile can serve as glacier structure and movement monitoring technology. It is also possible, of course, to study Earth crust structure in Antarctic region using such a technology.

6. Conclusion

Since it does not succeed in explain the peculiarities of spontaneous Earth electromagnetic noise in the frame of classical linear models, one should involve the nonlinear models of physical field interactions and their perturbation propagation in active inhomogeneous geological medium. Just such an approach gives the possibility to solve the set of problems arising during the analysis of geomagnetic noise generation, its super far propagation and in attempts of its practical use to study geological structure and geodynamical processes.

It is known that the evolution of the nonlinear systems can occur in different ways – the possibility of development and behavior plurality ways comes to take the place of linear unambiguity. The development of autowave conception of energy transformation and transfer and dynamics of the Earth is of great interest and actuality in such a context.

There are really three new model mechanisms of mechanic – electromagnetic transformation which can help to solve above problems. The polariton radiation arising due to creation and annihilation of different crystal lattice defects (mainly microcracks) can be the base mechanism of radiowave noise emission. The second mechanism consists in transition radiation (scattering) generated in the wave of complex permittivity which can forms on the front of “trapped” Rayleigh wave propagating along the fault. The third one is the mutual electromagnetic field and fluid concentration propagation of autosoliton type based on “reaction-diffusion equation system. Two last mechanisms are practically at the stage of problem formulation.

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