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A model of the generation of electromagnetic emissions detected prior to earthquakes

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ABSTRACT

Recent satellite and ground-based observations prove that during the formative period of earthquakes VLF/LF and ULF electromagnetic emissions are observed in seismogenic areas. This work offers an original model of self-generated electromagnetic oscillations of local segments of the lithospheric origins of the emissions. In the paper, the seismogenic area is considered to be an oscillatory-distributed system. This model simplifies physical analyses of the nonlinear effects and qualitatively explains the mechanisms that generate very low frequency electromagnetic waves in the period prior to an earthquake.

1. Introduction

During the period of the formation of strong earthquakes an earthquake's occurrence and often after an earthquake, MHz, kHz and ULF electromagnetic emissions are detected (Hayakawa and Fujinawa, 1994; Hayakawa, 1999; Hayakawa et al.,1999; Gershenzon and Bambakidis, 2001; Biagi et al., 1999, 2009, 2013; Hayakawa and Molchanov, 2002; Bahat et al., 2005; Pulinets et al., 2007; Eftaxias et al., 2007a; 2007b; 2009, 2010).

In the present paper, we try to explain this phenomenon using electrodynamics and create a model of the generation of LAI system self-generated electromagnetic oscillations.

From the early period of earthquake preparation, the segment of the Earth's crust where the incoming earthquake's focus will be formed, represents the system, which undergoes specific types of oscillations: the system is accumulating energy. However, the accumulated energy is also simultaneously released as a result of foreshocks, the main shock and aftershocks. In this view the system is oscillatory.

The extreme diversity of such oscillatory systems and their properties require the identification of common features in various oscillatory systems and their grouping into certain classes and types according to their most common characteristics.

A seismogenic zone can be a considered to be distributed system because the mass, elasticity (of the mechanical system), capacity and inductance (of the electric system) are uniformly spread throughout the entire in the whole volume of the system. It should be noted that in the earthquake preparation area each small element has its own capacity and inductance because of piezo-electric, piezo-magnetic, electrochemical and other effects.

Besides, the system can be considered to be distributed if the transfer time of the perturbations through the system is not less than the period of oscillation.

Thus, for distributed systems, quasi static terms generally are not satisfied. The primary motions in such systems are waves (Migulin et al., 1978). Thus, for electric fields in distributed systems, $rot\, \boldsymbol{E} \neq 0$. In this case the integral $\int_1^2 E_s ds$ depends on the integration path between points 1 and 2. Thus, we cannot introduce the notions of potential and capacity.

However, in double-wire or coaxial wires, if the model distance, b, between the wires is less than the wire length, l, and the wave length, λ $(b \ll l, b \ll \lambda)$, in the case of the low resistance of conductors, only transverse electromagnetic waves will propagate (Migulin et al., 1978).

Thus, in the plane, that is normal to the line, the distribution of these waves will coincide with the distribution of the electric and magnetic fields for the static case. Therefore, for small sections, dx, on the line, the theory of quasi-static currents is acceptable and

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potential, current, distributed capacity and inductance can be introduced.

Because the processes in the earthquake focal zone during the preparation period satisfy the conditions of distributed systems, we can introduce the linear inductance, L_0, and capacity, C_0, there. Therefore, the processes that occur during the period of earthquake preparation can be precisely described by a distributed system of double-wire lines.

The values of the linear inductance, $L_{0,}$ and capacity, $C_{0,}$ (the inductance and capacity per length unit, respectively) are determined by the geometry of the conductors and the properties of the medium. For the double-wire line model, if the distance between the wires is b, the electromagnetic wave length is λ and the condition $b \gg r$ is satisfied, where r is the wire radius, then (Migulin et al., 1978):

$$L_0 = \frac{4\mu}{c^2} \ln \frac{b}{r}, \qquad (1)$$

where c is the velocity of light in a vacuum, μ is the magnetic permeability of the medium, and the capacity is:

$$C_0 = \frac{\varepsilon}{4\ln(b/r)}, \qquad (2)$$

where ε is the dielectric permeability of the medium.

2. Description of the model

It has been demonstrated experimentally that during the formation of cracks in the period of earthquake preparation electric dipoles appear on the surfaces of the cracks (Freund et al., 2006; Eftaxias et al., 2007a, 2007b).

In a solid medium, a significant quantity of polarization charge may accumulate in areas, where heterogeneity at a definite linear scale has already formed or is in the process of formation.

Such polarization effects are often accompanied by electromagnetic emissions (Ikeya and Takaki, 1996; Yoshida et al., 1997), and in addition to the electrostatic effect, which forms and creates capacity, this, is a formal sign that the polarization is also accompanied by an inductive effect. However during the analysis of the possibility of an inductive interaction in the lithosphere–atmosphere system, many other inductive processes must be considered. With respect to seismic phenomena, the lithosphere probably is always the source of this effect. Therefore, we can assume that schematically we have to address a definite type of electromagnetic contour, the elements of which should be connected to the lithosphere.

Conditionally, the surface of the earth has a negative potential with respect to the atmosphere; therefore, prior to the piezo-effect, which is conditioned by the mechanical tensions in the rocks (Mognaschi, 2002; Triantis et al., 2008;Telesca et al., 2013), the segment of the lithosphere, where an earthquake preparing, can be considered to be negatively charged.

According to the avalanche-like unstable model (Mjachkin et al., 1975), in the focal zone of an incoming earthquake, at the second stage of its preparation, multiple crack nuclei along the length of the main fault begin to form and gradually grow. Therefore, the nucleus of the main fault can be imagined to be a conductor, the length of which significantly exceeds the characteristic size of its cross section.

As a result of the growth of tectonic stress, heterogeneity, i.e., zones of positive charge, appear in the earthquake preparation areas (Bleier et al., 2009). Similar to "Frankel's generator", in that segment of the Earth's crust there is an inductive polarization (Yoshino, 1991; Molchanov et al., 1993; Hayakawa and Molchanov, 2002; Liperovsky et al., 2008).

Generally, the polarization charge should be distributed over a surface, which should be limited by the fault or formed along the faults (Yoshino, 1991), that is, near the first conductor a polarized conductor of the same size and with an opposite charge should be formed by induction.

Because earthquake preparation takes place in relatively weak zone, with less solidity (Mjachkin et al., 1975; Morozova et al., 1999; Tada-nori Goto et al., 2005; Kovtun, 2009), the segment of earthquake preparation should be surrounded from top to bottom by rocks of relatively high solidity. However, considering that rock density increases with increasing depth, the primary rocks above the future fault will have a lower density.

In that case, the rate of heterogeneity due to the impact of the tectonic stress will be significantly higher in the less dense layer, that is, in the upper rock. Because the accumulation of polarization charge is connected with existing heterogeneities in rocks, a second polarization conductor should form above a fault, and be quasi-parallel to it. Therefore a main fault can be modelled as a double-wire conductor, the length of which greatly exceeds the size of its cross section.

There are data in the specialist scientific literature that state that during the earthquake preparation period, there are galvanic effects that can be regarded as seismogalvanic effects in the focal zone (Moroz and Vershinin, 2001). Thermally anomalous sections in the focal zone should also be considered.

Observations show that specific changes in electrical resistance of rocks, have characteristics of earthquake precursors (Sumitomo and Noritomi, 1986; Zhiliang and Surong, 1989; Du Xuebin, 1992; Bragin et al., 1992);

According to recent studies at depths of 5–10 km, along the seismic fault plane and in its vicinity the conductivity increases significantly, because, irrespective of the fact that the medium is heterogeneous, there are inclusions of high electrical conductivity in the form of the graphitization and *sulphurization* of rocks (Morozova et al., 1999; Tada-nori Goto et al., 2005; Kovtun, 2009). Under such conditions the above-referenced double-wire conduction layer can be closed in the Earth's crust, in high conductivity zones (layers) and can enable virtual conductors to create a contour.

In fact, if formally there are two, separated horizontal wires of opposite polarity in such a heterogeneous medium, where there are high electrical conduction inclusions in the form of graphitization and *sulphurization,* a structure similar to a vibrational contour should be formed, which might be locked by a vertical electric field.

It should be noted that during the second stage of earthquake preparation, when the avalanche-like cracking – process occurs, the tectonic stress approaches the threshold level, which is required to overcome the strength of the geological medium. Irrespective of the permanent growth of the tectonic stress, an earthquake does not yet occur, because part of the tectonic energy is used for the avalanching formation of cracks and their aggregation. At this stage, the mechanical energy is approximately constant. Thus, the above described distributed system will act in parallel, as a conservative system (which in turn is an idealized system) and has constant mechanical or electromagnetic energies, or both of the energies are oscillating together. Because pendular and electrical oscillations are among the simplest forms of conservative systems and because the earthquake focal zone during the final stage of preparation combines (with a definite accuracy) the properties of those systems, it might be allowable to similarly characterize the mechanical and electric oscillatory processes within it.

Therefore, if electromagnetic dissipation is not considered, the contour's self-generated frequency of oscillation is:

$$\omega^2 = \frac{1}{L \cdot C} \qquad (3)$$