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*Geophysics*

# Possibility of Resonant Amplification of VLF Electromagnetic Radiation Associated with Seismic Activity Near Tskaltsminda-Ureki Area

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(Presented by Academy Member Tamaz Chelidze)

**ABSTRACT. Magnetic sand, located at the Black Sea coast of Georgia, in resort Tskaltsminda-Ureki, between Supsa and Cholokhi rivers, represents a geomagnetic anomaly. The sand does not only occupy the narrow coastal zone, but stretches in the sea bottom. According to electric and magnetic surveys this territory is an anomalous area with sharp gradient of geomagnetic field. Specific geophysical characteristics of this place have interrelated factors: magnetite-rich sands from western part of the Adjara-Trialeti fold and thrust belt, carried by the Supsa River; seepage of seawater to the coastal area; the polarization effect arising from the movement of a conducting fluid in a magnetized porous rock. As a result, the accumulation of free and associated polarization charges and their relaxation by telluric currents and VLF (Very Low Frequency) electromagnetic radiation are possible. In the presented paper, a retrospective analysis was done for spectral characteristics of VLF electromagnetic radiation during earthquake series with moderate magnitudes (M = 4.1 - 5.5) in period of December 2012 – January 2013 in the Black Sea near the coast of the Republic of Georgia. During the Black Sea earthquakes signal intensity of 18.3 kHz channel, increased by up to 20 dB. However, propagation of VLF electromagnetic, radiation through a well-conducting sea water of considerable thickness is impossible. In such a case, attention should be paid to the contact of fault system, existing in earthquake focal zone, with the anomaly. The telluric currents generated in the focal zone of earthquakes can serve as an agent for electric inductive communication with the anomaly. This assumption is supported by existence of local magnetic anomaly in the study area, the physical properties of which can contribute to the resonant emission of VLF electromagnetic waves generated in the focal zone.** *© 2019 Bull. Georg. Natl. Acad. Sci.*

**Key words**: earthquake source physics, VLF radiation, LAI system

Detailed study of geomagnetic field in Tkaltsminda-Ureki began in the last decade of the previous century. Interest in this place is associated with the presence of magnetic sand. Specific geophysical characteristics of this place have interrelated factors: magnetite-rich sands from western part of the Adjara-Trialeti fold and thrust belt, carried by the Supsa River; seepage of seawater to the coastal area; the polarization effect arising from the movement of a conducting fluid in a magnetized porous rock. As a result, the accumulation of free and associated polarization charges and their relaxation by telluric currents and VLF electromagnetic radiation are possible [1].

In the presented paper two theoretical models will be used, allowing to relate mechanical parameters of earthquakes to VLF electromagnetic radiation. In particular, according to the first model, earthquake magnitude is estimated using seismic radiation energy, which is determined from body and surface seismic wave spectrum. It is known that the energy of any earthquake directly depends on the volume of seismic source $V_c$. Obviously, the part of energy spent on seismic radiation can vary significantly depending on state of the environment, as well as on magnitude and mechanism of the earthquake. To do this, it is necessary to determine the volume of the earthquake focus, which is a complex and an ambiguous task [2]. However, in cases of moderate magnitude earthquake, a fairly well-known and rather simple model [3], may turn out to be true. In particular, in this work we used some modification of the Bullen model, which is based on physical analogs between natural hydromechanical vibrations of a deformed liquid drop and mechanical vibrations of the earthquake source, both of natural and artificial (underground nuclear explosion), origin [4]. According to the model, earthquake source is divided into two areas: internal and external. Internal area is considered to be a zone of complete plasticity, where the medium fully loses its elasticity. This area was assumed to be about an order of magnitude smaller than the volume of earthquake focal zone. Here, irreversible changes and an explosive release of earthquake energy take place. Outer part of the earthquake focal zone is characterized by linear elasticity, from which seismic radiation propagates [3]. According to this model, an analytical equation was obtained, which determined discrete frequency spectrum of mechanical vibrations. After this, it is easy to calculate volume of plasticity zone of the earthquake focus. Consequently, this area is nothing more than a zone of "most of the released energy". Therefore, the part of total energy transformed into seismic radiation varies significantly for artificial and natural earthquakes.

The formula for the discrete frequency spectrum of natural oscillations of the earthquake focal zone in approximation of radial symmetry has the following form:

$$f_n = \frac{V_p}{2\pi R^2}\left[(n-1)(n+2)\frac{\left(\frac{R}{R_0}\right)^{n-1} - \left(\frac{R_0}{R}\right)^{n+2}}{\frac{1}{n}\left(\frac{R}{R_0}\right)^{n-1} + \frac{1}{n+1}\left(\frac{R_0}{R}\right)^{n+2}}\right]^{1/2}, \tag{1}$$

where $f_n$ is circular frequency, $n \geq 2$ ($n=0$ – corresponds to solely radial oscillations, which are excluded in incompressible medium, $n=1$ – progression motion), $R_0$ and $R$ - radii of plasticity and linear elasticity zones, $V_p$ – seismic body wave velocity [3].

Expression (1) allows to determine parameters of the earthquake source. To do this, it is enough to know at least two peak frequencies of the spectrum of seismic body waves. This problem can be significantly simplified if we assume that the medium is homogeneous in linear elasticity zone. In this case, it can be assumed that the oscillations are harmonic. Therefore, this model can be considered as sufficiently close to reality, since the sequence of frequencies according to formula (1) is quite close to harmonic series, which means that we assume: $\frac{f_3}{f_2} = 2$. So, parameter $\frac{R}{R_0}$ will be the root of the equation, which is the ratio of the first two equations from (1) (n=2 and n=3). It can be considered that in this case the root will be constant for any earthquake of moderate magnitude: $\frac{R}{R_0} = 1.92$. Further, using value of $f_2$ from experimental data, i.e. by the angle frequency of the spectrum of seismic body waves, from the equation (1) when *n=2*, it is possible to determine $R$ as well as the radius of the plasticity zone $R_0$. Thus, the main parameter determining solution to the inverse seismological problem is angle frequency, which can be determined by spectral analysis.

As a specific example we consider series of earthquakes that occurred in the Black Sea near the coast of Georgia (nominal center at N42.40, E41.00) in period of December, 2012 - January, 2013. The Black Sea is seismically active, where moderate magnitude M≥4 earthquakes take place. Discussed earthquake series are typical for the area, with left-lateral strike slip mechanism. This series was a swarm of events, including several medium-magnitude earthquakes, with the nominal center at: N42.41, E41.05 (Fig. 1). Among them were two strongest earthquakes $M_L$ = 5.5 at 2012/12/23 13:31:40 and $M_L$ = 5.4 at 2012/12/25 22:44:33 [5]. Spectral analysis of data corresponding to these two earthquakes showed that the main frequencies were within 1.3-1.6 Hz range. Accordingly, using expression (1) for characteristic value of $V_p \approx 6$ km/s, the following values of linear parameters of the earthquake source were obtained: $R \approx 2.02-1.64$ km and $R_0 \approx 1.05-0.85$ km. To estimate energy and magnitude of these earthquakes, volume of seismic source is necessary: $V_c = \frac{4}{3}\pi R_0^3$ by which the magnitude of the seismic energy can be estimated: $E_c = V_c \times e$ (where $e \approx 10^2$ $\mathrm{Jm}^{-3}$ is the characteristic value of energy density of elastic stresses). It is known that for moderate magnitude earthquakes the ratio of seismic energy to earthquake energy is $\eta \approx 10^{-2}$, i.e. seismic coefficient is $\approx 1\%$ [2]. Consequently, according to the model, the energy of these earthquakes is in range $E = \eta^{-1} E_c \approx (2.48-5)10^{13}$ J. Using formula from [6]

$$\lg E = 1.8M + 4 . \qquad (2)$$

These energies correspond to the range of local magnitudes $M_L$ = 5.2-5.4.

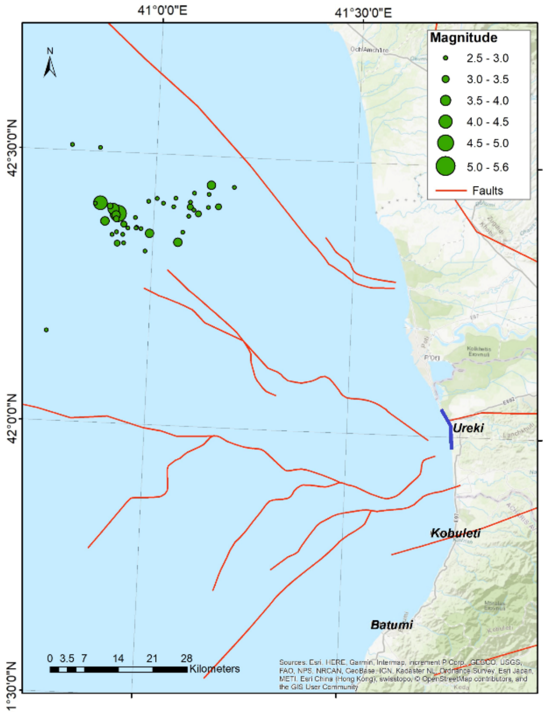


**Fig.1.** Green circles - earthquakes, red line – active faults, blue line – geomagnetic anomaly of Tskaltsminda-Ureki area.

**Model of natural electromagnetic oscillations of the local segment of the LAI system and Hypothesis of Tskaltsminda-Ureki magnetic anomaly resonant ability.** This model easily explains well known effect of changing the VLF spectrum of terrestrial electromagnetic radiation during preparation of an earthquake. Generally, fundamental spectral frequency is decreasing, which is most likely the result of an increase of characteristic linear size by merging of micro cracks in resulting fault. The mathematical idea of this model is represented by the formula [1]

$$\omega = \frac{c}{l}, \qquad (3)$$

where $\omega$ is the natural frequency of electromagnetic circuit corresponding to local segment of the LAI (Lithosphere-Atmosphere-Ionosphere) system, $c$ – the speed of light, $l$ – fault length.

In the case of the above-mentioned Black Sea earthquake series, there is an obvious ambiguity associated with the determination of parameter $l$. In particular, it can be considered length of the new fault, or comparable in length with one of the previously existing faults under the sea. It seems that VLF electromagnetic wave observation data from the Tabakhmela Ionosphere Observatory (near Tbilisi, N41.655, E44.754), where frequency range 16 – 24 kHz is observed [7], could bring clarity to this question.

significant increase in the intensity of VLF electromagnetic radiation, up to $\approx 20$ dB, was observed on 18.3 kHz channel (Fig. 3). According to formula (3), for 18.3 kHz frequency $l \approx 16$ km.

It is known that there is an ambiguity associated with generation of VLF electromagnetic waves mechanism. It is believed that the possible causes of this electromagnetic indicator of earthquakes may be an electro-piezo effect [8]. However, we cannot exclude the possibility of an alternative electro kinetic piezo effect. It is also possible that a

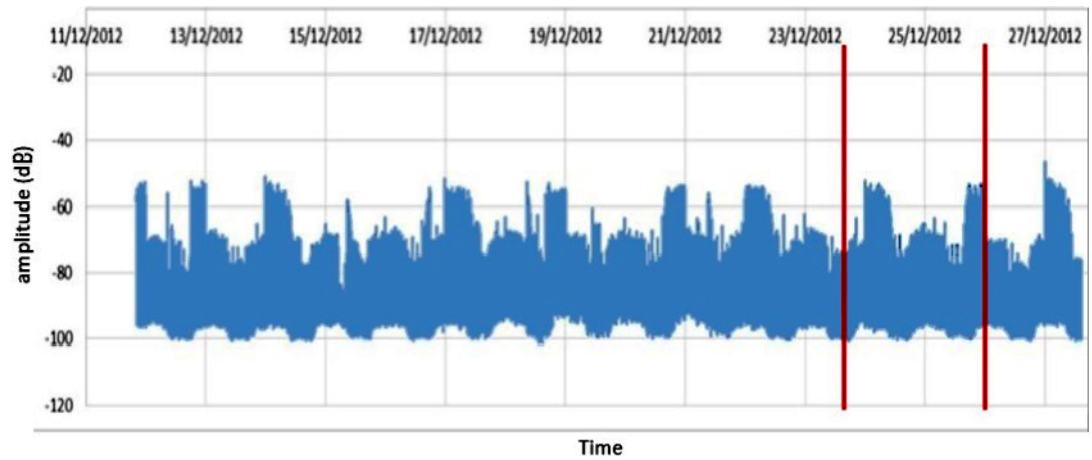


**Fig. 2.** Calm period data example for 18.3 kHz channel.

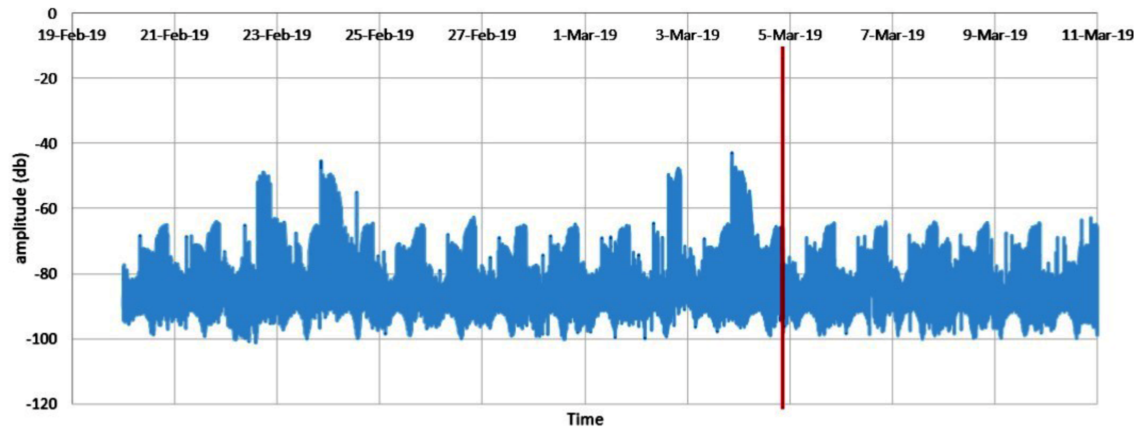


**Fig. 3.** VLF data for earthquake series, red lines – earthquake times.

Fig. 2 shows the data from 07/03/2011 – 12/03/2011 as a typical example of the amplitude variation of VLF electromagnetic radiation of the same signal during calm period. As it turned out, during the discussed earthquakes, the most

geomagnetic anomaly can itself generate electromagnetic waves. For instance, generation of electric charges is due to thermodynamic transformations in the hypocenter of future earthquakes [9]. Also, it is interesting that

Tskaltsminda-Ureki geomagnetic anomaly has characteristic linear size of about 15 km (between N42.031, E41.741 - N41.911, E41.769 and nominal center at N42.031, E41.741), which is close to $l$ from (3).

On the other hand, empirical formula that is valid for earthquakes with a magnitude of M ≤ 6.7 [10]

$$\lg l_0 = 0.24M - 0.16 . \qquad (4)$$

For instance, magnitude of the strongest of the Black Sea earthquake series is $M_L = 5.5$. Therefore, from (4) we obtain $l_0 \approx 16$ km. So, we have alignment of 3 values: values calculated with (3) and (4), as well as linear length of the magnetic anomaly (Fig. 1). It seems that such a coincidence cannot be random. Indeed, VLF electromagnetic radiation in the zone of magnetic anomaly can be considered as the result of general effect of magnetohydrodynamic (MHD) effect and phenomenon of electrolytic hydration of coastal medium. Thus, there is an opportunity to generate sufficiently strong local telluric currents and spontaneous electric fields arising in a well-conducting magnetized medium.

**Conclusions.** Geomagnetic anomaly can generate VLF electromagnetic radiation. For this, the existence of an electric induction coupling of earthquake focal zone and geomagnetic anomaly by telluric currents is sufficient. This hypothesis is supported by the fact that, during December, 2012 – January, 2013 events, 18.3 kHz channel amplitude was significantly larger than those of all other signals in the observed bandwidth. Such an increase in amplitude of 18.3 kHz channel, was probably due to effect of some local geophysical factors, which are characteristic for Tskaltsminda-Ureki geomagnetic anomaly. Also, we believe that linear length $l_0 \approx 15$ km of geomagnetic anomaly has an important role, which can be confirmed by data from Ivane Javakhishvili Tbilisi State University, the Tabakhmela Ionosphere Observatory, that shows amplitude increase on 18.3, kHz channel in different times. This hypothesis must be studied further. Truly, telluric currents in this area can arise due to induction of geomagnetic anomaly and earthquake focus, as well as other reasons, for example, strong geomagnetic perturbation.

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*გეოფიზიკა*

# სეისმურ აქტივობასთან დაკავშირებული ზედაბალი სიხშირის ელექტრომაგნიტური გამოსხივების შესაძლო რეზონანსული გაძლიერება წყალწმინდა-ურეკის მახლობლად

ნ. ყვავაძე* და ზ. კერესელიძე*

** ივანე ჯავახიშვილის თბილისის სახელმწიფო უნივერსიტეტი, მ. ნოდიას სახ. გეოფიზიკის ინსტიტუტი, დედამიწის ფიზიკისა და გეომაგნეტიზმის სექტორი, თბილისი, საქართველო*

(წარმოდგენილია აკადემიის წევრის თ. ჭელიძის მიერ)

ნაშრომში მოცემულია ივანე ჯავახიშვილის თბილისის სახელმწიფო უნივერსიტეტის ტაბახმელას იონოსფეროს ობსერვატორიაში (N41,655, E44,754) რეგისტრირებული მდს (მეტად დაბალი სიხშირის, 3-30 კჰც) ელექტრომაგნიტური გამოსხივების სპექტრული მახასიათებლების რეტროსპექტული ანალიზი. კვლევის მიზანი იყო, 12.2012-01.2013 წწ., შავ ზღვაში საქართველოს სანაპირო ზოლში (ნომინალური ცენტრი N42,40, E41,00) მომხდარი საშუალო მაგნიტუდების ($M = 4,1 - 5,5$) მიწისძვრების სერიის პროცესში გამოვლენილი მდს გამოსხივების 18,3 კჰც არხში ინტენსივობის მკვეთრი ზრდის (ამპლიტუდის ნახტომი $\approx 20$dB) შესაძლო ფიზიკური მექანიზმის განსაზღვრა. ჰიპოთეზის თანახმად, ინდუქციური ზეგავლენის აგენტის ფუნქციას ასრულებს ფოკალურ არეში გენერირებული ტელურული დენები. თეორიული ინტერპრეტაცია ეყრდნობა ვარაუდს, რომ თვით გეომაგნიტური ანომალიის არე შესაძლებელია წარმოადგენდეს მდს ელექტრომაგნიტური ტალღების გამომსხივებელს. ასეთი დაშვების საფუძველია ელექტრომაგნიტური ინდუქციური კავშირის ჰიპოთეზა ზღვაში მდებარე მიწისძვრების ფოკალურ არესა და გეომაგნიტურ ანომალიას შორის. კერძოდ, გამოყენებული იყო ლითოსფერო-ატმოსფერო-იონოსფეროს ლოკალური სეგმენტის საკუთარი ელექტრომაგნიტური რხევების მოდელი, რომლის თანახმად რხევების სიხშირის განმსაზღვრელ გამოსახულებაში შემავალი ხაზოვანი ზომა თანხვდება გეომაგნიტური ანომალიის გრძივ მასშტაბს. ამრიგად, იკვეთება ამოცანა, დაკავშირებული წყალწმინდა-ურეკის გეომაგნიტური ანომალიის რეზონანსული თვისებების შემდგომ კვლევასთან.

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