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Electrokinetic effect provided by long oceanic waves coming on shore

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Abstract

Electrokinetic effect (EK) caused by long oceanic waves in porous water-saturated rocks of seabed and shore is examined theoretically. One possible reason for this effect is the motion of groundwater due to the volume deformation of porous rocks by oceanic waves coming on shore. The same mechanism is responsible for seismoelectric effect observed during seismic waves passage through ground-recording station. In this study, we examine another mechanism in which the wave-produced variable pressure on the seabed plays a role of a piston pushing seawater through the seabed rocks into sandy or porous rocks of the seashore thereby exciting the EK effect. To estimate this effect, we first consider a long gravity wave and then solve 2D-problem on the pressure variations produced by this wave on the bottom. This solution is used to describe groundwater filtration in porous rocks subjected to the variable pressure of seawater. The EK current and telluric electric field in a porous medium are derivable through the pressure gradient of porous fluid. The amplitude of telluric electric field in a porous medium has been shown to decrease almost exponentially with distance from a shoreline. A penetration depth of the telluric field as a function of wave frequency in the range of 10-100 mHz was analyzed. A role played by EK effect in the generation of ULF natural electromagnetic noise in coastal zone was discussed.

Keywords: Seismology; Ground motion; Waves and wave analysis; Groundwater processes; Fluid geochemistry

1. Introduction

One of the most important sources of global natural electromagnetic noises is the large-scale electric currents in the ionosphere and magnetosphere. During magnetically quiet period the amplitudes of ultra-low frequency (ULF) geomagnetic and geoelectric perturbations in the upper conductive layer of the Earth's crust are about 1-10 nT and 1-10 μV/m, respectively, [e.g., Surkov and Hayakawa, 2014]. In the vicinity of seashore there are additional local sources of the ULF electromagnetic noise. One of the reasons for such local noises is the wave motion of seawater which is a good electrical conductor. When seawater moves in the Earth's magnetic field it produces electric currents in the conductive seawater that, in turn, result in local low-frequency perturbations of the Earth's magnetic field.

These kind of geomagnetic perturbations were observed from wind-generated and long gravity waves, during ocean tides, etc. The amplitudes of these perturbations in the lower atmosphere can reach 10 nT depending on the wave amplitude, meteorological conditions, the contrast between the conductivities of seawater and coastal rocks, and other factors [Bullard and Parker, 1970; Sanford, 1971; Fischer, 1979; Quinney, 1979; Tyler et al., 1998; Kuvshinov, 2008; Liu et al., 2019; Marshalko et al., 2020].

Another possible reasons for the generation of ULF perturbations of the Earth's electromagnetic field is the movement of charged atmospheric aerosols [Soloviev and Surkov, 1994; Sorokin, 2007; Sorokin et al., 2020] or extended aero-electric structures (AESs) [Anisimov et al., 1994, 2002], entrained by moving air. With a decrease in frequency, the spectral density of energy of such perturbations increases according to the power law. The entrainment of charged aerosols with wind can greatly affect the amplitude-frequency characteristic of electric fields not only in the atmosphere, but also in the ground. Alexandrov [1985] have reported evidence from ground-based ULF observations at Yakimvar Bay, Karelian Isthmus, Russia that variations of telluric electromagnetic field increased up to 2-32 μV/m with increasing the wind velocity from 3 to 7-10 m/s. In the coastal zone, an additional electric effect can be caused by changes with distance in the ratio between the concentrations of marine and continental aerosols [e.g., Ivlev and Dovgalyuk, 1999].

One more source of electromagnetic noise, both in the ground and in the atmosphere, is the electrokinetic (EK) effect caused by the movement of groundwater in sandy and porous rocks of the sea coast. The reason of this effect is that the surfaces of pores, channels and cracks absorb the ions of certain sign (more frequently negative) from the groundwater solution that results in charge buildup at the interphase boundaries [Frenkel, 1944]. An excess of ions of the opposite sign can be carried away by the flow of groundwater, thereby producing the EK current. In the coastal zone, the groundwater flow can occur due to the volume deformation of rocks by waves coming ashore [Egorov and Pal'shin, 2015]. In this case, the EK effect arises both in the bottom layer and on the shore. This mechanism of generation of telluric currents is similar in nature to the seismoelectric effect observed in porous water-saturated soils during the passage of seismic waves through ground-recording station [Eleman, 1965; Mogi et al., 2000; Balasco et al., 2014; Surkov and Pilipenko, 2015; Romano et al., 2018; Surkov et al., 2018, 2020].

In contrast to the above studies based on the traditional "deformation" mechanism of the EK current generation, this paper deals with another mechanism of the EK effect, which can be called "piston mechanism". In this mechanism, the variable pressure on the seabed produced by long oceanic waves result in the pushing/seepage of seawater through the porous bottom into sandy or porous rocks of the seashore followed by the generation of EK effect.

2. Variations in pressure on the seabed caused by a long gravity wave

In this study we consider the seabed and coast rocks which are covered with a layer of sandstone or other porous water-saturated rocks. Oceanic waves coming on the shore generate a variable pressure on the seabed thereby producing the motion of the groundwater in the porous rocks of the seabed and coast [Packwood and Peregrine, 1980; Longuet-Higgins, 1983; Massel, 2001; Belibassakis, 2012]. The EK effect in the porous water-saturated medium occurs due to the movement of ions contained in the groundwater solution. Under natural conditions, the excitation of the EK effect is most effective at low frequencies, since at high frequencies the inertia of ions becomes significant despite the viscous forces in the fluid that results in a decrease of the EK current. Therefore, we will take into account the effect produced only by low-frequency oceanic waves, such as long gravity waves (LGW).

At first we will consider the pressure and velocity variations on the seabed caused by LGW. These variations play a role of an external influence on the porous medium that causes gradient of pore pressure. To estimate the variable

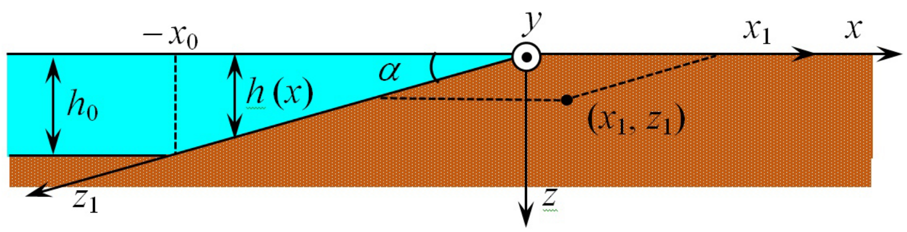

Figure 1. Model of medium.

pressure and velocity on the seabed surface, consider the model of medium in which the marine environment and porous water-saturated rock occupy a half-space $z > 0$ while the atmosphere occupies a half-space $z < 0$ (Figure 1). The plane interface between the marine environment and the coastal porous rock passes through the z_1-axis and the y-axis, which is perpendicular to the plane of Figure 1. The profile of the seabed $h = h(x)$ is described by a piecewise linear function of the following form:

$$h = \begin{cases} h_0 \dfrac{x}{x_0}, & (-x_0 < x < 0); \\ h_0, & (x < -x_0); \end{cases} \tag{1}$$

where $x_0 = h_0 ctg\alpha$ while the angle α is shown in Figure 1.

Suppose that a plane harmonic LGW propagates in the marine environment along the x-axis so that the wave phase velocity is perpendicular to the coastline. In this case, all functions depend only on the variables x, z, t and do not depend on y. Near the shore, where the wavelength of the LGW exceeds the depth h_0 of the reservoir, we use the linear approximation of “shallow water” [Monin et al., 1977; Pelinovsky, 2006]. In this approximation, the horizontal component of the fluid velocity is much greater than the vertical one and is independent of the z coordinate. Additionally, the wave-produced vertical displacement of the sea surface above the equilibrium level is much smaller than the sea depth, that is $\eta \ll |h|$. In such a case, a set of “shallow water” equations for the horizontal fluid velocity $U_x(x,t)$ and the vertical displacement $\eta(x,t)$ of the sea surface is given by

$$\begin{aligned} &\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x}(hU_x) = 0, \\ &\frac{\partial U_x}{\partial t} + g\frac{\partial \eta}{\partial x} = 0, \end{aligned} \tag{2}$$

where g is the free fall acceleration.

Let $\eta_{\text{inc}} = \eta_0 \exp(ik_0x - i\omega t)$ be the vertical displacements of the seawater surface in the LGW falling from infinity $(x < -x_0)$ to the seashore. Here η_0 and ω stand for the amplitude and wave frequency, respectively; $k_0 = \omega/V$ is the wave number, and $V = (gh_0)^{1/2}$ is the LGW velocity at $x < -x_0$.

In the region $-x_0 < x < 0$, the solution of the problem, which takes into account the wave reflected from the shore, can be written as [Monin et al., 1977; Pelinovsky, 2006]:

$$\eta(x,t) = \eta_m J_0\left(2\{-sx\}^{1/2}\right)\exp(-i\omega t). \tag{3}$$

Here we made use of the following abbreviations

$$\eta_m = \frac{2\eta_0 \exp(-ik_0x_0)}{\mathrm{J}_0(2k_0x_0) - i\mathrm{J}_1(2k_0x_0)}, \quad s = \frac{x_0\omega^2}{gh_0}, \tag{4}$$

where $\mathrm{J}_1(x)$ and $\mathrm{J}_0(x)$ denote Bessel functions of the first kind of the first and zero orders, respectively.

Substituting equation (3) for $\eta(x,t)$ into the second equation of set (2), we obtain the horizontal velocity of the seawater caused by LGW propagation:

$$U_x = u_x(x)\exp(-i\omega t), \quad u_x = -\frac{ig\eta_m s^{1/2}}{\omega(-x)^{1/2}} J_1\left(2\{-sx\}^{1/2}\right). \tag{5}$$

In what follows we use both the x and z coordinates and the oblique coordinates given by:

$$\begin{aligned} x_1 &= x + z\mathrm{ctg}\alpha, \\ z_1 &= z/\sin\alpha \end{aligned} \tag{6}$$

The wave-produced pressure variations on the bottom is derivable from the vertical displacement η through $\delta P_w(x,t) = \rho g \eta(x,t)$, where ρ is the seawater density. Applying this equation to the pressure variations on the inclined portion of the seabed ($x_1 = 0;\ 0 < z_1 < h_0/\sin\alpha$) we obtain

$$\delta P_w = p_w(z_1)\exp(-i\omega t), \quad p_w(z_1) = \rho g \eta_m J_0\left(2\{s z_1 \cos\alpha\}^{1/2}\right). \tag{7}$$

In a similar fashion one can use equation (5) in order to find the seawater velocity at the boundary with the porous medium.

3. Groundwater pressure in porous medium

Now let us consider the porous rocks of the seabed and coast. In the low frequency range, the change δP_p in the pore fluid pressure is determined by the equation [Frenkel, 1944]:

$$\frac{\partial \delta P_p}{\partial t} = D\nabla^2 \delta P_p - (K_s - K)\beta \frac{\partial \theta}{\partial t}, \tag{8}$$

where θ is the volume strain of the porous medium, and the parameter D plays a role of the diffusion coefficient of the pore fluid pressure. Here we made use of the following abbreviations:

$$D = \frac{n\beta k_p K_s}{\xi}, \quad \beta = \frac{K_s K_f}{(K_s - K)K_f + nK_s\left(K_s - K_f\right)}, \tag{9}$$

where ξ stands for the viscosity of the pore fluid; n and k_p are the medium porosity and permeability, respectively; K_f is the bulk modulus of compressibility of pore fluid, K_s is the bulk modulus of solid component, and K is the bulk modulus of dry porous rock (the medium skeleton without the pore fluid).

In order to exclude the contribution of the "deformation mechanism" to the EK effect from further consideration, we will neglect the volume strains, assuming that $\theta = 0$. In such a case, equation (8) describes the groundwater diffusion/filtration due to the variations in the seawater pressure applied to the surface of the porous medium. To solve this equation, it is convenient to use oblique coordinates (6). Let us seek for the solution of equation (8) in the form: $\delta P_p = p_p(x_1, z_1)\exp(-i\omega t)$. For simplicity, we will omit the exponential factor $\exp(-i\omega t)$ everywhere. Then equation (8) for the function $p_p(x_1,z_1)$ can be written as ($z_1 > 0$):

$$\frac{\partial^2 p_p}{\partial x_1^2} + 2\cos\alpha \frac{\partial^2 p_p}{\partial x_1 \partial z_1} + \frac{\partial^2 p_p}{\partial z_1^2} + \frac{i\omega}{D} p_p \sin^2\alpha = 0. \tag{10}$$

At the boundary of marine environment and porous media, the pore fluid pressure p_p has to be equal to the seawater pressure p_w while the normal component of the fluid flow density has to be continuous. In what follows we are interested in the distribution of the pore fluid pressure only near the coastline. Away from the coastline the boundary conditions of the problem have little effect on this distribution. Therefore, we assume that these boundary conditions are valid not only on an inclined section of the seabed, but also on its continuation, i.e. on the whole half-plane passing through the y and z_1 axes. From equation (7) it then follows that the boundary condition for the pore pressure becomes:

$$p_p(0, z_1) = \rho g \eta_m J_0\left(2\{s z_1 \cos\alpha\}^{1/2}\right). \tag{11}$$

Form the second boundary condition, i.e. the continuity of the fluid flow, it follows that the normal components of the seawater velocity, u_w, and the fluid velocity in the pores, u_p, are related via $(1-n)u_w = nu_p$. At this boundary $u_w = u_x(0, z_1)\sin\alpha$ since the vertical component of the seawater velocity was neglected. The fluid velocity in porous rocks is determined by Darcy law $\mathbf{u}_p = -k_p \nabla p_p/\xi$. By taking the projections of $\mathbf{u}_p$ and ∇p_p on the axis perpendicular to z_1-axis and using variables x_1 and z_1, the above boundary condition can be rearranged to give

$$-\frac{nk_p}{\xi\sin\alpha}\left(\frac{\partial p_p(0,z_1)}{\partial x_1} + \cos\alpha\frac{\partial p_p(0,z_1)}{\partial z_1}\right) = (1-n)u_x(0,z_1)\sin\alpha. \tag{12}$$

This equation does not take into account that the velocity $\mathbf{u}_p$ decreases near the seabed due to the seawater viscosity. This means that the seawater flow into a porous medium is slightly overestimated, and therefore the results of this study can serve as an upper estimate of the expected effect. However this approximation can be partly justified by a large spread of the measured values of n and k_p.

Substituting equation (11) for p_p and equation (5) for u_x into equation (12) and rearranging this equation, yields

$$\frac{\partial p_p(0,z_1)}{\partial x_1} = \rho g \eta_m(\zeta + \cos\alpha)J_1\left(2\{sz_1\cos\alpha\}^{1/2}\right)\left(\frac{s\cos\alpha}{z_1}\right)^{1/2}. \tag{13}$$

Here the parameter ζ is introduced, given by

$$\zeta = \frac{i\xi(1-n)\sin^2\alpha}{\omega\rho n k_p\cos\alpha}. \tag{14}$$

At the boundary of a porous medium with the atmosphere, the fluid pressure in the pores is approximately zero, since atmospheric pressure can be neglected. From here we obtain another boundary condition

$$p_p(x_1, 0) = 0, \quad (x_1 > 0). \tag{15}$$

The solution of equation (10) under requirements (11) and (13) at the boundary between the porous medium and marine environment and requirement (15) at the boundary with the atmosphere is found in Appendix.

4. Electrokinetic effect on the seashore

The volume-averaged density of the EK current in a porous water-saturated medium can be expressed from the fluid pressure gradient ∇p_p through $\mathbf{j}_{\mathrm{EK}} = -\sigma C_{\mathrm{EK}}\nabla p_p$, where σ stands for the average conductivity of a porous rocks, while C_{EK} is the streaming potential coupling coefficient which depends on the porosity and permeability of rocks, the temperature and mineral composition of the groundwater and other parameters of the porous medium [e.g., Surkov and Hayakawa, 2014]. The density of a conduction current is derivable from an electric potential φ through $\mathbf{j}_c = -\sigma\nabla\varphi$. Thus, the density of total current in porous medium is given by: $\mathbf{j} = -\sigma\left(\nabla\varphi + C_{\mathrm{EK}}\nabla p_p\right)$. In the coastal zone, the parameters σ and C_{EK} can depend not only on the porosity and permeability of rocks. A decrease in the groundwater salinity with distance from coastline can also affect these parameters. In order to derive analytical estimates of the EK effect and make our consideration as transparent as possible, we assume that these parameters are constant everywhere.

The stationary current distribution is described by the following continuity equation: $\nabla\cdot\mathbf{j} = 0$. If the medium is homogeneous then this equation is reduced to:

$$\nabla^2\left(\varphi + C_{EK}p_p\right) = 0. \tag{16}$$

At the boundary of porous medium and the atmosphere the normal component of the total current has to be zero; that is, $J_z = 0$ at $z = 0$. If a homogeneous porous medium occupies a half-space $z > 0$ bounded from above by the atmosphere, then equation (16) with this boundary condition possess a simple solution [Surkov and Hayakawa, 2014]:

$$\varphi = -C_{EK} p_p. \tag{17}$$

The meaning of this solution is that the conduction current and the EK currents cancel each other everywhere so that the total current in the porous medium is zero. It should be noted that this solution does not hold true near the seabed since a portion of the conduction current can flow through the boundary between the porous medium and marine environment. However, this approximate solution is valid in the porous medium away from this boundary, i.e. under the requirement that $z \ll x$.

The pressure p_p of the pore fluid can be found by applying the Laplace transform over the x_1 coordinate to equation (10) and boundary conditions (11), (13) and (15). The solution to this problem is found in the Appendix. In the case of shallow depths z, when $z \ll x$, the function $p_p(x,z)$ is determined by equations (A14), (A16) and (A18). Substituting these equations, as well as equations (4) and (14) for s and ζ into equation (17) and rearranging, we arrive at the final equation for the electric potential in porous medium

$$\varphi(x,z) \approx \frac{2\rho g z \eta_m C_{\mathrm{EK}}}{\pi} \left(\frac{x_0 \omega^2 \cos\alpha}{x g h_0}\right)^{1/2} \left\{\frac{i\xi(1-n)\tan\alpha}{\omega n k_p \rho} \mathrm{Im} M - \mathrm{Re} M\right\}, \tag{18}$$

where

$$M = \exp\left(\frac{i\alpha}{2}\right) K_1 \left(2\exp\left\{\frac{i\alpha}{2}\right\}\left\{\frac{x x_0 \omega^2 \cos\alpha}{g h_0}\right\}^{1/2}\right), \tag{19}$$

and K_1 denotes the modified first-order Bessel function.

The actual porous medium parameters may vary in a wide range. For example, typical values of the porosity n for granite and gneiss are (0.2-6)$\cdot 10^{-3}$, for sandstone 0.04-0.3, and for tuff 0.2-0.3 [Mavko et al., 2014]. The EK coefficient

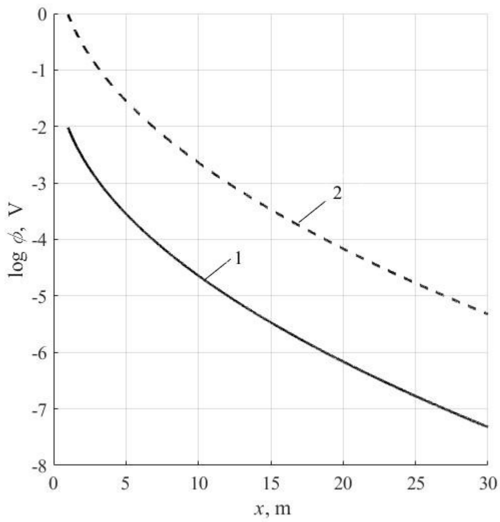

Figure 2. Decimal logarithm of the telluric electric potential in the porous rock of the seashore at a depth of 1 m as a function of distance to the coastline. The solid and dashed lines correspond to the rock permeability of 10^{-9} and 10^{-11} m^2, respectively.

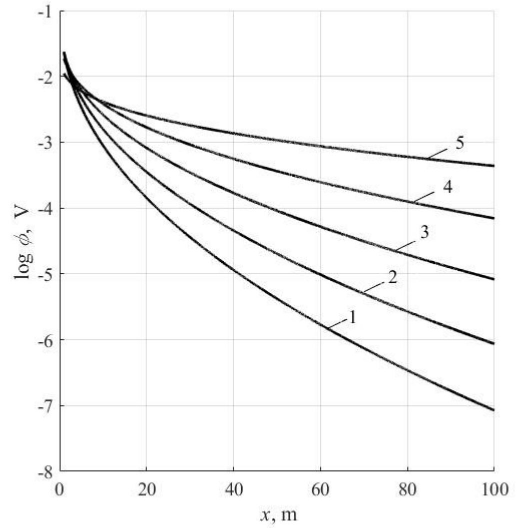

Figure 3. The same as in Figure 2 but for different LGW frequencies. The lines 1-5 correspond to the frequencies: $f = 0.1$, 0.08, 0.06, 0.04 и 0.02 Hz, respectively.

C_{EK} is typically in the range 10^{-8}-10^{-6} V/Pa depending on the porosity, permeability, concentration and mineral composition of groundwater, etc. [Jouniaux et al., 2000]. In standard geophysical practice, a set of grounded electrodes is used to measure the potential difference and the horizontal electric field in the ground. The model calculations of the telluric electric potential $\varphi(x,z)$ at the depth $z = 1$ m is displaced in Figure 2 as a function of distance x to the shore. In making the plot of φ we have used the following parameters: $n = 0.1$, $K_f = 2$ GPa, $K = 10$ GPa, $K_s = 20$ GPa, $\xi = 10^{-3}$ Pa·s, $\rho = 10^3$ kg/m^3, $C_{\text{EK}} = 10^{-6}$ V/Pa [e.g., Surkov and Hayakawa, 2014], $f = \omega/(2\pi) = 0.2$ Hz, $h_0 = 100$ m, $x_0 = 1$ km, $\eta_0 = 1$ cm. The solid and dashed lines in Figure 2 correspond to the permeability of porous media: $k_p = 10^{-9}$ m^2 (coarse sand) and 10^{-11} m^2 (fine sand), respectively [Packwood and Peregrine, 1980]. It is obvious from Figure 2 that the electric potential decreases almost exponentially with distance x away from the coastline. Therefore, the above mechanism of the EK effect, which has been termed "piston mechanism", may greatly affect the telluric electric field only near the coastline at distances of no more than several tens of meters.

Figure 3 shows the dependences of the electric potential in a porous medium on distance x for different frequencies of the LGW. The lines 1-5 correspond to the wave frequencies $f = 0.1$, 0.08, 0.06, 0.04 and 0.02 Hz, respectively. In

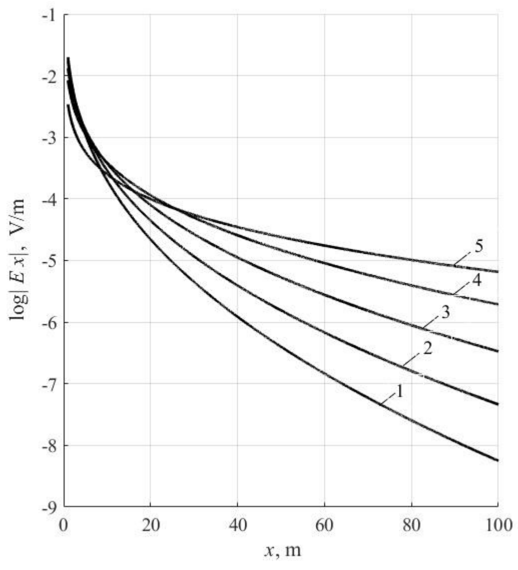

Figure 4. The same as in Figure 3 but for the horizontal projection E_x of the electric field.

making this plots we have used the above numerical values of the parameters and $k_p = 10^{-9}$ m^2. As is seen from this figure, the rate of potential decrease with distance x depends heavily on the frequency of the incident LGW. With the decreasing frequency of the wave, the telluric electric field becomes larger. This trend is mainly due to the fact that the argument of the modified Bessel function in equation (19) increases linearly with the wave frequency.

The horizontal electric field can be found by substituting equation (18) for the potential in the relationship $E_x = -\partial\varphi/\partial x$. Figure 4 displays the dependence of E_x on the distance x to the shore at the depth $z = 1$ m. Here we have used the same numerical values of the parameters as in Figure 3. It obvious from this figure that the telluric electric field in a porous medium decreases almost exponentially to the value comparable to or smaller than the level of natural electric noise (~1 μV/m) at distances from 40 to 150 m, depending on the value of the LGW frequency.

5. Discussion and Conclusion

From the above analysis, one may conclude that the EK effect on the coast caused by incident LGWs is provided by at least two different reasons. The first reason is due to the rock deformation by seismic waves that results from variations of pressure on the seabed caused by the LGWs propagation. The volume deformation of the porous rock must, in turn, be accompanied by the generation of the EK effect.

In this study we have examined another reason for the EK effect, which is not associated with the volume deformations of a porous medium. In such a case, the variable pressure on the seabed plays a role of a piston pushing seawater through the seabed rocks, which are connected by pores and cracks with the porous space of coastal rocks. These two physical mechanism of the phenomenon lead to the same result, i.e. filtration of the pore fluid, which is accompanied by the generation of the EK currents in porous rocks.

The theoretical analysis of our "piston model" has demonstrated that the EK effect produced by long oceanic waves can make a significant contribution to low-frequency electromagnetic noise on the seashore. The amplitude of the electrical perturbations due to the EK effect strongly depends on many factors including the permeability of seabed and coastal rocks, as well as the frequency of the incident LGW. Away from the shore, the telluric electric field in a porous medium decreases almost exponentially with distance. The characteristic penetration depth x_c, at which the electric field amplitude decreases by a factor of e, is $x_c \sim (4s)^{-1} \approx gh_0/(16\pi^2 x_0 f^2)$, whence it follows that the penetration depth deep into the coast increases with a decrease in the frequency f of the LGW. For example, in the wave frequency range of 0.02-0.2 Hz, the amplitude of the horizontal electric field at a depth of 1 m can decrease to a value comparable to or even lower than the level of background electric noise at distances from tens to hundreds of meters, depending on the wave frequency.

Measurements of electromagnetic fields caused by the long gravity waves are of particular interest for the purposes of detecting and monitoring tsunami waves. To accomplish this, magnetometers are usually installed on the shore or at the seafloor geomagnetic observatory. For example, Manoj et al. [2011] have reported the ground-based observations of the geomagnetic perturbations of 1 nT amplitude caused by the arrival of a tsunami wave after a strong Chilean earthquake on February 27, 2010. The magnetic perturbations $\delta\mathbf{B}$ caused by the telluric currents can be found from Maxwell equation: $\nabla \times \delta\mathbf{B} = \mu_0\sigma\mathbf{E}$ where μ_0 stands for the magnetic constant/magnetic permeability of free space. Whence we obtain the rough estimate $\delta B \approx \mu_0\sigma El$, where l denotes the characteristic scale of the perturbation region. The amplitude of the tsunami wave in the open ocean is approximately two orders of magnitude greater than the value $\eta_m = 1$ cm alluded to above. One may assume that the amplitude of the electric field caused by the tsunami wave will also be two orders of magnitude greater than that shown in Figure 4. Substituting $E = 10^{-2}$ V/m, $l = 10$ m and $\sigma = 10^{-2}$-10^{-1} S/m into the above ratio, gives the estimate $\delta B \approx 1\text{–}10$ nT, which is close to the observed values [Manoj et al., 2011].

This estimate is applicable until the tsunami wave arrival on the shore. The study of the later phase of seawater spreading deep into the seashore seems to be a much more complicated problem, since in such a case the nonlinear effects should be taken into account. In addition, there can be significant perturbations of the geomagnetic field resulted from the flow of conducting seawater.

The results of this study points clearly to the existence of the low-frequency electric noise caused by EK effect in the seabed and coastal rocks. In practice, the amplitude of this effect may vary greatly, since the actual values of various parameters of porous rock, such as porosity, permeability, streaming potential coupling coefficient, elastic constants that determine the ability of porous rocks to deform under stress, etc. may vary over a wide range.

Further experiments are necessary to sort out this interesting problem in the geophysics of the coastal zone and to distinguish between different mechanisms of natural electromagnetic noise.

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