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Interpretation of Measurement Results of the Potential Difference in Lake Baikal

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Abstract—A model is proposed in which the electrical voltage measured between the electrodes in Lake Baikal is a consequence of two effects: electrochemical processes near the electrodes and a positive charge current flowing through the lake. The electrochemical component of the voltage in the case of lead electrodes arises due to the difference in concentrations of carbonate anion—CO_3^{2-} at different depths. In the case of the use of chlorine-silver electrodes, only the effect of the positive charge current flowing through the lake is measured. We proposed an interpretation of an increase of electrical voltage registered in Lake Baikal during an earthquake in August 2008. The reason for the increase in voltage is the release of positively charged hydrogen-containing gases from the Earth's interior.

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1. INTRODUCTION

In our previous article (Bezrukov et al., 2018) we proposed a hydridic Earth electricity (HEE) model, in which the current of the Earth capacitor discharge passes through the Earth's crust and reaches the negative electrode of the Earth capacitor located under the Earth's crust. The current of the Earth capacitor charge is the jets of hot positively charged hydrogen-containing gases escaping from great depths mainly in the areas of rifts. Lake Baikal is also such a region (below we will simply use the word "Lake").

The composition of gases includes the positive ions of these gases and a hydrogen ion—a proton. The waters of Lake partially cool and dissolve these gases passing through the waters of Lake. Thus, the additional protons appear in the waters of Lake. These protons are the main carriers of the current in the water and join to the current of the Earth capacitor discharge. Therefore, in Lake we can observe in some places a current moving up, and in other places a current moving down. Moreover, we can expect that the magnitudes of these currents are much higher in Lake than the mean currents flowing in the atmosphere, and these currents can significantly fluctuate.

Experimental studies of the vertical component of the electrical voltage in Lake were done in (Korotaev et al., 2011) and (Korotaev et al., 2015). In the former lead electrodes and in the latter marine metrological Ag–AgCl electrodes were used in the measurements.

The goal of this article is to interpret experimental data from (Korotaev et al., 2011, 2015) in the frame of HEE model. In (Bezrukov et al., 2018) a relationship between HEE model and earthquakes was also examined. For that the authors used the model ideas about the processes taking place during earthquakes. The HEE model introduces the concept of excess of positive charge in the Earth's crust in the form of protons, which can lead to the formation of positively charged hydrogen-containing gases at the depths of the order of 10 km and consequently to the appearance of numerous pores and cracks at these depths. The phenomenon was observed in ultra-deep wells. The rapid release of these charged gases to the surface of the Earth can accompany an earthquake and even cause it, since the pressure of gases in the pores will fall. One can also imagine that the process of discharge of the Earth capacitor sometimes leads to electrical breakdown at great depths. This underground breakdown can also accompany an earthquake and even initiate it. Therefore, an additional goal of this article is to explain the reaction of the vertical component of electrical voltage in Lake to an earthquake in August 2008 reported in (Korotaev et al., 2011).

2. NATURE OF ELECTRICAL VOLTAGE DIFFERENCE BETWEEN LEAD ELECTRODES IN BAIKAL LAKE

The vertical component of the intensity of the natural electric field was studied in (Korotaev et al., 2011). The authors used the underwater installation with lead electrodes located on a vertical string with a submerged buoy. The distance between the electrodes was d = 1250 m. The installation measured voltage between the electrodes.

It is known (Vereshchagin, 1949) that there are anions Cl^-: 0.7; SO_4^{2-}: 5.0; CO_3^{2-}: 0.6–0.06; HCO_3^-: 63.6; PO_4^{3-}: 0.02–0.06 (the first figure is the concentration in mg/L on the surface, the second—at the bottom) in the water of the Lake. Only the anions Cl^-, SO_4^{2-} and CO_3^{2-} are potentially important since they form on surface of lead sparingly soluble chloride, lead sulfate and carbonate. $PbCl_2$, $PbSO_4$ (Mikhailov et al., 2008) and $PbCO_3$ (El-Egamy, 1996) have properties of electrodes of the second kind and are able to exchange Cl^- anions, SO_4^{2-} and CO_3^{2-}. However, the concentrations of Cl^- and SO_4^{2-} over the entire depth of Lake are the same. Therefore, we can neglect the electrochemical processes involving $PbCl_2$ and $PbSO_4$. The greatest interest is the concentration of CO_3^{2-} because with depth it changes. Therefore, we can assume that in the experiment (Korotaev et al., 2011) there was a case of a concentration galvanic element with carbonate-lead electrodes of the second kind exchanging carbonate anions CO_3^{2-}

$$PbCO_3 + 2e \leftrightarrow Pb + CO_3^{2-}. \qquad (1)$$

The waters of Lake serves as an ion bridge connecting the half-cells in this case: the cathode K (–) and the anode A (+), where K (–): $Pb/PbCO_3$//A (+): $Pb/PbCO_3$.

The work (El-Egamy, 1996) studied the reaction (1) and the electrode potential was given for standard conditions E_0 = –0.5 V. We can calculate the electrode potential for conditions of Lake using the Nernst equation. If we did not take into account the positive current flowing in Lake then the electromotive force ε of a concentration galvanic cell with carbonate-lead electrodes of the second kind will be equal to the difference of electrode potentials calculated from the Nernst equation:

$$\varepsilon = U_b - U_t = \frac{RT}{nF}\ln\left(\frac{[CO_3^{2-}]_t}{[CO_3^{2-}]_b}\right) = 0.028 \text{ V}, \qquad (2)$$

$[CO_3^{2-}]_t$ is the ion concentration near the upper electrode, equal to 0.6 mg/L; $[CO_3^{2-}]_b$ is the ion concentration near the bottom electrode; R is the universal gas constant of 8.31 J/(mol K); F is the Faraday constant 96485.35 K/mol; T is the absolute temperature in K; n is the number of electrons participating in the reaction (in our case for lead n = 2).

The current J flows in our electrochemical cell upward through a voltmeter and down through the Lake. We write the generalized Ohm's law for this closed circuit:

$$JR = \varepsilon - JR_1, \qquad (3)$$

R is the input resistance of the voltmeter; R_1 is the resistance of Lake to the current between the electrodes.

The resistance between two spherical electrodes with radius r placed in an infinite medium with a specific resistance ρ is known to be equal to:

$$R_1 = \rho/2\pi r.$$

According to (Rusinek et al., 2012) Lake water has ρ = 150 Ohm m. We can see that R_1 is much less than the input resistance of the voltmeter. Therefore, we will not take into account the term JR_1 in (3) further.

Equation (2) is valid for the case of the same temperature of both electrodes. However, at the depth of the upper electrode, the temperature of water changes during the year from 2.5 to 5.5°C, and at the depth of the lower electrode, the temperature is about 3.3°C. We can see from Eq. (2) that the electromotive force of the concentration element is proportional to temperature and a change in temperature of 3°C in the region of 0°C leads to a change in the electromotive force of only about 1%. Accounting for pressure changes with depth will also not lead to a shift in our estimate of the electromotive force (2), since water is an incompressible substance, and the number of water molecules around the electrode will not change with great accuracy with increasing pressure. An interesting fact is that the electromotive force is independent of the shape and size of electrodes for electrodes with a linear size greater than 1 cm (formulas (2), (3) and $R_1 = \rho/2\pi r$). If the electrodes were made of the material of a single crucible, the own difference of the electrode potentials during long-term operation should not exceed 0.5 mV (Shuleikin, 1968), which is much less than the value (2), therefore in this article we will limit ourselves to the estimate (2).

We now turn to the analysis of the real situation. As mentioned above the currents of charge and discharge of the Earth capacitor flow through Lake, let us denote their vertical resulting current density at the location of the string as $j_{ext}(t)$ and enter into Eq. (3):

$$J_{Pd}R = \varepsilon - j_{ext}\rho d. \qquad (4)$$

A positive value of j_{ext} corresponds to the direction of the current from top to bottom.

The current j_{ext} in the HEE model can change the direction if a large number of hot positively charged gases release from the depths at the location of the

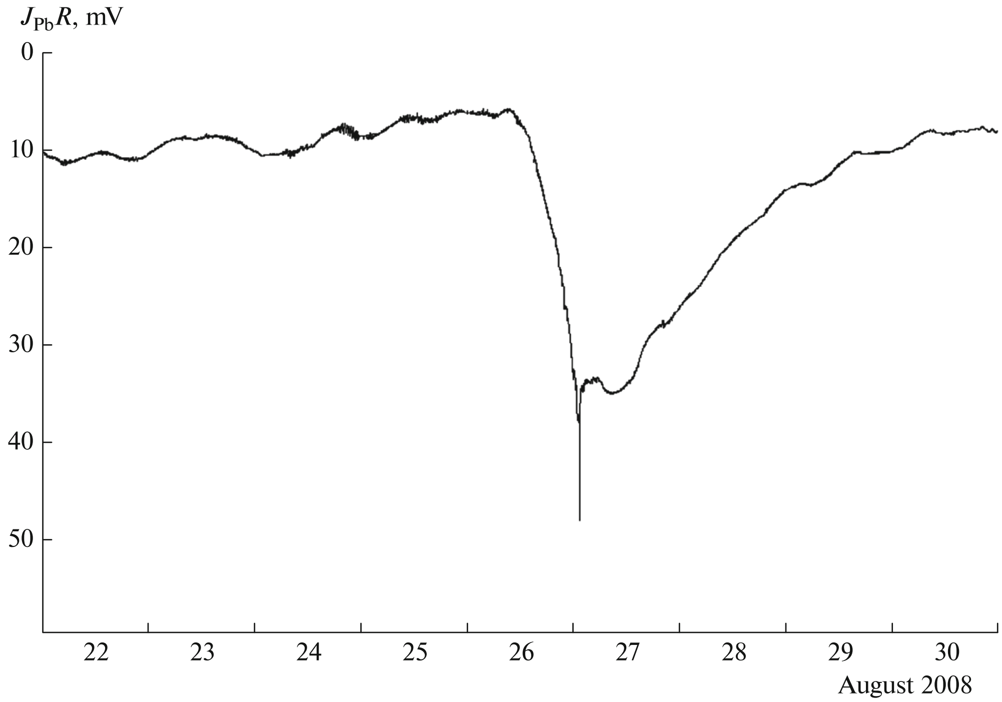

Fig. 1. The time dependence of the electric voltage between the vertically located lead electrodes with a distance between them of 1250 m in Lake Baikal. We recalculated the values on the vertical axis from the data of (Korotaev, 2011). Voltage was recorded every min. The short peak corresponds to the moment of the earthquake.

installation. The term $j_{ext}\rho d$ will change the sign in this case.

The experimentally observed in (Korotaev et al., 2011) value of $J_{Pb}R$ (see Fig. 1) before and after an earthquake is ~10 mV. From (4) and (2) it follows that in order to explain this value, the contribution from the external current which flows vertically downwards in August in Southern Baikal, 3 kilometers from the coast in unperturbed conditions, must be equal to:

$$j_{ext}\rho d = 18 \text{ mV}. \quad (5)$$

Thus, our model of two voltage sources: an electrochemical source and the movement of an excess positive charge in the waters of the Lake, predicted in HEE, allows us from (5) to estimate the value of the vertical resulting current density at the location of the string. It turned out to be $j_{ext} = 10^{-8}$ A m^{-2} at the time of measurement. This value is much higher than the average current density flowing in the atmosphere.

Note that our consideration predicts the variability of the measured electrical voltage in Lake in the case of usage of lead electrodes due to changes in concentration of carbonate ion in the surface layers of Lake due to respiration of microorganisms and due to photochemical reactions in algae. You can also expect that the measured voltage will depend also on the change in the concentration of free protons in the immediate vicinity of the surface of the electrodes.

3. NATURE OF ELECTRICAL VOLTAGE MEASURED BETWEEN CHLORINE-ELECTRODES IN LAKE BAIKAL

In (Korotaev et al., 2015), metrological Ag–AgCl electrodes were used. As noted above the concentrations of Cl^- ions in the near-surface and near-bottom layers of the Lake are the same (Vereshchagin, 1949). Therefore, a concentration galvanic cell does not arise in the case of Ag–AgCl electrodes. Equation (4) for Ag–AgCl electrodes takes the form:

$$J_{Ag}R \approx -j_{ext}\rho d. \quad (6)$$

The minus sign means that the direction of the current J_{Ag} coincides with the direction of the current j_{ext} and has the opposite direction compared to the case of lead electrodes if there is no significant output from the depths of hot positively charged gases in the installation area. The competition between the current of thermal protons going down in the region of the installation and the unstable current of hot gases rising up away from the installation can explain the j_{ext} instability observed in (Korotaev et al., 2015). The output of hot positively charged gases must exist continuously because Lake Baikal is an active seismic region. According to (Korotaev et al., 2015) during 2013 the J_{Ag} R value varied from 26 to 8 mV. The experimental value of J_{Ag} R was equal to 13 mV in August. From our analysis of the experiment with lead electrodes we obtained the estimate (5) for August 2008 $j_{ext}\rho d = 18$ mV.

One can see that these values for $j_{ext}\rho d$ obtained from the data for lead electrodes and from the data for chlorine-silver electrodes within our model are close in magnitude. Note that the HEE model predicts that the measured current should have the direction in the case of lead electrodes upwards most of the time (3) due to the presence of the electrochemical component.

4. ELECTRIC VOLTAGE REACTION TO EARTHQUAKE IN AUGUST 2008

The work (Korotaev et al., 2011) observed an increase in voltage during an earthquake in August 2008, the epicenter of which was located at a distance of 16.5 km from the string and at a depth of 17 km (see Fig. 1).

Moreover, the voltage increase began half a day before the earthquake from the level $J_{Pb}R \sim 10$ mV, and just before the earthquake it reached a value of ~37 mV. Then the installation registered a short pulse of ~10 mV at the earthquake moment. The voltage smoothly returned to the level of ~10 mV three days after the moment of the earthquake.

What does the installation actually register and why is it sensitive to an earthquake? What is the nature of the recorded short pulse during an earthquake moment?

Suppose that, in accordance with our model of the earthquake (Bezrukov et al., 2018), positively charged hot hydrogen-containing gases, which had arisen and accumulated at a depth of 17 km, formed a channel for reaching the surface in the area of the string with lead electrodes. In this case, j_{ext} in Eq. (4) can start to change quite quickly with time:

$$J_{Pb}(t)R = \varepsilon - j_{ext}(t)\rho d. \qquad (7)$$

Experimental data, according to our model, show that the release of hot gas began half a day before the moment of the earthquake. The gas flow increased until the moment of the earthquake, and this led to a decrease in the magnitude of $j_{ext}(t)$ and an increase in $J_{Pb}(t)R$. By the time of the earthquake, $j_{ext}(t)$ changed direction, i.e. the current in the Lake began to flow upwards. Thus, at the time of the earthquake:

$$J_{Pd}R > \varepsilon.$$

According to (2) $\varepsilon = 0.028$ V. This value is less than the experimentally observed voltage maximum just before the moment of the earthquake. After the moment of the earthquake, the gas flow began to decrease and it decreased to zero through the three days. The value of $J_{Pb}R = \varepsilon - j_{ext}\rho d$ returned to its value before the earthquake.

The rapid change in the recorded voltage at the time of the earthquake is due to pick-up of electromagnetic waves from the underground electrical breakdown by the electrical circuit of our electrochemical cell. Experimental data from (Korotaev et al., 2011) containing a rapid change in electrical voltage at the time of an earthquake are consistent with the idea of an underground electrical breakdown considered in the HEE model (Bezrukov et al., 2018).

5. CONCLUSIONS AND CONCLUDING REMARKS

A model is proposed in which the voltage measured between the electrodes in Lake Baikal (Korotaev et al., 2011, 2015) is the result of two effects: electrochemical processes near the electrodes and a positive charge current flowing through the Lake and predicted by the HEE model.

Note that in this paper we do not consider other frequently discussed effects that could lead to the appearance of measurable currents between the electrodes in the aquatic environment. One of these effects is the movement of charged ions carried by flows in the Earth's magnetic field. In our HEE model an additional argument arises in favor of this effect since the model implies the presence of additional positive charges—protons, the diffusion coefficient of which is large in water. However, for the considered installation with electrodes located in the near-surface and near-bottom layers of Lake Baikal, this effect is insignificant for the following reasons. First, the magnitude of the flows in Lake Baikal is not large, the characteristic horizontal subsurface and bottom flows are 2 cm/s. Secondly, the angle between the direction of flows at the location of the installation and the direction of the Earth's magnetic field is not great. The experimental results from the work (Korotaev et al., 2015) in which a search was made for the correlation between changes in the Earth's magnetic field and the magnitude of the electrical voltage between the electrodes in Lake Baikal support this reasoning. There is no such observed correlation.

Our consideration predicts the variability of electrical voltage in Lake. For the case of lead electrodes these variability must be caused due to both the changes in the carbonate ion concentration in the surface layers of Lake (due to the metabolic products of microorganisms and due to photochemical reactions in algae), and the variability of the value and direction of the positive charge current flowing in Lake.

We have proposed an explanation of the reaction of the vertical component of the electrical voltage in Lake Baikal to an earthquake in August 2008 observed in (Korotaev et al., 2011). The main idea is that before the moment of the earthquake and after there was a release of positively charged hydrogen-containing gases from the earth's depths in the region of the earthquake, and it affected the area of the installation. The rapid change in the recorded voltage at the time of the earthquake we associate with the electromagnetic pickup of the underground breakdown by the electrical circuit of the installation.

In the framework of the HEE model, we succeeded in self consistently explaining the experimental results for lead and chlorine-silver electrodes. The success of the HEE model in explaining the observed electrical phenomena in Lake Baikal could be a good argument for its validity.

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