Thermoelectrical Element of Earth’s Crust

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Abstract: A model of the natural thermoelectric element was developed. The basis of the element is long-lived deep faults with graphite ores inside, which provide continuous electrical connection between the upper part of Earth’s crust and the mantle. Temperature difference between them can reach 1000 °C and more because of the geothermogradient. That is why thermopower and thermoelectrical currents, which move directly upwards to arise (from the hot end to the cold one), appear in the geothermogradient because of the Seebeck effect. That is the reason why natural electric potentials of high intensity up to -2...-10 V are registered over graphite ores because of the presence of thermopower. Electrical characteristics of the geothermoelectric element of the Earth’s crust (thermoelectrical current, its density, total natural potential) were quantified. There is found a mathematical solution which allows to calculate the temperature of the geothermoelectrical element’s lower part, which is directly related to the overheated area of the deep tectonic process. There is also suggested a method of watching the dynamics of the total electric potential which is registered in the upper part of the geothermoelectrical element. Eventually, systematical observations over those total potentials can help to study tense zones of Earth and control the dynamics of thermal deep processes, which are often related to volcanic activity and seismic events. As a result, the resources of the geophysical method of the natural electric field can broaden greatly. It can help science to study directly both the dynamics of deep thermal processes of the Earth’s crust and its areas related to sources of tensions of exogenous and endogenous nature.

1. Introduction
For at least 100 years, scientists from different continents have been studying the nature of the natural electric field registered over metal electrical conductors [1-6]. At the present moment there are some specific achievements in understanding it. However, a model of that field nature for carbon-graphite rocks (here and below: CGR) has not been elaborated yet, though the latter are also natural electrical conductors [3]. The latter are widely spread over the planet, which is well known [7,8], and a lot of deposits of different metals of hydrothermal type predominantly are dimensionally connected to them [9-13]. There was performed a physical modelling with laboratory electrochemical cells imitating the natural electrochemical cells with electrodes from graphite ores, which not only confirmed that sulfide minerals can be formed electrochemically in natural conditions, but also allowed to understand the reasons why ores can be collomorphic, banded and zoned [14,15].

The main obstacle in making an electrochemical model is that laboratory-measured quantities of electrode potential of graphite samples cannot be compared with the intensity of the natural electric potential’s anomalies which are seen above CGR in natural conditions. For example, according to the experimental data, graphite and its analogues are related to chemically inert materials and can be...
characterized by electrode potential which is not more than 0.04 V predominantly at solutes concentration below 0.1%, however the potential can be close to the platinum potential +0.7 V at high solutes concentrations of 5%, 1% and 0.1% and when pH=1.3 – 2. [3]. Over the courses of the experiments with graphite samples, which were put inside different ores at their gradual freezing to −6 °C (0.1% NaCl solution), there were observed changes in potential quantities of the samples in the narrow range of −0.02...+0.04 V, that is nearly 50 times less than the ones observed in the conditions of perennially frozen ores of Polar Ural [15].

At the same time, in almost all the continents of Earth intensive anomalies of the natural electric potential ranged from -1...-3 V to -10 V: -2.85 V in Baikalia [16], -3 V in Africa [17], -5 V (Japan) [18], -10 V (Khabarovsk Krai) [19], -6...-10.2 V (Peru, Andean Volcanic Belt) [20]. Those values cannot be explained with just electrochemical processes, which can reach only theoretically maximum value equal to 1.23 V at electrolysis of water. That is confirmed by the contrasty and powerful RedOx processes of the oxidation zones currently proceeding within the borders of the Uzon caldera, Kamchatka, potentials of which reach only -200 mV [21].

At the present time, the problem of the natural electric field above sulfide ore bodies is almost solved. The nature of the fields, which were overseen above them (except CGR), is found out to be a geothermoelectrochemical one [15, 22]. At the same time there is a lot of information about extreme values of natural potentials over carbon-graphite thicknesses and graphitized ores, which gravitate to deep fault zones and have a continuous electroconductivity. This information gives the idea of looking for the origins of those fields not from the electrochemical point of view but from a more universal natural physical process. This problem is getting more important now, because there was confirmed the connection between the dynamics of those potentials with the deep thermal processes, which become more intensive where Earth’s crust and the mantle interact [23].

That is why the most possible geothermoelectrical nature model for CGR without any contradictions is developed in the article below, based on the analysis and generalization of the new data about the natural electric fields observed above CGR, including observations in volcano areas and additional laboratory experiments. The model is based on the presence of the thermolectric element of Earth’s crust (deep fault filled with graphite ores). The geotemperature difference is put to its upper and lower ends. That difference is the reason why the thermolectric element has thermopower and thermoelectric currents, because of the Seebeck effect.

2. Model of geothermoelectric Earth’s core element

There are a lot of studies on this problem nowadays, which showed that graphite and graphite rocks are widespread not only in Earth’s crust but in the mantel too, where the largest zones of high conductivity are registered making it difficult to further study the mantel on the depth with electromagnetic methods [7,24, 25,26]. Besides, over the last few decades’ geologists and geophysics have been actively studying deep faults not only as tectonic structures playing the main role in forming metal ore deposits, but also as main components of the planet, within which seismic processes happen, and the origins of those processes are on great depths. A lot of researchers, who study electroconductivity, discovered that deep and crust-mantle faults of the continental crust are traced by the linear intermittent lateral vertical zones of high electroconductivity, which is caused by electron conductive graphite formations widely expanded in the fault borders. Figure 1 shows a generalized section of such an inner fault geothermoelectrical element (GTEE) traced on the bottom surface by linear abnormal electric fields.

The reason why GTEE exists on a big stretch of geologic time is defined by periodically becoming more intensive deep thermal processes. Tectonic forces of different intensities and directions move inner blocks of the fault ores over many slip planes, along which a constant electrical connection appears. Usually, the latter can be explained by electron-conducting minerals appearing along slip planes: graphite, shungite, carbon, graphene. Those are transformed out of carbon ores depending on critical P, T.
Figure 1. Generalized geothermoelectric element (image) of a deep crust-mantle fault of the continental crust. (1 – graphite deposits; 2 – carbon-graphite ores inside GTEE; 3 – water solutions; 4 - The Mohorovičić discontinuity; 5 – zone of the active evolution of a deep thermal process; 6 – blocks of ores, sliding surfaces, tectonic discontinuous breaches; 7 – graph of the natural electric potential $U_\Sigma$, observed above GTEE; 8 - conventional sign of GTEE; 9 – charge signs of GTEE poles.)

On the other hand, GTEE is an electronical conductor. If the difference of temperatures $\Delta T$ is put to its ends, there must appear difference of potentials $\Delta \varphi$ between them, according to the Seebeck effect. The potential difference connects to the diffusive flow of excited (heated) electrons from the hot end to the cold one and can be calculated with the formula [27]:

$$\Delta \varphi = \Delta U^T = \int_{T_1}^{T_2} \beta dT,$$

where $\beta$ is coefficient of thermopower, 0.0001 B·grad$^{-1}$ for pure metals and 0.0015 B·grad$^{-1}$ for some semiconductors [27].

When $\Delta U^T$ is known, electric field tension $E_T$, which is applied to GTEE, can be defined from the equation:

$$E_T = \Delta U^T / H, \ V \cdot m^{-1}$$

where $H$ is vertical length of GTEE, m.

Field tension $E_T$ is about 3.4·10$^{-3}$ V·m$^{-1}$ if $H$ equals the thickness of Earth’s crust, for example, 30,000 m, and if potential difference $\Delta U^T$ equals 10.2 V, which corresponds to the maximum value, registered on the planet at the moment [20]. Affected by the tension, electrons within the GTEE get a directed motion from its warmed lower part to its cold upper part.

With the quantum theory of the electrical conductivity of electronical conductors and semiconductors let us use the following formulas [28-31] to calculate:

a) mean free path of the electrons displaced towards the $E_T$ field’s effect:

$$l = \frac{\sigma h (3\pi^2)^{1/3}}{e^2 n^{2/3}}, \ m$$
where \( \sigma \) is electroconductivity of graphite ores, graphite, S·m\(^{-1} \);
\( h \) is Planck's constant, 1.05·10\(^{-34} \), J·s;
\( e \) is effective electron charge, C (1.6·10\(^{-19} \));
n is the concentration (quantity) of electrons in the volume item of the electrical conductor (graphite), it is calculated for real conditions of free electron gas state at pressure \( p \), close to the bottom of Earth’s crust level according to the formula [32]:
\[
n = \frac{5 m_e}{\hbar^2} \left( \frac{3\pi^2}{2} \right)^{2/3} \frac{\pi^3}{5} p^{3/5}
\]
(4)
Substituting the known quantities: electron mass \( m_e = 9.11·10^{-31} \) kg and pressure \( p = 1.3·10^4 \) atm. (1.32·10\(^5 \) Pa) into (4) we can get electron concentration about \( n = 1.79·10^{28} \) m\(^{-3} \).

If the average quantity \( n \) and the known average electroconductivity \( \sigma \) of the graphite single crystal, when the electric current moves along its basic plane, 2.5 S·m\(^{-1} \) (0.3 - 0.5 Om·m) [33], is put into the formula the electron mean free path equals \( l = 4.24·10^{-15} \) m. As can be seen, the electron mean free path is extremely small and depends on the field tension \( E \), quantity.

b) electron drift velocity towards the effect of the electric field \( E \) according to the formula:
\[
\mathbf{v}_d = \frac{e E l}{\sigma m_e}
\]
(5)
where \( \mathbf{v} \) is the average velocity of thermal motion of electrons. To calculate it one can use the formula:
\[
\mathbf{v} = \sqrt{\frac{k T}{m_e \sigma}} \text{, m/s}
\]
(6)
where \( k \) is Boltzmann constant, 1.38·10\(^{-23} \) J·K\(^{-1} \);
\( T \) is temperature, K (taking it as 1.273.15 K or 1000 °C) for the lower part of the GTEE); If the mentioned quantities are put into the formula (6) one can obtain \( \mathbf{v} = 2.22·10^5 \) m·s\(^{-1} \). As can be seen, in both cases chaotic motion of the electrons goes at very high speed.

Substituting \( l \) and \( \mathbf{v} \) into the equation (5) one can obtain the average drift velocity of the electrons \( \mathbf{v}_d \) inside GTEE, which equals 5.72·10\(^{13} \) m·s\(^{-1} \).

However low electron drift velocity does not contradict the factual data: direct current sets up within the whole electrical network almost instantly regardless its length, if a current source of non-electrical origins is connected to the ends of such network. The difference of temperatures applied to GTEE can be such a source, and the GTEE "body" as an electric network. Along the circuit the electric field spreads at a speed close to the light speed \( c = 3·10^8 \) m·s\(^{-1} \). From that moment on a regularized but slow motion of electrons is fixed at the speed \( \mathbf{v}_d \) [29]. It can be concluded that the registered above the GTEE dynamics of the natural electric potential \( \Delta U^T \) is in phase with the \( E \) field dynamics and, accordingly, with the deep thermal processes taking place in real time (phase lag being not more than \( \tau = l/c = 10^4 \) s).

Hence, graphite formations in the deep fault zones can be considered as natural thermoelectric components of Earth. They may exist and be the direct indicators of temperatures of Earth’s inner shells because of several geological and geophysical preconditions. To prove it, monitoring measurement of the natural electrode potential \( U_x \) above GTEE must be performed. The potential is always the sum of the electrode own potential of the \( U_o \) conductor and the imposed thermopotential \( \Delta U^T \). At the same time the temperature of those shells is still quantified with indirect ways, which were first developed by R.J. Uffen and D.K. Tozer and V.A. Magnitsky, who suggested the theoretical and mathematical formulas [34-36].

Since there is a long-term electron flow motion in GTEE which are thermoelectric currents, it is important to find the quantity of those currents \( \mathbf{I} \) and their density \( \mathbf{J} \).

According to the Ohm's law, the integral equation on the right side of the formula (1) is a product of multiplication of the direct current \( \mathbf{I} \) and the ohmic resistance of conductive ores of GTEE \( R \), i.e. \( \Delta \phi = \beta \Delta T = \mathbf{I} \mathbf{R} \). The direct current \( \mathbf{I} \) quantity can be found if \( \Delta T \) has instantaneous values, i.e. is in dynamic mode:
\[
\mathbf{I} = \frac{\beta \Delta T q}{\rho H} = \frac{\sigma \Delta T q}{H},
\]
(7)
where \( \rho \) is the specific resistance of the GTEE ores, Om·m, and \( \sigma \) is its electroconductivity, S·m\(^{-1} \).
$Q$ is the quantity of GTEE surface (its section), $m^2$, and $H$ is GTEE height (its length), m. If $Q$ is replaced to the left part of the equation, the current density $J$ can be found from the equation (7):

$$J = \frac{\sigma \beta \Delta T}{H}, \text{A-m}^{-2}$$

(8)

The calculations show that the current density $J$ per thermoelectrical component area unit equals 8.3·$10^{-6}$ A·m$^{-2}$ if GTEE’s height $H=30,000$ m, graphite rocks electroconductivity $\sigma = 2.5$ S·m$^{-1}$ and the temperature difference $\Delta T = 1,000$ °C, which is put to the GTEE’s ends. At the same time, the quantity of the current going through the GTEE’s surface is not more than 1.67 A if the surface’s size is 50x4000 m$^2$. This electric current is a flow of electrons of not a big density. As it moves vertically along the GTEE it is not capable of dissipation in host rocks, which are mainly dielectrics with high resistance of $10^4$ – $10^8$ Ohm·m [37-40].

Systematic measurements of natural electric potential above different objects in the areas of volcanos and fumarolic outcrops in Japan, Italy, the Kamchatka Peninsula et al. is a convincing proof that deep temperature dynamics influence natural electric potential quantity [18,25,41-44].

To prove that temperature affects natural potential amplitude some laboratory experiments were performed with usage of electronic conductors when temperatures of their lower part were changing (figure 2). The experiment was performed for an inclined cupric plate placed in two electrolytic baths that excluded any influence of the electrolyte’s convective heat (figure 2,a). The measurements show that potential increment is quite big even if the applied to the conductor temperature difference in the range from 0 to $67^\circ$C (figure 2,b).

**Figure 2.** Results of experimental measurements of the natural electric potential when heating the lower part of the electronic conductor model.

Thus, natural electric potentials ($U_0$) registered on the bottom surface above electron-conductive graphite formations correspond to the fields of those conductors’ own electrode potentials $U_0$ (usually, $U_0 = 0.04$ V for graphite) and imposed thermopotentials ($\Delta U^T$), which are generated in the present geotemperature field:

$$U_i = U_E = U_0 + \Delta U^T$$

(9)

Those thermopotentials are the ones to determine pole signs of a polarized electronic conductor: when its upper part is less warmed (which happens usually), the potential anomaly, which is observed on the bottom surface, is registered as negative (fig. 1). When it is more warmed, the anomaly is positive.
3. Method of observation and calculation of the temperature of the deep processes of the Earth’s crust

The current density \( J \) can also be defined according to the quantum theory of the electrical conductivity of metals through the following equation [28,31,45]:

\[
J = e^2nE_T \frac{1}{p_F},
\]

(10)

where \( p_F \) is Fermi momentum, defined as:

\[
p_F = \hbar(3\pi^2n)^{1/3},
\]

(11)

If current density equations (8) and (10) are equal and the electric field tension \( E_T \) is expressed as \( \Delta U^T \) there can be found the formula:

\[
e^2n\Delta U_T \frac{1}{H_{PF}} = \frac{\sigma_B\Delta T}{H}
\]

(12)

From that one can find \( \Delta U^T \):

\[
\Delta U_T = \frac{\sigma_B\Delta Tp_F}{e^2n}
\]

(13)

However, this formula shown the initial moment of the thermopotential \( \Delta U^T \) forming and does not consider any correction of its change in time in the following dynamic process of increasing (or decreasing) density of electrons in the upper part of the GTEE. This correction factor was being found experimentally and theoretically [20,31]. The further data analysis showed that the ratio of the positive lower part of a polarized conductor to the negative upper part of it is more informative and can be presented as \( L = \delta_1/\delta_2 \). The most acceptable ratio turned out to be the \( L \) ratio when the value of a positively charged pole depends on the temperature and can be defined as the following:

\[
\delta_1 = \frac{H}{\Delta T^0.2}
\]

(14)

Then, having \( \delta_1 \) we can find the value of the negative pole: \( \delta_2 = H - \delta_1 \) or

\[
\delta_2 = H(1 - \frac{1}{\Delta T^0.2})
\]

(15)

After putting \( L \) into the equation (24) there will be:

\[
\Delta U_T = \frac{\sigma_B\Delta Tp_F}{e^2n}(1 - \frac{1}{\Delta T^0.2})
\]

(16)

Then the summarized natural electric potential (9) can be presented as:

\[
U_\Sigma = U_0 + \frac{\sigma_B\Delta Tp_F}{e^2n}(1 - \frac{1}{\Delta T^0.2})
\]

(17)

The final goal is to find the quantity of the temperature \( T_2 \) at the GTEE bottom, it can be derived from the equation (17):

\[
\frac{e^2n(U_\Sigma - U_0)}{\sigma_Bp_F} = \Delta T^{1.2}(1 - \frac{1}{\Delta T^0.2}),
\]

(18)

If \( \Delta T = T_2 - T_1 \) and \( T_1 \) is supposed to be equal 0 (\( T_1 = 0 \)) the equation (18) is as follows:

\[
\frac{e^2n(U_\Sigma - U_0)}{\sigma_Bp_F} = T_2^{1.2} - T_2
\]

(19)

An example of finding temperature \( T_2 \) from the equation (19): if the calculated left part of that equation equals 958,24 temperature \( T_2 \) will equal 411 °C with the help of the selection method (for cases when \( U_2 = 3 \) B, a \( U_0 = 0.5 \) B).

To find the temperature in the lower area GTEE and to watch its dynamics there is a method of monitoring measurements of the natural potential \( \Delta U^T \) above the electroconductive medium of deep faults.

In particular, measurements of the natural electric potential must be presented as its hodograph to observe temperature dynamics effectively and mathematically analyze it (figure 3). Natural electric potential hodograph is the connection between the potential amplitude with the time and coordinates of the monitoring \( GU = f(t,x,y,z) \). The most convenient way of representing this hodograph is a graph (figure 3,a), as it is in seismic tomography. The time (years, months, hours) is marked on the horizontal axis, potential amplitude (V, mV) is marked on the vertical one.
Figure 3. Results of observing the dynamics of the natural electric potential above GTEE:
a. hodograph of natural potential, schemed for the 4-year time period; b. combined graphs of the
natural electric potential, observed during the given time periods, according to the schedule.

Potential change velocity \( v_U \) in a chosen time interval \( \Delta t \) can be found with the help of hodograph \( GU \):

\[
v_U = \frac{\Delta U}{\Delta t} \text{ (mV·year}^{-1}, \text{ mV·month}^{-1}, \text{ mV·day}^{-1})
\]

(20)

Thus, for example, figure 1,a shows that \( v_U \) equaled 207.9 mV·month\(^{-1}\) or 6.8 mV·day\(^{-1}\) during the
period from the November to the December 2012. At the same time, hodograph tilt angle \( \theta_i \) in a
chosen time interval can be derived from the formula:

\[
\theta_i = \arctan \frac{b}{a}, \text{ deg.}
\]

(21)

The given parameters \( v_U \) and \( \theta_i \) are defined with less error at calculations with help of the
hodograph trend, which is a polynomial of the third degree \( y = ax^3 + bx^2 + cx + d \) as in the given example. The latter allows to remove random errors when measuring potential \( U \). When there is enough data of
monitoring and experiments, it is possible to determine critical values of \( v_U \) and \( \theta_i \) also bearing in
mind temperature \( T_2 \) dynamics derived from the formula (19) and using data of some other
geophysical methods. Those values with some other data can be used to improve forecasts of different
undesirable occurrences, such as earthquakes, volcano eruptions and so on.

4. Conclusion

It was found out that the deep faults with graphite ores within their borders are thermoelectric
elements of Earth’s crust (GTEE), which are characterized by having thermo e.m.f. and electric
currents. The latter allow to register natural electric potentials above a GTEE, which amplitude
dynamics correlates directly to the dynamics of the deep layer temperature of Earth’s crust and mantle.

The mathematical model of GTEE was developed and quantitative connection between the natural
potential amplitude and GTEE thermoelectrical parameters was gained.

One of effective ways of processing monitoring field measurements of the natural electric potential
(hodograph method) was considered to gain the most important characteristics of the potential’s
dynamics, such as potential change velocity per unit time and hodograph branch inclination quantity
of potential.

Active observation of the natural electric potential above thermoelectrical components of Earth’s
crust can make SP-technique more effective for geological survey and make it useful in studying both
dynamics of deep thermal processes within Earth’s crust and its areas related to different tension sources, exogenous and endogenous ones.

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