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TERRESTRIAL HETEROGENEITY AND GEOMAGNETIC VARIATIONS

Yu. D. Kalinin
Submitted by Academician L. C. Leybensor
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The study of a constant geomagnetic field and of its secular variations has led the author to the conclusion that inside the earth, at depths of the order of half the earth's radius, an irregular distribution of electric conductivity can be assumed to exist. In this article this assumption is examined on the basis of data for solar-diurnal variations. It is demonstrated that as a result of the heterogeneity of the earth's structure the principle harmonic of the outer part of a field of S-variations must induce in the earth a series of harmonics. A comparison of theory and observations leads to the conclusion that there is a very great probability of the existence of heterogeneities, equivalent to spheres with a diameter of 0.1 to 0.2 of the earth's radius, sunk to 0.3- 0.6 of the earth's radius, and with a conductivity 10-100 times greater than the conductivity of the rest of the earth.

Research on the geographic distribution of geomagnetism [1] and its secular variations [2] have led the author to the conclusion that in the earth, at depths of the order of 0.5 a (a being the earth's radius), there are extensive herterogeneities with respect to electric conductivity. Certain observations of other geophysicists confirm this conclusion. This article is a brief statement of the results of research on this question on the basis of data on solar-diurnal geomagnetic variations (S).

Schuster [3] was the first of many to use the method of spherical harmonic analysis in the study of S fields. He showed that the chief (outer) part of the field originated in the inosphere and that the lesser

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(inner) part was created by electromagnetic induction due to the chief part, within the earth. According to Schuster, that part of the earth's surface with a radius 10^3 kilometers less than the radius of the earth is electroconductive. He assumed that electroconductivity χ inside this sphere did not depend on the coordinates. Later research workers [4] demonstrated that there was a closer agreement between empirical χ data and the assumption that χ depended on coordinates in the form

$$\chi = k\rho^{-s},$$

where $\rho = \frac{r}{qa}$; r is the radius-vector (spherical coordinate); k, q and s are constants $(q < 1, s \not< 30)$.

There are many complications in the study of the general case, $\chi = \chi(r, \theta, \varphi)$. But let us study the simplest case: inside the earth let there be a spherical volume of radius qa with center at point (e, θ_0, Φ_0) and the conductivity in the sphere, χ_1 = const, differs from the conductivity χ of the rest of the earth. For the sake of simplicity, we shall assume that for the remainder of the earth $\chi = 0$. In view of the additive properties of potential, the latter assumption may when necessary be denied, and it may be assumed within sphere qa that $0 \neq \chi_1 \gtrless \chi$.

Let us see how the assumption of the presence of volume qa with $\chi = \chi_1$ affects the potential S.

The chief harmonic in the potential of the outer part of the diurnal wave of field S will be the harmonic S_2^1 to which the following expression for the potential corresponds:

$$V_2^{1e} = a\left(\breve{E}_2^1 \cos t + \breve{e}_2^1 \sin t\right)\left(\frac{r}{a}\right)^2 P_2^1(\cos\theta); \quad (1)$$

here r-is the radius vector from the center of the earth; t-is the local time; θ is the polar angular displacement; P_2^1-is a Legendre function of order 2 and degree 1; $\breve{E}_2^1$, $\breve{e}_2^1$-are empirical coefficients.

For spherical coordinates r_1, θ_2, φ_2 with origin at the point e with polar axis passing through the center of the earth and for a point on its surface with coordinates θ_0, Φ_0, the potential V_2^{1e} will be expressed in the following way:

$$V_2^{1e} = aE_2^1 e^{i(\Phi_0 - \pi)} e^{it'} \left(\frac{e}{a}\right) \times$$

$$\times \left\{-\frac{\sqrt{3}}{2}\sin 2\theta_0 \Pi_1 + \cos\theta_0 \cos\varphi_2 \Pi_1 + \frac{1}{2}\sin 2\theta_0 \cos 2\varphi_2 \Pi_2\right\}. \quad (2)$$

where

$$\Pi_0 = P_0(\cos\theta_2) + 2\left(\frac{r_1}{e}\right)P_1(\cos\theta_2) + \left(\frac{r_1}{e}\right)^2 P_2(\cos\theta_2),$$

$$\Pi_1 = \sqrt{3}\left(\frac{r_1}{e}\right)P_1^1(\cos\theta_2) + \left(\frac{r_1}{e}\right)^2 P_2^1(\cos\theta_2),$$

$$\Pi_2 = \left(\frac{r_1}{e}\right)^2 P_2^2(\cos\theta_2)$$

$$E_2^1 = C_2^1 e^{i\breve{\varepsilon}_2^1}, \quad \breve{E}_2^1 = C_2^1 \cos\breve{\varepsilon}_2^1, \quad \breve{e}_2^1 = -C_2^1 \sin\breve{\varepsilon}_2^1,$$

t' is the world time.

Expression (2) was obtained by the author from (1) by successive transformations of the coordinates and by the application formulae already in the literature [5] and of the following formula found by the author:

$$r^n P_n^m(\cos\theta_1) = e^n \sum_{k=n}^{k=n} \frac{1}{(n-k)!}\sqrt{\frac{(n+m)!(n-m)!}{(k+m)!(k-m)!}}\left(\frac{r_1}{e}\right)^k P_n^m(\cos\theta_2),$$

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where θ_1 is the polar angular displacement from point θ_0, Φ_0 at the origin of the spherical coordinates in the center sphere a.

The author showed that for $\theta_1 = \frac{\pi}{2}$ (the volume of the sphere of radius qa is located symmetrically with respect to the earth's equatorial plane) the potential V_2^{1e} will induce and for magnetic permeability $\mu = 1$ in the existing spherical volume of radius qa the potential:

$$V_2^{1i} = a I_1' e^{it'} \left(\frac{a}{r_1}\right)^2 \cos\varphi_2 \, P_1'(\cos\theta_2) + a I_2' e^{it'} \left(\frac{a}{r_1}\right)^3 \cos\varphi_2 \, P_2'(\cos\theta_2). \quad (3)$$

where

$$I_1' = I_{10}' e^{i\varepsilon_1'}, \; I_2' = I_{20}' e^{i\varepsilon_2'}, \; I_{10}' = C_2' e^{i\varepsilon_2'} A_1, \; I_{20}' = C_2' e^{i\varepsilon_2'} A_2.$$

$$A_1 = \frac{\sqrt{3}}{2} \cdot \frac{e}{a} q^2 \sqrt{\frac{\beta^2 - 2\beta + 2}{\beta^2 + \beta + 1/2}}, \quad A_2 = \frac{2}{3} q^2 \sqrt{\frac{\beta^2 - 3\beta + 9/2}{\beta^2 + 2\beta + 2}},$$

$$\varepsilon_1' = \Phi_0 - \pi + tg^{-1} \frac{5\beta}{2\beta^2 - \beta - 2},$$

$$\varepsilon_2' = \Phi_0 - \pi + tg^{-1} \frac{5\beta}{2\beta^2 - \beta - 6},$$

$$\beta^2 = \frac{4\pi^2 \varkappa q^2 a^2}{24 \cdot 60 \cdot 60}.$$

Expression (3) was obtained by the author as a result of applying to the selected particular case Lamb and Price's formula from the theory of electromagnetic induction of a sphere [6].

The potential V_2^{1i} in coordinates r, θ, φ are approximately expressed in this manner:

$$V_2^{1i} \approx a I_1' e^{it'} \left(\frac{a}{r}\right)^2 P_1(\cos\theta) + a I_2' e^{it'} \left(\frac{a}{r}\right)^3 \cos(\varphi - \Phi_0) P_2'(\cos\theta). \quad (4)$$

If a term with $\frac{e}{a}$ is introduced, the expression for V_2^{1i} will read:

$$V_2^{1i} \approx a I_1' e^{it'} \left(\frac{a}{r}\right)^2 P_1(\cos\theta) - a I_2' e^{it'} \left(\frac{a}{r}\right)^4 \sqrt{3} \frac{e}{a} P_3(\cos\theta) +$$
$$+ a\left(I_1' \sqrt{3} \frac{e}{a} + I_2'\right) e^{it'} \left(\frac{a}{r}\right)^3 \cos(\varphi - \Phi_0) P_2'(\cos\theta) +$$
$$+ a I_2' e^{it'} \left(\frac{a}{r}\right)^4 \sqrt{3} \frac{e}{a} \cos 2(\varphi - \Phi_0) P_3^2(\cos\theta). \quad (5)$$

In addition to using the well-known formulae [5], in obtaining expressions, (4) and (5), the author also used his own formula:

$$\frac{P_n^m(\cos\theta_2)}{r_1^{n+1}} =$$
$$= \frac{1}{r^{n+1}} \sum_{k=0}^{\infty} \frac{(-1)^k (k+n-m)!}{k!(n-m)!} \sqrt{\frac{(k+n+m)!(n-m)!}{(k+n-m)!(n+m)!}} \cdot \left(\frac{e}{r}\right)^k P_{k+n}^{m}(\cos\theta_1).$$

Comparison of formula (5) with the empirical expression for the potential of corresponding harmonics of the inner part of the field S

$$a(I_2' \cos t + I_2' \sin t)\left(\frac{a}{r}\right)^3 P_2'(\cos\theta) +$$
$$+ a(I_3^2 \cos 2t + I_3^2 \sin 2t)\left(\frac{a}{r}\right)^4 P_3^2(\cos\theta),$$

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gives

$$\left.\begin{aligned} T_2^1 &\approx \frac{\tilde{I}_2^1}{\cos(\varphi-\Phi_0)}, \quad U_2^1 \approx -\frac{\tilde{I}_2^1}{\cos(\varphi-\Phi_0)}, \\ T_3^2 &\approx \frac{\tilde{I}_3^2}{\cos 2(\varphi-\Phi_0)}, \quad U_3^2 \approx -\frac{\tilde{I}_3^2}{\cos 2(\varphi-\Phi_0)}, \end{aligned}\right\} \qquad (6)$$

where

$$T_2^1 = C_2^1 A_2 \cos(\tilde{\varepsilon}_2^1 + \iota_2^1 - \varphi) + C_2^1 A_1 \sqrt{3}\,\frac{e}{a} \cos(\tilde{\varepsilon}_2^1 + \iota_1^1 - \varphi),$$

$$U_2^1 = C_2^1 A_2 \sin(\tilde{\varepsilon}_2^1 + \iota_2^1 - \varphi) + C_2^1 A_1 \sqrt{3}\,\frac{e}{a} \sin(\tilde{\varepsilon}_2^1 + \iota_1^1 - \varphi),$$

$$T_3^2 = C_2^1 A_2 \sqrt{5}\,\frac{e}{a} \cos(\tilde{\varepsilon}_2^1 + \iota_2^1 - \varphi),$$

$$U_3^2 = C_2^1 A_2 \sqrt{5}\,\frac{e}{a} \sin(\tilde{\varepsilon}_2^1 + \iota_2^1 - \varphi).$$

Thus, if there is a spherical volume of radius qa in the earth, one harmonic S_2^1 of the outer part of the field S induces an infinite number of new harmonics, not a single one of which have the same order and degree as in the case of harmonics for a centrally-symmetrical earth.

On the basis of (6) it is possible to fix highly probable values for the characteristic constants: q, e, Φ_0, $\varkappa$.

In 1933, N. P. Ben'kova [7], using data for the S-field, obtained the following as the most probable values for $\varkappa_1$: $\varkappa_1 = 5.3 \times 10^{-12}$ CGS.

If it be assumed that $\varkappa$ has this value only in the volume of radius qa and that $\varkappa_1 = 0$ outside it, it is also necessary to assume that $q \approx 1$ and, consequently, that inside the volume of radius qa the value $\varkappa > \varkappa_1$ and $\varkappa_1$ outside the volume approximates Ben'kova's value.

Table 1

Coefficients of the Potential of the Field for 1933 in Units of 10^{-5} CGS

m	n	K_n^m	e_n^m	L_n^m	Y_n^m
1	2	3,03	-1,55	2,09	-0,83
2	3	-2,63	1,35	-1,09	0,69

Comparison of Ben'kova's empirical data given in Table 1 with the results of calculations leads to the conclusion that the most probable values are: $0.1 < q < 0.2$; $0.3a < e < 0.6a$; $10\varkappa_1 < \varkappa < 100\varkappa_1$. Hence, data for the S-field confirm our earlier assumption that at great depths in the earth there is a heterogeneous distribution of electric conductivity.

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