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Multicomponent Sounding by Establishing the Field of Polarizing Seam upon Its Excitation by Horizontal Electric Dipole

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Abstract. To expand the scope of unsteady electromagnetic fields in marine and land prospecting and mapping studies of deep-seated and/or polarized geological objects, such as oil and gas deposits, kimberlite bodies and other minerals, it is advisable to consider an engineering-analytical multicomponent model of an electrically conductive layer when excited by horizontal electric dipole – the classic causative agent of the formation of the field of horizontally layered media. To simplify analytical studies, the Cole-Cole dispersion model adopted for the polarized known plane S^{η} was adopted as polarizable electrically conductive layer. The components of analytical expressions are described that describe the establishment of the electromagnetic field of an induction-induced polarizing conductive layer — objects of hydrocarbon deposits and sulphide ore occurrences. To identify the deep horizontal inhomogeneities of the section, equations are given that describe multicomponent fluxes of magnetic induction of polarized formation.

1. Introduction

One of the main tasks of multicomponent studies is the observation of the horizontal component of magnetic induction, which together with the vertical component expands the amount of information obtained about deep geoelectric heterogeneities, for example, such as zones of oil-water contacts, oil and gas deposits, boundaries of kimberlite bodies, tectonic disturbances, sulfide ore occurrences and etc. [15,21,25].

Currently, many researchers have experimentally established the occurrence of double induced polarization during the electromagnetic excitation of oil and gas deposits, sulfide ores and some other objects. In this case, the occurrence of induced polarization can serve as an indicator of oil and gas deposits, sulfide ore occurrences. In this regard, the development of engineering and analytical models for the establishment of electromagnetic components of magnetic induction of induction-polarizable conductive layer seems relevant, has practical and scientific significance.

2. Presentation of a problem

In accordance with the physical and mathematical formulation of the electrodynamic problem, we present the object of research in the form of an induction-polarized conductive layer approximated by the S^{η} plane — polarizing longitudinal conductivity adapted to the conductive layer by the most common and widely tested Cole-Cole model [2,12,17].

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$$S^{\eta}(\omega) = S_0[1 + (\mathrm{i}\omega\tau)^k]/[(1-\eta)(\mathrm{i}\omega\tau)^k]\#(1)$$

where S_0– frequency-independent longitudinal conductivity, τ – relaxation time, η – object polarizability ($0 \leq \eta \leq 1$), i – imaginary unit, k – the coefficient of the distribution range of the relaxation time, for simplicity, taken as unity (Debye model, the most acceptable for the practice of field establishment) [11,12].

To simplify the analytical analysis, we limit the relaxation time to $\tau \geq 10^{-5}$ s, which is experimentally tested for geological objects and implemented in practice [11,12].

Horizontal electric dipole with moment P_e will be placed at height h=-z from the S^{η} plane at the origin of the cylindrical coordinate system (r, φ, z), combined with the Cartesian coordinate system (x, y, z) and directed along the x axis.

The medium containing the S^{η} plane is described by the Laplace equation:

$$\nabla^2 A_Z = 0$$

Degenerate boundary conditions are used on the plane S^{η} [19].

3. Analytical analysis

Components of the magnetic induction of field formation are determined in the form of relations:

$$B_z = \frac{\partial A_x}{\partial \mathrm{y}};\ B_x = \frac{\partial A_z}{\partial \mathrm{y}};\ B_y = \frac{\partial A_x}{\partial \mathrm{z}} - \frac{\partial A_z}{\partial \mathrm{x}};$$

$$\begin{aligned}
B_y(t) \ =\ & \frac{\mu P_э}{4\pi} e^{-\frac{t}{2\tau}} \Bigg\{ -\frac{\alpha}{(\alpha^2 + r^2)^{\frac{3}{2}}} - \frac{\alpha + 2kt}{[(\alpha + 2kt)^2 + r^2]^{\frac{3}{2}}} + \frac{\mu S}{(\alpha^2 + r^2)^{\frac{1}{2}} 2\tau(1-\eta)} \\
& + \frac{\mu S}{(1-\eta)2\tau[(\alpha + 2kt)^2 + r^2]^{\frac{1}{2}}} \Bigg\} \\
& + \frac{\mu P_э}{4\pi} e^{-\frac{t}{2\tau}} cos\varphi\ \langle -\frac{1-\eta}{\mu S} \frac{x}{2r^{\frac{5}{2}}} \left[\frac{\alpha}{(\alpha^2 + r^2)^{\frac{3}{2}}} - \frac{3\alpha x}{(\alpha^2 + r^2)^{\frac{5}{2}}} \right] \\
& - \frac{1}{2} \frac{x}{r^{\frac{5}{2}}} \frac{(1-\eta)}{\mu S} \Bigg\{ \Bigg[\frac{(\gamma^2 + r^2)^{\frac{1}{2}} - \gamma + 2\gamma(\gamma^2 + r^2)}{(\gamma^2 + r^2)^{\frac{3}{2}}} + \frac{1}{r} \frac{x(\gamma^2 + r^2)^{-\frac{1}{2}} + 2x}{(\gamma^2 + r^2)^{\frac{3}{2}}} \Bigg] \\
& - \frac{3x(\gamma^2 + r^2)^{\frac{1}{2}} - \gamma + 2\gamma(\gamma^2 + r^2)}{(\gamma^2 + r^2)^{\frac{5}{2}}} \Bigg\} - \frac{x}{r^{\frac{5}{2}} \tau(1-\eta)} \left[\frac{2x}{(\gamma^2 + r^2)^2} - \gamma \right] \\
& - \frac{x}{2r^{\frac{5}{2}}} \frac{2\tau + \mu S}{\mu S \tau(1-\eta)} \left[\frac{(\alpha^2 + r^2)^{\frac{1}{2}} - \alpha}{(\alpha^2 + r^2)^{\frac{3}{2}}} - \frac{1}{2} \frac{1}{(\alpha^2 + r^2)} \right] * \left[-3 - \frac{2x}{(\alpha^2 + r^2)^2} - \alpha \right] - \frac{1}{2} \frac{x}{(\alpha^2 + r^2)^{\frac{3}{2}}} \\
& + \frac{x}{2r^{\frac{5}{2}}} \frac{2\tau + \mu S}{\mu S \tau} \left[-\frac{x - \gamma}{(\gamma^2 + r^2)^2} + \frac{3x\gamma \left[(\gamma^2 + r^2)^{\frac{1}{2}} - 1 \right]}{(\gamma^2 + r^2)^{\frac{5}{2}}} + \frac{\gamma(\gamma^2 + r^2)^{-\frac{1}{2}} - 1}{(\gamma^2 + r^2)^{\frac{3}{2}}} \right] \rangle
\end{aligned}$$

$$
\begin{aligned}
B_z(t) \;=\; & -\frac{\mu P_э}{4\pi} e^{-\frac{t}{2\tau}} \langle sin\varphi \Bigg\{ \frac{1}{2r} \Bigg[\frac{(\alpha^2+r^2)^{\frac{1}{2}}+1}{(\alpha^2+r^2)^{\frac{3}{2}}} - \frac{\alpha(\alpha^2+r^2)^{-\frac{1}{2}}+1}{(\alpha^2+r^2)^{\frac{1}{2}}} \Bigg] \Bigg[-\frac{1}{2r} * \frac{\gamma(\gamma^2+r^2)^{\frac{1}{2}}-\gamma}{(\gamma^2+r^2)^{\frac{3}{2}}} \\
& + \frac{(\gamma^2+r^2)^{-\frac{1}{2}}-1}{(\gamma^2+r^2)^{\frac{1}{2}}} \Bigg] - \frac{\mu S}{(1-\eta)2\tau r} \frac{\alpha}{(\gamma^2+r^2)^{\frac{1}{2}}} \Bigg\} \\
& + \Bigg\{ -\frac{(1-\eta)}{2\mu S} \frac{y}{r^{\frac{5}{2}}} \Bigg[-\frac{\alpha y}{(\alpha^2+r^2)^2} + \frac{3y}{(\alpha^2+r^2)^{\frac{5}{2}}} \Bigg] + \frac{\alpha}{(\alpha^2+r^2)^2} + \frac{y}{(\alpha^2+r^2)^2} - \frac{1}{4\tau} \frac{1+\gamma}{(\gamma^2+r^2)^{\frac{3}{2}}} \\
& + \frac{(1-\eta)}{2\mu S} \frac{y}{r^{\frac{5}{2}}} \Bigg[\frac{\gamma y}{(\gamma^2+r^2)^2} + \frac{3y\left[(\gamma^2+r^2)^{\frac{1}{2}}-\gamma\right]}{(\gamma^2+r^2)^{\frac{5}{2}}} \Bigg] + \frac{\frac{1}{2}\gamma(\gamma^2+r^2)^{\frac{3}{2}}+1}{(\gamma^2+r^2)^{\frac{1}{2}}} - \frac{y(\gamma^2+r^2)^{-\frac{1}{2}}\gamma-1}{(\gamma^2+r^2)^{\frac{3}{2}}} \Bigg\} \\
& - \frac{k}{y} \\
& - \frac{y}{r^{\frac{5}{2}}} \Bigg\{ -\frac{y}{(\gamma^2+r^2)^2} - \frac{\alpha y}{(\alpha^2+r^2)^2} - \frac{3y}{(\alpha^2+r^2)^{\frac{7}{2}}} - \frac{y\gamma}{(\gamma^2+r^2)^2} + \frac{y}{(\gamma^2+r^2)^{\frac{5}{2}}} + \frac{1}{y} \\
& - \frac{y}{r^{\frac{5}{2}}} \Bigg[\frac{2\gamma y}{(\gamma^2+r^2)^2} - \frac{2y\gamma}{(\gamma^2+r^2)} - \frac{2\gamma y}{(\gamma^2+r^2)^2} - \frac{\gamma y}{(\gamma^2-r^2)^2} \Bigg] + \frac{1}{\tau} \frac{y}{(\gamma^2+r^2)^{\frac{3}{2}}} \\
& - \frac{1}{2} \frac{y}{r^{\frac{5}{2}}} \Bigg[-\frac{y\alpha}{(\alpha^2+r^2)^2} + \frac{3y\left[\alpha(\alpha^2+r^2)^{-\frac{1}{2}}-1\right]}{(\alpha^2+r^2)^{\frac{5}{2}}} - \frac{k(2y-y\gamma)}{yr^{5/2}(\gamma^2+r^2)^2} \Bigg] \Bigg\} \rangle
\end{aligned}
$$

where $\gamma = \frac{2(1-\eta)}{\mu S}$; $k = \frac{1-\eta}{\mu S}$; $\alpha = 2h + z$; S – longitudinal conductivity of seam; η – polarization; t – observation time; μ – magnetic permeability; h – distance from the S plane to the field source; P_e - electric dipole moment, B_z, B_x, B_y – components of magnetic induction along the x, y, z coordinate axis respectively; A_x, A_z – potential vectors along the x and z axis respectively.

Figure 1 (a, b) shows the $B_z(t)$, $B_y(t)$ electro-sounding curves as an example, which show the change of sign of these components in the presence of induction-induced polarization, which can serve as an indicator of mineral resources and ice masses [7, 11, 23, 24].

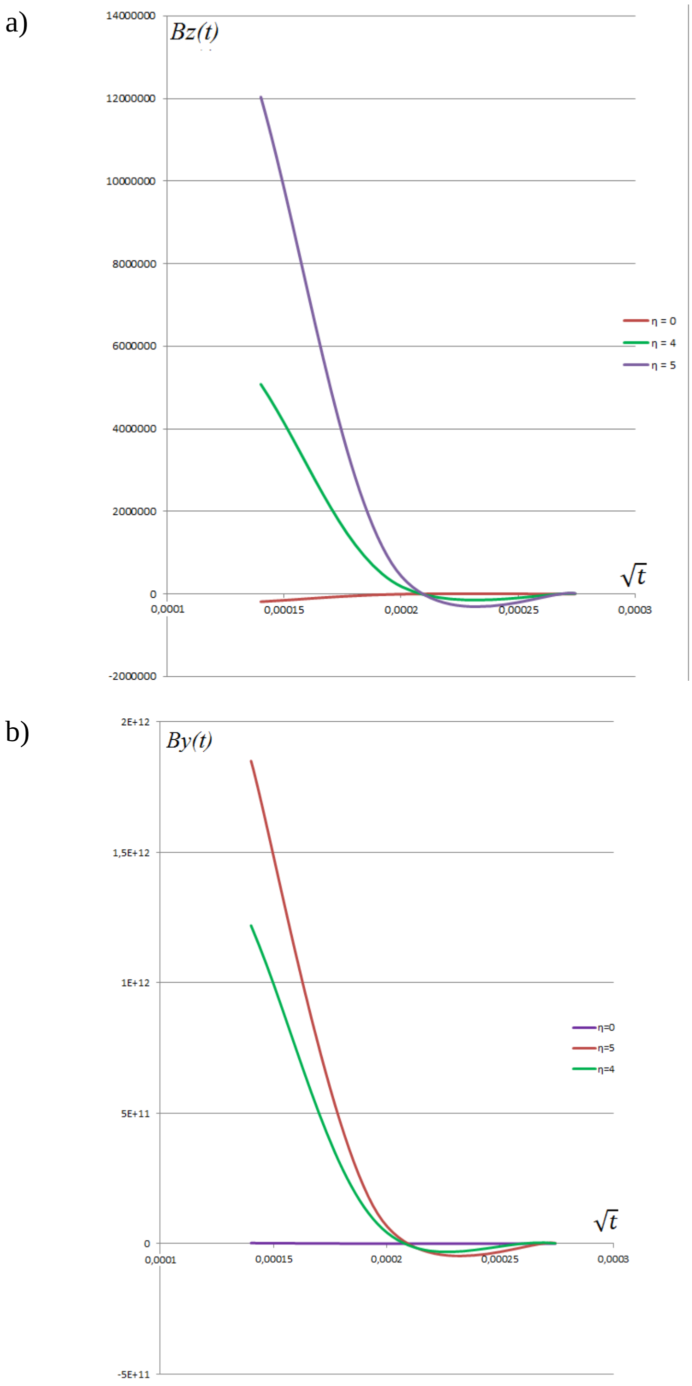

Figure 1. Sounding graphs of the components of magnetic induction of electrically conductive induction-polarizing seam: (a) component $B_z(t)$, (b) component $B_y(t)$.

4. Conclusion

Pulse analytical models of the components of magnetic induction of horizontal electric dipole of induction-polarizing conductive layer are considered, into which the most common generalized Cole-Cole formula, which describes the induction-induced polarization, which is adapted to the conductive layer, is introduced, which is one of the signs of an oil and gas deposit, sulphide ore manifestation and other inhomogeneities.

An analysis of the components of an unsteady electromagnetic field, its integral characteristics of electrically conductive induction-induced polarizing media significantly expands the possibilities of pulsed electrical exploration in prospecting-mapping and structural-tectonic studies.

Negative values of the components of the sounding curves of field formation can be one of the signs of existence of an oil and gas deposit, sulphide ores and other polarizing objects.

Engineering and analytical models describing the pulsed components of magnetic induction are presented in elementary functions, in which the relationships of all parameters of the processes of induction-induced polarization are viewed.

References

[1] Balakin A I, Myasnikov I F and Saygakov A N 1979 Rol otritsatelnykh anomaliy MPP pri poiskakh sulfidnogo orudeneniya *Razvedka i okhrana nedr* pp 35-7

[2] Cole K S and Cole R H 1941 Disspersional absorption in dielectrics. Alternating current characterictics *J.Chem. Phys.* **9** 4 pp 341-51

[3] Egorov I V and Pospeev A V 2015 Sravnitelnyy analiz istochnikov nestatsionarnogo elektromagnitnogo polya *Geofizika*. **1** pp 26-30

[4] Gitarts Ya I, Rabinovich B I, Finogeev V V and Forgang S V 1987 Metodika mnogokomponentnykh zondirovaniy s apparaturoy “Krion” *Proc. Rezultaty primeneniya metoda zondirovaniya stanovleniem polya v rayonakh Sibirskoy platformy* (Novosibirsk: SNIIGGiMS) pp 4-12

[5] Goldman M, Mogilatov V, Haroon, Levi E and Tezkan B 2015 Signal detectability of marine electromagnetic methods in the exploration of resistive targets *Geophysical Prospecting* **63** pp 192-210

[6] Goryunov A S, Kisilev E S and Ovcharenko A V 2010 Prognoz neftegazonosnosti elektrorazvedochnymi metodami *Geofizika* **5** pp 24-8

[7] Hatylla A and Dmitriev D 1981 On the use of transient EM-method over a sulphide are body under sallow sea water *Geol. geshem. and Geophys. Investigat. Eastern Part Balt. Shield. Pap. 10 Gen. Meet., Rovaniemi* (Helsinki) pp 189-95

[8] Kamenetsky F M, Stettler E H and Trigubovich G M 2010 *Transient Geo-electromagnetics* (Munich)

[9] Kamenetskiy F M, Vakulskiy A A, Drabich P P and Timofeev V M 1985 Issledovanie integralnykh perekhodnykh kharakteristik v impulsnoy induktsionnoy elektrorazvedke Preprint **88**

[10] Kaufman A A and Morozova G M 1970 *Teoreticheskie osnovy metoda zondirovaniy stanovleniem polya v blizhney zone* (Novosibirsk: Nauka)

[11] Kozhevnikov N O 2012 Bystroprotekayuschaya induktsionno-vyzvannaya polyarizatsiya v merzlykh porodakh *Geofizika* **53** 4 pp 527-70

[12] Kozhevnikov N O and Antonov E Yu 2007 Inversiya dannykh MPP s uchetom bystro protekayuschey induktsionno vyzvannoy polyarizatsii: chislennyy eksperiment na osnove modeli odnorodnogo polyarizuyuschegosya poluprostranstva *Geofizika* **1** pp 42-50

[13] Korolkov Yu S 1987 *Zondirovanie stanovleniem elektromagnitnogo polya dlya poiska nefti i gaza* (Moscow: Nedra)

[14] Rabinovich B I and Finogeev V V 1983 *Metodicheskie rekomendatsii po analizu zondirovaniy stanovleniem polya v blizhney zone (ZSB) v gorizontalno-neodnorodnykh sredakh* (Novosibirsk: SNIIGGiMS)

[15] Nebrat A G, Sochelnikov V V and Kisel S A 2008 K voprosu o primenenii metodov elektrorazvedki pri prognoze kharaktera UV-nasyscheniya *Geofizika* **5** pp 57-8

[16] Nim Yu A, Popkov P A and Adarov T D 2013 Induktsionno-vyzvannaya polyarizatsiya elektroprovodnogo plasta pri ego impulsnom vozbuzhdenii vertikalnym magnitnym dipolem *Razvedka i okhrana nedr* **12** pp 39-41

[17] Nim Yu A, Popkov P A, Romanova L P and Illarionova M G 2017 Modelirovanie impulsnogo potoka magnitnoy induktsii polyarizuyuschegosya geologicheskogo plasta pri ego vozbuzhdenii vertikalnym magnitnym dipolem. *Geologiya i mineralno-syrevye resursy Severo-Vostoka Rossii* **2** (Yakutsk: Izdatelstvo dom SVFU) pp 479-85

[18] Pelton W H, Sill W R and Smith B D 1983 Interpretation of complex resistivity and dielectric data *Geophysical transactions* **29** pp 297-330

[19] Sheyman S M 1947 Ob ustanovlenii elektromagnitnykh poley v Zemle *Prikladnaya geofizika* **3** pp 5-55

[20] Sheyman S M, Isaev G A and Poletaeva N G 1981 Vliyanie polyarizuemosti gornykh porod v metode perekhodnykh protsessov *Proc. Metody razvedochnoy geofiziki, teoriya i praktika interpretatsii v rudnoy geofizike* pp 40-53

[21] Tikshaev V V and Sidorov V A 1973 Integralnyy sposob postroeniya krivykh stanovleniya polya *Prikladnaya geofizika* **71** pp 122-8

[22] Timofeev V M, Mamaev V A and Kamenetskiy F M 1985 Izmerenie potoka magnitnoy induktsii neustanovivshegosya polya *Razvedochnaya geofizika* **101** pp 58-63

[23] Veltsov J N, Epov M J and Antonov E Yu 2002 Reconstruction of Cole-Cole parameters from IP induction foundling data *J. of the Balkan Geoph. Society* **5** 1 pp 15 20

[24] Weidelt P 1982 Response characteristics of coincident loop transient electromagnetic systems *Geophysics* **48** pp 1325-30

[25] Zhuravleva R B, Ulitin R V, Krestanin B A and Usanin V L 1972 Vliyanie vyzvannoy polyarizatsii na krivye stanovleniya MPP na primere mednokolchedannogo mestorozhdeniya *Razvedka geofizika* **78** pp 57-61