Using the Carotazh Method to Determine the Electrical Characteristics of the Earth's Subsoil

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Research Article

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Abstract

Logging is a detailed study of the structure of the well incision by descent and ascent of a geophysical probe. It is often used to determine the electrical conductivity of terrestrial depths. To do this, the sides of the well deepen the electrodes, and they are fed into the depths of a constant electric current. However, if you use natural or artificial electromagnetic waves, it becomes possible to determine the dielectric permeability of terrestrial rocks at depth. To do this, the surface impedance is first measured on the surface of the earth, and then by measuring at a certain frequency of the electromagnetic field in the well hole, the electrical conductivity and dielectric permeability of terrestrial rocks are calculated by fairly simple formulas. Such measurements can be carried out by standard measuring systems, adding only a narrow frame with wire winding to measure the magnetic field.

Keywords: Carotazh, Impedance, Electromagnetic Field, Electrical Conductivity, Dielectric Permeability.

Introduction

Since the beginning of the last century, with the help of the French brothers of engineers Schlumberger, the method of oil and gas deposits has been widely used VES (vertical electrical sensing), when electrodes are inserted into the surface of the earth and a permanent or low-frequency electric current is fed on them [1-3]. Measuring the electrical potential between the electrodes, it is possible to judge the electrical conductivity of terrestrial depths, and already by these values to predict the presence and power of minerals [4,5]. However, this ignores another useful electrical characteristic of the rocks, their dielectric permeability. The values of dielectric permeability, coupled with conductivity, can also and should characterize the presence of certain rocks in the depths of the earth. As we show, to do this, we need to use natural or artificial variable electromagnetic fields from different sources – radio stations and specialized emitters. In this case, you can use already having measurement systems, such as SIM (superficial impedance measurements [6]), with the addition of a magnetic sensor - frame with winded electrical wires. The dimensions of the frame only need to be narrow to fit in the well hole.

Measurement method

First, the superficial impedance is measured δ [7]. This uses a frame that is usually part of the equipment SIM. Then a similar frame is first made, but has other dimensions to fit freely in the well. The calibration of the new frame is made by measuring the known surface impedance given. Then a new frame and an ungrounded insulated electrical wire are lowered as a probe to the depth of the well. The new frame measures the horizontal component of the magnetic field H_φ , and vertical electric wire vertical component of the electric field E_z. Cylindrical coordinates are chosen so that the direction to the source of the electromagnetic field of some (circular) frequency ω selected for the axis r. The vertical z coordinate is directed from the surface of the earth to the atmosphere. Component H_φ is a horizontal, and orthogonal axle r and z. Above, the superficial impedance δ can be called tangential because it is based on horizontal components of the magnetic field H_φ and electric fields E_r , and calculated according to a known formula

$$\delta = -\frac{1}{\mu_{0m}c}\frac{E_{r0}}{H_{\varphi 0}}\Big|_{z=0}. \qquad (1)$$

In here μ_{om} - magnetic constant, c – the speed of light.

Measured impedance by the value of the electromagnetic field component in the well can be called normal impedance δ^n. It is calculated by formula

$$\delta^n = -\frac{1}{\mu_{0m}c}\frac{E_r}{H_\varphi}, \qquad (2)$$

and turns out to be equal

$$\delta^n = \frac{k_0^2}{k^2}\sqrt{1-\delta^2} = \frac{\delta^2}{\sqrt{1-\delta^2}}. \qquad (3)$$

Here the wave number in the atmosphere $k_0 = \omega/c$, and a square of wavelength in the earth's media

$$k^2 = \frac{\omega^2}{c^2}\left(\varepsilon + \frac{i\sigma}{\varepsilon_0\omega}\right). \qquad (4)$$

In here ε_0 - dielectric constant, ε and σ - the resulting dielectric permeability and electrical conductivity of the earth's rock at depth. Normal impedance, as the result (3) shows, does not depend on the vertical coordinate. If the media is homogeneous, regardless of the depth of the probe's sinking into the well, normal impedance will always be the same. However, the real earth environment is heterogeneous, so the normal impedance measured at different depths of the probe will be different. This circumstance will allow to judge the properties of rocks lying in the depths of the lithosphere, in particular the presence of minerals.

Theory

Two methods can be used to calculate the electromagnetic field component. The first is to create a wave equation with a source for vector potential. For the latter, the solution is expressed in the form of Sommerfeld's integral, from where all the components of the fields are located. The second simpler method is to compile a wave equation for the only non-zero component of the magnetic field H_φ. This method was implemented by solving the wave equation by separating the variables in the [8]. For the convenience of links, here are the results of calculations for the non-zero component of the electromagnetic field in a solid media, expressed through the given surface impedance (K – constant, non-playing role in determining impedance):

$$H_\varphi = -i\frac{k_0}{\mu_{0m}}\sqrt{1-\delta^2}\,\frac{K}{\sqrt{r}}\exp\left(-i\omega t + ik_0\sqrt{1-\delta^2}\,r - ik_0\frac{1-\delta^2}{\delta}z\right) \quad (5)$$

$$E_r = i\omega\delta\sqrt{1-\delta^2}\,\frac{K}{\sqrt{r}}\exp\left(-i\omega t + ik_0\sqrt{1-\delta^2}\,r - ik_0\frac{1-\delta^2}{\delta}z\right) \quad (6)$$

$$E_z = i\omega\delta^2\frac{K}{\sqrt{r}}\exp\left(-i\omega t + ik_0\sqrt{1-\delta^2}\,r - ik_0\frac{1-\delta^2}{\delta}z\right) \quad (7)$$

Now, according to (1), we find that the value of δ is exactly the superficial impedance. And from the formula (2) the result (3) follows.

When normal impedance is known from the measurements, it is now easy to restore the values of dielectric permeability from the result (3):

$$\varepsilon = \mathrm{Re}\frac{\sqrt{1-\delta^2}}{\delta^n}, \quad (8)$$

and electrical conductivity:

$$\sigma = \varepsilon_0\omega\,\mathrm{Im}\frac{\sqrt{1-\delta^2}}{\delta^n} \quad (9)$$

If the values are known for prior reasons Ɛ , σ and with them a square of wave number (4), the given surface impedance can be calculated from the ratio of (stemming from (3))

$$\delta = \frac{k_0}{k}\sqrt{\frac{1}{2}\left(\sqrt{1+\left(\frac{2k}{k_0}\right)^2}-1\right)}. \quad (10)$$

Conclusion

In geo-intelligence there is a carotazh method of exploration of the earth's bowels. At the same time, it becomes possible, with the help of constant or low-frequency currents, to establish the distribution of electrical conduction of the earth's bowels in depth. It is shown here that with the help of variable electromagnetic waves from different sources, it is possible to restore not only the distribution of electrical conductivity, but also the dielectric permeability of rocks in the depth of their burrowing. This is possible a more detailed and informative study of the distribution of different rocks in the lithosphere, in particular, and minerals. To do this, it is necessary only to the standard research complex additionally have a magnetic sensor of such form to freely place in the well-used in carotazh.

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