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Automation of oil and gas exploration by active seismic electric method

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Abstract. The paper considers the issues of automation and improving the performance of the field work by the seismic electric method. It is shown that the measurement scheme used today is not optimal. It leads to a long-term deployment of the measuring installation, as well as the inability to use it in difficult geological and climatic conditions. The authors of the paper propose to use special magnetic antennas for recording the electromagnetic field, which eliminate all the drawbacks of grounded electric dipoles. It is shown that if simultaneously registering the various components of the electromagnetic field, it is possible to estimate the depth of the productive layers. The data of observations of seismic electrical effects in the gas-condensate field for various x, y, z components are given.

1. Introduction

The basis of the seismic electric method application for hydrocarbon detection was described in [1]. In this case, specialized sources of the electromagnetic field and seismic radiation are used. The technology assumes the use of 6 URAL-class vehicles in the ground version, as well as the use of several boats in case of the sea performance. The system operates in a pulsed mode as follows: first, a seismic pulse is given, and then, with a small delay, an electromagnetic pulse is given. Reception of signals in the latest variations of this method is carried out both on the streamer of seismic receivers and on the streamer of grounded electric dipoles. The delay time of the electromagnetic pulse is selected manually and corresponds to the expected depth of the productive formations. Thus, the system with two active emitters of seismic and electromagnetic fields has a number of significant drawbacks, such as weight and size indicators, temporary performance of work, as well as the inability to use in difficult conditions (mountains, taiga, swamps).

The further development of the technology was the use of the so-called “semi-active” method, when the active source of the electromagnetic field is excluded from the measurement scheme. The authors of papers [2–5] described the theory and practice of conducting field work, as well as the results of observations. The disadvantages of this technology can be attributed to the fact that the deployment of an electric dipole spit is impossible or is associated with large labour costs in difficult geological and climatic conditions, for example, in winter, the use of electrodes is impossible because of the freezing of the soil. By experience, many authors indicate that the maximum efficiency of this method is achieved when working at frequencies up to 90-100 Hz.



The authors of the paper have already carried out the work “semi-active and passive [6] methods. It was shown that the use of an active seismic source makes it possible to estimate the depth of the reservoir due to the calculation of the signal delay time. The passive version of this method, without using active field sources, allows for the primary detection of productive anomalies. Estimation of the depth in this case is possible only conditionally. The standard measurement scheme of the seismic electric method is shown in figure 1.

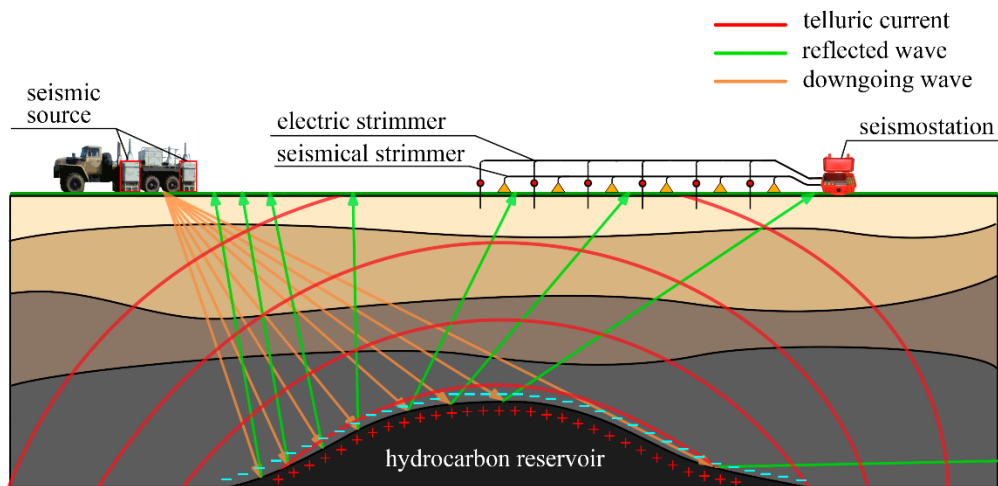


Figure 1. Standard measurement scheme for seismic electric method.

This paper reviews the issues of automating the standard (“semi-positive”) seismic electric method of hydrocarbon detecting through the use of specialized magnetic antennas. In this case, there are two options: exclusion of electric dipoles from the measurement scheme, registration of the electromagnetic field is carried out only by magnetic antennas, thus increasing the productivity of field work. It also makes possible to use this method in winter, when there is soil freezing. The second option is the sharing of electric dipoles and magnetic antennas, which will allow us to estimate more accurately the depth of the hydrocarbon deposit by calculating the conductivity at different depths.

2. Methods and materials

According to the experience [7], to register the magnetic component of the electromagnetic field, it is required to register values of sufficiently small amplitude of the order of 10^{-4} - 10^{-6} A/m, which is possible only through specialized magnetic antennas. The antenna is shown in figure 2. The antenna for recording signals with an amplitude of the order of $1 \mu\text{V}$ in the frequency range from 0.1 to 100 Hz will be a magnetic coil with 290 thousand turns and a rectangular ferrite core of 31x26x800 mm and a magnetic permeability of 700.

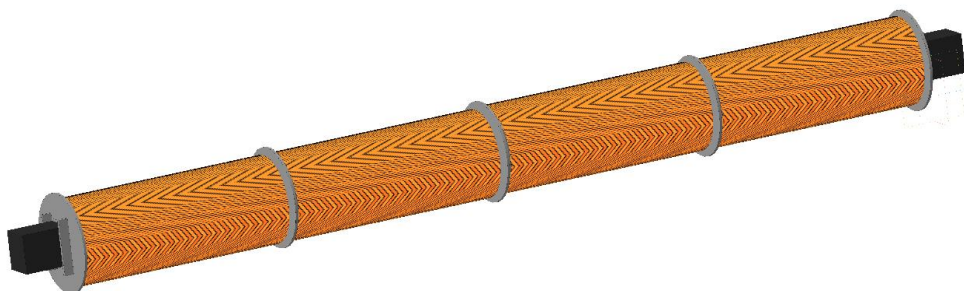


Figure 2. The magnetic antenna.

The use of such an antenna will allow registering a magnetic component of the electromagnetic field, which is caused by the presence of a seismic electric effect. The use of three such antennas will allow us to simultaneously register the three orthogonal components of the magnetic component of the electromagnetic field. This method with simultaneous registration of the E and H components of the electromagnetic field consists in calculating the specific apparent resistance at various frequencies according to the formula:

$$\rho_T = \frac{|Z|^2}{2 \cdot \pi \cdot f \cdot \mu_0}, \quad (1)$$

where ρ_T – apparent resistance measured in ohms/m, Z - impedance of the lower half-space, f - frequency, μ_0 - vacuum permeability. And taking into account [10], the impedance for a layered half-space will be determined by the following formula:

$$Z_n = \sqrt{-i \cdot 2 \cdot \pi \cdot f \cdot \mu_0 \cdot \rho_1 \cdot R_n} \quad (2)$$

where R_n – reduced impedance of a layered half space, ρ_1 - homogeneous half-space impedance. Thus, by registering various E and H components of an electromagnetic field, a cut can be made both in terms of conductivity and seismic electric effect.

An estimate for the conductivity of sedimentary rocks $\sigma_2=10^{-3}-10^{-2}$ indicates that signals with amplitudes of 10–160 μV for frequencies from 1 to 20 Hz will be observed for an electric dipole equal to 200 meters on the Earth's surface. These amplitudes correspond to the values that are observed in the practice of field work [8].

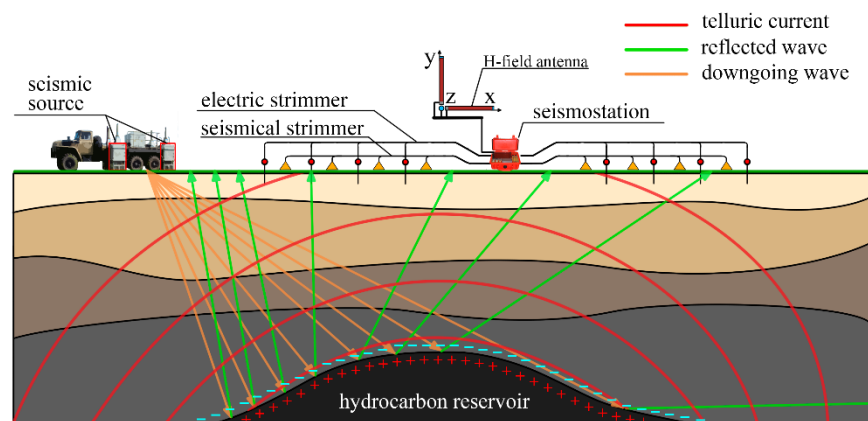


Figure 3. Measurement scheme using specialized magnetic antennas.

Consequently, in order to minimize the influence of space heterogeneity and the nonstationarity of the natural noise of the natural fields of the Earth, the dipole length should be minimized in order to ensure an acceptable signal-to-noise ratio. The search for the maximum value of the seismic electric effect in this case can be carried out using the following formula:

$$R_{ij}(\tau) = \max\left(\frac{1}{T} \cdot \int S_i(t) \cdot E_j(t - \tau) dt\right), \quad (3)$$

where $S(t)$ is a signal received by a seismic receiver and $E(t)$ – electric dipole signal, T – signal observation time, i, j – starting counts of $S(t)$ and $E(t)$ signals, τ – time shift for calculating the intercorrelation function. The obtained values of i, j in this case show the delay of the seismic signal relative to the electrical one, which also allows us to estimate the depth of the hydrocarbon deposit, which according to the author is an important sign for determining the depth of the hydrocarbon deposit.

Therefore, for the practice of field work when building a profile of observations, it is also necessary to build graphs of i_n and j_n delays for different frequencies, which will make it possible to estimate more accurately the depth of the underlying layers.

Automation of work in this case will be achieved by calculating these parameters in real time, which will reduce labour costs and automate the measurement process.

3. Results and discussions

As it was mentioned above, the authors of this paper have already recorded signals at the Bystryansk field (Krasnoyarsk Region). In the paper, figure 4 shows the data obtained according to the measurement scheme shown in figure 1. The seismic receiver and the centre of the grounded electric dipole was (200m) at the distance of 400 meters, the sampling frequency was 1 kHz. The measurements were carried out in automatic mode with simultaneous recording of seismic and electrical signals to the seismic station manufactured by SGD. Processing was carried out by calculating the mutual correlation function of signals shifted relative to each other at different time intervals in order to compensate for the delay of seismic signals.

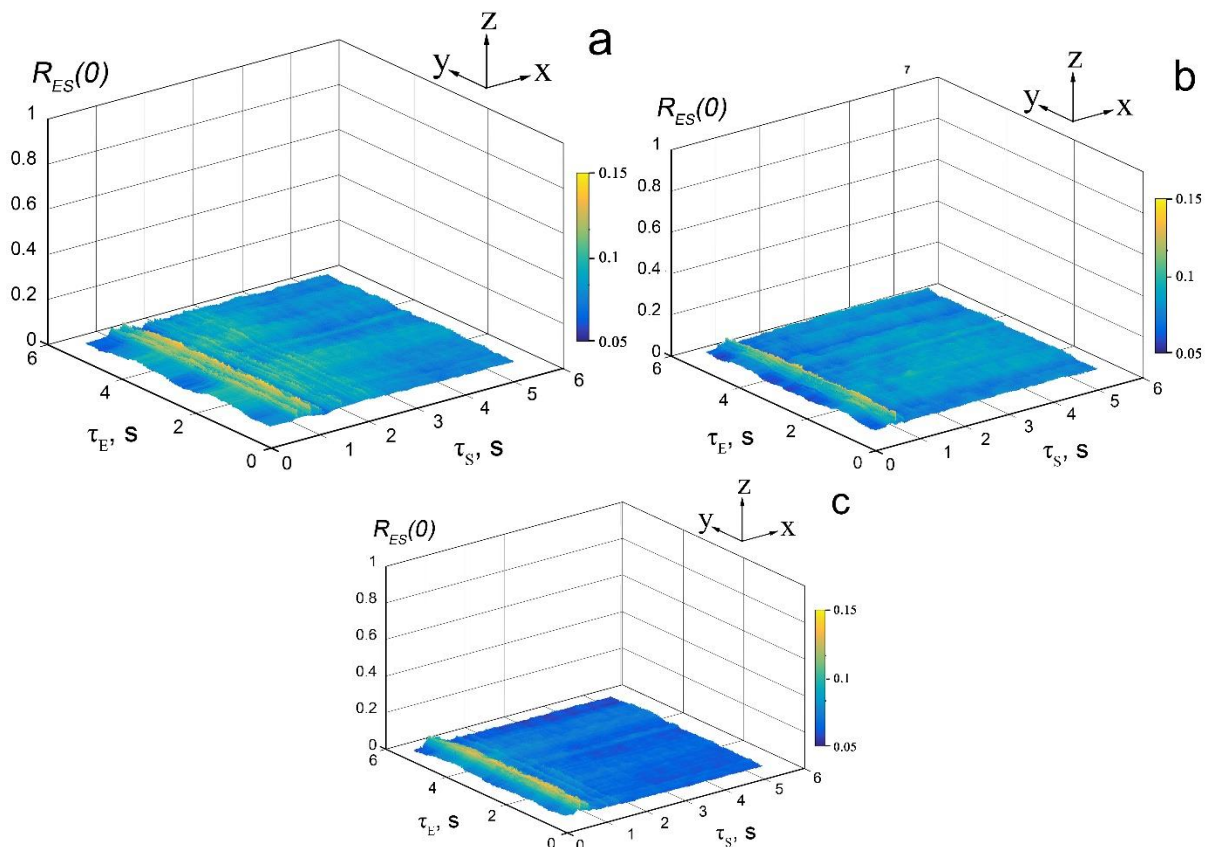


Figure 4. Observations of the seismic-electric method for various x, y, z components of the seismic signal.

As it can be seen from the figures, the pre-time registration of seismic fields at a single seismic station allows us to automate the process of collecting geophysical information, and in the post-processing mode it is possible to estimate the depth of the layers and the conductivity of the underlying soil. Thus, as it can be seen from the graphs obtained, the propagation speed of various X, Y, Z components of seismo-acoustic waves is different, and as a result, the assessment of seismic-electrical effects, the depth

of the layers should be carried out taking into account this discrepancy. The most obvious option is to calculate the arithmetic mean time lag of the seismic signal of the various components.

At the shift time $T = 1c$, the maximum of the mutual correlation function is observed (with values of the order of 0.1) for almost all times of the signal shift received at the grounded electric dipole.

4. Conclusion

Thus, the automation of the measurement process during the operation of the seismic electric method consists in the use of specialized magnetic sensors, the use of standard inputs of a digital seismic station for recording the components of the electromagnetic field. The processing of the data can be carried out in conjunction with the processing of seismic data. According to the authors, the use of such a measurement scheme eliminates the existing shortcomings of the standard seismic electric method.

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