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Determination of reflection coefficient contrast in medium over hydrocarbon accumulation

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Abstract. The article analyses the method of searching for hydrocarbon accumulation on the basis of determining the reflection coefficient contrast. Experimental research on hydrocarbon accumulation of the Republic of Belarus is carried out. Was used a method for estimating the reflectivity of the medium over hydrocarbon accumulation under the influence of electromagnetic waves with linear polarization based on the contrast of reflection coefficients between the measurement points of the investigated profile and the calibration measurement point located outside accumulation. The anomalous behaviour of the reflection coefficient contrast was found to correspond to the hydrocarbon boundary. The results of experimental research confirmed the increase in the accuracy of determining the boundaries of hydrocarbon accumulation based on the method of determining the reflection coefficient contrast. The obtained research results can be used in exploration geophysics.

1. Introduction

The problems considered in this article are relevant for the creation of methods for searching and delineation of hydrocarbon accumulation [1 – 3]. Increasing the accuracy of hydrocarbon boundary delineation can be achieved on the basis of studies of the real and phase components of the surface impedance of medium over accumulation using dual-frequency signals [4]. The discovery of new hydrocarbon accumulation is becoming the most important task for the improvement of the energy sector in Belarus and Uzbekistan. Easy-to-find hydrocarbon accumulation at shallow depths (1-3 km to 5 km) are exhausted over time, forcing the development of complex sections and exploration at deeper sites with complex climatic conditions [5]. 3D specific resistivity models of medium in the Barents Sea based on the acquisition of inverted CSEM data help to identify areas of interest with minimizing exploration risks [6]. Advances with CSEM conducted in the 1980s in Australia and Europe for resistive reservoir/carbonate mapping laid down a strategy for developing equipment and modelling techniques, improving economics and reducing exploration costs several times [7]. The principles of calculations of electromagnetic fields created by charged particles near dielectric objects have a wide field of application [8]. The use of a downhole system can be applied to reservoir monitoring [9]. The processing of the acquired information plays an important role, for example, the response curves from multiple pulses are averaged to reduce noise with integration into time windows [10]. Three-dimensional imaging

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methods based on the vertical-vertical method with controlled signals provide information on the specific impedance of geological medium [11]. The accuracy of structure mapping is improved by magnetotelluric and seismic methods [12]. The application of transient CSEM methods for shallow water (at depths less than 500 m) in a gas field in Norway is based on a linear electric field [13]. In [14], the authors use a systematic approach of the theory of incorrect problems with interpretation of magnetotelluric and magnetovariation modes. The authors have accumulated extensive experience in resistivity logging for reservoir monitoring [15].

The purpose of this research is to improve the accuracy of hydrocarbon reservoir boundary delineation.

2. Research methodology

The set task is solved by the fact that in the method of electrical exploration of hydrocarbon accumulation the investigated profile is irradiated by electromagnetic wave with the angle of incidence θ = 300 at fixed frequencies with vertical polarization, receive the reflected signal in the measurement points of the investigated profile and determine the boundary of hydrocarbon accumulation by anomalous values of the measurement index. Irradiation is carried out with a two-frequency electromagnetic wave in modes with a low-frequency signal in the frequency range of 1 - 10 MHz and with a high-frequency signal in the frequency range of 700 - 1000 MHz with amplitudes $E_2 = 0,1\ E_1$ and $E_2 = 10\ E_1$, where E_1 is the amplitude of the low-frequency signal and E_2 is the amplitude of the high-frequency signal, at the points of the reflected signal reception the reflection coefficient from the investigated profile is measured, and the position of the accumulation boundary is determined by the anomalous values of the reflection coefficient contrast between the measurement points of the investigated profile and the calibration measurement point located outside the accumulation.

When selecting the frequency range 700 - 1000 MHz, the method of estimating the reflectivity of the medium over hydrocarbon accumulation under the influence of electromagnetic waves with linear polarization by the contrast of reflection coefficients between the measurement points of the investigated profile and the calibration measurement point located outside the accumulation was used by the formula [2]:

$$\Delta R = 20\, lg\left|\dot{R}_k - \dot{R}_i\right|, \quad (1)$$

where: $\dot{R}_k$– reflection coefficient at the calibration measurement point located outside the accumulation;

$\dot{R}_i$ – reflection coefficient at the measurement points of the investigated profile.

The value of the reflection coefficient at the calibration measurement point located outside the accumulation for electromagnetic waves with vertical polarization is determined by the formula:

$$\dot{R}_k = \frac{\dot{\varepsilon}_k sin\alpha - \sqrt{\dot{\varepsilon}_k - cos^2 \alpha}}{\dot{\varepsilon}_k sin\alpha + \sqrt{\dot{\varepsilon}_k - cos^2 \alpha}} = \left|\dot{R}_k\right| exp(j\varphi_k), \quad (2)$$

where: $\dot{\varepsilon}_k = \varepsilon_k - j\frac{\sigma_k}{\omega\varepsilon_0}$ – complex dielectric permittivity of the underlying surface;

ε_k – dielectric permittivity of a homogeneous underlying surface;

σ_k – conductivity of homogeneous underlying surface;

ω – circular frequency of electromagnetic waves;

ε_0 – dielectric constant;

α – angle of incidence of electromagnetic waves;

φ_k – phase of the reflection coefficient from a homogeneous underlying surface;

$\left|\dot{R}_k\right|$ – modulus of reflection coefficient from homogeneous underlying surface.

Reflection coefficient at the measuring points of the investigated profile

$$\dot{R}_i = \frac{\dot{b}_1 \cos\alpha + \dot{b}_3(cos^2\alpha - 1)}{\dot{b}_2 \cos\alpha + \dot{b}_4(cos^2\alpha + 1)} = \left|\dot{R}_i\right| exp(j\varphi_i), \quad (3)$$

where: $\dot{b}_{1,2} = \sqrt{\dot{\varepsilon}_R \dot{\varepsilon}_L} \mp 1$,

$\dot{b}_3 = \sqrt{\dot{\varepsilon}_R} + \sqrt{\dot{\varepsilon}_L}$,

$\dot{b}_4 = \dot{\varepsilon}_R + 2\dot{\varepsilon}_R\dot{\varepsilon}_L + \dot{\varepsilon}_L$,

$|\dot{R}_i|$ – modulus of reflection coefficient from anisotropic medium;

φ_i – phase of reflection coefficient from anisotropic medium.

To generate electromagnetic waves to study the properties of the medium over hydrocarbon accumulation, we choose a two-frequency signal:

$$\vec{u}(t) = \vec{u}_1(t) + \vec{u}_2(t) = U_1 \cos\omega_1 t + U_2 \cos\omega_2 t, \quad (4)$$

where $U_1, U_2, \omega_1 = 2\pi \cdot f_1, \omega_2 = 2\pi \cdot f_2$ – amplitudes and frequencies of these electromagnetic waves. The measurement modes are determined by the coefficients of amplitudes ratio of the two waves and their frequencies

$$k_u = \frac{U_2}{U_1}, k_\omega = \frac{\omega_1}{\omega_2} \quad (5)$$

The mode of the powerful low-frequency signal is determined by the amplitude and frequency ratios:$k_u \ll 1, k_\omega \ll 1$, powerful high-frequency signal mode – $k_u \gg 1, k_\omega \ll 1$.

The accumulation boundary is determined by the anomalous values of reflectance contrast between the measurement points of the investigated profile and the calibration measurement point located outside the accumulation.

3. Discussion of results

Experimental research is carried out on Yuzhno-Tishkovskoye, Marmovichi of hydrocarbon accumulation in Gomel region.

Irradiation of the investigated area of the earth surface with two-frequency electromagnetic wave with vertical polarization at frequency f_2 = 700 MHz with frequency f_1 = 1 MHz (example 1) in modes of powerful low-frequency (mode I) and powerful high-frequency signals (mode II) was carried out. In mode I k_u = 10^{-1}, k_ω = $1{,}43 \cdot 10^{-3.}$ In mode II k_u = 10^1, k_ω= $1{,}43 \cdot 10^{-3}$. The magnitude of the reflected signal was used to determine the contrast of reflection coefficients between the measurement points of the investigated profile and the calibration measurement point. The measuring points were set at 100m intervals for Yuzhno-Tishkovskoye hydrocarbon accumulation, at 50 m intervals for Marmovichi hydrocarbon accumulation and for Geological hydrocarbon accumulation along a straight path connecting the reference point and the measuring points.

At the field boundary (points 550, 1030 for Yuzhno-Tishkovskoye hydrocarbon accumulation and points 250, 400 for Marmovichi hydrocarbon accumulation) the contrast of reflection coefficients increases up to values of 3.20 dB (mode I) and 2.90 dB (mode II) at the point 550 m. There is an increase in contrast to values of 3.80 dB (mode I) and 3.70 dB (mode II) at 250 m.

There is an increase in contrast to values of 3.50 dB (mode I) and 3.00 dB (mode II) at the point 1030 m. There is an increase in contrast to values of 3.70 dB (mode I) and 3.50 dB (mode II) at 400 m (See fig. 1 - 4).

Irradiation of the investigated area of the earth surface with a two-frequency electromagnetic wave with vertical polarization at frequency f_2 = 850 MHz with frequency f_1 = 5 MHz (example 2) in modes I and II was carried out. In mode k_u = 10^{-1}, k_ω= $5{,}88 \cdot 10^{-3}$. In mode II k_u = 10^1, k_ω = $5{,}88 \cdot 10^{-3}$. The magnitude of the reflected signal was used to determine the contrast of reflection coefficients between the measurement points of the investigated profile and the calibration measurement point.

At the field boundary (points 550, 1030 for Yuzhno-Tishkovskoye hydrocarbon accumulation and points 250, 400 for Marmovichi hydrocarbon accumulation) the contrast increases up to values 3, 00 dB (mode I) and 3.00 dB (mode II) at the point 550 m, to the values 3.20 dB (mode I) and 3.10 dB (mode II) at the point 1030 m, to the values 3.60 dB (mode I) and 3.90 dB (mode II) at the point 250 m, to the values 3.50 dB (mode I) and 3.90 dB (mode II) at the point 400 m.

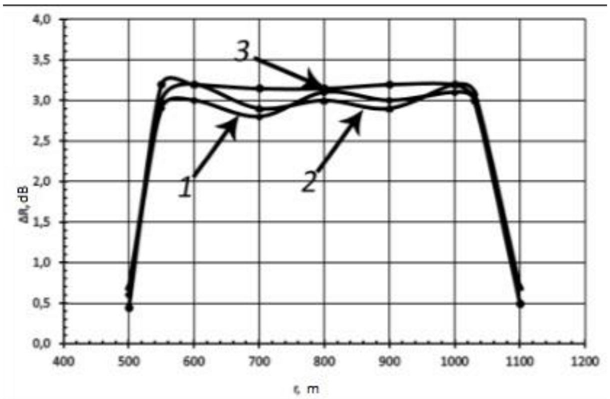

Figure 1. Research for Yuzhno-Tishkovskoye field of hydrocarbon accumulation, mode I:
1 – Example 1; 2 – Example 2; 3 – Example 3

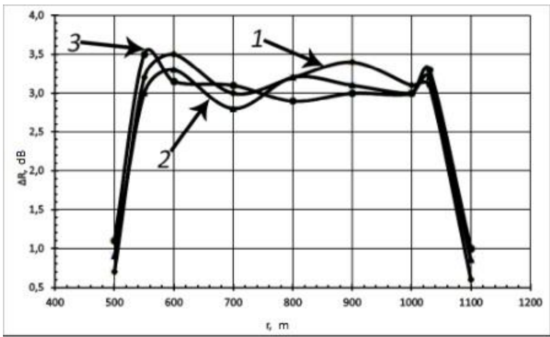

Figure 2. Research for Yuzhno-Tishkovskoye field of hydrocarbon accumulation, mode II:
1 – Example 1; 2 – Example 2; 3 – Example 3

Irradiation of the investigated area of the earth surface with a two-frequency electromagnetic wave with vertical polarization at f_2 = 1000 MHz with frequency f_1 = 10 MHz (example 3) in modes I and II was carried out. In mode I k_u = 10^{-1}, k_ω = $10 \cdot 10^{-3}$. In mode II k_u = 10^{1}, k_ω = $10 \cdot 10^{-3}$. According to the magnitude of the reflected signal, the contrast of reflection coefficients between the measurement points of the investigated profile and the calibration measurement point was determined.

At the field boundary (points 550, 1030 for Yuzhno-Tishkovskoye hydrocarbon accumulation and points 250, 400 for Marmovichi hydrocarbon accumulation) the contrast increases up to values 3, 50 dB (mode I) and 3.20 dB (mode II) at 550 m, to 3.30 dB (mode I) and 3.00 dB (mode II) at 1030 m, to 4.00 dB (mode I) and 4.00 dB (mode II) at 250 m, to 3.90 dB (mode I) and 4.00 dB (mode II) at 400 m.

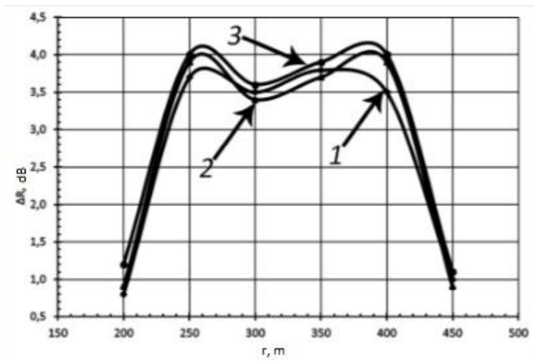

Figure 3. Research for Marmovichi field of hydrocarbon accumulation, mode I:
1 – Example 1; 2 – Example 2; 3 – Example 3

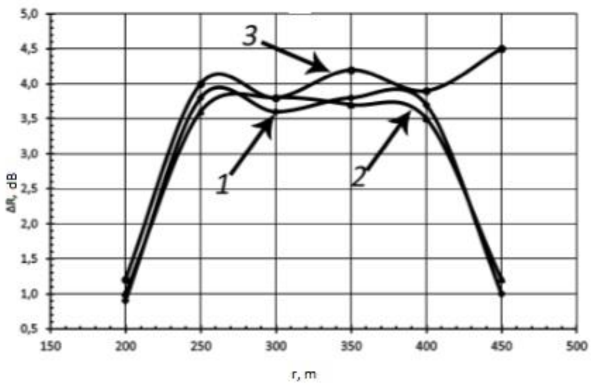

Figure 4. Research for Marmovichi field of hydrocarbon accumulation, mode II:
1 – Example 1; 2 – Example 2; 3 – Example 3

The accuracy of measurements was defined as the difference between the distances corresponding to the deposit boundary (known value) and those determined by this method, expressed in per cent.

The results of the conducted research confirmed the increase of accuracy of hydrocarbon accumulation boundary definition of the claimed method by 20 - 30 %.

4. Conclusion

As a result of the conducted research, it should be noted:

- The application of a wide range of frequencies improves the accuracy of field boundary delineation based on the determination of reflectance contrast.
- Determination of reflection coefficient contrast in two modes contributes to the improvement of resolving power of accumulation delineation.
- Improving the informative value of methods of searching for hydrocarbon accumulation due to the variation of the ratio of the amplitudes of the two waves and their frequencies by the coefficients.

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