Use of 3-D seismic data for detection of hydrocarbon traps within the northern side of the Dnieper-Donetsk Depression

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SUMMARY

The modern approach to prospecting and exploration of gas and oil traps within the northern side of the Dnieper-Donetsk depression is considered. The results of volumetric seismic surveys performed in this region indicate a decrease in the efficiency of traditional technologies for predicting hydrocarbon traps, which are based on the analysis of structural and tectonic models. In some cases, the use of only the structural factor does not give positive results. This is due in part to the absence of major structural traps. Accordingly the development of such deposits may not achieve the desired profitability. The scheme of location of geological bodies and structures promising for the presence of hydrocarbons is given, from which the next results follow. A significant part of the structures that are conventionally considered promising are characterized by a low probability of hydrocarbons. The practice of drilling wells on such structures confirms this conclusion. It is concluded that the increase in the efficiency of prospecting, exploration and development of gas and oil deposits in this region is related to the use of direct indicators of hydrocarbons. The efficiency of application of different sets of seismic attributes is analyzed. The most appropriate way to interactively analyze the volume distributions of seismic attribute values has been defined. Examples of detection of hydrocarbon traps and determination of their physical properties, which are confirmed by drilling wells, are given. Keywords: seismic image, seismic inversion, multi-attribute classification, direct hydrocarbon indicators.

Introduction

Modern approaches to the search for hydrocarbon traps in the Dnieper-Donetsk depression involve the use of volumetric seismic data as quite informative. Together with the construction of the structural-tectonic model, the distributions of the values of seismic attributes are studied, which allow to obtain quantitative characteristics of the physical properties of rocks. In some cases, this allows to accurately detect hydrocarbon traps of any type. Exploration of lithological hydrocarbon traps is of considerable interest for the licensed areas of the northern side of the Dnieper-Donetsk depression. A series of articles is devoted to the study of such traps, in particular (Vyzhva et al., 2018a, 2019a), as well as abstracts of reports at international conferences (Vyzhva et al., 2018b, 2019b; Streltsova et al., 2019). The results of these works show that lithological traps are quite common within the northern side of the Dnieper-Donetsk depression, and their exploration is of practical interest. Detection of lithological traps is based on the analysis of the values of seismic attributes that have a certain physical meaning. Quite informative for the detection of lithological traps are such seismic attributes as acoustic impedance, including the relative acoustic impedance, the envelope of the seismic signal, the instantaneous frequency. Also of interest are seismic images obtained from seismograms with limited ranges of seismic beam angles. Such images are used to obtain AVO attributes and determine the nature of the saturation of rocks with hydrocarbons. The distribution of longitudinal and transverse velocity ratio values is also often used to detect lithological hydrocarbon traps. These and some other seismic attributes are also called direct indicators of the presence of hydrocarbons. It is clear that the physical content of these indicators does not limit their use to detect only lithological traps. They are used with equal success to detect the presence of hydrocarbons in traps of any type, including structural. However, the main approach to detecting non-structural traps is the use of direct hydrocarbon indicators.

Technology of detection of lithological hydrocarbon traps within the northern side of the Dnieper-Donetsk depression.

When selecting and testing such technology, the authors aimed to obtain reliable and at the same time stable solutions. The solution to this problem is based on determining the appropriate relationship between the complexity and stability of the algorithms used. Regarding the determination of the properties of lithological traps, the desire to improve the accuracy of solutions is always faced with the need to complicate the technology and use seismic data with increased requirements for their quality. However, the vast majority of the results of seismic surveys for one reason or another are characterized by a fairly high level of interference. In particular, this is typical for seismograms recorded on the northern side of the Dnieper-Donetsk depression, as well as for the results of their processing, including three-dimensional seismic images of the geological environment. And if the complexity of the technology gives positive results for synthetic seismic data, then for real data, the opposite results are often observed. They are associated with instability in the calculation of seismic attributes from seismograms and seismic images with a low signal-to-noise ratio. In such cases, minor errors in seismic data cause significant errors in the distribution of seismic attribute values used to detect and determine the characteristics of lithological hydrocarbon traps.

Given these considerations, the authors conducted a series of experiments and tests to determine the optimal set of seismic attributes to detect lithological hydrocarbon traps on the northern side of the Dnieper-Donetsk depression. An important attribute is the envelope of the seismic signal. The signal envelope attribute always has positive values that reach the maximum value of the amplitude of the seismic record. It helps to highlight the so-called bright spots on seismic records, which correspond, for example, to the accumulation of gas. Bright spot is a term used to describe anomalous high-amplitude zones in seismic, which are usually interpreted as a gas indicator in sedimentary rocks or productive strata. Bright spots may be associated with hydrocarbon formations and potential hydrocarbon traps. The attribute also helps to highlight changes in lithology that may be poorly reflected in seismic images.

The next necessary attribute is the relative acoustic impedance. The initial data for calculating the relative acoustic impedance are seismic traces in the form of sequences of reflection coefficients (Taner, 1992). The calculation of the relative acoustic impedance is to solve the differential equation. The exact solution of the differential equation requires additional conditions or additional information. In this case, such information is the low-frequency trend of the acoustic impedance. To take this trend into account, a priori information is used in the form of acoustic impedance values in wells.

It should be noted that the acoustic impedance, as well as the relative acoustic impedance, is characterized by a stable correlation with the porosity of rocks. This follows from the clear physical meaning of this attribute. Small values of relative acoustic impedance correspond to low velocity and density, which characterizes the rock with high porosity.

Calculating the volume distributions of seismic attributes values is part of the technology for detecting lithological hydrocarbon traps. However, no less important part of it is to determine the method of their analysis. The main task of such an analysis is to identify so-called geological bodies. Such bodies are defined as connected groups of cells that have certain properties. The main approaches to the identification of geological bodies with certain properties in the Dnieper-Donetsk depression are considered in the works (Vyzhva et al., 2019a, 2019b).

Examples of detection of hydrocarbon traps within the northern side of the Dnieper-Donetsk depression.

Consider the part of research area, which has a size of about 500 sq. km. Figure 1 shows a scheme of the location of geological bodies that are promising for the presence of hydrocarbons. In this case, the color palette does not carry any information about the distribution of values of seismic attributes. Different geological bodies are shown in different colors for ease of visual perception. All geological bodies belong to the Carboniferous sediments. The lines in the scheme show the structures found in the sediments of the Carboniferous age, which are considered promising for the presence of hydrocarbons for traditional structural seismic exploration. Different structural plans are presented in different colors.

The analysis of scheme in Figure 1 shows significant differences between classical perspective structures and geological bodies determined using direct hydrocarbon indicators. Only the north-western part of this area is characterized by the coincidence of found structures and geological bodies saturated with hydrocarbons. The relationship between potentially promising structures and the actual location of hydrocarbon traps of different types, resulting from the scheme shown in Figure 1 are typical for the northern side of the Dnieper-Donetsk depression. In this case the recommendation for wells positions only on the basis of a positive structural factor leads to low success of their drilling. This is evidenced by numerous negative results of drilling in this area. Thus, for successful drilling of hydrocarbon wells it is necessary to use direct indicators of the presence of hydrocarbons for both structural and non-structural traps.

Consider the example of the detection of a gas-saturated geological body in the sediments of the productive horizon M-3 of the Moscow stage of the Middle Carboniferous system. To do this, turn to Figure 2 a, which shows the corresponding geological body with an area of 0.5 sq. km, which is a classic lithological hydrocarbon trap. Lines and color palette determine the depth of the reflective

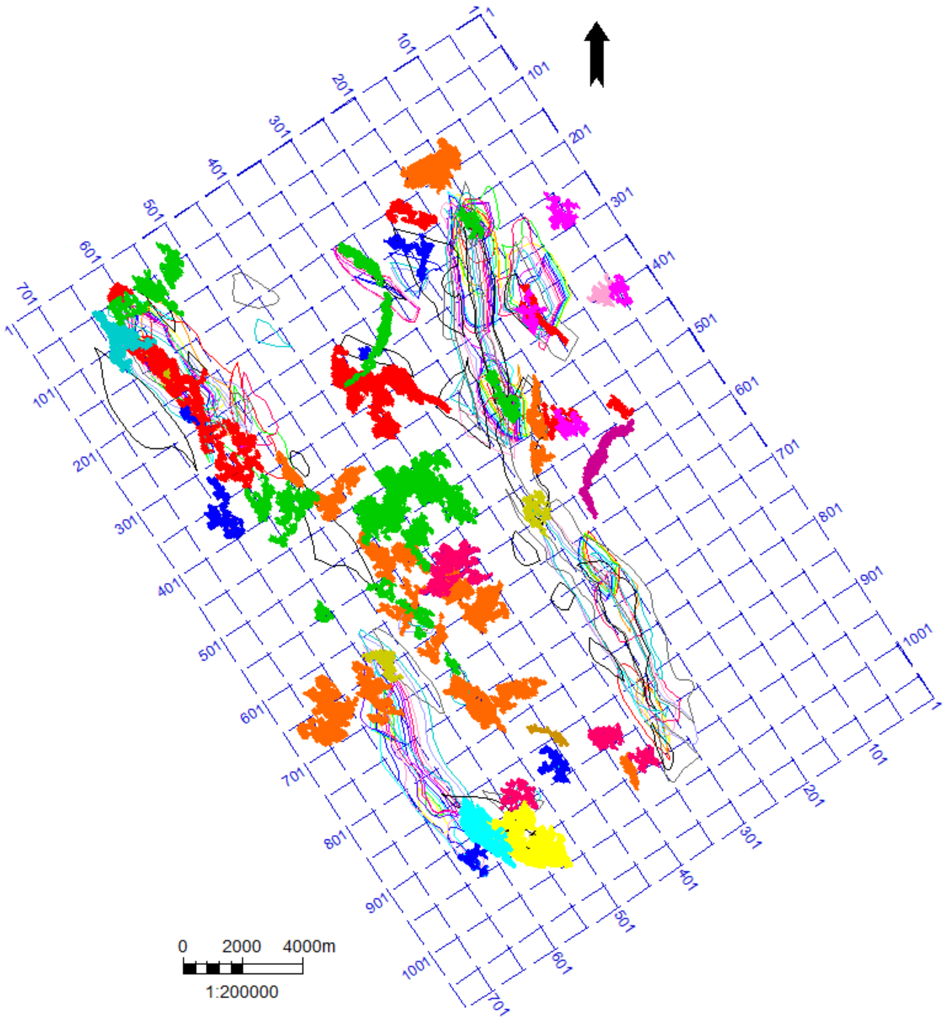
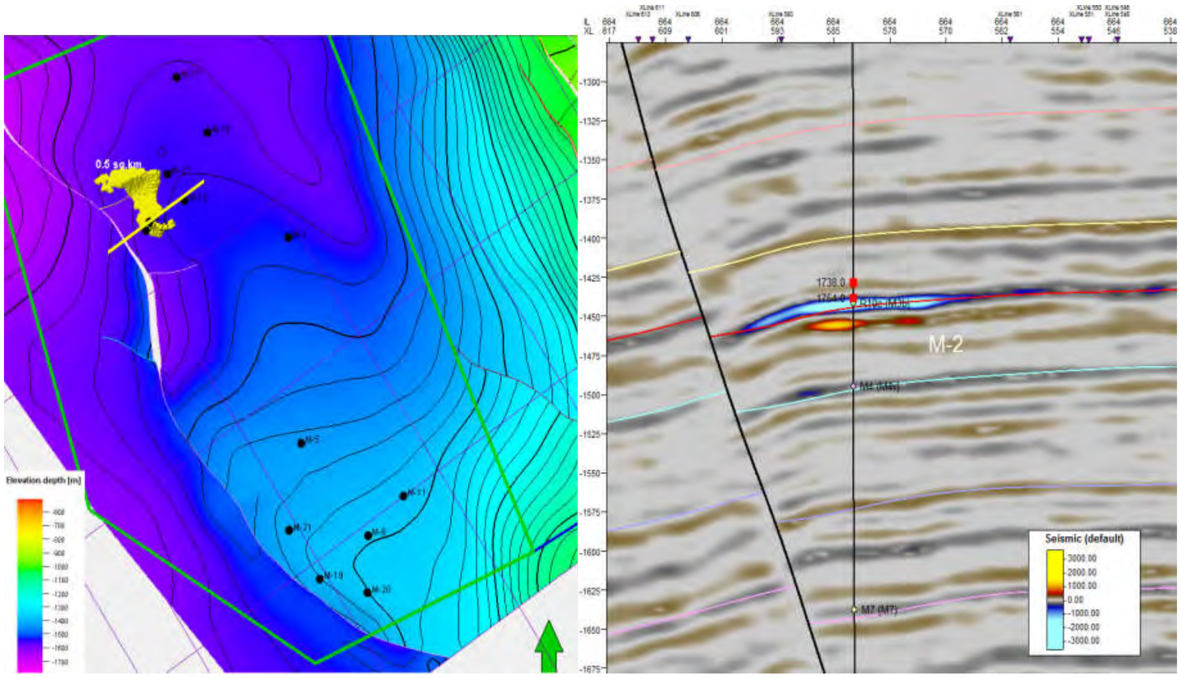


***Figure 1** Layout of geological bodies and structures promising for the presence of hydrocarbons*

boundary in the sediments of the productive horizon M-3 of the Moscow stage of the Middle Carboniferous system. The source data used a three-dimensional seismic image, built on seismograms of common sources with a limited range of seismic rays. In this example, the range of inclination of seismic rays is 10-30 degrees. The section of such a seismic image is shown in Figure 2 b, and its position in the plan is shown in Figure 2 a by line crossing the lithological gas trap. In this example, the informativeness of the seismic signal envelope was sufficient to detect a lithological gas trap.

The presence of gas in the lithological trap is confirmed by a vertical well, which is shown in Figure 2 b. The red dots show the perforation intervals. The gas deposit corresponds to the large amplitudes of the signals of the seismic image waves, which are shown in blue. In other words, the gas deposit shown in the seismic image looks like a classic bright spot. The above vertical section also contains additional important information. Below the gas deposit is a horizontal zone of increased amplitudes of seismic wave signals. It is called a flat spot and determines the contact between gas and water.

Acoustic impedance or relative acoustic impedance can be used to estimate rock porosity and to calculate gas reserves in a lithological trap. However, in this case, the determination of porosity and calculation of gas reserves was made according to logging studies in a well drilled through this trap.



a) b)

Figure 2 *Gas-saturated geological body in the sediments of the productive horizon M-3 of the Moscow stage of the Middle Carboniferous system (a); vertical section of a three-dimensional seismic image obtained from seismograms of common sources with a limited range of seismic beam angles (b)*

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