Use of 3C 2D seismic technology to identify oil-bearing reservoirs

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Summary:

3C multi-wave seismic technology in combination with the 2D surveys allows to supplement seismic images with more detailed information about the reservoir properties of rocks and their saturation type. This technology includes the construction of velocity ratio (Vp/Vs) maps which are correlated with the Poisson coefficient distribution maps. In practice, such method likely increases the efficiency of geological exploration and implements a large economic potential.

Introduction:

The use of Poisson's ratio on assessing hydrocarbon presence in key reservoir intervals has been the focus of increased interest lately. Theoretically, the Poisson's ratio should decrease with high hydrocarbon saturation and increase in water-saturated formations. The results of different field experiments, obtained on sites with known reservoir features, confirm this regularity (Puzyrev, 1997). The relevant data for two oil-bearing areas are shown in figure 1.

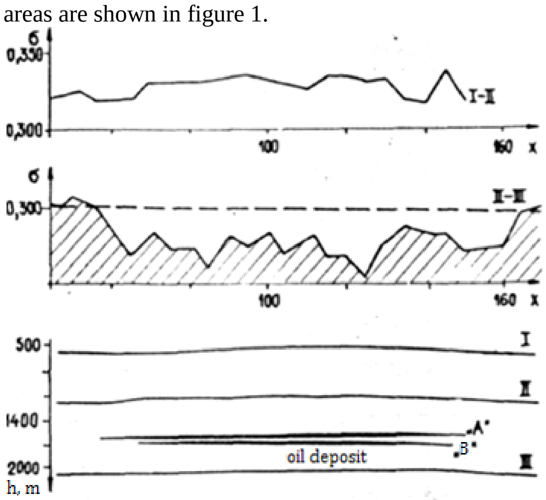

Figure 1: Anomalies of the Poisson's formation ratio in the area of oil deposits based from two oil fields of Western Siberia: I-II - Poisson's ratio in an "empty" layer between seismic horizons I and II; II-III - Poisson's ratio in the reservoir containing the deposit, between horizons II and III. From Puzyrev (1997).

Margrave *et al.* (1998) discussed several problems associated with the practical realization of such methodology in a 3D 3C way. According to their research, maps of Vp/Vs ratios were calculated across the Channel-to-Wabamun interval. Vp/Vs ratios less than 1,8 define productive reservoir facies and are a valuable exploration attribute for that particular place. But because of the high cost of acquiring, processing, and interpreting 3D 3C data, such methodology is still not justified by having the additional S-wave information and direct measurements of Vp/Vs ratio at each particular hard-to-recover oil reservoirs.

This contribution describes the importance of using of 3C 2D seismic exploration technology in hard-to-recover reserves, by using a case study from the Van-Yeganskoye oil field in Khanty-Mansi Autonomous district, Western Siberia. According to the physicochemical properties and composition, the class of this Cenomanian oils belongs to the heavy naphthenic group, which its development is associated with a complex of problems. First, such oils have very high viscosity, being hundreds of times higher than the viscosity of the produced water. This fact makes it difficult for the oil to be displaced by water. Second, all the Cenomanian oil deposits concentrated in that area contain massive gas caps, requiring a non-traditional way of geophysical exploration to locate such reservoirs (Kashirtsev et al., 2013).

Theory and/or Method:

The physical basis of the 3C 2D seismic survey is quite simple. Two wave modes are provided by 3C data: the P-P mode and the P-SV mode. When a vertical-displacement force is applied to the surface of an elastic half-space, an illuminating SV wavefield is created at the source station in addition to an illuminating P wavefield. The depth point of the P-wave reflection where it transgresses into the P-SV wave is not symmetrical between the acquisition and reception points.

The source of seismic vibrations is placed into open holes, in order to avoid additional interference waves caused by the steel casing strings of the well. Figure 2 shows a radial observation system for exploring the near wellbore space. It consists of a general view of the arrangement of the reception lines with three-component receivers of the reflected exchange (P-SV) and monotypic (P-P) waves.

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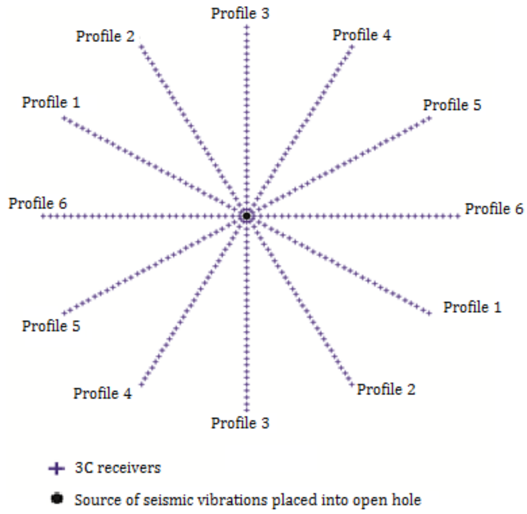

Figure 2: Radial scheme of the arrangement of the reception lines with three-component receivers. The source of seismic vibrations is in the central part of the circuit. There are also six 2D seismic profiles with three-component receivers located symmetrically in relation to the source.

The down-hole vertical-displacement source, which is situated inside the still drilled well, provides elastic vibrations from the depth below the low velocity zone (25-30 meters under surface). This is due to the fact that the further digital & magnetic recording of seismograms of the P-SV wave has less quality than in the P-P wave. So the main reason of such displacement of the source is to avoid any additional influence of the low-velocity zone that makes the recording of P-SV wave transverse extremely problematic.

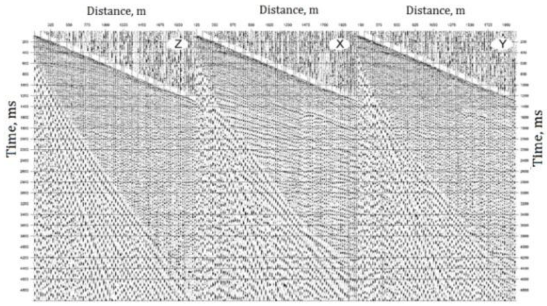

Figure 3: Seismograms for three components (from the 3C VSP data). Z-component corresponds to a P wave, X- and Y-components – transverse waves of different polarization, SV and SH.

The seismograms clearly show the dependence of the propagation velocity of different types of elastic waves, according to the signal-to-noise ratio. It is worth noting that the propagation of transverse waves in an anisotropic field occurs along two horizontal orthogonal components. The SV wave (X-component on the Figure 3) propagates along the direction of fracturing of the rock strata, while the SH wave is transverse-directed. Y-component seismograms have the lowest recording quality, especially in the deep zones, because recording them is almost entirely covered by the pre-surface (Rayleigh type) interference waves. In general, the Y-component data carry an important information only at shallow depths, supplementing data of the X-component for further interpretation (Hardage et al., 2011). In particular, it refers to areas with the complex rock structure, which is often complemented by different rock disjunctive disturbances.

This technology implies analogue three-component receivers, located at a small distance from each other on the reception profiles. The device's mechanism of action consists of three different signals received along three axes of propagation of elastic seismic waves. Following this, medium vibrations in different directions are being recorded. Then, with the help of a converter, seismograms are transferred to an electrical signal along seismic traces, which is a function of the vibration of the elastic medium. In addition to interpretation data for the three-component receivers, the seismic traces are translated into three-component data records (time profiles) along 2D seismic profiles, according to the arrangement of the reception lines with three-component receivers which were described above. It is obvious to say that this scheme is economically justified, since only one source of oscillations is used. This scheme is also quite convenient to data interpretation - construction of the Poisson's Poisson coefficient map. We get 3C data at equal distances from the well (source location), in all directions. It is necessary to note that this exploratory well contains known data from prior drilling results. Areas between the neighboring receiver profiles are also subjected to thorough interpolation, which is simplified due to the rather high density of the data obtained for each of the 3C receivers.

Examples:

This technology was successfully tested at the Van-Eganskoye oil field. The results below verify the rationality of the method used.

We give the data of the mathematic modeling of the summary wave field, which is based on the results of the preliminary 3C VSP along the well. Arrows on the Figure 4 indicate the places of the most intense reflections of the P-wave and also local indication of reflective horizons.

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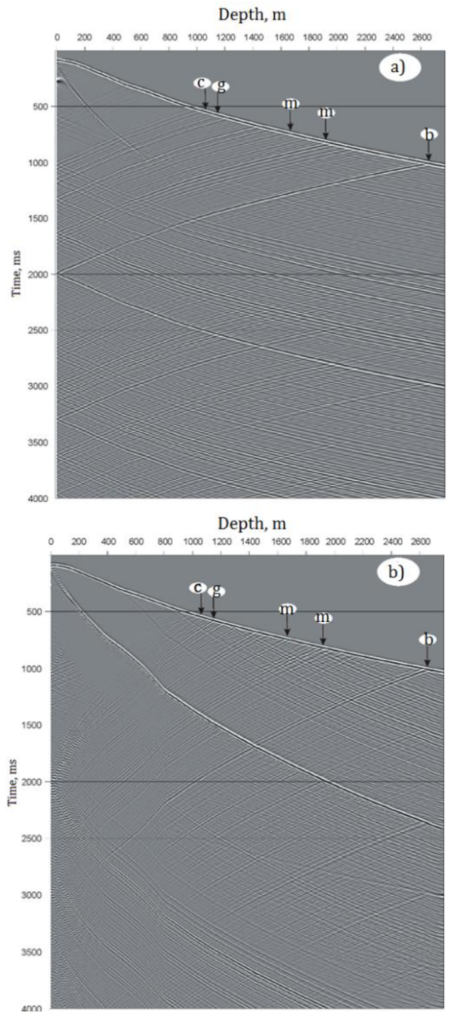

Figure 4: Synthetic seismograms a) along the vertical component (Z), b) along the horizontal component (X).

Then we show the time profiles obtained from 2D 3C profiling data after the introduction of the necessary kinematic corrections based on Z- and X-components. The vertical scale in the presented data records below (Figure 5) is compressed approximately by a factor of 2, for the convenience of determining the ratio of the in-phase axes. This is needed in order to account for the different propagation speed of elastic waves of different types and, consequently, the arrival time of the wave. In addition, you can see the spectra of the intensity of the passage of waves (in the lower right corner), emphasizing the rational being compressing the time axis on these data records.

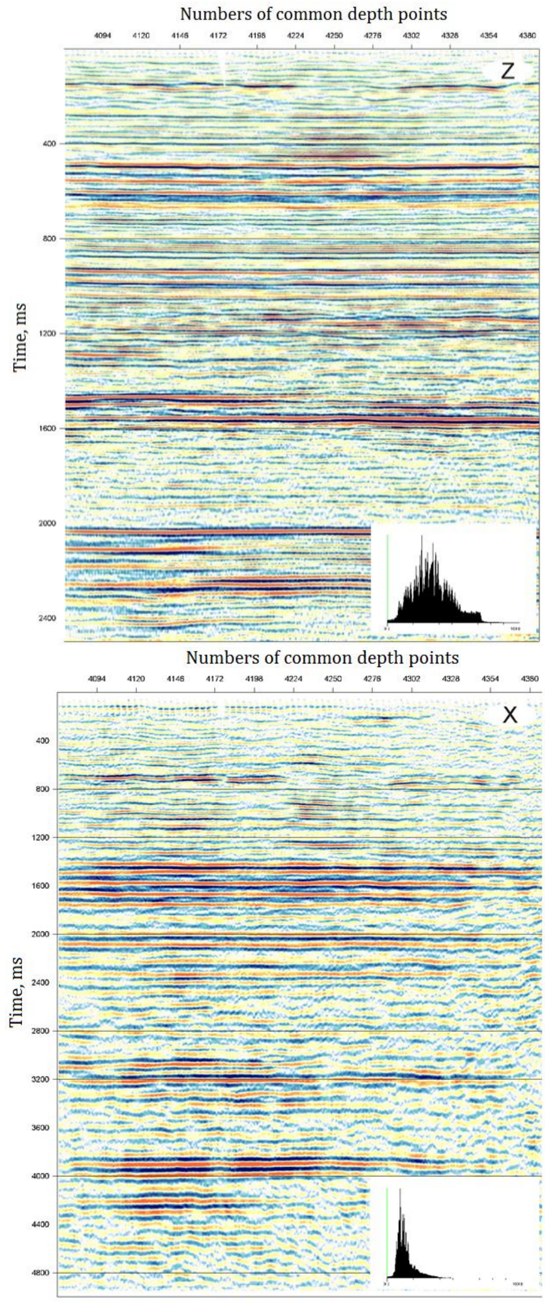

Figure 5: Time profiles along the 2D 3C profile along Z- and X-components.

According to the time section of the Z-component, two distinct reflecting boundaries can be traced there, corresponding to the top Aptian unit (the arrival time is about 1400 mini-seconds) and the top Valanginian unit (arrival time about 2000 mini-seconds). The third reflection can be traced (the arrival time is about 600 ms), although it cannot be isolated with a 100% confidence. Based on the average ratio of arrival time of reflected waves of different types from the modeling data presented above (Figure 4, a, b), these two time profiles are compared with each other with a minimum error. Therefore, as a result of comparing the Z-component time profile data with the X-component one, it is possible to identify an additional reflecting horizon corresponding to the roof of the Cenomanian strata (the time on the X-component time profile is 1500 mini-seconds).

The final stage of 2D 3C seismic data interpretation includes construction of a layer distribution map of the values of the complex parameter γ=Vp/Vs (Figure 6) correlated with the Poisson's ratio.

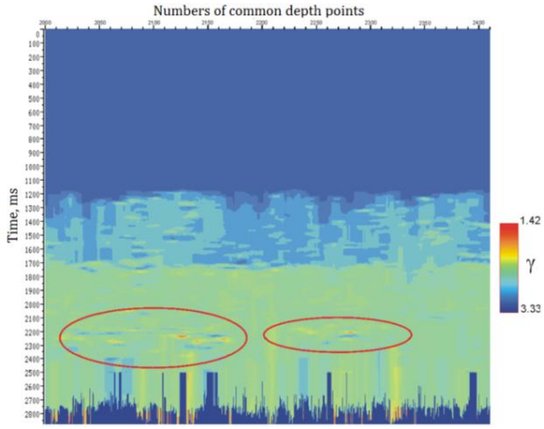

Figure 6: The layer map of the distribution of the values of the complex parameter γ=Vp/Vs; γ=(1,42-3,33) corresponds to values of Poisson's ratio σ=(0,01-0,45).

The lowest values of the Poisson's ratio correspond to the oil deposits. This assumption about the presence of oil-saturated zones, proposed by the results of 2D 3C seismic survey (Figure 6), was proved by the drilling results.

Based on the results of the 3C registration, a 2D profile of the distribution of the Poisson's ratio was constructed (Figure 7). The allocated section corresponds to the position of the water-oil contact, the presence of which was also confirmed by further drilling.

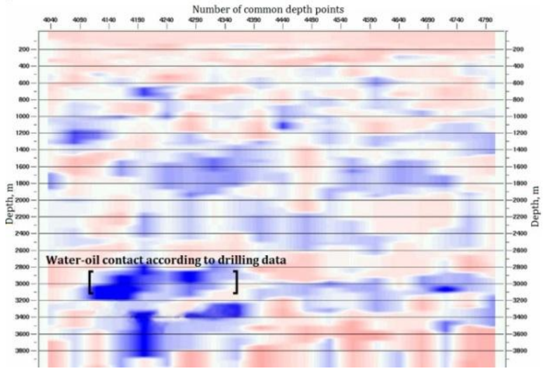

Figure 7: Profile of distribution of the Poisson's ratio according to the results of 2D 3C registration.

Thus, a detailed analysis of the 2D 3C seismic survey results (determination of the Poisson's ratio) made it possible to minimize the error in the identification of the oil-saturated zone in relation to non-traditional reservoirs of Western Siberia.

Conclusions:

Poisson's ratio indicates the fluid saturation of rocks, the lower its index, the more saturated the rock is with oil and gas. This fact facilitates the identification of this particular oil-bearing reservoir. We presented in this article innovative 2D 3C seismic technology to enable optimizing the development of hard-to-recover reserves of hydrocarbons concentrated in unconventional reservoirs in Western Siberia. The total hydrocarbon reserves in such formations, judging by its higher surface area throughout the region, are estimated from 0,8 to 2,1 trillion tons, and the potential for incremental recovery of oil reserves is estimated to be not less than 30-40 billion tons.

The method allows us to obtain information about the parameters of the reservoirs. This information is in the characteristics of the waves reflected from the structural heterogenities. The values of their basic parameters in the medium depend on the structure, texture of the rocks, their fluid content, which in turn are related with lithology, porosity, and other properties that have a natural or technogenic origin.

At last, it should be noted that this strategy is possible only with the close integration of geophysics, geology and drilling, including the creation of a spatial geological model of the deposit and the calculation of oil reserves.

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