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Fracturing is Distinctly Revealed by Duplex Wave Migration

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Summary

During the development of one of the oilfield from the Timano-Pechorsky basin (Russia) was detected a substantial difference in the productivity of a well on the background of a lithologically consistent carbonate reservoir. Several approaches were used in order to detect the fracturing zone by using seismic data: geometric attributes, coherency, wave-field spectral decomposition. Duplex wave migration, performed in the last step, not only confirmed the previous obtained results but also allowed a more detailed discrimination of separate lineal anomalies and a ranking by their permeability / cut-off properties. In this report we have examples that show the use of duplex waves in order to detect and trace sub-vertical fracture zones within reservoirs from different oilfields in the world.

Introduction

Timano-Pechorsky basin is characterized by a wide presence of fractured reservoirs, originated as a result of active tectonic adjustments. It is considered an excellent "proving ground" to study fracture zones of a tectonic genesis is an oilfield with a reservoir consisting of layers of carbonate sediments with a total thickness of around 100-150 meters.

Theory and/or Method

Duplex wave – is a wave that is reflected twice: first time from the sub-horizontal layer, then from a sub-vertical layer (or in the opposite order) and then it reaches the surface and gets recorded. Until quite recently in surface seismic was assumed that the imaging of sub-vertical boundaries was not possible since reflection from those boundaries never reached the surface. The duplex wave properties were studied in works [1, 2 and others] where it is shown that their energy is strong enough to be used in the exploration of geological targets.

Examples

Nine wells were drilled during the oilfield's exploration step by using the information from 2D seismic sections. The reservoir properties were obtained from core data and they seem to be consistent in the area. However, flow rate tests in adjacent wells differ a lot: from 5-7 m^3/day to 300 m^3/day

The exploration stage of the field's life was concluded after conducting 3D seismic survey that helped to better detail the geological aspects of the sedimentary section: the structural plan of the oilfield got more complex with multiple morphological structures: domes, anticlines, horsts and others.

The analysis of the geometrical form of the reflector surface (top of the reservoir) showed that high flow rates are related to those wells located in zones of increasing surface curvature. Based on the assumption that in zones of intensive layer bending, the forming rocks will be under extension forces and break-down forces that will lead to the creation of fracture zones, it was decided to drill the first production well (№12) on a location with the same high surface curvature value. The hypothesis of the connection between the location of fracture zones and zones with regions of gradient inclinations was proved. The testing of the well №12 showed an oil flow rate of 190 m^3/day with a pressure drawdown of 0.11 MPa

The next drilled well which according to existing well log data and core data was characterized with the best reservoir properties and the biggest oil pay net in the entire oilfield showed a production rate of 6 m^3/day, even after all the well stimulation efforts. At this point, nobody had doubts about the existence of fracture zones and its significant impact in the development of the oilfield.

Subsequent fracture studies were conducted in a wide front: microscopic core studies, special well log methods (mainly acoustic), hydrodynamic studies, interpretation of seismic data. In 11 were performed sonic logs (XMAC). Several supposedly fractured interlayers were detected in the borehole section by using the results obtained from well-logging (electric logging) methods and from mud-loss drilling information. About 200 formation pressure measurements (3-15 for each well), 9 well flow rate measurements and two observation well testing were performed on all producing wells during all years of development.

Pressure transient test results allowed calculating the productivity factor and the permeability coefficient. Depending on the mode of pressure reading and on the choker size used, the above mentioned coefficients changed in wide-range interval, which is characteristic for fractured reservoirs: The behaviour of exposed fractures is very sensitive to the pressure drawdown created during measurements. Nevertheless, in the majority of wells in the oilfield the average value of the productivity factor fluctuated from one to the first hundreds m^3/day/MPa. Six wells stand up where the productivity factor exceeded 1000 m^3/day/MPa reaching up to 4000 m^3/day/MPa

These wells were subject to special attention (as far as allowed by the existing set of studies on each one). It was revealed that the cause of the high well productivity can be explained by the existence of a crushing interval in the solid carbonate rocks together with the intersection of the wellbore with a fracture zone. Is this kind of macro-fracturing that can be determined with pressure transient tests and it also maybe measurable with seismic waves.

These six leading wells were used for a subsequent calibration of the seismic attributes that are aimed to detect fracture zones in the interwell space. In order to confirm our thoughts we first verified the structural map of the reflector's surface (top of the reservoir). Despite that on the map we can see lineal areas with higher than usual gradient inclination values; a clear dependency between these values and the productivity rate values of the wells was not found. Coherence cube is another traditional seismic attribute used to detect faults and, in particular cases, fracture zones. During the interpretation of coherence cubes, the interpreter should keep in mind that non-coherence can be observed not only due to faulting but due to other causes such as abrupt lithological changes, different type of noise that were not removed during seismic processing including processing errors. Therefore, is not surprising to find that a clear dependency between the well's productivity ratio values and coherence values was not found as well. Frequency dependent attributes such as wavefield spectral analysis is another seismic attribute used to map fracture zones. A peculiarity of these attributes is the dependence of the frequency of the reflected wave from the size of the object. The amplitude fields from different frequency values reflect anomalies of different sizes which are difficult to analyse in one joint crossplot. This way, all above mentioned interpretation techniques are not effective enough for this oilfield and can be only used in a qualitative level and only jointly, based on the assumption that the common anomalies for all these techniques are the fracture zones and an anomaly unique just to one of them can be treated as induced noise.

The statistical analysis of the resulting duplex wave cube shows a high correlation coefficient value (0.94) between the absolute amplitude values and the well's productivity rate values (see figure 1-A). This type of dependency can be interpreted as follow: the high permeable fracture zones are represented by a sub-vertical boundary of crushed rocks which have reduced density and velocity in comparison with the adjacent undisturbed rocks. The impedance difference at the edge of the fracture zone affects the reflection coefficient value and the absolute amplitude value: the stronger the rock is crushed the brighter is the reflection, the higher is the permeability and therefore the well productivity is higher. A negative reflection is obtained from the fracture zone boundary that is the nearest to the receiver station. A positive reflection is formed from the far away boundary. This way, a couple of extreme reflections can be related to a permeable fractured zone of a tectonic genesis.

The duplex wave cube was compared with the results from the observation well testing. In the first polygon (figure 1-B, 1-C) the well №6 is the stimulating well and the reacting ones are the 14 and 38. Based on the distribution of the linear seismic anomalies, the layer in between wells 6 and 38 still keeps an undisturbed matrix structure (figure 1-C, Left). The velocity of pressure change (piezoconductivity coefficient) between these wells will characterize the properties of the undisturbed porous reservoir. At the same time, a permeable zone can be traced in between wells 6 and 14; this zone divides the parts of the porous reservoir that are revealed by the studied wells. When the direction of the observation well testing is perpendicular to the fracture zone, the later will become a barrier for the fluid trying to propagate by the path of least resistance. By the way, the piezoconductivity coefficient measured in well 38 was five times higher than in well 14, despite the fact that this well is located 100 metres farther away (figure 1-C, right table).

In the second polygon the pressure change in the reacting well 17 was recorded one hour after starting the extraction in the stimulating well 2 (see figure 1-D). The layer conductivity between these wells is 20 times higher than in the matrix collector (figure 1-D, right table). This way observation well testing also confirms the spatial location of the high-permeable zones.

Conclusions

- Duplex wave migration is a direct method to detect tectonic-type fracture zones
- Zones of open fracturing in the horizontal and stratigraphical cube sections are observed as a two phase reflection where the negative phase is originated by the edge of the fracture zone that is located the closest to the receiver station and the positive phase is originated at the farthest edge of the fracture zone.
- The discrimination of crush zones from duplex waves is supported by pressure transient tests and these zones can be recommended for subsequent production drillings.

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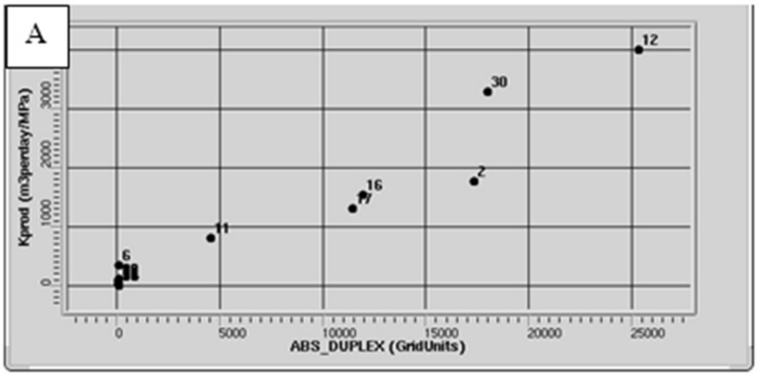
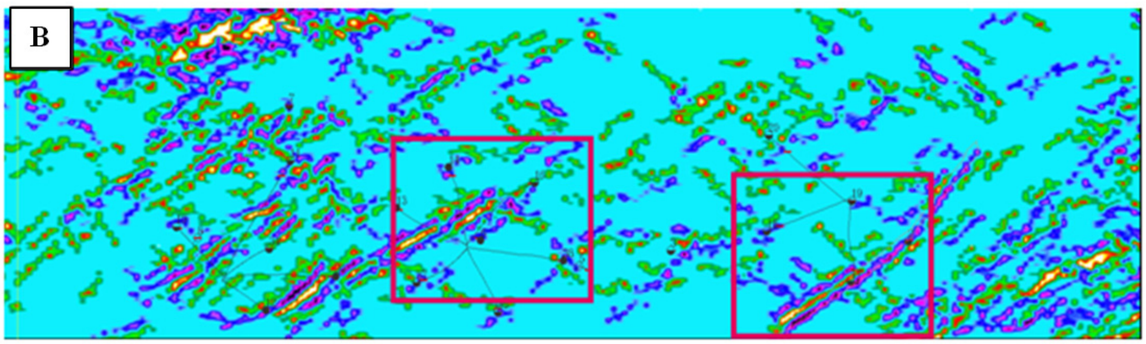
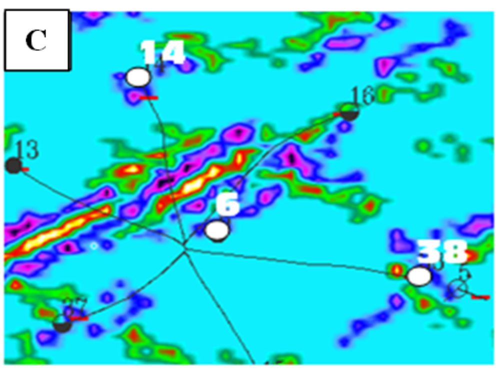
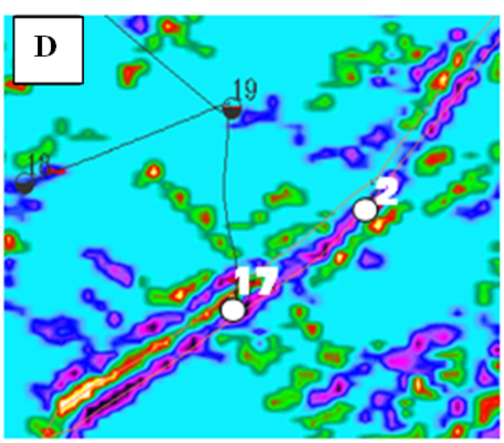






Polygon N.1 Well N.6 – Stimulating Well Wells N. 14,38 reacting wells		
Value	Well 14	Well 38
Distance to the stimulating well (top of the layer) [m]	702.2	834.2
Piezoconductivity coefficient of the layer [cm^2/s]	**1526**	**7313**



Polygon N.2 Well N.2 – Stimulating Well Wells N. 17 reacting wells	
Value	PBU*
Distance between wells [m]	700
Piezoconductivity coefficient of the layer [cm^2/s]	**127379**
Permeability coefficient of the layer [k] MKM^2	14.9
Layer thickness [m]	1.62
PBU=Pressure Build Up	

Figure 1: Confirmation of results of Duplex wave migration by pressure transient tests and pressure interference tests.