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CSP-Method Prospecting of Fracture-cavernous Reservoirs in the Bazhen Formation of the Salym Oilfield

G.N. Erokhin (Immanuel Kant Baltic Federal University), A.N. Kremlev* (Antel-Oil Co.), L.E. Starikov (Immanuel Kant Baltic Federal University), V. V. Maltcev (RN-UganskNeftegas) & S.E. Zdolnik (RN-UganskNeftegas)

SUMMARY

DEDICATED – Case Studies in Diffraction Imaging and Interpretation.
The problem of oil reservoirs prospecting in the Bazhen formation in the West Siberia is exciting and difficult. Exciting - because the Bazhen formation's oil reserves are estimated up to 7 billion tons and difficult - due to its fracture-cavernous nature. The results of oil reservoirs forecasting in the Bazhen formation of the Salym oilfield are presented. The forecast is based on using scattered seismic waves extracted from the 3D multichannel seismic data by the original CSP prestack migration method. Shown that this approach enables to obtain much more reliable reservoirs forecasting map and reservoirs model than conventional processing and interpretation methods.

Introduction

The Salym oilfield located in the central part of the Western Siberia on Surgut dome was discovered in 1965 when oil inflow with production rate about 600 cubic meters per day was obtained from the Bazhen formation (well #12). Then it was first proved oil productivity of fracture-cavernous reservoirs in the Bazhen formation.

The Bazhen formation has an Upper Jurassic age and it is composed by bituminous shale (clay) rocks with carbonate and siliceous intercalations. This formation has rich organic content. Its oil reserves are estimated from 5 to 7 billion tons. Though 135 oil deposits on 54 oilfields were discovered to date in the Bazhen formation, these discoveries have more occasional than systematic character.
The reason – conventional seismic is not suited for fracture and cavernous reservoirs prospecting. It is because the reservoirs of such kind do not reflect but scatter seismic energy and the amplitudes of scattered waves are 1-2 orders less intensive than that of the reflected ones. The last forms strong noise which masks the scattering objects.

Up today more than 200 wells are drilled on the Salym oilfield. However, logging investigations and conventional 3D seismic methods disable to reveal the rule of reservoir location in the Bazhen formation neither in area nor in depth.

CSP method

We present the results of the Salym oilfield Bazhen formation investigation using scattered waves. The scattered waves are extracted from conventional 3D multichannel seismic data by an original CSP (Common Scattering Point) prestack migration method (Kremlev, Erokhin, 2011). This method is based on the exact solution of the inverse scattering problem for the acoustic wave equation. The acoustic field $u = u(\vec{r}, \vec{r}_0, t)$, exited at the point $\vec{r}_0 \in R^3$ at time $t = 0$, satisfies the Cauchy problem

$$\Delta u - \frac{1}{c_0^2}\left(1 + a(\vec{r})\right)u_{tt} = \delta(\vec{r} - \vec{r}_0)\delta(t)$$
$$u\big|_{t<0} = 0$$

Here c_0 is the background velocity, function $a(\vec{r})$ describes the velocity inhomogeneities, $\vec{r} \in R^3$. The solution of this problem in Born approximation (Kremlev, 1985; Kremlev, Priimenko et al, 2011) is the linear integral operator $\hat{L} = \hat{L}(\vec{r})$ of a convolution type. This operator enables to calculate the function $a(r^{\to})$ using scattered field $u(\vec{\rho}, \vec{\rho}_0, t)$, which is registered in receiver point $(\vec{\rho}, 0)$ for different source $(\vec{\rho}_{0,0})$ locations. The receivers and sources both are located on the day surface $z = 0$. It was found that for the aim of scattering objects investigation this operator $\hat{L}$ can be split into two parts. It makes possible to calculate separately the space distribution of the diffractors $a(\vec{r})_{diffr}$ and the space distribution of the reflectors $a_{refl}(\vec{r})$

$$a_{diffr}(\vec{r}) = \hat{L}_{diffr}(\vec{r})u(\vec{\rho}, \vec{\rho}_0, t)$$
$$a_{refl}(\vec{r}) = \hat{L}_{refl}(\vec{r})u(\vec{\rho}, \vec{\rho}_0, t)$$
$$\hat{L} = \hat{L}_{diffr} + \hat{L}_{refl}$$

So, the CSP method allows to calculate two independent seismic cubes: a conventional cube with reflectors and a new cube with diffractors – the image of space distribution of acoustic impedance inhomogeneities (cracks and cavernous filled with fluids). Both cubes are used then for complex interpretation by technique elaborated by L. Starikov and A. Kirichek.
The CSP method was implemented on a special computer cluster with 12 Teraflops performance as a self-contained software using Message Passing Interface (MPI) parallelization technique. It was tested

on a large amount of synthetic models. The model typical for the Western Siberia is consisting from layered media and weak diffractors inclusions. The multichannel seismic data were calculated and processed. The results of conventional processing and the CSP processing are presented in Figure 1. It is clearly seen that the CSP processing removes the reflectors and permits visualization of the scattering objects – diffractors.

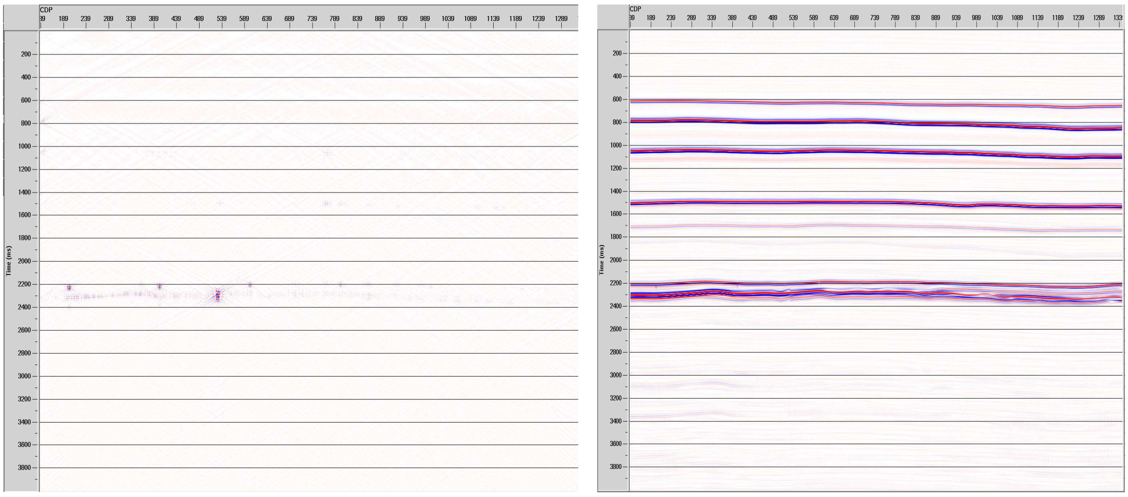

Figure 1 *Diffractors (left) and conventional (right) time sections for West Siberia model*

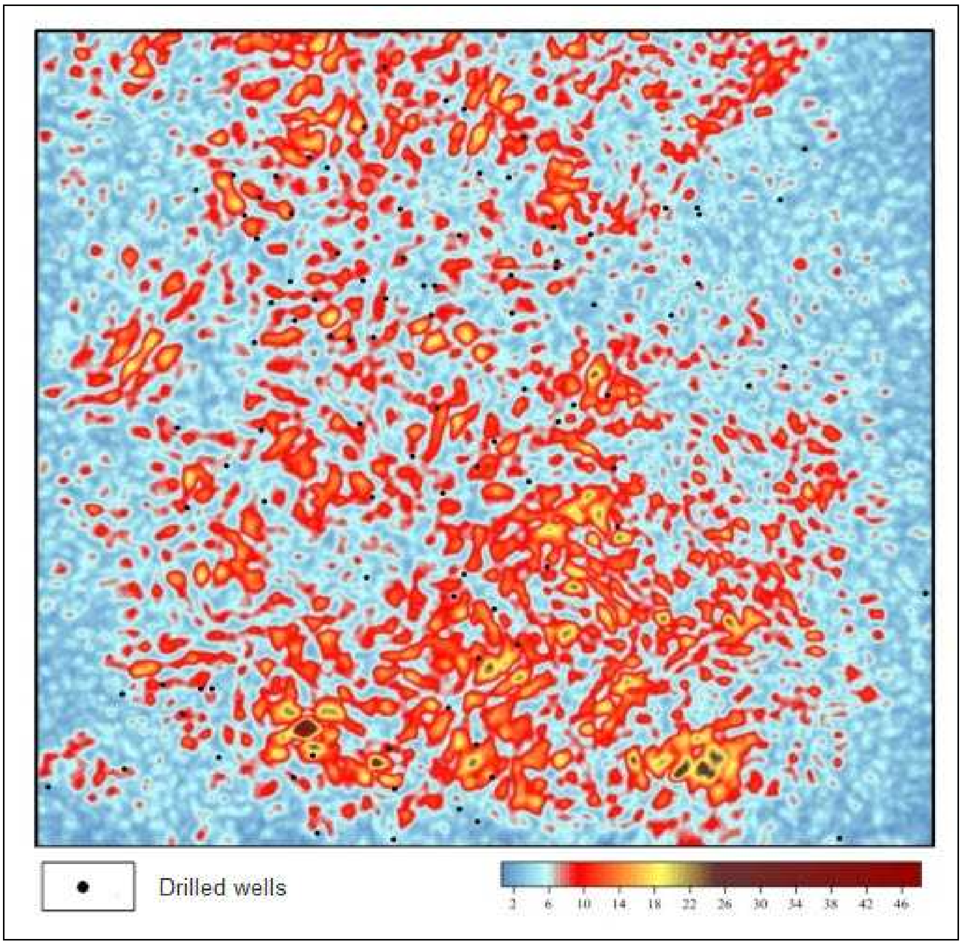

Figure 2 *Diffractors map of the Bazhen formation*

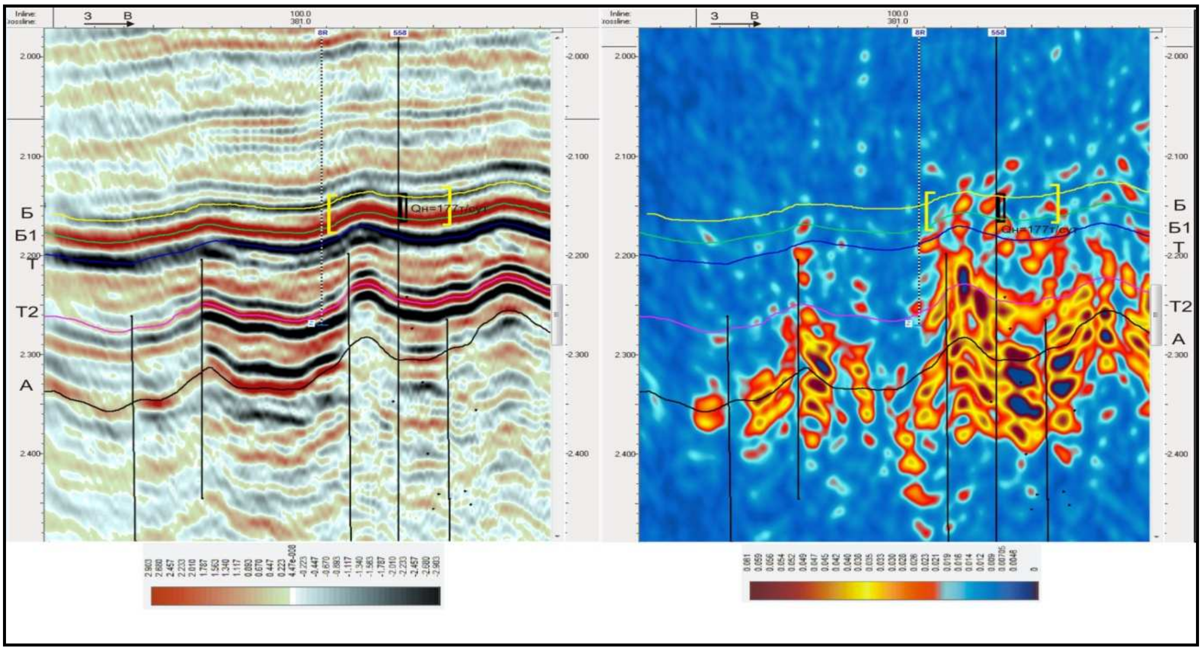

Figure 3 *Reflectors (left) and diffractors (right) time sections*

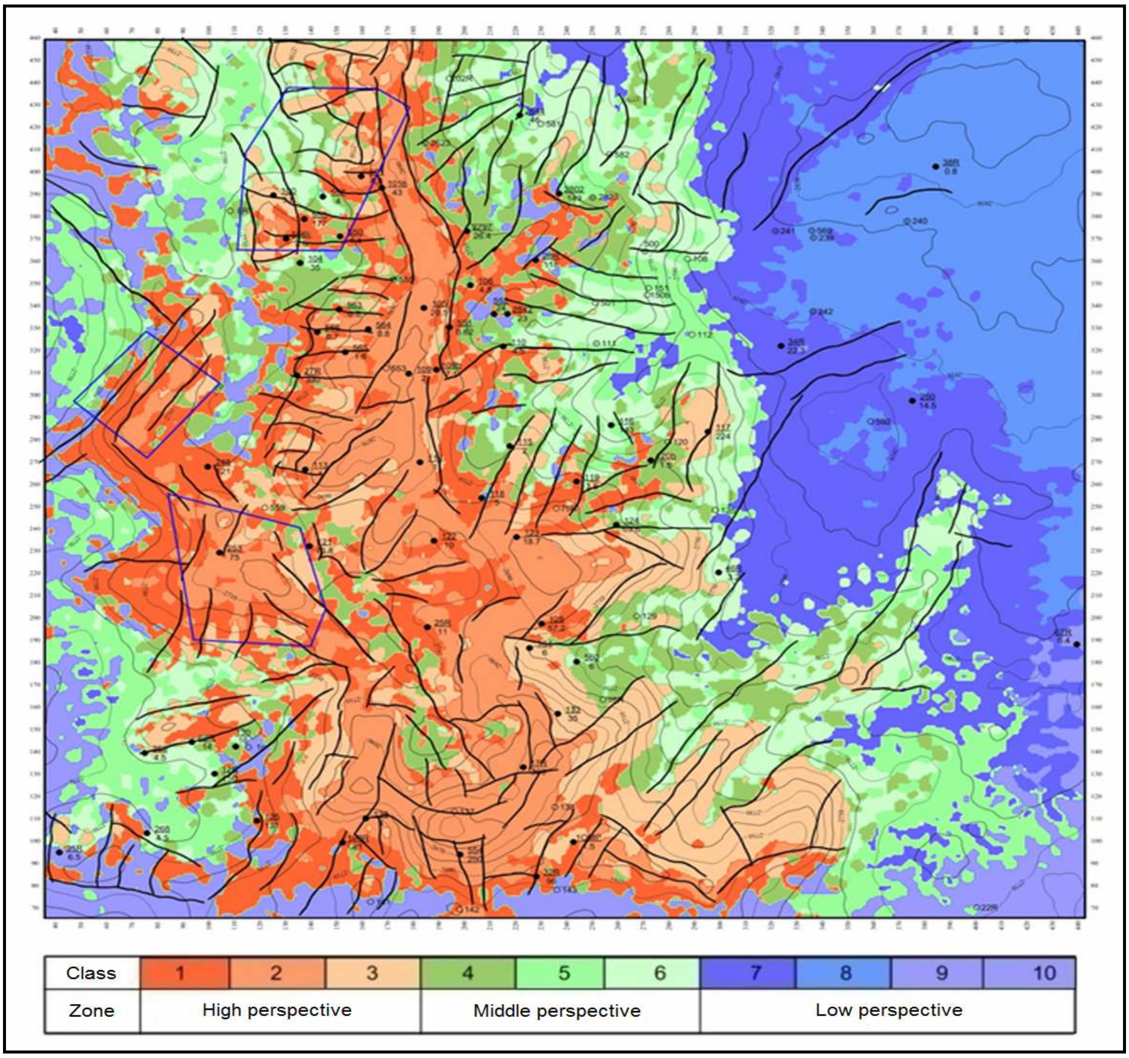

Figure 4 *Perspective oil reservoirs map of Bazhen formation based on cluster analysis*

Fracture and cavernous reservoirs forecasting

In Figure 2, the Bazhen formation map of diffractors is displayed. Here and after strong diffractors are presented in red. Cracks and cavernous filled with fluid are mostly acoustically contrast and work as strong diffractors. Zones with no fractures do not scatter seismic energy (weak diffractors) and are presented in blue. The diffractors level which distinguish reservoirs from non fracturing zone was calibrated using the results of well testing. Since there are no wells with water inflow from Bazhen formation then all high amplitude diffractors anomalies are interpreted as oil reservoirs. In Figure 2, most productive wells (70%) are located in zones with diffractors' high amplitude. In Figure 3, typical reflectors (left) and diffractors (right) time sections are displayed. For further interpretation fault block model, using both diffractors and reflectors cubes, was built. Within the Salym oilfield faults crack not only Bazhen formation but upper and lower caprock layers too. If the upper caprock layer is corrupted - the oil migrated to lower Cretaceous sandstones. If the lower caprock layer is corrupted - the oil due to anomalous high differential pressure migrated to middle Jurassic sandstones. To take it into account cluster analysis was done with diffractors maps of the Bazhen, lower Cretaceous, middle Jurassic layers and structural map of Bazhen formation. The area was divided into 9 classes which were joined into 3 zones: high, middle and low perspective – Figure 4. Cluster analysis increases the location of productive well in perspective zone up to 80%.

Conclusions

Using scattered seismic waves by means of special processing of the conventional seismic 3D data by the CSP method enable to build adequate (reliable) 3D geological model of the fracture-cavernous oil reservoirs in Bazhen formation of Salym oilfield.

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