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Time-lapse AVO/AVA Analysis in a CHOPS Heavy Oil Field

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Summary

The characterization of heavy oil fields is improved by the use of time-lapse seismic data. These data provide valuable information regarding the changes occuring in the reservoir during hydrocarbon production and recovery processes. This information is unique because it provides three-dimensional elastic properties in the reservoir over time. Amplitude versus offset/angle (AVO/AVA) analysis has been applied to get the desired information - mainly the gas presence in the reservoir. We used time-lapse pre-stack seismic data in a cold production heavy oil field to monitor the production-related changes and the developemnt of foamy oil in the reservoir. We also could show how brine and saturated unconsolidated sands have different time-lapse AVO responses

Introduction

Time-lapse seismology is an essental tool to monitor the reservoir in a 4D sense. The hydrocarbon production in the reservoir changes the elastic properties of the seismic data. This helps us to detect those changes over time by use of time-lapse seismic data. Amplitude versus offset/angle is a standard technique in seismic analysis which is applied to pre-stack seismic gathers. The purpose of AVO analysis is to derive different rock properties by analyzing offset/angle-dependent seismic amplitudes. The mathematical basis of AVO analysis is given by the Zoeppritz equations (1919). Zoeppritz derived the amplitude of reflected and transmitted waves at an interface by applying of conservation of stress and displacement across a layer boundary. Different approximations to the Zoeppritz equations were presented to help us to understand how various elastic parameters impact the modeled seismic amplitudes. The most common approximation is the Aki-Richards's equation (1980), which is expressed in the Equation 1. Aki and Richards derived their equation by assuming a small contrast between layer properties.

$$R_{PP}(\theta) \approx A\,\frac{\Delta V_P}{\overline{V_P}} + B\,\frac{\Delta V_S}{\overline{V_S}} + C\,\frac{\Delta\rho}{\bar{\rho}} \tag{1}$$

Where A, B, and C are AVO parameters which are the function of Vs/Vp ratio and angle of incidence. Δ is the operator giving the difference in velocity or density between two layers across the interface and $\overline{V_P}$, $\overline{V_S}$, and $\bar{\rho}$ are the average values in P-wave velocity, S-wave velocity, and density, respectively.

Time-lapse AVO/AVA analysis attempts to derive different AVO parameters in different seismic surveys and derive the difference between these elastic properties and attribute these changes to main production-related changes in the reservoir.

Time-lapse seismic data were available for this case study. The first survey (called the base survey) was acquired in 2003 and the second survey (called a monitor survey) was acquired in 2009. The recovery method in this heavy oil is CHOPS. CHOPS is a cold production heavy oil production with sand technique in heavy oil industry. CHOPS simultaneously extracts heavy oil with sand with cavity pumping.

Due to sharp gradient changes in the areas close to the CHOPS wells, the dissolved gas turns into the bubbles within the oil. This produced gas is one of main mechanism of heavy oil production by CHOPS. Undersanding these foamy oil zones is very critical in the developement of the CHOPS method. AVO analysis is very helpful in detecting the gas zones in the reservoir. Here, we will show how time-lapse AVO can better detect these foamy oil zones in CHOPS heavy oildfields.

As mentioned earlier, the Aki-Richards approximation depends on three parameters A, B, andC which mostly called amplitude, gradient, and curvature, respectively. Figure 1 shows the AVO behavior for the base and monitor surveys at the the reservoir level. As it is clear, the absolute amplitude at the monitor seismic increased and the AVO curves for both the base and monitor seismic surveys are different.

The 3D AVO analyis by the Aki-Richards approximation was applied to the base and monitor seismic volumes. Then the difference between the base and monitor seismic surveys was extracted for each parameter. Figure 2 shows the difference map of AVO parameters of A,B, and C. It is clear that gradient difference map could show the anomalous zones better.

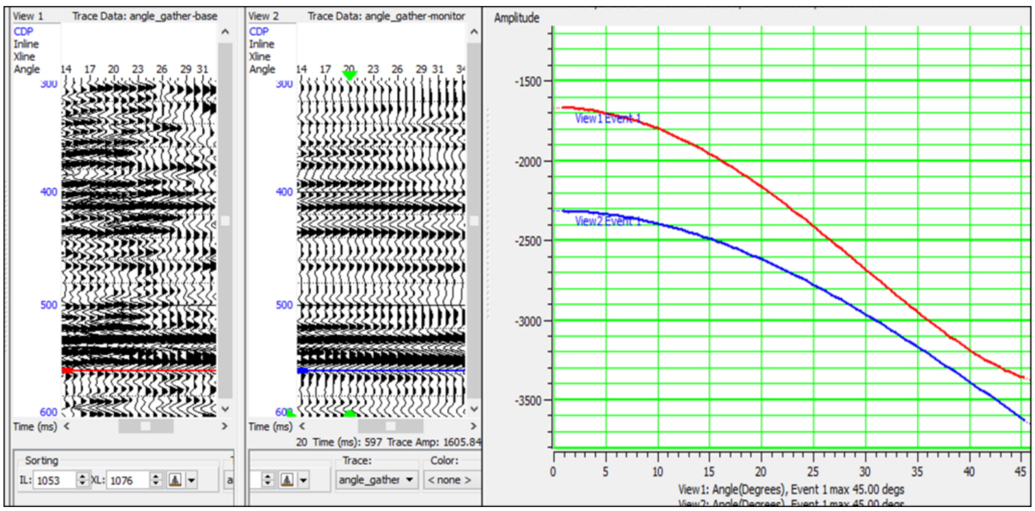

Figure 1. AVO behavior in the base (red) and monitor (blue) seismic surveys at the the reservoir.

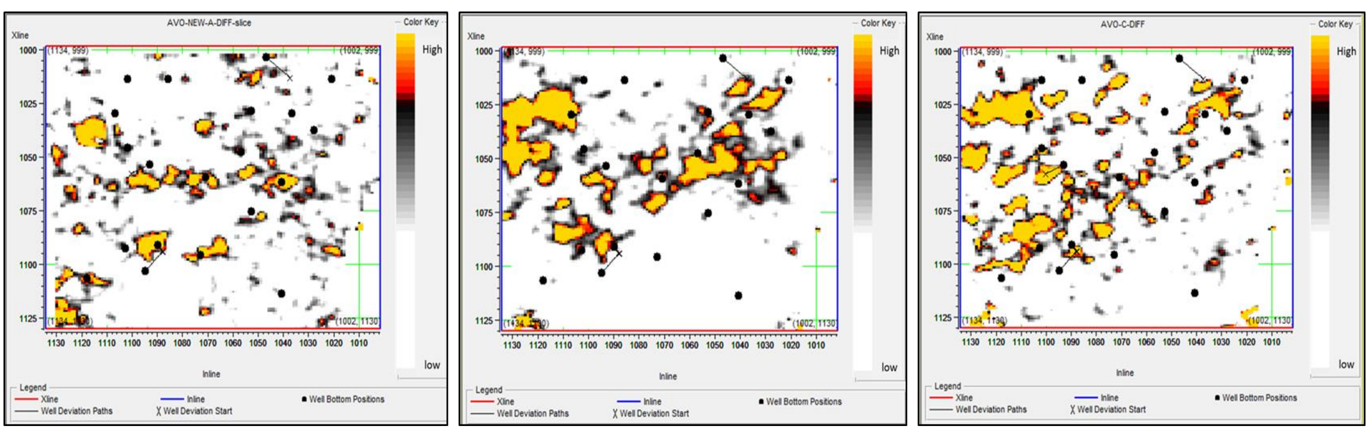

Figure 2. The difference map of AVO parameters A (left),B (middle), and C (right).

AVO/AVA forward modeling

Gassmann substitution modeling (Gassmann, 1951) was used to define different fluid substitution scenarios to interpret the changes that we can notice from the time-lapse AVO/AVA analysis. The saturated bulk modulus, according to Gassmann equations, can be given as:

$$K_{sat} = K_{dry} + \frac{\left(1 - \frac{K_{dry}}{K_m}\right)^2}{\frac{\phi}{K_{fl}} + \frac{1-\phi}{K_m} - \frac{K_{dry}}{K_m^2}} \tag{2}$$

where ϕ is the porosity, K_{dry} is the bulk modulus of the dry porous frame of the rock, K_{fl} is the bulk modulus of the fluid and K_m is the bulk modulus of the mineral. The assumptions in this equation are that the pore space is interconnected and the pore pressure is in equilibrium.

We defined three fluid substitution models as:

- A: Water saturation=20% oil saturation=80%
- B: Water saturation=10% oil saturation=90%
- C: Water saturation=20%, oil saturation=70%, gas saturation=10%

A is the in-situ condition of one of CHOPS well in the studied area. B and C are two different fluid models we defined to investigate their AVA behaviors. After creating target logs for conditions B and C, AVA forward modeling by Aki-Richards method was performed to generate the three angle gathers which correspond to the well logs for condition A, B, and C respectively. Figure 3 shows the result of generating three sets of synthetic angle gathers and their corresponding AVA behaviors. It is evident that the presence of gas affects the AVO behavior compared to in-situ condition where the gas is not present.

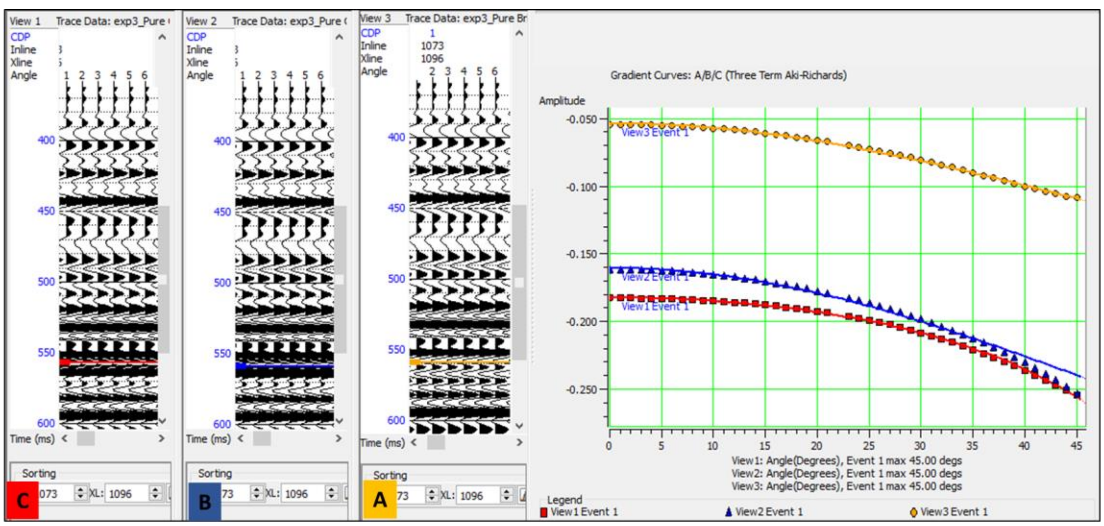

Figure 3. Forward modeling results and their AVA behavior for three conditions A (yellow),B (blue), and C (red).

Time-lapse AVO/AVA attributes

One of highly applicable fluid indicators is the fluid factor. Smith and Gidlow (1987) proposed the fluid factor attribute as a method to derive the deviations from the Castagna's mud-rock line (Castagna et all, 1985).

$$\Delta F = R_P - 1.16 \frac{V_s}{V_P} R_S \tag{3}$$

where Rp and Rs are the P-wave and S-wave reflectivities at zero offset.

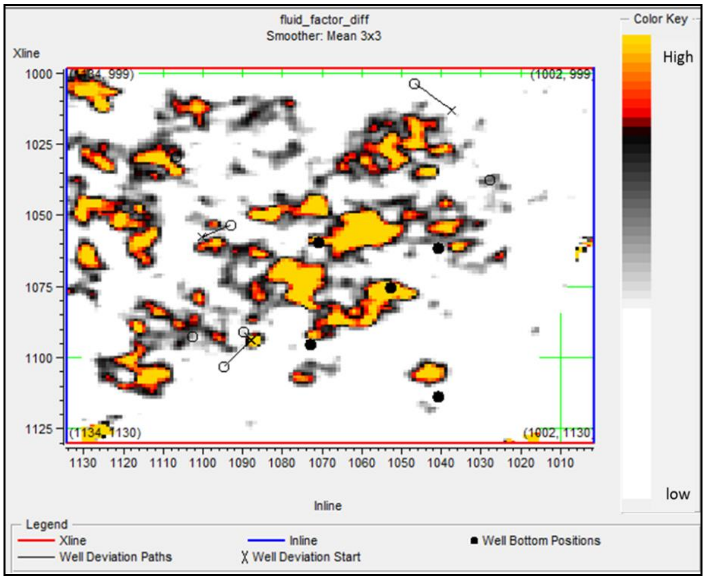

Figure4. The fluid factor difference between base and monitor seismic surveys.

Figure 4 shows the fluid factor difference between the base and monitor seismic surveys in total area of the base map. These anomalous areas correlated well with the oil and gas high production zones and can be attributed to the foamy oil zones which developed during the time between the base and monitor seismic surveys.

Conclusions

Considering the results of AVO/AVA modeling, it was concluded that different fluid substitutional models give various AVO responses. Since AVO analysis is more sensitive to the gas presence, time-lapse AVO analysis was performed in a CHOPS heavy oilfield to monitor production-related changes and also development of foamy oil zones. The Aki-Richards approximation was used to derive amplitude, gradient, and curvatures for the base and monitor seismic surveys. Difference maps for these attributes showed the anomalous zones in the studied area. Time-lapse seismic attributes from AVO results were also extracted to help to maximaize the information taken from the time-lapse AVO analysis. In this paper, we showed how fluid factors can highlight the production-related changes in the reservoir. These changes can be attributed to the foamy oil zones in the studied CHOPS heavy oil reservoir.

Acknowledgements

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