Examples of the Seismic Imprint of Cold Heavy Oil Production

Ken Hedlin*
Husky Energy, Calgary
kenneth.j.hedlin@huskyenergy.com
and
Arthur Chan
Husky Energy, Calgary

Summary

An overview of some of Husky's experience with seismic monitoring of cold heavy oil production (CHOPS) is given. In 2002, models were created to simulate the effect of pore pressure decrease and the resulting exolved gas. These showed a large decrease in acoustic impedance resulting in a large amplitude response. This change in amplitude was observed on wells at the intersection of two 2D seismic lines acquired pre and post production. Next, a 2D – 4D experiment showed a good correlation of amplitude changes with cold production. Following that, a 3D experiment was conducted. It highlighted amplitude anomalies that appear to correlate very well with production. A comparison between existing 2D lines and the 3D highlight the changes due to CHOPS.

Introduction

Heavy oil comprises a significant portion of Canada's annual oil output. However, production rates using conventional techniques are low because of high oil viscosity. Several methods have been developed to enhance production rates – steam assisted gravity drainage (SAGD), vapor extraction (VAPEX), and CHOPS. With CHOPS, a progressive cavity pump is used to enhance flow rates by producing sand, oil, brine and gas resulting in a decrease in pore pressure. This causes gas to come out of solution, reducing the oil viscosity and increasing the flow rate of foamy oil (Firoozabadi 2001). Mayo (1996) noted anomalous seismic amplitudes attributable to CHOPS. Since then, research has been done on the rock physics by Chen et al (2003), Zhang (2007) and Lines et al (2008)and time lapse monitoring (Zou et al 2004). These results suggest that there should be a seismic footprint from CHOPS. Optimal placement of infill wells could then be enhanced through knowledge of drainage patterns of existing wells.

Table 1: Model parameters (Ron Sawatsky , Frank Wong)

	In Situ	Cold Production
Pore pressure	3 MPa	.5 MPa
Gas saturation	0%	10%
Brine saturation	21%	
Oil saturation	79%	
OVP	10MPa	
Temperature	21C	
GOR	7.5	
Oil Density	11.5 API	
Gas Gravity	.56	
Salinity	50,000 ppm	
Porosity	30%	

Models

This work began in 2001 when our Heavy Oil engineering group asked if the effects of cold production could be detected using seismic data. The first step undertaken was to model the seismic response to the change in reservoir conditions. Using the model parameters in Table 1, a rock physics model was created. The Gassman fluid substitution gives a significant decrease in P wave velocity and Vp/Vs ratio at 10 % gas saturation (Figure 1). An offset model was created using well logs from a representative well and varying sand thickness from 0 to 12 meters. The results were stacked and shown on the left of Figure 2. There was a clearly a detectable difference in amplitude between the in situ and production models. The fluid factor was also extracted from the model gathers and is shown on the right of Figure 2. There is a clearly a fluid factor anomaly in the production model.

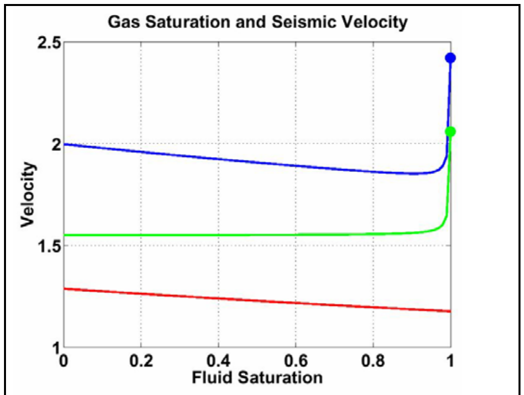

Figure 2: Velocity vs fluid saturation

2D

To see if these model results could be seen in existing seismic data, a search was done for 2D seismic lines intersecting at a cold production well – one line shot prior to cold production and one line shot some time after commencement of cold production. A few such examples were found in 2002. In Figure 3, the amplitude envelope of two orthogonal intersecting lines is compared. The amplitude envelope was chosen to eliminate potential phase differences between the two vintages of data. The first line was shot and processed in 1997, the well was drilled in 2000, and the second line was shot in 2001. The highlighted zone shows a high amplitude anomaly at the well location on the 2001 data that is not present in the 1997 data. This encouraged Husky to try a 2D – 4D experiment. Two 2D lines originally shot in 1997 were selected. After acquisition, several cold production wells had been drilled along the lines. Using the same acquisition parameters, these lines were re shot in 2002. Then both vintages of data were processed with the same processing flow. A comparison of the amplitude envelope of both vintages of one of the lines is shown in Figure 4 with the anomalous amplitudes highlighted in the boxes. These anomalies correlate well with the cold production wells. However, the red vertical line corresponds to the location of the well with the largest cumulative production and there is no visible anomaly. This well did stop producing a year before acquisition of the 2002 data.

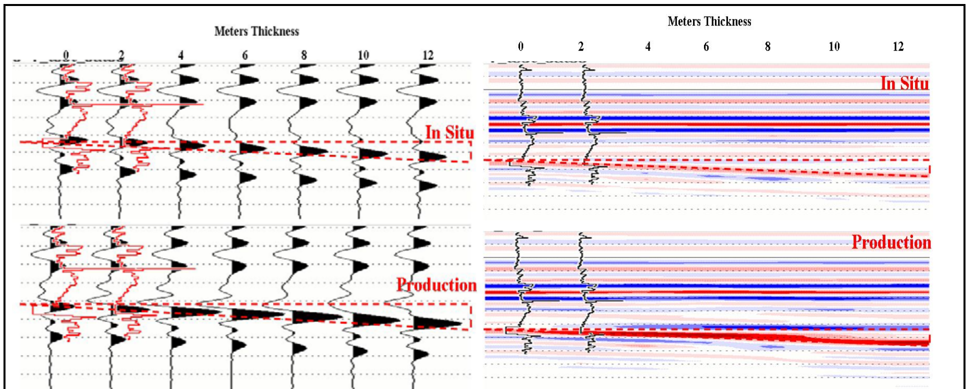

Figure 2: Model parameters (Ron Sawatsky , Frank Wong)

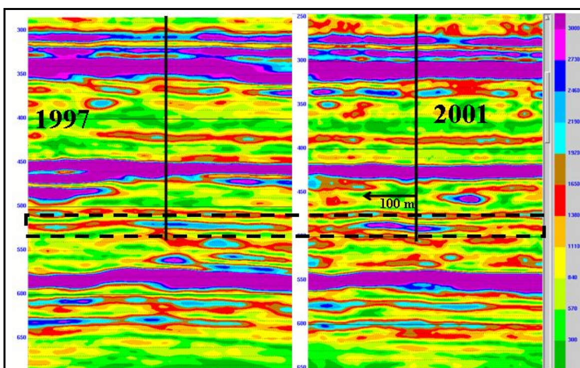

Figure 3: Intersecting 2d lines with well at the intersection

3D

The 2D experiments appeared to show that cold production has a significant imprint on the seismic response. These encouraging results led to a 3D survey in 2003. An area where several cold production wells had been drilled into a thick sand was chosen to improve the likelihood of directly detecting a seismic response to CHOPS. An arbitrary line through the 3D survey (Figure 5) shows amplitude anomalies at the well locations. A map view of a window through the amplitude envelope data at the productive zone is shown in Figure 6 with the existing wells labeled in black. There is a good correlation of the amplitude anomalies with the well locations. The shape and orientation of the anomalies varies. An infill drilling program was designed based on these results. The infill well locations are labeled in red. A map of the envelope of the fluid factor reflectivity shows similar anomalies (Figure 7). Other seismic attributes and rock properties (not shown) such as acoustic impedance, coherence, and spectral decomposition support the location and shape of the anomalies. There were three 2D lines that crossed the survey. To test for 4D effects, the 2D line shown in Figure 6 was reprocessed with similar parameters to the 3D, and the 3D data was remigrated and output to the 2D line bin centers. The amplitude envelope of the resulting 2D – 4D is shown in Figure 8. The black lines mark locations of wells under cold production and the red lines mark the locations for infill wells drilled in 2004. The red arrows highlight zones of anomalous amplitude on the 2003 data not present on the 1997 data (blue arrows).

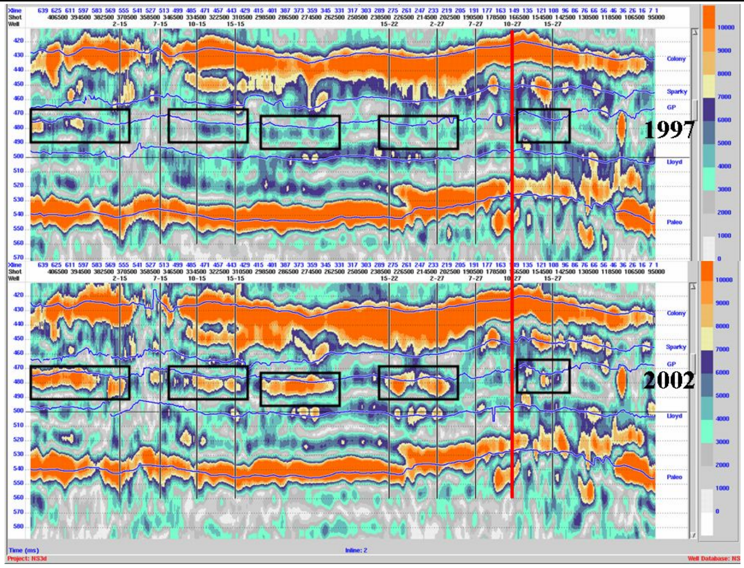

Figure 4: Time lapse 2d, 1997 top, 2002 bottom. The boxes hilight zones of time lapse amplitude changes. The red line locates the well of largest cumulative production.

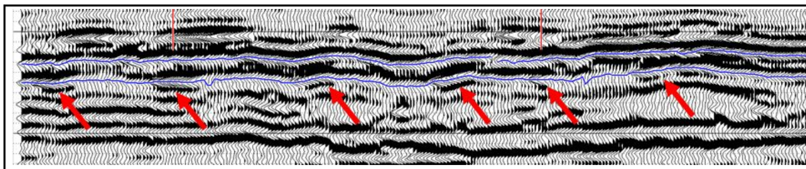

Figure 5: Arbitrary line through 3D showing amplitude anomalies at CHOPS wells.

Offset synthetic gathers were created for the circled well in Figure 7 and a fluid substitution of 10% gas was done to simulate cold production. In Figure 9 on the left are 2 gathers from the 3D at the well location within the drainage area. In the middle are the two model gathers – the leftmost simulating cold production and the right one representing the reservoir before production. The two gathers on the right from the 3D are near the well, but just outside the drainage area. Both model gathers appear to tie the data well. This suggests that the Gassman fluid substitution is a reasonable approach and is supported by Zhang (2007) and Lines (2008).

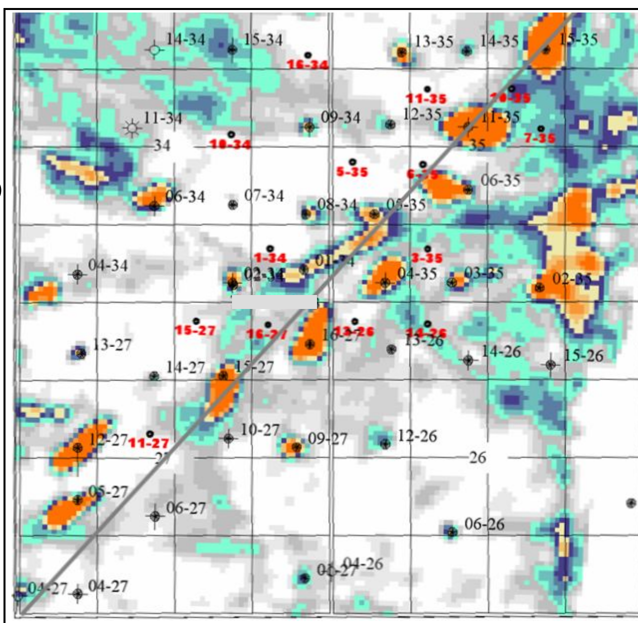

Figure 6: Amplitude envelope anomalies at CHOPS wells.

Conclusions

1D, 2D, 3D, and 4D experiments showed that CHOPS can give a significant seismic response on the seismic data. These responses can be used to position infill wells. If appears that the synthetic response from doing a Gassman fluid substitution closely matches the change observed in seismic data.

Acknowledgements

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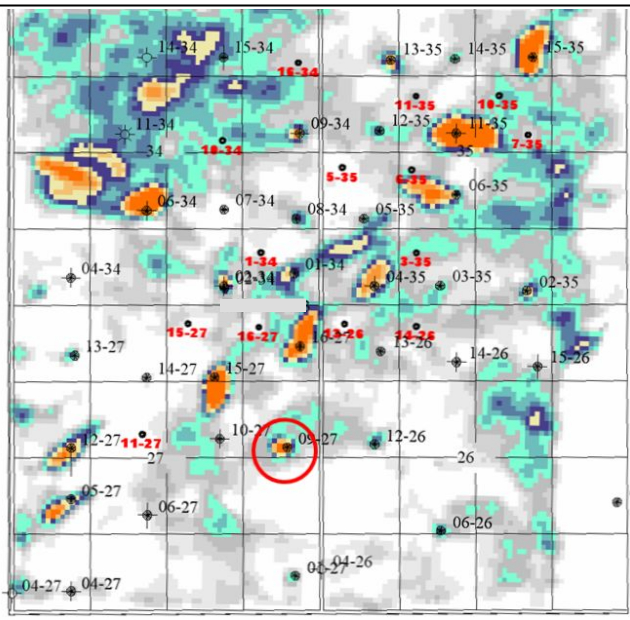

Figure 7: AVO fluid factor anomalies at CHOPS wells.

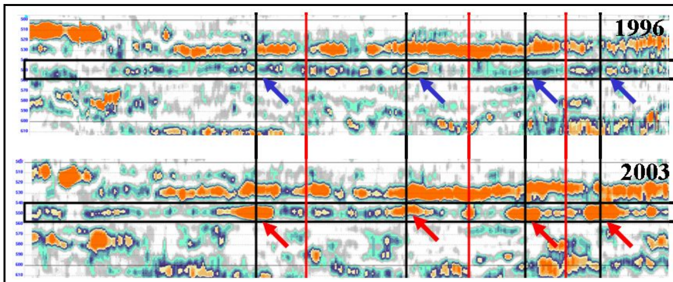

Figure 8: 4D of 2D line (1996) top and extracted 2D from 3D (2003) bottom. Amplitudes at the red arrows (2003) are not present in 1996 at the blue arrows.

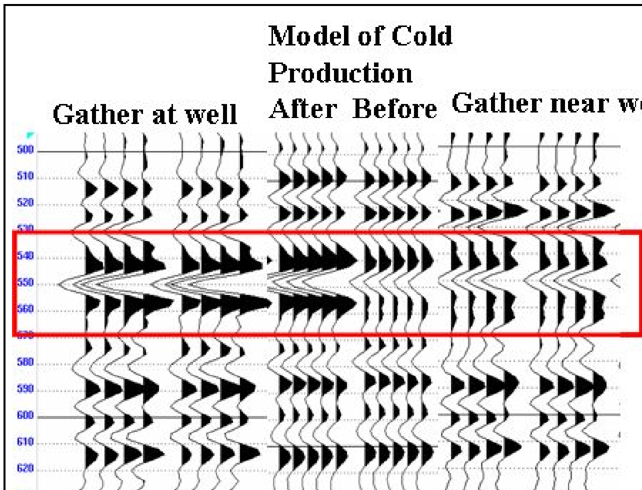

Figure 9: On the left – 2 gatherrs at the well location circled in Figure 7. Middle – 2 model gathers, the right in situ, the left after Gasssman (1951) fluid substitution. Right – 2 gathers near circled well, but in an undrained zone.