PS Integrated Monitoring of Steam Chamber Development using Time-Lapse PP-PS Joint Inversion: A Case Study of Oil Sands Reservoir, Canada*

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Search and Discovery Article #42411 (2019)**
Posted August 5, 2019

*Adapted from poster presentation given at AAPG 2019 Annual Convention & Exhibition, San Antonio, Texas, May 19-22, 2019
 DOI:10.1306/42411Bo2019

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Abstract

The M field is in the Athabasca oil sands region of Alberta, Canada. The oil sands reservoir is about 200 meters in depth within the Lower Cretaceous Upper McMurray formation, which belongs to a marine shoreface deposit environment. Because the crude oil has the properties of high gravity, high density and high viscosity, the oil sand is of solidity and cannot be produced directly. SAGD (Steam Assisted Gravity Drainage) was the primary recovery method for this special reservoir and has been used for a while in this development region. But the production capacity of different horizontal well platforms varies greatly. So, the key to improve the production is how to predict the change of developed chamber and developing chamber. Based on the petrophysical analysis, the changes of Vp/Vs in different periods can reflect the variation of temperature, pressure and saturation of the oil sand reservoir. In this paper, a high-precision time-lapse rock physics model has been built to estimate Vp/Vs of different development periods. And the time-lapse PP-PS joint pre-stack inversion has been carried out based on the 4D3C (4-dimensional, 3 component) seismic data, including Base (2016) and Monitor (2018) multi-component seismic surveys. The developed chamber, predicted by Vp/Vs decreasing, high temperature and high gas saturation, indicates the past production by the time of the Monitor seismic acquisition. And the predicted result is consistent with the observation wells and cumulative oil production. The developing chamber predicted by Vp/Vs increasing, indicates the future production, which is important for optimizing production performance.

Integrated monitoring of steam chamber development using time-lapse PP-PS joint inversion: A case study of oil sands reservoir, Canada

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AAPG ACE 2019 ANNUAL CONVENTION & EXHIBITION
19-22 May • San Antonio, Texas

Introduction

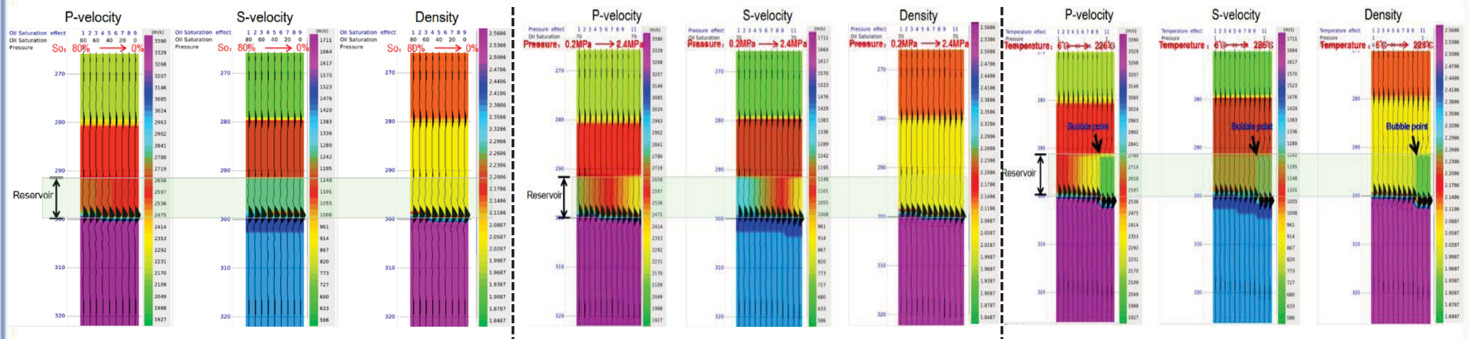
The study area is located in the Athabasca oil sands region of Alberta, Canada. The oil sands reservoir is about 200 meters in depth within the Lower Cretaceous Upper McMurray formation, which belongs to a marine shoreface deposit environment. Because the crude oil has the properties of very low gravity, high density and high viscosity, the oil is of solidity and cannot be produced directly. SAGD (Steam Assisted Gravity Drainage) is the primary recovery method for this special reservoir and has been used for one year in this development region. But the production capacity of different horizontal well platforms varies greatly. So the key to improve the production is how to predict the developed and developing steam chamber.

The development of steam chamber is monitored by time-lapse multi-component seismic data (2016 and 2018) and logging data (dipole sonic, residual reservoir saturation (RST) tool and thermocouples etc.) from multiple observation wells in production pads. The proposed integrated method achieves a good result which is consistent with the observation wells and cumulative oil production.

Key Techniques

(1) Rock physics modeling

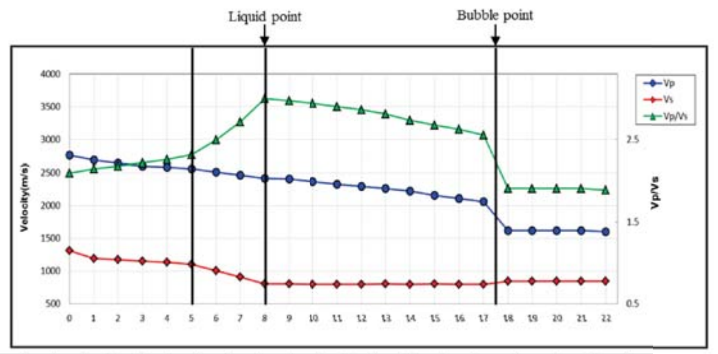
Based on the virgin reservoir and steam injection operation parameters, the changes in the reservoir elastic properties were modeled by using the Gassmann equation. The average porosity is about 30%, the initial oil saturation is 80%, initial temperature is 6C, and initial reservoir pressure is 0.2MPa.



(a) Oil saturation modeling; (b) Fluid pressure modeling (c) Temperature modeling

Figure1: Forward modeling

The above forward modeling was based on the classical Gassmann theory. However, the oil sands reservoir in this area belongs to super heavy oil. Because of the viscous property of heavy oil, the Gassmann model cannot meet the demands. During SAGD development processing, oil sands will undergo "phase transition" from quasi-solid to liquid with the temperature increasing. The conventional single rock physical model cannot accurately describe the phase transformation. Therefore, integrating the Kato's study results of laboratory data (Kato et al., 2008) with Gassmann theory, a combined rock physics model with different pressure and temperature was proposed. Based on the combined rock physical model, the time-lapse simulation of elastic parameters in production process was carried out (Figure 2). It can be divided into four stages.



Step	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
P(MPa)	0.4	0.6	0.8	1	1.2	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
T(℃)	6	6	6	6	6	6	16	26	36	56	76	96	116	136	146	156	166	176	186	196	206	216	226
So(%)	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	70	30	30	30	30	30

Figure 2: Elastic parameters change during steam injection

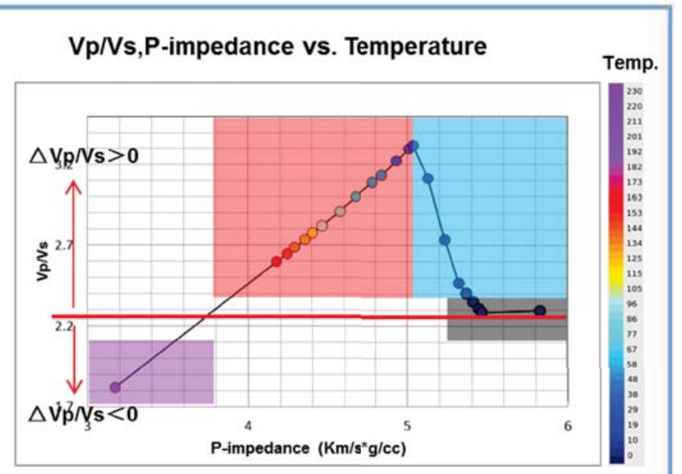


Figure 3: Crossplot of Vp/Vs, P impedance and temperature

(2) Time-lapse pre-stack PP-PS joint inversion

The 3D difference of Vp/Vs ratio were predicted by time-lapse pre-stack PP-PS joint inversion. Prior to inversion, 4D calibration and PP-PS registration were performed. 4D calibrations were carried on both PP and PS seismic data between baseline and monitor surveys to remove the spurious seismic differences caused by acquisition, processing and other factors, leaving only the differences related to production. 4D calibration mainly include phase and time shift, shaping filter and amplitude normalization above the production zone and time variant shifts in the reservoir. PP-PS registration was carried on both baseline and monitor survey. The workflow includes PP and PS well ties, Vp/Vs ratio model building, global domain conversion and seismic event matching.

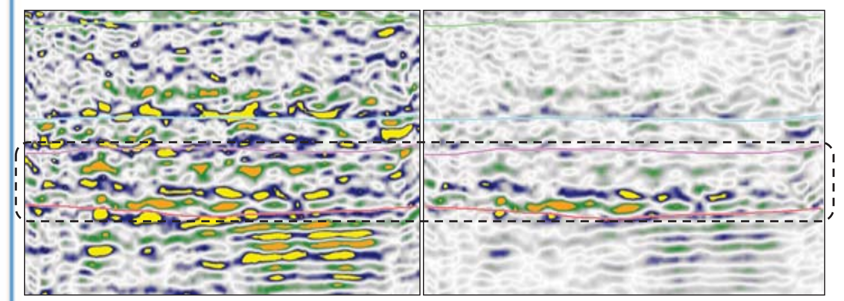


Figure 4: PP amplitude difference section before (left) and after (right) 4D calibration

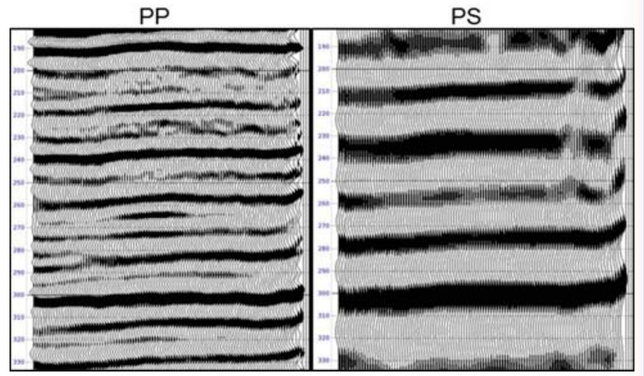


Figure 5: PP-PS registration

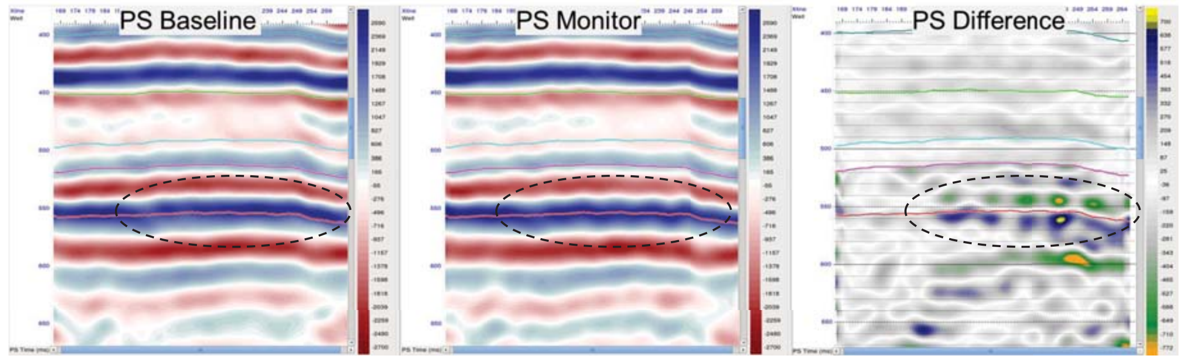


Figure 6: PS Baseline, Monitor and Difference seismic sections

For baseline survey, the initial model is established by using the original curve directly. Unfortunately, time delays caused by velocity changes in the monitor survey can adversely affect the inversion comparison. Fortunately, the time delay information can be used to enhance the inversion process and provide information that is below the seismic bandwidth. For the monitor survey, the initial model building is divided into two steps. The first step is to interpolate the time-lapse logging curves (Figure 7) generated by the combined rock physics model. The second step is to use the difference of time horizons between time-lapse PP data and PS data to calculate P-velocity and S-velocity scalers to adjust the low frequency model of monitor survey. Through the time-lapse pre-stack PP-PS joint inversion, the Vp/Vs difference volumes were generated (Figure 8). The Vp/Vs increasing reveals the future production zone (green and light blue). The Vp/Vs ratio decreasing indicates these zones are developed steam chambers (yellow and red), where the oil has been produced.

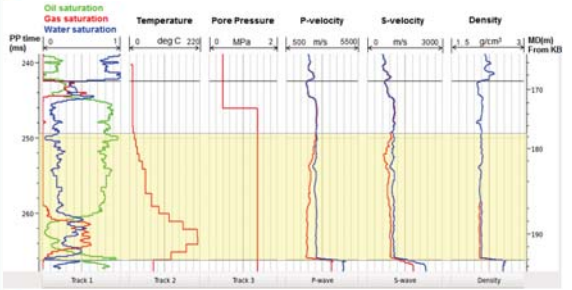


Figure 7: The original logging curves (blue) and time-lapse logging curves (red)

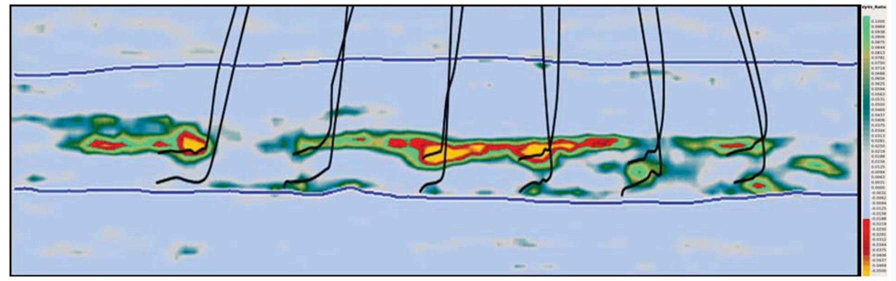


Figure 8: Vp/Vs difference section

Results

Through the multi-attributes analysis and neural network, temperature and gas saturation volumes were achieved further (Figure 9). Integrating all the information, the steam chambers was obtained by using different threshold values of Vp/Vs ratio, temperature and gas saturation. The developed steam chamber (purple), extracted from Vp/Vs decreasing, high temperature (>180 ℃) and high gas saturation (>40%), reveal the post or current production. The developing steam chamber (yellow), extracted from Vp/Vs increasing, temperature (>30℃) and gas saturation (>10%), reveal the future production.

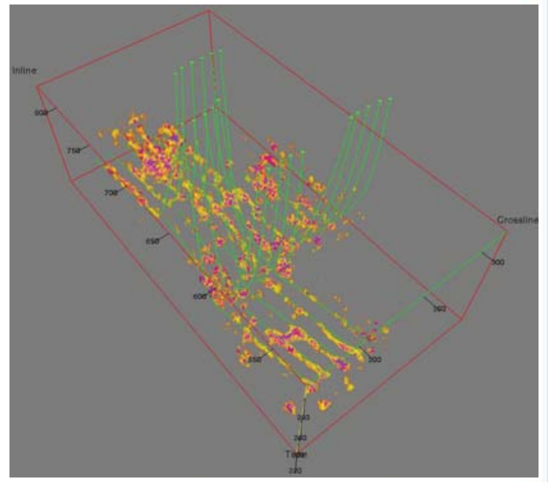


Figure 9: The 3D view of steam chamber

Conclusions

(1) For oil sands reservoir, Vp/Vs is the most sensitive to production according to the time-lapse rock physical analysis.

(2) The time lapse amplitude differences of PS data are more interesting. And PP-PS joint inversion can achieve the more accurate Vp/Vs.

(3) Integrate Vp/Vs, temperature and gas saturation, the developed and developing steam chambers were identified and characterized, which is consistent with the actual data.