One seismic source and receiver couple to detect steam effects on legacy data in Surmont, Canada.

Introduction

Surmont is a heavy oil field located in northeast Alberta currently being developed by a joint venture between ConocoPhillips and Total. A pilot project started in 1997 using Steam Assisted Gravity Drainage (SAGD) as improved oil recovery method to develop the field. This technique utilizes a pattern of horizontal well pairs that continually inject steam into the reservoir to mobilize the heavy oil so it can be produced (Byerley et al., 2009). To monitor the enhanced oil recovery process, highly repeatable 4D seismic surveys have been completed every 6 months over the years. Apart from the 600km² of 3D seismic, there are now about 1500 wells, most of which are covered by the 3D: a very dense and well-known area that has cost millions of dollars of investment.

In order to maximize the value of information while controlling costs, a novel light seismic monitoring approach has been "blind-tested" on existing well and 4D data. The concept requires the use of only one source and one receiver location optimally placed in the field to monitor a spot in the subsurface, using time lapse shots to detect 4D changes in the zones of interest. Subsurface changes linked to variations of constraints, temperature, pressure and saturation can be tracked in the non-migrated domain by comparing seismic traces acquired over time by each source/receiver couple.

The objective of this blind test was to see if the steam had reached one zone and not another without knowing previous reservoir history. The results obtained after the survey have then been compared to existing 4D vintages and well data to (in)validate said approach. The bigger picture was to see if this focused detection approach could complement or help space 4D campaigns in specific locations where the uncertainty remains high while controlling costs. In a never-ending fluctuating Oil & Gas environment, such solution could represent an affordable alternative to conventional monitoring techniques.

Material and Methods

The results discussed in this paper utilized the 4D design made of permanent single-component analogue geophones buried 6 meters below the surface and 125g dynamite charges loaded in cased shot holes at 6-meter depth. Such a design makes sure that each 4D monitor survey re-occupies the same exact shot and station locations that were used for the 4D baseline survey, ensuring maximum repeatability (Byerley et al., 2009). The dataset used in this paper focuses on Pad 101N, where a 4D baseline was acquired in 2010, followed by 7 monitors every 6 months from March 2012 until March 2015.

For this blind test, three spot locations have been defined by ConocoPhillips on a well pad for which the reservoir history and behaviour was not known to SpotLight. The goal was to see how this approach focused on spots could track the steam chamber dynamics and match with observation wells data from 2010 to 2015. The three spot locations defined by ConocoPhillips for the blind test are presented in Figure 1. The spots were deliberately placed on observation wells to allow a reliable correlation between what is observed at each spot and the collected data at the observation wells.

Figure 1 *Blind-test scenario on PAD101 North. Spot locations have been defined over observation wells in order to correlate the detections of the steam chamber variations. Reservoir depth is 450m.*

A survey design was completed to find the optimum source and receiver locations per spot using the migrated data of 2010. The objective of this phase is to retrieve the best source and receiver's locations out of the entire survey design used in the 2010 3D base campaign to be able to detect a reliable 4D effect on each of the monitors for specific spot locations (see Morgan et al., 2020 for more details). The optimum trace selection follows a specific sequence, including inverse ray tracing, semblance criteria and when applicable petroelastic modelling. Furthermore, signal to noise ratio, surface constrains, or absorption were also considered in these optimum selections.

The optimum traces extracted from each monitor are displayed in Figure 2 for Spot 3. Thanks to the optimum selection phase performed during the survey design and the operational model, the repeatability reaches on average 0.25 of Normalized Root Mean Square for one shot every 6 months highlighting the quality of this onshore semi-permanent seismic acquisition system implemented in the Surmont field. This NRMS was computed on a 100ms window, in the overburden area, avoiding any 4D effects at reservoir level.

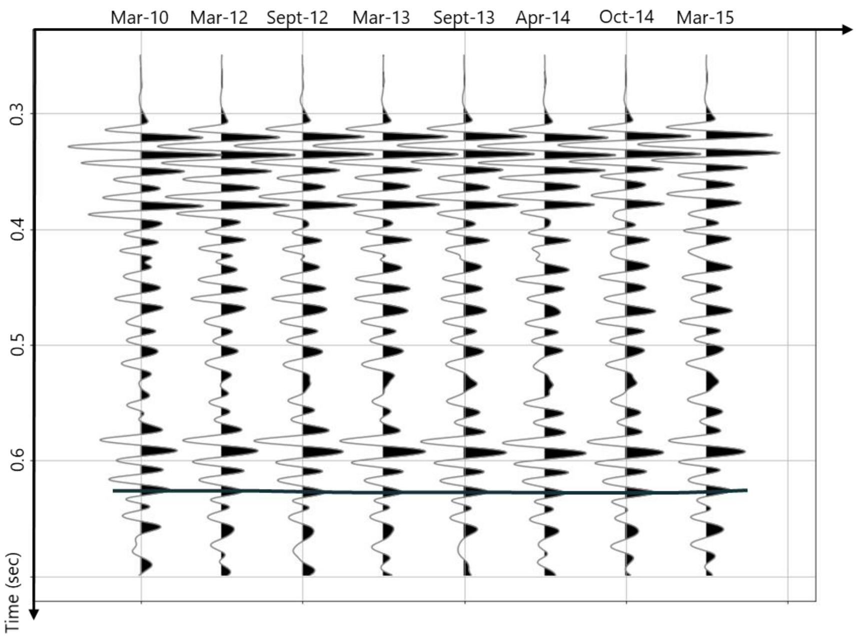

Figure 2 *Processed antenna (40-80Hz) for Spot 3, reservoir horizon is indicated by a black line.*

The seismic traces changes reflect many effects such as weather or water table variations and, of course, the 4D reservoir effects of interest. To separate reservoir and overburden effects from the rest, a reference horizon above the reservoir is used to correct the dataset using time-shifts compensation over time. Once the correction is validated, the seismic data only contains the 4D effect at reservoir level: the detection can now be performed.

Results: Post-mortem analysis

The acoustic properties of heavy oil sands exhibit a strong response to temperature changes resulting in significant velocity decrease through zones in the reservoir which have been thermally altered by the SAGD process. This unique response makes it possible to utilize time shift method to monitor thermal evolution of the steam over time (Byerley, 2009). A time-shift detection has been computed over the 8 traces (corresponding to the base and the 7 monitors) for each Spot. Results are shown in Figure 3. Sensitivity analysis shows than uncertainties of picking are in average lower than 0,5ms on these data.

Spot 1 (black line, circles) shows that the time-shift variations remain under the noise level: time-shift values do not exceed 1 millisecond; suggesting no visible 4D effect.
The second spot (orange, squares) shows an effect building up over time from 0 to 4 milliseconds starting in March 2013. The last detection point for spot 2, which shows a decrease in terms of time-shift can possibly be explained by a lower repeatability of the last monitor (i.e. the NRMS value is about 1.5 for this monitor compared to 0.35 in average for the other traces of this spot). This poor repeatability could be avoided by implementing few shots per source position to reduce noise when acquiring the data.
Finally, the time-shift plot for Spot 3 (blue, triangles) in Figure3, shows a continuous increase from the baseline in 2010 to the last monitor in 2015: a variation up to 7 milliseconds is observed, suggesting the building of a 4D effect which started at the beginning of 2010.
After the presentation of these results, temperature data from observation wells was shared by ConocoPhillips to compare these hypotheses to field observations and fact-check this new detection approach. The comparison is shown in Figure 3.

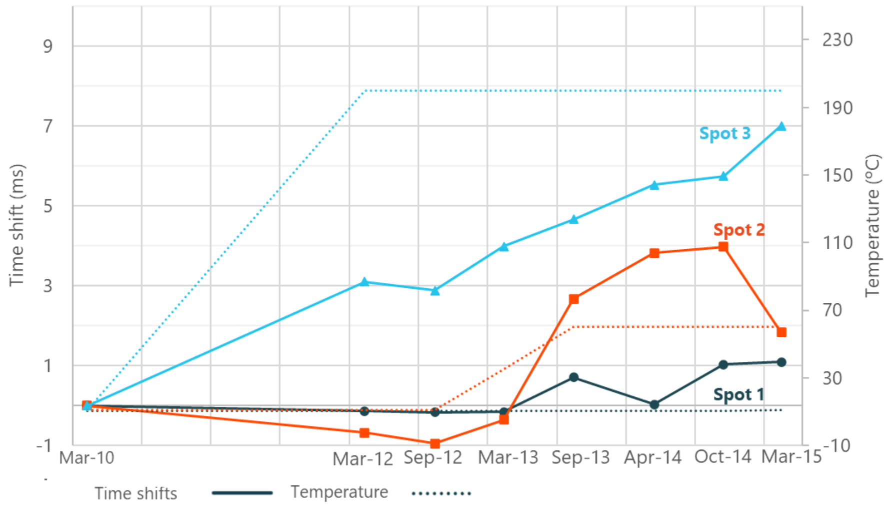

***Figure 3** Time-shift plots (solid lines) for each spot & temperature data (dotted lines) from the observation wells in the vicinity of each spot.*

From Figure 3, we can see that the temperature and time-shifts follow similar trends for each spot with a fast increase of temperature for spot3, a minor increase 3 years later for spot 2 and no temperature variations for spot 1.
The process of steam injection leads to a large number of modifications, at reservoir level and above, associated with temperature, saturation, pore pressure and constraints changes. For instance, the injected steam increases the temperature within and adjacent to the steam chamber and thus introduces thermal

expansion effects (Chalaturnyk & Polikar, 2004). The evolution of those physical parameters will impact the wave velocities and reflectivity. Positive time-shifts, corresponding to a decrease of velocity, observed here are coherent with expected and measured 4D responses in a SAGD case (Lerat et al., 2009).
Regarding this light and focused monitoring, we deliver a qualitative information about the reservoir dynamic on the area of uncertainty.

Conclusion

In this paper, a novel light and focused seismic detection approach has been successfully tested to monitor the SAGD process in a pad of the Surmont heavy oilfield. The technique consists in monitoring 4D changes in the subsurface with just 1 source/receiver couple optimally placed at surface. This non-migrated 4D seismic detection offers an agile & cost-effective solution for monitoring purposes.

3 spots were indicated on a pad by ConocoPhillips to blind test the approach and detect changes induced by the steam. After a survey design consisting in retrieving the most contributory seismic traces to the spot's illumination and the corresponding source/receiver couples, time-shift changes were plotted for all 3 spots and were all successfully fact-checked with temperature data from observation wells, confirming the qualitative variations attributed to the dynamic of the steam chamber.

Therefore, this blind test has successfully demonstrated the ability and reliability of this focused seismic monitoring approach to detect 4D changes every 6 months in precise subsurface locations a.k.a. spots. With just one seismic source/receiver couple, it is possible to monitor the evolution of the steam chamber at reasonable cost and therefore space the 4D campaigns so that they can be triggered only when really needed. Thanks to these results, a field measurement with this new approach is currently held to monitor the development of the steam chamber in another pad of the Surmont field.

This approach highlights the applicability of a light operational model made of a single shot from an impulsive source and an optimal receiver location. In areas where signal to noise ratio is excellent on raw legacy data, these data could be used as a base to implement the methodology. Compared to onshore, offshore raw data usually have a much better signal to noise ratio. Therefore, an offshore reservoir monitoring application of this technique is under development using legacy data.

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