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Light time-lapse seismic monitoring for SAGD: a new approach & operational model

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Summary

Steam Assisted Gravity Drainage (SAGD) techniques are commonly used to develop oil sand fields in Alberta, Canada. To monitor the enhanced oil recovery process and caprock integrity, highly repeatable 4D seismic surveys have been completed over the years, and numerous fields have been equipped with permanent receiver layouts and cased shot locations.

A light and novel innovative seismic approach to monitor SAGD operations in Surmont on a pad had been blind tested on legacy data. It has proven the possibility to monitor steam effect by extracting time-shifts matching temperature data on optimal raw seismic traces acquired every 6 months between 2010 and 2015. This success led to the planning of a specifically designed field measurement on another in the Surmont area. For this monitoring, 4 different areas with approximately 20 spots repeating only 17 shots locations & 20 receiver locations were designed. The goal of this field acquisition was to assess the capability of the method to perform reliable 3-months time-lapse monitoring to better capture reservoir dynamics.

An efficient collaboration between the operator (ConocoPhillips), the seismic acquisition provider (Echo Seismic) and the processing start-up (SpotLight) was key to optimize the operational model, thus leading to detections better reflecting the reservoir dynamics. Critical areas to be monitored were indicated by the operator, with the processing company designing the optimal source & receiver locations and acquisition parameters using existing 3D data that were then passed on to the acquisition provider. The acquisition was performed and feedbacks about the in-field accessibility to help further optimize future detection were provided. Finally, the processing company presented the detection results to the operator.

In this paper the workflow & operational model is presented with a focus on how we were able to reduce the number of sources & receivers needed to provide reliable information about the area’s dynamics. We then present the detection results obtained on each 4 areas with a comparison of some of the observation wells. Finally, detection threshold, method limitations, further optimization & ways forward are discussed.

Innovative operational model

An innovative, light, and focused seismic acquisition has been tested in Canada, Surmont in 2021. The objective is to further increase the overall comprehension of the steam dynamics through time by increasing the temporal monitoring frequency thanks to a lighter, quicker and cost-effective seismic detection system.

Operating 3D surveys in Surmont usually requires several weeks for mobilization, acquisition and demobilization operated by large seismic crews of over 40 people. During this significant amount of time, more than 1700 dynamite shots using permanent buried cased holes are performed and simultaneously recorded by 2500 buried geophones on a permanent layout. Given these limitations both in time and costs, 3D seismic images are usually completed at the best every six months in order to track the steam chamber spreading through time.

Over the lifetime of a pad, critical areas to be monitored can be defined in order to validate or invalidate production hypotheses. Some can be monitored using observation wells to precisely measure and calibrate temperature and pressure effects over sensitive areas. Unfortunately, in some cases, cost and/or surface obstructions makes it impossible to consider smooth drillings for monitoring purposes. The studied pad in this paper is a good example as roads are facilitating transportation and accessibility on the field while sometimes preventing vertical drilling to monitor sensitive areas.

This is one of the reasons why a new operational model of this innovative, light and focused monitoring technique, validated on the first pad (Brun et al., 2021) was implemented on this field.

Four areas to be monitored were identified in the reservoir. The major aim of this study is to monitor more frequently than every 6 months a critical area under a highway, where it is not possible to drill any observation well. Two out of the 3 other areas are located on observation wells to correlate the seismic detection with temperature and pressure data.

The goal of the study was to optimize the acquisition effort while providing reliable focused 4D detections. On a week of operation (i.e. 5days), for a 2-person seismic crew, considering travel, line clearing, mobilization, shooting and demobilization on the field, 19 shot locations and 20 active receivers (Figure 1, left) and 3 sources and 3 receivers on the pad of the previous study where acquired. Such a light seismic operational model requires 90 times less shot locations decreasing both time and prices to monitor steam effects. Considering such a setup, one acquisition every 3 months is economically & geophysically viable.

The 2 pads, being only 7km away, made it possible to perform an additional 3 source and 3 receiver locations, thus optimizing further the operational model.

Figure 1 – Left: Seismic acquisition design with both 3D permanent design in grey (1700 shots casing and 2500 buried geophones taking several weeks to operate) and the light focused acquisition system (19 sources locations – blue stars and 20 geophones recordings – red triangles operated in a 5 days). Right: Monitoring map associated with the light and focused acquisition design. The dashed white lines stand for the horizontal well design. The four red dots are the original four spots to be monitored on the area. The 20 pink dots are the common-mid point locations that were acquired in addition during the June acquisition campaign to validate the operational model.

Several acquisition patterns were tested (as shown in figure1):

- The original Spot acquisition made of a single source and receiver location to focus measurement at one precise location, detection results in this paper will focus on these 4 positions.
- A line of common-mid points (up to 30m lateral spatial error) to map the lateral steam evolution along a producer well
- A patch of co-located common-mid points to get more redundancy over an area

Such a light monitoring layout can fill-in the gaps left by conventional 4D seismic, increasing the fluid dynamics comprehension over time. Indeed, a light and focused seismic acquisition is being performed and planned every 3 months since February 2021 on this pad.

Acquisition

Data acquisition involves the firing of repeated dynamite shots from optimally chosen shot locations. Dynamite is the preferred source as it eliminates the possibility of source signature variations due to changing ground conditions with the seasons and the weather (Figure 2). Acquisition involves a drilling crew and small layout, pickup and shooting crew. Geophones are permanently located in cased boreholes and are used repeatedly for multiple data acquisitions. Autonomous recording techniques are used to eliminate the need for a recorder and personnel associated with it. The small crew results in few man hours for this type of recording, which benefits from a safety and cost perspective. Data obtained today indicate time ties are within ten microseconds, and this is considered excellent. Production depends on distances involved, number of shots and geophones but generally speaking the recording goes quickly. Stringing a number of spots in one field or area will provide very competitive pricing for the information that is gained from this process.

Figure 2 – Left: seismic source location: permanent buried cased holes. Right: Seismic crew loading a source location with 125g of dynamite during the acquisition campaign in February 2021.

Workflow

Seismic surveillance imaging for steam injection needs is often used. Focused detections have also been used since 2020 on the Surmont area on legacy seismic data from 2010 to 2015 (Brun et al., 2021).

Monitored area in the reservoir (spots) are considered to design the novel acquisition layout in order to select the optimal source and receiver location according to a seismic baseline (Morgan et al., 2020). Thanks to this optimized workflow, the monitored area does not represent a common-mid point approximation, but actually refers to the spatial area highlighted by seismic reflections. Furthermore, each designed source/receiver pair has the best signal to noise ratio to illuminate and therefore monitor each spot. The initial seismic baseline of the pad is analysed in order to retrieve the best wave propagation path in the subsurface enabling the extraction of a reliable 4D effect on the targeted area of the reservoir.

Steam injection patterns are usually highlighted using time shifts as 4D seismic attributes. Detection thresholds associated depends on the repeatability level achieved mainly due to the acquisition and data processing. It is then critical to ensure a maximum repeatability in equipment and locations used (Jervis et al., 2012) as well as optimal source-receiver antennas to ensure the best signal to noise ratio possible. As demonstrated over the first field, time-lapse seismic using dynamite shots into permanent casings allow for maximum repeatability with a correlation coefficient of more than 80% prior processing and until 98% after time-lapse processing from one monitor to another. To make sure that each antenna can be usable for detection, it was stated to perform 3 shots at each source locations for every spots. Spot 1 (Figure 3) is showing an excellent repeatability with a correlation coefficient of 98% on average between the 3 surveys.

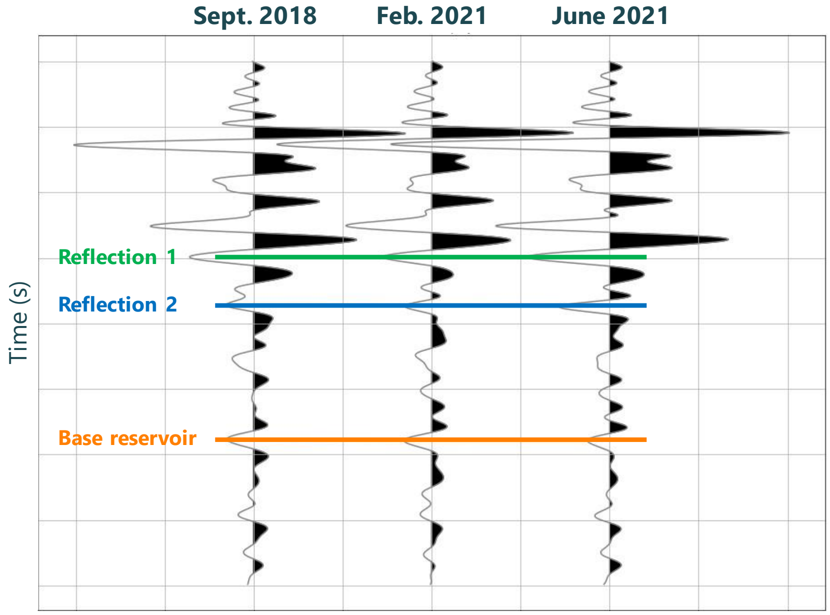

Figure 3 – Spot 1 time-lapse optimal source-receiver data showing 98% average correlation above reservoir from one monitor to another.

Results

The seismic trace can be influenced by many different effects such as the weather or water table variations (affecting the whole trace) and the 4D effects happening in the reservoir (affecting the trace at and under the reservoir). To separate the reservoir and overburden effects from each other, a reference horizon above the reservoir is used to correct the dataset using time-shift compensation over time. This reference horizon is picked over the original shot-point coming from the baseline of 2018 which includes the optimum trace used for the detection (Brun et al., 2021). Once the overburden variation is corrected, the only remaining 4D effect is the one happening at reservoir level.

Spot 1 shows a 1ms time-shift between September 2018 and February 2021 which can be explained by a 3-year timelapse between the 2 surveys. A time-shift of 10µs between February and June 2021 is also observed. It was stated that no steam effect has been detected in this area for those dates (Figure 4).

Spot 2 shows a growing time-shift effect from 2018 to June 2021, reaching a value of 2.31ms. It is stated that steam effect has been detected in this area.

Spot 3 shows time-shift values remaining around 0ms, suggesting that the steam injected in the reservoir does not reach this area.

Spot 4 shows as Spot 2 a time-shift effect building over time that goes up to 2.53ms, suggesting that the steam effect is detected in this area.

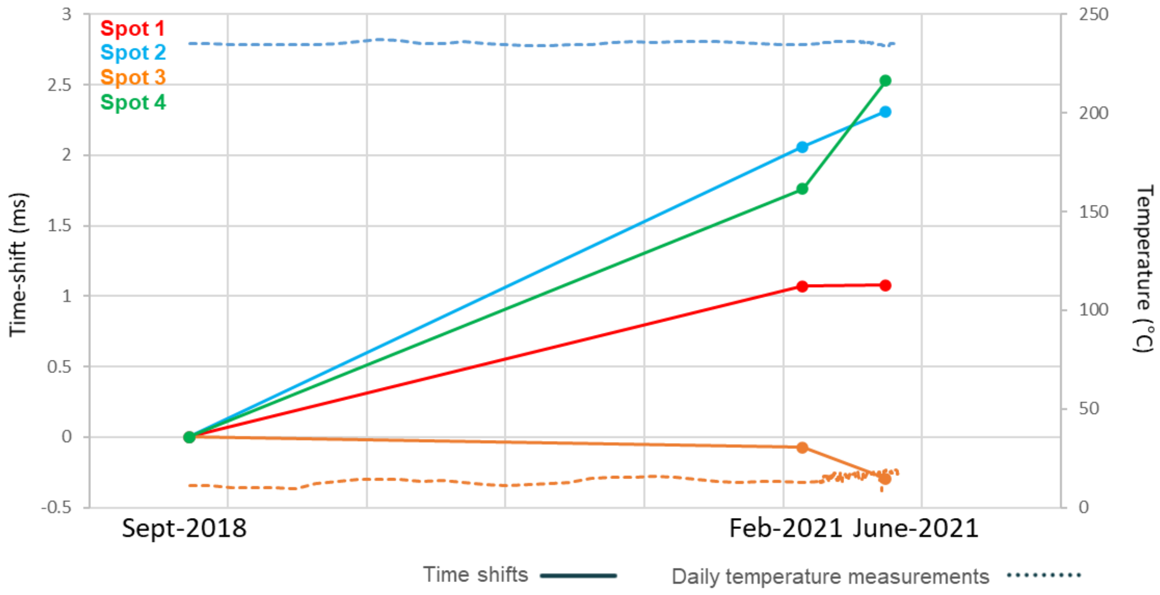

Figure 4 – Time-lapse seismic detections and temperature data from associated observation wells.

Validation: corelation with observation wells

After presenting these detection results, it was possible to correlate the variations with temperatures at two observation wells located at Spot 2 – blue curve and Spot 3 – orange curve.

- The observation well on Spot 2 shows a constant temperature over time of approximately 235°C, meaning that the steam is detected in this area, which is coherent with the time-shift values that were computed.
- The observation well on Spot 3 shows a constant temperature around 12°C, which mean that the steam is not reaching this area, once again the time-shift values computed are coherent with the observation well values.

These correlations show the strength of the SpotDetection, giving a focused information very frequently at specific locations with very limited equipment on the surface. Away from the observation wells, spot 1 & 4 detection results could now be trusted and used as calibrated points for dynamic reservoir model interpretation & prediction.

Conclusion

The innovative light monitoring layout presented in this paper can fill-in the gaps left by conventional 4D seismic acting as agile observation wells, increasing the fluid dynamics comprehension over time. The non-invasive and data centric approach allows for a cost-effective and quick steam mobility assessment in the subsurface. The acquisition layout can evolve with the life of the field to track the steam chamber dynamic.

Various acquisitions patterns can be implemented and mutualization with neighbouring pads will further increase acquisition & cost efficiency.

The computed time shifts at each spot give information on the steam dynamics at reservoir level. Seismic detections were correlated with temperature measurements and showed matching results.

This light seismic survey will be performed every 3 months from February 2021 to February 2022 to assess the steam chamber spreading over time and validate production scenario.

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