Permanent, continuous & unmanned 4D seismic monitoring: Peace River case study

Cécile Berron, Laurène Michou, Benoit De Cacqueray, Florian Duret, Julien Cotton and Eric Forgues; CGG

Summary

The seismic monitoring solution presented here is a permanently buried, fully automatic, and continuous seismic acquisition and processing system. It ensures remarkably repeatable daily seismic.

Our specific calendar oriented 4D processing flow is described and applied on a monitoring system installed for Shell on their Peace River project to provide daily monitoring of a heavy oil production pad.

The main observation is that 4D attributes vary a lot even when looking at very short calendar periods. This continuous monitoring information gives significant insights into reservoir activities and offers new opportunities to better understand the short term dynamics of the reservoir.

Introduction

One of the most common *in situ* methods to enhance heavy oil recovery is steam assisted production. As steam generation is expensive, it is important to optimize steam injection programs and avoid waste. This requires appraising the volume of reservoir stimulated on a frequent calendar basis.

In conventional 4D seismic and especially onshore, positioning errors, ambient noise and lack of acquisition repeatability drastically decrease the chance of success to observe small reservoir changes due to production.

In order to provide very frequent seismic acquisition for land reservoir monitoring, CGG has developed an autonomous unmanned permanent seismic monitoring system, known as SeisMovie^{TM}. This repeatable technology enables to detect or image daily reservoir variations.

Such a system has been installed on a production pad of the Peace River heavy oil reservoir in Alberta, Canada for Shell (Lopez et al., 2015). The seismic monitoring has been ongoing since May 2014. We present the 4D processing flow driven by the specificities of this unique seismic monitoring acquisition.

Permanent, buried, repeatable, unmanned, and continuous

Our 4D seismic acquisition system differs from conventional 4D time-lapse seismic methods through six main characteristics:

Permanent, buried sources and receivers ensure perfect positional repeatability and improve both 4D signal to noise ratio and signal repeatability, thanks to the insulation from surface noise and near surface variations (Cotton & Forgues, 2012).

Reliable piezoelectric seismic sources ensure the repeatability of the emission system as shown by Schisselé et al., 2010.

Once installed the seismic acquisition system if fully unmanned. There is no crew onsite, and therefore zero HSE exposure. As such, the total cost of monitoring becomes virtually independent of the number of repeated acquisitions and is amortized over time. Continuous monitoring of reservoir activity is made possible: daily 3D seismic data are acquired and processed. These specific acquisition characteristics drive the 4D processing flow.

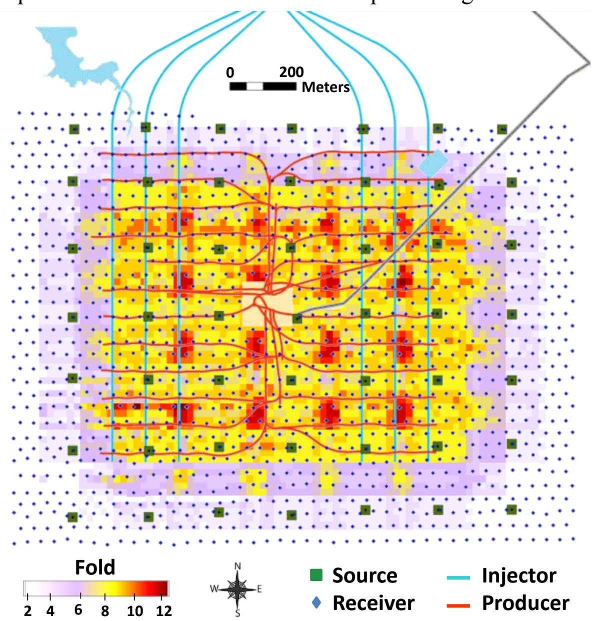

Figure 1: Peace River seismic acquisition system of permanent buried sources (squares) and buried receivers (blue dots) for continuous reservoir monitoring of horizontal well injectors (blue) and producers (red). The background color is the acquisition fold.

Peace River Monitoring

Figure 1 presents the acquisition geometry installed on a production pad at Peace River: 1490 hydrophones are buried at 20 m depth and 49 sources at 25 m depth. The source grid is 200 m by 220 m and the receivers are 40 m spaced. The monitored area is 1.8 km by 1.6 km.

The survey is sparse: the average fold is 8 on a 20 m bin size (background color of Figure 1).

The system monitors the reservoir activity of 24 East-West horizontal producers and 6 North-South horizontal injector wells (Figure 1).

DOI http://dx.doi.org/10.1190/segam2015-5813292.1

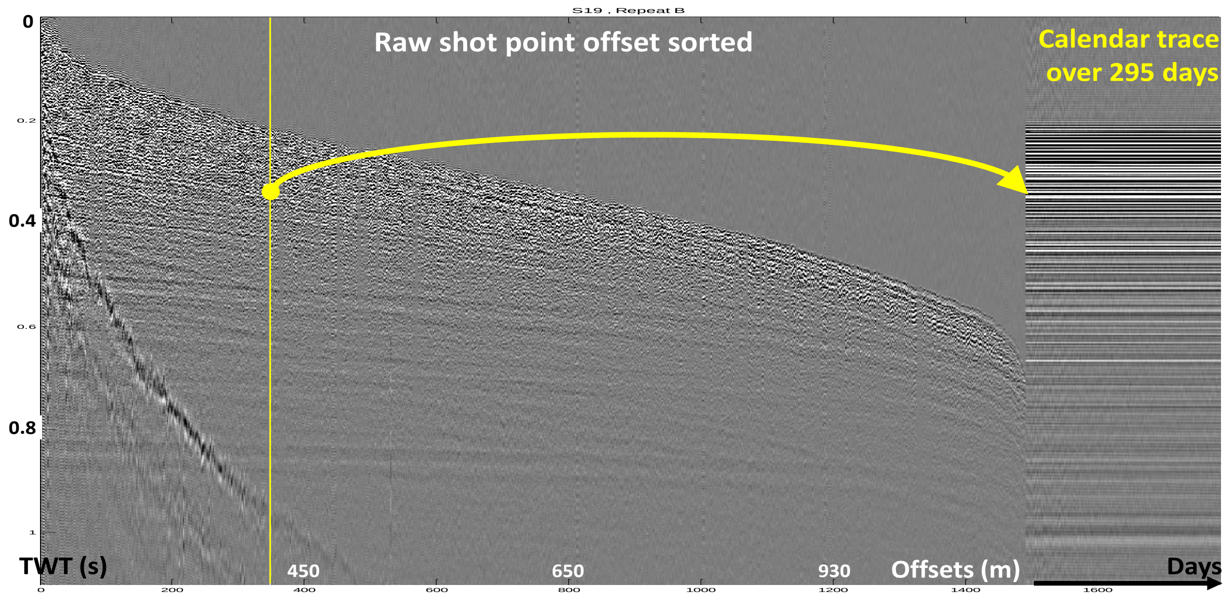

Figure 2: Left: Daily raw shot point sorted by offsets for the 1490 hydrophones. Right: one raw daily response of a single hydrophone channel over the first 295 days. The stability of the calendar trace highlights the repeatability of the acquisition.

Calendar oriented 4D processing flow

The aim of the current processing sequence is to provide: daily Pre-Stack Time Migrated (PSTM) seismic cubes, 4D seismic attributes and QC. Processing flow was delivered two months after the first day of monitoring. The automatic processing workflow is described below.

First step: We keep the same number of traces over days. If for any reason the acquisition is interrupted, the missing data is replaced by the latest available records ("copy & paste"). In practice, since May 2014 and after 300 days of acquisition, only 0.35% of the traces have been replaced and none since November. There has been no failure for all the buried equipment. Figure 2 shows a daily raw shot point and one raw calendar trace of the input data. It represents the daily response of a single hydrophone channel. The stability of the calendar trace highlights the repeatability of the acquisition.

Second step: In order to homogenize spatial sensors sensitivity differences, a spatial amplitude compensation is applied. The coefficients are kept constant for the entire monitoring period.

Third step: To correct residual variations, data are stabilized by a scalar in the calendar domain. A Root Mean Square (RMS) stabilization calculated above the reservoir is applied per source and per receiver. It is the only processing step that tends to compensate for remaining unwanted calendar changes.

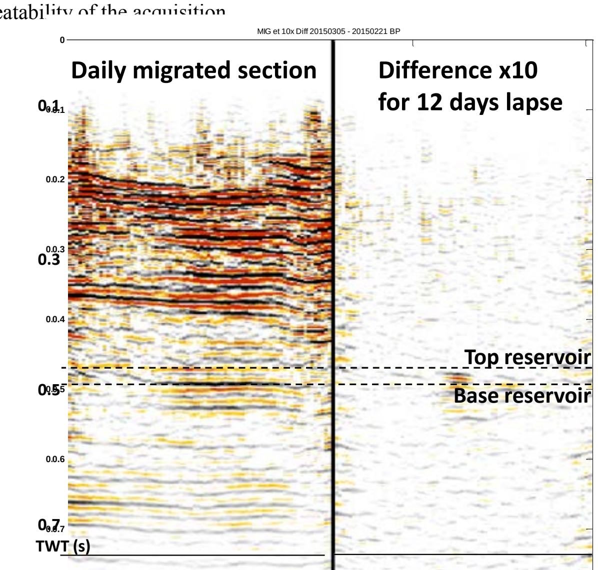

Figure 3: Migrated inline of a daily acquisition (left section) and the difference multiplied by 10 between this vintage and a baseline taken 12 days before (right section). This East-West inline is taken along a producer well during the steam injection period.

Fourth step: The data are Pre-Stack Time Migrated with a 3D velocity model kept constant over days. Figure 3 illustrates a migrated section of a daily acquisition and the differences over 12 days. As observed, at reservoir level the reflectivity appears weaker on the western side which highlights the reservoir heterogeneities.

DOI http://dx.doi.org/10.1190/segam2015-5813292.1

Clear 4D seismic variations are observed at reservoir level. Furthermore, no significant variation is observed above the reservoir, which is a first illustration of the repeatability and quality of the processed seismic data. The frequency content of the 4D migrated seismic data covers a [30-150] Hz band pass.
On certain areas short term variations of free surface reflections (ghosts) had a significant impact on the measured 4D attributes, and thus needed to be removed through dedicated calendar deghosting step (Cotton & Forgues, 2012). In the particular context of the Peace River project though, measured 4D attributes are well correlated with reservoir activity (Figure 4). No major footprint of near surface variations on the 12 days monitoring scale is observed; currently no specific deghosting process is implemented.

4D attributes

On a daily basis, several 4D attributes are automatically computed on the migrated cubes. Some attributes are used to quantify the repeatability of the monitoring to provide a confidence map of the observed variations. Other attributes, such as time shift variations, give significant insight into reservoir activity.

Figure 4 illustrates sixteen snapshots of time shift variation maps at reservoir level between September 2014 and March 2015. Snapshots are taken every 12 days. Time shift variations are computed against a sliding baseline 12 days behind of the current monitor in order to enhance short term variations. They are computed using trace-by-trace cross correlation with a sliding window of 60 ms on the migrated seismic data. The time line shown above the maps contextualizes the snapshots during the reservoir production. The first six maps, “a” to “f”, are computed during a blow-down period (i.e. a production period to reduce the reservoir pressure). Maps “g” to “p” are calculated during the steam injection period.

A first observation is that in some areas time shifts vary a lot even when looking at very short calendar periods. This unprecedented dense calendar information offers new opportunities to better understand the short term dynamics of the reservoir.

During the blow-down period, a velocity slowdown (*i.e.* decrease of time shift according to the calculation convention taken) is observed along one East-West horizontal producer.
Steam injection was initiated in mid-November, via the six North South injectors. It was followed by the clear observation of time shifts along the two eastern injectors. No significant variation is measured on the western injectors.
About 45 days after the start of steam injection, a velocity increase is suddenly observed where the velocity slowdown was measured during the blown-down period (blue spot on maps “j” to ”l”).
As the baseline is sliding, no time shift variation means that travel times are kept constant compared to the previous period, as for example snapshots “e” and “n”.

Time shift maps provide a significant overview of the reservoir activity not only on areas where variations are measured but also where no change is observed. The supplementary areal information provided by seismic monitoring should be closely linked with well measurements for further interpretation.

Conclusion

The continuous monitoring of steam assisted production on the Peace River site is achieved by a fully unmanned, permanently buried seismic monitoring system with an automatic acquisition and processing workflow. The 4D processing workflow is driven by the main characteristics of this onshore continuous seismic monitoring. Daily 3D seismic data are automatically processed to provide daily 4D time lapse attributes.
The monitoring gives significant insights into the reservoir activity and highlights short term calendar variations that would be missed by conventional time lapse 4D seismic. Linked with well information, the continuous seismic monitoring could help optimize production and enhance heavy oil recovery.

Acknowledgments

The authors would like to thank Shell for their kind permission to present this work.

DOI http://dx.doi.org/10.1190/segam2015-5813292.1

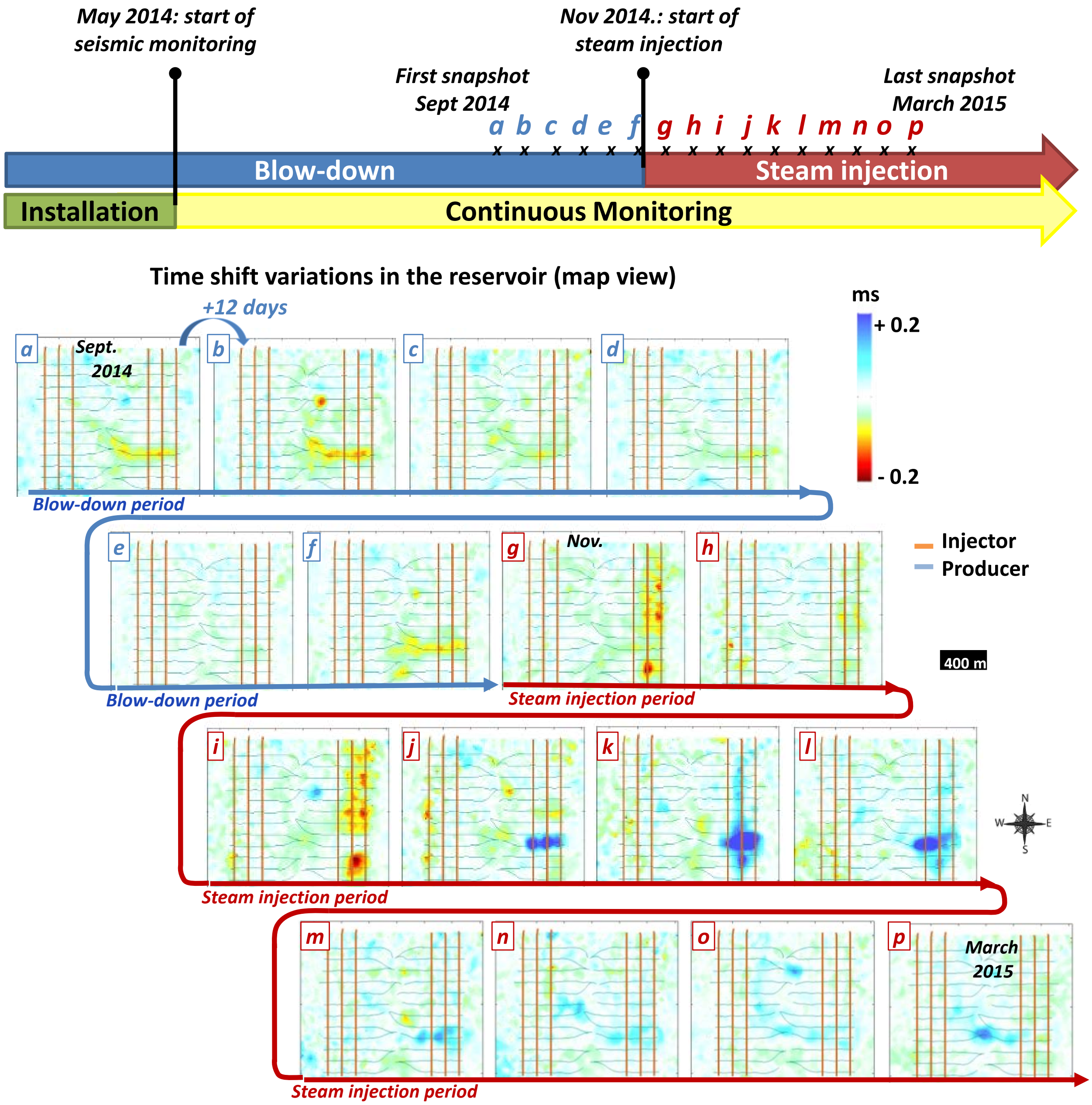

Figure 4: Top: Calendar time line of reservoir production. Bottom: time shift variations at reservoir level over seven months. Snapshots are taken every 12 days. Baseline is sliding and is taken 12 days before monitor.

DOI http://dx.doi.org/10.1190/segam2015-5813292.1

EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2015 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Cotton, J., and E. Forgues, 2012, Dual-depth hydrophones for ghost reduction in 4D land monitoring: 82nd Annual International Meeting, SEG, Expanded Abstracts, doi:10.1190/segam2012-0668.1.

Lopez, J. L., P. B. Wills, J. R. La Follett, T. B. Barker, Y. Xue, J. K. Przybysz-Jarnut, M. Van Lokven, R. R. Brouwer, and C. Berron, 2015, Real-time seismic surveillance of thermal EOR at Peace River: Canada Heavy Oil Technical Conference, Society of Petroleum Engineers, Paper SPE-174459-M.

Schisselé, E., E. Forgues, J. Echappé, J. Meunier, O. de Pellegars, and C. Hubans, 2010, Seismic repeatability — Is there a limit?: 72nd Conference & Exhibition, EAGE, Extended Abstracts, V021.