Focused and continuous ultra-light seismic monitoring: a gas storage example

Élodie Morgan[1], Mikael Garden[2], Alexandre Egreteau[2], Yessine Boubaker[1], Kevin Gestin[1] and Jean Luc Mari[1]
[1]SpotLight, Massy, France
[2]OMV, Vienna, Austria

Summary

Common appraisal methods for oil and gas reservoir often begin with 3D seismic and exploration wells. These technologies provide spatial recognition along with focused stratigraphy and subsurface resources content. Even though models and simulations predict a reservoir dynamic, measuring this key component in time complements spatial technologies while providing relevant information regarding field optimization. Further intents to go towards continuous monitoring have demonstrated the capability for seismic to detect reliable short-term calendar 4D effects that would be missed by conventional 4D seismic. These techniques have proven efficiency yet remain expensive; this paper presents a new light seismic asset monitoring solution.

An ultra-light continuous monitoring method has been developed to focus on a specific “spot” location defined by reservoir engineer studies. To illuminate a given spot, a seismic spread, composed of one receiver and one source position, is defined by analysis of existing 3D seismic data. This procedure allows for a very high temporal density monitoring tool targeted at a specific reservoir location and is economically attractive.

This production case study gives further understanding about an active gas storage dynamic showing encouraging results for such a light asset monitoring tool and paves the way for focused and continuous seismic monitoring.

Introduction

Common appraisal methods for oil and gas reservoir often begin with 3D seismic and exploration wells. These technologies provide spatial recognition along with focused stratigraphy and subsurface resources content. Even though models and simulations predict a reservoir dynamic, measuring this key component in time complements spatial technologies while providing relevant information regarding field optimization. Such an approach is already extensively used in history matching to update reservoir models. Time lapse seismic (Mari et al., 2011) gives significant insight regarding reservoir activity. Further intents to go towards continuous monitoring have demonstrated the capability for seismic to detect reliable short-term calendar 4D effects (Berron et al., 2015) that would be missed by conventional 4D seismic (Bertrand et al., 2013). These techniques have proven efficiency yet remain expensive; this paper presents a new light seismic asset monitoring solution.

An ultra-light continuous monitoring method has been developed to focus on a specific "spot" location defined by reservoir engineer studies. To illuminate a given spot, a seismic spread, composed of one receiver and one source position, is defined by analysis of existing 3D seismic data. A "de-migration" process provides the location of source and receiver. The acquisition parameters are source-receiver distance and azimuth of the source-receiver line. This procedure allows for a very high temporal density monitoring tool targeted at a specific reservoir location and is economically attractive.

This production case study gives further understanding about an active gas storage dynamic located above a producing oil reservoir. The Vienna basin pilot detection project shows encouraging results for such a light asset monitoring tool and paves the way for focused and continuous seismic monitoring.

Method

This method requires reservoir engineers to identify key subsurface areas where temporal dynamics can impact the initial production scenario. Providing a continuous 4D effect detection on those targeted areas allows for reservoir model validation and eases operational decision making.

Spot locations were indicated by the operator using a production scenario and assumptions on the field activity to surround reservoir dynamic. The survey design was computed by analysis of the exploration 3D seismic: depth migrated seismic, raw data and anisotropic velocity model. The de-migration process was performed based on seismic dips and P velocities.

Best locations for sources and receivers are chosen from the resulting de-migration "common spot gather" (CSG). Optimum criteria over seismic traces are determined to avoid ground-roll, surface noise generator or artefacts such as guided waves, cavities or gas clouds (Figure 1). This selection process is critical to define a source-receiver pair that provides a target detection as clean as possible.

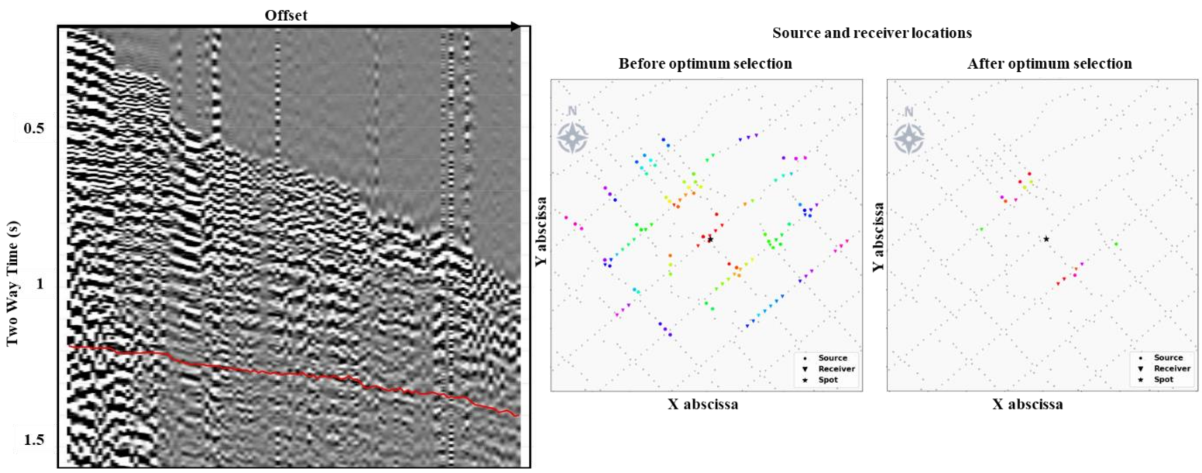

Figure 1 *A common spot gather example with oil reservoir in red (left). Source-receiver pairs before (middle) and after optimum selection (right).*

A spot is a subsurface uncertainty area defined by 4 dimensions: x, y, z or TWT (Two-Way Time) and calendar time frame for uncertainty. The 3-dimensional spot size follows the Fresnel zone concept and depends on depth, velocity gradient, offset and frequencies (Monk, 2010). The spot, in this particular case, can be seen as a circular volume with a 150 m radius and 15m thickness.

To monitor 4 spots simultaneously, 6 source-receiver pairs were computed as optimum locations, including 3 vibrated positions. This survey design took into consideration surface obstructions and allows redundancy over two spots (Figure 2). Receiver positions were designed as buried hydrophone antennae at 15m, 20m and 25m depth. Calculation showed that 50 daily sweeps from a small vibroseis truck were mandatory to retrieve an acceptable signal to noise ratio according to the initial 3D seismic data (Bianchi et al., 2002).

Figure 2 *Survey design including receiver antennae (R1 to R6, in dark blue), sources (S1 to S3, in light blue) and spots (Spot 1 to 4, in orange).*

Time-lapse processing

The small vibrator is located on a cemented pathway and its baseplate remains on the ground for approximatively an hour, enough time to emit 50 sweeps. Each hydrophone daily recording is aligned on its first sweep first arrival before daily stack as the source and soil compaction cause a small timeshift drifting over time (Jervis et al., 2012).

A daily record is similar to an offset VSP composed of 3 traces associated with the 3 hydrophones located at 15, 20 and 25m depth. Arrival times of reflected waves are increasing when hydrophone depth is decreasing. On the contrary, events reflected on the free surface (ghosts) have increased arrival times when hydrophone depth is increasing. Consequently, events could be separated by an apparent velocity filter, but due to the limited number of sensors a Single Value Decomposition (SVD) filter has been used instead. After wave separation by SVD filtering, upgoing waves are flattened (according to the 25m hydrophone first arrival) and stacked.

This processing sequence enhances signal to noise ratio and attenuates ghosts. It is repeated for all daily records in order to obtain a spot section, for which horizontal axis represents the calendar time (Figure 3). The semi-permanent reservoir monitoring system shows an excellent onshore repeatability measured between 1-5% NRMS from one daily processed stack to another.

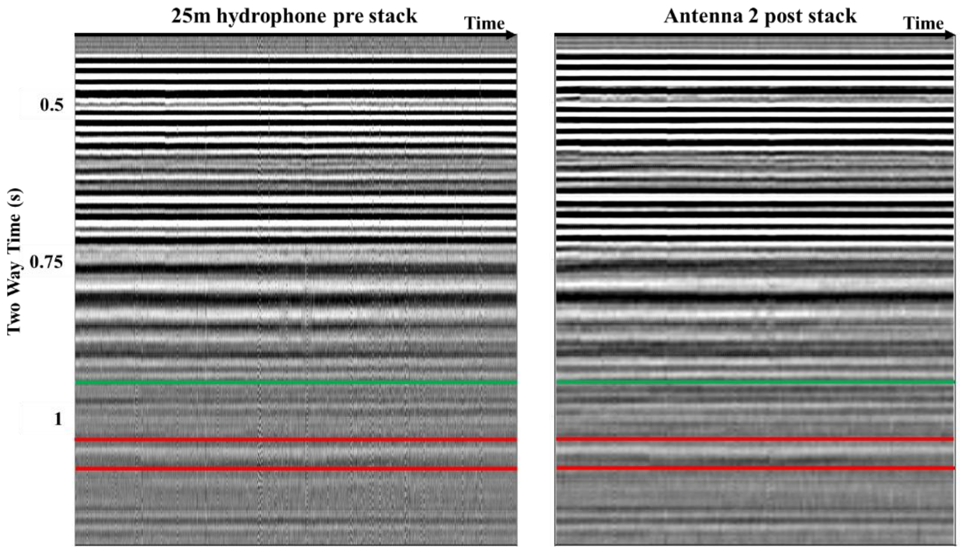

Figure 3 *132 days of continuous data with 50 sweeps per day: single 25m hydrophone (left); daily 3-hydrophone antenna stack (right). Gas storage is indicated in green and oil reservoir top and base in red.*

Such spot sections are then used for monitoring. The seismic data set still contains many effects, such as source drifting over time, weather, water table variations and of course reservoir 4D effects. To separate reservoir and overburden effects, a wide reference correlation window above the gas storage is used to correct the dataset using time shifts compensation over time. The daily water table level of the area is correlated with overburden time shifts showing that each water table elevation phase seems to precede a positive time shifts period. After overburden time shifts compensation, time shifts are computed at gas storage level (Figure 4). Antenna 1 shows a 4D effect building up around day 204.

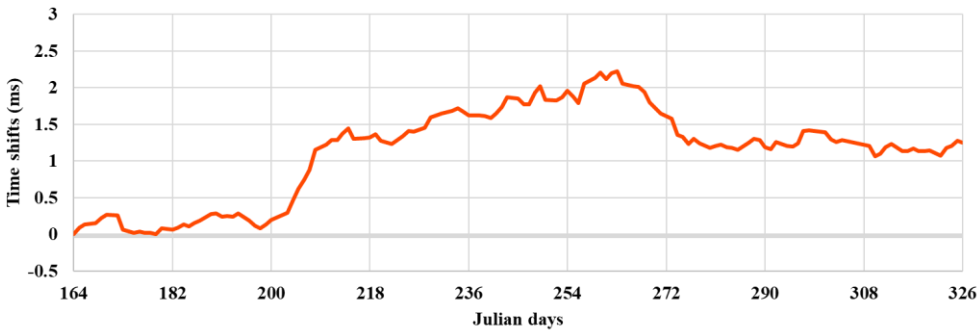

Figure 4 *Spot 1 - Time shifts at storage level compared to first day (6-points sliding average)*

The same time shift compensation was applied on a second antenna, monitoring a spot 400m away. We observe a 4D effect building up around day 224, twenty days after spot 1 (Figure 5). These two antennae show a strong 4D effect with a delay, compatible with a “production effect”.

Figure 5 *Spot 2 - Time shifts at storage level compared to first day (6-points sliding average)*

Conclusions

The pilot project demonstrates that we detect a coherent 4D effect at reservoir level with one source and one receiver antenna when a feasibility study is performed using a pre-existing 3D seismic of the field. Choosing optimal locations for sources and receivers is a key point to ensure that we are looking at the desired part of the reservoir with optimal signal to noise ratio. The second condition is acquiring enough data, at a very high temporal frequency, with acquisition parameters designed to optimize repeatability so that we can follow overburden drifting and/or 4D effects over time.

Preliminary results on gas storage seem coherent with gas injection as an increase of pressure or gas saturation will result in a decrease of P velocities, and thus a positive time shift as observed in this study. These results highlight the gas storage dynamic far from wells and must be correlated with production data from the gas field. Further integration with production data is ongoing.

Such light-asset focused monitoring tool for production gives insight regarding the reservoir dynamic, helping field optimization. It must be tested on other geological environments and production cases to assess its reliability and determine possible limitations as well as potential new opportunities.

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