Smart seismic field monitoring in a complex desert environment: an agile focused monitoring solution

Yessine Boubaker[1], Habib Al Khatib[1], Elodie Morgan[1], J.L. Mari[1], Said Abri[2], Saif Azri[2]. [1]SpotLight, [2]PDO

Summary

Seismic full field monitoring of onshore reservoir is often met with operational and geophysical barriers. Fields in operations are usually more and more obstructed over time preventing the repeat of baseline 3D layout. Carbonates are known to lower the 4D seismic response to fluid substitution and are requiring highly repeatable systems to be efficiently monitored (Barker, 2008). This is largely because the acoustic response of carbonates has been shown to be highly variable and there has been some debate regarding the applicability of Gassmann's equation for predicting the impact of changes in saturation on the acoustic properties of carbonates. Finally, the complex geology near the surface generates a strong ground roll that had been observed on the 3D gathers. This observation allowed us to anticipate and define a reception antenna allowing us to address this matter. To overcome the above challenges, a smart seismic field monitoring method is designed that enables to focus the seismic measurements on specific areas to "calibrate" the lateral expansion of the steam injection and the shallow sour gas. The method is using a data mining approach on the existing exploration 3D seismic to identify the optimal source and receiver locations, antennae, and acquisition parameters.

Introduction

Field A is a low permeability fractured carbonate oil reservoir discovered in 1971 in central Oman. This large oil accumulation at 200-400m depth subsea is trapped in shallow Cretaceous limestone units. The anticlinal structure is a result of a deep salt diapir below. Since 2011, PDO implements thermally-assisted gas-oil gravity drainage (TA-GOGD) as Enhanced Oil Recovery (EOR) technique. To monitor the steam front lateral expansion and potential high permeability connectivity, PDO is interested in using seismic monitoring. Full field 4D seismic is a proven technique for steam injection monitoring (Smith et al, 2019). However, Field A shows three challenges that are common in Middle East: a highly obstructed surface, predominant seismic surface waves and a carbonate geology that requires very repeatable seismic to be monitored.

In Field A, hundreds of wells were drilled, and large facilities including hundreds of kilometers of pipelines and flowlines were installed to treat water and generate steam (HMR, 2003). As a result, the field is now so surface-obstructed that it is physically challenging to redeploy the seismic equipment needed to acquire a full field 4D seismic (Figure 1). The last 2001 seismic campaign mobilized more than 61 thousand source points and 66 thousand receiver points for a total of 105 067 783 records. On the 9km², 20% of the original 3D traces can't be re-acquired discarding 4D full field seismic as an operationally viable solution.

To address this seismic monitoring need, a new agile seismic monitoring approach operationally compatible with Field A infrastructures was implemented. This method focuses the seismic measurement on strategic locations called "spots" to validate the production hypothesis and flow models.

Method

The light and agile monitoring project started in 2020 with 18 spots location chosen to follow the expected dynamic effects. Amongst these 18 spots, 14 were located at the edge of the expected steam front border in 2020 for conformance monitoring, 2 spots on the overburden above the reservoir to monitor the possible development of shallow steam pockets at the center of the survey. 2 additional spots used to track a potential connection between two geological structures. The spots positions need to be challenged and agreed upon by stakeholders, from geophysicists to reservoir engineers, with regards to the 3D migrated cube and the local production history and expertise. PDO performed petro-elastic modeling that estimated a recordable 4D seismic response of Field A to steam injection.

To illuminate each given spot, a minimal seismic spread composed of one receivers antenna and one source position is defined using the available 2001 3D seismic data of the field. This approach was successfully implemented for steam monitoring in Canada (Brun et al, 2021). Existing seismic images are used as a travel-map of all the wavefield within the subsurface that can be mined to find out the optimal traces to be repeated to detect changes without creating an image. This data mining approach on existing 3D seismic has the advantage of avoiding the common mid-point versus real world position approximation as dips can reach up to 12° on Field A. Furthermore, using all the raw data in a Common Spot Gather visualization gives further information on signal to noise ratio (Morgan et al, 2020), coupling and non-reflection waves (ground roll, guided waves…). The survey design aims at selecting the optimal source and receivers locations to enhance signal to noise ratio and repeatability through analysis of the existing seismic data and design the acquisition parameters.

On Field A as for most oil fields in desertic areas (Barker, 2008), the seismic data is affected by surface waves. FK filtering appears as the most promising method thanks to its simpleness and efficiency to separate surface and reflected waves. The 2001 3D data were used to design a receiver's antenna, dense enough to filter out surface waves. It was decided to use "oversized" antennae which could be downsized for future monitors.

An agile acquisition setup

Acquisition was postponed for a year due the pandemic crisis, and original spots locations had to be updated to fit the expected steam conformance showing how adaptable the focused and agile monitoring technique is. In a few weeks, the survey design was updated for the new spots. In addition to geophysical attributes, current subsurface obstructions are considered with the operator and the scouting team to choose the optimal surface equipment's location with an easy access for the seismic vibrotruck. To ensure the best repeatability possible, the vibrotruck must keep its plate down and vibrate several times (Jervis et al, 2012). Receivers are -when physically possible- located away from noise sources (such as roads and infrastructures) (Figure 1).

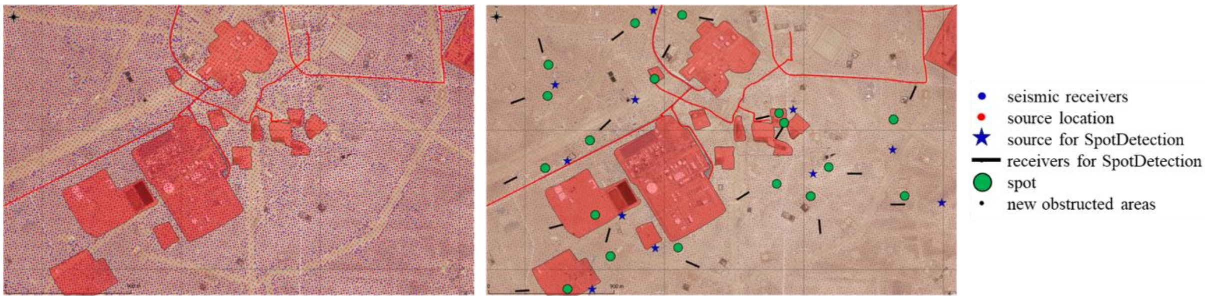

Figure 1 Left: Field A with seismic 3D layout and new obstructed areas. Right: Field A with the SpotDetection layout, the spots locations, and the new obstructed areas.

The figure 1 shows the 18 spots to be monitored in 2022 with a total of 11 sources positions and 18 receivers lines. Each receiver line is composed of 100 receivers spaced by 1m for a total of 1800 geophones. As for the source, two vibrotrucks were used with the following acquisition parameters: 50 sweeps per source station, sweep length of 55 seconds, sweep range from 8 to100 Hz. The acquisition took 8 days (including the mobilization and demobilization). A repeatability test was performed on one source location to assess stability of the system in time.

Conclusion

When conventional full field 4D seismic aren't feasible economically, environmentally and/or operationally, a smart seismic monitoring approach combining flow models, data mining on previous 3D seismic data, GIS and a strong link with the operations teams was implemented. On Field A, it has been possible to plan a focused monitoring seismic survey on a highly obstructed and desertic oil field in Oman. The lightness and agility of the solution represents an opportunity for these fields to calibrate models for conformance and caprock integrity to further enhance and secure production capabilities.

This light and focused monitoring solution proved its agility with a quick adaptation of the monitoring design, between the 2020 design & the 2022 update, showing adaptability to the underground new uncertainties and the field obstruction considerations. Down scaling the monitoring survey to a few critical spots allows to focus effort, design and equipment to maximize signal to noise ratio and repeatability. The acquisition was performed in 8 days which makes it possible to consider more frequent focused monitoring.

2022 base and monitor surveys will be processed to extract 4D attributes that could be correlated to the other field measurements and flow model assumptions to support EOR. The lightness and agility of this technology paves the way for seismic monitoring in obstructed area. Frequent monitoring could be envisaged when a strong 4D effect signature is expected like steam and carbon capture and storage.

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