Addressing the desertic carbonate CCUS monitoring challenge: lessons learnt from a case study from Sultanate of Oman

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Introduction:

Seismic monitoring of geological CO_2 storage in desert environments dominated by carbonate reservoirs faces two critical challenges: seismic repeatability and 4D subtle signal. Repeatability is challenged by the complex and time-varying nature of the near surface in these environments, which generates strong surface waves and low-repeatable seismic signals over time (Smith et al., 2019). This noise, coupled with the weak 4D signal expected from injection into a stiff carbonate reservoir, makes mapping the time lapse signal very challenging (Smith et al, 2018).

To mitigate the near-surface effects and generate a clear seismic image, an increasing number of seismic sensors are required. To increase further the seismic repeatability, permanent buried receivers and extremely precise source positioning (Smith et al, 2018) coupled with a dedicated complex processing sequence appear to be mandatory to provide 4D images. However, deploying such a setup is costly, logistically challenging and environmentally unfriendly. If the economics of CCUS may justify such investment, it is not applicable for CCS. This is where innovative technology comes into play.

A first deployment of focused seismic monitoring, applied on a heavy oil field in central Oman, utilizes a light and cost-effective focused monitoring solution. The implementation of this technology has allowed for the identification of necessary adaptations and operational limits specific to carbonate reservoirs. Understanding these nuances is crucial for tailoring effective monitoring strategies in such challenging geological contexts. By reducing costs and adapting to surface conditions, this technology could enable CCS monitoring in desert environments.

Predictive maintenance:

Instead of monitoring the CO_2 plume itself which will require expansive layout as demonstrated above, predictive maintenance (Al Khatib et al, 2024) aims at validating the main injection hypothesis and monitor identified risks on critical areas identified as “Spots”. This approach breaks the “image” paradigm and enable new operational model. This innovative monitoring technology was successfully implemented on CCS/CCUS field in Canada (onshore, Brun et al, 2023), and in Denmark (offshore, Ollivier et al, 2023). One implementation of the technology was done in 2022 in Oman and will be presented in this paper.

Field background and focused seismic operational model:

To monitor the steam front evolution over this field and test the innovative monitoring technology, 18 spots locations were determined. It is made of 11 source locations and an antenna of 100 receivers spaced by 1m to filter out the ground roll (Boubaker et al, 2022). Two light and focused seismic monitoring surveys were acquired between January 2022 and January 2023 with a total of only 6 days of operations. The acquisition also included a repeatability test during baseline acquisition and will be discussed hereinafter.

On each source location, a total of 50 vibrations were performed to increase the signal to noise ratio as well as to eliminate the compaction effect highlighted by Jervis et al, 2018. These repeated shots are economically viable as only 11 source locations were acquired.

Data processing and results:

The processing results of the two-monitoring datasets show the efficiency of filtering out the ground roll. However, a low repeatability still remained between both acquisitions. Thus, a repeatability study has been carried out using a combination of source and receiver antenna, outside the ground roll range which correspond to longer offsets. This antenna was compared before and after processing. The results confirmed the main hypothesis: the quality of the signal outside the ground roll range is better as the correlation coefficient showed higher values compared to the previous results (Figure 1). The ground roll was identified as the main source of non-repeatability and signal instability that a dense antenna of geophone installed at the surface cannot filter effectively enough given the subtle 4D signal change expected.

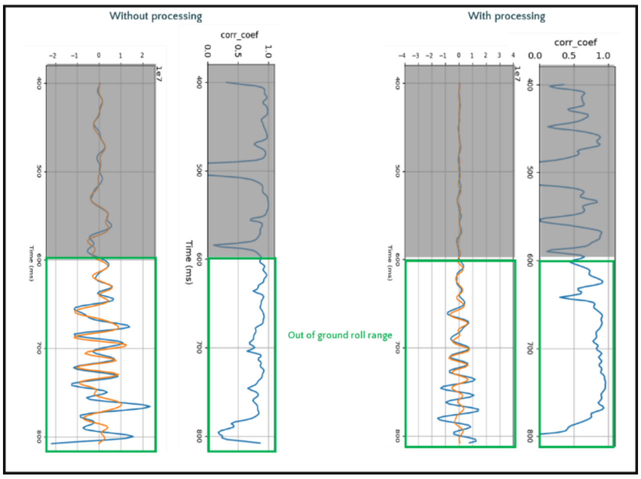

Figure 1 : Comparison of the correlation coefficient before and after processing on a seismic antenna outside the ground roll.

Lessons learned:

This light seismic monitoring project objective was to test and challenge the concept of the focused seismic monitoring from the operational side in such complex environment. These results are the first step of many toward successful and cost-effective monitoring in one of the most challenging environments. Multiple lessons were learned, and new solutions were proposed:

- The importance of the source positioning was assessed using repeatability indicators and showed the necessity of maintaining an exact source position between acquisition (Jervis and al). Thanks to a limited number of source locations, we were able to mark the ground and avoid expensive positioning solution while ensuring an almost perfect positioning.
- Stacking in the energy of several vibrations were highly beneficial to increase the repeatability.
- Desertic shallower reservoirs are not suitable for focus seismic detection due to the high velocity of ground roll. All reflection waves offset are affected by it.

CCS reservoirs are mostly deeper than few hundred meters, allowing larger offset windows. In such depth it is likely that some reservoir reflection offsets will not be affected by the ground roll. During the survey design step, a specific attention will be taken to choose optimal antenna outside of the ground roll area to preserve the signal stability and improve the quality of the processing.

Conclusion:

The project has achieved its main objectives to understand the operational model limits when working in a very obstructed area and to be the first focused seismic monitoring method in the Middle east. Additional work needs to be done to unlock the potential of the CCS in the middle east where conventional seismic monitoring is challenging. Multiple lessons learned on the operational side and the technical processing side were acquired and the suggested way forwards will increase the knowledge and shape the future of the low cost focused seismic monitoring as a solution for CCS monitoring in the Middle East.

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