Introduction

Time-lapse seismic in desert environments is a notoriously difficult geophysical challenge. The constantly evolving near-surface environment, which includes sand dune migration and seasonal variations, results in high levels of 4D noise when using conventional surface seismic acquisition. In addition, stiff carbonate reservoirs are less sensitive to changes that occur as a result of fluid composition and/or pressure changes, resulting in weak 4D signal. The success of seismic monitoring depends on the level of this 4D signal compared to the non-repeatable noise. Therefore, to detect small reservoir changes in these conditions, a highly repeatable acquisition system needed to be developed, minimising all sources of non-repeatability as far as possible. To determine the feasibility of conducting time-lapse seismic in desert conditions, various acquisition configurations were tested on a 2D profile to establish the optimum setup for data repeatability at the reservoir of interest.

Time-lapse feasibility tests

A fully buried, permanent acquisition system is desirable to minimise non-repeatable noise resulting from near-surface changes over time. However, field tests using buried piezoelectric sources (red crosses in Figure 1) were found to be insufficient to image the reservoir of interest. This was likely the result of near-surface scattering and will require the development of a stronger source to become a viable option in the future. A semi-permanent system, consisting of buried sensors and surface Vibroseis sources, is another option. To test the effect of this system on image quality and data repeatability, sensors were installed at four depth levels (Figure 1). Eighty geophones were installed at each depth level (10, 20 and 30 m) over a line of approximately 2.4 km. A small array (12 bunched sensors at each receiver station) of surface geophones were also installed for comparison.

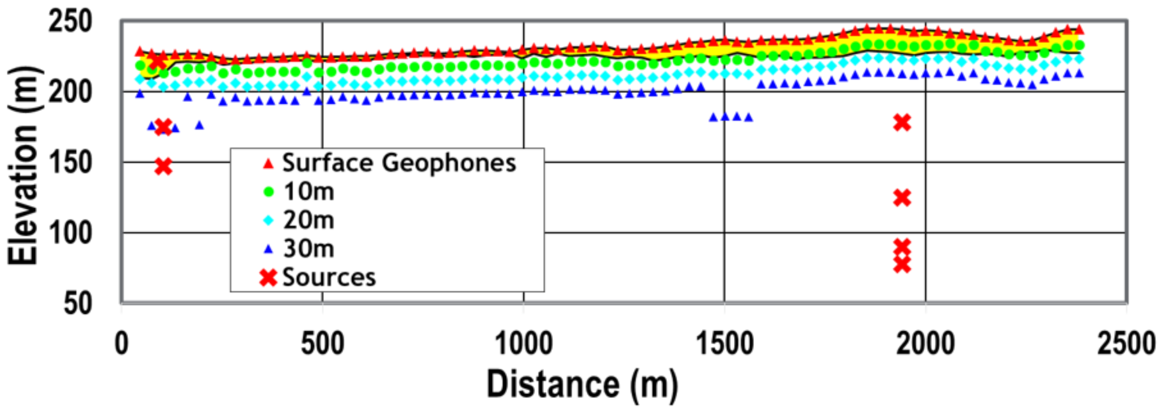

Figure 1 *Cross-section through the test-site showing the acquisition configuration for the feasibility study.*

A dense source carpet of 7.5 m by 7.5 m spacing over nine source lines was implemented to provide sufficient fold to enhance SNR and ensure adequate sampling for noise removal. Six repeat surveys were acquired over a period of approximately four months to determine the seismic repeatability.

The resulting CDP stacks produced from the four sensor levels are shown in Figure 2a. In general, improving image quality with increasing sensor depth is observed. Significant enhancements are found in the stack produced from 30 m sensors compared to the equivalent from surface bunched geophones. Superior event continuity and signal bandwidth is likely the result of the receivers being placed beneath the overlying sand layer, which extends to a depth of around 20 meters on the right side of the line.

A similar trend is observed when analysing the data repeatability in Figure 2b. Here the stack differences between the first two surveys are displayed at the same scale, essentially showing the level of 4D noise in the data (note that no 4D signal was expected at this time). The surface data clearly contains far higher levels of 4D noise than the datasets from buried sensors, likely the result of surface wave contamination of the primary signal and near-surface changes over time. The level of data repeatability is quantified using the normalized root-mean-square (NRMS) metric (Kragh and Christie, 2001) in a window about the reservoir of interest. This shows that the best stack repeatability is achieved with sensors installed at 30 m depth. However, the largest NRMS reduction is achieved by burial beneath the first 10 m of the near surface.

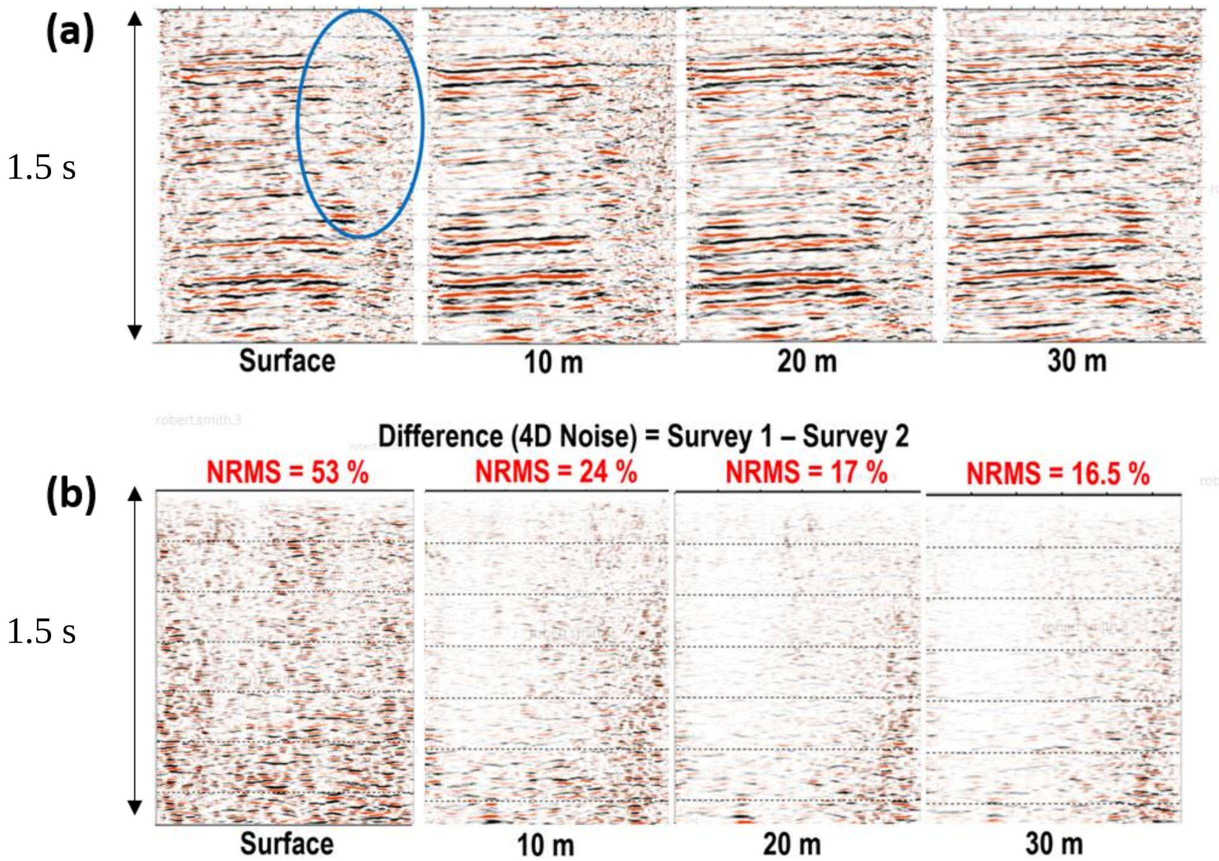

Figure 2 *Effect of sensor depth on data quality and repeatability: (a) CDP stacks produced from sensors at four depth levels (surface, 10 m, 20 m, 30 m) and (b) corresponding differences between the first two surveys acquired three weeks apart.*

Vibroseis repeatability

Buried receivers are an essential component of achieving highly repeatable data in a desert environment. However, the requirement to use surface sources adds an additional dimension to the repeatability challenge. While the sensors are fixed in position in the subsurface, more effort needs to be applied to the source positioning to ensure that repeatability is not compromised. Although source positioning is far easier to repeat on land than in marine surveys, more stringent requirements are placed on land acquisition (Bakulin et al., 2012) due to the close proximity to a complex near-surface layer (including sand dunes and karsted limestone).

To analyse the effect of source position error on data repeatability, the early arrivals for a fixed buried receiver (30 m) were analysed (Jervis et al., 2012). The NRMS was computed on a small window about the early arrival events between the repeat surveys and plotted against source position change (Figure 3). A general trend of decreasing repeatability with increasing geometry error is apparent, although it is worth highlighting that even close to zero position change, the NRMS varies considerably. This is likely a result of a number of factors, including changes in near-surface properties, baseplate azimuth, coupling and Vibroseis mechanical/hydraulic changes.

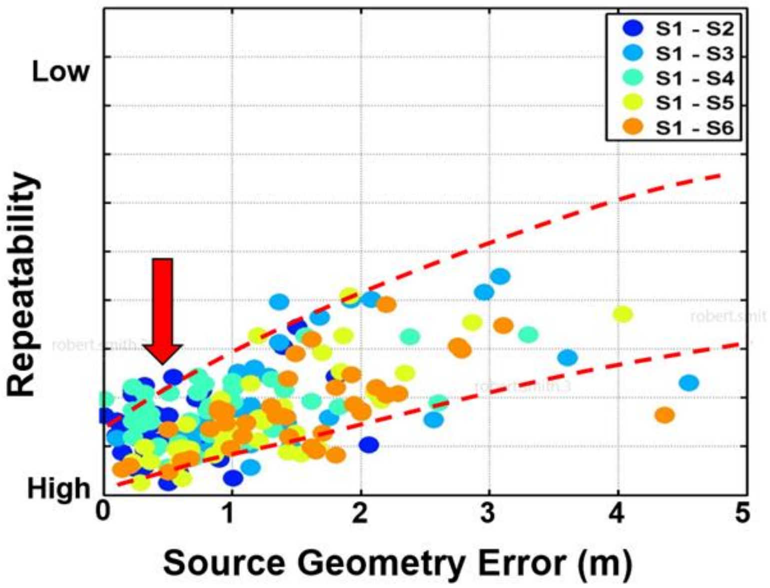

Figure 3 *Early arrival repeatability as a function of source positioning error*

Conclusions

A hybrid acquisition system, using buried sensors and surface Vibroseis sources, was found to be the optimum design for time-lapse seismic in a desert environment. Although a fully buried acquisition system is the ideal solution for data repeatability, buried piezoelectric sources were found to be ineffective at imaging the target of interest in the presence of a complex near surface. Stronger buried sources will need to be developed to make this a viable alternative in the future.

Different receiver configurations, with shallow burial between 0 and 30 m, were evaluated using a surface Vibroseis source grid. Image quality and data repeatability were found to improve significantly with increasing sensor depth, with the best results obtained from sensors buried 30 m below the surface. This is likely the result of the geophones being beneath the surface sand layer and some of the near-surface karsting, significantly reducing the amount of surface noise recorded in the data and sensitivity to near-surface changes. In addition to buried sensors being a key component of time-lapse seismic in a desert environment, careful consideration must also be given to minimize source positioning errors which can significantly contribute to overall data repeatability.

Acknowledgements

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References

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