X040

Buried Sources and Receivers in a Karsted Desert Environment

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SUMMARY

To evaluate repeatability of emerging seismic technologies for future 4D seismic reservoir monitoring studies on Middle East carbonate reservoirs, a seismic field acquisition test was conducted over an onshore field in Saudi Arabia. The effects of near-surface complexity (in the form of sand and karsts) as well as large surface temperature variations are illustrated and quantified by 4D attribute analysis using permanent piezoelectric seismic sources. Even though measured repeatability does not reach values observed in non-desert environments, we show that burying receivers dramatically improves the wavelet amplitude stability. As the complex near-surface scattering layer appears to be thicker than initially expected with the presence of karsts down to a depth of 40 m, we conclude that deeper burial of sources and receivers below the most complex part of the near surface may potentially let us use lower-fold seismic data for reservoir monitoring in complex near-surface desert environments.

Introduction

To evaluate repeatability of emerging technologies for future 4D seismic reservoir monitoring studies on Middle East carbonate reservoirs, a seismic field acquisition test was conducted in an onshore field in Saudi Arabia. One of the aims of this experiment was to analyze the influence of near-surface conditions on seismic data repeatability and quality using permanent seismic sources. In this test, we examined two piezoelectric vibrators continuously emitting a very stable, low-energy signal recorded by geophones at the surface and cemented at various depths along a 2D line. The use of permanent sources allowed a precise analysis of the signal stability in a 4D context. The high geological complexity of the karsted near surface covered with sand strongly affected the signal quality. Observations lead us to confirm that the best signal repeatability is obtained when both sensors and sources are buried below the karsted zones.

Acquisition geometry and data quality

A comprehensive 4D pilot survey took place in an onshore carbonate field in Saudi Arabia. Only tests related to permanent sources are described in this paper. Figure 1 shows part of the line of receivers that were deployed. Eighty receiver locations were spaced at 30 m intervals, with four depth levels deployed at each station: at the surface and at 10 m, 20 m, and 30 m depths respectively.

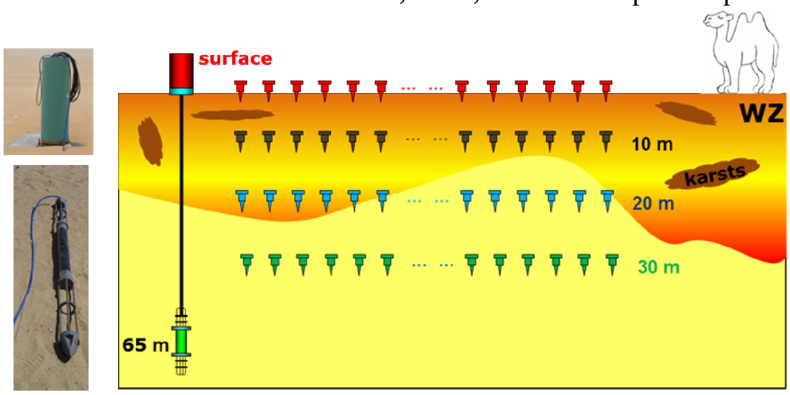

Figure 1 *The experimental acquisition geometry. Sensors are deployed at four different depths, whereas piezoelectric sources are placed at the surface and at a 65-m depth.*

Two piezoelectric sources vibrated continuously over a 4 to 148 Hz frequency range: one located at the surface and one cemented at a depth of 65 m. The buried source vibrated for 132 days, and the surface source which was bolted to a reinforced concrete pad, vibrated for 64 days. Automated and real time processing provided a reconstructed shot record equivalent to a three-hour sweep eight times per day. Additional signal-to-noise enhancement was obtained by summing data over longer periods of time. Stacking of eight days of buried source data produced the gather shown in Figure 2. Pre-stack single-fold data showed little sign of reflections. While this is normal for surface seismic data in this area, it suggests that either signal penetration from a permanent source is limited in karsted environments, or the depth of source-receiver burial is insufficient to reduce dominant noise to a level where reflections can become visible, or both.

Surface versus buried receivers

Near-surface complexity strongly affects wave propagation (Bridle et al., 2006). Shallow reflections are hardly visible on a single shot gather stacked over eight days (Figure 2). Drilling operations conducted for buried sensor deployment confirm the presence of karsts down to a 45-m depth on 22 of the 80 sensor locations, with cavities of up to 5 m in height. Near-offset diffractions and strong surface noise contamination at far offsets complicate P-wave imaging of the subsurface. An unconsolidated surface sand layer varies in thickness from 1 m to 20 m and further complicates seismic wave propagation. A quantitative stability analysis of 4D attributes during 10 days of continuous recording illustrates the improvement in repeatability obtained by burying sensors. Given the short time interval of this experiment, no 4D signals are expected to be recorded. Figure 3 shows a wavelet over a 40 ms time window selected from the first break arrivals for offsets between 525 m and 825 m as represented by the yellow boxes in Figure 2. Time and amplitude variations are calculated using the cross-correlation of the daily wavelet with its median over calendar time. Time variations up to 1 ms for surface sensors are reduced to 0.14 ms for receivers buried at a 30-m depth (Figure 3). In addition, a maximum 34% daily amplitude variation for the surface receiver is reduced to 4% for the deepest receivers. Environmental noise such as construction and drilling activities in the field appear to be largely attenuated by the shallow near-surface. Temperature and moisture variations influencing the propagation through the weathering layer are also largely mitigated by burying receivers (Figure 6).

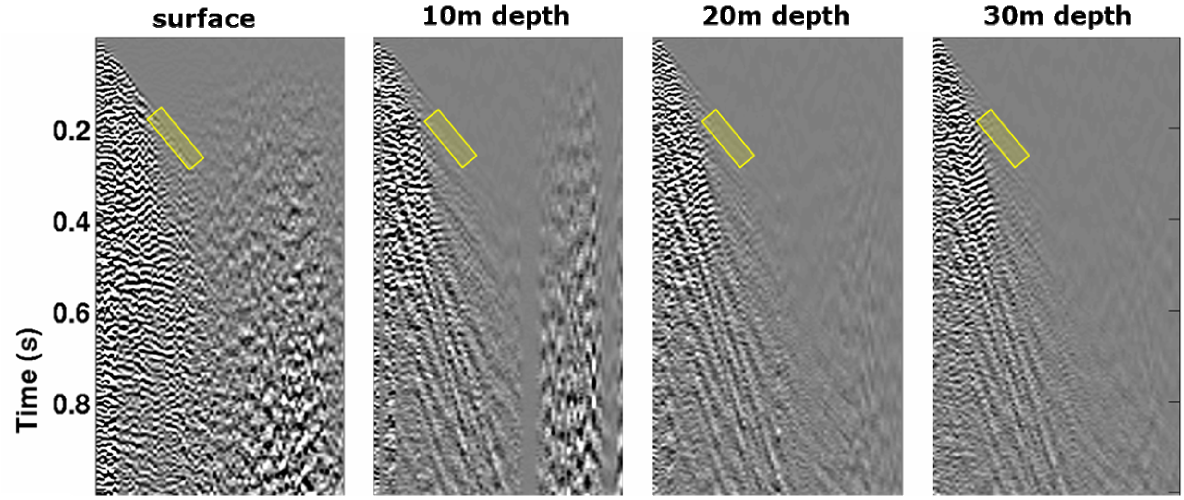

Figure 2 *Common-source gather summed over 8 days for piezoelectric vibrator at 65 m depth. Only spherical divergence is applied for display purposes. The window selected for first break wavelet stability analysis is shown in yellow. There are a few dead sensors evident at the 10-m depth level. Industrial noise visible at far offsets is naturally attenuated by the burying of sensors.*

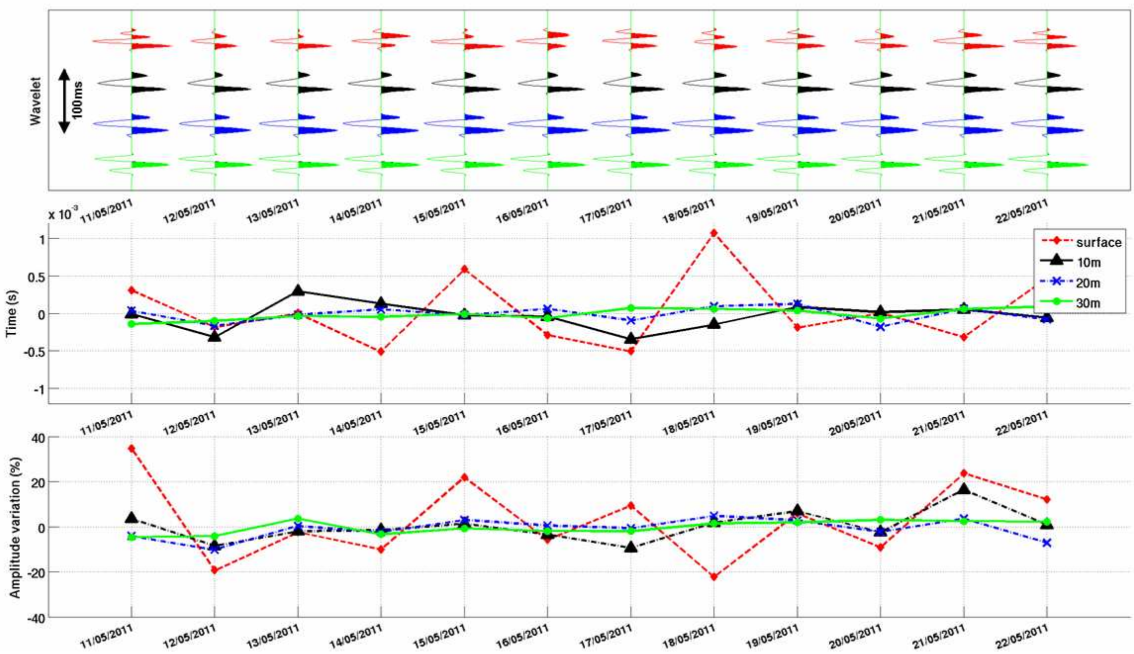

Figure 3 *First break wavelet stability improvement according to the geophone depth of burial for 12 days analysis of the buried piezoelectric source. Stability is increased by a factor of 10 from surface to 30 m deep geophones.*

Surface versus buried sources

Improvements obtained by burying sources are analyzed by comparing two different piezoelectric sources at the same receiver location. One source is bolted to a concrete platform at the surface and the other cemented at a 65 m depth. Daily wavelet variations are clearly qualitatively larger for the surface source (Figure 4) than for the buried source (Figure 5), even though the surface source has up to 30 dB more power than the buried source at 60 Hz due to source design.

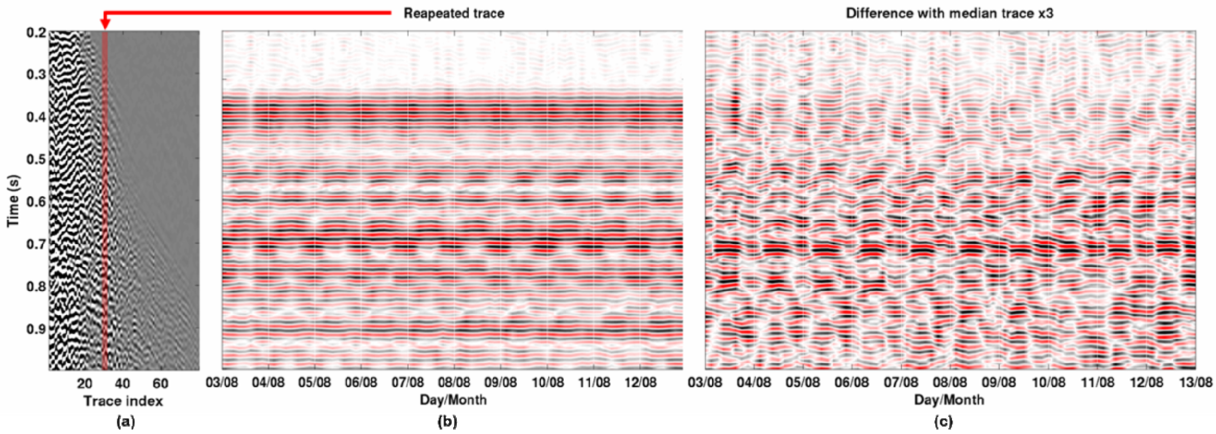

Figure 4 ***(a)*** *Surface source shot gather recorded on geophones buried at 30 m depth after 64 days of stacking showing a selected trace for the analysis. On panel* ***(b)****, over a 50 to 100 Hz bandwidth, the same selected trace at 645 m offset is displayed every 3 hours over 10 days. On panel* ***(c)****, the difference between the selected trace and the median calendar traces is displayed at a 3x scale. Night and day variations can be seen due to near-surface temperature variations (not shown here). Receiver-side ghost reflections (at 0.7 s for instance), crossing the near surface twice, show more daily variation than the more stable direct arrival around 0.3 s.*

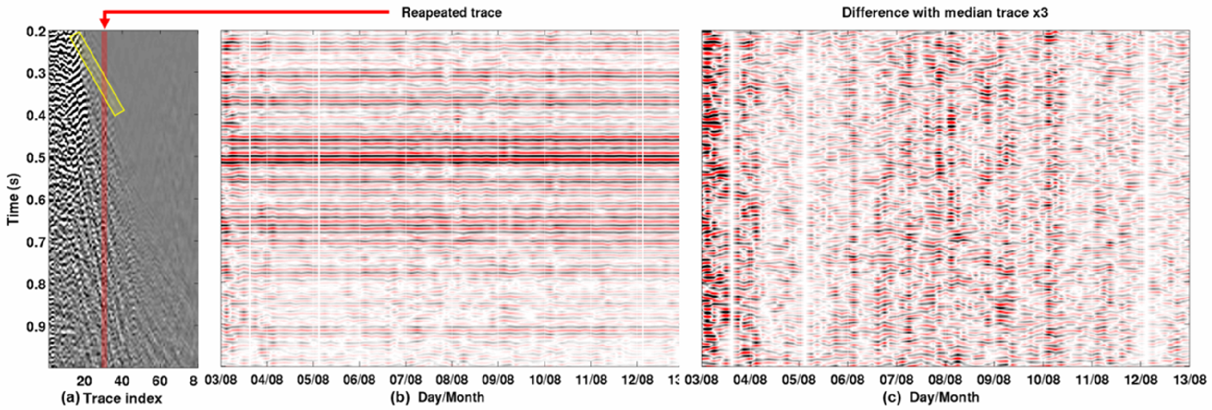

Figure 5 ***(a)*** *A buried source shot gather after 64 days of stacking showing selected traces displayed in the same manner as Figure 4 panels* ***(b)*** *and* ***(c)****. Dead traces are discarded due to reconstruction artifacts. In (****a****), the yellow window highlights data selected for wavelet analysis.*

In this example, variations are quantified by estimating 4D attributes on a wavelet rather than on single traces to enhance the signal-to-noise ratio. As shown in Figure 5(a), a 40 ms wavelet is derived by summing 30 adjacent mid-offset traces (from 225 m to 1125 m). Figure 6 shows a direct correlation between temperature and wavelet amplitude variations for the surface source where the signal is strongly influenced by the very shallow weathered layer (i.e., the first few centimeters which are affected by the daily temperature changes). These variations range up to 0.5 ms for the traveltime and 40% for the amplitude. This diurnal temperature effect is less noticeable on data acquired using the buried source. Buried source data variations are smaller than surface data variations (0.4 ms traveltime differences and up to 20% amplitude variations) and show poor correlation with temperature. These results emphasize the challenges for seismic imaging and, specifically 4D monitoring, in Middle East desert environments. The seismic repeatability achieved for this study is significantly worse than similarly measured repeatability (obtained with the same hardware) observed in other geological settings and environments. In non-desert environments, typical variations using buried vibrators range up to 0.01 ms and 1% in time and amplitude respectively (Schisselé et al., 2009).

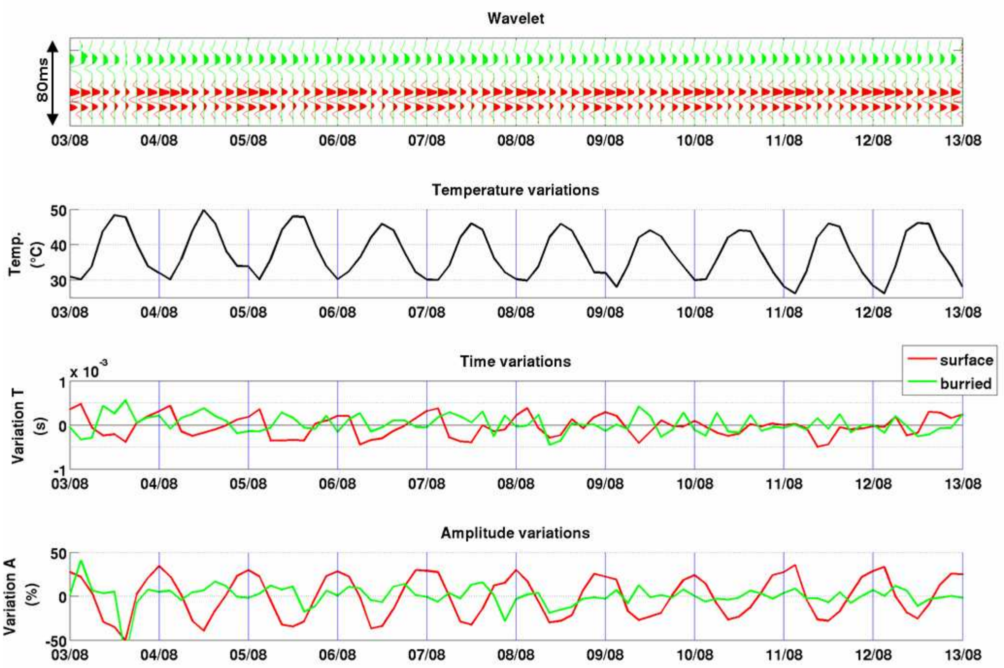

***Figure 6** Time and amplitude 4D attribute variations over 10 days measured over a narrow time window on a wavelet for both surface and buried sources. A measurement is made every 3 hours. The influence of daily temperature variations are clearly observed for data acquired with a surface source, in contrast to data from the buried source, where this diurnal variation is much less obvious. Surface source data are shown in red and buried source data in green.*

Conclusions

The effects of near-surface complexity and variability have been illustrated and quantified by 4D attribute analysis over an onshore carbonate field in Saudi Arabia. As observed in other environments (Schisselé et al., 2009), buried source and receiver survey design greatly reduces detrimental non-repeatability effects caused by daily changes in the near surface. Burying receivers to avoid complex karsting, surface scattering, and large surface temperature variations improves the wavelet amplitude stability by up to ten times. Even though observed repeatability does not reach values observed in non-desert environments, it clearly shows that burying receivers deeper would bring better data repeatability for reservoir monitoring.

Several key issues are identified to improve penetration and repeatability. An increase in source power is required for permanent sources to be useful in this challenging highly scattering and attenuating karsted environment. The complexity of the recorded wavefield shows us that the source and receivers are buried within the complex near surface. Further field experimentation with deeper burial (> 50 m) and a better understanding of near-surface complexities is required to evaluate the viability of low-fold data for monitoring.

References

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