Benefits of Hydrophones for Land Seismic Monitoring

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Summary

CGGVeritas has conducted for Shell Canada a 4D project based on a network of buried mini-vibrators associated with buried sensors. This paper shows a comparison of signal and noise recorded on different types of sensors (surface DSU, buried geophones and hydrophones). We conclude that buried hydrophones provided the best data quality: a) they are free of shear wave, b) they present a better Signal to Noise ratio (20dB gain), c) they show better repeatability. Therefore, hydrophones are also well adapted for permanent seismic land acquisition used in 4D monitoring.

Introduction

CGGVeritas has conducted for Shell Canada a 4D project on an existing oil field in Alberta, Canada. The deployed technology consists of a permanent seismic acquisition system that uses a network of buried mini-vibrators and buried sensors. Burying the sources and sensors below the weathering zone allows an incomparable repeatability of the seismic signal which leads to measurements of greater accuracy to detect weaker 4D signals.

In this paper we compare the data recorded on different types of sensors (surface Digital Seismic Unit, buried conventional analogue geophones and buried hydrophones) installed along the central line of a larger acquisition survey where we studied the signal repeatability. We conclude that buried hydrophones provided the best data quality, because they are free of shear waves, and they present a better Signal to Noise ratio and show better repeatability.

Acquisition & Data

Permanent piezoelectric mini-vibrator seismic sources were cemented at a depth of 80 meters in dedicated boreholes. During the 84 days of data acquisition, sources vibrated simultaneously and continuously using a technique based on mono frequency emissions. This continuous acquisition is associated with real time processing to provide daily shot points of 2.5s in length over a 5 to 220 Hz bandwidth with adequate signal to noise ratio. The seismic signal is recorded with different types of surface and buried sensors (buried conventional analogue 3C geophones (Oyo-nail), buried hydrophones (Sercel-MP44) and surface 3C digital accelerometer (Sercel-DSU3). The sensors are buried at a depth of 12m. The present study is restricted to a sensor comparison on the 63 receiver point locations located on the central line with source #5 as described in Figure 1.

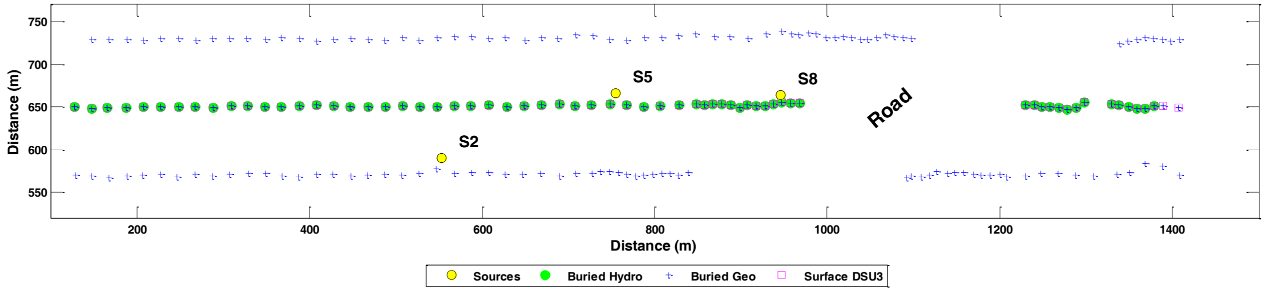

Figure 1: Survey acquisition map centred on the middle line where the three types of sensors are.

The resulting shot gathers for day 1, source #5 and the three types of sensors of the central line are presented on Figure 2 (vertical component only). Each sensor is corrected for its instrumental response. The digital accelerometers (DSU) data is converted in m/s. An impedance of $2*10^6$ kg/m^{-2}/s^{-1} (1600 m/s * 1225 kg/m^3) is used to balance hydrophone and geophone responses. This correction is applied to all data presented here. A geometrical spreading compensation is applied for display.

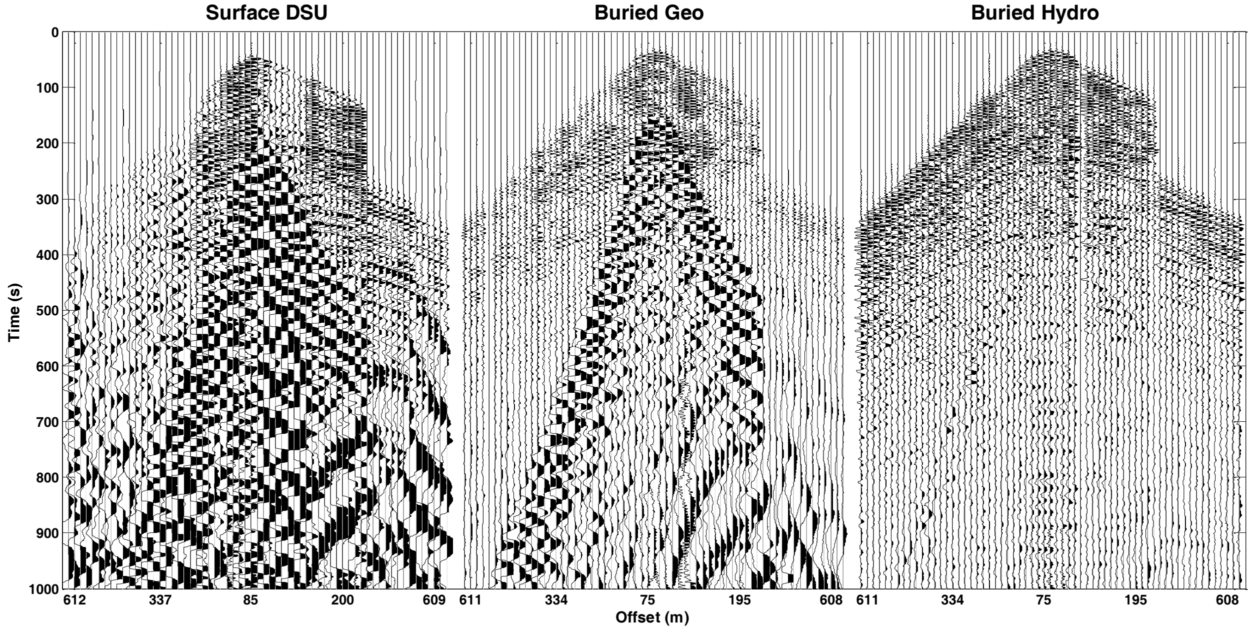

Figure 2: Signal from source #5 recorded along the central line. From left to right: surface DSU, buried vertical geophone @12m, buried hydrophones @12m. A sensor response correction is applied to compare the same unit. A geometrical spreading compensation is applied for display. A strong low frequency well pump's noise is visible on the East side.

Signal to noise ratio and therefore reflection continuity are significantly better for buried sensors than for surface sensors (especially around the target zone ~440 ms). Buried hydrophones look the best.

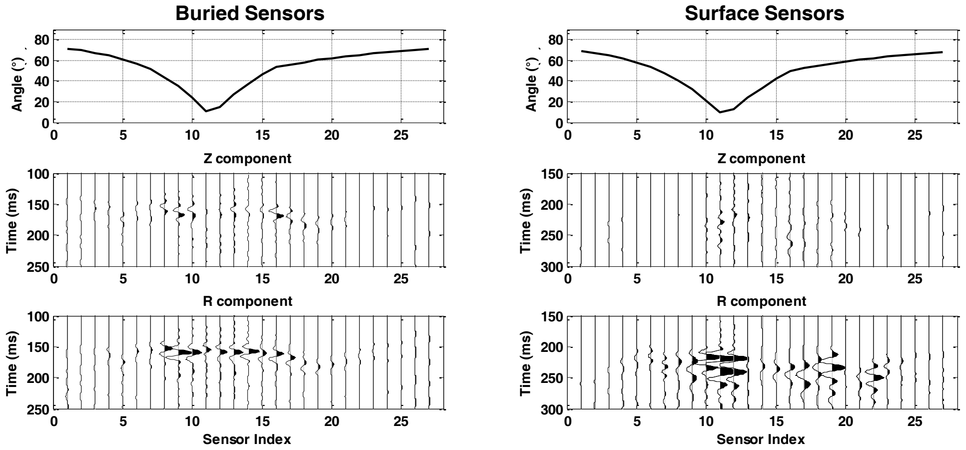

Figure 3: Flattened S-wave arrival for buried and surface sensors. From top to bottom: Propagation angle, Vertical component, Radial component. The S-wave source radiation is maximal for 45° propagation angle.

The noise cone which hides the near offset P-wave reflections on the surface DSU and buried geophones consists of S-waves which are not recorded by hydrophones. Our buried piezoelectric vibrator source generates not only P-waves but also S-waves. P-waves radiate mostly along the vertical direction and S-waves at 45°.Figure 3 represents the flattened first arrival S-wave on the radial and vertical components of the buried and surface near-offset sensors. The effect of the S-wave source radiation pattern is obvious on the buried vertical component and the surface radial component. The ray path from the source to the buried sensors is close to linear showing that radial amplitudes are indeed higher than vertical amplitudes for angles lower than 45°. On the contrary, due to a very slow S-wave velocity in the near surface, these S-waves impinge nearly vertically on the surface sensors. Figure 4 to Figure 6 compare signal and noise behavior versus frequency for the three types of sensors. Figure 4 represents the amplitude spectra of the first arrival recorded by the sensor located at the vertical of source #5. As expected, the buried geophone and hydrophone have almost exactly the same frequency content. The surface sensor shows a tilted spectrum. The higher low frequency amplitude is due to the lower surface impedance. The lower high frequency amplitude is due to absorption in unconsolidated near surface (muskeg).

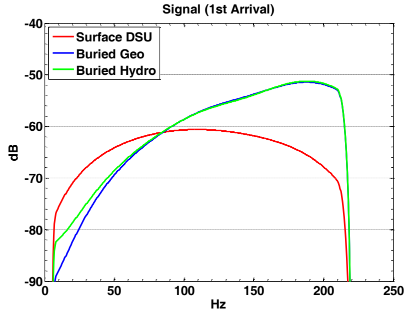

Figure 4: Signal spectra of first arrival for sensors above the source.

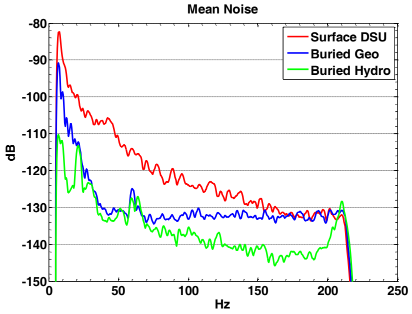

Figure 5: Spectra of mean ambient noise measured before the 1st arrival.

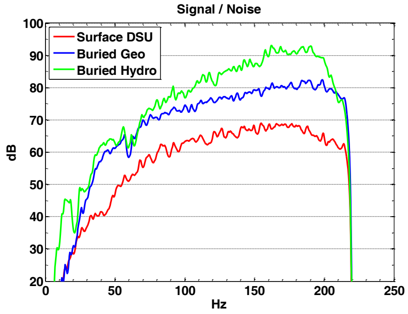

Figure 6: Signal to Noise ratio spectra.

Figure 5 shows the noise spectrum measured before the first arrival and averaged over different locations along the line. It shows a maximum around 10 Hz and is notably weaker (20 to 26 dB) on the hydrophones. This noise, displayed on Figure 7 for the three types of sensors, is generated by well production pumps in the vicinity. It is obvious that hydrophones are far less sensitive to that type of noise, which leads to higher S/N for low frequencies compared to buried geophones.

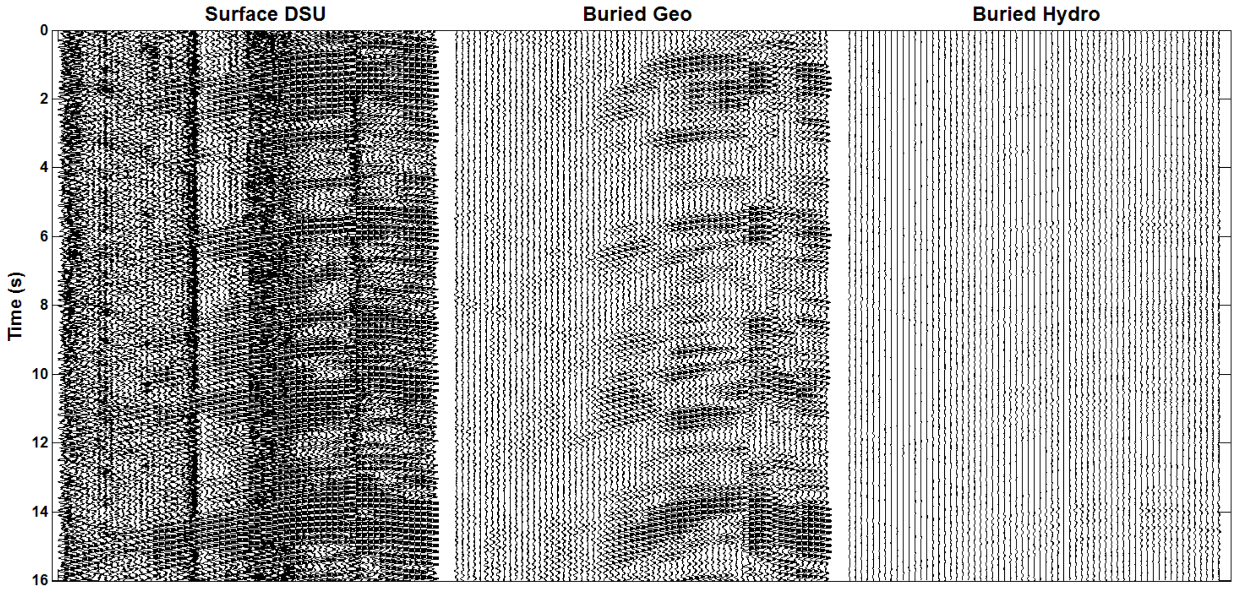

Figure 7: Raw noise data for the three types of sensors. The seismic events are generated by several nearby well production pumps. Hydrophones are far less sensitive to this type of waves.

The flat response of buried geophones above 70 Hz is interpreted as thermal noise in the preamplifier in the recorder. The higher sensitivity of hydrophones allows the observation of seismic noise up to at least 150 Hz. The higher noise level of surface sensors remains above thermal noise for all frequencies. The S/N advantage of the buried hydrophones is shown on Figure 6. In this experiment, burying geophones brings 12 dB S/N gain. Using hydrophones provides an additional gain of 20 dB on the low frequency noise and 6 to 10 dB above 100 Hz.

Precision & Repeatability

Our buried piezoelectric mini-vibrator seismic sources are extremely repetitive. Previous experiments in area without production have shown that the measured signal variations were mainly due to near surface variations (Schisselé et al. 2008). To study the seismic repeatability, we calculate the predictability (PRED) versus the NRMS (Kragh and Christie, 2008) for the 84 acquisition days (Figure 8). Values are computed on reflections in sliding time windows excluding the first P-wave arrival and the S-wave cone. The colors give an indication of the offset: near offsets in blue, far offsets in red. Surface DSU are much more dispersive and a lot of points are outside the zoom area. Hydrophones have a general better PRED & NRMS compared to the two other types of buried sensors. As expected, the repeatability decreases (increase of NRMS and decrease of PRED) with the offsets because of the lower S/N ratio.

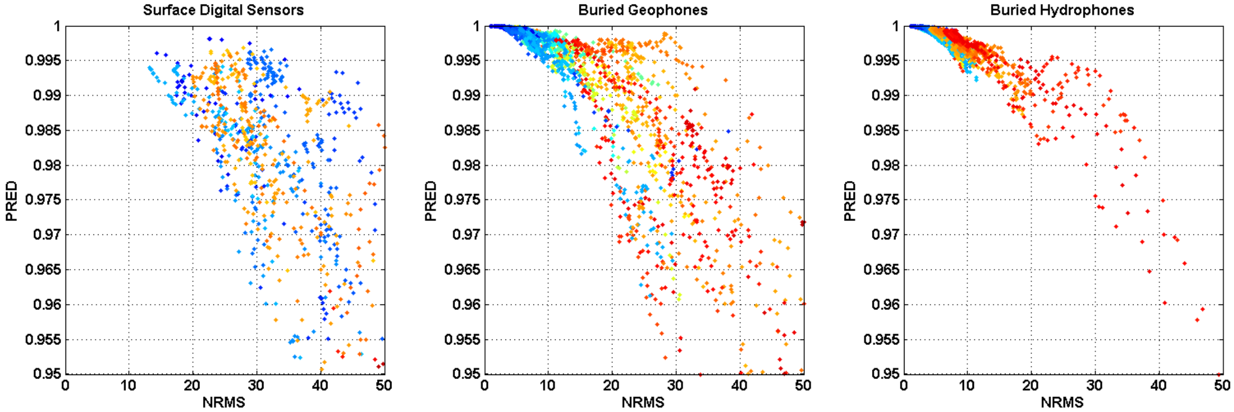

Figure 8: Predictability versus NRMS calculated for the three types of sensors over the 84 repeated acquisitions. Near offsets in blue, far offsets in red. Hydrophones have a better repeatability.

Conclusions

Burying sensors improves S/N ratio & repeatability. In this experiment, this improvement is 12dB. Hydrophones are not sensitive to S-waves. Moreover, conventional hydrophones used in this environment show a higher sensitivity to P-waves than geophones. As a result, using hydrophones provides an additional S/N boost of up to 20dB and hence higher repeatability. Therefore, given the strong S-waves generated by our buried source, we conclude that buried hydrophones are also well adapted for permanent seismic land acquisition used in 4D monitoring where the highest possible repeatability is needed.

Acknowledgements

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References

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