

Advanced Seismic Acquisition Solutions Using Extended Frequency Source Technology for Exploration in Complex Geological Environments

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Introduction

Interest in low-frequency marine source technology is rapidly increasing. Wolfspar (Dellinger *et al.*, 2016) and the Tuned Pulse Source (TPS) (Ronen and Chelminski, 2017) have been designed to provide low frequency data for Full Waveform Inversion (FWI). The Gemini extended-frequency source (Brittan *et al.*, 2020) has been designed to generate low frequencies and higher frequencies. The Gemini technology is based on a single-element (8000 cu. in.) source design that generates low frequencies down to ~ 1.5 Hz for FWI while preserving the mid-frequency range of the seismic bandwidth for sub surface imaging, making it suitable as the sole source for a range of exploration objectives. It produces significantly less energy above 800 Hz compared to conventional airgun arrays, lowering the impact on marine mammals. The last five years have been notable for the commercialisation and increased utilization of the new source technology. Here we review our recent experience and results using Gemini in conjunction with deep tow multisensor streamers in large scale exploration surveys in the Eastern Mediterranean and West Africa, and with sparse OBN geometries in the Gulf of America (GoA).

Combining deep tow multisensor streamers with extended frequency sources

Several projects have recently demonstrated the value of combining extended frequency sources and deep tow multisensor streamers deployed in novel seismic acquisition solutions, including the utilisation of hybrid source solutions in extended long offset acquisition (Offshore Energy news release, 2021) and one-sided wide azimuth (WAZ) (Donaldson *et al.*, 2024) configurations. Following three successful seismic surveys in the Eastern Mediterranean, another survey using the one-sided WAZ technology was acquired offshore Angola in early 2025 (Widmaier *et al.*, 2025). Twelve 10 km long streamers towed 150 m apart and a total of six Gemini sources were deployed (Figure 1, left). Preliminary results demonstrate both good resolution for shallow imaging above the salt and the benefits of the low frequency rich data for elastic FWI based velocity model building of the complex salt and sub-salt geology (Figure 1, middle and right).

The omni-directional nature of single-element sources simplifies de-signature, de-bubble and FWI. Integral to the success are a stable wavelet and an accurate estimate of the wavelet using near field hydrophone (NFH) data. Figure 2 shows the wavelet stability achieved during the Angola survey, as well as the close correspondence between the NFH derived and the seismic data derived wavelet.

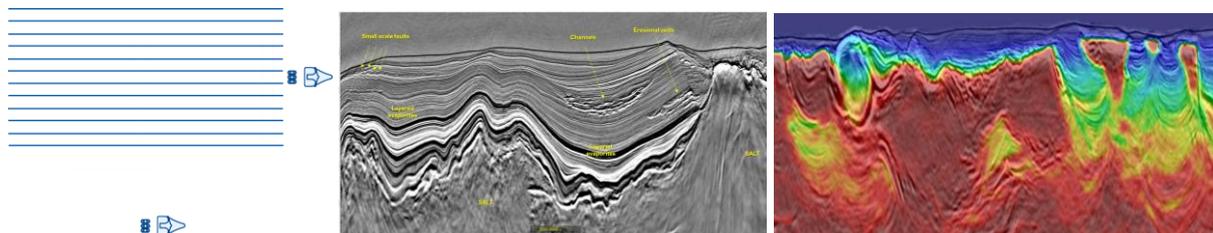


Figure 1: One-sided wide azimuth configuration with 6 active Gemini sources, i.e., both the streamer and the source vessel are towing a triple source configuration (left). Preliminary PSDM stack showing good resolution (middle) and 6Hz elastic FWI model with RTM stack overlaid (right).

Sparse OBN surveys with extended frequency sources

A key consideration in OBN acquisition is source-side efficiency. Leveraging the experience of wide tow sources for streamer acquisition, recent OBN surveys in the Gulf of America (GoA) have increased both the number sources and the spread width to increase efficiency (Figure 3). Dual or triple source acquisition using conventional sources on a 50 m x 100 m shot grid has been common

for deep water sparse OBN surveys until a few years ago. Single-element sources compared to standard source arrays reduce operational complexity and enable wider tow of multiple sources. Further optimization of the air delivery has recently enabled wide-tow quad source acquisition with 100 m source separation, resulting in a 50 m x 100 m shot grid. This means a 33% source-side efficiency gain in addition to increased low frequency output for FWI compared to conventional triple source operations in the GoA.

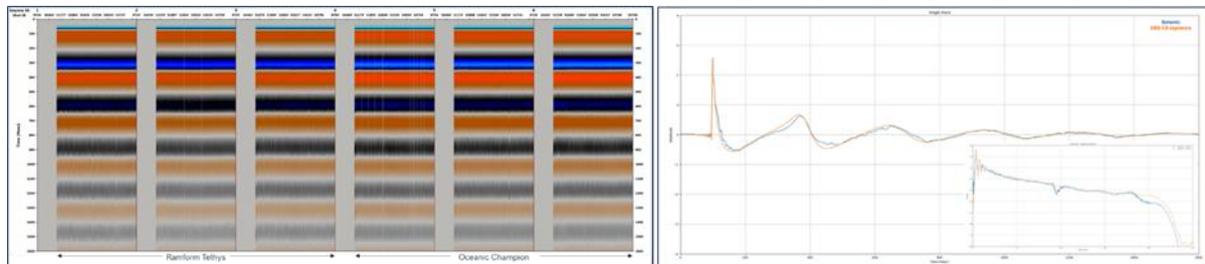


Figure 2: Sequence of shot-by-shot far fields for each of the six Gemini sources (left). Average far field signature compared to the wavelet derived from the seismic data (right).



Figure 3: Leveraging the flexibility of single-element sources: Four Gemini replace four standard source arrays (left) and enable an efficient wide-tow quad configuration for sparse OBN (right).

Conclusions

Utilisation of low and extended frequency source technology in seismic exploration is rapidly increasing. We have shown how extended frequency source technology combined either with innovative streamer geometries or sparse OBN enables improved imaging in complex geological settings. The single-element nature of the Gemini source reduces towing complexity and enables more efficient wide-tow multi-source acquisition solutions.

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