Introduction

The Equatorial Margin of Brazil presents a new frontier basin with high potential and prospectivity but faces challenges in prospects maturity and development. Besides the sheer size of the margins and the variability of geology and petroleum systems, year-long strong currents create particularly challenging and inefficient marine seismic programs. On top of that, environmental concerns present a limiting factor in productivity, often accounting for more than 20% of standby time and extending acquisition time, for large programs, by months.

New marine source technology, designed after the initial design of Wolfspar® (Dellinger et al., 2016), were primarily developed to provide better low frequencies to aid velocity model building. As these new sources have reduced sound levels at higher frequencies, they are considered more environmentally friendly and could decrease mammal exclusion zones and the overall environmental impact (Goertz et al., 2025). However, because these point sources are larger in volume, refill times can affect operational efficiency and compromise shot density, especially for streamer surveys, which remain the workhorse of Equatorial Margin exploration.

In this abstract, we present recent examples from both OBN and streamer acquisition done solely with the Gemini source (Brittan et al., 2020). Gemini is an extended-frequency source that provides enhanced low frequencies compared to conventional marine source arrays for velocity model building while maintaining higher frequency content for imaging. Across several projects, we have acquired data with an 8,000 cu. in. volume type in various streamer, sparse OBN, and, more recently, denser OBN configurations.

We believe extended-frequency source technology will become an integral part of new acquisition programs in deepwater Equatorial Margins, as it currently offers the best balance of bandwidth, data density, and operational efficiency.

Extended-Frequency Source

Gemini is an extended-frequency source designed as a compact single-element seismic source to enhance low-frequency energy in the approximately 1–4 Hz range while maintaining energy across the seismic bandwidth. The new source technology is fully compatible with conventional seismic source vessels, utilizing standard compressor systems, high-pressure manifolds, umbilical winches, and deck-handling equipment.

We have implemented calibrated Gemini source signature modelling in the Nucleus+ marine source software. Comparison with other traditional conventional source arrays demonstrates its extended-frequency range. Gemini delivers 10-15 dB on the low end and 5–10 dB reduction on the high end, which we later show using real data examples. As most recent deepwater discoveries on conjugate margins have been stratigraphic in nature (Reuber et al., 2026 submitted), survey designs must include both low- and high-frequency energy emission and sampling.

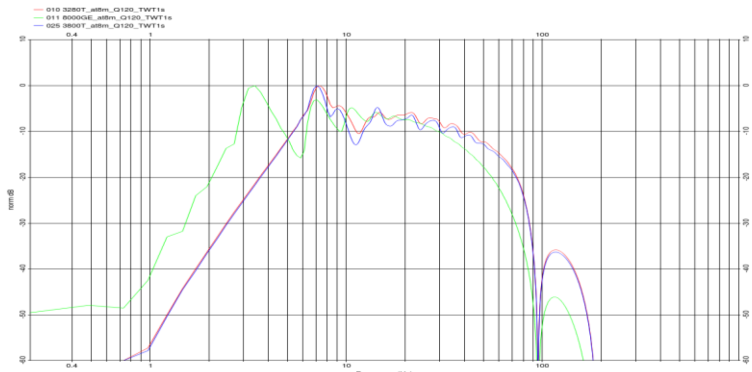

Figure 1 *Gemini (green) source signature amplitude spectrum compared to a conventional marine source arrays (red and blue), with Earth filter applied.*

Similar to other low frequency sources, we see that the reduced high-frequency emission both in infield tests and through environmental modeling (Goertz et al., 2025). One of the main benefits is reduction of exclusion zones for marine mammals that allows for less stops during source effort and hence spending less time and less HSE exposure.

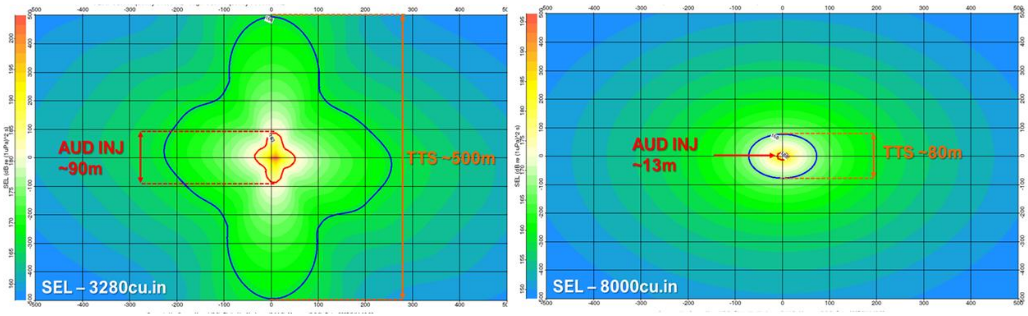

Figure 2 *Environmental modeling of weighted SEL comparing a conventional marine source array and the Gemini extended-frequency source. Results confirm significantly smaller exposure zones for Gemini (compare red and blue isolines on each map).*

OBN projects with extended-frequency sources

Sparse OBN surveys have revitalized exploration in the GoM/GoA by enabling superior velocity models and improved imaging of existing fields and deeper, older plays. Long offsets and full-azimuth data combined with large-volume (~5,000 cu. in.) conventional source arrays have enabled FWI to update complex salt geometries and velocities in post-salt and sub-salt trends. Improving low frequencies through new marine source technology such as TPS (Ronen and Chelminski, 2017) and Gemini is the next step in advancing GoM/GoA exploration.

While these recent programs provide new and complementary long-offset data, they remain exploration-focused and cover very large areas. Tailored survey design and efficient acquisition are essential to maintaining commercial viability. One way to improve efficiency is through wide source-tow with multiple sources. In recent projects we used the Gemini quad-source configurations and also tested a hexa-source solution to maximize efficiency.

For Amendment Phase 4, data were acquired on a 75 m × 75 m source grid with two source vessels each towing a quad source setup and minimum crossline offset of 30 km. We designed this survey as a highly efficient survey without compromising data density or low-frequency quality. The source volume was 8,000 cu. in. and nominal operating pressure 2,000 psi, with signal recorded up to 60 km away. Since then, on newer phases, Amendment West 1 and the APEX survey, we improved further with 50 m source intervals and 100 m source separation.

Figure 3 *Acquiring data with extended-frequency source technology - efficient acquisition using wide-tow quad-source (Amendment Phase 4) and hexa-source subset (Amendment West 1).*

Intermediate results from Amendment Phase 4 confirm the benefits of low frequencies: we are able to recover model error and build salt using very low starting frequencies for elastic FWI (0.9 Hz). Figure 4 shows comparisons between fully processed data from conventional sources and intermediate products from the survey using extend frequency source technology. Low frequencies help model building and allow images of steep dips and complex structures deeper in the section.

Beyond sparse OBN, a working solution for denser node grids in combination with Apparition-style shooting has been developed (Ten Kroode et al., 2026, submitted). Refill rates are improved continuously by upgrading equipment, new umbilicals, and in-water pressure regulators.

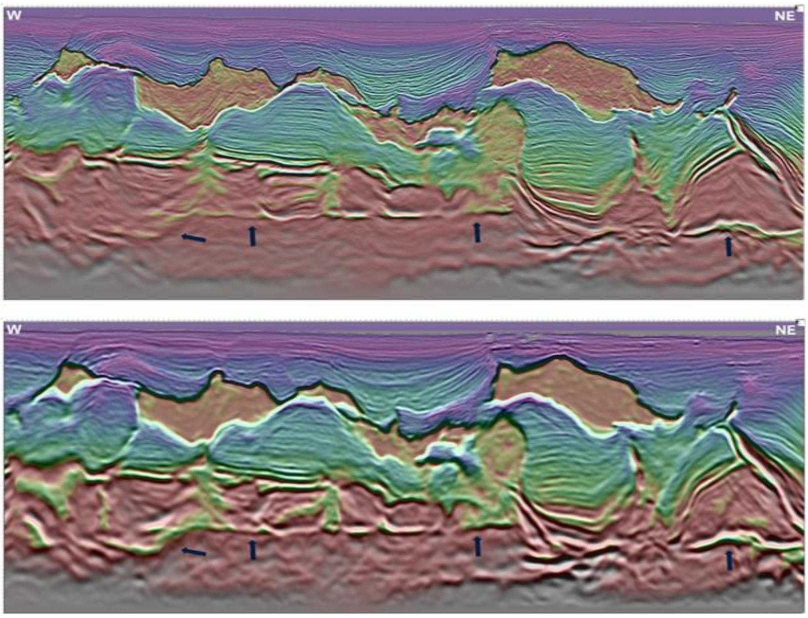

Figure 4 *Arbitrary line showing elastic FWI model overlay with FWI image from conventional gun array (top) and extended-frequency source (bottom). Even at an intermediate stage of processing (6 Hz), Amendment Phase 4 show with Gemini source shows improved deep basement imaging and geologically more plausible structures, mostly because of better low frequencies.*

Streamer projects with extended-frequency sources

We have acquired several large-scale exploration surveys using deep-tow multisensor streamers combined with extended-frequency source technology in basins with complex geological settings, including salt basins of the Eastern Mediterranean and West Africa (Widmaier et al., 2025). For a multi-client project offshore Angola, we designed a one-sided WAZ survey, with both the streamer and source vessel using triple Gemini and shooting the six sources at a 16.667 m pop interval at a nominal source pressure of 1,900 psi. The streamer vessel was towing twelve 10 km long multisensor at 150 m separation. Vessel speed was optimized without slowdowns from refill cycles or shot density.

Although we did not acquire as rich an azimuth distribution as in OBN examples, we still see the additional source vessel provides increased density and increased azimuthal illumination for both imaging and velocity model building. Elastic FWI starts at 1.5 Hz and provides improved updates to complicated salt and carbonate geometries. As for higher frequencies, we achieve excellent imaging of small-scale features, as shown in Figure 7. We also derived several geometric and amplitude attributes such as spectral decomposition, which look indistinguishable from data shot with conventional arrays.

Future trends

Extended-frequency source solutions can expand into other survey designs beyond those shown here. Dense-node, conventional streamer NAZ, and hybrid solutions in geologically complex settings such as volcanic margins in the Potiguar Basin can all benefit from the new source technology.

As with any new technology, continued learning and improvements to both equipment, operations and processing are required. For example, processing workflows for both OBN and streamer projects needed adjustments to properly handle and QC the low frequencies provided (Baldock et al., 2026 submitted). On the acquisition side, we implemented improvements such as optimized near-field hydrophone positioning for more reliable shot-by-shot source monitoring, upgrading pressure regulators for both OBN and streamer operations, and defining hybrid designs complementing large volume sources with conventional airguns.

Conclusions

As exploration progresses into deeper water of the Brazil Equatorial Margins, we present new extended-frequency marine source technology as a solution to enable efficient, more environmentally friendly acquisition with no compromise on data quality. Based on streamer and OBN case studies presented here, we show that we get broadband dataset – better low frequencies for velocity model building and adequate higher frequencies for imaging compared to conventional source arrays. The projects have demonstrated that Gemini solutions compared to other low frequency sources allow acquisition, with higher shot density which extends the shelf life of the seismic data and extends its use beyond exploration purposes.

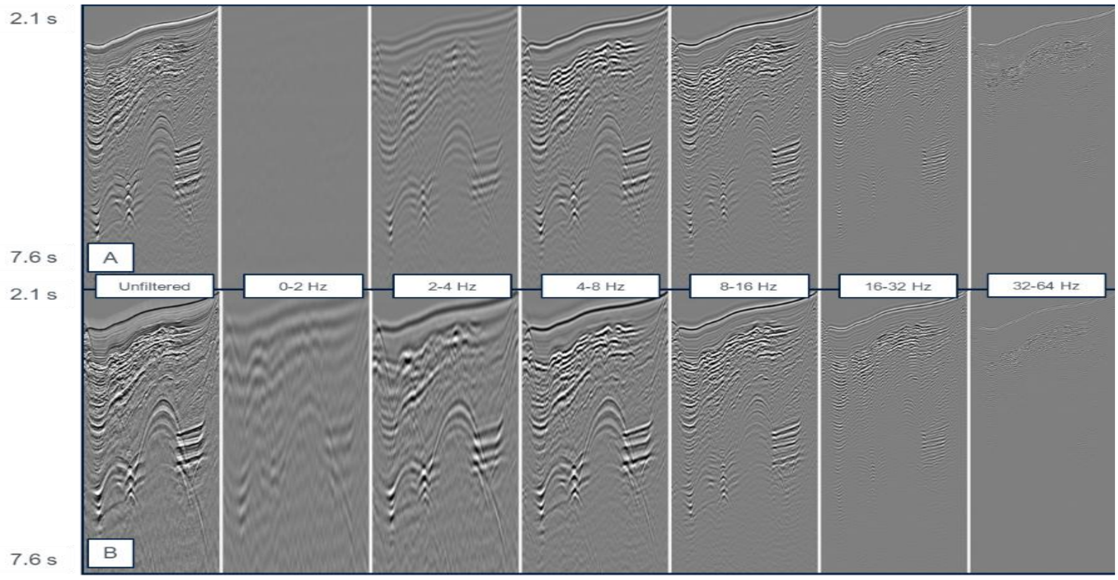

Figure 5 *Octave panels from conventional (A) and extended-frequency (B) sources from the Angola streamer data. Notice the improved low-frequency content and S/N in the first two octave panels.*

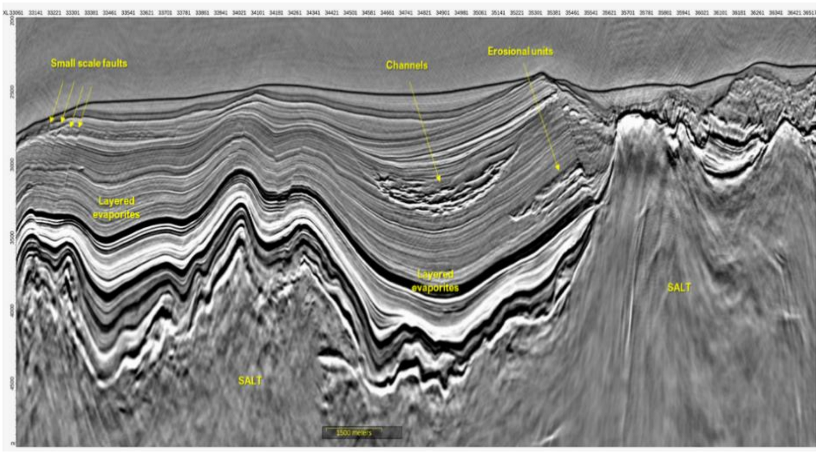

Figure 6 *Fast-track PSDM stack from Angola showing preserved high-frequency content and interpretation of small-scale features.*

References

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