Advancing subsalt imaging in the US Gulf: operational and technical innovations in seismic data acquisition from the Laconia sparse OBN program

Authors

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Abstract

The Laconia program marks a major advancement in the design and execution of long-offset, low-frequency (LOLF) ocean-bottom node (OBN) seismic acquisition programs for subsalt imaging in the US Gulf. With more than 18,000 km² of source coverage and over 8,000 node locations, this multi-phase program builds on recent breakthroughs in full-waveform inversion (FWI) methodologies, sparse OBN geometry, and new source technology. A low-frequency–rich source (LFS)—the Sercel Tuned Pulse Source (TPS)—was used. The LFS was used to deliver LOLF OBN data with offsets greater than 50 km and ultra-low-frequency signal down to 1 Hz in the Garden Banks and northern Keathley Canyon. This LOLF OBN data enables the application of FWI to address long-standing challenges in salt velocity model building and in imaging the Wilcox Paleogene play beneath the notoriously complex salt structures in this region. The use of 150-day endurance nodes and a large node inventory enabled acquisition of ultra-long offsets consistently across the entire survey, demonstrating the scalability of multi-client OBN for basin-scale projects. Real-time telemetry of down-sampled hydrophone data enabled early FWI testing, allowing interpreters to gain insights on 5 Hz acoustic OBN FWI volumes three months before the fast-track delivery. Results from early-out FWI demonstrate substantial improvements in imaging the complex subsalt structures by resolving the velocity of overburden allochthonous salt and mobile shales. The program was executed with exceptional HSE performance, demonstrating a strong commitment to protecting people and the environment. The Laconia program sets a new benchmark for cost-effective, high-impact seismic acquisition and imaging at basin scale, delivering geophysical and geological value in structurally complex offshore environments, reducing structural and depth uncertainty beneath salt, and de-risked future drilling decisions.

Introduction

Seismic imaging in the deepwater of the US Gulf continues to demand innovative approaches due to the complexity of the geologic settings. In recent years, full-waveform inversion (FWI) has emerged as a powerful tool for velocity model building and subsalt imaging, resulting in step-change improvements in subsalt images never seen before (Shen et al., 2017; Shen et al., 2018; Zhang et al., 2018; Wang et al., 2019; Wu et al., 2022). It has also quickly become clear that FWI is most effective when long-offset, full-azimuth, and low-frequency data are available. Workflows based on wide- or full-azimuth towed-streamer data, even with the most advanced FWI algorithms, have reached performance limits, as streamer data lack the low-frequency signal-to-noise ratio (S/N) and the offset and azimuthal coverage needed to build accurate models and resolve complex structures such as highly deformed salt bodies and mobile shale formations (Lin et al., 2018; Ren et al., 2022).

Building on the proven value of sparse OBN geometries and recent advances in low-frequency seismic sources (Merritt et al., 2024), the Laconia program (see map in Figure 1) was designed to deliver a transformational uplift in model accuracy and structure clarity. With more than 18,000 km² of source coverage and over 8,000 node locations, Laconia integrates long-offset sparse OBN acquisition with a low-frequency-rich source (LFS)—an enhanced pneumatic source with high output at low frequencies below 2 Hz. This combination addresses long-standing constraints in FWI performance related to cycle skipping and limited diving wave illumination in subsalt zones (Figure 2).

Executed over a nine-month period with a five-vessel fleet, the Laconia Phases I and II survey maintained on-schedule performance despite multiple weather interruptions, delivering stable source and data quality across all acquisition phases. The program was executed with exceptional HSE performance, recording over 528,000 exposure hours with zero environmental incidents and a Total Recordable Case Frequency (TRCF) of 1.89—demonstrating a strong commitment to protecting people and the environment while delivering complex, high-impact seismic operations. Quasi-real-time QC of down-sampled hydrophone data, enabled via the data telemetry systems onboard, allowed for the validation of 1 Hz signal content and early FWI updates—setting the stage for accelerated interpretation workflows.

This article outlines the advances in survey design, acquisition configuration, operational execution, and geophysical outcomes of the Laconia program, with an emphasis on its ability to reveal deeper geological features through high-fidelity model building and imaging.

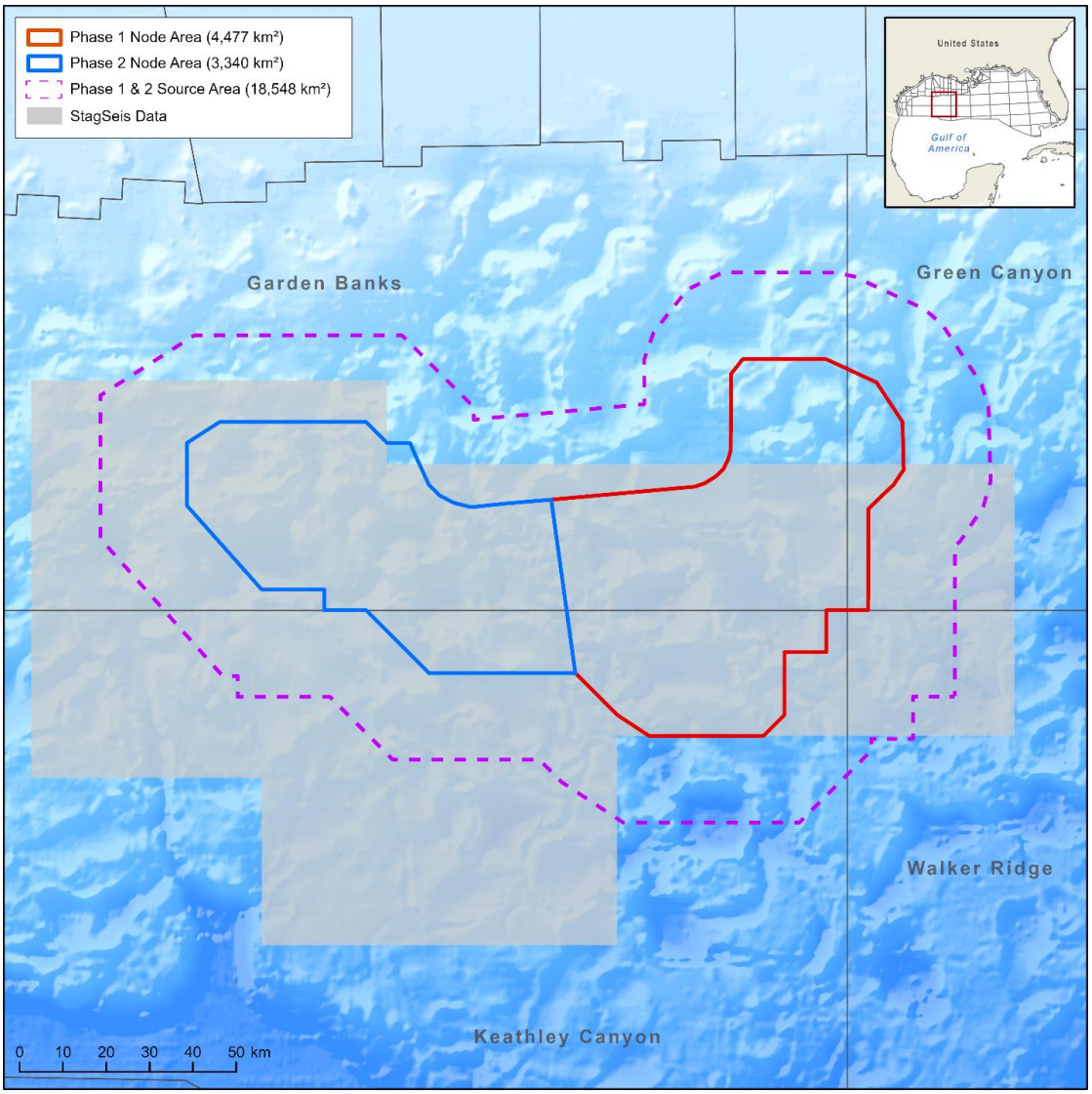


Figure 1. Location map of the Laconia Phases I and II survey in the deepwater Gulf of America. The red polygon delineates the Phase I node deployment area (4,477 km²), and the blue polygon outlines the Phase II node area (3,340 km²). The magenta dashed line represents the combined source area for both phases, including a 20 km shot halo, totaling 18,548 km². Gray boxes indicate the footprint of legacy StagSeis™ data coverage across Garden Banks, Keathley Canyon, Walker Ridge, and Green Canyon.

Geophysical rationale, survey design, and acquisition geometry

The Laconia program was designed to maximize the effectiveness of FWI in one of the most structurally complex regions of the US Gulf. Building on synthetic studies by bp (Dellinger et al., 2017; Lin et al., 2021) and practical lessons from the Momentum project (Merritt et al., 2024), two geophysical parameters were identified as essential: (1) offset ranges exceeding 30 km to enable diving wave penetration of subsalt targets, and (2) low-frequency content with high S/N down to 2 Hz, ideally 1 Hz, to drive robust FWI velocity updates.

While effective in delivering high-frequency content suited for structural imaging, conventional air gun sources tend to offer limited S/N at ultra-low frequencies (<2 Hz), which can limit the effectiveness of FWI in the presence of large velocity errors. Enhancing low-frequency S/N is particularly beneficial for improving model convergence and interpretability in these challenging environments. In addition, streamer-based acquisition geometries are often restricted by narrow azimuths and limited long-offset content, which may result in insufficient diving wave illumination. Wide- or full-azimuth towed-streamer (WATS or FATS) surveys improve azimuth and offset coverage relative to conventional streamer designs, but even the best full-azimuth streamer solutions still fall short of what can be achieved with OBN acquisitions. To address these challenges, Laconia adopted a sparse OBN geometry acquiring ultra-long offset data (exceeding 50 km) using a new purpose-built low-frequency pneumatic source. A few such low-frequency sources have become available commercially in recent years (Rentsch et al, 2022; Ronen and Chelminski, 2017; Udengaard et al, 2024). The TPS, designed by Viridien's Sensing & Monitoring business, was chosen for Laconia. It is a completely new design engineered to operate at lower pressures and emit larger volumes of air with a long rise time and dominant bubble oscillations. Figure 3 shows that the new data delivers signal down to 1 Hz.

By fulfilling both geophysical criteria—low-frequency richness and long-offset illumination—the Laconia survey design enabled FWI to resolve complex deep velocity anomalies that have eluded previous imaging efforts using legacy streamer surveys.

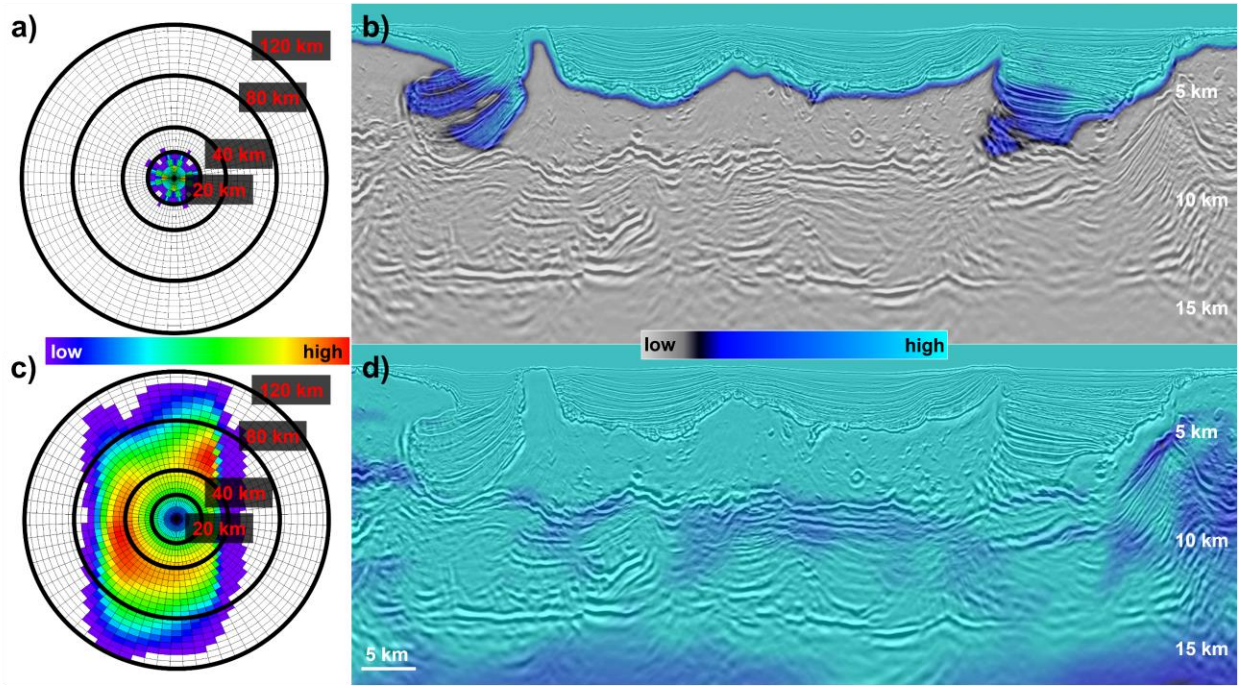


Figure 2. Top: Rose diagram and diving wave illumination from legacy FATS survey. a) Acquisition fold and azimuth distribution showing the full-azimuth towed-streamer geometry achieved through multi-vessel and multi-pass operations. Although this geometry provided broad coverage, the long-offset content was constrained by limitations of the towed streamer spread. b) Seismic volume

overlay with diving wave illumination obtained using FATS data. Bottom: Rose diagram and diving wave illumination from the Laconia program. c) Azimuthal fold coverage from Laconia sparse OBN survey, showing ultra-long offset coverage—exceeding 100 km in many directions—compared to legacy towed-streamer geometries. d) Overlay of diving wave illumination on the seismic volume highlights the uplift in subsalt illumination achieved with the Laconia survey.

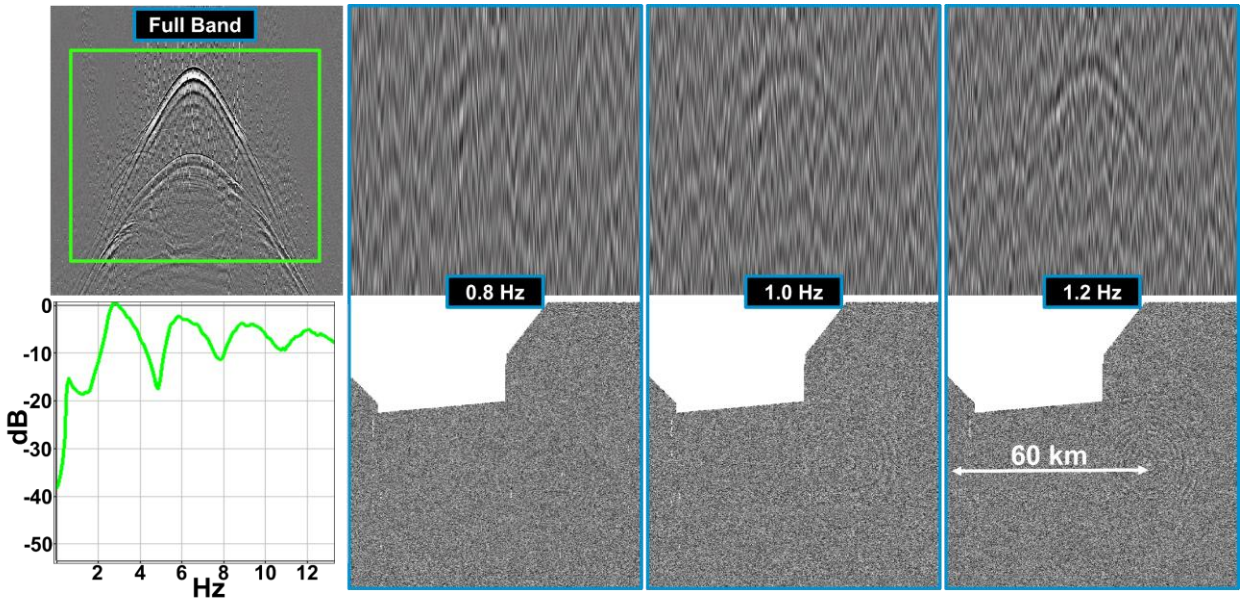


Figure 3. Raw data QC from the Laconia survey. Top row: Common Receiver Gather showing the full-band signal (left) and corresponding bandpass filters isolating low frequencies below 0.8 Hz, 1 Hz, and 1.2 Hz high-cuts. Coherent diving wave energy is visible down to 1 Hz, demonstrating the effectiveness of the LFS in generating ultra-low-frequency content. The blending noise from the adjacent source unit (deployed from the same vessel with 200 m crossline separation) is observable on the upper left, a result of this dual-source wide-tow configuration. Bottom row: Average amplitude spectrum of the data on the left shows a bubble oscillating at a resonance frequency of 2.7 Hz. Frequency slice “phase rings” at 0.8-1.2 Hz validate the presence of coherent signal across the critical 1–1.2 Hz range.

The Laconia I & II survey implemented a staggered node layout covering ~336 OCS blocks (~8,000 km²) with a nominal inline spacing of 800 m and crossline spacing of 1,200 m. This node geometry matched the Momentum survey layout, while the Laconia survey introduced further enhancements in source configuration. The Momentum survey employed an array configuration with two LFS units towed in close proximity (20 m apart) and fired simultaneously. Thanks to execution experience gained on the Momentum survey and the newly enhanced source deployment technology, Laconia increased the crossline separation between these two LFS units to 120–200 m (Figure 4) and fired them in single point source mode with independent dithering between firings. This staggered firing increased shot density without raising the total emitted energy, effectively doubling shot line coverage per sail line (Ji et al., 2025).

The source grid was acquired using 400 m sail line spacing with flip-flip shooting on time with ±1.5 s dithering between shots. This created an extensive shot footprint with over 1.5 million shots and a 20 km effective shot halo. This design extended the source

coverage to ~800 OCS blocks, enabling data capture at ultra-long offsets well beyond 50 km (Ji et al., 2025).

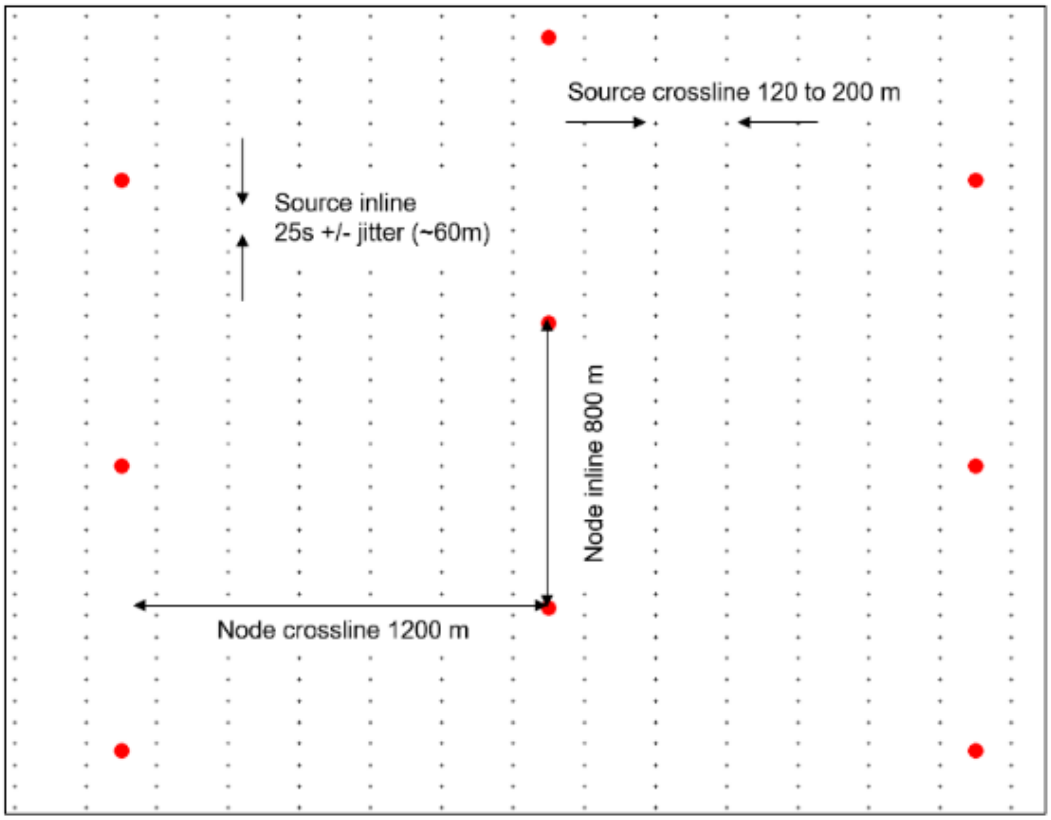


Figure 4. Preplot layout for nodes and sources in the Laconia I & II survey. Node spacing was 800 m inline by 1200 m crossline, yielding a receiver density of 1 node per square kilometer. Dual sources were fired every 60 m inline and every 200 m crossline, with a randomized dither of ±1.5 s applied to a 25-second shot interval—resulting in a shot density of ~83 shots per square kilometer. The diagram shows inline stagger of 400 m between node lines and a wide-tow source configuration with 120–200 m crossline separation.

Importantly, the acquisition geometry was tailored to satisfy offset constraints such that the diving wave could penetrate deep through key subsalt formations. Simulation results and early FWI test results confirmed the effectiveness of this design, showing improved energy propagation through allochthonous salt and mobile shale—geobodies known to impede imaging in legacy streamer-based surveys (Merritt et al., 2024; Jonke et al., 2024).

As Figures 5a and 5b illustrate, the Laconia layout ensured consistent azimuthal coverage and a balanced offset distribution, setting a strong foundation for subsequent FWI and imaging workflows.

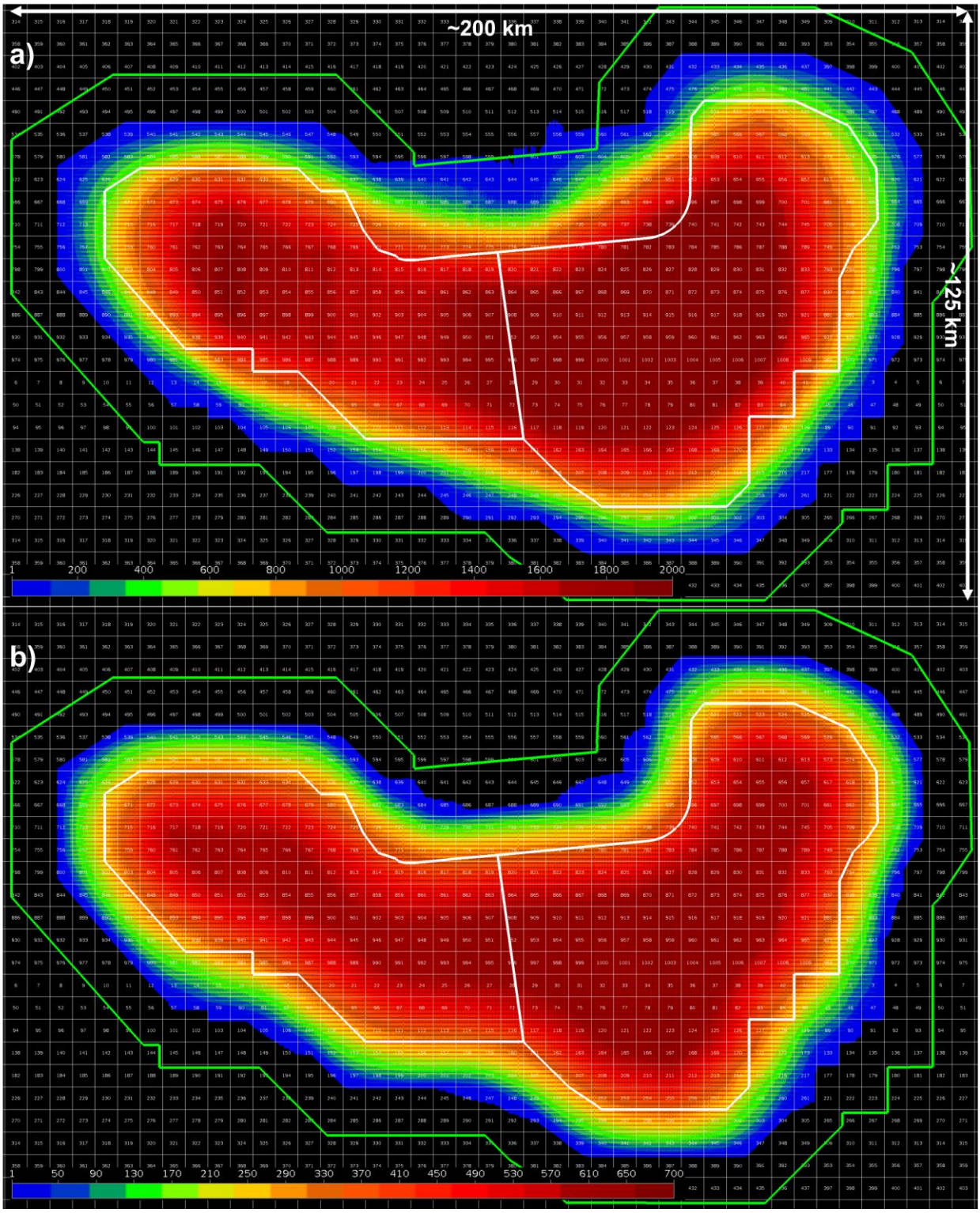


Figure 5: Offset fold maps for the combined Laconia Phases I and II node areas, computed on a 100 m × 30 m CDP grid. a) The full-offset fold distribution reflects uniform coverage across the 800 × 1200 m sparse OBN layout, supported by consistent long-offset shooting. b) This view isolates the contribution of near- and mid-offset (<30 km) data to the fold, illustrating dense and consistent coverage throughout the central node patch. The background is an OCS block map; each block is roughly 4.8 km x 4.8 km.

Breakthroughs in seismic source technology

The Sercel TPS low-frequency-rich source was a cornerstone of the Laconia program's low-frequency acquisition strategy. To meet the project's geophysical goals—including ultra-long offset coverage and enhanced FWI performance—TPS units with 28,000 in³ chambers were deployed as single-point sources. This configuration targeted the 1–2 Hz band, where conventional air guns are weakest, enabling better resolution of large-scale velocity errors often associated with complex salt structures.

The TPS design includes a large cylindrical air chamber with near-360° radial ports and a smooth release mechanism engineered to reduce high-frequency energy and avoid cavitation-producing water jets. This architecture supported Laconia's FWI objectives by improving low-frequency signal quality and minimizing environmental impact (Ronen and Chelminski, 2017). For the Laconia program, the dual LFS system was configured with asynchronous dithers and 120–200 m crossline separation, improving crossline sampling without increasing the emitted energy per unit area.

The LFS was tested with chambers ranging from 600 to 28,000 in³. Figure 6 shows the relationship between bubble frequency and chamber volume across pneumatic sources. The bubble period, T, is proportional to the cubic root of volume, V, times pressure, P:

$$T \propto \sqrt[3]{VP}$$

Despite operating at only half the pressure of conventional air guns, the much larger volume of the LFS enables significantly longer bubble periods, producing useful signal down to ~1 Hz—critical for low-frequency FWI.

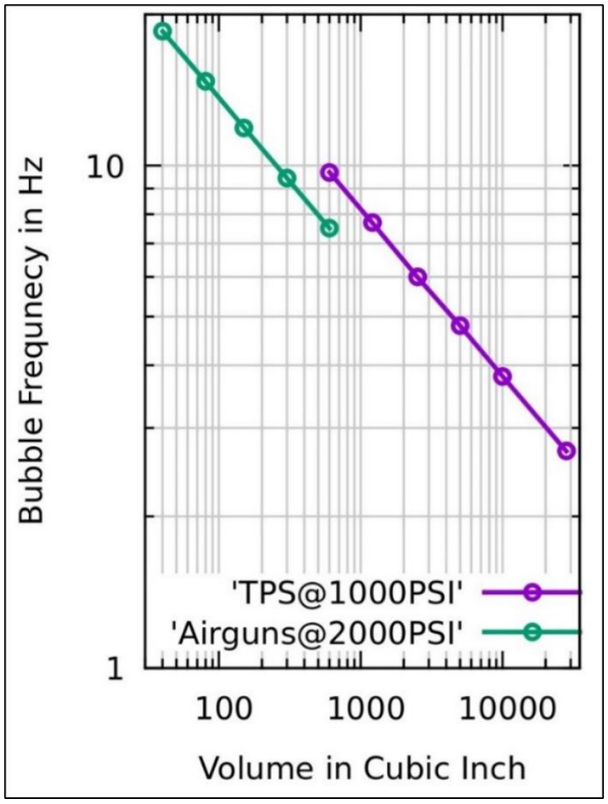
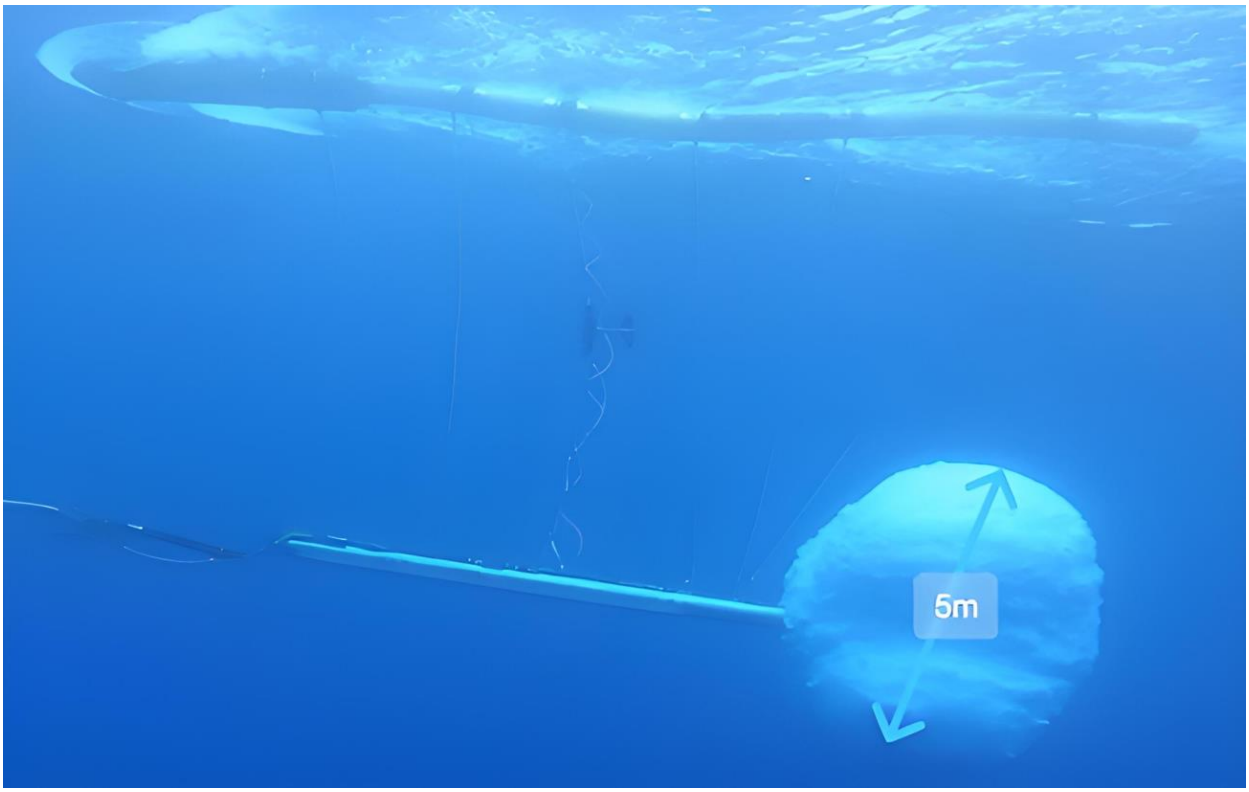


Figure 6. Bubble frequency versus chamber volume for air guns and LFS systems. Air guns (green) operate at 2,000 PSI and range from 40 to 600 in³, while LFS (purple) operates at 1000 PSI with volumes tested up to 28,000 in³. The circles denote examples of chambers at various volumes. LFS is designed to discharge large volumes of air. The smallest volume tested so far is 600 in³. The largest volume tested so far is 28,000 in³. Despite operating at lower pressure, LFS achieves significantly lower bubble frequencies, producing useful signal down to ~1 Hz—critical for enhancing low-frequency content for FWI. The discontinuity in the slope between the air guns and the LFS is due to the pressure difference between the two systems. Note that because the bubble period is proportional to the cubic root of the pressure multiplied by the volume, the relation between the volume and the bubble frequency is linear on this log-log plot.

At its resonance frequency of 2.7 Hz, the 28,000 in³ LFS configuration used in Laconia produced signal levels ~28 dB higher than a typical air gun array (



). While its high-frequency output is lower, Shang et al. (2023) demonstrated that effective processing of near-field hydrophone data can recover signal up to 60 Hz.

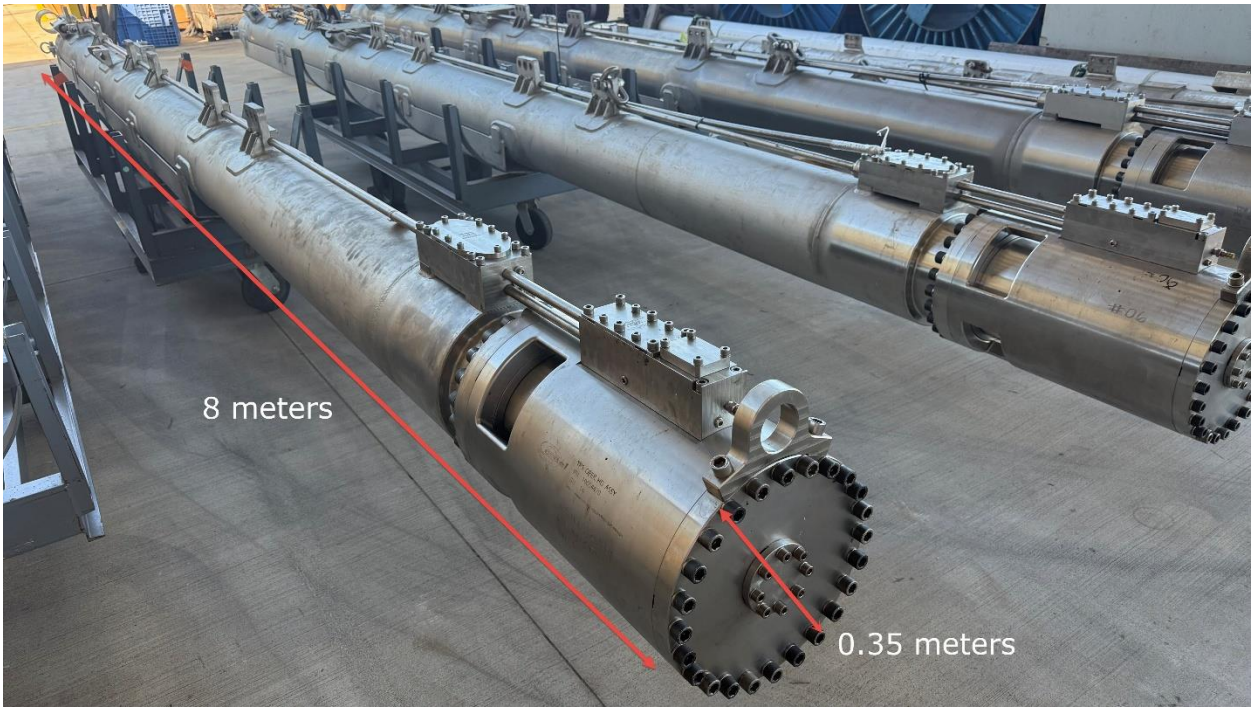


Figure 7. TPS on the assembly line. The full unit is approximately 8 meters long. The head on the right is mounted on a 28,000 in³ firing chamber—as used in the Laconia survey. One of four radial ports is visible. Two additional heads can be seen stored beneath the workbench in the background.

Without the need for complex source arrays, the LFS enhanced operational efficiency through simplified deployment logistics and reduced shot-to-shot variability. The LFS was used as a single-point source (Figure 8). Compared to conventional arrays where the signature is azimuth and dip angle-dependent, single-point sources produce perfectly isotropic radiation. They are not subject to intra-array geometry variations from shot to shot and therefore have more stable signatures. Its lower sound pressure level (SPL)—approximately 8 bar-m, or 12 times lower than a typical air gun array—helped avoid receiver saturation, also known as max-level overdrive, and improved the dynamic range between weak diving waves at far offsets and strong direct arrivals in the near offsets. Additionally, the longer rise time reduced the SPL slope to ~1 bar-m/ms, compared to 3 bar-m/ms for a single air gun and up to 90 bar-m/ms for a 30-gun array. Because pressure slope is proportional to particle acceleration, a lower slope implies reduced potential for environmental disturbance.

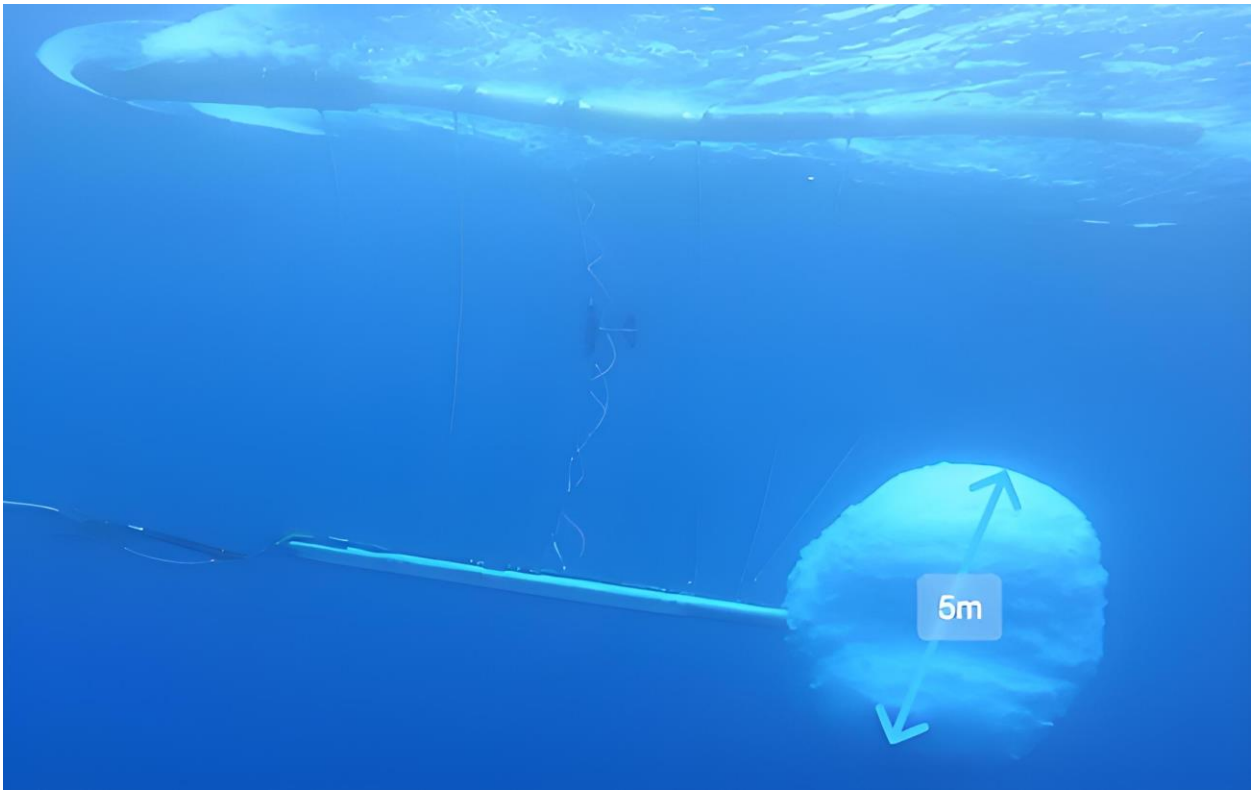


Figure 8. Underwater view of the LFS during firing. Unlike conventional air guns deployed in arrays, the LFS functions as a single-point source, generating a large oscillating bubble with a radius of over 2 m and a period of almost 400 ms. The point-source design

offers operational benefits such as faster deployment and recovery, lower technical downtime, and enhanced geophysical performance, including reduced risk of receiver overdrive, consistent shot-to-shot signature, improved shot positioning, and a more isotropic radiation pattern.

Environmental and safety performance were further supported by specific design features of the LFS (Figure 9). Its air-filled mid-chamber and zero-acceleration firing flange eliminate water jet cavitation common in conventional air guns. Air guns, originally designed to emulate explosive sources, rely on an acceleration distance and water-filled mid-chambers. The acceleration distance causes quicker opening of the ports providing the shorter rise time that was requested by customers who had been using explosive sources. The water in the mid chamber is discharged at high velocity and generates high-frequency noise. By contrast, the TPS has zero acceleration distance, and its air-filled mid chamber avoids cavitation, reducing unnecessary environmental impact. A safety feature of the TPS is that the firing chamber is filled and emptied directly from the umbilical, rather than through the operating chamber—eliminating the risk of auto-firing and improving crew safety.

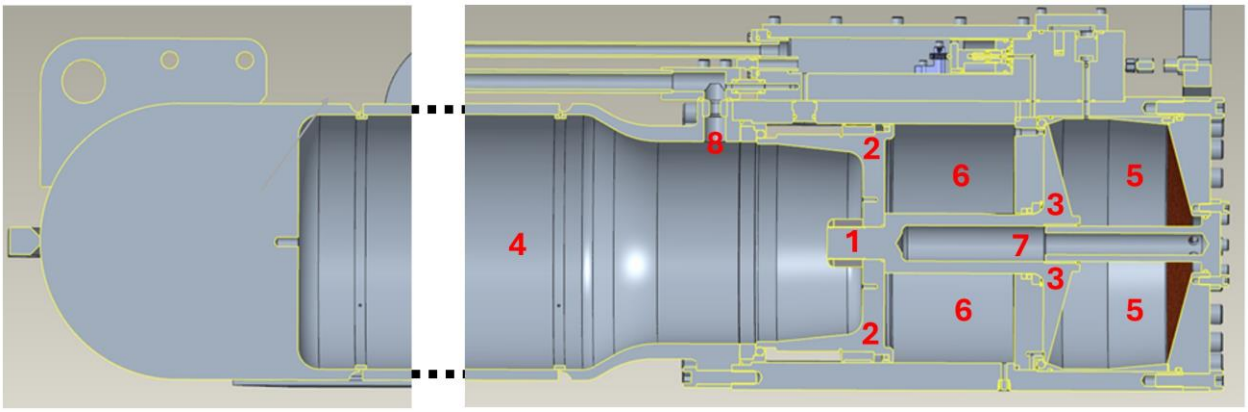


Figure 9. Schematic cross-section of the TPS. The shuttle assembly (1) consists of a shaft and two pistons: a firing piston (2) and an operating piston (3). This source contains four air-filled chambers: the large firing chamber (4), the operating chamber (5), the mid chamber (6), and the shaft chamber (7), which collectively control piston motion and prevent ballistic behavior. The use of air in all chambers avoids cavitation—a common issue in water-filled air guns. Air is supplied and drained via an orifice (8) located outside the shaft, preventing unintentional auto-fires and enhancing crew safety.

To meet Laconia's acquisition parameters—including rapid shot cycling, reliable pressure control, and integration with standard umbilicals—an in-sea Pressure Regulator System (PRS) was developed and deployed, mounted between the umbilical and the source. This in-sea unit regulates pressure from the vessel's manifold and ensures consistent chamber recharge rates regardless of umbilical configuration.

Figure 10 shows the PRS, and Figure 11 illustrates its impact on refill time. Pressure on the umbilical dry side ranged from 1,060 to 1,800 psi, depending on compressor settings. A downstream pressure sensor measured pressure recovery after shots fired at 0 and 25 seconds. The LFS was ready to fire again when pressure reached 1,000 psi, which occurred in ~25 seconds at 1,060 psi and in approximately half that time at 1,800 psi. This demonstrated the scalability of LFS shot rates with available pressure and confirmed PRS effectiveness in maintaining consistent source performance during high-duty-cycle acquisition.

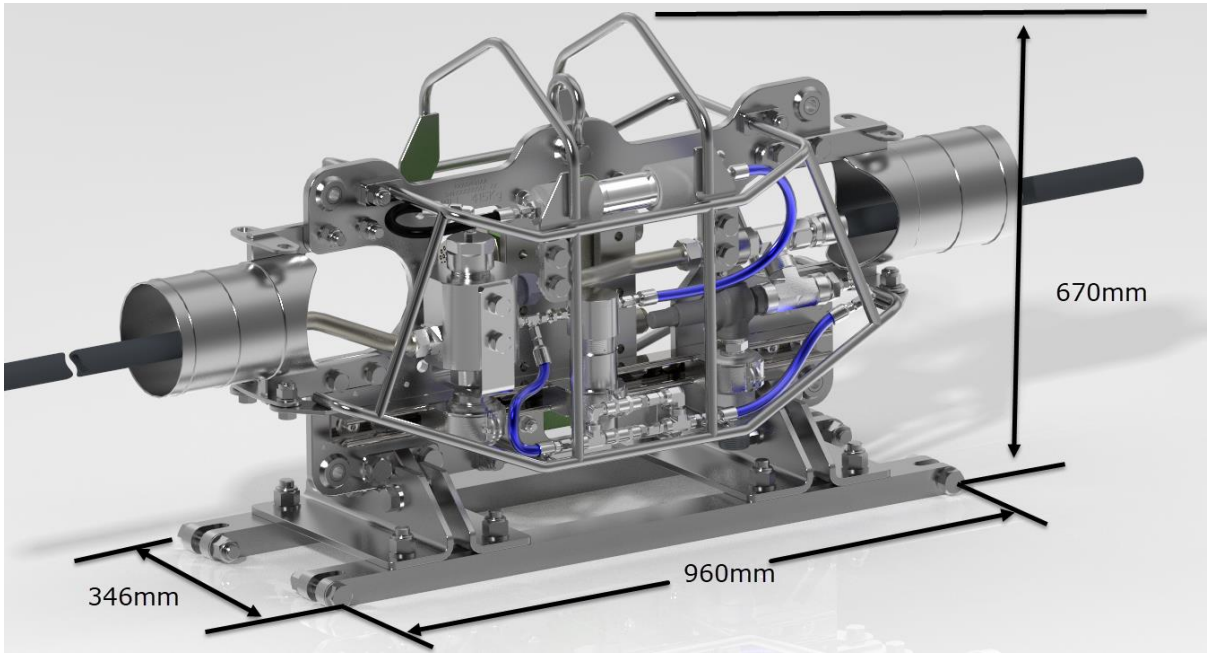


Figure 10. Rendered image of the pressure regulation system. The system is responsible for modulating the firing and recharge pressure of the firing chambers. It features high-precision pneumatic control components with reinforced stainless-steel framing for structural integrity. Note the blue high-pressure lines for controlling air routing and the compact configuration designed for integration within vessel deck layouts.

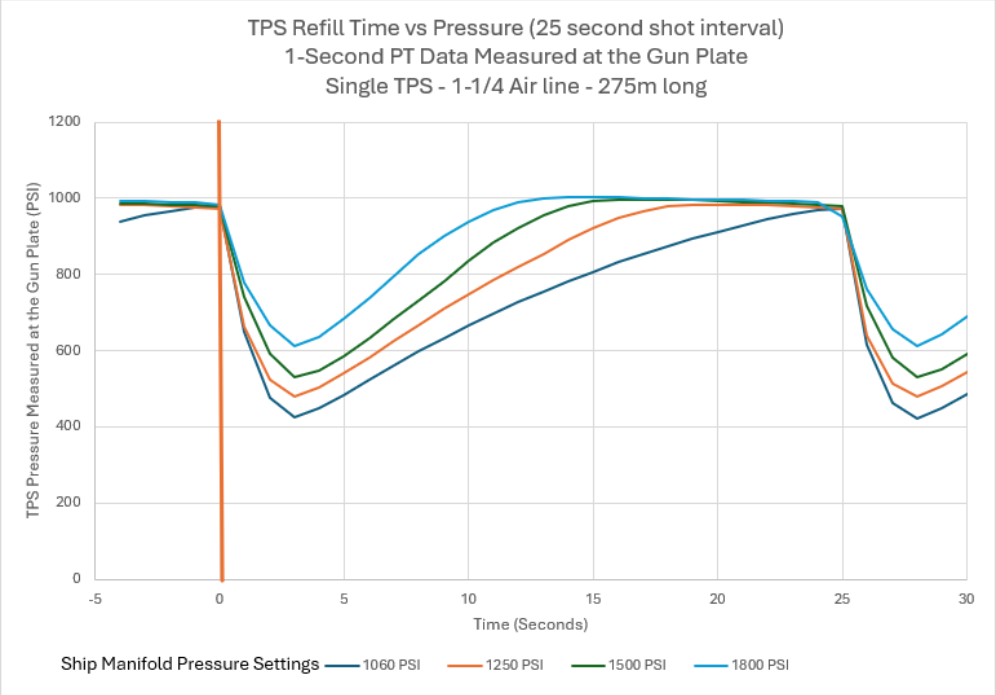


Figure 11. Refill time versus vessel manifold pressure. Pressure was measured at the gun plate (downstream of the PRS) at 1 s intervals following source activation at 0 and 25 s. At the moment the shot is fired, pressure at the firing chamber drops sharply (not shown), triggering recharge from the umbilical. Refill rates depend on the manifold pressure: at 1,060 PSI, the LFS returns to 1,000 PSI readiness in ~25 s, while at 1,800 PSI, the system recharges in approximately half the time. These results demonstrate refill rate scalability with available pressure, influencing maximum achievable shot rate.

Operational efficiency, cost, and scalability strategies

Executing the Laconia program required careful orchestration of technology, logistics, and vessel coordination to meet ambitious data quality and turnaround goals in a challenging offshore environment. Despite multiple significant weather disruptions over a nine-month period, the survey was completed on schedule with no lost-time HSE-related incidents, underscoring the strength of the operational planning and execution framework.

The campaign mobilized five vessels: two source vessels equipped with dual LFS , two node-handling vessels for deployment and retrieval, and one support vessel. Over 200 offshore personnel were deployed in round-the-clock operations, spanning a node footprint of ~336 OCS blocks (~8,000 km²). These operations delivered a receiver carpet of more than 8,000 node locations and over 1.5 million source shots, extending shot coverage to nearly 800 OCS blocks (~18,000 km²) including a minimum 20 km shot halo (Ji et al., 2025).

One of the most compelling outcomes of the Laconia program was its demonstration that high-end subsalt imaging using sparse OBN geometry and low-frequency sources can be achieved at scale without a prohibitive cost. The survey design leveraged lessons from previous programs to maximize efficiency across three critical dimensions: shot coverage, node density, and acquisition duration.

Sparse geometry with purposeful illumination

The use of sparse OBN geometry—800 × 1,200 m node spacing— was a deliberate cost-control strategy. By optimizing placement to achieve sufficient fold and offset coverage for FWI, the project reduced node count while still satisfying model-building requirements. Strategic staggering of node lines optimized spatial sampling without increasing the receiver count (Lin et al., 2018).

Similarly, the source configuration, while unconventional, contributed to cost efficiency. The dual-source arrangement with 120–200 m crossline separation and independent dithering allowed for denser source XL sampling while maintaining the same vessel count and fuel budget as a conventional dual-source setup. The extended 20 km shot halo and ~46,000 km of total shot lines maximized the value of each sail line.

Effective node deployment/retrieval management

The use of long-endurance deepwater nodes with battery life exceeding 150 days allowed extended deployment cycles and reduced handling frequency. Combined with a large node inventory, this enabled the expansion of XL offset from 30 km to about 40 km. The consistent receiver footprint and strategic planning underscored the scalability and economy of large multi-client OBN programs. This approach ensured efficient asset utilization and helped demonstrate that operational reliability and geophysical quality can coexist in large-scale surveys.

Source reliability and compatibility

Initially, the operation was constrained by refill time dependency on a specific umbilical diameter to regulate air pressure delivery, limiting the umbilical length and the separation between the port and starboard sources to 120–140 m with a 400 m sail line interval. The PRS was developed during the surveys and enabled longer umbilicals and the operational flexibility of physical crossline interval separation between sources deployed from the same vessel—an important factor in minimizing acquisition footprint overlap to a uniform 200 m crossline interval. The development and integration of a dedicated pressure regulator module enables LFS deployment across the industry. This enhancement allows the LFS to function effectively with any conventional source acquisition system, eliminating the need for custom rigging or infrastructure modifications.

From a source reliability perspective, the performance of LFS exceeded expectations. Despite its novelty compared to conventional air guns, and thanks to lessons learned and improvements made after the Momentum survey, source technical downtime for Laconia

was kept below 4%, on par with mature systems. This success reflects the robustness of the TPS design, as well as strong collaboration between acquisition and technical support teams. The high uptime ensured consistent signal quality and energy output, critical for maintaining the integrity of a seismic dataset built to maximize low-frequency energy for FWI.

Real-time processing and turnaround acceleration

A critical enabler of both efficiency and early imaging was the integration of quasi-real-time data telemetry. Upon each node retrieval, hydrophone data were downsampled to 16 ms and streamed to shore via the on-board telemetry capabilities. This meant that the processing team could conduct quality control and FWI tests while the acquisition was still underway. The survey started in mid-2024, and retrieval of the first 2,000 nodes ready for FWI testing was completed by December 2024. By early January 2025, a test dataset of ~2,000 nodes was already being processed, and by late February—just 40 days after the retrieval of the final node from Phase I—the team delivered a full-area 5 Hz acoustic full-waveform inversion (AFWI) model and image volume.

The seamless handoff between offshore acquisition, real-time telemetry, and early imaging workflows created a highly compressed feedback loop. Interpreters were able to assess geologic features in the 5 Hz AFWI model well in advance of the fast-track volume release, gaining valuable lead time for prospect evaluation. This operational synergy across vessels, data systems, and teams reflects a maturing model for efficient, high-impact seismic programs in deepwater exploration (Ji et al., 2025).

Operational partners and technical support

Operational support teams contributed to the operational efficiency and technical robustness of the Laconia OBN campaign through a dedicated onboard presence focused on acquisition optimization and quality control. Positioned on the Sanco Sword vessel, acquisition optimization specialists served as a bridge between Viridien and the acquisition contractor, facilitating real-time communication, situational awareness, and execution alignment. The team supported acquisition with reshoot planning, transit times monitoring, and providing continuous time and motion analysis. High-resolution positional QC was performed—validating 99.8% node placement within 5 m of preplot targets—and supported compliance with survey specifications through navigation attribute validation. Weekly reporting, web-based Marlin dashboards, and productivity tracking tools aided operational visibility and decision-making. These contributions added value in managing geophysical risk and maintaining technical integrity throughout this complex deepwater acquisition program, contributing to overall project efficiency and delivery.

Modular and replicable framework

Ultimately, the success of Laconia underscores how sparse OBN acquisition with a low-frequency emphasis is both scalable and replicable in other basins—especially where complex overburden precludes reliable imaging with streamer-only geometries. The modular nature of LFS deployment and sparse node layout allows adaptation to basin size, risk profile, and investment thresholds.

Geophysical and geological results

The early-out imaging results from Laconia Phase I confirmed the transformative impact of combining long-offset sparse OBN with LFS-driven low-frequency content and FWI. FWI updates derived from the initial 2,000-node test set had already delivered significant uplifts in velocity model accuracy and structural clarity compared to previous streamer-based solutions.

Comparative FWI analysis between streamer and OBN inputs revealed stark contrasts (see Figure 12). While streamer FWI appeared to improve subsalt reflector continuity at some locations, its updates below the diving wave penetration depth were very limited. The Laconia OBN FWI, by contrast, produced proper updates aligned with geologic expectations, leading to more accurate and interpretable structural outcomes thanks to its high S/N ratio at low frequency and long-offset coverage.

The mobile shales imaged in the Laconia OBN volume emerged as critical geologic features. Although their presence had been inferred from regional geology, their geometry and seismic expression remained elusive in legacy datasets. The Laconia dataset provided the first clear and consistent images of these bodies, revealing their sharp velocity contrasts relative to surrounding sediments. These features play a similar geophysical role to salt: distorting wavefields and complicating inversion unless properly resolved. Laconia imaging revealed these bodies with great detail, improving risk assessment for exploration wells near these features. The Mesozoic section and deeper basement structure became apparent on the OBN AFWI model and OBN AFWI Image (Figure 12). Large sections of deep salt missing from the streamer FWI were detected and updated by the OBN AFWI. The LOLF OBN AFWI update already provides a step-change in image quality compared to what could be achieved with streamer data.

Additionally, OBN-enabled FWI enhanced the delineation of the highly rugose base-of-salt surface and deeper reflectors within the Wilcox play. These improvements are pivotal for drilling decisions, as the interplay between salt geometries, mobile shale deformation, and potential reservoirs directly impacts prospectivity and well planning.

Together, the Laconia results suggest that the combination of sparse OBN and low-frequency source is not only a technological milestone—it is a practical toolset for unlocking complex geologic provinces with meaningful operational efficiency.

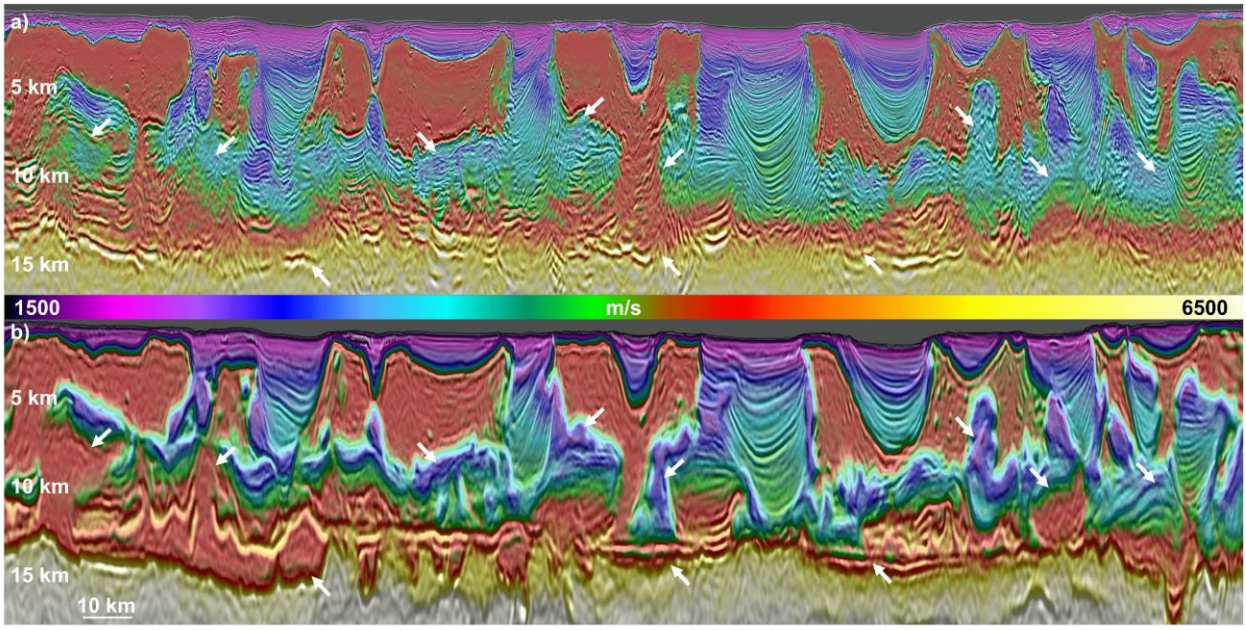


Figure 12. a) 15 Hz streamer RTM and 6 Hz streamer AFWI model overlaid b) 5 Hz OBN FWI Image with 5 Hz OBN AFWI model overlaid. The LOLF OBN AFWI completely redefines the subsalt velocities. Extensive slow-velocity zones are detected. The Mesozoic section is clearly delineated, and the complexity at basement level becomes visible. Arrows mark zones of slow-velocity mobile shales, improved basement reflectivity, large-scale changes to the Mesozoic, and detection of deep salt missing in the streamer AFWI model.

Seismic wave propagation within the Earth is elastic by nature. The acoustic assumption in AFWI breaks down at places where large impedance contrasts induce strong elastic effects. Unexplained elastic energies not only blur the sharp velocity boundaries in the AFWI model, they also manifest themselves as noise, which reduces the S/N of the AFWI velocity model. Incorporating elastic propagation into the FWI engine allows modeled data to better match real data in terms of both phase and amplitude. For Laconia, a 5 Hz elastic FWI (EFWI) update was carried out using the LOLF OBN data starting from the 5 Hz LOLF OBN AFWI velocity model. Figures 13a and 13c show a reduction in the salt halo at both TOS and BOS on the EFWI model. Including elastic effects in FWI allows for better explanation of the data, leading to improved convergence and fewer artifacts. This results in sharper formation interfaces, better event continuity, and higher S/N on the EFWI Image than its acoustic counterpart (Figures 13b and 13d). Anisotropy parameters were updated based upon well information. The subsequent 5 Hz LOLF OBN EFWI update reduced misties of major salt boundaries and key subsalt events to ~1% or less on average.

The 5 Hz LOLF OBN EFWI provides another step-change improvement over AFWI. However, to move beyond large-scale structural interpretation, higher resolution is needed. With the kinematics resolved by the 5 Hz LOLF OBN EFWI update, underlying

FATS streamer data, with its denser spatial sampling, is incorporated into the inversion for higher-frequency updates. The 12 Hz OBN+streamer EFWI update shows increased resolution top down on both the model and FWI Image. The salt halo is also further reduced with the increase in frequency. The improvement in resolution subsalt is obvious with small-scale features and sedimentary layers becoming visible on the 12 Hz EFWI Image. This increase in resolution is critical for understanding detailed structure at the reservoir level. The 12 Hz OBN+streamer EFWI model and EFWI Image (Figures 14c and 14d) can be compared against what can be achieved with streamer data (Figures 14e and 14f). The 12 Hz EFWI Image offers similar or better resolution to the 15 Hz streamer RTM with far superior illumination and S/N.

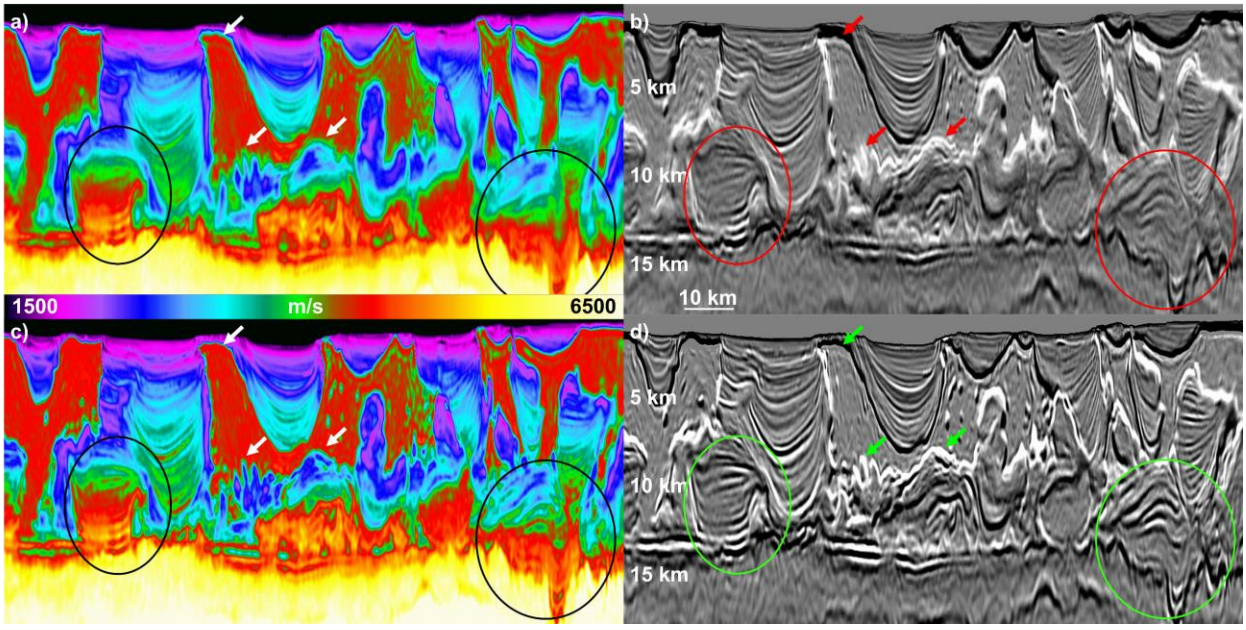


Figure 13. Comparison of FWI velocity models and FWI Images from AFWI and EFWI for the Laconia survey. (a) AFWI velocity model and (b) corresponding AFWI Image. (c) EFWI velocity model and (d) corresponding EFWI Image. The EFWI update refined salt boundaries and improved velocity definition in subsalt overpressure zones, resulting in enhanced image clarity and continuity compared to AFWI. Arrows indicate areas of sharpened salt boundaries. Circles mark zones of clear improvement in resolution and S/N on the EFWI model and EFWI Image.

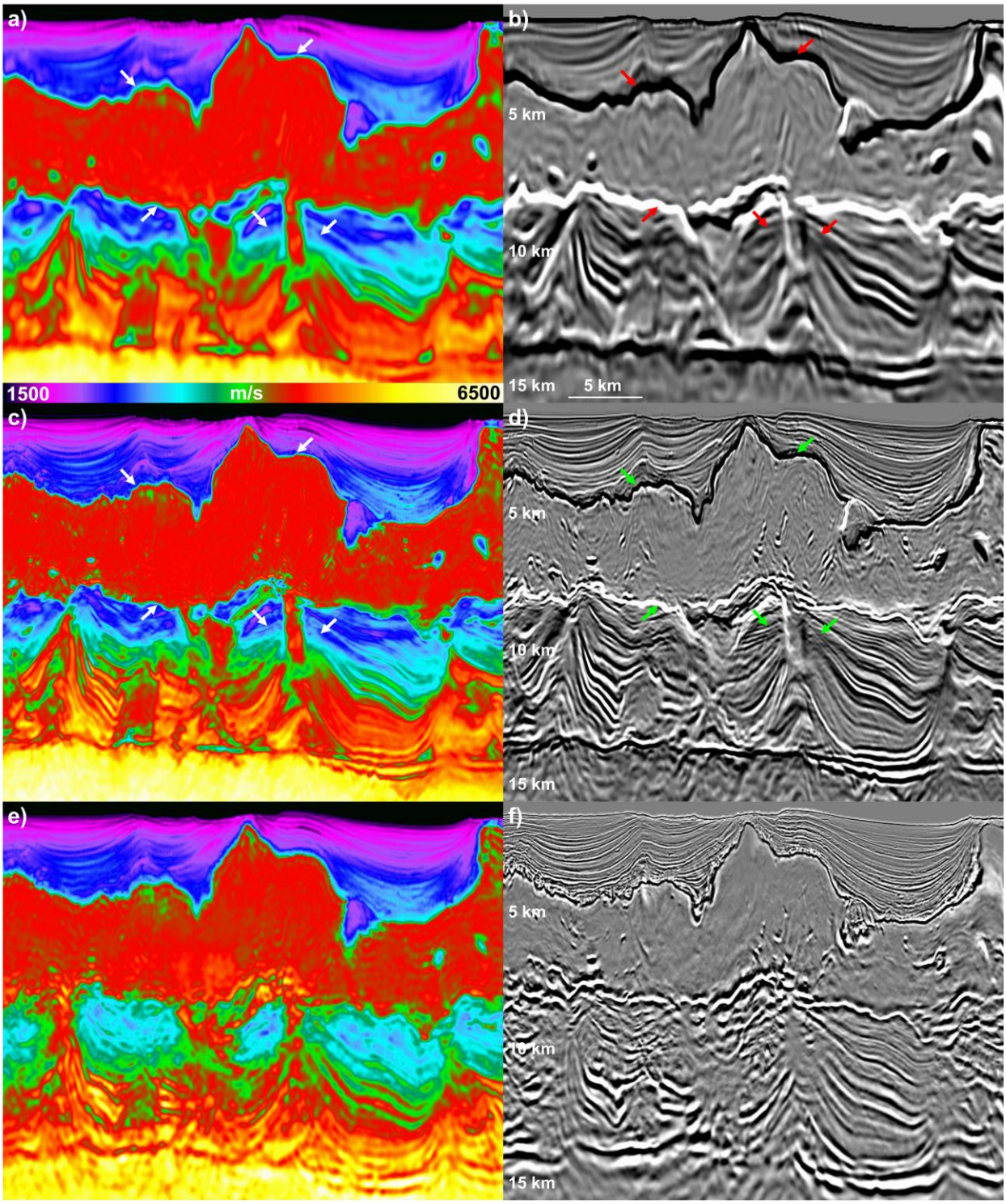


Figure 14. a) 5 Hz OBN EFWI model and b) EFWI Image, c) 12 Hz OBN+streamer EFWI model and d) EFWI Image, and e) 6 Hz streamer AFWI model and f) 15 Hz streamer RTM image. The salt halo continues to shrink moving to higher frequency and both model FWI Image resolution increase top down moving from 5 Hz to 12 Hz. Comparison of the 12 Hz OBN+streamer EFWI model and EFWI Image against the 6 Hz streamer AFWI model and 15 Hz RTM makes clear the benefit of the improved kinematics from the OBN update and the superiority of the FWI Imaging algorithm as fine-scale events can be tracked from the deeper subsalt to the feeder flank.

Discussion

The Laconia program sets a new benchmark for scalable seismic acquisition in geologically complex deepwater environments. It demonstrated that sparse OBN acquisition—when paired with low-frequency source technology and EFWI—can deliver transformative subsalt imaging.

Geophysically, the program validated that a purpose-driven acquisition design—featuring ultra-long offsets, low-frequency signals down to 1 Hz, and full azimuthal coverage—leads to more accurate velocity models and structurally consistent images. Geobodies that historically impeded imaging, including mobile shales and complex salt geometries, were resolved with greater clarity. These improvements directly benefit interpretation in the Wilcox Paleogene and Mesozoic plays by enabling deeper structural understanding and reducing geologic uncertainty.

Operationally, the program showed that the low-frequency sources that we used are reliable—with less than 4% downtime—and compatible with conventional acquisition systems, thanks to the introduction of a pressure regulator system near the source. This enabled source separation beyond 200 m on a single vessel, improving design flexibility and field efficiency. The campaign also logged over 528,000 exposure hours without environmental incidents and maintained a TRCF of 1.89, underscoring its HSE performance.

The integration of 150-day battery life nodes and low-latency telemetry enabled consistent ultra-long offset coverage and accelerated time to imaging, with a 5 Hz AFWI model delivered just 40 days after acquisition. The long-endurance node inventory minimized redeployments and enhanced crossline offset coverage—supporting the scalability of multi-client programs.

Strategically, Laconia offers a modular and replicable model for future frontier exploration, particularly in basins where streamer-based surveys are limited by overburden complexity or illumination gaps.

The sparse OBN geometry and dual-source wide-tow configuration optimized vessel time and coverage efficiency, delivering basin-scale illumination without a proportional cost increase.

The combined AFWI→EFWI workflow reduced structural and depth uncertainty beneath the salt canopy by improving low-frequency constraints and elastic consistency along complex interfaces. By combining the sparse LOLF OBN data with the underlying streamer data a higher resolution EFWI model and EFWI Image can be generated.

These improvements directly de-risk future drilling by clarifying trap geometries, fluid-sensitive intervals, and velocity hazards in the Wilcox and deeper Mesozoic sections.

Conclusions

The step change achieved in Laconia subsalt imaging confirms the effectiveness of the proposed LOLF sparse OBN plus FWI combination in areas with complex geology, emphasizing the importance to acquire FWI-friendly data—with the necessary offsets, frequencies, and azimuthal coverage. The project highlights the practical scalability of such designs, which has been further improved when coupled with innovations developed and implemented during the project, for example, the pressure regulator system.

Higher-frequency EFWI using both OBN and legacy streamer data provides an even richer characterization of subsalt reservoirs. Ultimately, Laconia confirms that the convergence of innovative acquisition design, operational scalability, and advanced FWI algorithms unlocks new levels of imaging fidelity in deepwater exploration.

Ultimately, Laconia demonstrates that the path to better imaging lies not in acquiring more data, but in acquiring the right data in the right way—at the right scale.

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Their collective contributions to operations, technical innovation, and interpretation were essential to advancing this work.

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This research received **no specific grant from any funding agency** in the public, commercial, or not-for-profit sectors.

The authors declare **no competing interests**.

Data and materials availability

Acquisition data and derived products from the Laconia program are **proprietary** to Viridien and its partners and are **not publicly available**. Aggregate metadata required to reproduce the survey design (e.g., node spacing, source parameters) are included in this article. Additional non-confidential information may be provided **upon reasonable request** and subject to commercial and confidentiality constraints.

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