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Unlocking Geological Insights with «nSeis» High-Resolution Seismic Processing

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Abstract Summary.

The development of innovative algorithms, combined with increased computational resources, has led to new tools for seismic data processing. Enhancing the vertical and lateral resolution of seismic data by two to three times is now becoming a reality. Geological bodies that were previously hidden by interference and other distortions on standard seismic sections are now distinctly visible in high-resolution sections after «nSeis» post-processing. The method maintains spectral balance while significantly enhancing seismic resolution, without introducing any phase distortion. In other words, the events remain exactly in the same position but can be visualized with a higher level of detail after «nSeis». The key lies in shifting the focus from conventional broad structural boundaries to smaller-scale geological heterogeneities, which are now mappable. For features that imply lateral facies variation—such as stratigraphic pinch-outs, areas with faults of various magnitudes (ranging from large faults to smaller-scale fracture systems), and zones where tuning effects introduce significant uncertainty— «nSeis» interpretation enables enhanced resolution. However, interpreting high-frequency seismic data poses several challenges. The increased level of detail in the wave field requires meticulous well-tie calibration, precise reflection correlation, and careful construction of structural-tectonic and seismic facies models. The ultimate outcome is the generation of new, internally consistent hydrocarbon field models, offering improved insights for exploration and production strategies.

Introduction

For decades, the limited resolution of conventional seismic data has constrained geological analysis, often leaving small faults, facies changes, or thin reservoir layers undetectable. Geologists frequently encountered explanations like “seismically invisible faults” to account for discrepancies in fluid contacts or reservoir connectivity observed in wells. Standard spectral enhancement tools have reached their limits, unable to provide the detail needed for modern exploration challenges.

The «nSeis» technology overcomes these barriers by applying advanced algorithms to standard seismic cubes (PSTM or PSDM), eliminating the need for costly new surveys. By extending the seismic spectrum into high frequencies, it reveals fine-scale heterogeneities critical for non-structural reservoirs, such as lithological, stratigraphic, or tectonic traps. As the industry shifts toward these complex systems, where subtle variations control hydrocarbon flow, «nSeis» enhances reservoir characterization, reduces drilling risks, and improves reserve estimates.

This paper outlines the «nSeis» methodology, compares its performance to conventional approaches, and demonstrates its impact through practical applications. We also address the interpretive complexities of high-resolution data and propose strategies to maximize its value in exploration and production.

The «nSeis» Technology

Seismic resolution hinges on the high-frequency boundary of the spectrum. Vertical resolution is traditionally defined as one-quarter of the wavelength, limiting the ability to distinguish thin layers, while lateral resolution is constrained by the Fresnel zone. However, layers thinner than this limit can influence wavelet shapes, embedding subtle clues about their properties. The nSeis" technology takes advantage of this by analyzing harmonic packets within the seismic spectrum to extend it into unrecorded high frequencies.

Figure 1 illustrates a reservoir model and the spectrum of its synthetic seismic trace, highlighting harmonic packets that enable spectral extension. The «nSeis» algorithm uses nonlinear analysis to extract high-frequency components absent in raw data, maintaining signal stability and avoiding phase distortion. Figure 2 shows how this approach extends the frequency spectrum into the high-frequency region, significantly enhancing resolution.

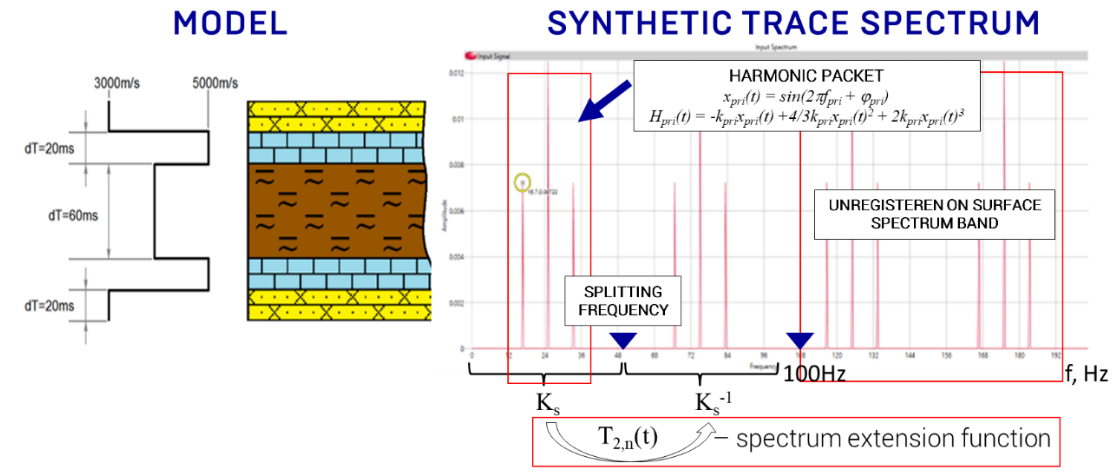

Figure 1. Reservoir model and the spectrum of the corresponding synthetic seismic trace with frequency packets and their shape description.

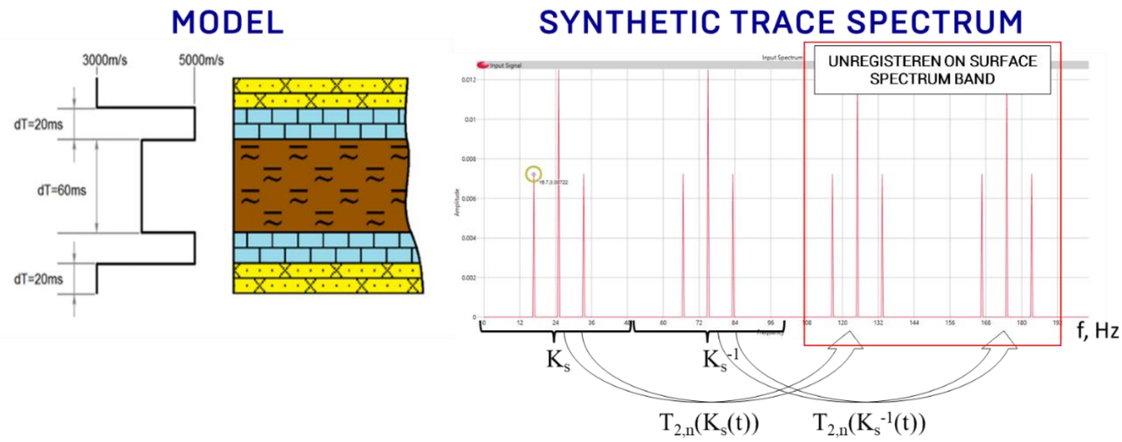

Figure 2. Extension of the frequency spectrum to the right (into the high-frequency region)

Requiring only a standard seismic cube, «nSeis» integrates seamlessly into existing workflows, making it a cost-effective solution. Compared to traditional techniques like Wiener deconvolution, which often amplify noise when boosting high frequencies, «nSeis» delivers a clean, interpretable signal. Figure 3 (top) presents a seismic cube from the Poseidon gas field, where «nSeis» enhances detail without noise contamination. Figure 3 (bottom) compares deconvolution and «nSeis» results above 90 Hz, with «nSeis» achieving a 2.6-fold resolution increase while remaining interpretable, unlike deconvolution's noisy output. This clarity enables visualization of thin beds, minor faults, and facies transitions, critical for reservoir analysis.

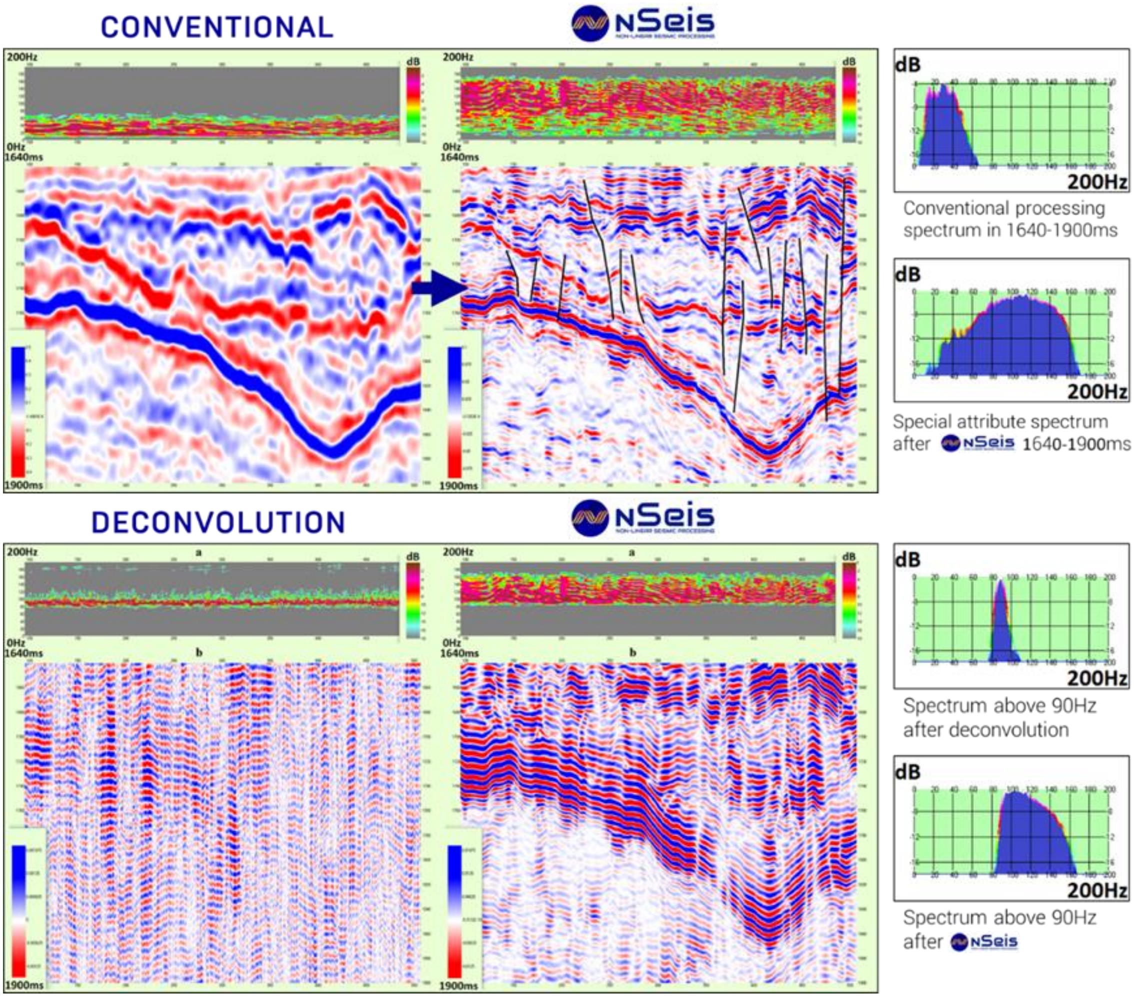

Figure 3. Fragment of the conventional seismic record (left top) and «nSeis» high-frequency extended section (right top). Deconvolution result above 90 Hz (left bottom), «nSeis» section above 90 Hz (right bottom)

Interpretation Challenges and Solutions Results

High-resolution «nSeis» data enriches the wavefield with additional seismic phases, small-amplitude faults, and geological bodies, providing valuable geological insights but increasing interpretive complexity. The finer detail demands adjustments to standard workflows to fully leverage its potential.

- Well-Tie Calibration: Enhanced resolution requires precise alignment with well data to ensure accurate horizon identification. Small discrepancies, often overlooked in standard data, become significant in «nSeis» cubes, requiring robust calibration techniques to validate ties.

- Reflection Correlation: The increased number of visible phases complicates horizon tracing across a cube. Interpreters must meticulously correlate reflections, often relying on high-fidelity data like vertical seismic profiling to confirm alignments and avoid errors.

- Structural and Facies Modeling: The wealth of detail requires more sophisticated tectonic and facies models. High-resolution data can reveal subtle features like erosional surfaces or localized seals, prompting interpreters to revise assumptions about reservoir architecture.

These challenges are offset by significant benefits. «nSeis» resolves ambiguities in geological models, enabling precise mapping of complex features. For example, it can clarify stratigraphic relationships or fault patterns that standard data obscures, improving structural accuracy and reservoir delineation. The enhanced resolution also supports better amplitude analysis, revealing thin layers critical for understanding reservoir connectivity.

Applications in Complex Reservoirs

The «nSeis» technology excels in environments where conventional seismic data struggles, particularly non-structural reservoirs. Stratigraphic pinch-outs, fault-controlled systems, and zones affected by tuning effects benefit from enhanced resolution, providing clearer insights into reservoir geometry and fluid dynamics. By resolving fine-scale heterogeneities, «nSeis» improves the understanding of hydrocarbon flow units, guiding well placement and development strategies.

In clastic formations, «nSeis» is particularly effective, resolving thin sand bodies that appear as weak or indistinct reflections in standard data. This allows interpreters to map fluvial or levee systems with greater precision, enhancing reservoir characterization. The technology also aids in fault analysis, identifying small-amplitude fractures that influence reservoir compartmentalization, which standard data often misses.Beyond structural mapping, «nSeis» refines fluid contact models. In cases where conventional data fails to explain variations in oil-water contacts, «nSeis» can distinguish isolated accumulations, providing a more accurate reservoir framework. These insights reduce uncertainties in reserve estimation and optimize production planning, making «nSeis» a valuable tool for complex geological settings.

Unexpected Benefits

An unanticipated advantage of «nSeis» is its variable effectiveness across lithologies. Clastic formations, especially those with thin bedding, exhibit greater resolution gains than high-velocity carbonates due to richer harmonic packets in their spectra. This makes «nSeis» particularly suited for layered sequences, where it resolves individual beds within what standard data presents as a single reflection.

Another benefit is the ability to analyze thin layers separately. In conventional data, a single reflection often integrates the response of multiple beds, obscuring their individual properties. «nSeis» separates these layers, enabling detailed amplitude and geometry studies. This is critical in continental deposits, where distinguishing meandering sand bodies or other heterogeneities improves reservoir modeling. The technology also enhances the visibility of subtle features, such as minor faults or facies transitions, that are critical for understanding reservoir dynamics. By providing a clearer picture of these elements, «nSeis» supports more informed decision-making in exploration and development, reducing risks and improving economic outcomes.

Conclusions

The «nSeis» technology represents a breakthrough in seismic processing, delivering high-resolution data that unlock new geological insights. By revealing fine-scale heterogeneities, it refines models of complex reservoirs, improves reserve estimates, and optimizes production strategies. While interpreting high-resolution data requires greater precision, the results—clearer structural mapping, resolved fluid contacts, and enhanced amplitude analysis—justify the effort. As the industry increasingly targets non-structural traps, «nSeis» offers a powerful tool to address modern exploration challenges, driving efficiency and accuracy in hydrocarbon development.