GEOGULF2021
AUSTIN
October 27–29, 2021

Enhanced Resolution Seismic and New Subsurface Insights: Miocene Section, St. Mary Parish, Louisiana

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ABSTRACT

In this study, traditional 3D seismic data were enhanced in an effort to attain an improved understanding of the subsurface with a focus on the Miocene section. To achieve this objective, an innovative spectral extrapolation algorithm was applied following a structural noise cancelation process. By taking advantage of the well-known harmonic resonance phenomenon, this process enables amplitude estimation at frequencies near or below the noise threshold of the data. The periodicity of layer reflectivity within the input spectrum enables prediction of its behavior beyond the input spectrum limits, thereby augmenting the resolution of the seismic data.

The resulting seismic volume imaging improvements led to: (1) increased apparent vertical separation of sedimentary layers (seismic detuning), (2) improved definition of their lateral continuity, and (3) enhancement of structural and stratigraphic discontinuities throughout the section. These details of the subsurface are extremely important for both exploration (mapping and drilling of new prospects) and development (field delineation and compartmentalization).

INTRODUCTION

The Miocene sedimentary section of present-day southwestern Louisiana (Fig. 1) was formed within proximal to distal, deltaic to slope, and deep-water depositional environments. Multiple oil and gas bearing reservoirs (characterized by 15–30% porosity and 100–2500 mD permeability ranges) have been discovered and produced over the years in the area.

Egorov, V., C. I. Puryear, R. Tharimela, and J. Jurasin, 2021, Enhanced resolution seismic and new subsurface insights: Miocene section, St. Mary Parish, Louisiana: GeoGulf Transactions, v. 71, p. 63–68.

Figure 1. Map of Louisiana showing location of St. Mary Parish (in yellow) and approximate location of the *Planulina* sands trend (red outline).

The Jeanerette Oil Field was discovered in 1935; the first well reached a total depth of 7514 ft. The Jeanerette structure is associated with a salt dome and has complex faulting (Dobie, 1970). 3D seismic data were acquired over the Jeanerette Oil Field, with the primary objective of improved imaging of the lower Miocene *Planulina* sand reservoirs. The "*Planulina* sands" are a sequence of outer slope/turbiditic interbedded sands and deepwater shales deposited along the paleo-shelf trend extending from Assumption Parish, Louisiana, to the east into southeast Texas to the west. Within the Jeanerette Field, the reservoirs range from 6–40 ft net pay and 10,000–15,000 ft depth. This play has been actively explored and produced since the first Cameron Parish discovery in 1945. However, due to the complex geology, it remains a challenging play to explore, as demonstrated by recent mixed results of exploratory and development drilling programs.

METHODS

We apply structural noise cancelation followed by a process of spectral extrapolation to expand the frequency content. The structural noise cancelation uses dip-steering in order to eliminate noise along reflectors using a median smoothing filter. The results often improve the continuity along reflectors and serve as a pre-processing step for inversion and machine learning workflows.

Conventional seismic data provide a limited window into the frequency spectrum of the earth's subsurface reflectivity. Generally, the frequencies recovered after earth filtering and seismic processing have truncated the spectral content and are not adequate to define thin layers, faults, carbonate formations, etc. The lack of frequency content is equivalent to a "blurring" effect in the time domain that directly impacts the interpreter's ability to not only understand stratigraphic connectivity but ultimately to develop a coherent geological history for the subsurface region of interest. In order to mitigate this shortcoming, the interpreter utilizes well information in conjunction with the seismic, which can help resolve issues proximal to the well but does little to resolve interpretation ambiguities far from the well. Thus, drilling decisions are made based on band-limited 3D information and the process is susceptible to significant uncertainty. Once a well is drilled, the "ground truth" is found only in a 1D sense and the field development process continues at significant cost as the true subsurface picture is slowly unraveled.

Spectral extrapolation technology reduces the pitfalls of the conventional approach by generating high-resolution seismic data at the beginning of the exploration, production, or development process. The result is an enhanced version of the seismic data containing extended frequency content that can be used as the basis for improved reservoir characterization. Instead of following the approach of boosting the amplitudes at noisy frequencies using an inverse operator, our process takes advantage of the reflectivity harmonics that exist within the existing seismic data band. These superimposed layer harmonics are the frequency-domain equivalent of the time-domain layer responses in the seismic data. Using spectral inversion (Puryear and Castagna, 2008), we capture these responses within the usable seismic spectrum and reliably reconstruct them in the null (or noise) space. Thus, the frequency content of the earth's reflectivity is recovered to the extent that pre-existing noise, wavelet estimation, and processing errors permit. To remove frequencies beyond the reliability threshold, the spectrally extrapolated data are simply high-cut. The results are validated by well information where available and used as a fit-for-purpose frequency- enhanced substitute for the original seismic data. While well control is desirable for phase calibration, it is not strictly required for this process. In such exploration settings, the interpreter can make use of enhanced stratigraphic/structural visualization to identify exploration targets.

The process has been applied to a case study using low quality onshore seismic data (Garcia-Leiceaga et al., 2020), more than doubling the frequency content. The results honor the well, and after conventional impedance inversion, reveal enhancements that refine the interpretation of the architecture and connectivity of the reservoir. By propagating the spectral extrapolation through the reservoir characterization workflow, the geoscientist will achieve greater confidence in his/her understanding of the subsurface and placement of future wells.

RESULTS

The results of the spectral extrapolation show increased stratigraphic detail for interpretation. Figure 2 illustrates the process in the frequency domain. The original data spectrum is shown in blue and has a useful bandwidth of approximately 10–40 Hz. The spectrum of the result after structural noise cancelation (SNC) is shown by the orange line. The SNC has a greater effect at high frequencies, as the random noise that is canceled by the SNC tends to preferentially dominate at the high end of the spectrum. The green line shows the spectral extrapolation (SE) result. Using this process, the bandwidth of the data has been extended considerably, which corresponds to increased resolution and stratigraphic detail in the time domain. Furthermore, the amplitudes at the input frequencies are approximately matched up to 30 Hz so that further inversion and attribute computations retain the low frequency information. Figure 3 shows inline sections of the data. There appears to be a package of down-lapping strata in the original seismic data (black circle). The SNC process increases the continuity and interpretability of the data, while preparing it for SE. Finally, the SE is applied to the SNC data, which has

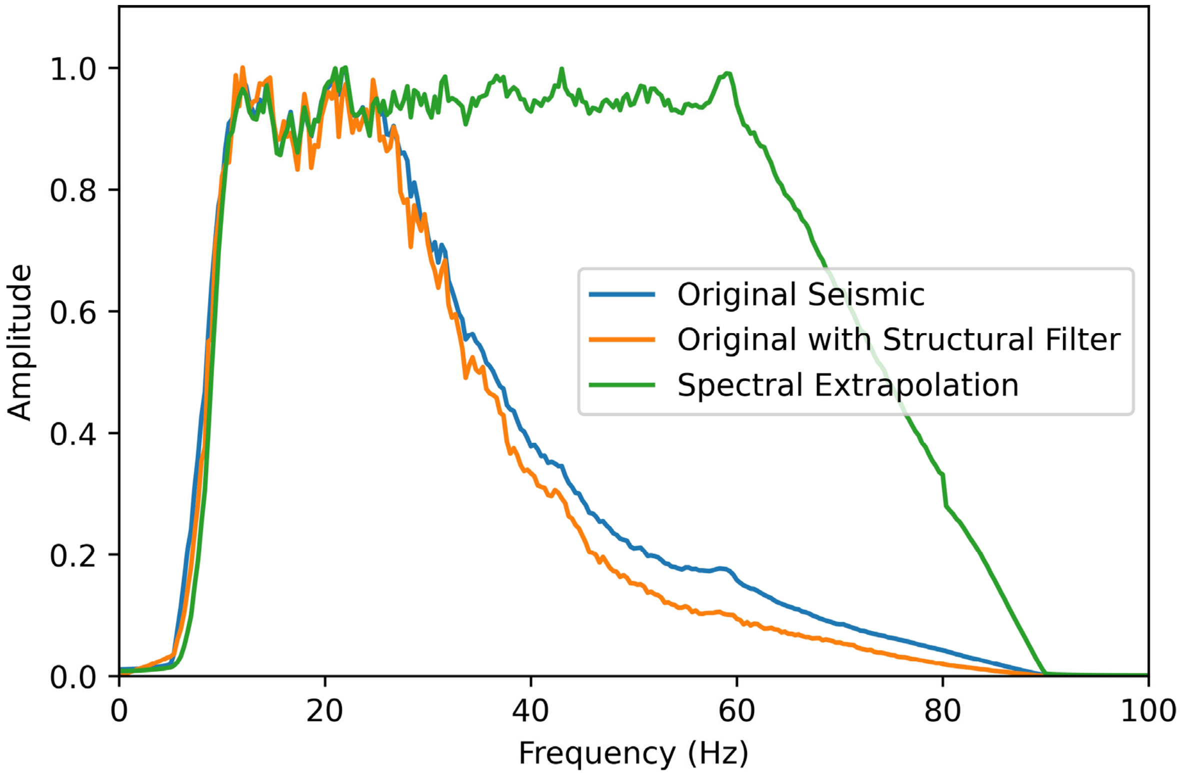

Figure 2. Spectra for the original seismic data (blue), structurally filtered original seismic data (orange), and spectral extrapolation (green). Note that high frequencies are preferentially canceled by the structural filter. The spectral extrapolation significantly widens the band.

increased signal/noise within the wavelet band. The downlapping features and other stratigraphic details are sharper on the SE, enabling enhanced interpretation or input to seismic inversion or machine learning.

SUMMARY AND CONCLUSIONS

We applied a SNC process followed by SE to the Jeanerette seismic dataset with particular focus on the Miocene hydrocarbon-bearing section. The process extrapolates harmonics in the input band and projects them outside of the original spectrum (into the null space). The bandwidth is thereby extended in the spectrally extrapolated volume. Inline and time sections show increased stratigraphic and structural detail for interpretation. In particular, we note increased event continuity on the time slices (Fig. 4). The inline sections show apparent downlapping stratigraphic features and significant enhancement of detail on the SE. We continue comparative 3D seismic interpretation of the original and SE data in order to understand the additional information provided by the SE within the geological context of the Jeanerette Field.

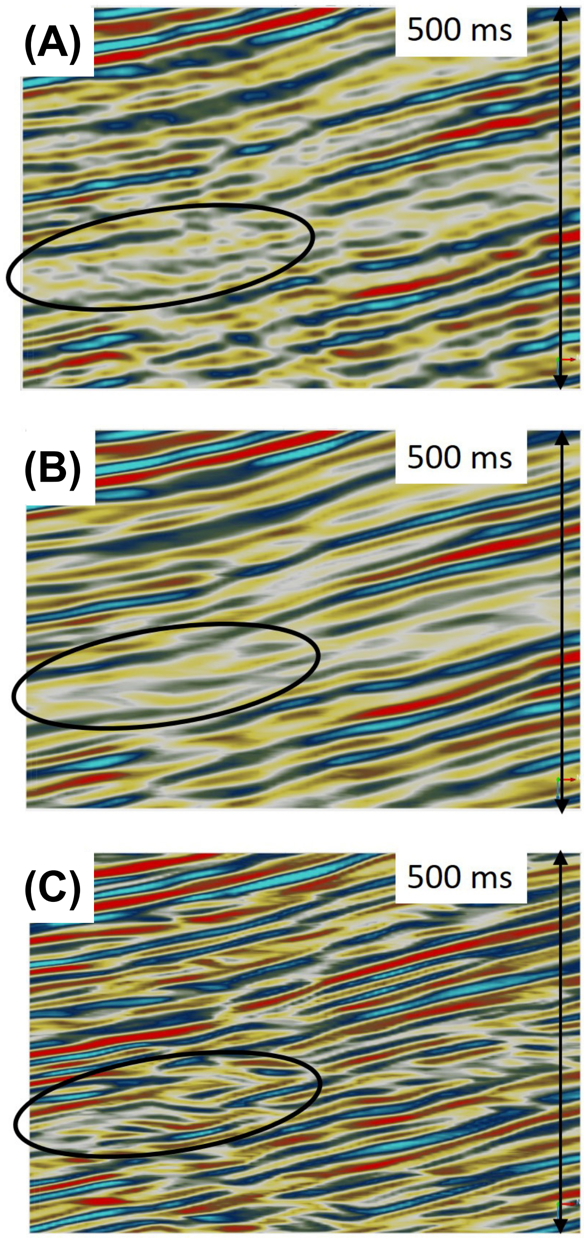

Figure 3. Cross-section on: (A) original seismic data, (B) original seismic data with structural filter, and (C) spectral extrapolation. Note that the spectral extrapolation sharpens the apparent downlapping features (black circles) and other stratigraphic details.

ACKNOWLEDGMENTS

We thank Radiant Oil & Gas for permission to publish the work.

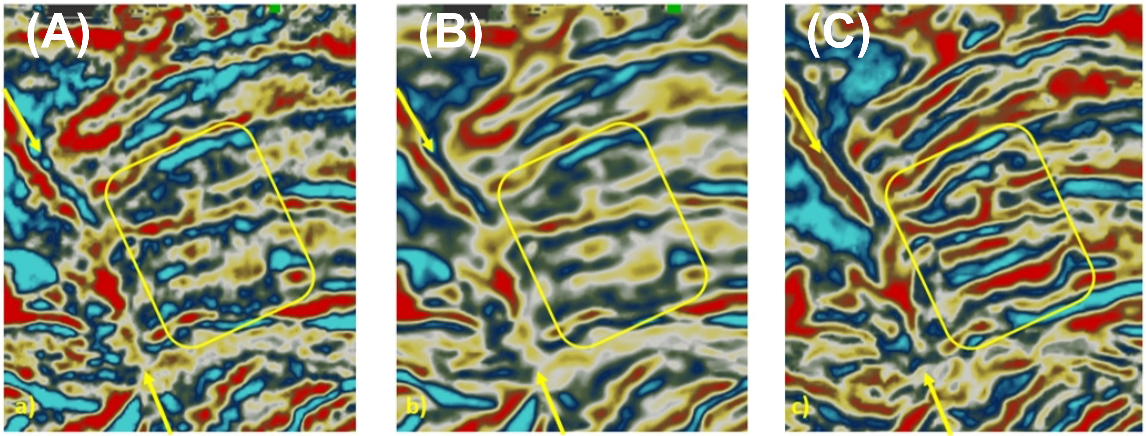

Figure 4. Time slices on: (A) original seismic data, (B) original seismic data with structural filter, and (C) spectral extrapolation. Note that the spectral extrapolation enhances more subtle details and improves continuity (in yellow outline). A large fault is also highlighted by the yellow arrows.

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