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Enhancing the Resolution of Seismic Data using Spectral Blueing Technique at North Silah Deep Oil Field, Fayoum Area, North Western Desert, Egypt

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Abstract

North Silah Deep Oil Field lies in the North Silah Deep Development Lease within Fayoum concession in Egypt's northern Western Desert. In the domain of reservoir prediction, the application of spectral blueing for seismic resolution enhancement proves crucial for separating involved details within the Abu Roash "G" Member sand reservoir in the North Silah Deep Oil Field. This reservoir exhibits both vertical and lateral heterogeneities, primarily attributed to the Late Cenomanian Abu Roash 'G" Member, characterized by shale, carbonate, and intermittent sandstone streaks, some of them containing shale content.

This study utilizes spectral blueing to enhance seismic resolution, providing insights into Abu Roash "G" sand reservoir. In the North Silah Deep Field, spectral blueing reveals isolated channels and assists in mitigating uncertainties regarding reservoir connectivity.

The methodology employs seismic spectral blueing, a technique enhancing vertical resolution by shaping the seismic spectrum. The workflow involves generating a reflectivity series, deriving an operator, and applying it to the seismic data. Steps include estimating average seismic spectra, computing well reflectivity spectra, fitting trend lines, calculating operator amplitude spectra, maintaining seismic phase, and convolving the seismic volume.

Application of spectral blueing demonstrates notable improvements in seismic data frequency characteristics, contributing to enhance vertical resolution. The methodology is applied to the study area, illustrating discernible differences between original and enhanced seismic data. The heightened frequencies captured by spectral blueing offer a clearer and more detailed representation of subsurface geological characteristics, providing valuable insights for reservoir characterization and future drilling decisions.

Introduction

In the context of reservoir prediction, the enhancement of seismic resolution through spectral blueing emerges as an essential tool for understanding the details of the Abu Roash "G" Member sand reservoir in the North Silah Deep Oil Field. This reservoir showcases both vertical and lateral heterogeneity due to the presence of predominant component of the Late Cenomanian Abu Roash 'G" Member which is characterized by shale, carbonate, and intermittent sandstone streaks, some of them contain shale content.

Fayoum concession is located about 100 kilometers southwest of Cairo Governorate and is an integral part of Egypt's diverse topography. The North Silah Deep Development Lease situated within the expansive El Fayoum Concession in the northern Western Desert of Egypt and located between latitudes 29º 21' 58.3" N and 29º 26' 1.9" N & longitudes 30º 52' 58.8" E and 31º 00' 0.23" E as shown in Figure 1.

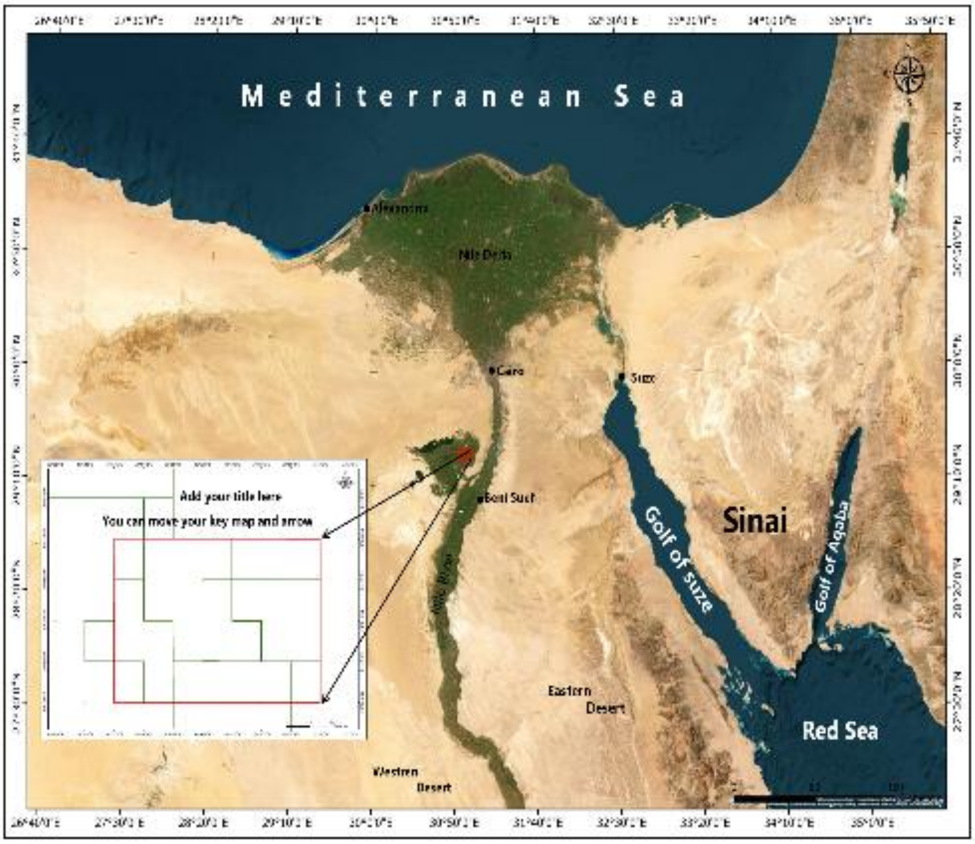


Figure (1): Location map of the North Silah Deep Development Lease study area.

The Gindi Basin, situated in the northern Western Desert of Egypt, stands as a significant sedimentary basin for the exploration of hydrocarbons in the region. The entire northern Western Desert, including the Gindi Basin, features the Upper Cretaceous Abu Roash Formation, spanning from Late Cenomanian to Coniacian. This formation is further divided into seven members, designated as A, B, C, D, E, F, and G, arranged from top to bottom (EGPC, 1992).

Members B, D, and F predominantly consist of clean carbonates, whereas A, C, and E members are characterized by fine clastics (sandstone, siltstone, and shale) along with limestone intercalations. The deposition of the Abu Roash Formation occurred under shallow marine conditions among highly fluctuating sea levels. Members B, D, and F were laid down during relatively high sea-level intervals, while C, E, and G members were deposited during comparatively low sea-level episodes (EGPC, 1992) as shown in Figure 2.

A compressional tectonic phase, associated with the Laramide tectonic event, exerted a strong influence on the Upper Cretaceous sedimentary succession throughout the sedimentary basins in the northern Western Desert, including the Gindi Basin. This compressional episode commenced during the Santonian age and persisted into the Early Tertiary due to NW-SE compressive stress resulting from the movement of Africa relative to Laurasia (Moustafa, 2012) as shown in Figure 3.

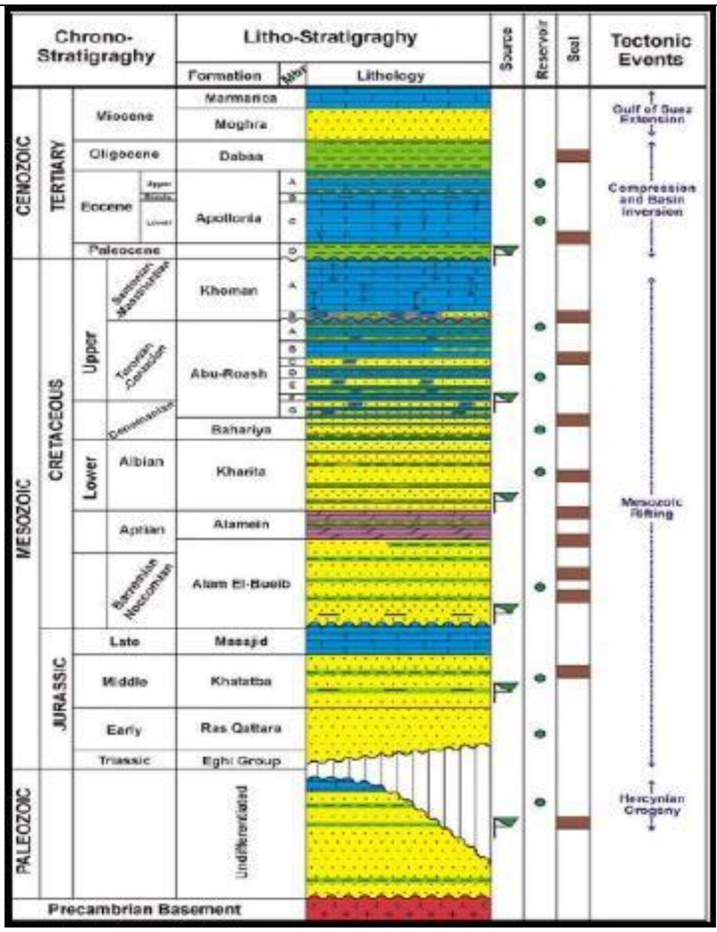


Figure (2): Generalized stratigraphic column of the north Western Desert of Egypt. (After, Moustafa et al. 2003)

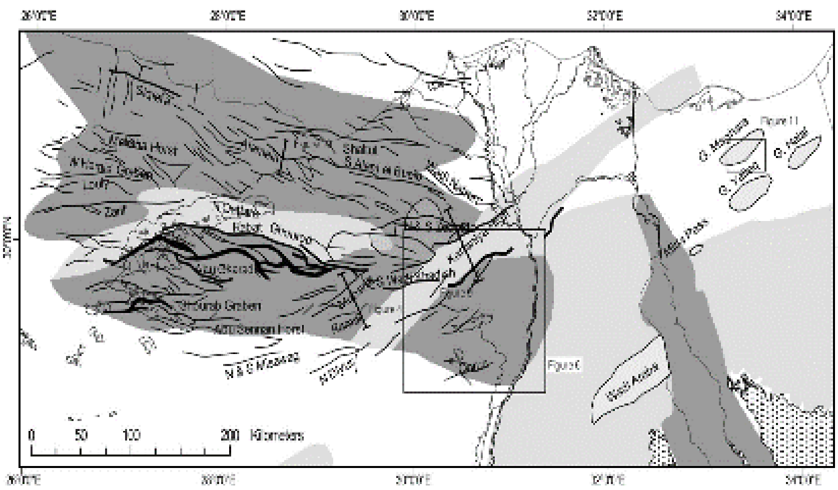


Figure (3): Regional fault map of the northern Western Desert (T.G. Bevan, A.R. Moustafa 2012)

By leveraging **spectral blueing** to increase seismic resolution, valuable insights gained into the lithology and physical properties of the Abu Roash "G" sand reservoir. Petrophysical parameters such as total and effective porosity, fluid saturation, and reservoir quality exhibit notable variations linked to the distribution of facies changes. This heightened resolution becomes pivotal as it directly influences the dynamic model of the reservoir, facilitating improvements in flow unit productivity. Moreover, it aids in identifying promising zones for refining the dynamic model and strategically selecting drilling locations.

Within the North Silah Deep field, the utilization of spectral blueing reveals numerous isolated channels, each delineated by lithological barriers. Additionally, an extensive layer of abrasive sandstone covers the field. Analyzing the refined facies distribution achieved through spectral blueing helps mitigate uncertainties regarding reservoir connectivity and occurrences. This refined information plays a pivotal role in effectively characterizing the reservoir community, identifying areas with optimized flow unit productivity potential, and guiding informed decisions for future drilling operations.

Seismic Spectral Blueing Methodology

Seismic Spectral blueing is a technique that enhances the vertical resolution of seismic data by boosting the high frequencies and shaping the spectrum to match the Earth's reflectivity (Fletcher et al., 2008). It is based on the observation that higher frequencies have higher amplitudes in geological settings, which is often lost during seismic processing. By applying a spectral shaping operator to the seismic data, the technique aims to improve the quality and interpretation of subsurface geological features. The initial seismic data underwent a transformation into reflectivity through the application of oversampling, resulting in the generation of a novel sparse-spike reflectivity series. This series was carefully crafted by assigning weights based on the interpolated amplitudes at all maxima and minima, following the methodology outlined by Young and Wild (2005). Spectral blueing techniques are conventionally applied on poststack seismic data and shape the seismic data spectrum based on the observed earth reflectivity to attain a zero-phase wavelet with a flatter spectrum, resulting in improved seismic resolution (Lancaster and Whitcombe, 2000; Blache-Fraser and Neep, 2004).

Seismic Spectral Blueing systematic approach ensures a comprehensive and controlled enhancement of seismic frequency attributes, contributing to an improved interpretation and understanding of subsurface geological features. Prestack and poststack Spectral blueing techniques increase seismic resolution in the same manner; that is, by enhancing higher frequencies within the seismic frequency band (Kazemeini, S. H., et al., 2010). The **workflow** is displayed in Figure 4, presenting a schematic diagram illustrating the methodology employed for Seismic Spectral Blueing.

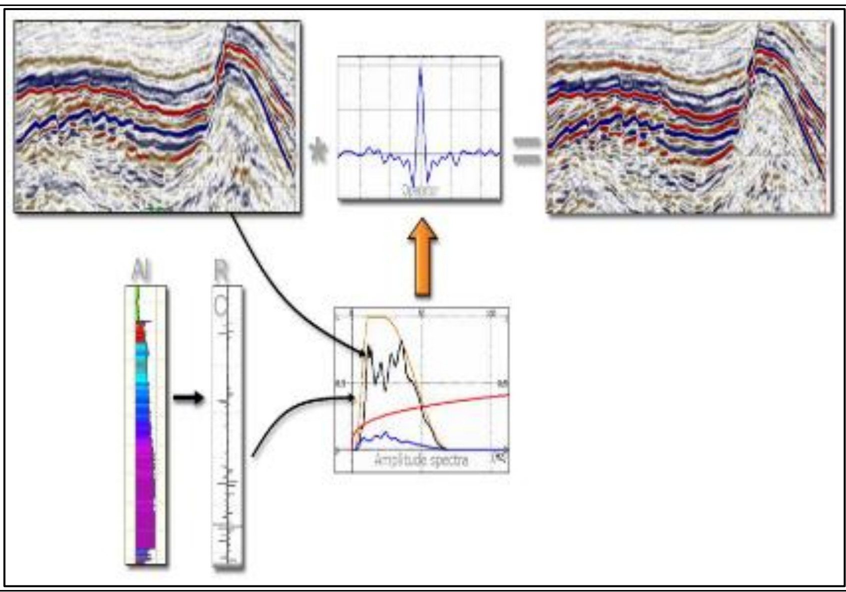


Figure (4): Schematic diagram depicting the workflow for Seismic Spectral Blueing (after PaleoScan, 2023).

In the enhancement workflow, the initial step entailed generating a reflectivity series by synthesizing well logs with seismic data. This reflectivity series, serving as a representation of subsurface geological features, assumed a crucial role in the subsequent stages of the process. Building upon this reflectivity series, an accurately derived operator was formulated. This operator, crafted through the careful alignment of well logs with seismic data, was specifically designed to interact with and convolve the enhanced seismic data.

Seismic Spectral Blueing Workflow encompasses a series of methodical steps designed to enhance the frequency characteristics of seismic data. The stepwise process involves:

1) Estimating the average seismic spectrum that initiated by calculating the average seismic spectra, providing a baseline representation of the frequency content within the seismic data as shown in Figure 5.

2) Computing wells reflectivity spectra in a log/log scale: A process used to compute the reflectivity spectra of wells, utilizing a log/log scale to capture a comprehensive view of the frequency variations as shown in Figure 6.

3) Fitting a trend line for average well amplitude spectrum: Employ a trend line fitting technique through the well spectra to derive the average well amplitude spectrum offering insights into the overall amplitude distribution as shown in Figure 7.

4) Computing operator amplitude spectrum: Calculate the designed operator amplitude spectrum by using the seismic and well spectra, ensuring a tailored operator that aligns with the desired frequency enhancements as shown in Figure (8a) with the operator in time Figure (8b). This figure illustrates the mean seismic spectrum (depicted in red) alongside the mean well reflectivity spectrum (shown in green). A spectral blueing operator, represented by the blue curve, has been meticulously designed to span frequencies from 8 to 60 Hz. The purpose of this operator is to harmonize the mean seismic spectrum with the mean well reflectivity spectrum, effectively demonstrating the adjustment process across the specified frequency range.

5) Maintaining Seismic Phase (Zero Phase): Retain the seismic phase, specifically zero phase, to preserve the temporal characteristics of the seismic data during subsequent processing steps.

6) Convolving the input seismic volume with spectral blueing operator: Execute the convolution of the original seismic volume with the spectral blueing operator in time domain, incorporating the frequency adjustments derived from the well information. This step aims to enhance the overall frequency response of the seismic data.

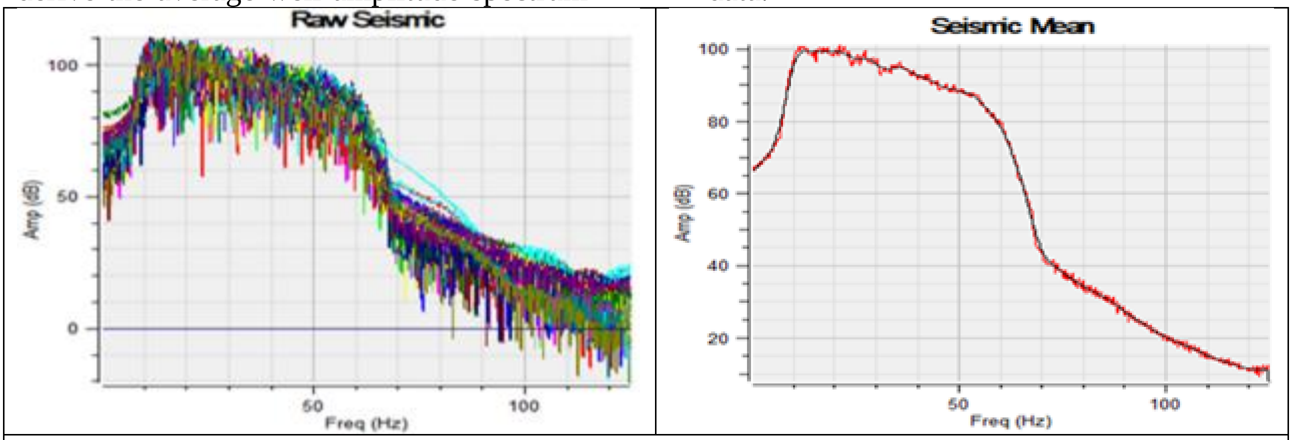


Figure (5): Original seismic spectrum; actual trace spectrum (left) and mean spectrum (right).

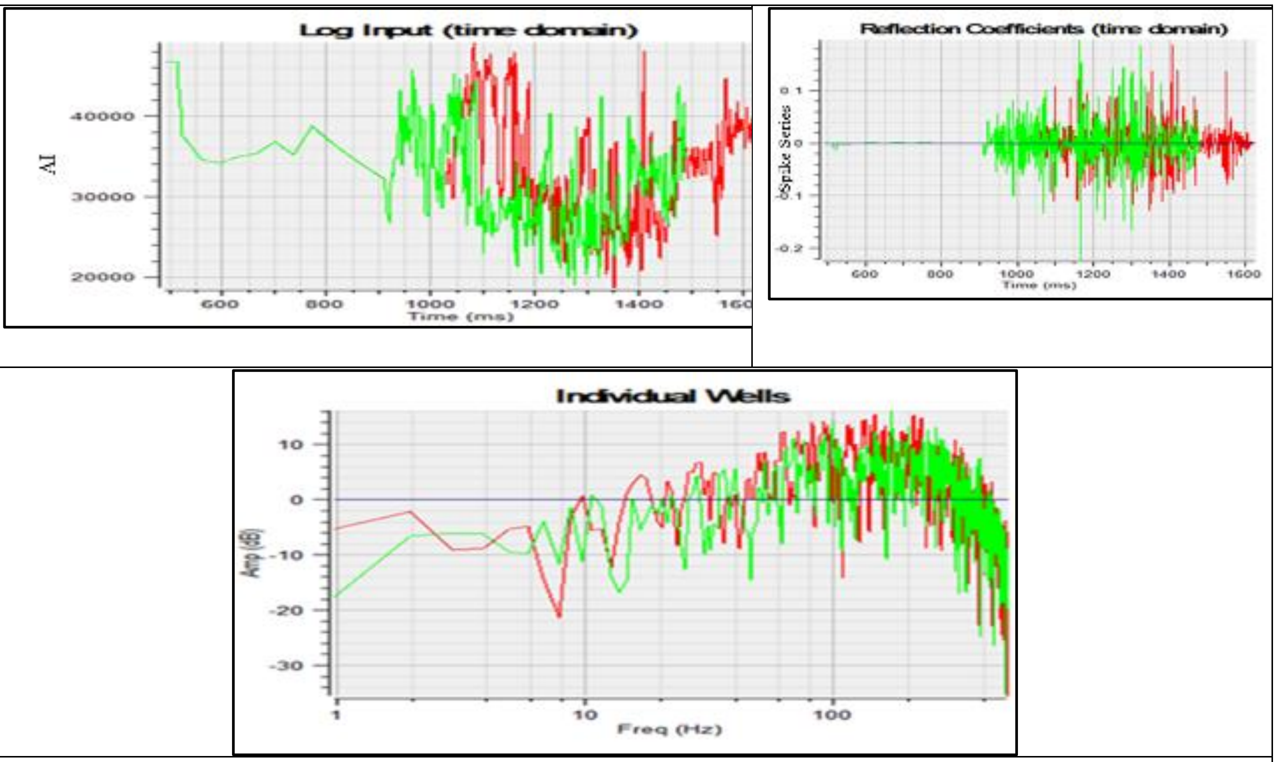


Figure (6): AI logs of wells in time domain (A), reflection coefficients (B) and reflection coefficients in frequency domain (C).

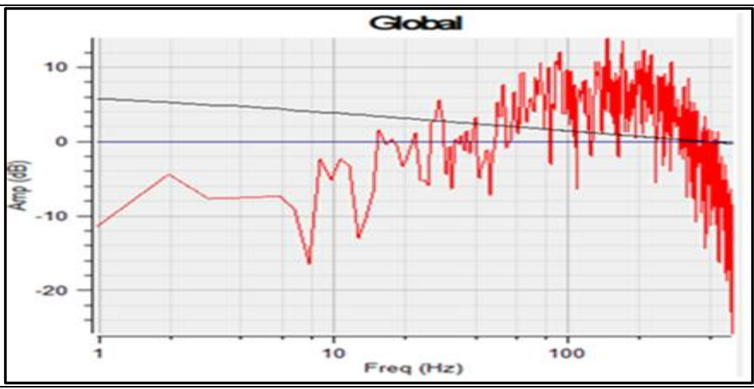
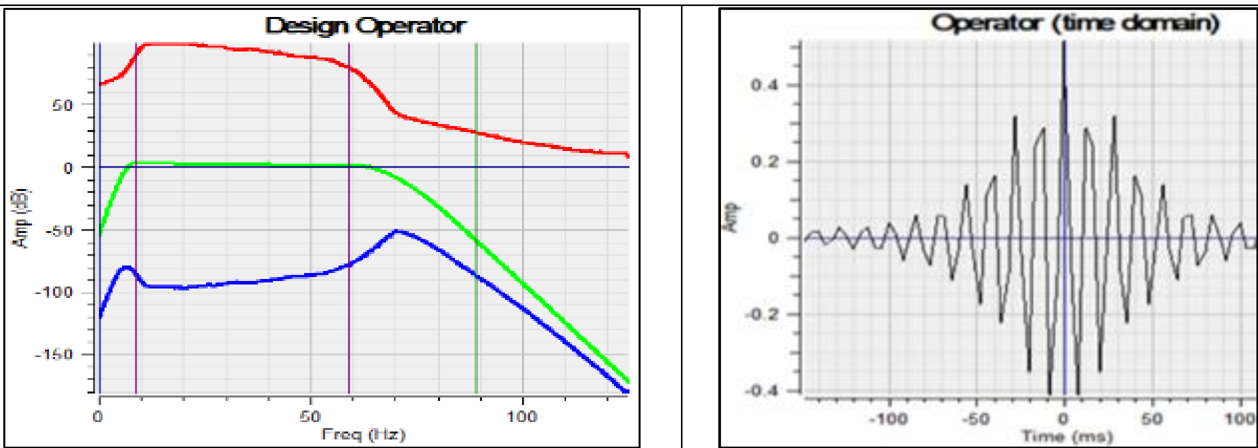


Figure (7): Trend line of well amplitude spectrum in frequency domain.



(A) **(B)**

Figure (8): Designed operator amplitude spectrum in frequency domain (A) and the operator in time domain (B).

Application of Spectral Blueing for Enhancing Resolution of Seismic Data at Study Area

The amplitude spectrum of seismic data manifests discernible changes prior to and subsequent to the implementation of seismic spectral bluing. These alterations illuminate variations in both **frequency** content and **amplitude** distribution. The spectral blueing procedure is specifically engineered to amplify the amplitudes of higher frequencies, thereby achieving a more equilibrium spectrum closely resembling the geological spectrum. This augmentation significantly contributes to an enhanced vertical resolution and heightened interpretability of the seismic data. Figure 10 visually elucidates these transformations, providing a simple representation of the influence of **seismic spectral blueing** on the amplitude spectrum. Noteworthy, adjustments include a **rise** in low-frequency components from **11 Hz to 8** Hz, an increase in high-frequency components from 48 Hz to 60 Hz post-spectral blueing, and a discernible elevation in the **dominant frequency** from **28 Hz to 35** Hz as shown in Figure 9.

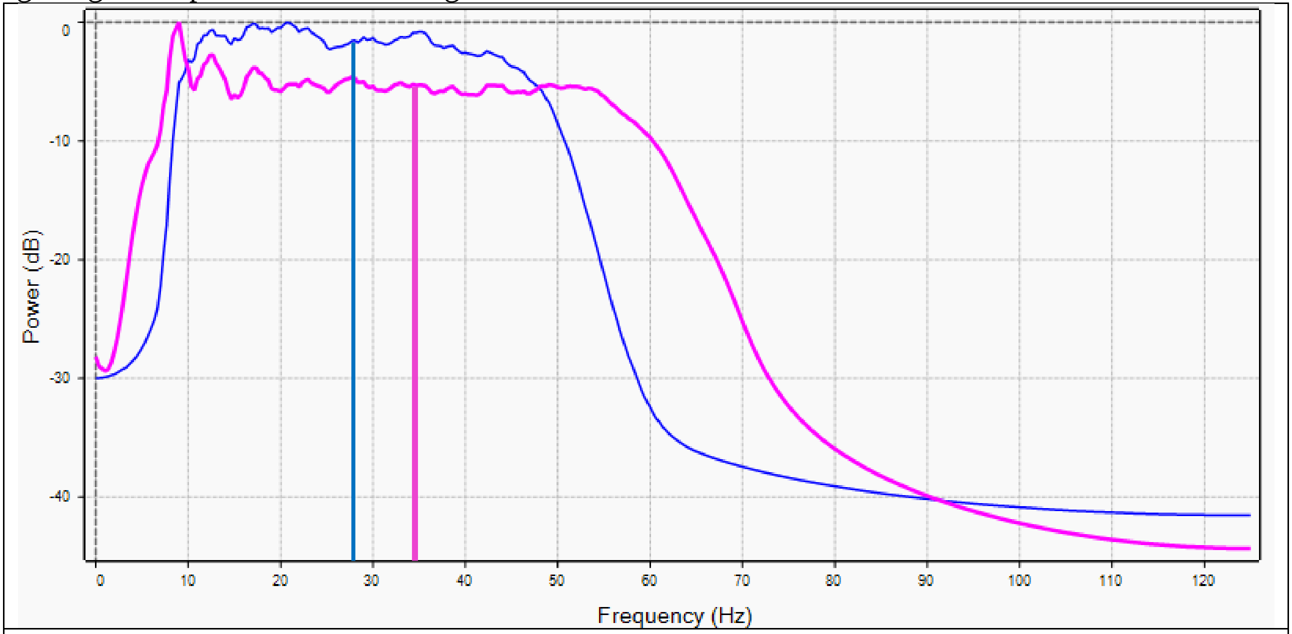
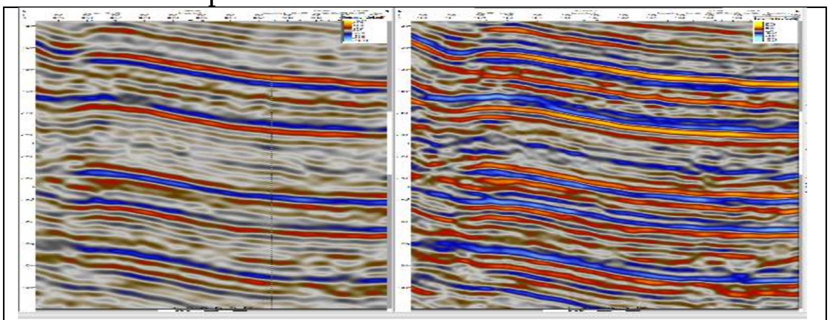


Figure (9): The amplitude spectrum comparison involves the original seismic data, represented in blue, and the data after spectral blueing, depicted in magenta.

In Figure (10), a visual representation showcases the obvious differences between the original seismic data and its enhanced counterpart after undergoing spectral blueing. This enhancement process is notably characterized by the introduction of heightened frequencies and an enhanced continuity of small-scale features within the seismic data.

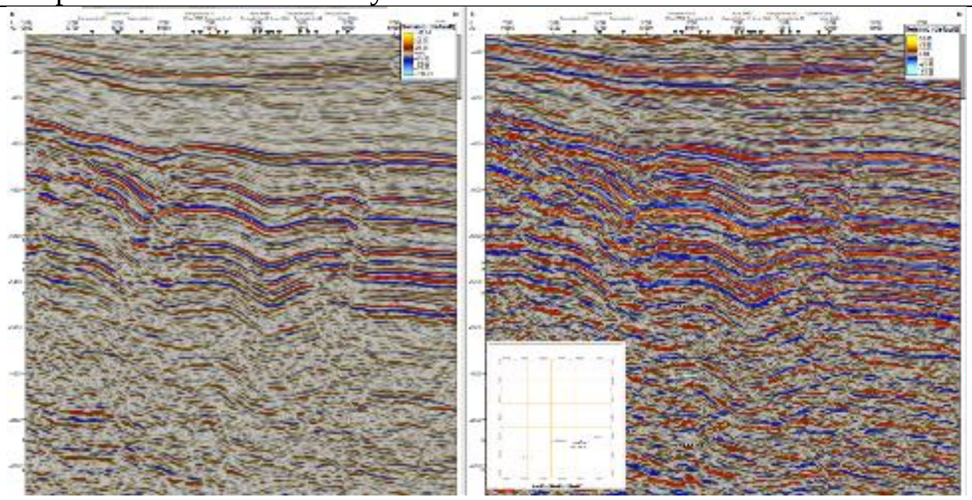


(A) **(B)**

Figure (10): Comparison between original data Inline 3500 original seismic section (A) and spectral blueing data of the same line (B).

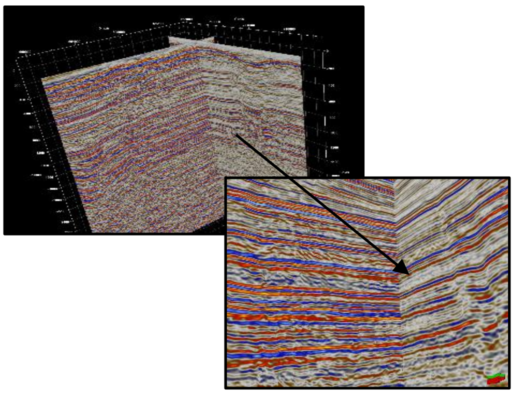
Figures (11, 12 and 13) illustrate a comparison between the original seismic data and the same data after spectral blueing (Inline 3590, Inline 3730, Crossline 11030 and Inline 3400) reveals a notable enhancement in frequency across the entire sections. The process of spectral blueing specifically targets the augmentation of frequencies, resulting in a discernible improvement in the frequency content throughout the seismic data. This enhancement is visually evident when comparing the two sets of data, demonstrating the effectiveness of spectral blueing in achieving a more pronounced and refined representation of the frequency spectrum. The side-by-side comparison visually highlights the increased prominence and clarity of frequencies in the spectral blued data, contributing to an improved overall quality and interpretability of the seismic information.

The added high frequencies contribute to a more comprehensive representation of the signal, capturing finer details in the geological structures and resolve the **thin** layer detection that was below seismic resolution in the original seismic data. The improved continuity observed in small features further refines the overall quality of the seismic data. These enhancements are pivotal in augmenting the dataset's resolution, providing a clearer and more detailed depiction of the subsurface geological characteristics.



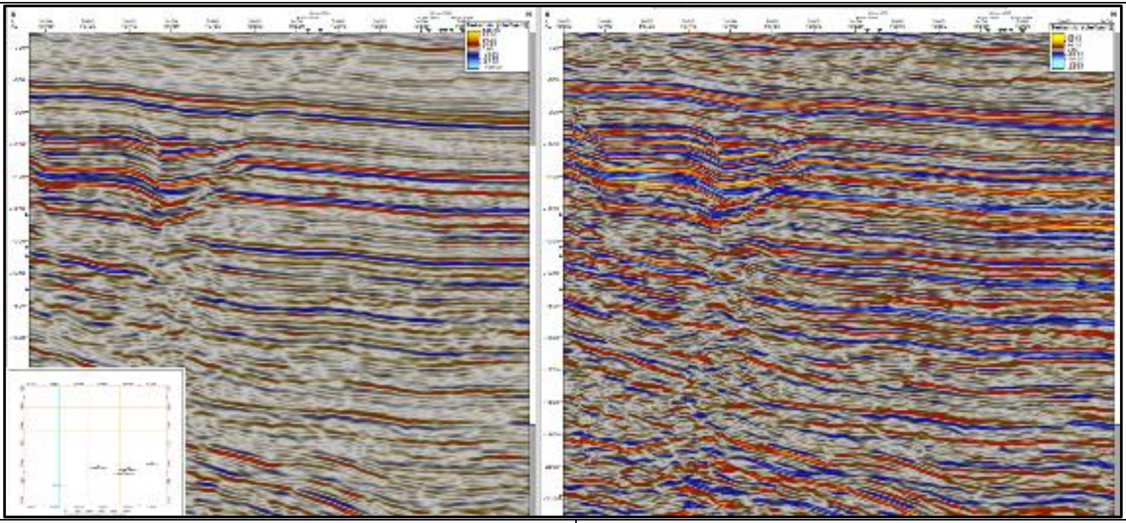
(A) Inline 3590 original seismic section. **(B) Inline 3590 after Spectral Blueing.**

Figure (11): Comparison between original data and Spectral Blueing data showing frequency enhanced along the section.



(A) Inline 3730 after Spectral Blueing. **(B) Cross line 11030 original seismic section.**

Figure (12): Comparison between the original seismic data along 11030 crossline and the seismic data subjected to Spectral Blueing on 3730 inline at the intersection points demonstrating the heightened frequency characteristics observed uniformly across the entire section.



(A) Inline 3400 original seismic section.	**(B) Inline 3400 after Spectral Blueing.**

Figure (13): A comparative analysis illustrating the contrast between the original seismic data and the data subjected to Spectral Blueing.

Figures 14 and 15 illustrate two seismic sections crossing NSD-1.1 well. These seismic sections, denoted as Inline 3630 and Crossline 10840, play a crucial role in revealing a previously undetected thin layer of the Lower Abu Roash "G" sand reservoir, measuring 30 feet in thickness. Initially, this reservoir posed a challenge as it was not clearly distinguishable in the original seismic data, indicating a resolution limitation. However, with the implementation of Spectral Blueing, an advanced processing technique, there was a substantial enhancement in the seismic data. Spectral Blueing significantly improved the resolution, enabling precise delineation and visualization of the Lower Abu Roash "G" sand reservoir. This enhancement is clearly visible in the detailed depiction of the reservoir in the seismic sections.

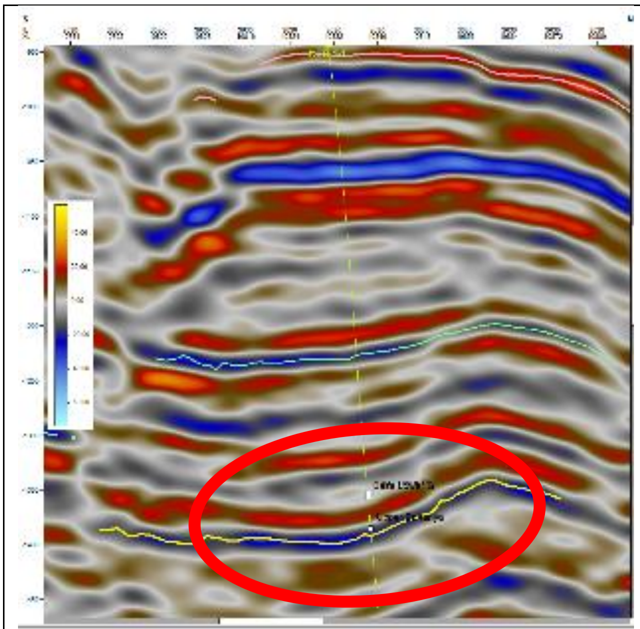
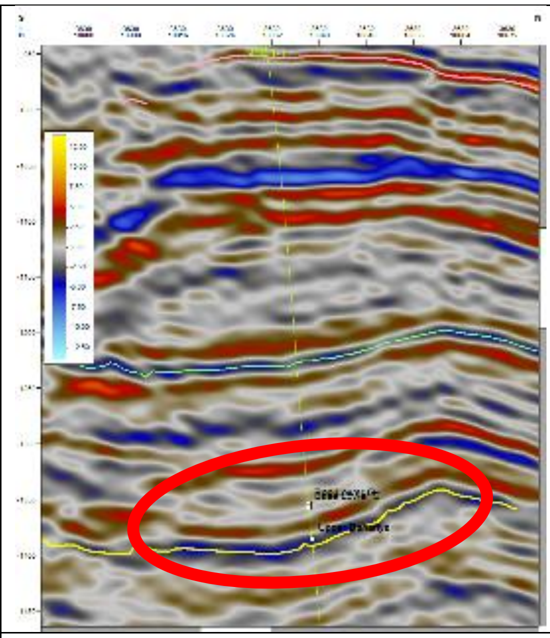
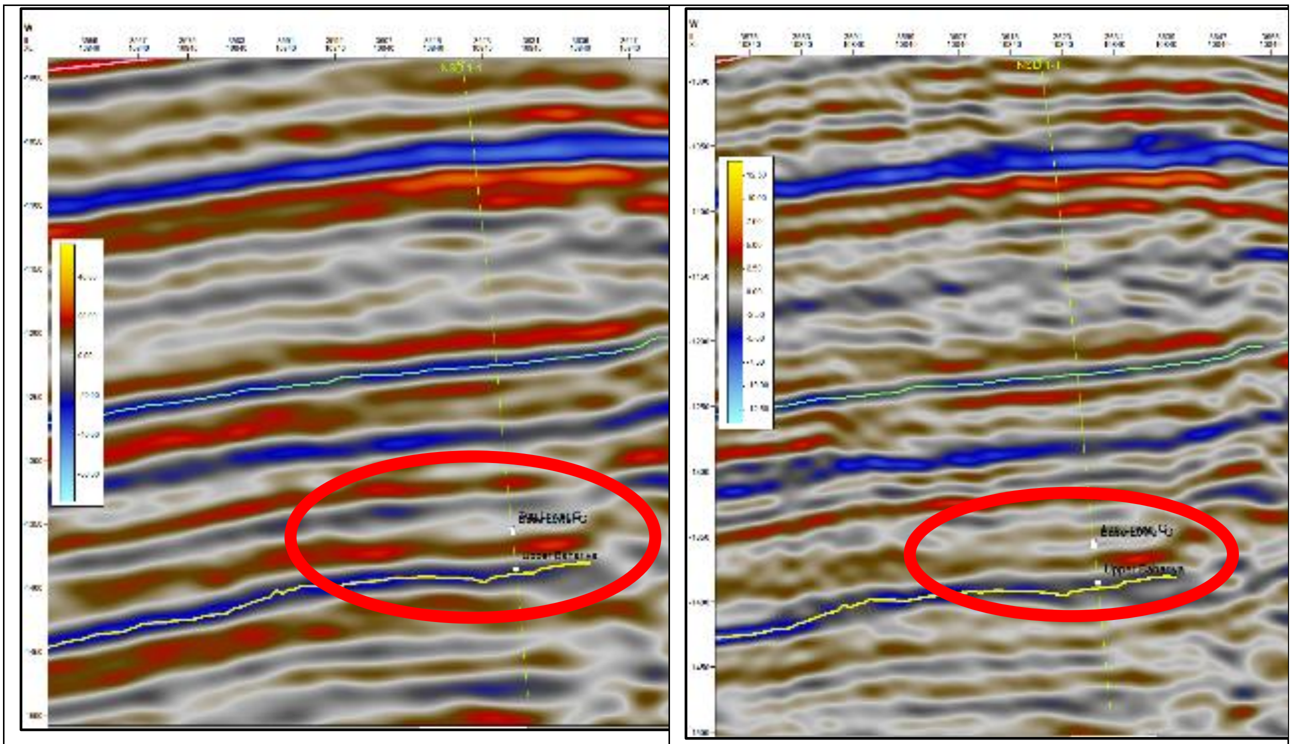
	
(A) Inline 3630 original seismic section.	**(B) Inline 3630 after Spectral Blueing.**

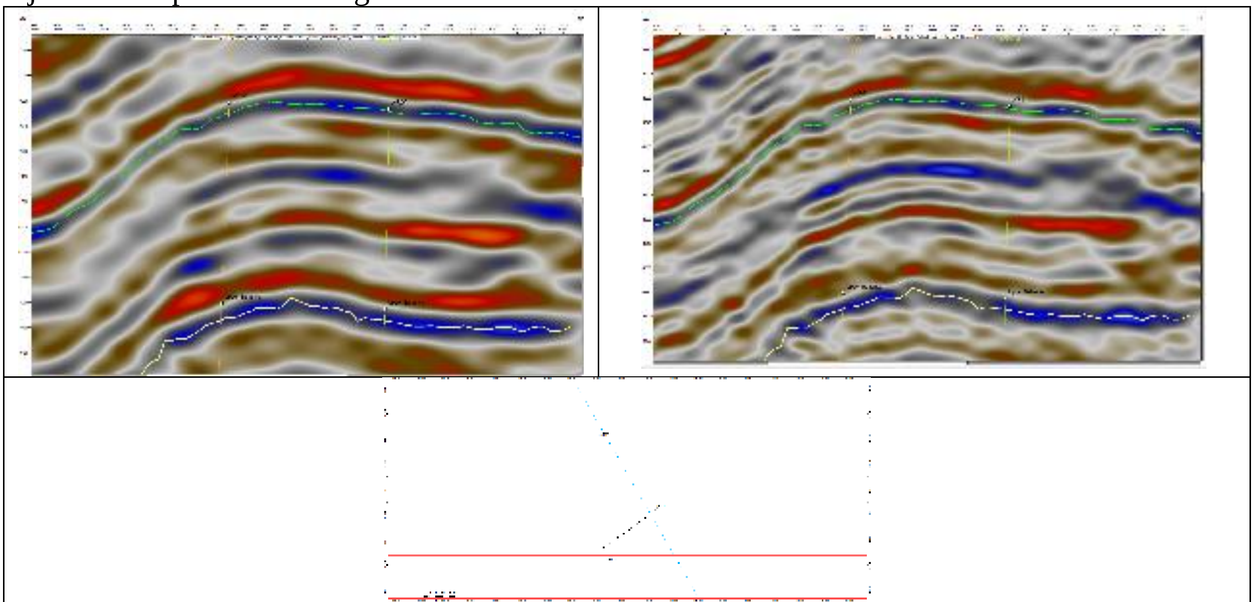
Figure (14): Comparative between the original seismic data and the data subjected to Spectral Blueing.



(A) Crossline 10840 original seismic section. | **(B) Crossline 10840 after Spectral Blueing.**

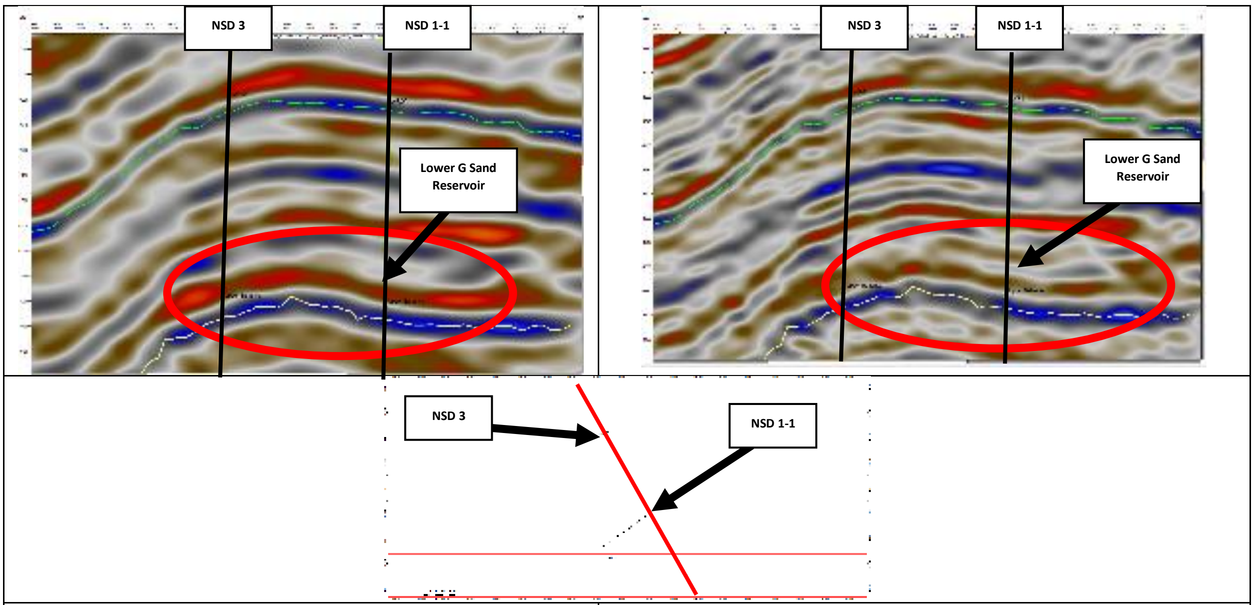
Figure (15): Comparative between the original seismic data and the data subjected to Spectral Blueing.

Figure 16 depicts an arbitrary NW-SE seismic section that intersects the targets of NSD-1.1 and NSD-3X deviated wells. It is noted that, the reservoir of the lower Abu Roash "G" is absent in NSD-3X from the well data. The Figure provides a comparison between the original seismic data and the data subjected to spectral blueing. The enhanced higher frequency content resulting from spectral blueing has aided in delineating the sand extension. In contrast, the sand response of the lower Abu Roash "G" reservoir highlighted with red circle, which is not discernible in the original seismic data, it becomes more visible in the spectral blueing data.



(A) Arbitrary original seismic section. | **(B) Arbitrary after Spectral Blueing.**

Figure (16): NW-SE arbitrary seismic section that intersects the targets of NSD-1.1 and NSD-3X.



(A) Arbitrary original seismic section. **(B) Arbitrary after Spectral Blueing.**

Figure (16): NW-SE arbitrary seismic section that intersects the targets of NSD-1.1 and NSD-3X.

Summary and Conclusions

This research introduces spectral blueing as a method to enhance seismic resolution, focusing on its application to the seismic data of the study area. Spectral blueing is a technique that amplifies high frequencies in seismic data incorporating the frequency adjustments derived from the well information, improving vertical resolution and aiding in the identification of geological features. The methodology involves generating reflectivity series, computing operator amplitude spectra, and convolving the seismic volume with the spectral blueing operator while preserving seismic phase.

Results from spectral blueing reveal significant improvements in frequency content and amplitude distribution, particularly enhancing the representation of small-scale features and thin layers within the seismic data. Figures and comparisons demonstrate the efficacy of spectral blueing in delineating the lower Abu Roash "G" sand reservoir and enhancing overall seismic interpretation. The study concludes that spectral blueing is a valuable tool for enhancing seismic resolution and improving understanding of subsurface geological features, particularly in complex reservoir environments like the Abu Roash "G" sand reservoir in the North Silah Deep Oil Field.

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