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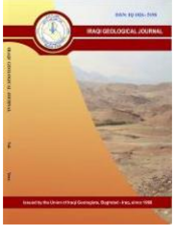

Integrated Seismic Attributes as a Tool to Delineate the Oligocene Channels Architecture, Baltim Field, Offshore Central Nile Delta, Egypt

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Abstract

The hydrocarbons in the Nile Delta area are produced from both clastic and non-clastic reservoirs, with ages ranging from the Early Cretaceous to the Plio-Pleistocene. The study area is situated in Baltim field offshore, Central Nile Delta, approximately 10 kilometers off the Egyptian coast (Fig. 1). The main producing reservoir in Baltim field is Abu Madi Formation (Miocene age) as there were many discoveries in the last decades resulting in most of the area had been considered as a brown field. Nowadays, the Oligocene section is considered as the hope for new hydrocarbon potentiality in the deep section (below Miocene). Among the drilled sedimentary sequence in the Nile Delta, Tineh Formation (Oligocene age) contains multiple levels of reservoir rocks with high-quality reservoirs including: Satis-1, Satis-3, Notus-1, Tineh-1, Atoll-1 & Salamat-1 (Fig. 2). This work's objective is to delineate the different channels of the Oligocene section in trial to add more reserves to the field. One of the main challenges for the exploration of these deep reservoirs is to delineate the reservoir geometry itself. A strong tool for improving bed thickness imaging and mapping, geologic discontinuities and channel delineation is the spectral decomposition technique providing more details than the conventional amplitude extractions. So, in this work, we applied the spectral decomposition tool to track the geometric dimensions of the Oligocene channels. RGB color blending performed from 10, 16, and 20 Hz represents the most significant geological features to get a better picture of the channel's geometry. After determining the channel's boundary by using the RGB blending, the channel geo-body was extracted. This technique helps in reducing the uncertainties of hydrocarbon exploration. Consequently to the integration between RMS amplitude maps and the channel geo-body that was extracted from the spectral decomposition, Oligocene channels became clearer and the boundaries well defined.

Keywords: Nile Delta; Spectral decomposition; RGB blending; Egypt

1. Introduction

Although channelized hydrocarbon-bearing reservoirs and subsurface structures can be imaged and delineated using standard seismic characteristics, it's not the best approach for defining accurate geometry (Court, 2009; Inyang, 2009; Veeken, 2007). The integration between the normal seismic amplitude and the variety of other seismic attributes give us a powerful tool for the geophysical and

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geological modeling. Among these attributes instantaneous phase and acoustic impedance to identify structural and stratigraphic patterns which used to reveal hydrocarbon

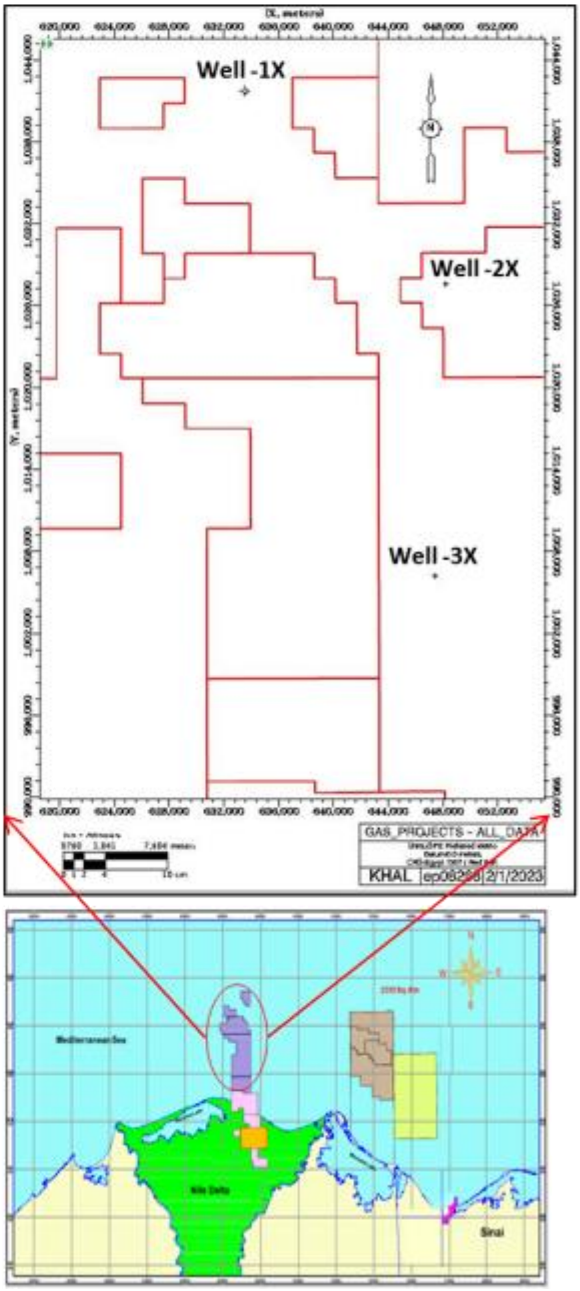

Fig.1. Location Map of the Study Area (Matresu et al., 2013)

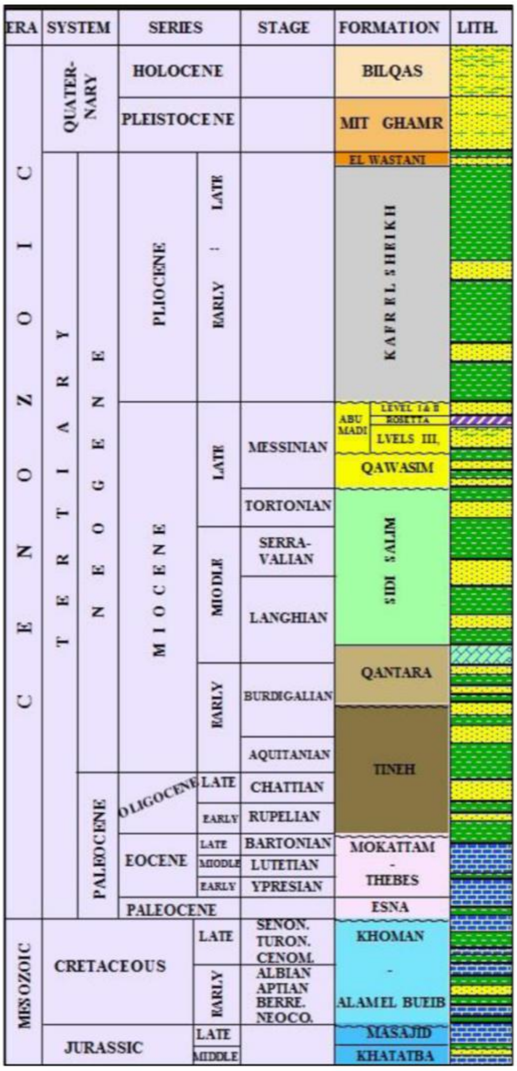

Fig.2. Regional Stratigraphy Column for Nile Delta

accumulation indications such as mound configurations, flat spots denoting hydrocarbon-water contact, and lateral facies variations, suggesting a clastic depositional system with potential organic compound accumulation zones (Ali et al., 2020), also cylindrical shaped chaotic behavior of seismic signal to recognize gas chimney which is a common feature in north of Baltim field. Gas chimney caused by gas scattering through cap rocks. These chimneys originate from hydraulic fracturing due to gas leakage from deep accumulations, resulting in overpressure conditions during Plio-Pleistocene deposition (Helal et al., 2015). In this paper we concentrate on the application of one of the most important seismic attributes which is spectral decomposition, so the objective of this work is to integrate between the normal seismic amplitude and spectral decomposition attributes to delineate the different channels of the Oligocene section in trial to add more reserves to Baltim field. Spectral decomposition is a useful tool for visualizing and mapping geologic discontinuities and temporal bed thickness (Treitel and Lines, 2001; Pendrel, 2006). Spectral decomposition can be used to identify facies and stratigraphic sequences such as floodplain boundaries, reef boundaries, channel sands, valley-fill sands, and thin beds. It can also help with complex faulting and reservoir modelling in some cases. Spectral decomposition transforms seismic data into the frequency domain by computing and applying a Gaussian tapered window centered at a time instance then computing the frequency spectrum by Fourier transformation. The length of the calculation window is important. A large window provides good frequency resolution. Better frequency resolution enhances frequency characteristics of a signal at a given instance. Combining or animating a selected series of spectral decomposition images yields an unprecedented understanding of stratigraphic facies boundaries, structural and stratigraphic depositional controls, and reservoir geometries. Red Green Blue blending of multi-frequency images is the most effective way to render the wealth of available information. One of the most significant mathematical techniques for converting the time domain into its frequency components is the Discrete Fourier Transform (DFT). This process yields a range of discrete frequency cubes that the interpreter can use to identify the amplitude and phase tuned to particular wavelengths.

2. Geological Setting

The Nile Delta Province is rapidly emerging as a major gas province, with significant yet-to-be-discovered estimates (Kirschbaum et al., 2010). Four major sub-areas comprise the greater Nile Delta area: (1) the southernmost portion, known as South Delta Block; (2) the northeastern basin which represent the most part of the current Nile Delta and is the main hydrocarbon producing; (3) the Nile Cone, known as the deep-water area comprising thick sediments of Plio-Pliestocene; and (4) the relatively stable Levant Platform, which is composed of thinner, deep-water pro-delta sediments. The north Delta basin comprises the eastern, central, and western sub-basins. Hemdan and Jonathan (2008) argued that the depositional history of the Nile Delta basin has been influenced by multiple tectonic events, which, together with eustatic variations, controlled sediment supply to the basin and accommodation space. During the Jurassic to Early Cretaceous the Tethyan rift margin was transpressionally inverted (Ayyad, 1996). This event consisted of intermittent uplift phases, which culminated in the late Eocene. Many of the pre-Messinian structure in the Nile Delta are related to the deformation caused by this event. During the Late Eocene to Oligocene, with the opening of the Gulf of Suez, Egypt was tectonically tilted northwards towards the Mediterranean (Hemdan and Jonathan, 2008). Oligocene to Early Miocene sediments are well developed north of an E-W trending hinge line where major subsidence occurred. Abdel Aal (2000) argued that the structural pattern of the area is the result of a complex interplay between three main fault trends; see Fig. 3, namely; The NW-SE oriented Misfaq-Bardawil (Temsah) fault trend, the NE-SW oriented Qattara-Eratosthenes (Rosetta) fault trend and the E-W faults delineating the Messinian salt basin. Most of the fault movement appears to be Late Cretaceous in age. This is indicated by the onlap of source rock prone Late Cretaceous and Early Tertiary deep water sediments. By the Late Miocene, the structural relief was covered by basinal sediments. While in the Temsah trend a Pliocene wrench fault activity is evident. This movement is contemporaneous with oblique sub-duction. Baltim Field is situated within the Central Sub-basin, which is bounded to the NW and NE by the Rosetta and Barduwil (or Misfaq) fault zones. The dominant structural trend within the Central Sub-basin is NNW-SSE. Baltim Field is situated within the Central Sub-basin, which is bounded to the NW and NE by the Rosetta and Barduwil (or Misfaq) fault zones. The dominant structural trend within the Central Sub-basin is NNW-SSE (Fig.3). Baltim fields were awarded in January 1992 to the partners International Egyptian Oil Company (IEOC) and American Oil Company (AMOCO). Baltim fields are offshore gas and condensate reservoirs located into the northern part of the Abu Madi Paleovalley, located around 15 kilometers off the coast of Egypt in the offshore Nile Delta, where water depth of the Mediterranean Sea varies between 45-60 m. The length of Baltim fields is about 40 km and its width is about 12 km. The field had an original acreage of 552 km^2.

Oligocene section consists of turbidity channel fill sandstone units. Numerous reservoir sandstone units were created as deltas as a result of erosion from the topographically high regions to the south and the emerging portions of the Gulf of Suez. The deep, mainly unexplored play, for these deltaic reservoirs and the corresponding deep-water fans represent spans a substantial portion of the Mediterranean Sea even the Nile Delta. Oligocene to lower Miocene shale of the Qantara Formation also contains some fair to good source potential (Dolson et al., 2001). Siliciclastic sediments of Tineh Formation are belonging to the middle and late Oligocene time, while marly facies of Dabaa Formation represents the Early Oligocene age.

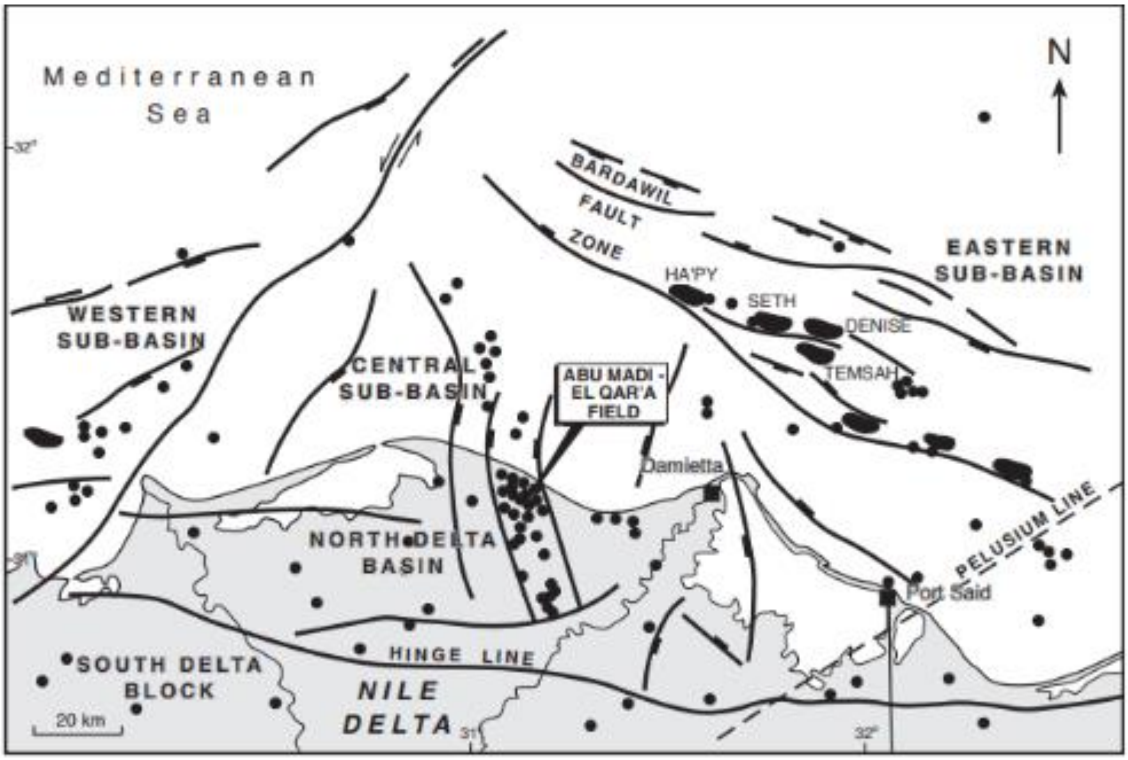

Fig.3. Structure of the Nile Delta at the Top of the Lower Miocene (Kamel et al., 1998)

3. Methodology

Spectral decomposition is a powerful seismic data analysis technique that reveals the frequency content of seismic signals, aiding in the identification and delineation of geological features often missed in conventional amplitude data. There are several spectral decomposition techniques, which can generally be classified into three main categories: Discrete Fourier Transform (DFT), Continuous Wavelet Transform (CWT) and Matching Pursuit Decomposition Transform (MPDT). Each one offer unique advantages and limitations in terms of time-frequency resolution and computational complexity (Rojas, 2008). These techniques enhance seismic interpretation by improving thin bed resolution, identifying stratigraphic features, detecting direct hydrocarbon indicators, and characterizing reservoirs through frequency-dependent responses (Chopra and Marfurt, 2007). The spectral components exhibit the effects of the geology with different channel thicknesses and infill exhibiting different spectral responses (Del Moro, 2012). A particular frequency band has tuning effects that make some structures more noticeable. This attribute is highly beneficial for addressing the issue of thin-bed sand layers. Generally, higher frequency components tend to better represent thinner beds, whereas lower frequency components are more effective for depicting thicker beds (Fig. 4).

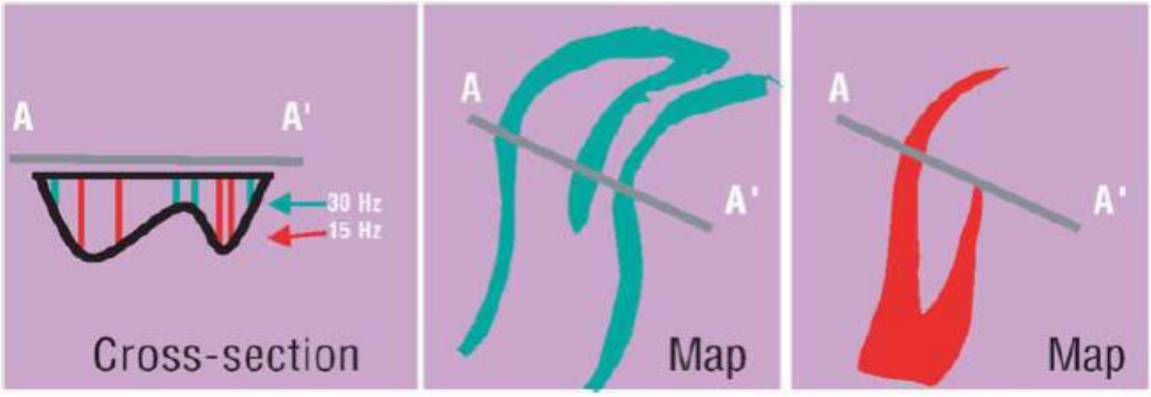

Fig. 4. The effect of thin bed tuning in different frequencies (Laughlin et al., 2002)

The Discrete Fourier Transform (DFT) method of spectral decomposition described in this study is based on a phase-independent, qualitative and quantitative method of spectral decomposition, (Partyka, 1999). In the frequency domain, seismic reflections, exhibit distinctive characteristics. These characteristics on the amplitude spectrum's map view were derived from the tuning volume. The first stage involves translating amplitude or phase data into the frequency domain in order to identify the window of interest surrounding a particularly smooth seismic horizon. Using Discrete Fourier Transform (DFT), in other words, a new volume of frequency in the z-direction is created; a typical volume would contain 100 slices that indicate amplitude or phase at 1-100 Hz. “Tuning cube" is the name given to such a volume. The outcomes from this volume offer a rich snapshot of subtle reservoir properties (Fig. 5). Baltim field was covered by 3D seismic survey acquired in 2005, covering an area about 552 square kilometers with bin size (12.5x25) m. The Oligocene reservoirs were classified into 6 reservoir units starting from Oligocene 1 to Oligocene 6, time horizons of these units were interpreted, this work will focus on the first channel or reservoir unit Oligocene-1 because this is the clearest channel or reservoir unit. Traditional seismic data analysis was done using Decision Space Geo-science (DSG) Landmark software, showing that the Oligocene section frequency ranging from 0 to 120 Hz (Fig. 6a). Notably, the Oligocene-1 channel predominant frequency observed in the seismic data ranged from 5 to 20 Hz (Fig. 6b).

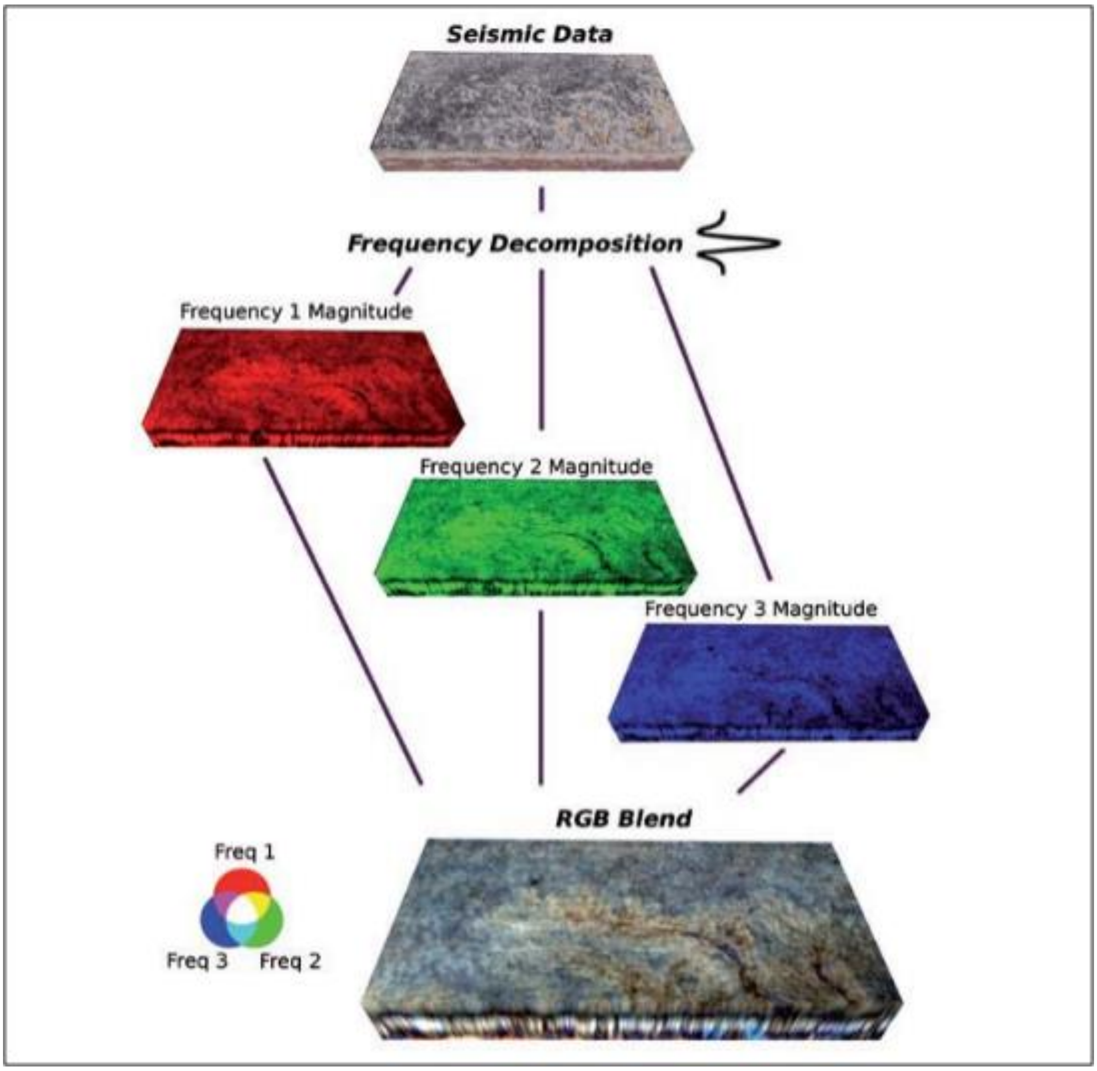

Fig. 5. Simplified Workflow of Spectral Decomposition (McArdle et al., 2012)

From the amplitude spectrum, the seismic cube can be decomposed into various frequency cubes. This process allows for the creation of multiple cubes, each containing distinct frequency content and by displaying the frequency slices included within the Oligocene-1 channel, we can notice the lateral variations in spectrum peaks across channel which related mainly to the thickness of the channel (Fig. 7). By analyzing the full bandwidth amplitude of Oligocene-1, the initial channel appears well-defined from an architectural perspective. However, a discontinuity is evident in the middle section, taking the form of a dim area within the channel. This feature is attributed to late-stage mud-filled channels that obscure seismic amplitudes. These low-quality facies or small faults, which fall below seismic resolution, might partition the channel into two compartments. The channel fairway was difficult to be defined from the normal time amplitude due to the branching in the northern portion of the channel (Fig. 8 a). After the determination of the dominant frequencies, three primary frequency cubes are selected and visualized using Red, Green, and Blue (RGB) color blending where each color represents a certain frequency range tailored to the desired thickness interval for visualization. In this approach

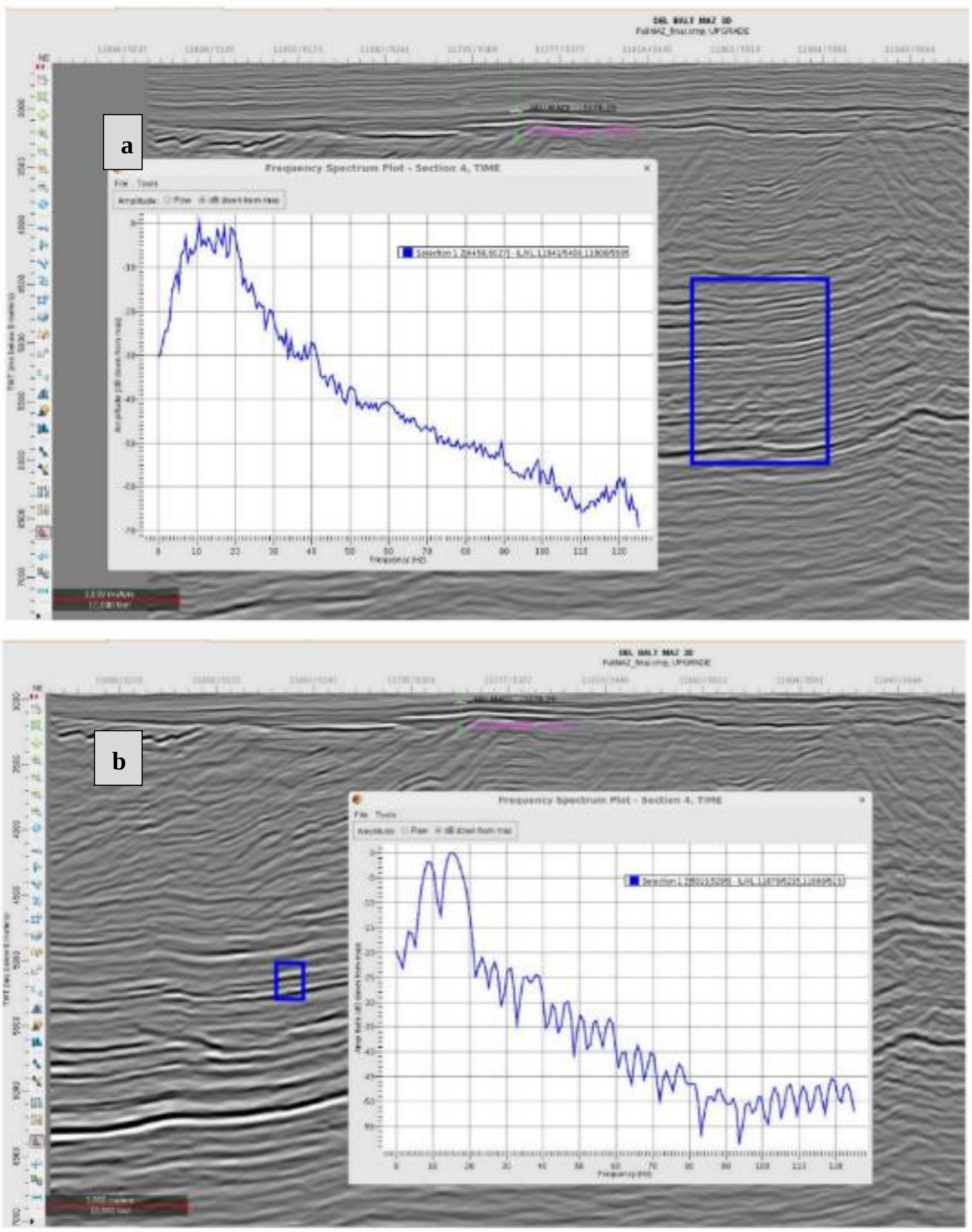

Fig. 6. (a) Amplitude Spectrum for the Full Stack Seismic Data within the Interval 4500–6000 ms Including Almost all the Oligocene Section (b) Amplitude Spectrum for the Full Stack Seismic Data within the Interval 5000–5300 ms Including the First Reservoir Oligocene-1

approach, the lowest frequency is matched with the thickest part of the channel, while the highest frequency corresponds to the thinnest part. The seismic dataset is characterized by three distinct frequency ranges as the minimum frequency of 10 Hz is denoted by the color red, while the predominant frequency of 16 Hz is represented by green. Finally, the dataset's highest frequency range, 20 Hz, is indicated by the color blue (Fig. 8 b). Using also DSG Landmark software and by utilizing diverse opacity settings for different amplitudes, the Oligocene-1 sand reservoir unit is extracted as geobodies (Fig. 9, 10 and 11).

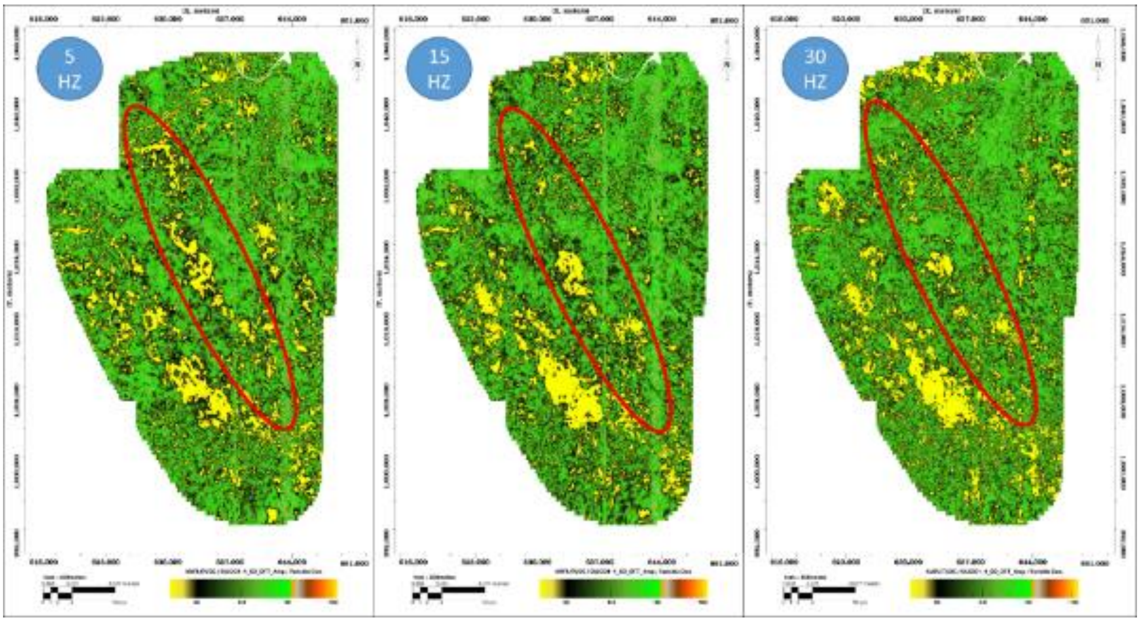

Fig.7. Different Frequency Slices Showing the Lateral Variations of the Oligocene-1 Channel Frequency Which Related Mainly to the Channel Thickness (The More Thickness the less Frequency)

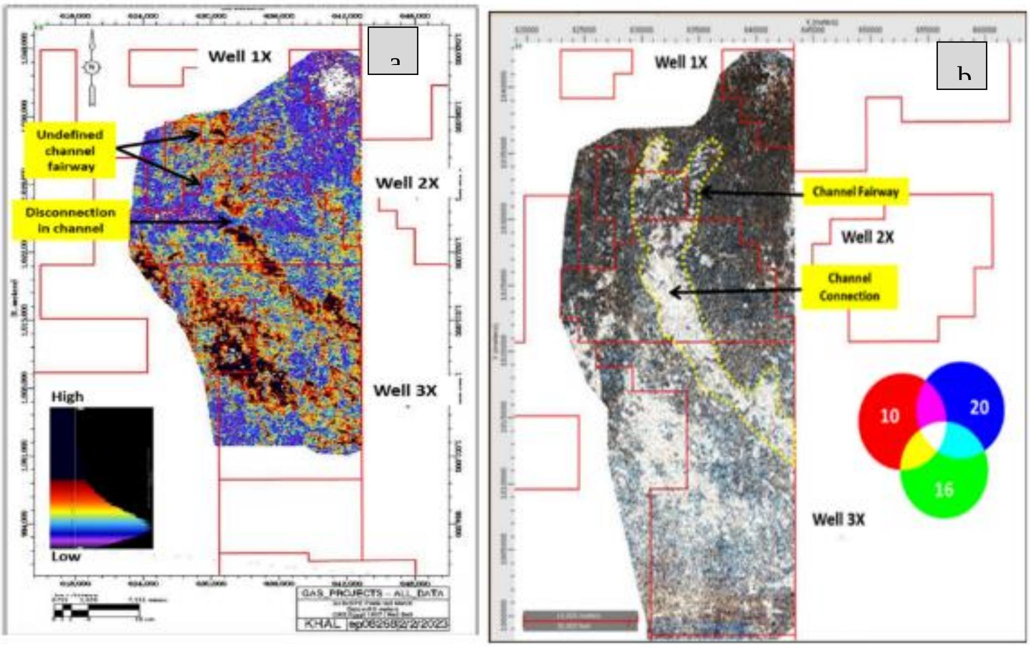

Fig. 8. (a) Top Oligocene-1 Maximum Negative Amplitude Map. (b) Oligocene-1 RGB Color Blended Frequencies Map

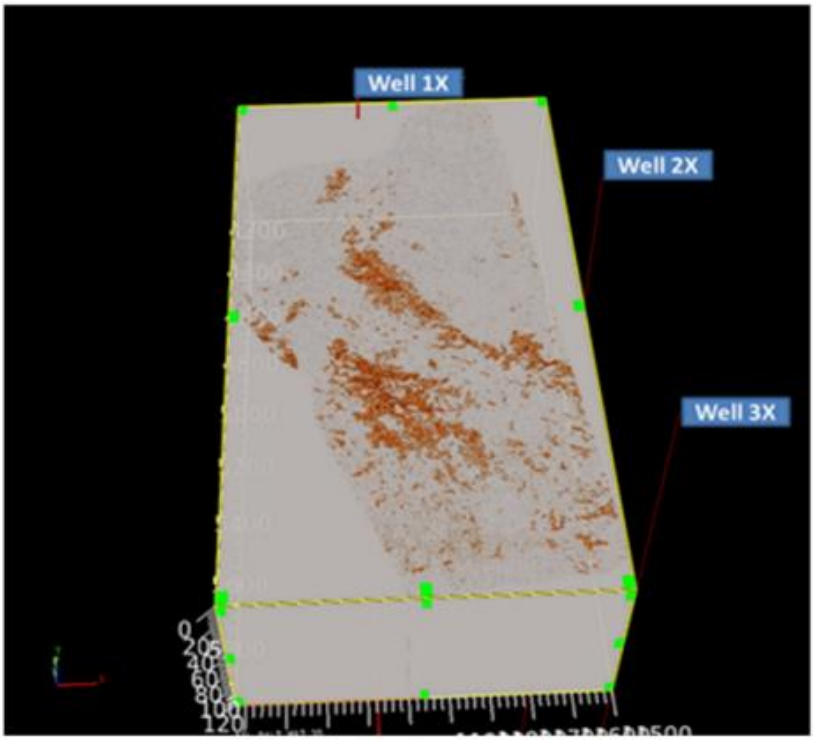

Fig. 9. Isolation of the Channel Body by Rendering

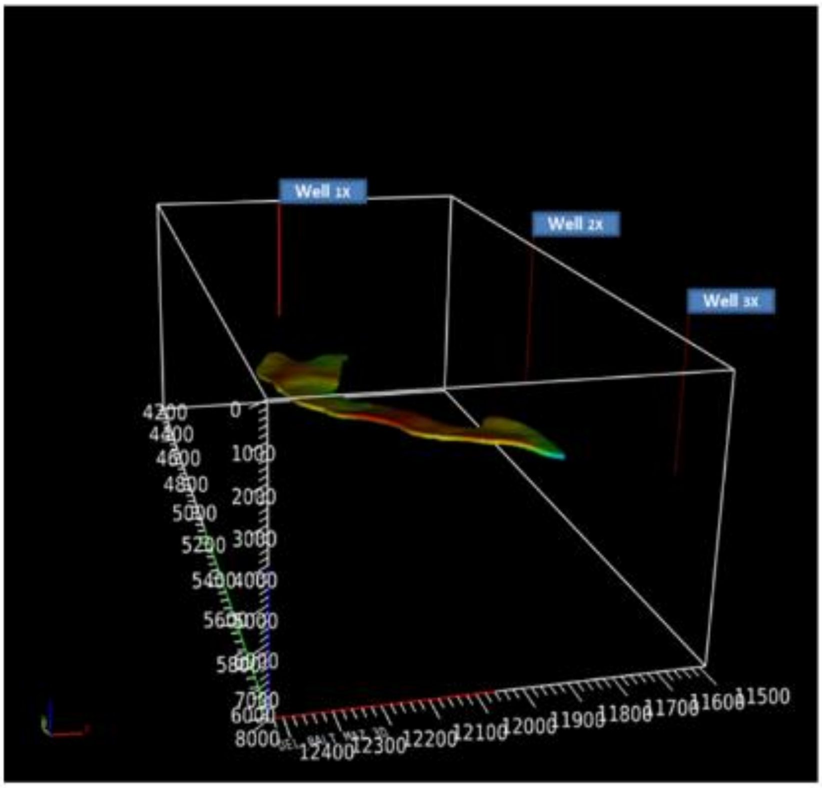

Fig.10. N-S 3D View of the Channel Body

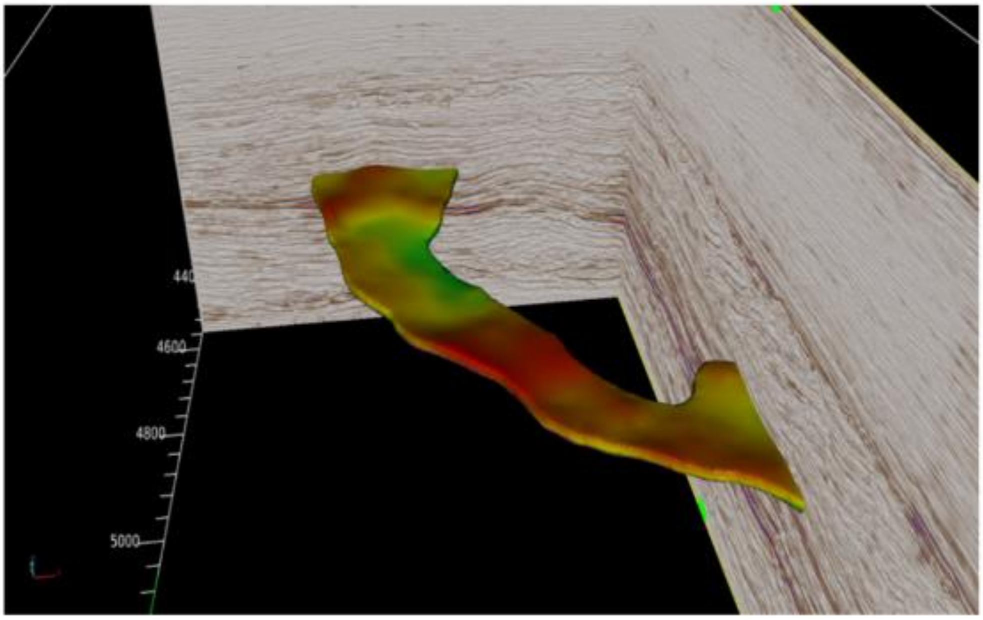

Fig. 11. 3D View of the Channel Body Intersecting Inline and Crossline Seismic Data

4. Results and Discussion

In Egypt, Oligocene section is characterized by steeply dipping strata and complex structural features, particularly in regions such as the Gulf of Suez and the Nile Delta. These complexities are due to tectonic activities, including extensional forces and faulting associated with the Red Sea rifting. The Pre-Stack Time Migration (PSTM) is effective in imaging these steeply dipping and intricate structures, but due to the unavailability of such data, other seismic attributes like spectral decomposition also play a crucial role. Spectral decomposition, which focuses on the frequency content of seismic waves rather than their phase, enhances the identification and delineation of geological features that might not be visible in conventional seismic amplitude data. This technique is particularly useful in resolving thin beds, identifying stratigraphic features and detecting direct hydrocarbon indicators in complex geological settings.

Upon integrating the outcomes of spectral decomposition with the time amplitude map, the disjointed segments of the channel in the time amplitude map became more distinct and interconnected in the RGB map. This phenomenon suggests that the observed discontinuity results from channel thinning in this specific region, which remains unresolved in the seismic data due to limitations in seismic resolution. Also from the RGB map we can note that the northern segment of the channel exhibits greater clarity compared to its appearance in the time amplitude map. This discrepancy likely arises from unfavorable facies conditions inside this particular section of the channel. Notably, the prevalence of white color across most of the channel signifies the coexistence of all frequency ranges and relates to the thickest portions of the channel. Finally, using the extracted channel geo-body can serve in the hydrocarbons volume calculation, risk assessment and also for the 3D static reservoir model construction which lead to best location for the deep targets prospects.

5. Conclusions

Integration of several seismic attributes is regarded as an effective method for defining sand reservoirs. One of them, spectral decomposition (SD), provides a more precise definition for identifying stratigraphic architecture and structural elements. In cases involving gas and water-bearing channel complexes, where conventional time amplitude data struggles to determine channel geometry and connectivity, spectral decomposition proves valuable for identifying and delineating channel fairways boundaries. Geologic features can be precisely defined if they are extracted as a geo-body helping in the 3D reservoir modeling.

Recommendation

It is recommended to integrate the outcomes and results from this study with the AVO and inversion modeling to estimate lithology and fluid saturation.

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