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Integrated seismic tools to delineate Pliocene gas-charged geobody, offshore west Nile delta, Egypt

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A B S T R A C T

Nile delta province is rapidly emerging as a major gas province; commercial gas accumulations have been proved in shallow Pliocene channels of El-Wastani Formation. Solar gas discovery is one of the Turbidities Slope channels within the shallow Pliocene level that was proved by Solar-1 well.

The main challenge of seismic reservoir characterization is to discriminate between Gas sand, Water sand and Shale, and extracting the gas-charged geobody from the seismic data. A detailed study for channel connectivity and lithological discrimination was established to delineate the gas charged geobody.

Seismic data, being non-stationary in nature, have varying frequency content in time. Spectral decomposition of a seismic signal aims to characterize the time-dependent frequency response of subsurface rocks and reservoirs for imaging and mapping of bed thickness and geologic discontinuities. Spectral decomposition unravels the seismic signal into its constituent frequencies.

A crossplot between P-wave Impedance (Ip) and S-wave Impedance (Is) derived from well logs (P-wave velocity, S-wave velocity and density) can be used to discriminate between gas-bearing sand, water-bearing sand, and shale. From Ip vs. Is crossplot, clear separation occurs in the P-impedance so post stack inversion is enough to be applied.

Integration between Inversion results and Ip vs. Is crossplot cutoffs help to generate 3D lithofacies cubes, which is used to extract facies geobodies.

1. Introduction

Although the conventional seismic attributes help in imaging and delineation of subsurface features, channelized hydrocarbon bearing reservoirs within the deltaic depositional systems, but it is still not an optimum tool for detailed geometry description is needed (Court, 2009; Inyang, 2009; Veeken, 2007).

Any complex time series (time domain) could be transformed into its initial frequency components (frequency domain) via Spectral Decomposition analysis which uses several mathematical methods such as Discrete Fast Fourier Transform (DFFT) and Continuous Wavelet Transform (CWT). The disadvantage of CWT is that it's wavelet dependent where a choice of which wavelet to use is considered (Ricker, Morlet or Meyer). The DFFT on the other hand unravels the signal in time domain to its initial frequency contents at the frequency domain. The transformed results include a variety of discrete common frequency cubes which allow the interpreter to see amplitude and phase tuned to specific wavelengths. Spectral decomposition is proven to be a robust approach for seismic interpretation. It is used for mapping temporal bed thickness to indicate stratigraphic traps and to delineate hydrocarbon distribution (Treitel and Lines, 2001; Pendrel, 2006).

Discriminating the lithology and fluid content is the main challenge after delineating the channel architecture using Spectral Decomposition analysis, so seismic-inversion feasibility study should be done. Rock Physics cross plots of well log data could determine the relationship between the desired rock property such as water saturation, clay volume, lithology and elastic property that could be obtained from seismic inversion such as P-

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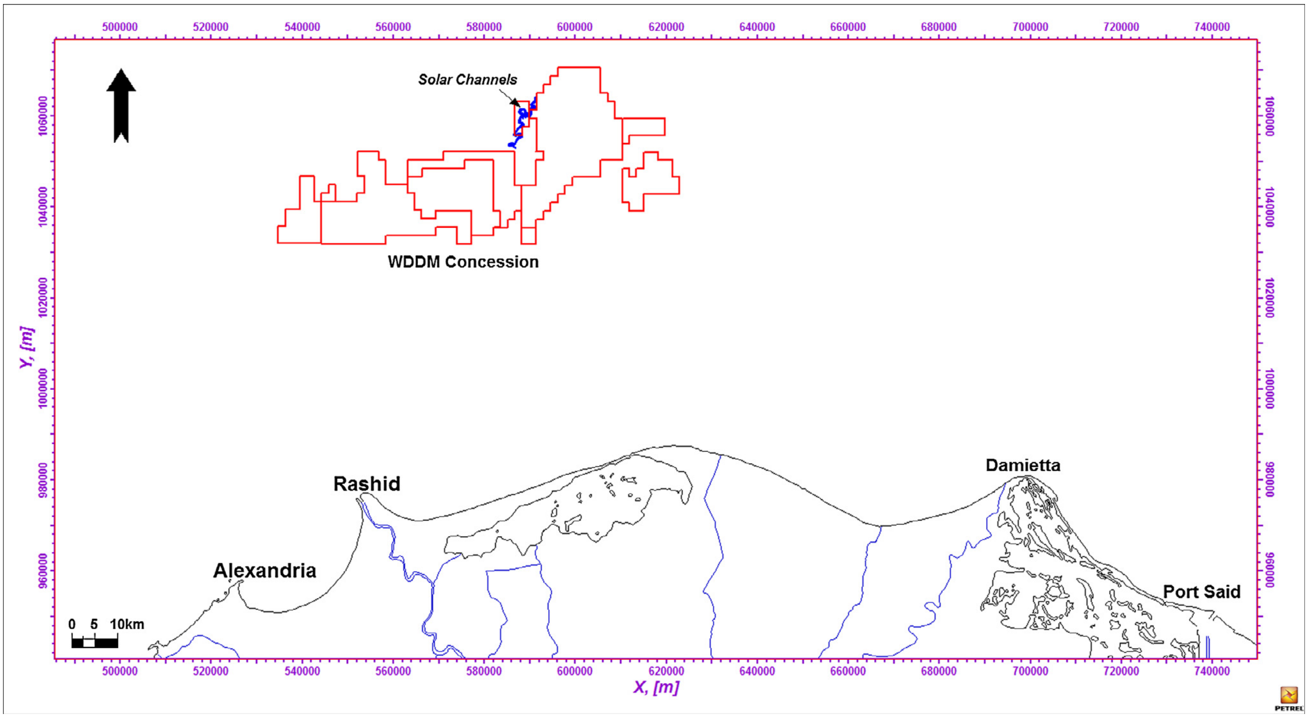

Fig. 1. Location map showing Solar channels (both channels take the same meandering architecture), West Delta Deep Marine (WDDM) concession, offshore West Nile Delta, Egypt.

impedance and S-impedance. If there is a high correlation between elastic and rock property, and the reservoir rock can be discriminating gas sand, water sand and shale; then the seismic inversion is feasible and discrimination could applied on seismic data. Cross plot between P-Impedance (the product of P-wave velocity and Density) with S-Impedance (the product of S-wave velocity and density), could help in lithology separation and pore fluid type identification. If the separation occurs in the P-Impedance, a Post-Stack Inversion is enough to be applied. Though, if the separation occurs in the S-Impedance, a Pre-Stack Inversion should be applied (Russell and Hampson, 1991; Russell, 2005).

The reflections of seismic waves from subsurface layers illuminate potential hydrocarbon accumulations. As waves reflect, their amplitudes change to reveal important information about the underlying materials. Seismic amplitude inversion uses reflection amplitudes, calibrated with well data, to extract details that can be correlated with porosity, lithology, fluid saturation/content and geomechanical parameters. Russell defined seismic inversion as "the process of extracting from the seismic data, the underlying geology which gave rise to that seismic". Inversion results showed high resolution, enhanced the interpretation, and reduced drilling risk (Veeken, 2007; Lindseth, 1979).

In practice, a lot of methods are used to perform post-stack Acoustic Impedance (AI) inversion. It can be subdivided into two main approaches: band-limited (iterative) inversion and broadband inversion, which in its turn includes the model-based inversion, also called deterministic inversion which recovers absolute impedances. Model-based inversion makes use of an initial geologic model, based on the impedance data (derived for example from interpolation of P-wave sonic and density logs), structural information (interpreted seismic horizons to guide the interpolation of the initial model), and a wavelet extracted from well location after correlation with full-angle stack (Russell and Hampson, 1991; Russell, 2005; Treitel and Lines, 2001; Court, 2009).

2. Geologic setting

The Nile Delta province is rapidly emerging as a major gas province, highly prolific, with significant Yet To Find (YTF) estimates (Court, 2009; Harwood et al., 1998; Kirschbaum et al., 2010; Samuel et al., 2002; Steel et al., 2003).

Solar is a Pliocene gas discovery in the West Delta Deep Marine concession (WDDM) located approximately 100 km north off the present day shoreline of Egypt (Fig. 1) in water depths between 800 and 1000 m. WDDM concession is located in the Mediterranean Sea around 110 km NE of Alexandria (Katamish et al., 2005; Steel et al., 2003). Two channels have been identified vertically in Solar discovery (penetrated by Solar-1 well). In this paper, they are named as the Red channel (Upper – Gas bearing) and Yellow channel (Lower – Water bearing). Both channels exhibit a combined stratigraphic/structural trapping style and were deposited in a confined deep marine turbiditic environment (Fig. 2). Laterally both channels are stratigraphically side sealed (pinch out) against the background muds. The overall northwards dipping nature of the channel creates dip closure to the north. To the south, stratigraphic closure is interpreted at the head of the channel. The vertical seal is El Wastani claystone. The well location was optimized to penetrate relatively high amplitude, thick section at the intersection of the two channels. The Red channel is about 10–12 km long, 400–500 m wide and 40 m average gross thickness.

3. Data interpretation

The Solar field is covered by 3D seismic, acquired in 2006 and processed in 2007. No multiple reflections, or even small multiplicative events, were seen on stacked–migrated seismic sections, particularly in the vicinity of the target reservoir zone.

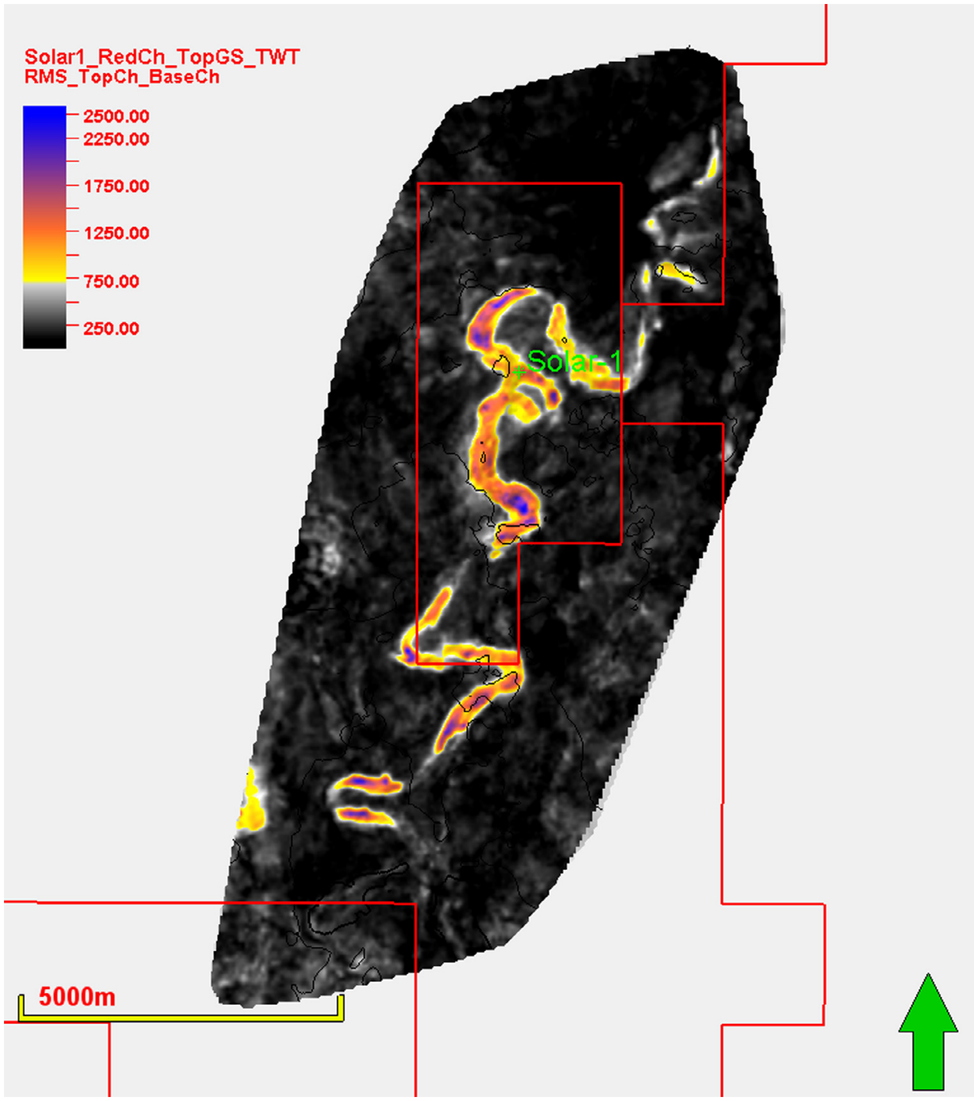

Fig. 2. Root-Mean-Square (RMS) attribute map (between top Red channel to Base Red channel) showing the NE-SW trending Solar Red channel.

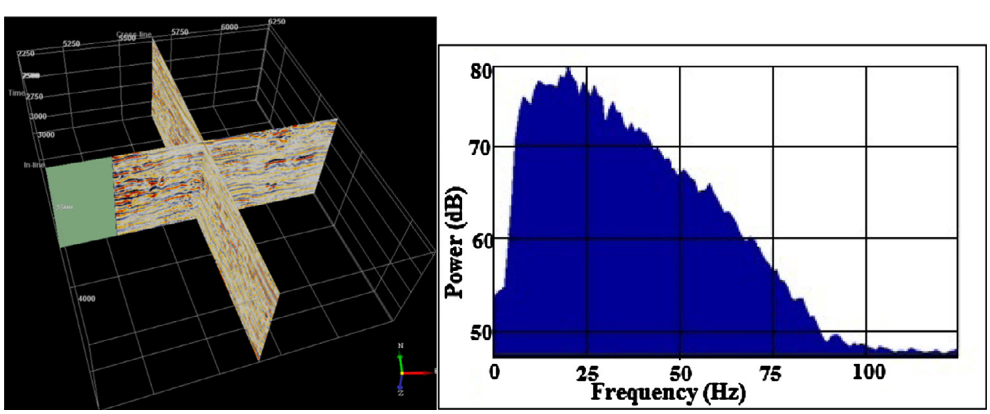

Fig. 3. Seismic inline and crossline at Solar area (left), with its amplitude spectrum for the full stack seismic data within the interval 2200–3000 ms. (right).

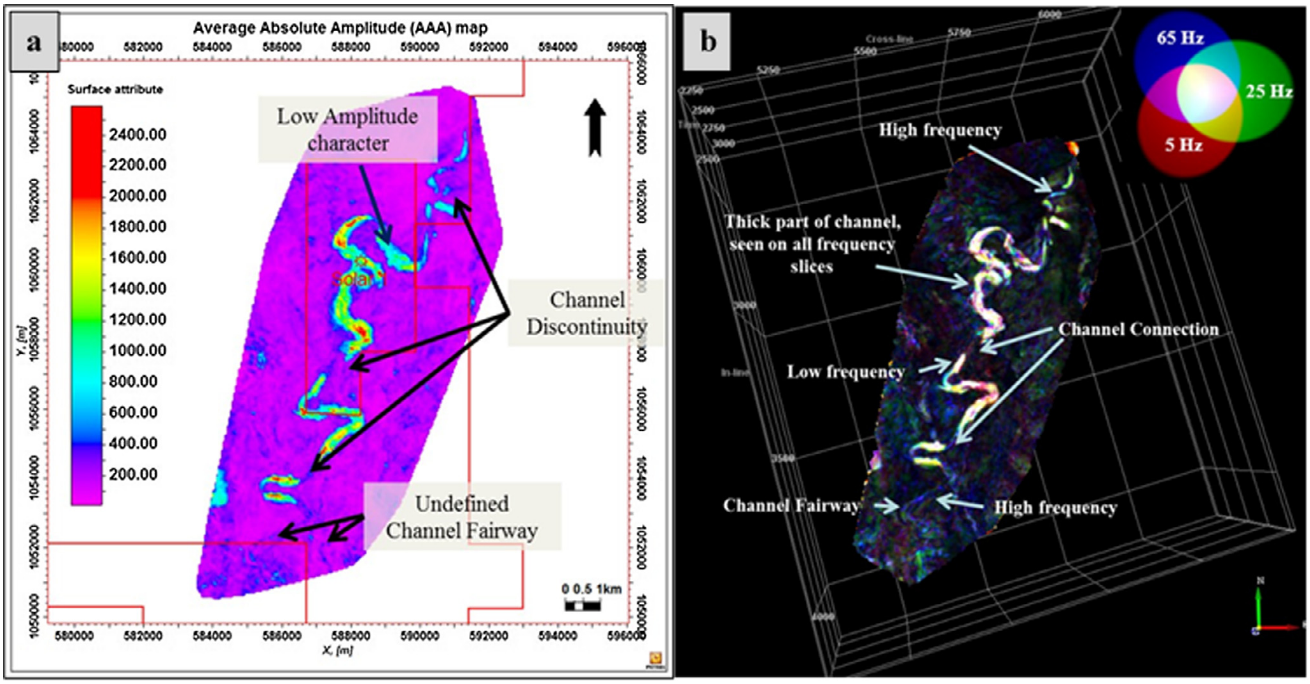

Fig. 4. (a) Average magnitude (AAA) attribute map over the top Solar Red channel shows a low amplitude character in some parts of the channel, discontinuities on the channel fairway, and the poorly defined fairway at the south. (b) RGB Color blended frequencies map over the top Solar Red channel. The map shows the channel connectivity which couldn't appear on the AAA map, the channel fairway is better defined at the southern part.

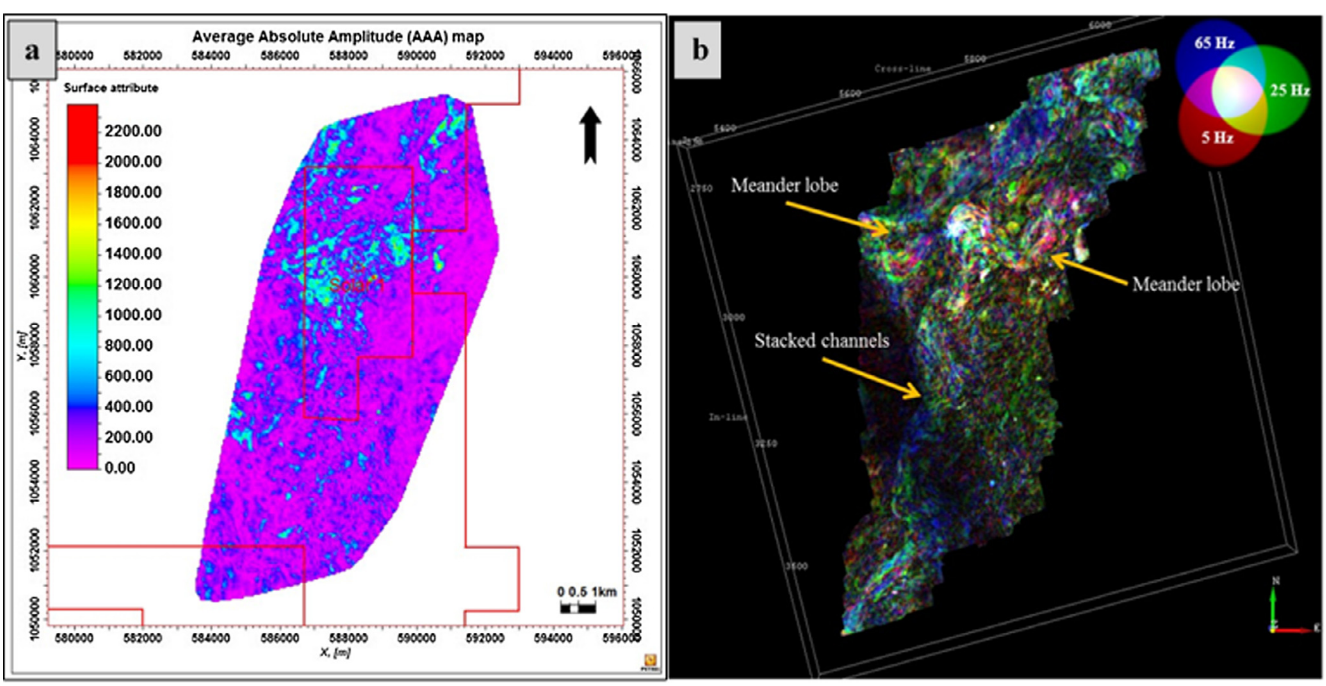

Fig. 5. (a) Average Absolute Amplitude (AAA) map over Top Solar Yellow (water) channel. Notice the poor reservoir architecture/definition. (b) RGB Color blended frequency map over Top Solar Yellow (water) channel. The stacked channels which form the Yellow channel are more obvious.

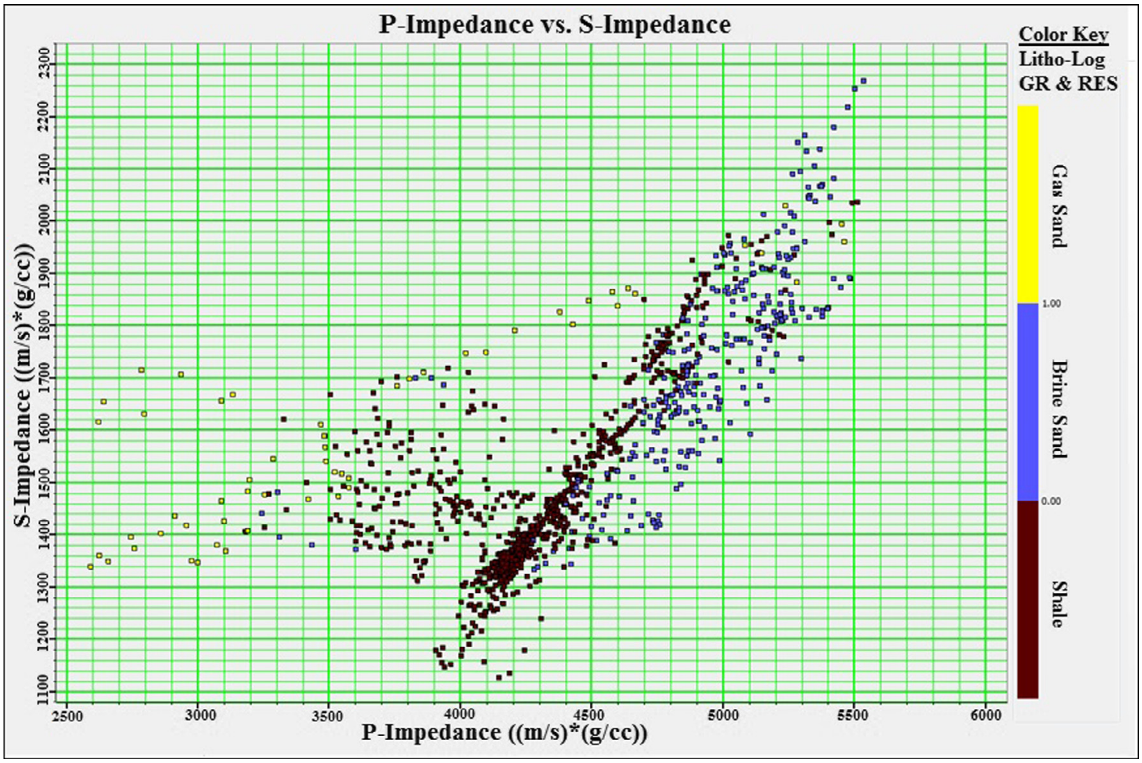

Fig. 6. Cross plot between P-Impedance (X-axis) and S-Impedance (Y-axis), with a lithology log as a color bar (calculated from GR and Resistivity logs). Clear separation between gas sand, brine sand and background shale is obvious.

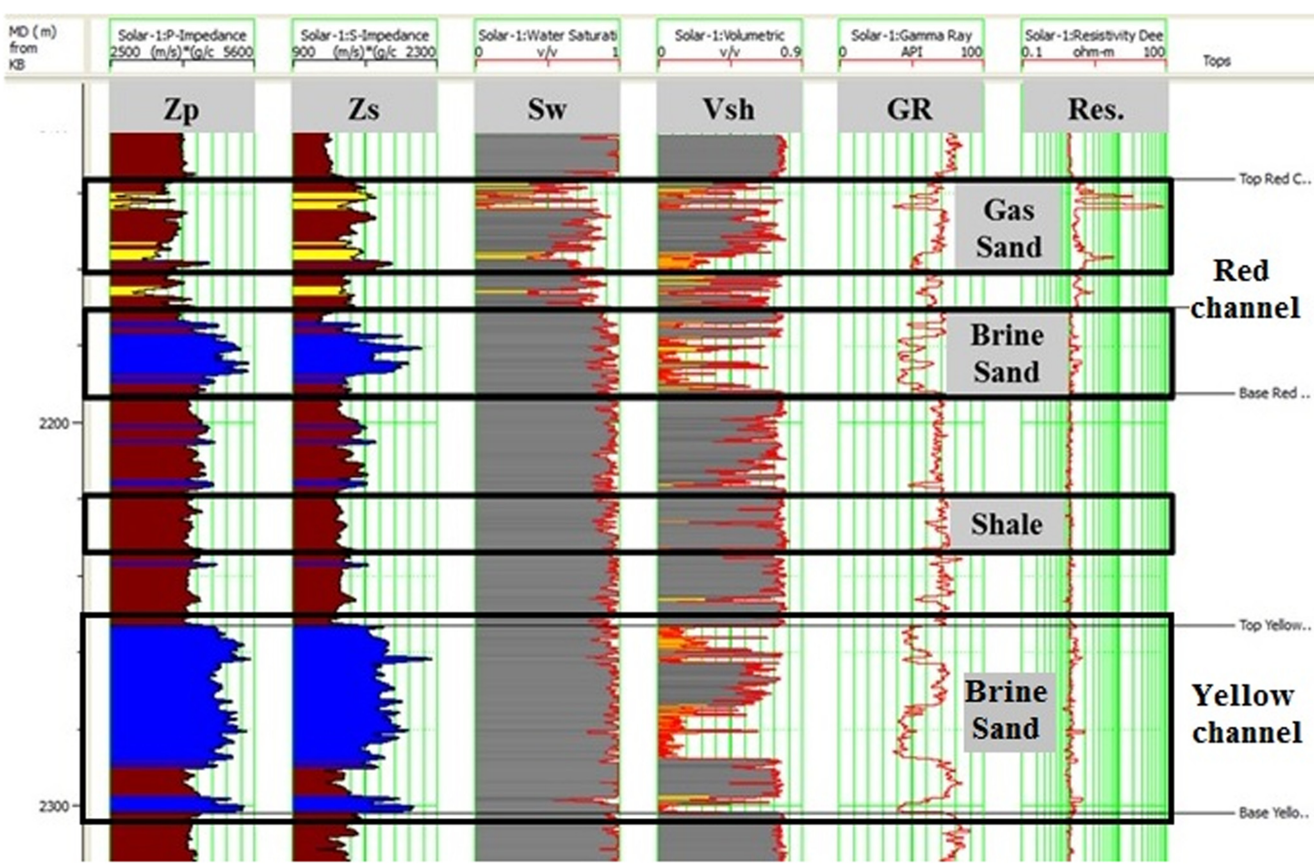

Fig. 7. Log section for P-Impedance vs. S-Impedance and their correlation with water saturation, clay content, gamma ray and resistivity logs. The section shows a good lithology and fluid separation.

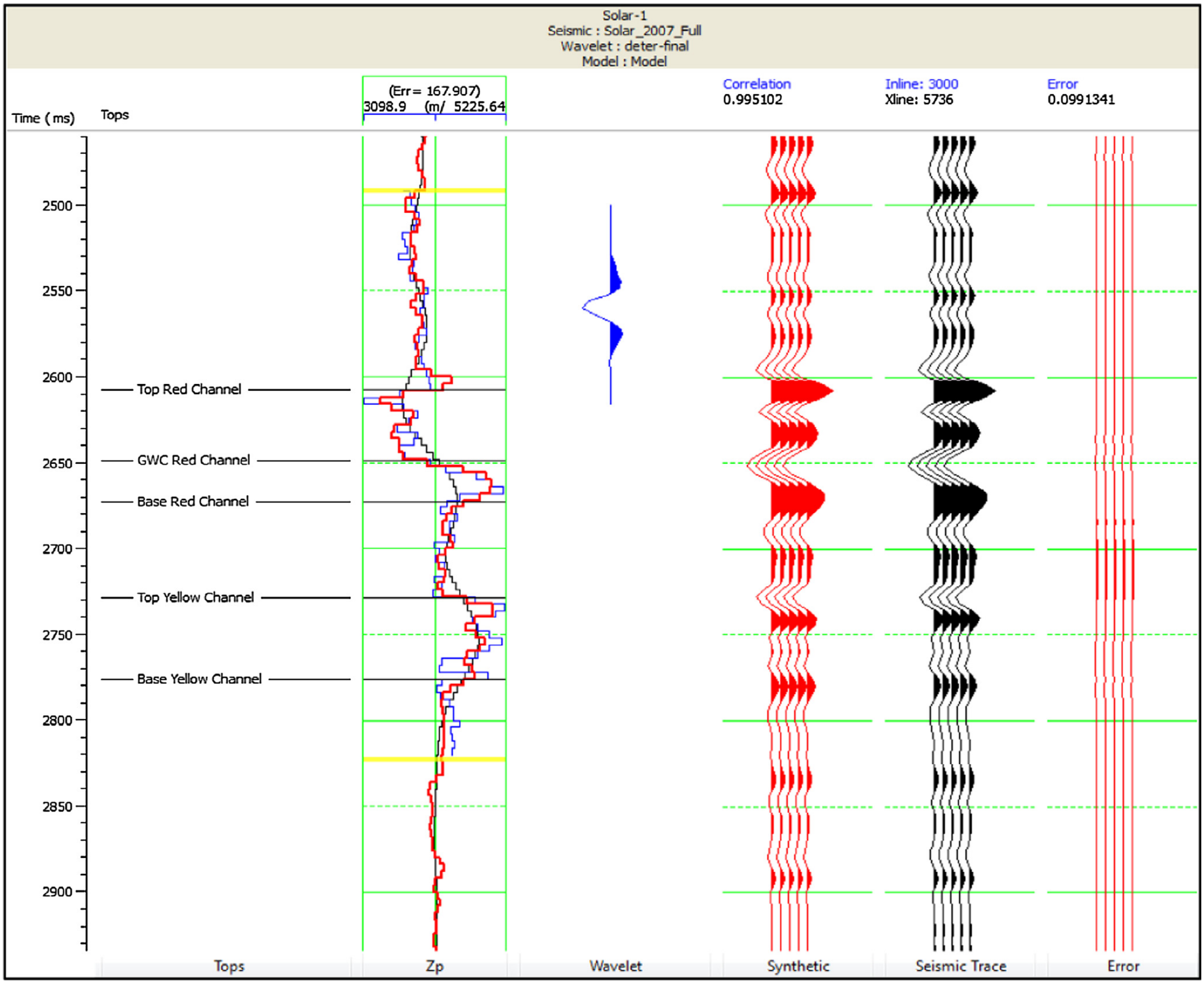

Fig. 8. Inversion analyses at well (right) showing the excellent correlation (0.99) between the synthetic (red) and the seismic trace data (black). On the left, P-impedance inverted logs (red) overlay the original logs (blue).

Data were extensively visualized, colored-contoured (mapped) and conventionally interpreted. Three time horizons, within which the fluid-bearing Red channel exists were interpreted; namely, 'Top Red Ch Gas Sand', 'Base Red Ch Gas Sand' and 'Base Red Channel'.

4. Methodology

Before running the spectral decomposition analysis, the dominant frequency of the seismic data should be measured by analysing the amplitude spectrum of seismic data (approximately 20–25 Hz for the study, Fig. 3). The channel fill tuning frequency may be either greater or less than the overall seismic dominant frequency. Spectral decomposition is run in order to analyze different frequencies of the seismic volume, observes the different bands and examines each band volume. The spectral decomposition workflow focused on processing Discrete Fast Fourier Transform (DFFT) around a very smooth seismic horizon interpretation and transforming the amplitude or phase data into the frequency domain.

From the amplitude spectrum, seismic cube could be unraveled to different frequency bands, and several seismic cubes could be produced each with a specific frequency content, as follow; (5 Hz–15 Hz–25 Hz–35 Hz–34 Hz–55 Hz–65 Hz–75 Hz). Then, Red-Green-Blue (RGB) color blended maps are generated to define the frequency corresponding channel definition; where each color corresponds to a specific frequency range. The three frequency ranges are 5 Hz (adjusted for the lowest frequency range in the seismic dataset) in Red color, 25 Hz (adjusted for the dominant frequency in the seismic dataset) in Green color and 65 Hz (adjusted for the highest frequency range in the seismic dataset) in Blue color. The color blending display helps to optimize the channel thickest and high quality segment(s) of the channel, which appears as the white color (where the three RGB frequencies co-exist) on the display.

A comparison between the full band-width conventional seismic attribute represented by the Average Absolute Amplitude (AAA) map (Fig. 4a) with the frequency band-limited attribute represented by the RGB color-blended map (Fig. 4b) shows that the later helps delineate channel architecture, connectivity and thin

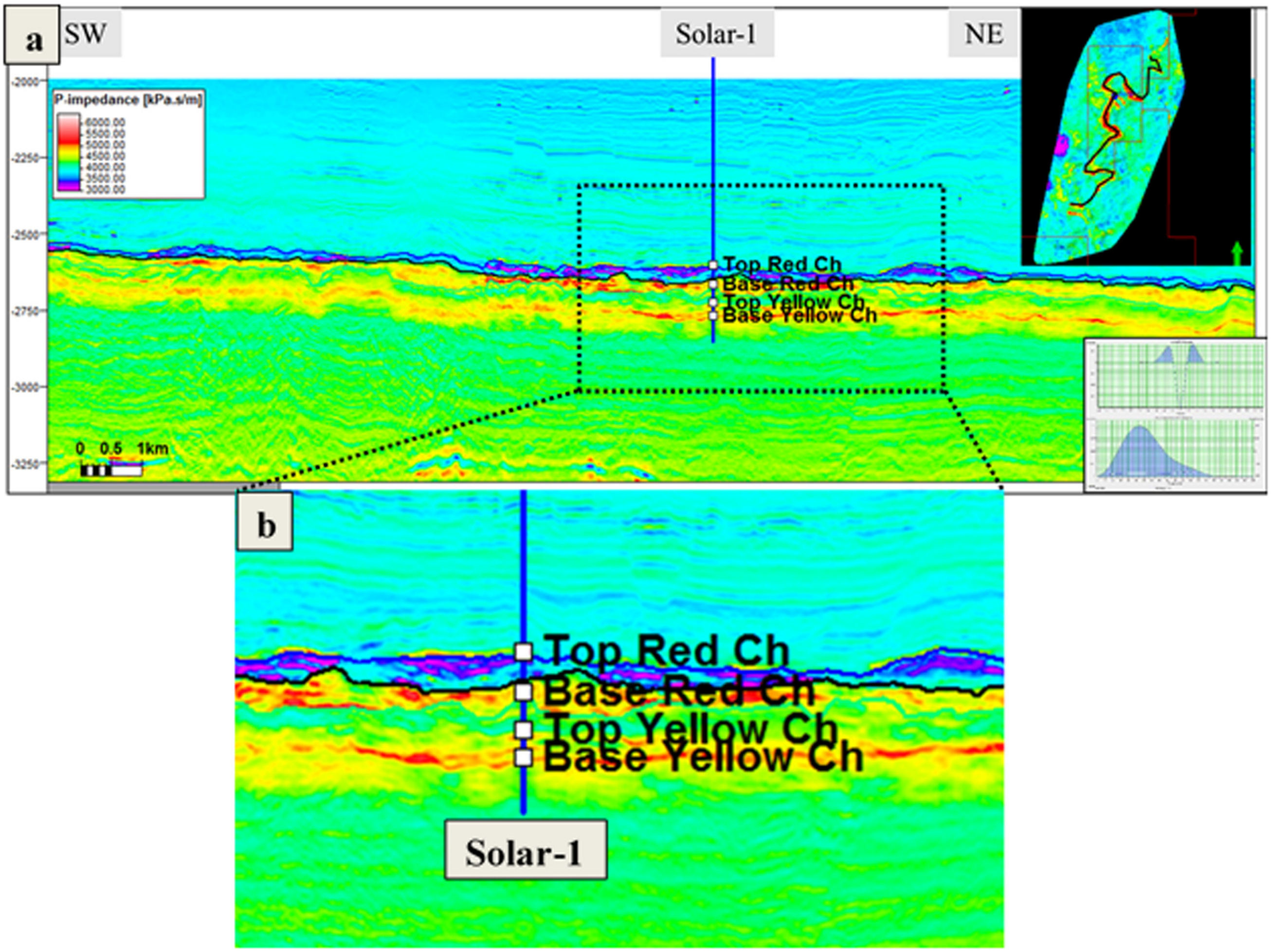

Fig. 9. (a) Cross-section of the Model-Based inversion results along Solar channel. The deterministic wavelet used is shown on the right. The map shows the arbitrary line through the channel. (b) A clear inversion separation appears along Solar-1 well location.

beds definition. The dim parts at the middle of the channel on the AAA map appear to coincide with the low frequency range in the spectral decomposition map (in red color). This means the channel seems to be connected. The southern part of the channel coincides with the high frequency range on the spectral decomposition map (in blue color), which defines the channel fairway. Some parts of the channel appear in white color on the spectral decomposition map, i.e.; all frequency ranges present (the three RGB frequencies co-exist) this corresponds to the thickest parts of the channel.

As spectral decomposition results, represented by the RGB color blended map at Solar Red channel, gave better channel delineation than the conventional attributes (AAA), the same workflow was applied with the aim of investigating features of the lower channel (Yellow channel). AAA map and the RBG color blended map were created (Fig. 5a and b respectively). The spectral decomposition map shows more details compared to the average absolute amplitude (AAA) map. The Yellow channel appears to consist of water wet multi-stacked channels. Consequently, the frequency band-limited RGB color-blended map of Yellow channel helps to delineate the channel architecture rather than the full band-width conventional attribute (AAA) map.

Fig. 6 shows a cross-plot between P-impedance (X-axis) and S-impedance (Y-axis) color coded by lithology calculated from Gamma-Ray and Resistivity logs. It is apparent from this figure that a good distinction is observed between gas sandstone, brine sandstone and shale in P-Impedance values. It has been possible to set P-Impedance cutoffs for the three rock units that are: Gas Sand < 3600 $(m/s * g/cc)$, Brine Sand > 4600 $(m/s * g/cc)$ and $3600 >$ Shale > 4600 $(m/s * g/cc)$, these cutoffs are represented on the well section in Fig. 7. This means that Post-Stack Inversion should be sufficient enough for lithology and fluid type discrimination.

Model-based post-stack inversion was applied to the seismic data. The inversion result at the well location was compared to the original log Solar-1 well as shown in Fig. 8. In general, the inverted AI was comparable to the well-log impedance.

Fig. 9 shows an arbitrary line that passes through Solar-1 well in the acoustic impedance cube produced from the inversion to show vertical and lateral variations in impedance.

The previously defined impedance cut-offs observed from rock-physics cross plots were applied to the inversion result and a discrete 3D facies cube that defines the three rock units was generated. An arbitrary line passing through Solar-1 well over this cube is shown in Fig. 10a and b. Note the distinction between Gas Sand (yellow color), Brine Sand (blue color) and background shale (brown color) on the cross section. Geobodies representing the Gas Sand and Brine Sand were extracted from the facies cube Fig. 11a and b. The two extracted bodies (Fig. 12) were then used for reservoir static modeling.

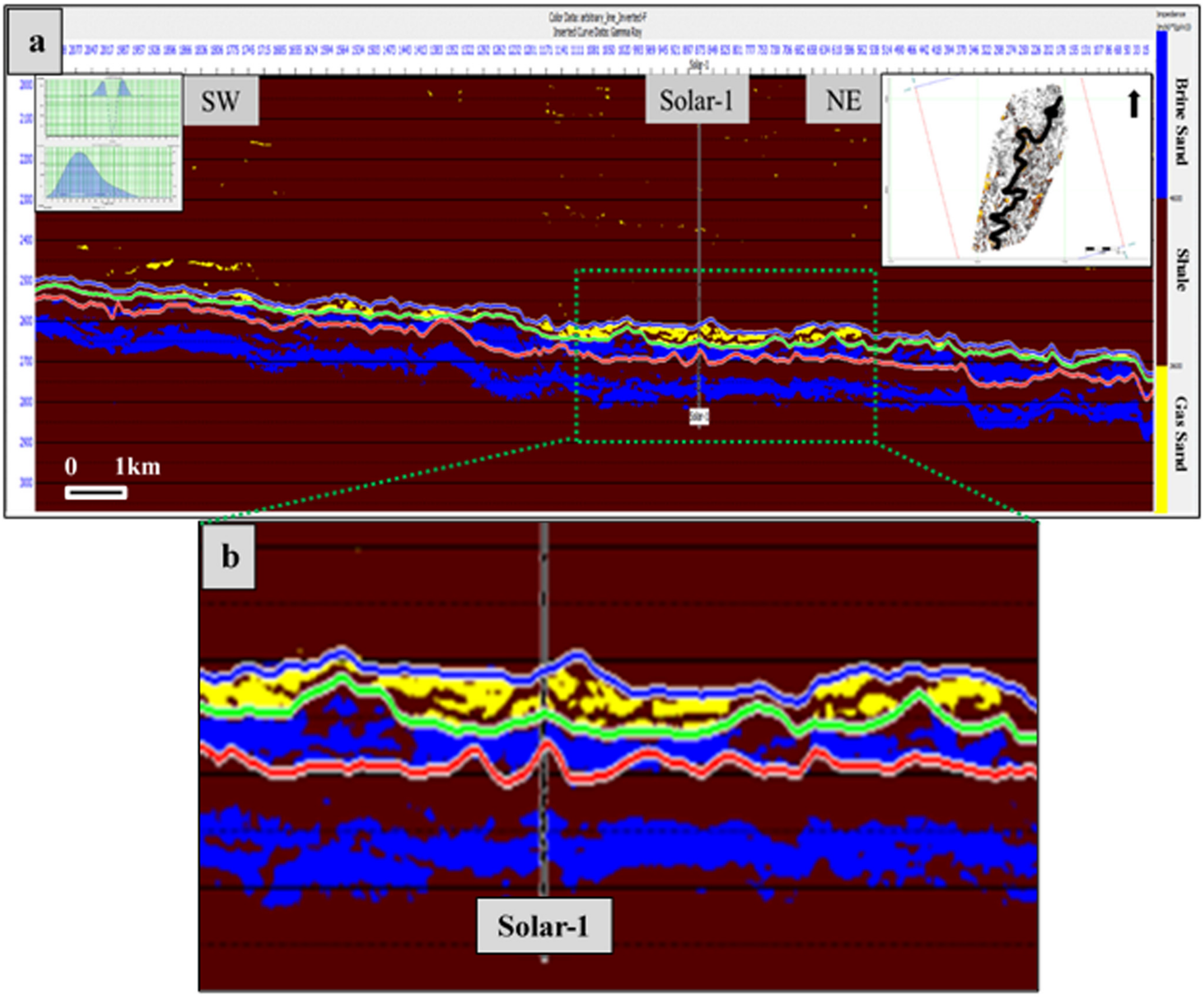

Fig. 10. (a) An arbitrary line passing through the Solar channel on the facies cube after using p-impedance cut-offs. It shows the excellent separation between Gas Sand (yellow color), Brine Sand (blue color) and background Shale (Brown). (b) A clear contrast appears along Solar-1 well location.

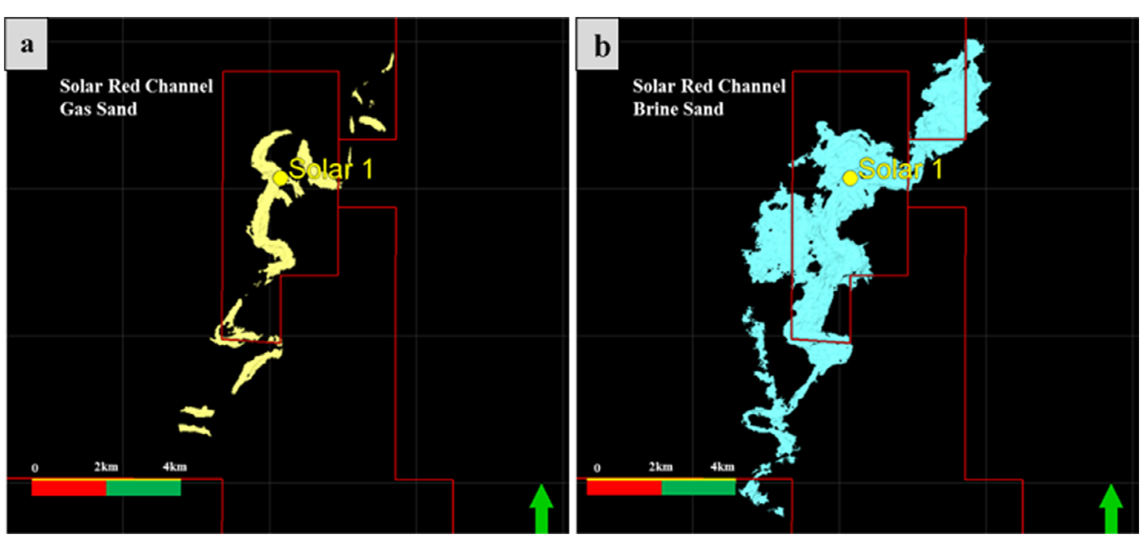

Fig. 11. (a) Gas Sand geobody extracted at Solar Red channel. (b) Brine Sand geobody extracted at Solar Red channel. Both after applying p-impedance cut-offs and generating facies cube.

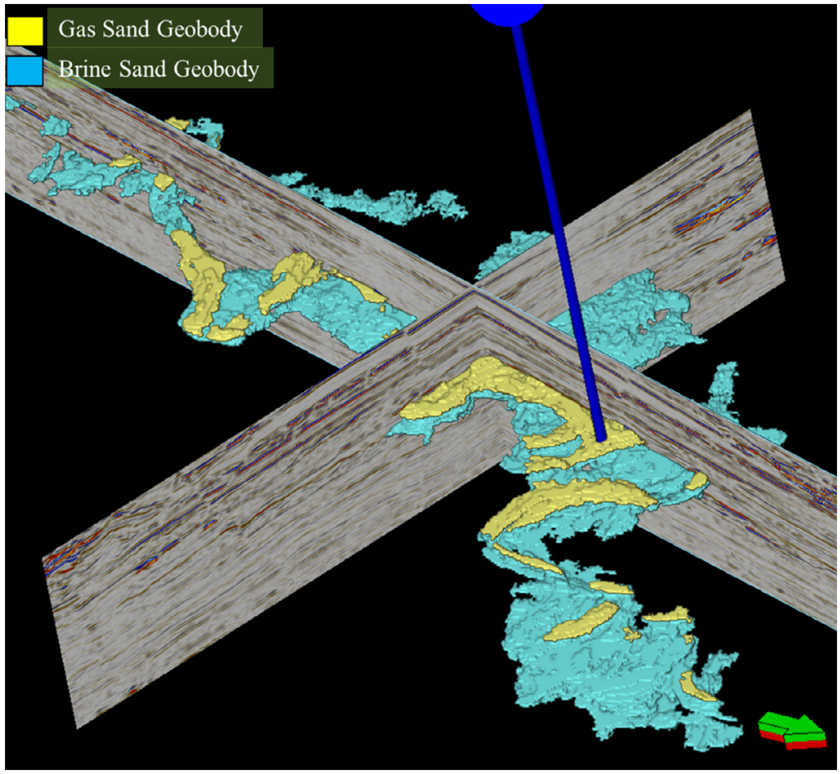

Fig. 12. Gas sand geobody and Brine sand geobody for Solar Red channel intersecting inline and crossline seismic data.

5. Conclusion

Spectral decomposition helped to identify the channel fairways and delineate the channel geometry and connectivity at both gas and water bearing channel complexes which don't stand out very well in the normal time attribute (AAA map).

Inversion feasibility study should be undertaken before performing any seismic inversion technique to decide whether the inversion is beneficial or not. It helps define proper property cutoffs that allow generating 3D litho-facies cubes which could be used to extract facies geobodies.

Acknowledgments

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