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Integrated seismic and well gamma-ray analysis for delineation Sienna channel depositional architecture, offshore West Nile Delta, Egypt

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ABSTRACT

The Nile Delta gas reservoirs are dominated by Plio-Pleistocene and Miocene channel deposits which became nowadays the key player for gas production in Egypt. These channelized features are spectacularly imaged on high-quality seismic data, this paper deals with channel geomorphology imaging using different geophysical and geological tools for better under-standing its architecture and fairway delineation in Sienna field also delineating some reasons for reservoir compartmentalization in the studied area which acts as an analogue for the marine slope channels in Pliocene reservoirs within West Delta deep marine concession (WDDM).Seismic attributes were used like Root Mean Square (RMS) amplitude extraction, Ant tracking and Spectral decomposition and finally pre-stack seismic inversion products. By correlating seismic signature with wells log data, four depositional cycles in the Sienna channel were identified which are stacked upon each other in Sienna canyon. The reason for Sienna system compartmentalization maybe not only effect by faults density but also facies quality which is changes from well to another as a result of distal deposits of turbidity slope channels. The location of new wells could be more precisely delineated for further reservoir development in Sienna channels.

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Reservoir; seismic; characterisation; channel geometry

1. Introduction

Huge gas discoveries have been achieved during the last decades in the deep-water of the Nile Delta especially in Pliocene and Miocene sequences. Exploration across the Nile Delta started by onshore Messinian incised valleys then offshore discoveries which made on the extension of this play and subsequently on new plays such as the Pliocene shallow marine reservoirs of the Rosetta field(Kijtzscii 1984)(EGPC [Egyptian General Petroleum Corporation] 1994)(Eid et al. 2019). Sharaf et al., 2014. Studied the Sienna area in the framework of lithofacies analysis and integrate with seismic data as Seismic time slices indicate that the Sienna channel complex consists of an unconfined channel system with clearly defined evolution stages. Most probably influenced by sea-level oscillation. The reservoir is characterised by fine grain siltstones and sandstone interbedded with mudstones and shale that were accumulated in relatively low energy, slope environment (Samuel et al. 2002). Also, Pan Li et al., 2017 Studied slope channel fill architecture but the model was a clastic dominated system and stated that the mixed coarse- and fine-grained channel complex set of the studied area represents a major building block of the slope channel system (ca. 7–9 km wide and 400 m thick) along with Canyon San Fernando, Baja California, Mexico. It is bounded by an erosion surface (ca. 70 m maximum relief) that is filled by a coarse-grained lower succession, representing braid-like channel fills at the channel belt axis (Helal et al. 2015).

Sienna field is located in the Eastern portion of the West Delta Deep Marine (WDDM) concession (Figure 1). The WDDM Concession is situated roughly 90 kilometres away from the Nile Delta shoreline and approximately 120 km North-East of Alexandria in water depths ranges from 250 m to 850 m as shown in (Figure 1). Sienna channels are considered as turbidity slope channels that running from South to the North towards the Mediterranean basin. It produces from Kafr-El-Sheikh Pliocene gas reservoirs (Rashid Petroleum Company internal); these reservoirs are very clear in seismic sections as they act as direct hydrocarbon indicators (DHI). Seismic attributes extractions as ant tracking were applied to the seismic data passing through amplitude maps then spectral decomposition method. The spectral decomposition method was applied by using several mathematical analyses such as Discrete Fast Fourier Transform (DFFT) and Continuous Wavelet Transform (CWT) to convert the time domain time series to its initial frequency domain. These methods help us in this study; 1) fix and de-risk the drilling of new wells; 2) delineation of Channel fairway; 3) discriminate the lithology from seismic signature by

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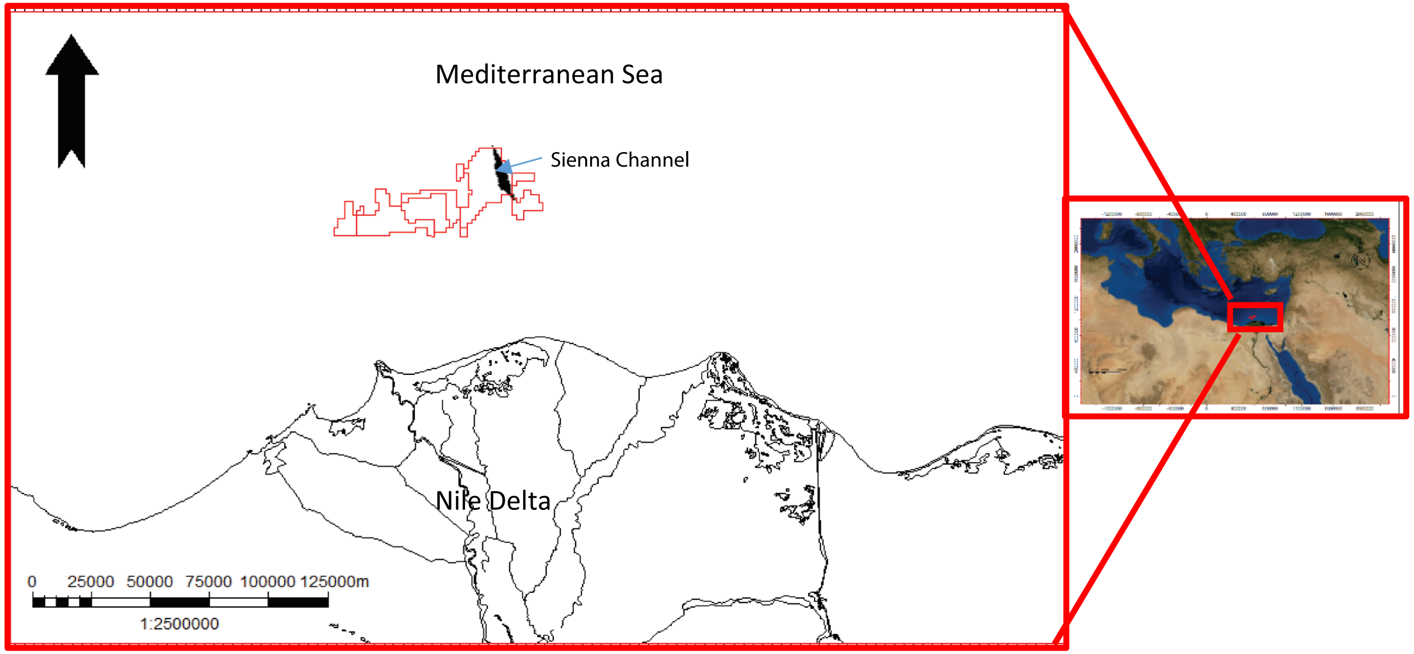

Figure 1. Satellite image of onshore and offshore Nile Delta showing West Delta Deep marine (WDDM) concession location relative to the shore line and a pop-up map showing Sienna development lease (study area).

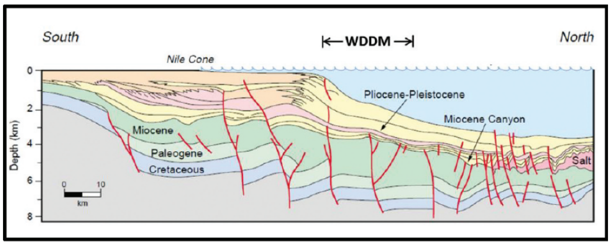

Figure 2. Geological cross-sections through the onshore and offshore Nile Delta showing WDDM CONCESSION including the study area modified after (Aal et al. 2000).

conducting seismic inversion analysis after delineating the channel architecture using spectral decomposition and Seismic amplitude maps.

Rock physics establishes a bridge between geophysical observations to geological parameters, nowadays, becomes very important for reservoir characterisation and best for prediction lithology continuity through the field. Various rock physics models have their unique applications like VP/Vs (velocity of primary waves and velocity of secondary waves, respectively) ratio is perfect for lithology delineation. Seismic reflectivity from subsurface layers shows potential hydrocarbon accumulations as a direct hydrocarbon indicator from an amplitude signature. (Eid et al. 2019) discussed the study area but in this paper, the workflow is enhanced and modified to match new results. 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(Bartov et al. 1980) (Veeken 2007).

In practice, seismic maps, attributes, well log data were integrated to enhance Sienna channel morphology and architecture which is the main challenge that obstacle reservoir productivity and hydrocarbon recovery.

2. Geological setting

The Sienna Block is located in a tectonically active region of the Eastern Mediterranean, whereas the Nile Delta's formation which controlled by a complex interplay of sedimentation and active faulting (Aal et al. 2001). The WDDM concession is affected by major tectonic events that shaped the present-day alignment as Northeast, Southwest trending Rosetta fault, and the East Northeast, West Northwest Nile Delta offshore anticline. These structural features have been shaped due to wrench tectonics (Sehim et al. 2002) because of the rotational movement of the African plate towards the Eurasian plate (Dolson et al. 2005).

The Nile delta region occupies a key position within the plate tectonic development of the eastern Mediterranean and Levantine. It lies on the northern margin of the African plate which extends from the subduction zone adjacent to the Cretan and Cyprus arcs to the Red Sea where was rifted apart from the Arabian plate (Cowan et al. 1998). The Nile Delta area has a long history of subsidence and deposition that probably began in Jurassic or earlier times. Between the Jurassic and the Eocene, the area was dominated by platform and basin sediments and by detrital deposits from the Oligocene onwards (Reading and Richards 1994).

The stratigraphic succession of the Sienna field is composed of Bilgas, Mit Ghamr, El-Wastani, and Kafrel Sheikh Formations where Kafrel Sheikh is the main producing reservoir in this field as shown in (Figure 3). Sienna Field is believed to be a slope channel complex deposited on the Nile delta slope in the late-Pliocene within Kafr El Sheikh Package (Figure 4) (Harwood et al. 1998).

3. Methodology

Sienna field suffered from numerous reservoir productivity issues, like reservoir quality and depositional

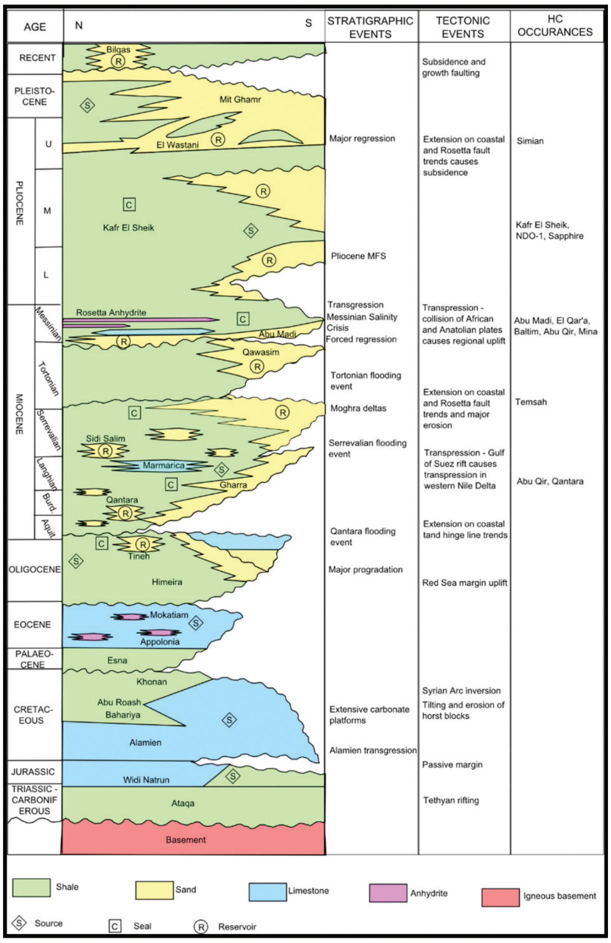

Figure 3. Nile Delta tectonostratigraphic showing key stratigraphic and tectonic events and hydrocarbon occurrences. This chart was devised for this project using tectonostratigraphic charts (Deibis et al. 1986, Cowan et al. 1998).

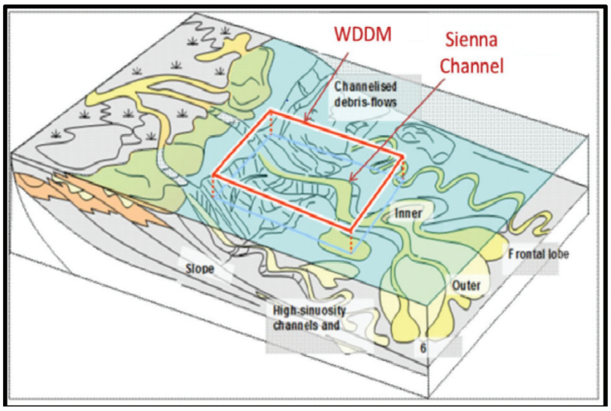

Figure 4. 3D schematic diagram of the depositional model of turbidite slope channels after (Helal et al. 2015) the study area.

history. The study area has three main wells but the study concentrates on only two wells according to the available data. The reservoirs were covered by 3D surveys and seismic attributes and features were identified using the 2006 survey acquired by Rashid Petroleum Company. The below chart summarises the working steps (Figure 5).

3.1. Data set

The data set was used for this study includes suites of full-stack seismic data, seismic inversion lines, spectral decomposition analysis, and gamma-ray logs. This study was performed using petrel 2015 (Schlumberger), Open detect 2015, and HR 10 (CGG) software. Lithologies and reservoir packages were delineated using the gamma-ray log. To ascertain whether the mapped horizons were hydrocarbon-bearing, seismic amplitude attributes analyses were carried out by integrating complete workflow (Figure 5).

3.2. Interpretation

Many maps were constructed starting from ant tracking which uses a series of unique seismic attributes in a workflow to identify and track faults from an unbiased perspective through 3D seismic volumes as the interpretation of faults in 3D seismic volumes can be a tedious task and influenced by the predefined bias of the interpreter. The area is dissected by numerous faults which have a big effect in reservoir compartmentalisation as these faults act as barriers for lateral facies change in the channel itself as shown in ant tracking extraction of the seismic data in (Figure 6). Sienna structure is believed to be a combination stratigraphic/structural accumulation with up-dip (southern) fault closure, down-dip (northern) closure, and stratigraphic closure (eastern and western channel margin pinch out) along the length of the channel.

A post-stack attribute that computes the square root of the sum of squared amplitudes divided by the number of samples within the specified window was used and called RMS Map (Root Mean Square). RMS maps are very important for lightening hydrocarbon zones; however, these maps are sensitive to noise as it squares every value within the window. RMS was extracted from top to base Sienna channel as shown in (Figure 7), where the channel is running from South East to North West directions and the study wells NN-1 and NN-2 are located in the core of the channel. It seems that faults have a clear effect in amplitude signature as dimming in fault areas. Figure 8 shows a 3D visualisation of the channel fairway to better imagine channel architecture.

The next step in the study is to apply another seismic spectral decomposition attribute (Frequency attributes); these attributes separate seismic anomalies inside each trace depending on their frequency content. Spectral decomposition starts from decomposed each one dimension (1D) trace from its time domain into the corresponding

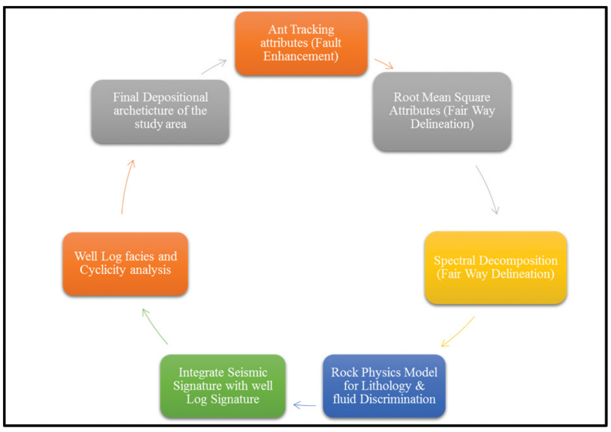

Figure 5. Work flow for channel architecture delineation.

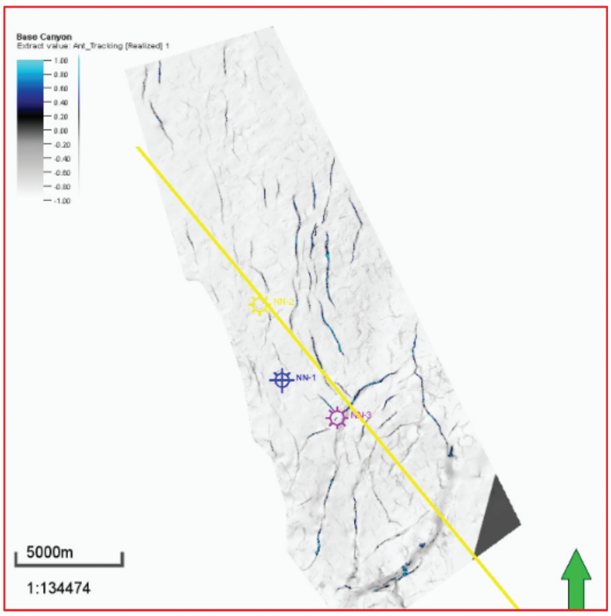

Figure 6. Ant tracking extraction on base Sienna channel.

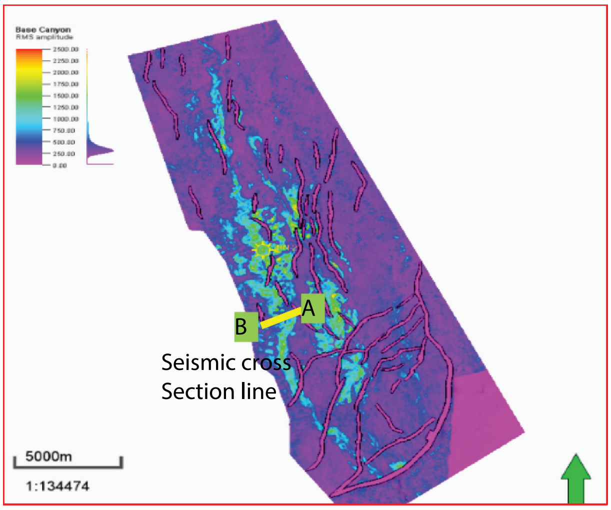

Figure 7. RMS from top to base Sienna Channel on base channel structure contour map.

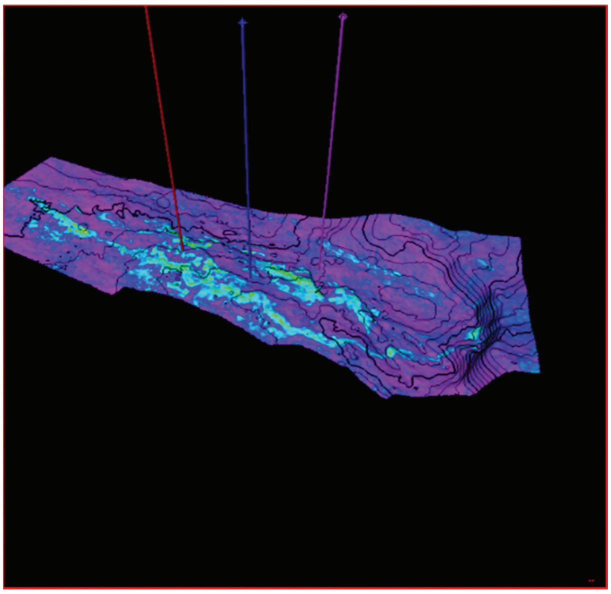

Figure 8. RMS from top to base Sienna Channel on base channel structure Contour map in 3D view.

2D in the time-freq domain as Fourier transform. Seismic data is always filtered at a various frequency ranges to clear certain geological features that may not be clear in the other frequency bands as shown in (Figure 9), in this figure, the fault polygons were overlaid upon the spectral image. This image clarifies one of the reasons for reservoir compartmentalisation as the area is dissected by several faults. Different extraction windows were performed from the top of the Sienna channel to display the depositional history of the channel. Figure 10 demonstrates the abandonment stage of the channel where shale volume increases and sand volume decrease which is a typical response in a Bouma slope channel sequences with finning upward cycle. Channel depositional history became clear after conducting colour blending upon

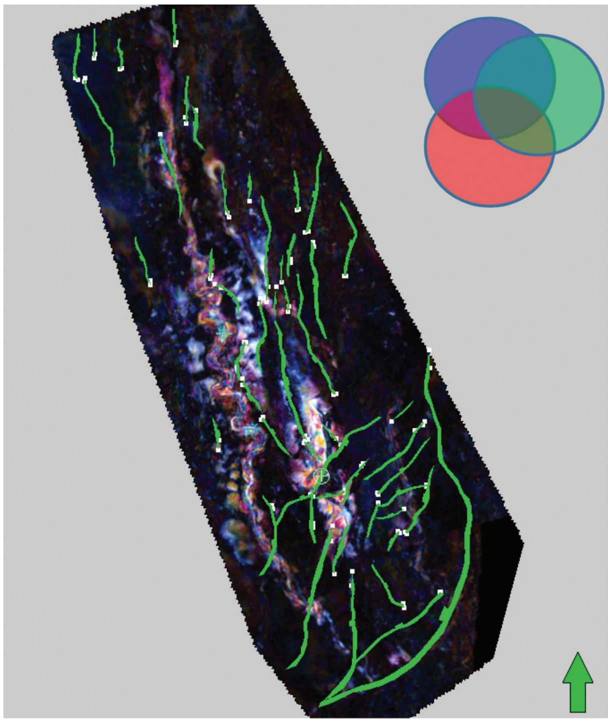

Figure 9. RGB colour blended frequencies map over Sienna channel spectral decomposition analysis; the coloured circles above represents frequency content of the attribute maps as Blue: High, Green: Intermediate and Red: Low. Extraction window is 75 m below the top of the channel.

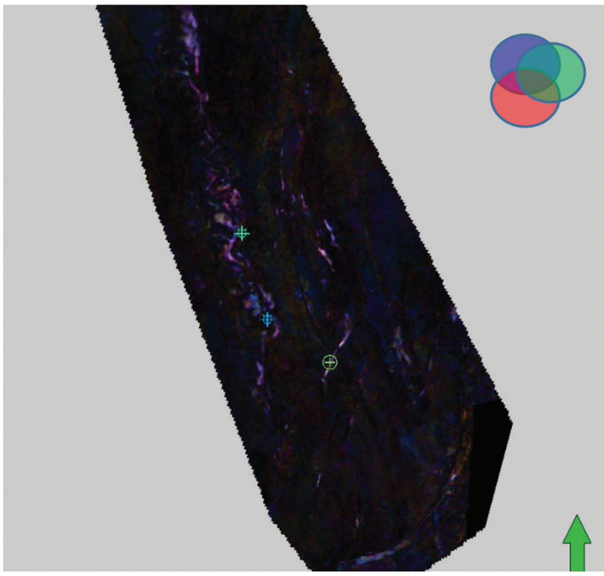

Figure 10. RGB colour blended frequencies map over Sienna channel spectral decomposition analysis; the coloured circles above represents frequency content of the attribute maps as Blue: High, Green: Intermediate and Red: Low. Extraction window is 10 m below the top of the channel.

frequency cubes (12 Hz, 24 Hz, and 36 Hz). The base reservoir was overlain by spectral image (extraction 120 m below top reservoir) as seen in (Figure 11) which demonstrates the initial stage of the channel development; it starts by courser sands at the base.

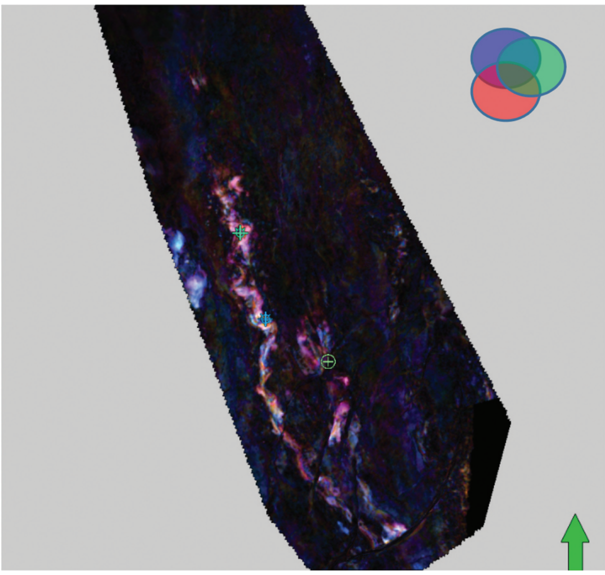

Figure 11. RGB colour blended frequencies map over Sienna channel spectral decomposition analysis; the coloured circles above represents frequency content of the attribute maps as Blue: High, Green: Intermediate and Red: Low. Extraction window is 120 m below the top of the channel.

Now, channel fairway is identified from different geophysical attributes, also the channel development from the base as seen in (Figure 11) to the top as seen in (Figure 10) which acts as deepening upward cycles also identified. The previous tools were used laterally in the 2D map view, but the depositional cycles from seismic are needed to be identified vertically. Figure 12 shows a seismic section along NN-1 well, where the bright amplitude is so clear; it is called direct hydrocarbon indicator (DHI), as obvious amplitude appears in the hydrocarbon-bearing reservoir which is gas sand in our study area. The gamma-ray log is loaded upon the seismic section and matched with seismic amplitudes response after that, it has become clear that channel is subdivided into four depositional cycles vertically with the seismic resolution, these four stacked channels are cutting each other as lateral amalgamation inside the main Sienna canyon which typically slopes channel depositional sequence.

By plotting Acoustic Impedance (Zp) Versus VP/Vs ratio (products from pre-stack seismic before inversion) the lithology, as well as the fluids, are discriminated against and separated along the x-axis as shown in (Figure 13). The increasing of Acoustic impedance and Vp/Vs indicates water saturation increases and brine sand predominates (Zone-1 in the cross plot), this happens when water replaces gas and consequently, the rock becomes stiff than before and rock density increases that is why increasing in Zp accompanied with increasing in Vp/Vs ratio. By this method, the Sienna channel could be classified into gas sand, water sand, and shales zones by assigning cut-offs upon inverted seismic volumes as shown in (Figure 14).

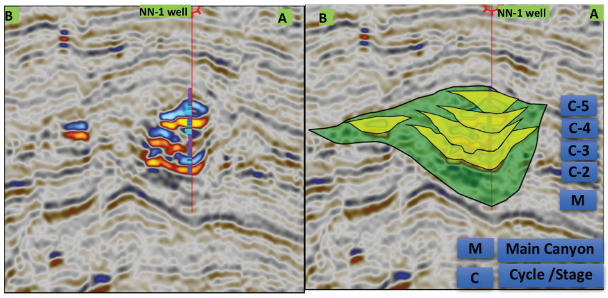

Figure 13. Seismic line through Sienna channel to highlight depositional cycles in Sienna field, for line location look to Figure 7.

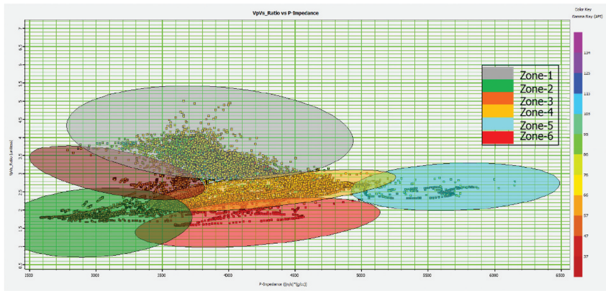

Figure 12. Rock Physics cross plot between Vp/Vs (y-axis) and Zp (x-axis) to discriminate between lithology and fluid. Zone-1 represents shale background, Zone-2, Zone-3, and Zone-6 represent Gas sands with different rock quality, and Zone-4 represents shaly sand and Zone-5 represents water sand.

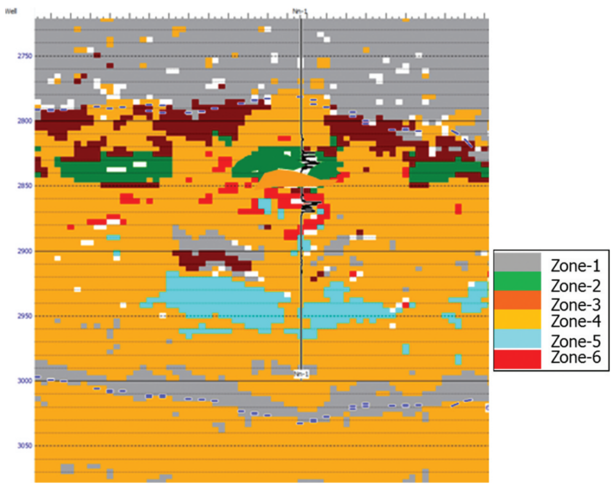

Figure 14. Shows assigned cut-offs from previous cross plot for inverted Vp/Vs cube, where zone-2 is gas sand, Zone-1 is water sand, Zone-3 and Zone-4 are back ground.

The gamma-ray pattern from NN1 well as shown in Figure 15(a) was compared with a seismic pattern to recognise the four internal channels architecture inside the Sienna main channel.

From NN1 well, the facies were characterised by course to medium sand, siltstone, and mudstone. Sienna channels are characterised by coarser clastics at the base of the canyon with fining upward sediments at the top. Each depositional cycle encounters the same depositional patterns and the next

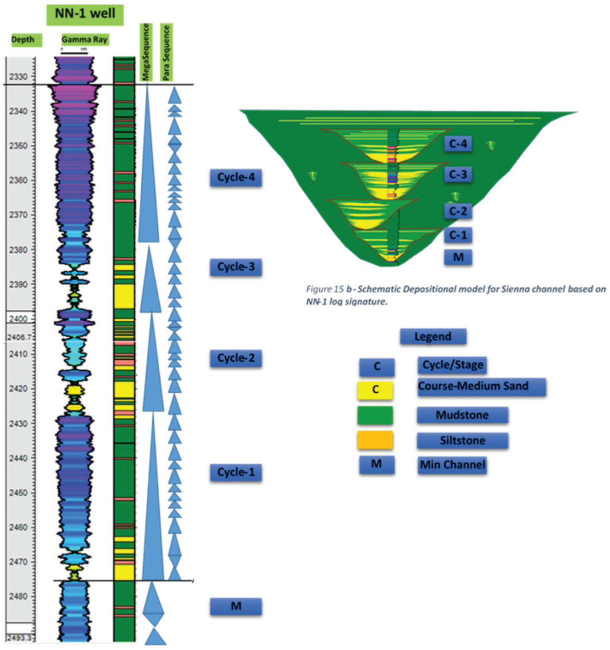

Figure 15. NN-1 a-well depositional cycles from GR log.

depositional cycle will erode the top part of the older one and deposit the coarser

Figure 15(b) represents a schematic cross-section combined with an exaggerated gamma-ray log for NN-1 to clarify multi-stack channels of the study area and it is obvious that the well-penetrated levee part in cycle number two; that is why the well encountered low net to gross in this part. The Sienna channel comprises two main branches with canyon fill which comprises multiple stacked channels, typically consisting of a core area of channel sands with complex turbidity thin-bedded levied wings and a belt area of stacked channel sands, background shale, and heterolithics and thinly bedded levees. Figure 16 shows a correlation between NN-1 and NN-2 wells through Sienna channel, it is clear that sand ratio increases in NN-1 area and this is logic as this well is in the proximal part from the source area and as going distally, sand content becomes less and another reason for that is the well penetrated more levee parts of the multi-stacked channels which cut upon each other. The NN-2 well proved also four mega sequences and Para sequences of the channel.

4. Results

We able to understand the Sienna channel deposition environment stages from channel incision to initial valley fill to incision and fill until reaching the final stage of the channel abandonment from the integration the seismic maps, attributes, inversion model and gamma and wells logs data as shown (Figure 17) and described as following:-

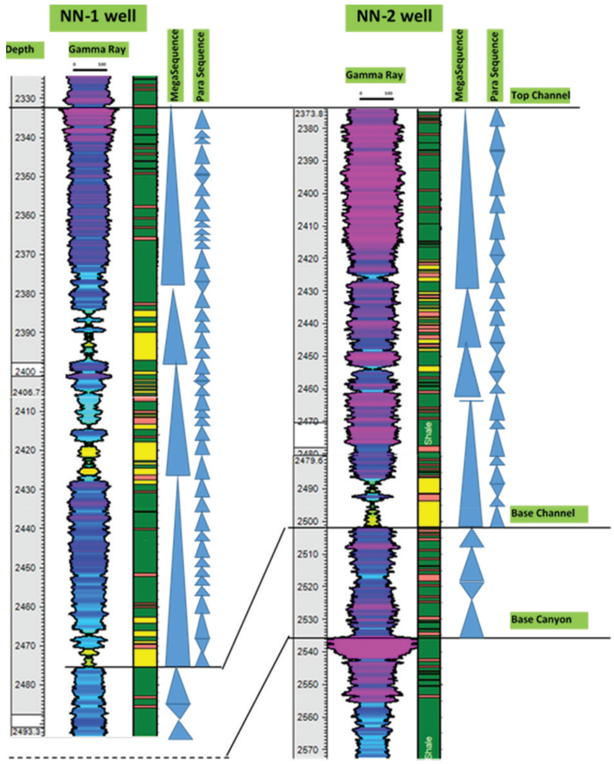

Figure 16. Correlation panel between NN-1 and NN-2 wells through Sienna channel.

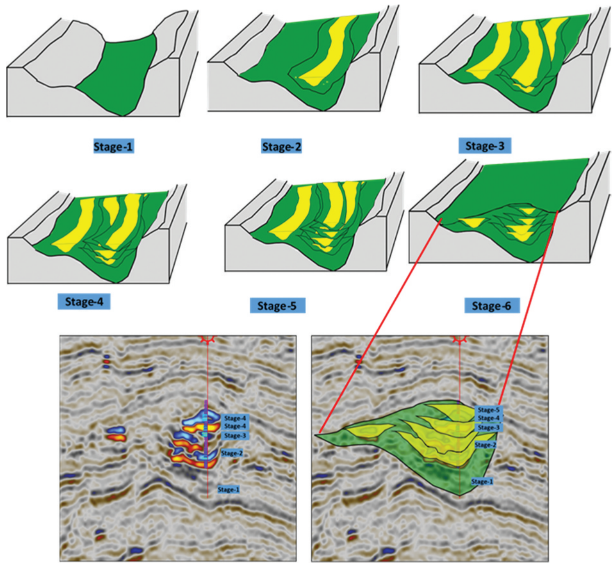

Figure 17. Stage I of the channel development: Channel Incision; Stage II of the channel's development: Initial valley fill; Stage III to V of the channel's development: Reincision and fill.

4.1. *Stage I: channel incision*

Erosion of the channel was probably caused by a combination of two processes; first, by the action of high-density gravity flows erosive bypassing the Nile Delta slope before deposition on the Mediterranean Basin floor, and second, by mass wasting on the margins of the developing channel (Figure 17). Slumping cannot be distinguished on seismic data because it involves shale-prone deposits (with no acoustic contrast) (Schlumberger 1995).

4.2. Stage II: initial valley fill

In many of the channels, there is a clear high amplitude "sheet" immediately overlying the basal slumps which can be recognised from a clean gamma-ray pattern as shown in (Figure 15) (Figure 16) also very clear in RMS amplitude maps (Figure 7). The lower sand unit is overlain by a variable, but generally, upward-decreasing sand–shale ratio succession that filled the initial slope valley cuts.

4.3. Stage III: re-incision and fill

One of the characteristic features of the Sienna channel systems is the degree of re-incision. This re-incision is spectacularly imaged on seismic sections (Figure 17) and areal amplitude extractions. The incising channels typically have a lower aspect ratio than the main slope valleys and, in cases, have cut down through the lower channel valley sheet units. The 2-D seismic data show that some of the re-incised channels are infilled by low-amplitude deposits, which are interpreted to be predominantly shales.

4.4. Stage IV: channel abandonment

Termination of the coarse-grained fill of the main channels has occurred in two main ways. In several channels, the coarse fill is immediately overlain by slump deposits, which plugged the remaining accommodation space in the system. In other channels, there is a clear abandonment succession with thin, sheet-like sands passing up into thin-bedded turbidites, thin sand laminae, and end with hemiplegics (Figure 17).

5. Conclusion

Sienna field is a Pliocene channel with a long history of erosion and deposition with four depositional cycles stacked upon each other. This became clear after correlating seismic signature with well log data; starting from attribute maps passing through a rock physics model "lithology and fluid discrimination" to gamma-ray logs which enhance lithology interpretation and channel depositional cycles finning upward cycles'. Sharaf et al. (2014) studied the sienna area but little bit using seismic techniques to enhance the depositional history of the channel as seismic methods helped us a lot to clear understand reservoir architecture but Sharaf et al. (2014) studied more in lithofacies analysis which is a good point after constructing more accurate model analysis.

Integrating both geophysical and geological data, channels are identified and mapped, consequently, the location of the new wells could be optimised for further reservoir development as seen in the Sienna field case study. This solves the main challenge in the area "channel architecture and fairway delineation".

Disclosure statement

No potential conflict of interest was reported by the authors.

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