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INTEGRATED APPROACH TO PREDICT THE DEPOSITIONAL ARCHITECTURE OF SLOPE CHANNELS; A CASE STUDY OF SIENNA CHANNEL, OFFSHORE WEST NILE DELTA.

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Abstract

Slope channels are considered the main clastic reservoirs in many regions especially the continental slopes all across the world. In some cases, these channels are stacked together and laterally amalgamated. This paper is about channel geomorphology imaging using different geophysical and geological tools to better define its architecture and fairway delineation. The Nile deposits are assumed to be a type locality for this kind of channels as huge channelized features are imaged in the continental slope of the African plate. Many channels are targeted for hydrocarbon exploration in this area like Sienna channel which lies offshore west Nile Delta and used as a case study in this paper. 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. Workflow started by using seismic attributes like Root Mean Square (RMS) amplitude extraction and Spectral decomposition analysis. These attributes highlighted the channel geometry and its evolutional history through geological times. Pre-stack seismic inversion products; Vp/Vs ratio and Acoustic impedance, discriminated gas sand, water sand from shale background and this helps to highlight facies association. Depositional cycles are differentiated using gamma-ray log. By integrating all the data, channels were clearly identified and mapped. Consequently, the location of new wells could be optimized for further reservoir development as seen in this case study of "Sienna channel''.

Introduction

Huge gas discoveries were made during the last decades in the deep water especially in continental slope deposits which lies at the Rivers mouth. Most of these deposits are channelized features resulting from subaqueous sediment flow. Oil exploration and production face many difficulties to track these slope channels which spreads over a wide zone and failure cases of reservoir penetrations in an optimum location are common. This paper discusses the integrated way to highlight and track channelized features using both seismic and well data. The Nile Delta is considered to be a world-class for that kind of channel deposits especially in the Pliocene and Miocene sections. A lot of slope channels are running from south to north toward Mediterranean deep waters. Sienna channel lies in the Eastern part of a concession called West Delta Deep Marine (WDDM) Figure1. This channel is used as a case study to validate the workflow and method of the study.

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 filed (Kijtzscii et al.1984; EGPC, 1994; Harwood et al.1998).
WDDM concession that is situated roughly 90 kilometres away from the Nile Delta shoreline and approximately 120 km North-East of Alexandria in water depths range from 250m to 850m as shown in Figure 2. Sienna field is turbidite slope channels which running from South to North toward Mediterranean basin. This field produces from Kafr-El-Sheikh Pliocene gas reservoirs; which are very clear on 3D seismic images and give direct hydrocarbon indicators (DHI) response on seismic reflectivity cubes. However, one of the challenges in the study area is the reservoir compartmentalization and reservoir architecture. Some methods were used to overcome these challenges starting from some seismic attributes extractions like ant tracking passing through amplitude maps then spectral decomposition approach. Another challenge in the study area is discriminating the lithology from seismic signature and seismic inversion could overcome this challenge.

Ordinarily, 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).
Rock physics establishes a bridge between geophysical observations to geological parameters, nowadays, become very important for reservoir characterization and best for prediction lithology continuity through the field, accordingly, various rock physics models have their unique applications like VP/Vs (velocity of primary waves and velocity of secondary waves respectively) ration is perfect for lithology delineation. Seismic reflectivity from subsurface layers shows potential hydrocarbon accumulations as a direct hydrocarbon indicator from amplitude signature. 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 et al., 2007; Lindseth et al., 1979).

In Practice, Seismic maps, attributes, well log data were integrated to enhance Sienna channel morphology and architecture which are the main challenges that depress reservoir productivity and hydrocarbon recovery if not fully understood.

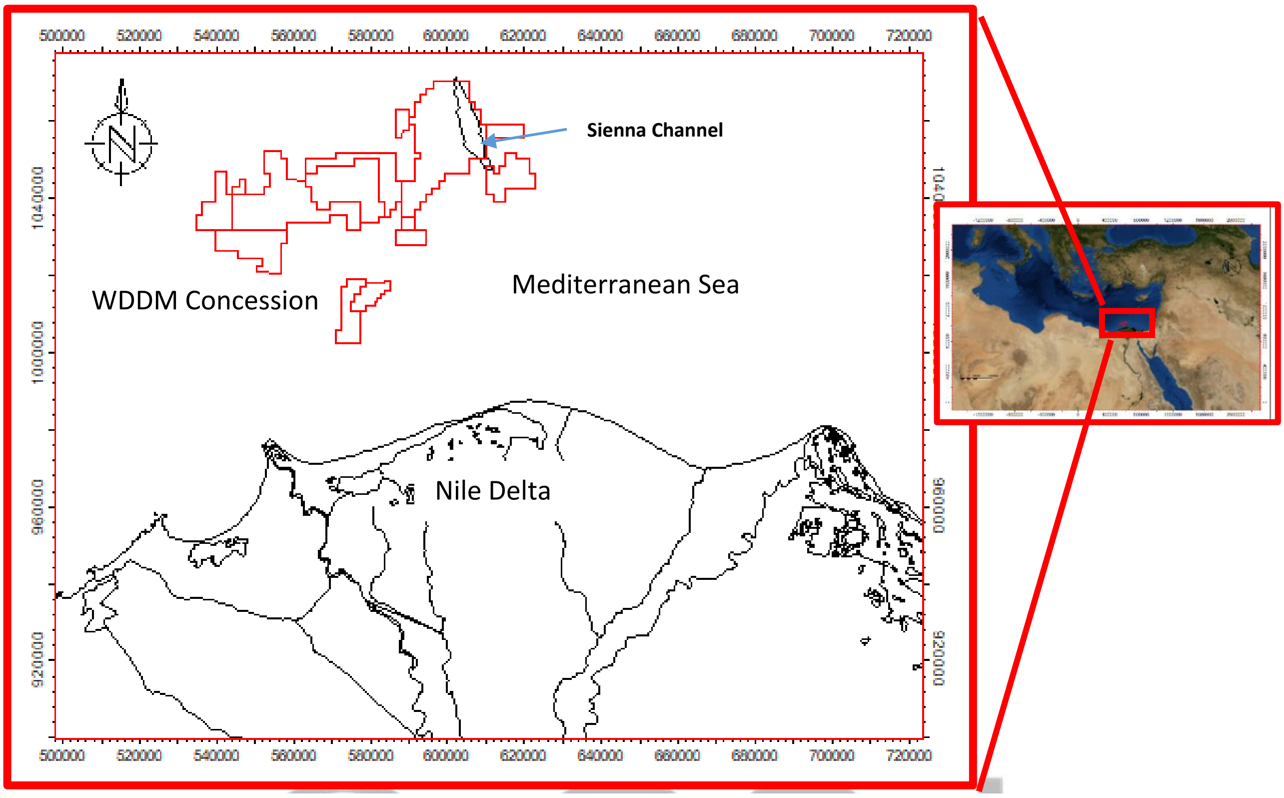

Figure 1 Satellite image of onshore and offshore Nile Delta showing West Delta Deep marine (WDDM) concession location relative to the shore line and a pop-up map showing Sienna development lease (study area).

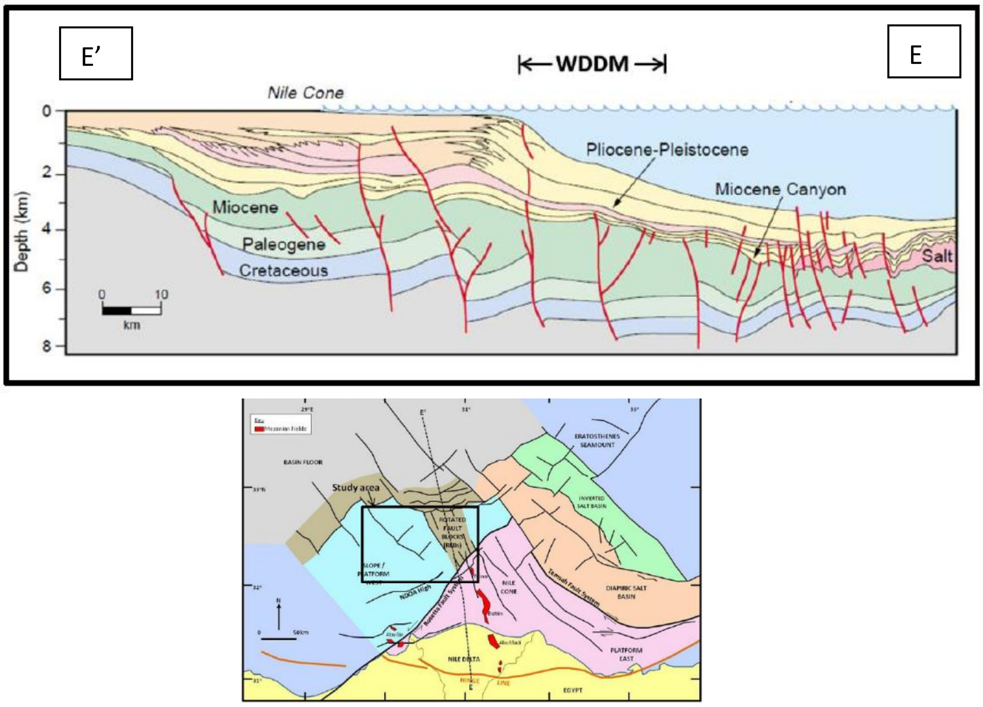

Figure 2 Geological cross-sections through the onshore and offshore Nile Delta showing WDDM CONCESSION including the study area modified after (Aal et al, 2000).

Geological Setting

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

Nevertheless, 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, that was rifted apart from the Arabian plate (Gowan et al.1998), moreover, 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 (Schlumberger, 1995).

The stratigraphic succession of Sienna field is composed of Bilqas, Mit Ghamr, El-Wastani, and Kafr el-sheik Formations where Kafr el-sheik is the main producing reservoir in this field as shown in Figure 3. Helal et Al.,(2015) reported that Sienna Field is believed to be a slope channel complex deposited on the Nile delta slope in the late- Pliocene within Kafr el-sheik Package Figure 4.

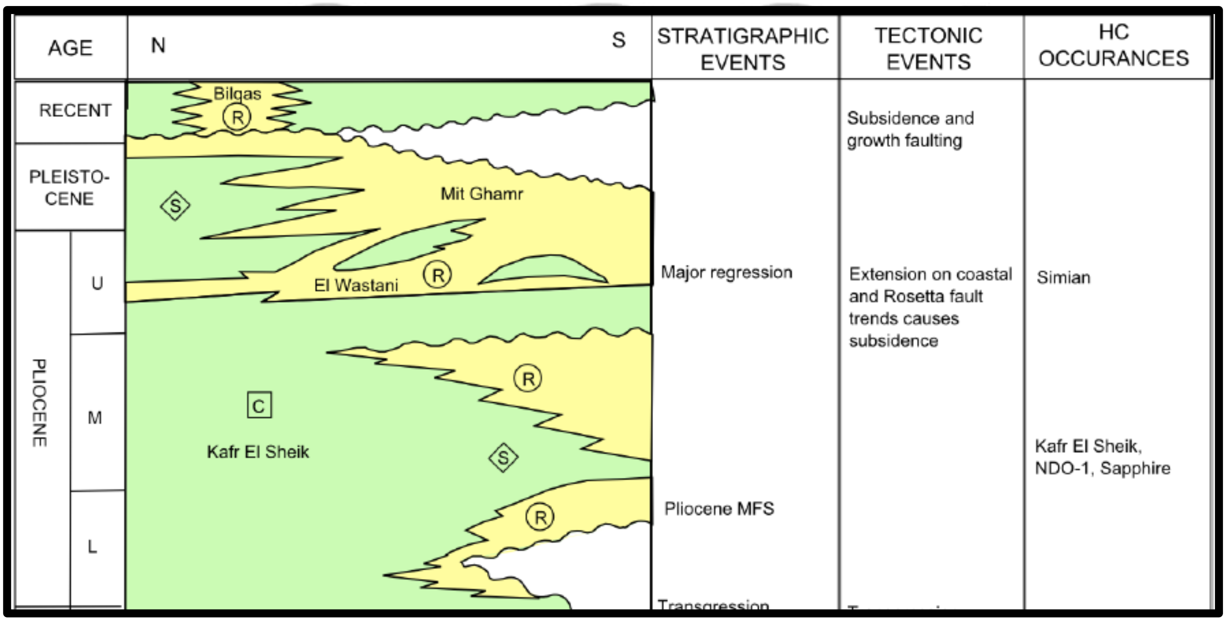

Figure 3 Nile Delta Plio-Pleistocene tectonostratigraphic showing key stratigraphic and tectonic events and hydrocarbon occurrences. This chart was devised for this project using tectonostratigraphic charts (Deibis et al.1986; Dolson et al.2005).

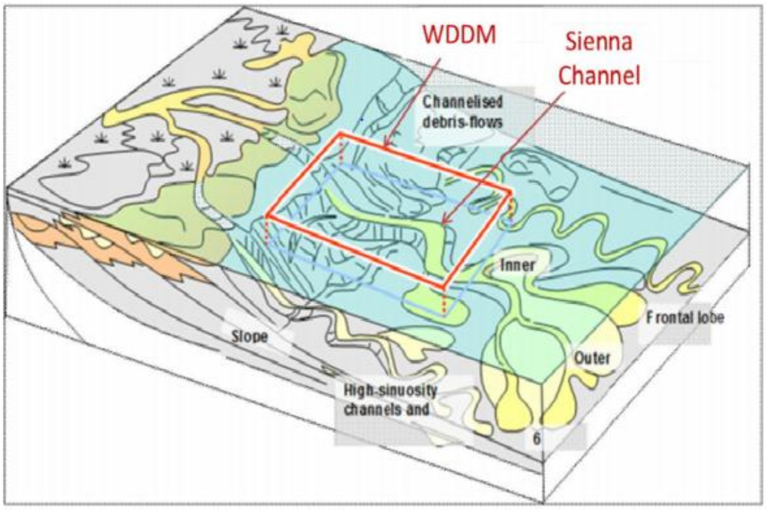

Figure 4 3D schematic diagram of the depositional model of turbidite slope channels after (Reading et al. 1994) Red Polygon the study area.

Methodology

Sienna field suffered from numerous reservoir productivity issues, like reservoir quality and depositional history. Therefore this study integrates seismic anomalies with well log cyclicity for delineating the channel architecture, and to identify some reason for further reservoir compartmentalization. The study area has three main wells with different free water level and the area is dissected by several faults systems. The workflow is shown in Figure 4

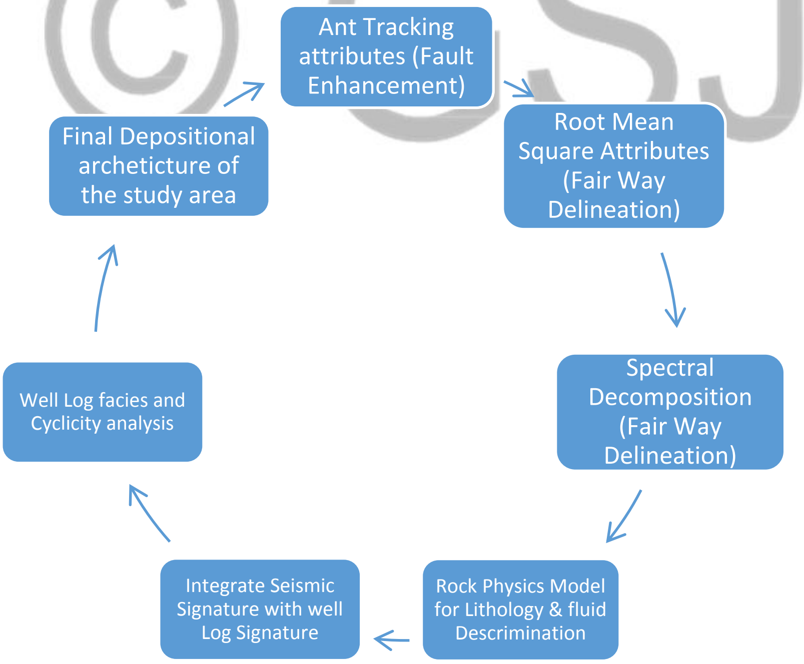

Figure 5 Work Flow for Channel Architecture Delineation

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, Open detect and HR soft wares. Lithologies and reservoir packages were delineated using the gamma-ray log. In order to ascertain whether the mapped horizons were hydrocarbon-bearing, seismic amplitude attributes analyses were carried out.

Interpretation

Sienna trap is believed to be a combination stratigraphic and structural accumulation with up-dip (southern) fault closure, down-dip (northern) closure and stratigraphic closure (pinch out on eastern and western channel margin) along the length of the channel as seen in Figure 6. The Sienna channel consists of 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 thin-bedded levees. Some maps were constructed using a series of unique seismic attributes to identify and track faults from an unbiased perspective through 3D seismic volumes. Accordingly, Figure 7 shows ant tracking extraction on top of the Sienna reservoir. The field area is dissected by numerous faults which have a big impact on reservoir compartmentalization. Since these faults act as barriers for reservoir productivity in addition to the lateral facies change in the channel itself. 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 "RMS Map (Root Mean Square)" was used. Consequently, RMS maps are very important for lightening hydrocarbon zones, however, these maps are sensitive to noise as it squares every value within the window. Nevertheless, RMS was extracted from top to base Sienna channel as shown in Figure 6, where the channel is running from SE to NW directions and the study wells NN-1 and NN-2 are located in the core of the channel. The attribute extraction shows that faults have a clear effect on amplitude signature as dimming in fault areas as well. Figure 8 shows a 3D visualization of the channel fairway to better imagine channel architecture.

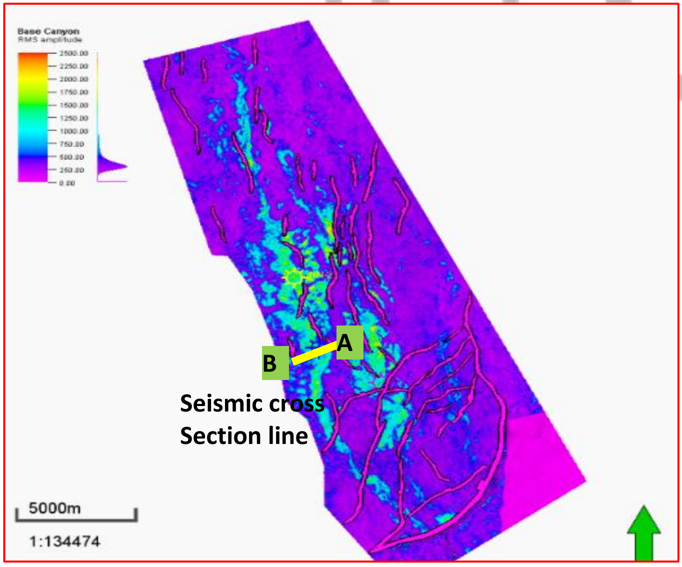

Figure 7 RMS from top to base Sienna Channel on base Channel structure contour map

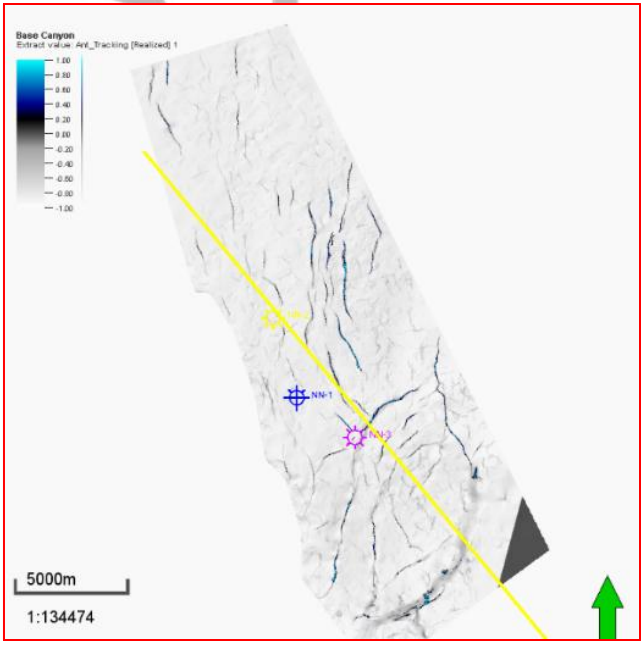

Figure 7 Ant tracking extraction on base Sienna channel

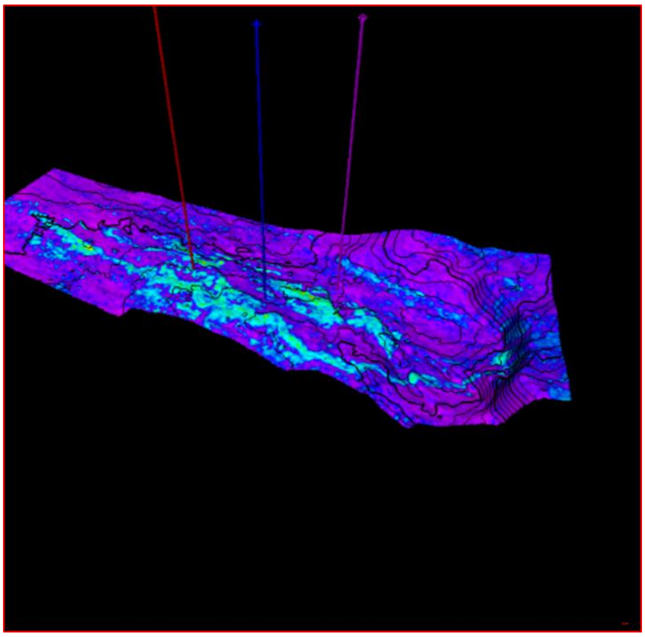

Figure 8 shows 3D visualization of the channel fairway to better imaging channel architecture.

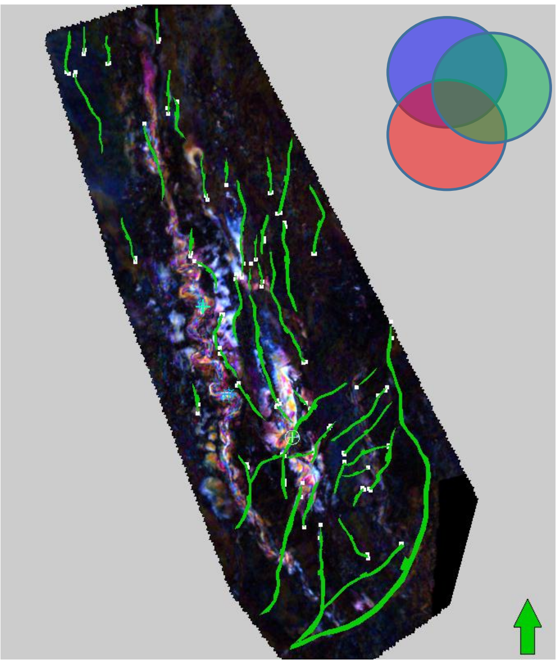

Figure 9 RGB color blended frequencies map over Sienna channel '' Spectral Decomposition) analysis; the colored circles above represents frequency content of the attribute maps as Blue: High, Green: Intermediate and Red: Low. Extraction window is 75 m below the top of the channel

the next step according to the applied workflow is to apply another seismic spectral decomposition attribute (Frequency attributes). These attributes identify seismic anomalies inside each trace depending on their frequency content.Spectral decomposition starts from decomposing each one dimension (1D) trace from its time domain into the corresponding 2D in the time-freq domain by methodology such as Fourier transform, Winger-Ville distribution. nevertheless, 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 which the fault polygons were overlaid upon the spectral image. This image clarifies one of the reasons for reservoir compartmentalization as the area is dissected by several faults. consequently. Different extraction windows were performed from the top of 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 decreases which is a typical response in a Bouma slope channel sequences with finning upward cycle. Channel depositional history became clear after conducting color blending upon frequency cubes (12 Hz, 24 Hz, and 36Hz). The base reservoir was overlain by spectral image (extraction 120m below top reservoir) as seen in Figure 11 which demonstrates the initial stage of the channel development; starts by courser sands at the base.

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. The previous tools were used laterally in 2D map view, but the depositional cycles from seismic are needed to identify channel vertically. Figure 12 shows 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. The Gamm and seismic amplitudes show that channel is subdivided into four depositional cycles, these four stacked channels cut each other as lateral amalgamation inside the main Sienna canyon which typically slope channel depositional sequence.

Generally, by plotting Acoustic Impedance (Zp) Versus VP/Vs ratio (products from pre-stack seismic inversion) the lithology as well as the fluids are discriminated 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 stiffer than before and rock density increases that’s why increasing in Zp accompanied by increasing in Vp/Vs ratio. By this method, Sienna channel could be classified into gas sand, water sand and shales zones after assigning cut-offs upon inverted seismic volumes as shown in Figure 14.

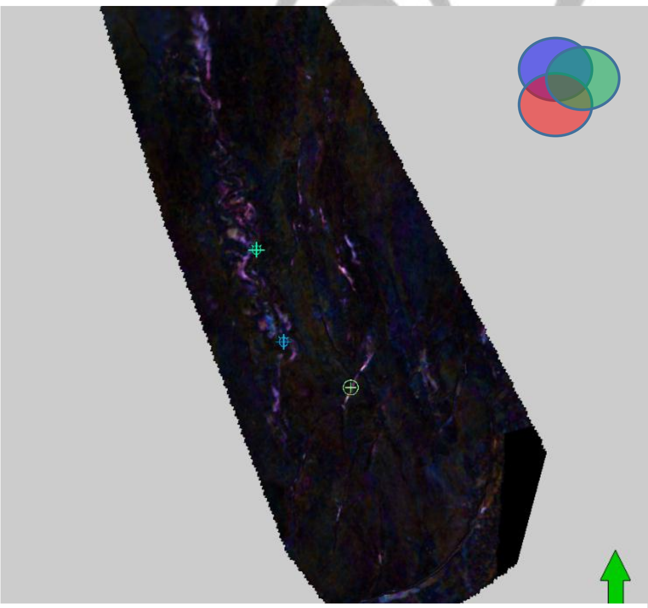

Figure 9 RGB color blended frequencies map over Sienna channel ‘’ Spectral Decomposition) analysis; the colored circles above represents frequency content of the attribute maps as Blue: High, Green: Intermediate and Red: Low. Extraction window is 10 m below the top of the channel

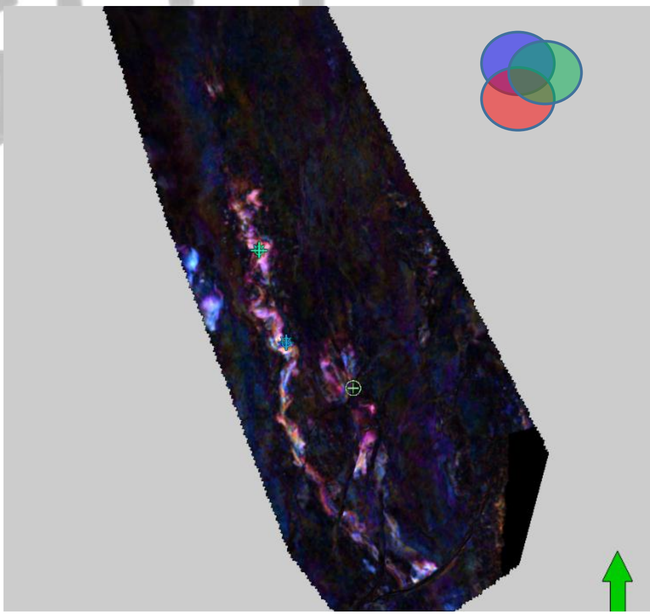

Figure 8 RGB color blended frequencies map over Sienna channel ‘’ Spectral Decomposition) analysis; the colored circles above represents frequency content of the attribute maps as Blue: High, Green: Intermediate and Red: Low. Extraction window is 120 m below the top of the channel

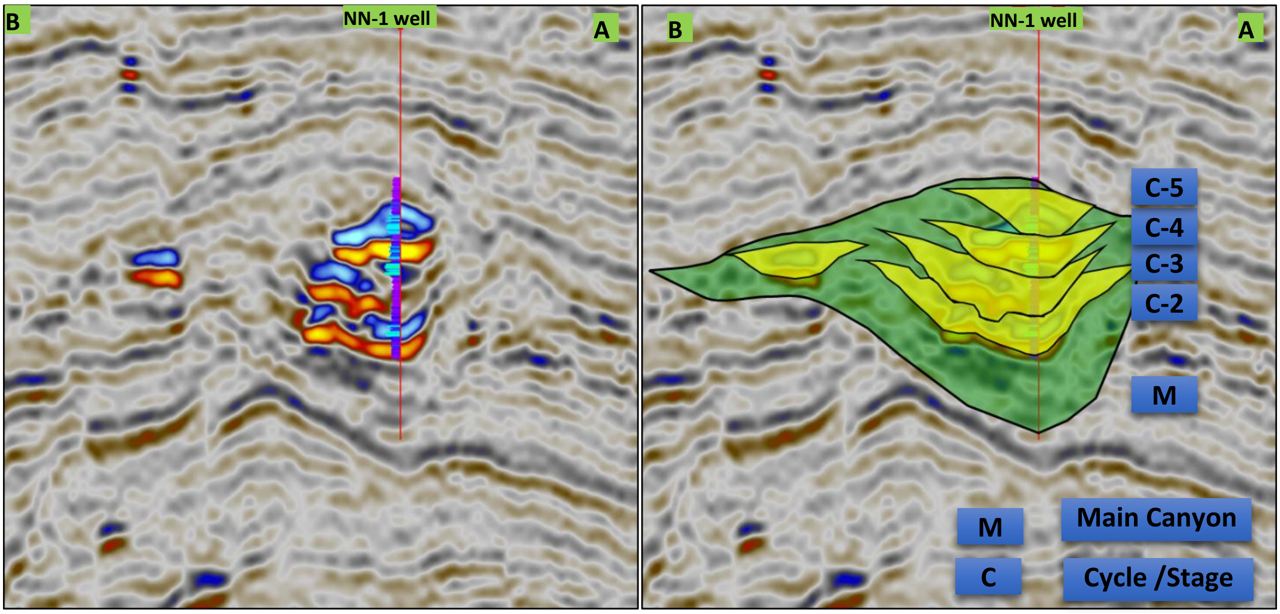

Figure 12 Seismic line through Sienna channel to highlight depositional cycles in Sienna field, for line location look to ***Error! Reference source not found.***

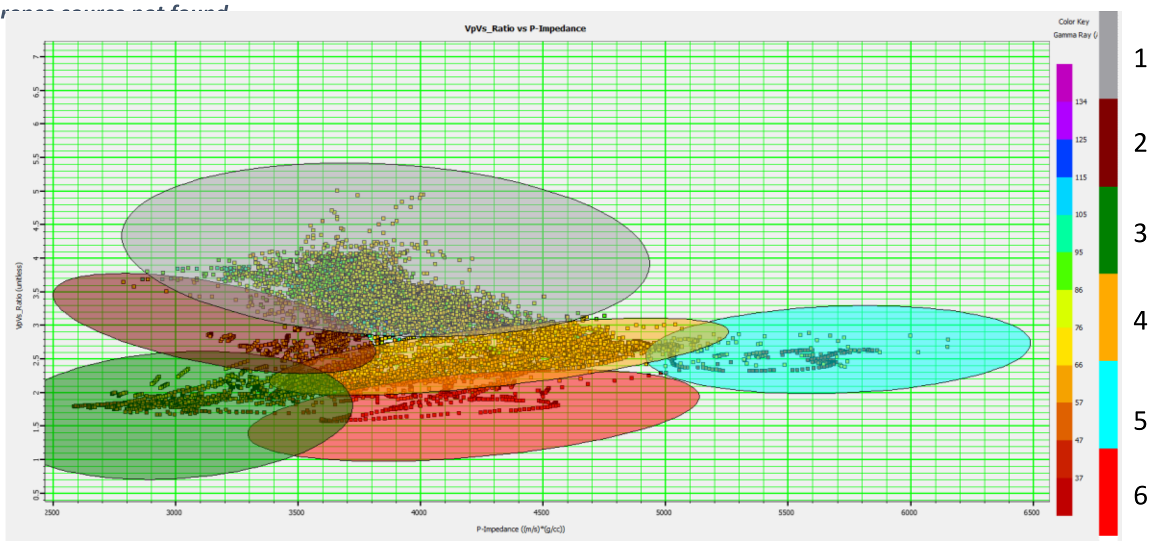

Figure 11 Rock Physics cross plot between Vp/Vs (y-axis) and Zp (x-axis) to discriminate between lithology and fluid. Zone-1 represents shale background, Zone-2, Zone-3, and Zone-6 represent Gas sands with different rock quality, Zone-4 represents shaly sand and Zone-5 Represents water sand.

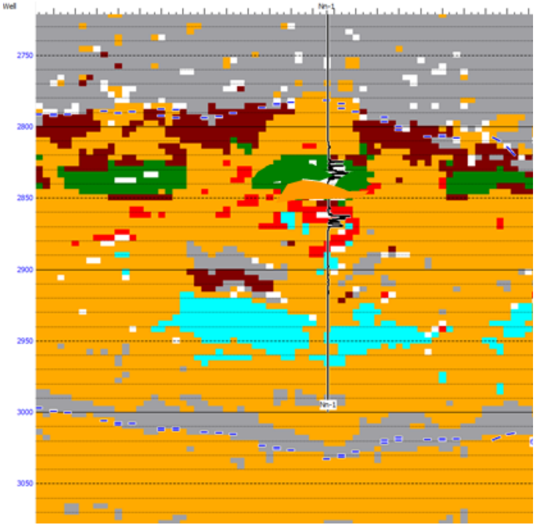

Figure 11 shows assigned cutoffs from previous cross plot for inverted Vp/Vs cube, where zone-2 is gas sand, Zone-1 is Water sand, Zone-3 and Zone-4 are back ground shales

Another workflow was conducted to enhance this interpretation and recognition of the four internal channelized architecture inside Sienna main body from seismic, was gamma-ray pattern and response from NN-1 well as seen in Figure 15a. The well was analysed and showed different facies; course to medium sand, siltstone and mudstone where the channel starts by courser clastics at base of the canyon transforming into finer sediments at the top. Each depositional cycle encounters the same depositional patterns and the next depositional cycle will erode the top part of the older one and deposit the coarser sediments. For high-resolution subdivision for these four cycles, para sequences are made with multicycles so the well is subdivided into four mega cycles with more than forty-six para or micro cycles as seen in Figure 15a.

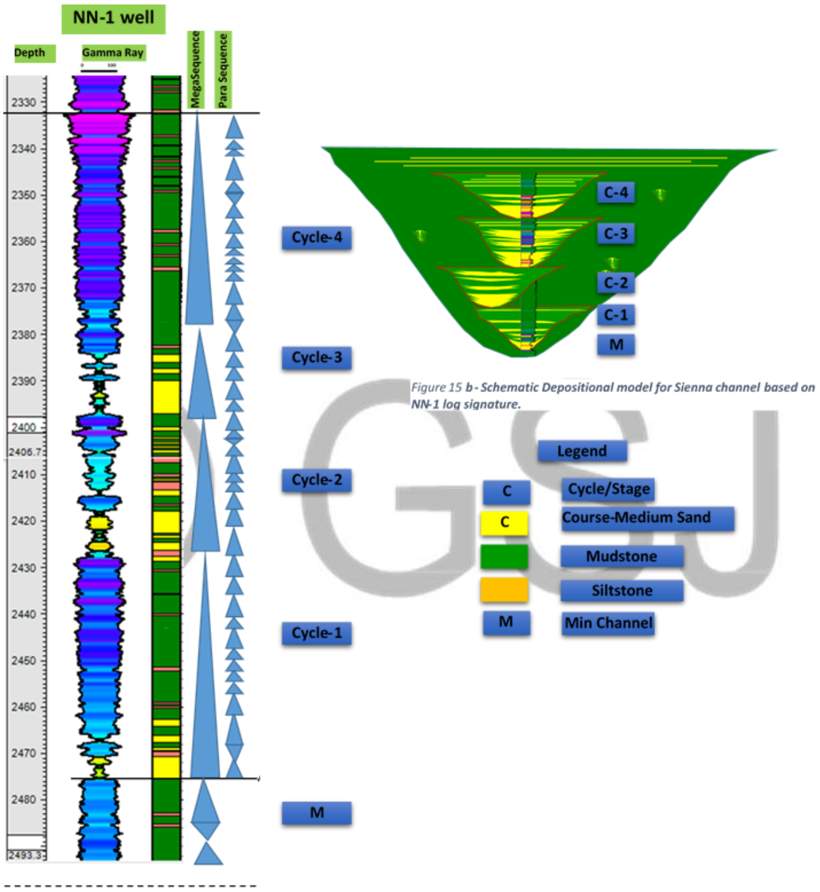

Figure 15 b - Schematic Depositional model for Sienna channel based on NN-1 log signature.

Figure 13 NN-1 a-well depositional cycles from GR log

Figure 15b represents 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 the levee part in cycle number two; which explains the low net to gross which encountered by the well. 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 distally, the sand content becomes less. Another reason for that, is the well penetrated more levee parts of the multi-stacked channels which cut upon each other. NN-2 well proved also four mega sequences and Para sequences of the channel.

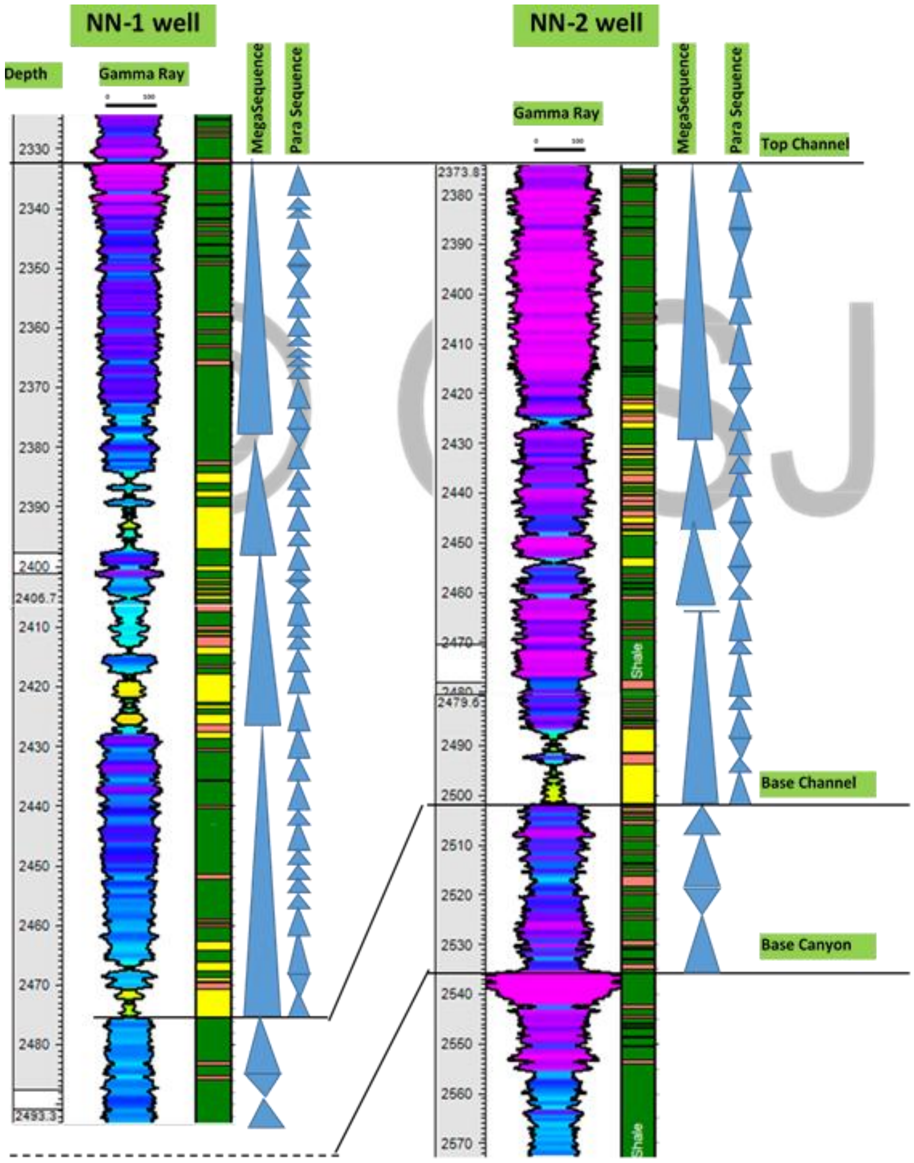

Figure 14 correlation panel between NN-1 and NN-2 wells through Sienna channel

Results

The integration of seismic amplitudes, maps, attributes, inversion model and well log data, allows interpreter to predict the depositional stages of turbidite channels like Sienna case study and the evolutional history of this kind of channels could be noted starting from stage one (channel incision) passing through stage two (Initial valley fill) then stage three (Re-incision and Fill) to the final stage (channel abandonment) as shown below and Figure 17.

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 prior to 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) (Samuel et al.2002).

Stage II: Initial Valley Fill

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

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, as shown in 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 sections show that some of the re-incised channels are infilled by low-amplitude deposits, which are interpreted to be predominantly shales.

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 finally, hemiplegics Figure 17.

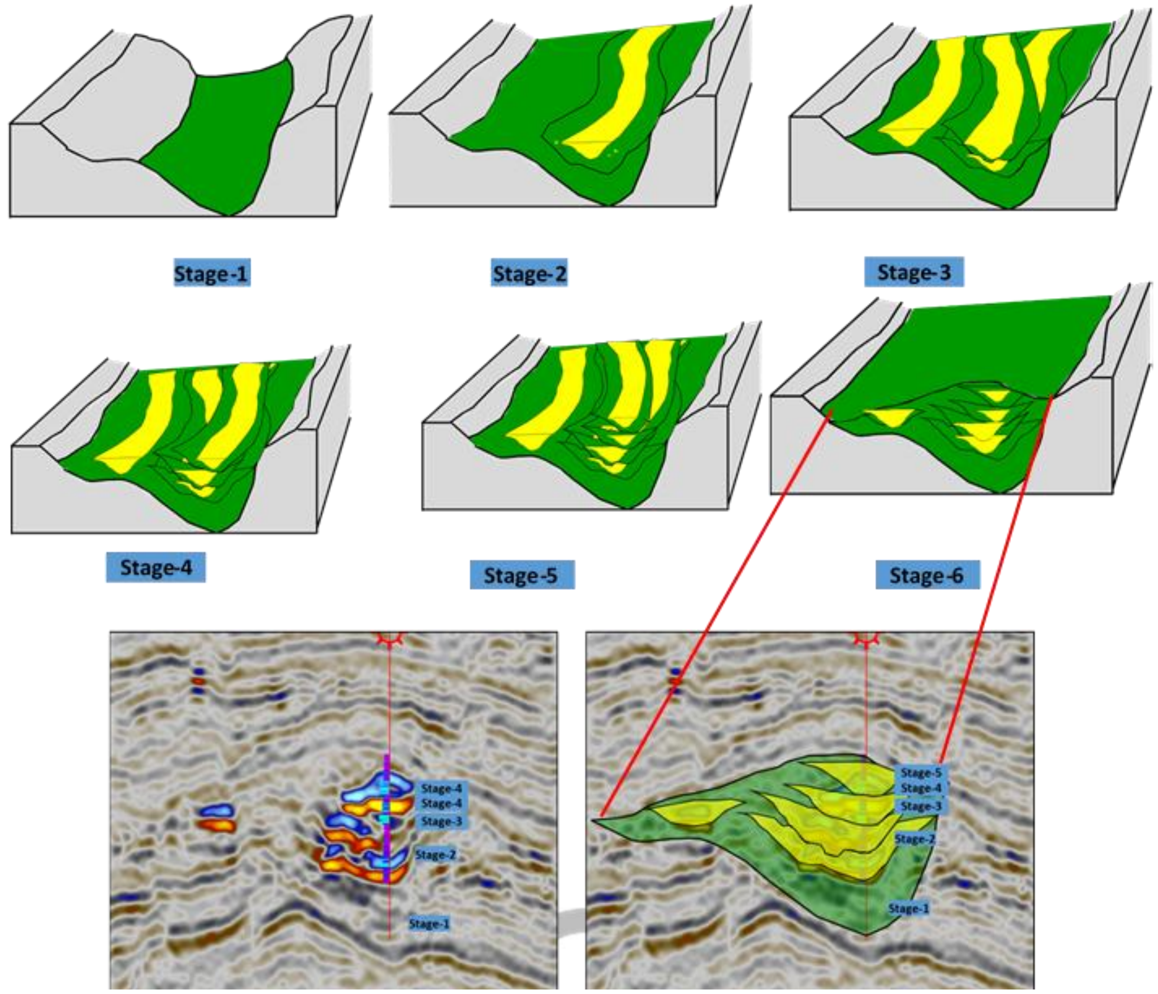

Figure 15 Stage I of the channel development: Channel Incision; Stage II of the channel's development: Initial valley fill; Stage III to V of the channel's development: Reincision and fill.

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'.

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

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