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Application of Seismic Attributes for Pliocene Turbiditic Channel Reservoirs Delineation, Denise Field, Offshore Eastern Mediterranean, Egypt.

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DENISE Field is located in Temsah concession, at the eastern part of the offshore Nile delta with the extension of the field area is about 160 sq. km., about 60 km. off the coast line, North East of Damietta and North West of Port Said. The main reservoirs of Denise Field are Pliocene Denise sands which are divided into three different reservoirs: upper Denise sand, middle Denise sand, and lower Denise sand. The two main reservoirs in terms of areal extension and production are the upper and lower Denise sands. These reservoirs are mainly composed of sandstone of turbiditic origin, which are expressed as bright spot seismic amplitude anomalies as one of the most common Direct Hydrocarbon Indicators (DHI), with a clear flat spot seismic feature representing the gas water contact in the proven area. While faraway about this area it is problematic to delineate the reservoirs, due to the low reflectivity that produced by the huge thickness of Pliocene shales. Similarly, the low resolution of shallow interval with missing data due to the existence of the drilling platform in time of acquiring the seismic data.

The purpose of this paper is to delineate the two main reservoir levels; upper Denise sand and lower Denise sand through regional structure and stratigraphy seismic interpretation using the power of seismic attributes. The seismic interpretation workflow was an integrating process between conventional seismic interpretation and seismic attributes extraction and interpretation, where the interpretation was refined continuously based on the seismic attributes results.

With the aid of related seismic attributes, seismic interpretation has been done and refined for the top upper Pliocene surface as well as the two reservoirs of interest. Amplitude maps along the reservoir surfaces and multiple seismic attributes have been extracted resulting in a good delineation and linking of the reservoirs and their equivalent prospect areas in the field. Finally, the integration of these tools confirmed the areal extension and distribution of these reservoirs and the existence of three new prospect locations in the field to be proposed for drilling.

Keyword: Denise Field, Seismic Attributes, Seismic Amplitude Interpretation, Pliocene Reservoir.

Introduction

The Nile Delta cone is one of the emerging gigantic and prospective gas provinces in the Eastern Mediterranean basin that still seems to hide most of its potential. The area of study (Figure 1), Denise Field, is located in Temsah Concession of Nile Delta offshore region in a water depth around 80-90 m with the extension of the field area is about 160 sq. km, about 60 km off the coast line, North East of Damietta and North West of Port Said. It lies between latitudes 31° 43’ 41.10” and 31° 59’ 45.39” N, and longitudes 31° 58’ 30.03” and 32° 13’ 27.01” E.

The aim of the paper is to redefine the structure

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interpretation over the field through applying and integrating different seismic interpretation techniques to study structural evolution and the stratigraphic features of Plio-Pleistocene sediments.

Through integration of conventional interpretation and seismic attributes we aim to determine regional, field, and minor scale structural features as well as correlate different reservoir stratigraphic levels. By using different seismic attributes for better structural interpretation and reservoir extension and distribution delineation in the field, it's expected to propose new prospects for future drilling.

Geologic Setting

The Plio-Pleistocene play is associated with slope and basin-floor turbidites in the form of channel/channel-levees and sheet sands/sandstone enveloped in Plio-Pleistocene shale and supported by seismic amplitude anomalies. This play has been extensively and successfully explored and exploited in the external domain of Nile Delta and Mediterranean basins in the last decades. It is structurally controlled by listric normal faults with wide rollover anticlines within the Pliocene section which seems to be detached at top Messinian where minor extension is still provided from the deep-seated faults. These extension stresses cause system unbalancing inside the Pliocene section that contains thick shale content causing two effects: 1) Listric faults with minor detached at top Messinian (brittle unconformity surface) and 2) Shale swelling inside Pliocene with rollover anticline. The continuous subsiding seems to be related to reactivated deep seated faults, with thick shale overburden that adsorbs stresses by compaction and releasing it from the sides away from the fault by flowing (Abdel Aal, et al., 1994).

In the study area, the interaction between tectonic and sedimentation is more evident and diffused. Most faults in the study area didn't reach until the sea floor, so classified as "buried growth faults". Northern from Denise Field (Tuna development lease), the faults affect the sea floor which are named "active growth faults". The first faults activity is recorded in the Middle Pliocene with the displacement of most of the early Pliocene succession and the deposition of a thick middle-late Pliocene section. The origin of these faults has been related to a thick evaporitic interval and to the latest movements of pre-existing Miocene positive structures, in addition to huge sedimentary input, sourced from west or south west (Abd-Allah et al, 2012).

The general sub-surface Stratigraphy of Nile delta (Figure 2) is based on sub-surface geological data gathered from wells and previous studies. The Pliocene cycle defined by Rizzini et al., 1978 is subdivided into Kafr El Sheikh and El Wastani Formations (Abu El-Ella, 1990).

Sedimentation of the Pliocene in Nile Delta consists of a deep marine sequence of Early Pliocene age unconformably overlying Abu Madi (Central sub basin) and Rosetta (Eastern sub basin) Formations. These marine sequences are the shaly sediments of the Kafr El Sheikh Formation. These grades upwards, toward the top of the formation, into littoral and fluvial sands referred to El Wastani Formation, constituting the upper part of the Pliocene cycle. The Pliocene cycle is underlying the Pleistocene/Holocene, transgressive cycle of Mit Ghamr and Bilqas Formations. This stratigraphic nomenclature for the formations (rock units) is modified after Rizzini et al., (1978).

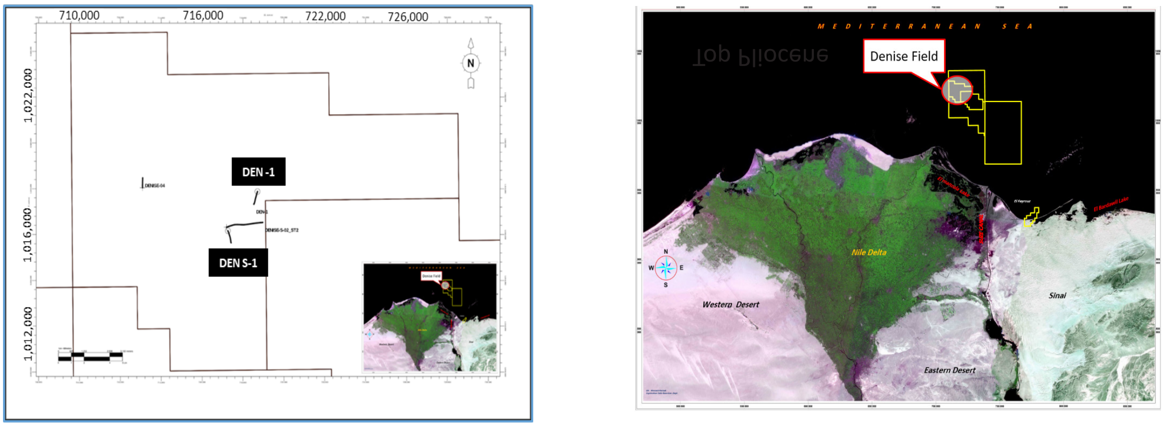


Fig. 1. Location map of the study area.

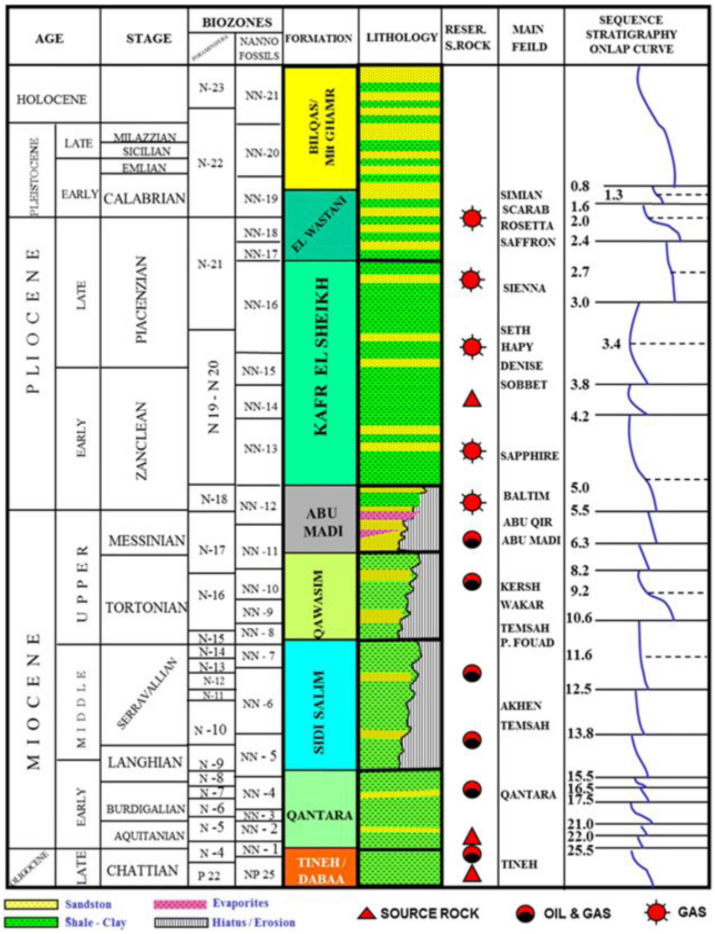


Fig. 2. Generalized litho-stratigraphic column of Nile Delta. Modified after (Rio et al, 1991).

Dataset and methodology

In order to detect and delineate the turbiditic channel Pliocene reservoirs, it is needed to apply conventional seismic interpretation and seismic attributes and integrating their outcome.

Dataset

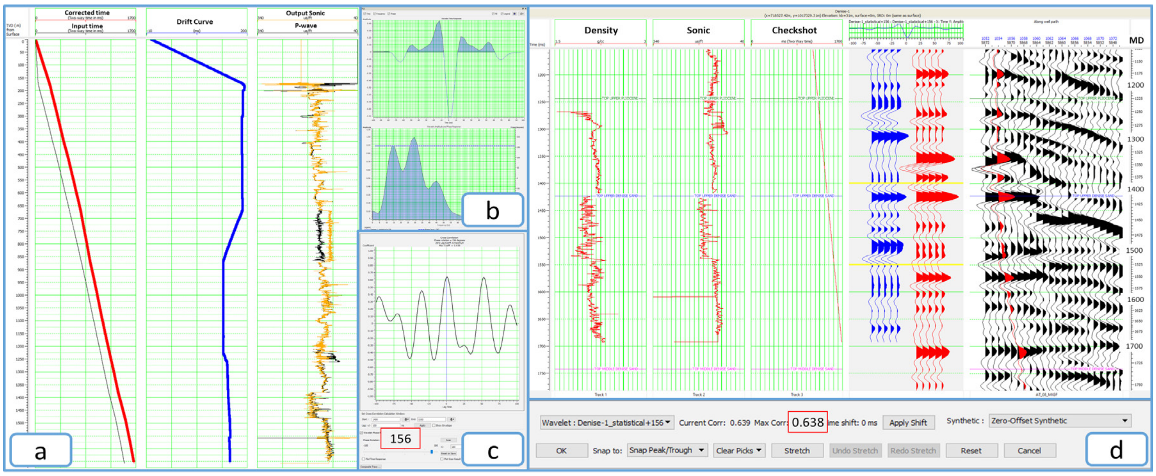
The dataset consists of 3D post-stack seismic data covering Denise Field and two wells including logs of gamma ray, deep resistivity, neutron porosity, density, sonic logs, and check shots. The first well, Denise-1, is targeting the shallower reservoir (Upper Denise sand), while the second well, Denise South-1, is targeting the lower reservoir (Lower Denise sand).

Seismic to well tie

The workflow started by performing seismic to well tie for the two wells to generate synthetic seismograms. In seismic to well tie process, statistical wavelets were generated using the available seismic dataset around the wells and scanned the phase shift to confirm the reverse polarity of the seismic dataset.

Figure (3) shows the steps for Denise-1 well synthetic generation, starting with check shot correction and sonic calibration, then using the statistical wavelet extracted from traces near the well, and scanning for the phase shift which finally resulted in a reverse polarity wavelet conforming with the seismic data polarity with an accepted phase residual. The correlation between the synthetic seismic trace and seismic data exceeded 60 percent with an excellent match at upper Denise sand reservoir level.

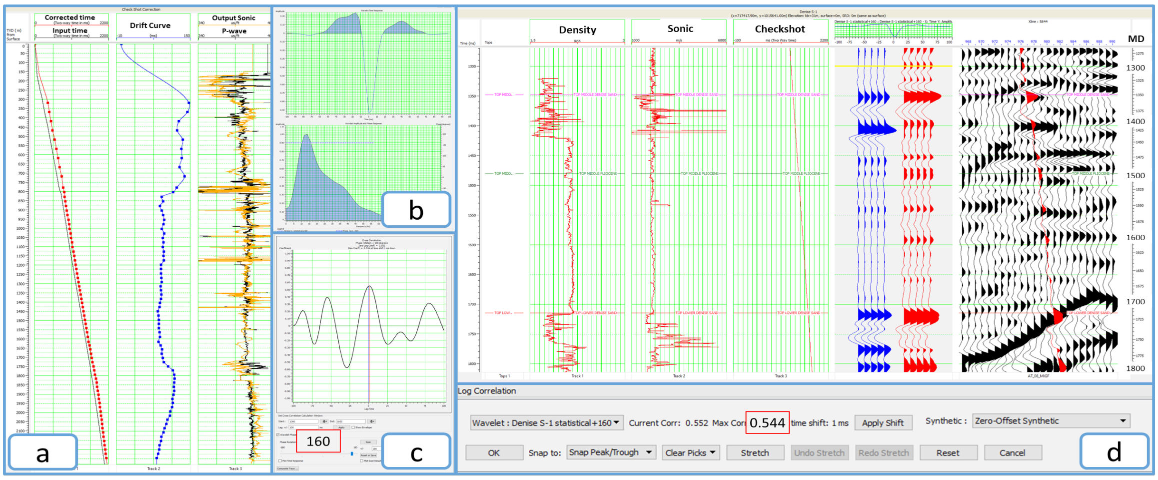
Figure (4) shows the same procedure of seismic to well tie for Denise south-1 well with a correlation of 53 percent with a good match for lower Denise sand reservoir. The correlation for the two generated synthetic seismograms is a bit low due to low resolution seismic data which can be noticed from amplitude spectrum in Figure (3) and Figure (4).



Wavelet : Denise-1_statistical+156 Current Corr: 0.639 Max Corr: 0.638 ime shift: 0 ms Apply Shift Synthetic : Zero-Offset Synthetic

Snap to: Snap Peak/Trough

Fig. 3. Seismic to well tie in Denise-1 well. (a) Sonic calibration, (b) extracted statistical wavelet scanned and rotated 156° after phase rotation maximum correlation in(c), and (d) synthetic seismic trace generation with correlation of 0.638.



Wavelet : Denise S-1 statistical+160 Current Corr: 0.552 Max Cor 0.544 time shift: 1 ms Apply Shift Synthetic : Zero-Offset Synthetic

Snap to: Snap Peak/Trough

Fig.4. Seismic to well tie in Denise south-1 well. (a) Sonic calibration, (b) extracted statistical wavelet scanned and rotated 160° after phase rotation maximum correlation in(c), and (d) synthetic seismic trace generation with correlation of 0.544.

Conventional Seismic Interpretation

After seismic to well tie, the next step is to start picking seismic reflectors. Interpretation started with picking top upper Pliocene reflector, as the main time boundary for Pliocene sequence. The interpretation of top upper Pliocene is an important kick off as this surface and its structures will be used as an initial guide for interpreting and extending other horizons interpretation through the field. In total, Seismic interpretation was carried out for five seismic reflectors; top upper Pliocene surface, top sea floor and top Rosetta surfaces to understand the initiation and vertical migration of faults affecting the plio-pliestocene section, and then finally the two main reservoirs of top upper Denise and top lower Denise sands.

Seismic Attributes

Seismic attributes are calculated by mathematical manipulation of the seismic data main components which mainly are time, amplitude, phase, frequency, and waveform (Caineng Zou et al, 2013). During seismic wave propagation through different earth interfaces and layers, these characteristics change significantly (Aminzadeh and Dasgupta, 2013). Approximately, there are more than 300 computable seismic attributes with the number of commonly used seismic attributes is around 50 – 60 (Ming Li and Yimin Zhao, 2014). In this paper, the attributes applied are instantaneous phase, cosine of instantaneous phase, discontinuity, fault likelihood, reflection strength, perigram, sweetness, as well as extracting the root mean square amplitude maps.

In addition, stratigraphic attributes were blended with structural attributes.

In Figure (5), it is noticed the low reflectivity due to the huge thickness of Pliocene shales and the low resolution of shallow interval with missing data due to the existence of the drilling platform in time of acquiring the seismic data. The seismic attributes extraction and interpretation has been an effective and useful for the horizon and faults interpretation especially away from the clear high impedance contrast areas that are characterized by low reflectivity and low seismic resolution. Figure (5) is a comparison of non-interpreted and interpreted NE-SW crossline passing through Denise-1 and Denise south-1 wells.

Results and Interpretation

Instantaneous phase and cosine of instantaneous phase cubes were extracted and used for a better seismic interpretation. They look like highly gained seismic data (Fig. 6). Seismic reflections on instantaneous phase and cosine of instantaneous phase sections are then easier to follow because they address the phase component and remove the amplitude component contrasts that usually mask reflection continuity (Barnes, 2016). For this reason, they are both considered as a perfect continuity attribute.

Fault likelihood attribute is one of the most powerful structural attributes. It represents the probability of faults at each sample location (Imran et al., 2021) This attribute was mainly effective in capturing and interpreting major faults as well as minor faults that are mostly difficult to detect using conventional seismic data. The unique process of fault likelihood attribute includes many enhancement steps that start with creating a smoothed filtered volume and then creating slope volume, semblance volume, thinning volume, and tracking volume. This resulted in finally creating a structure oriented filtered volume with a better and more detailed fault interpretation. Because of these post processing techniques involved in fault likelihood attribute extraction, it gives more detailed faults orientation than the discontinuity attribute (Fig. 7 and Fig. 8).

Seismic attribute maps were also used interchangeably with seismic mapping to delineate the reservoir channels extension and to confirm the possible hydrocarbon potential areas. Root mean square (RMS) amplitude surfaces were extracted with a suitable interval window of extraction to represent the reservoir interval. RMS amplitude maps show the areal extension of both levels of upper Denise and lower Denise reservoirs. Another useful use of RMS amplitude maps is extracting the amplitude maps on Near stack seismic volume and Far stack seismic volume. Comparison of far and near RMS amplitude maps can be used as a quick indicator of Class 3 AVO anomaly (Figure 9). However, RMS amplitude maps are extremely affected with the low resolution of seismic data and the lack of coverage due to platform existence before acquiring the seismic data acquisition.

Other attributes were extracted; Instantaneous amplitude, perigram, and sweetness, using the same extraction window to better highlight the reservoir delineation and overcome the low resolution of conventional seismic data.

Instantaneous amplitude is a measure of amplitude, commonly named as "envelope" or "reflection strength". It represents the amplitude magnitude of the sinusoid trace at a given time or at a given window about that time. It is independent of polarity and phase of seismic data (Barnes, 2016). Instantaneous amplitude highlights bright spots, dim spots, and all Direct Hydrocarbon Indicators (DHIs) anomalies in general.

Perigram is the amplitude envelope (reflection strength) with the low frequency component removed. It is suggested that such a display would make the locations of energy maxima more obvious in the seismic section (Gelchinsky et al. 1985). Perigram has essentially the same uses as reflection strength; but because perigram data has both positive and negative values, it can be analyzed with the standard color maps and can be subjected to trace mixing or other data enhancement processes.

Sweetness is an attribute designed to identify "sweet spots", which are oil and gas prone places. It is defined as response amplitude divided by square root of response frequency. Response amplitude is the value of the envelope at the envelope peak, while response frequency is an attribute that records instantaneous frequencies at envelope peaks. Sweetness definition is motivated by the observation that sweet spots tend to be characterized seismically by strong amplitudes and low frequencies. Reflection strength and instantaneous frequency often are substituted in place of response amplitude and response frequency to produce a more variable sweetness measure (Barnes, 2016). Figures (10 and11) show the reflection strength, perigram, and sweetness attributes for both upper Denise and lower Denise sand reservoirs respectively.

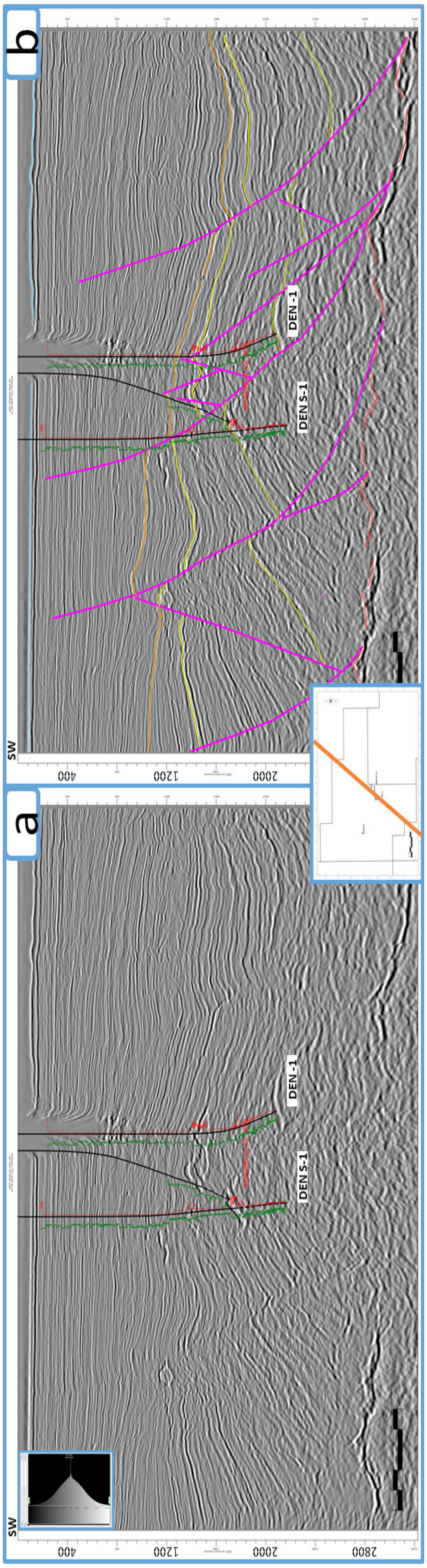


Fig.5. Seismic Cross-line 5844: A comparison between un-interpreted (left) and interpreted (right) Seismic section passing through Denise-1 and Denise south-1 wells, showing the main structures, interpreted horizons, and reservoir levels with gamma ray (green) and resistivity (red) well logs .

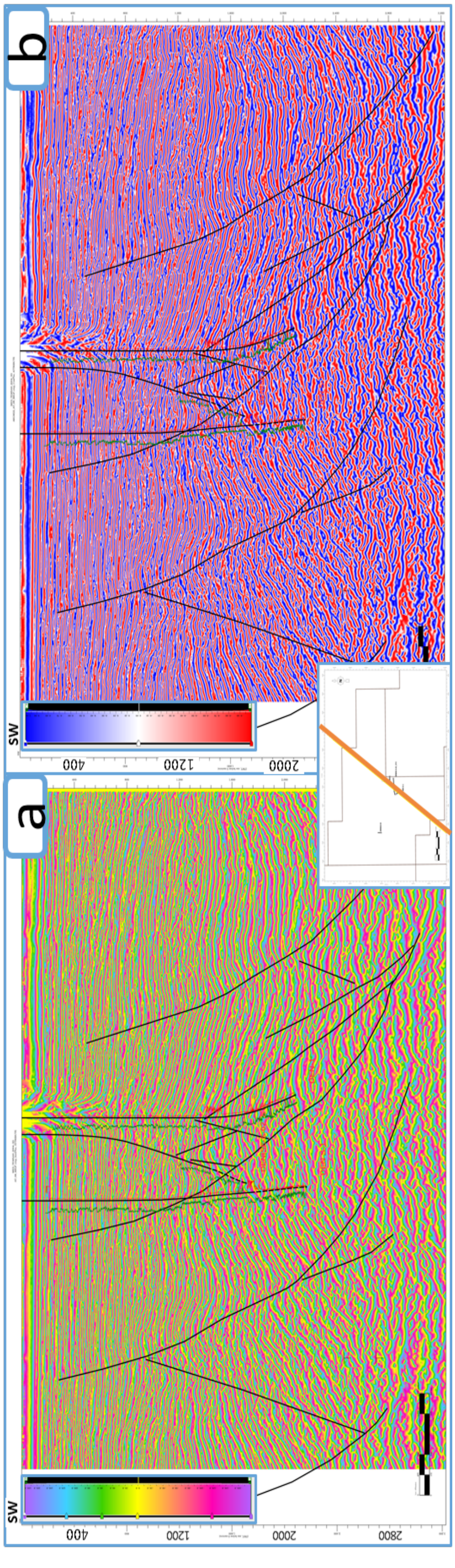


Fig. 6. Seismic Cross-line 5844: Instantaneous phase attribute (left) and Cosine of instantaneous phase (right).

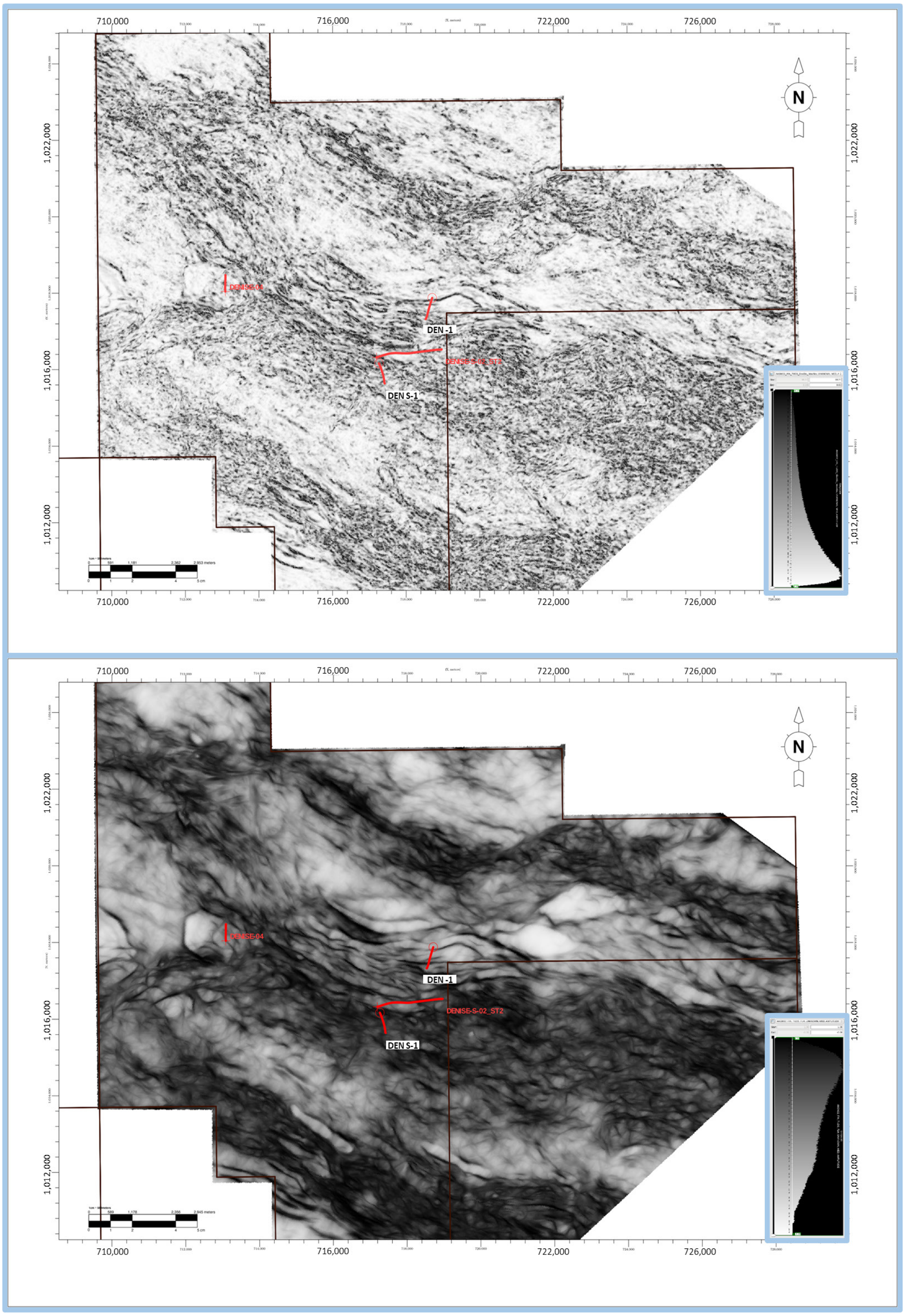


Fig. 7. A comparison between horizon based Discontinuity and Fault Likelihood attributes. Above, is Upper Denise sand Discontinuity attribute map, while below, is Fault Likelihood attribute map.

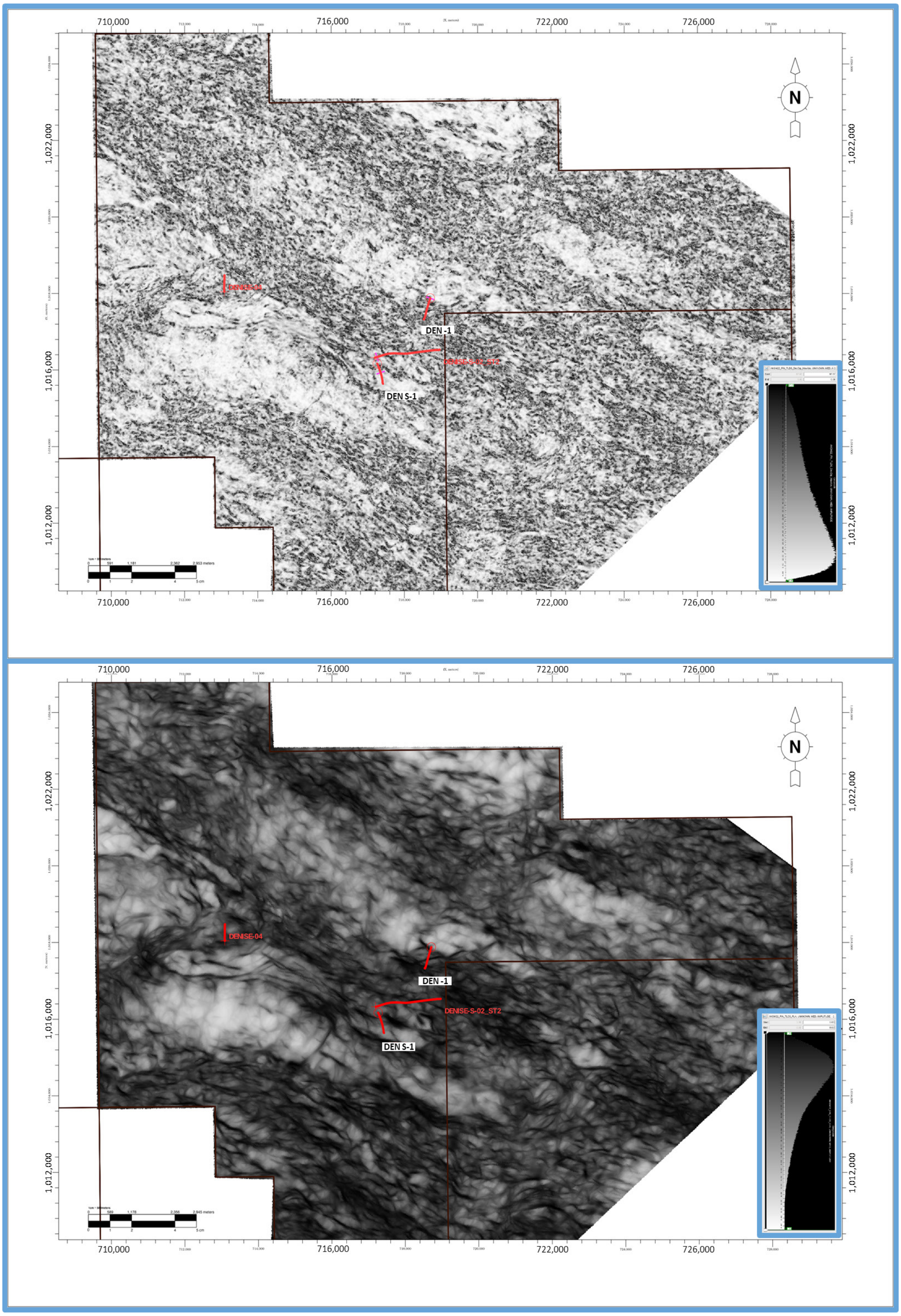


Fig. 8. A comparison between horizon based Discontinuity and Fault Likelihood attributes. Above, is Lower Denise sand Discontinuity attribute map, while below, is Fault Likelihood attribute map.

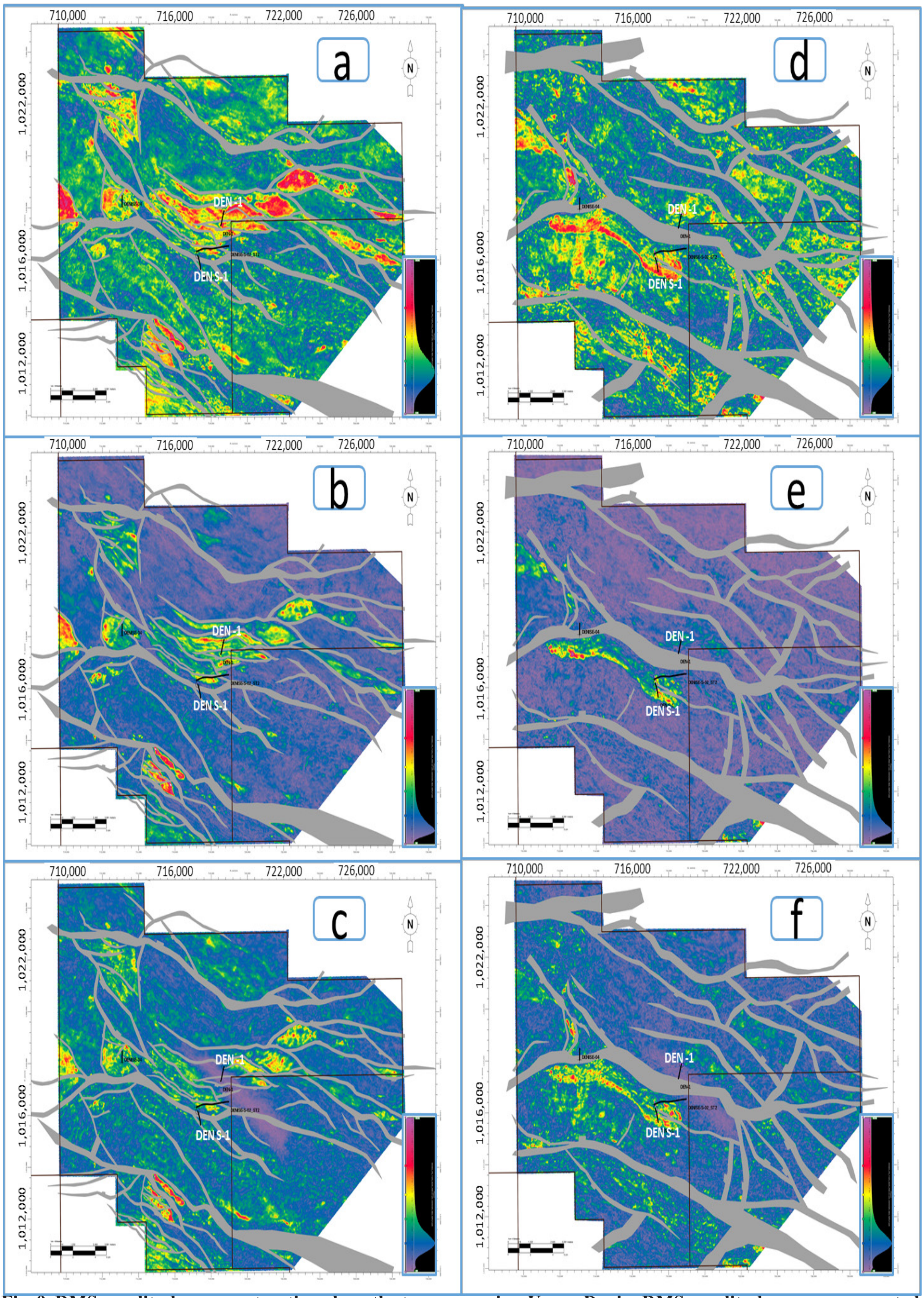


Fig. 9. RMS amplitude maps extraction along the two reservoirs: Upper Denise RMS amplitude maps represented in Full (a), Far (b) and Near (c). While Lower Denise RMS amplitude maps represented in Full (d), Far (e), and Near (f). Quick look on Far and Near amplitude maps indicate class 3 AVO anomaly.

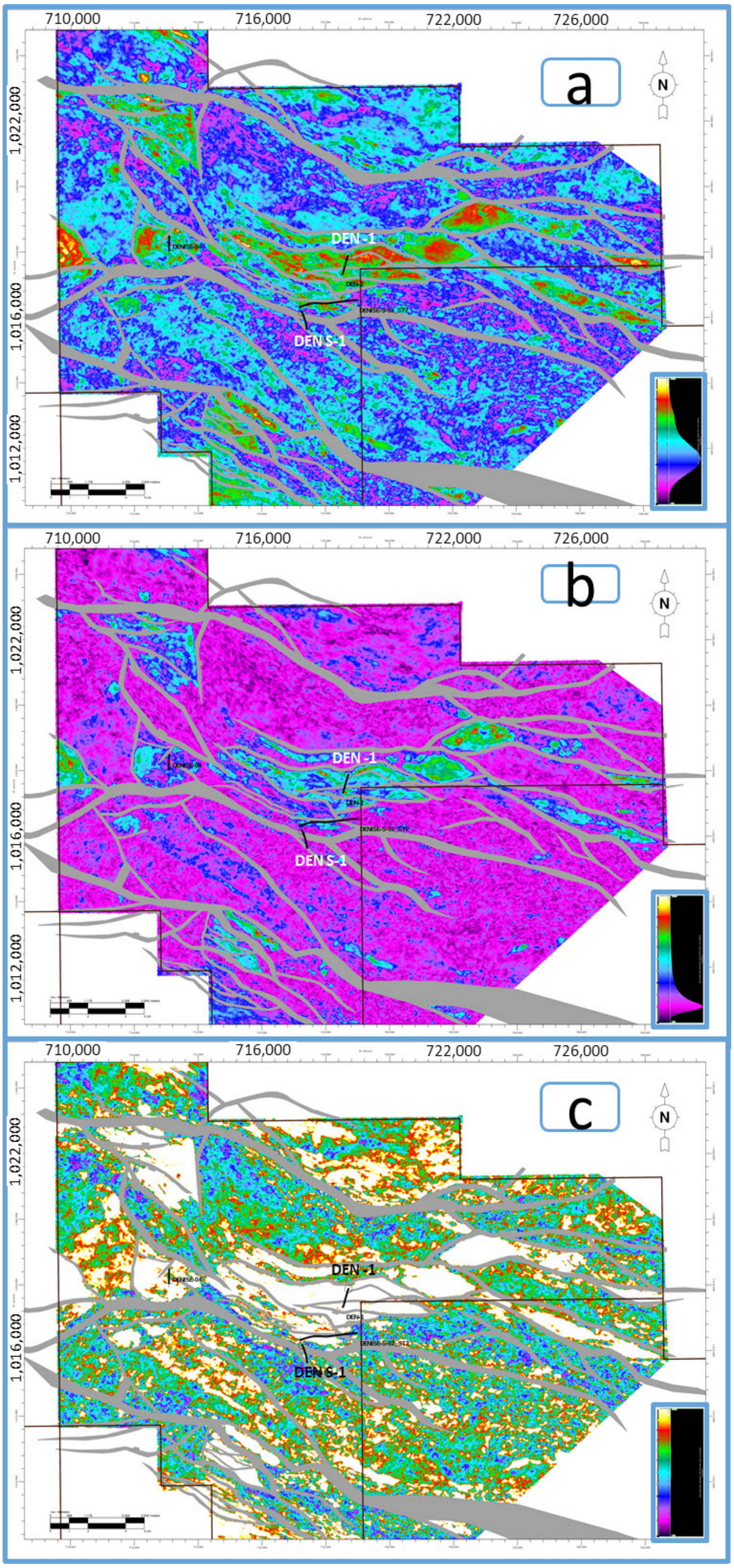


Fig.10. Reflection strength (a), perigram (b), and sweetness (c) attribute maps for Upper Denise sand.

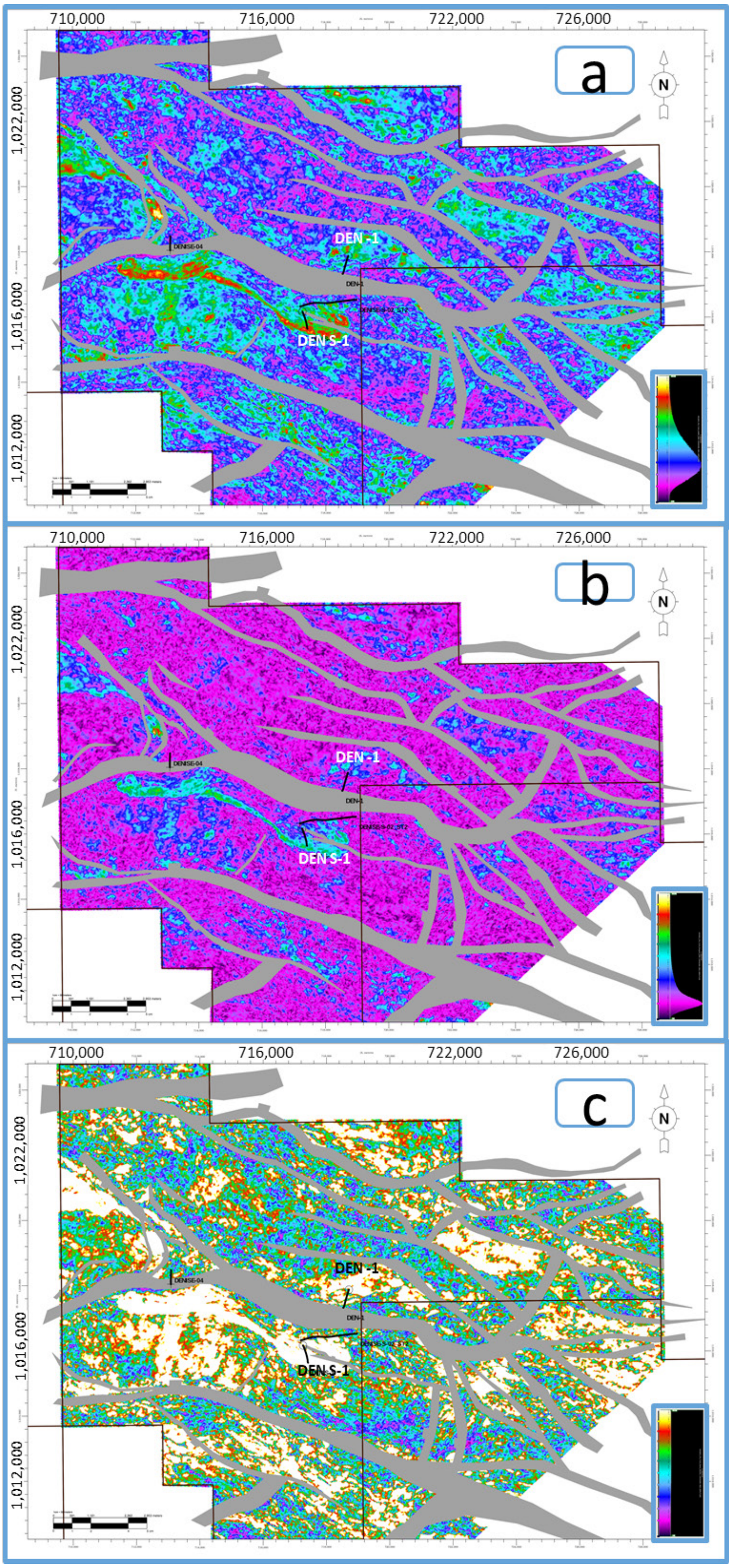


Fig. 11. Reflection strength (a), perigram (b), and sweetness (c) attribute maps for Lower Denise sand.

Integrating the results and surface attribute maps from these three stratigraphic attributes helped in defining the equivalent reflectors through the field and strengthen the confidence in interpretation where no control points are available. Away from the wells, to South and to East, new prospects have become clear and easy to detect. Anomalous area of instantaneous amplitudes, perigram, or sweetness values indicate the possibility of gas bearing sand equivalent to the same levels in the drilled wells in the main field.

With the aim of getting the maximum benefit of volume attributes extracted, the concept of multi-attribute blending was utilized through the power of visualization and opacity function. This is done by overlaying a semi-transparent foreground attribute that is related to stratigraphy or geophysical information on top of a background attribute that highlights geological structure so that both are visible. One of the advantages of multi-attribute blending is when structural attribute looks like illuminated apparent topography that suggests 3D subsurface geologic structure (Barnes, 2016). Blending of stratigraphy indicating attributes such as RMS amplitude, reflection strength, sweetness, or perigram with structural attributes such as discontinuity or Fault Likelihood (FLH) strengthen the relation between stratigraphic and structural representation as shown in Figure (12) and Figure (13).

Another strategy we used here is strengthen the structure component through multiplication of Fault Likelihood attribute with the dip guided discontinuity attribute. Blending the previously mentioned stratigraphy attributes with this new created structure attribute is powerfully increase highlighting the structure orientation and increasing the sharpness and presentation of structural component (Figures 12 and 13).

By integrating seismic interpretation with seismic attributes, the final time surface grids for both reservoirs were created and refined. Using the velocity information of the available wells represented in calibrated sonic logs after synthetic generation and integrated time depth tables (Figure 14), Depth maps were then created which in integration with the amplitude maps and attributes extracted (Figure 15 and Figure 16) defined the reservoir areal extension and highlighted the prospect areas.

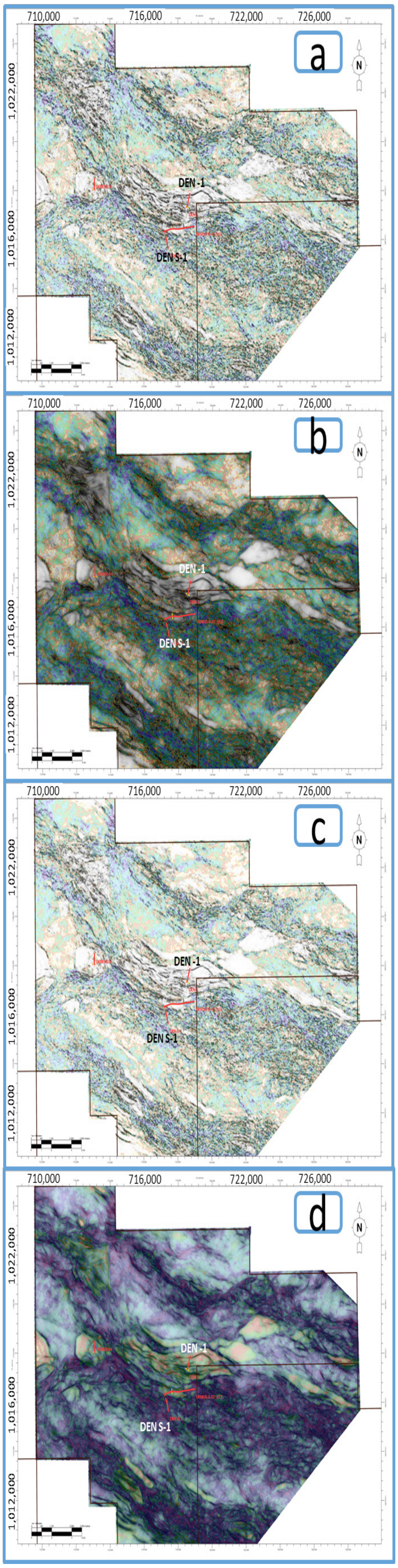


Fig. 12. Multi-attribute blending maps of Upper Denise sand. Different maps represent different attributes blending where (a) is sweetness attribute blended with dip guided discontinuity, (b) is sweetness blended with Fault Likelihood, (c) is sweetness blended with structure blended attribute of discontinuity multiplied by fault likelihood, and (d) is reflection strength blended with discontinuity and fault likelihood.

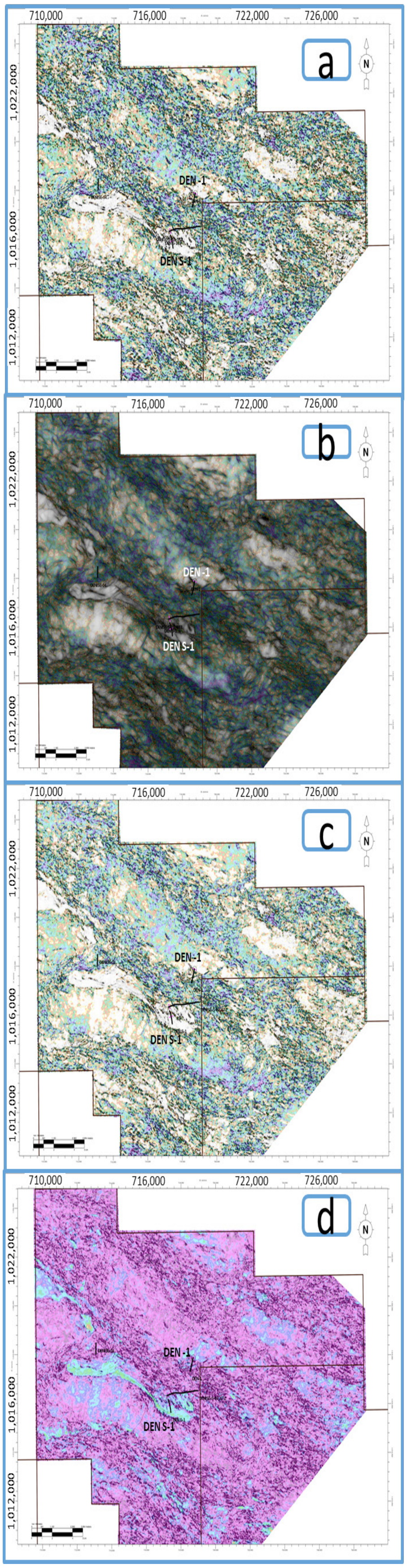


Fig. 13. Multi-attribute blending maps of Lower Denise sand. Different maps represent different attributes blending where (a) is sweetness attribute blended with dip guided discontinuity, (b) is sweetness blended with Fault Likelihood, (c) is sweetness blended with structure blended attribute of discontinuity multiplied by fault likelihood, and (d) is perigram blended with discontinuity and fault likelihood.

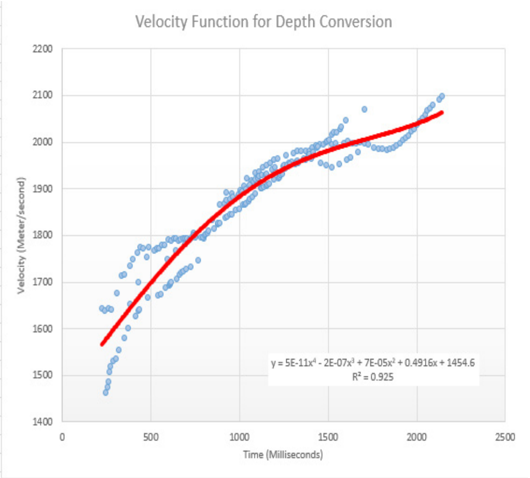


Fig. 14. Velocity function used for depth conversion using the integrated time depth tables after sonic calibration.

In Figure (15), Upper Denise sand final depth map with integration of the blended structural-stratigraphic attribute map have effectively highlighted the structures affecting the reservoir and the areal extension of the reservoir where the already drilled and drained area is highlighted in orange polygons and arrows, and the proposed extension of the reservoir and new prospects to the east and south in black arrows.

In Figure (16), Lower Denise sand structures have been effectively mapped and the extension of the reservoir has been identified. Integration of Lower Denise sand final depth map and blended seismic attribute map highlighted the main body drilled in orange polygon and arrows, and new prospects to East and South in black arrows.

Conclusion

The integrated seismic data interpretation as a result of conventional seismic interpretation, seismic attributes analysis, and multi-attribute blending of the two reservoirs of interest exhibited an enhanced mapping and correlation all over Denise Field. While instantaneous attributes such as reflection strength, perigram, and sweetness displayed the reservoir extension. Structure attributes such as discontinuity and Fault Likelihood enabled more accurate and detailed fault interpretation to clear the structural relationship between different blocks. Final depth maps of the two reservoirs in integration with enhanced multi-attribute blended maps confirmed the areal extension of the reservoir and highlighted areas of prospects that need further investigation.

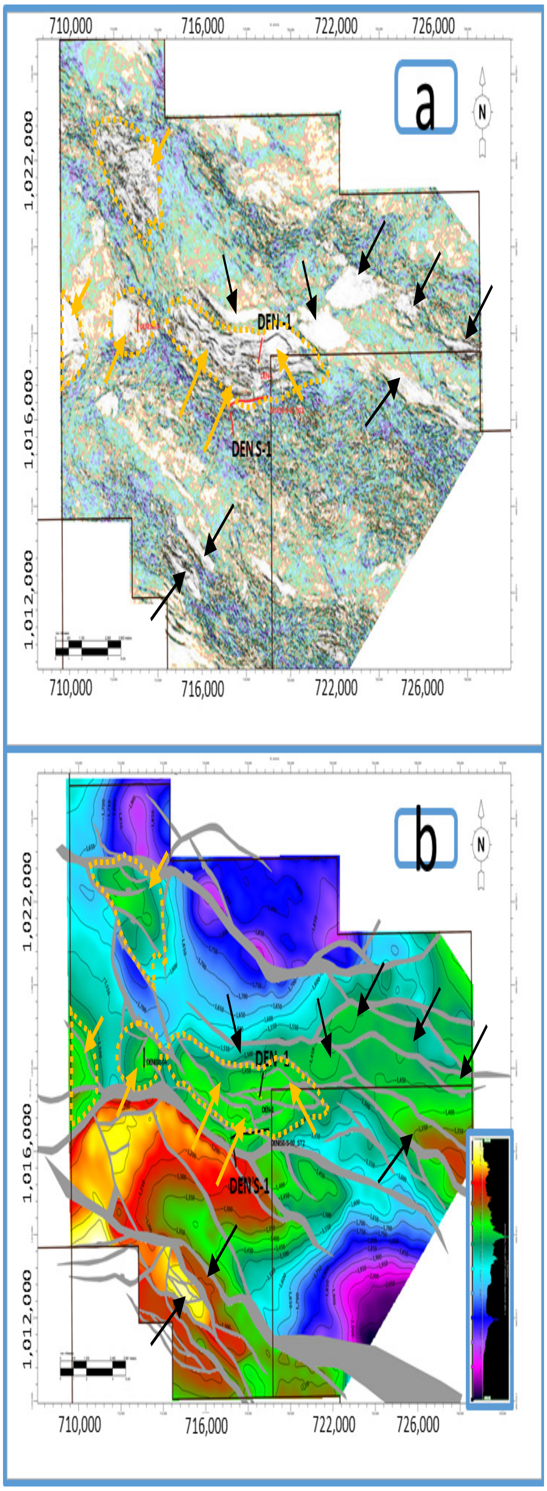


Fig. 15. Upper Denise sand reservoir multi-attribute blending map of sweetness, discontinuity, and fault likelihood (a), and final depth map after using the velocity function equation (b). Orange arrows and polygons refer to drained area, while black arrows refer to new proposed prospects.

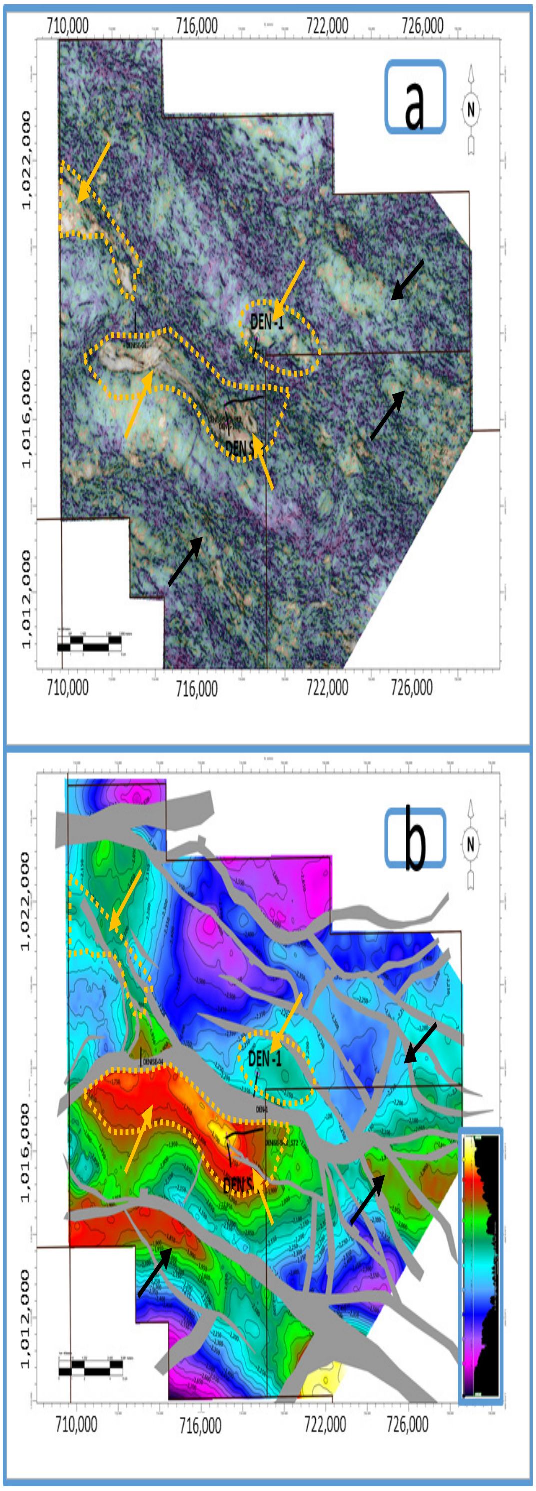


Fig. 16. Lower Denise sand reservoir multi-attribute blending map of reflection strength, discontinuity, and fault likelihood (a), and final depth map after using the velocity function equation (b). Orange arrows and polygons refer to drained area, while black arrows refer to new proposed prospects.

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إستخدام السمات السيزميه لتحديد خزان البليوسين ذو القناه الرمليه المختلطة، حقل دينيس، شرق البحر الأبيض المتوسط ، مصر.

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يقع حقل دينيس في منطقة امتياز التمساح، في الجزء الشرقي من دلتا النيل البحرية حيث تبلغ مساحة الحقل حوالي ١٦٠ كيلو متر مربع، و يبعد حوالي ٦٠ كيلومتر قبالة خط الساحل، شمال شرق دمياط وشمال غرب بورسعيد. الخزانات الرئيسية في حقل دينيس هي رمال دينيس البليوسينية التي تنقسم إلى ثلاثة خزانات مختلفة: رمال دينيس العليا، ورمال دينيس الوسطى، ورمال دينيس السفلى. الخزانان الرئيسيان من حيث المساحة تحت السطحيه والإنتاج هما رمال دينيس العلوية والسفلية. تتكون هذه الخزانات بشكل أساسي من الحجر الرملي، والذي يتم التعبير عنه سيزميًا بشذوذ قيم السعه السيزميه و التي تتمثل في بقعه مضيئه كواحده من أكثر المؤشرات الهيدروكربونية المباشرة شيوعًا، مع وجود تمثيل سيزمي أفقي واضح يمثل الحد الفاصل بين المياه و الغاز في منطقة الخزان المثبتة بالحفر. في حين أنه بعيدًا عن هذه المنطقة، من الصعب تحديد الخزانات، بسبب الانعكاس السيزمي المنخفض الذي ينتج عن السماكة الهائلة لصخور البليوسين. وبالمثل، فإن البيانات السيزميه تكون منخفضة الجوده للجزء الزمني الضحل بسبب وجود منصة الحفر في وقت الحصول على البيانات السيزميه.

الغرض من هذه الورقة البحثيه هو تحديد المستويين الرئيسيين للخزان؛ رمال دينيس العليا ورمال دينيس السفلية من خلال التراكيب الجيولوجيه الإقليميه والتفسير السيزمي الطبقي باستخدام قوة السمات السيزميه.

كانت أعمال التفسير السيزمي عملية متكاملة بين التفسير السيزمي التقليدي واستخراج الخصائص السيزميه وتفسيرها، حيث تم صقل التفسير باستمرار استنادا إلى نتائج السمات السيزميه.

بمساعدة السمات السيزميه ذات الصلة، تم التفسير السيزمي توضيح أعلى سطح البليوسين وكذلك الخزانين المهمين. تم أيضًا استنباط و رسم خرائط السعة على طول أسطح الخزان والسمات السيزميه المتعددة مما أدى إلى تحديد وربط جيد للخزانات و مناطق جديده للحفر في هذين الخزانين في منطقة الدراسه. وأخيرا، أكد التكامل بين استخدام التطبيقات المختلفه الإمتداد الأفقي و توزيع هذه المكامن و وجود ثلاثة مواقع متوقعه جديده في الحقل يُقترح حفرها.