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3D SEISMIC INVERSION FOR TERSA OIL FIELD, El FAYIUM AREA, WESTERN DESERT, EGYPT

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النمذجة العكسية للبيانات السيزمية ثلاثية الأبعاد، بحقل ترسا منطقة الفيوم، الصحراء الغربية، مصر

الخلاصة: يقع حقل ترسا في الجزء الشمالي من منطقة امتياز الفيوم في شمال شرق الصحراء الغربية بجمهورية مصر العربية، جنوب بحيرة قارون، وهو احد الحقول المنتجة لشركة بتروسيلة في منطقة الامتياز، منذ سنة ٢٠٠٩، ويعتبر في مرحلة التنمية.

وعلى مدى التاريخ الجيولوجي للمنطقة تعرضت منطقة الدراسة لحركات تكتونية متعددة مثل انعكاس الحوض الترسيبى ونظام القوس السوري، وقد تركت هذه الاحداث أثار واضحة وعميقة على التراكيب الجيولوجية بالمنطقة، كما أثرت بشكل مباشر على تواجد الهيدروكربونات وإنتاجية المنطقة.

تم عمل خرائط تركيبية للتكوينات الصخرية الأساسية بمنطقة ترسا، عن طريق استخدام البيانات السيزمية ثلاثية الأبعاد بالإضافة لتسجيلات الآبار المتاحة من الآبار المحفورة بالمنطقة. النتائج أوضحت وجود مناطق تأثير تكتونية تشمل عدة فوالق بإتجاهات مختلفة مثل الشمال الشرقي، كذا الشمال الغربي، مما كان لها عظيم الأثر في تجميع المواد الهيدروكربونية.

تحتوي بيانات الموجات الانعكاسية السيزمية على معلومات تتجاوز مظاهر التراكيب الجيولوجية والعمق، بل يضع كل سطح طبقة إنعكاس بصمة تحتوي على معلومات أكثر من إنها موجات منعكسة مثل الكثافة والسرعة. ومن أجل تحسين الإنتاجية بحقل ترسا تم عمل نمذجة عكسية للبيانات السيزمية ثلاثية الأبعاد لحساب والحصول على أكثر إحتمالية حدوث هذه الخصائص فيم وراء الانعكاسات السيزمية، ولقد تمت معالجة النموذج الأولي بعدة محاولات للوصول لنموذج نهائي ذو دقة عالية.

ولقد أعطت النتائج فرصة لفهم أعمق لمنطقة البحث وخصائصها الجيولوجية، مما قد يساعد لوضع خطة تنمية أكثر دقة لتحسين إنتاجية المنطقة وزيادة الإنتاج لمستويات قياسية.

ABSTRACT: *Tersa area lies within El Fayum concession, in the eastern part of the northern Western Desert of Egypt, to the south of Qarun lake (Fig. 1). Tersa area is one of the producing fields for Petrosilah oil Company in El Fayum concession since 2009, the field currently under development. The study area has a long history of tectonic movements, many deformation zones affect and are controlling the potentiality of the area. Structural configuration through interpretation of high resolution PSTM 3D seismic reflection data, as well as the available drilled wells, play a good role to define the different deformations. The result shows deformational zones in the area, including different sets of fault orientations. The seismic reflection data contain more information rather than the structural and depth data, each reflector print has its own characteristics on the reflected waves. In order to enhance the field productivity, a post stack inversion performed, to assess the area beyond the conventional interpretation. To apply a model-based inversion technique for the 3D seismic data, the generated initial model was processed through a number of iterations, to construct a reliable P-impedance inverted model. Although the 3D seismic data of El Fayum area is not processed for the true amplitude recovery data, the result offered a better understand for the study area and its properties distribution, which can be considered as significant indication for the future development plan for the field to increase the productivity.*

INTRODUCTION

Geologically, El Fayum Concession is located at the southern part of El Gindi Basin in the north eastern corner of Western Desert. El-Fayum area lies within the unstable shelf of the pan African plate (Said, 1962). It is characterized by the presence of a very thick section of Apollonia Formation.

The field is elongated in the ENE.WSW direction, and surrounded by many productive fields. The field is tectonically affected by a lateral strike-slip movement, which plays, significant role in forming the structural style of the area (Moustafa, 2008). The field, discovered in late 2009, have multi productive pays from different blocks and closures, with the challenges of structural and stratigraphic complication and is still beyond the full capacity of production.

Seismic data inversion was technologically started around 1980, when the algorithms of wavelet amplitude and phase spectra extraction became available (Lindseth, 1979), as a process to better understanding the convolution of the seismic wave with the earth reflectivity content beneath the surface, which would enhance the prediction of reservoir characterizations, to improve and enhance the hydrocarbon productivity.

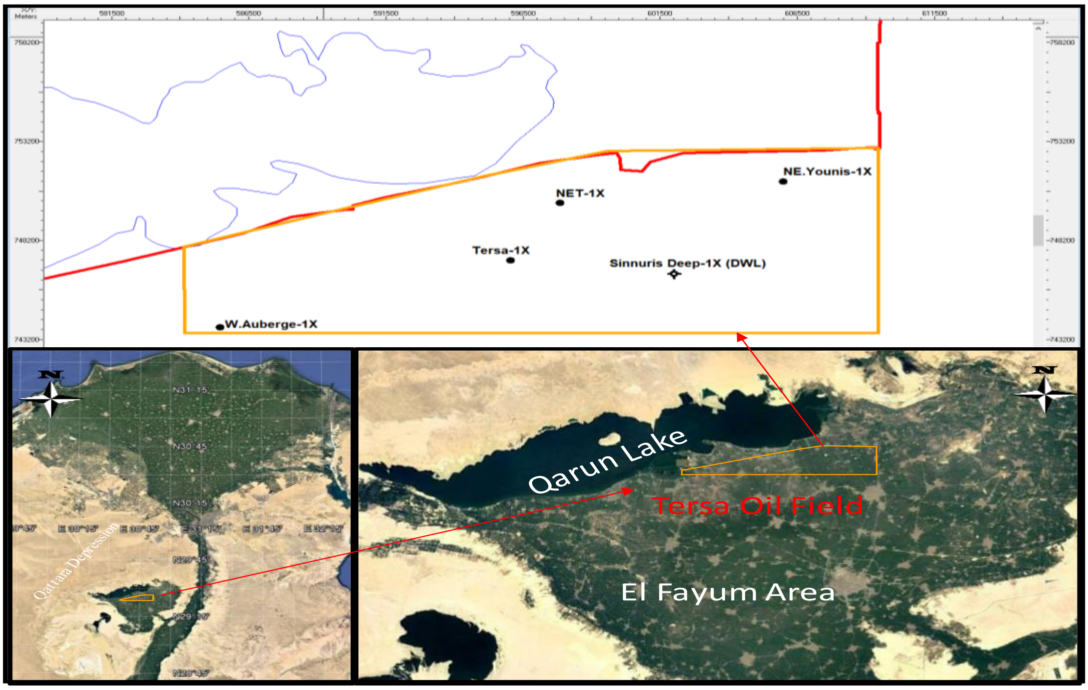

Fig. (1): Location map of Tersa oil field.

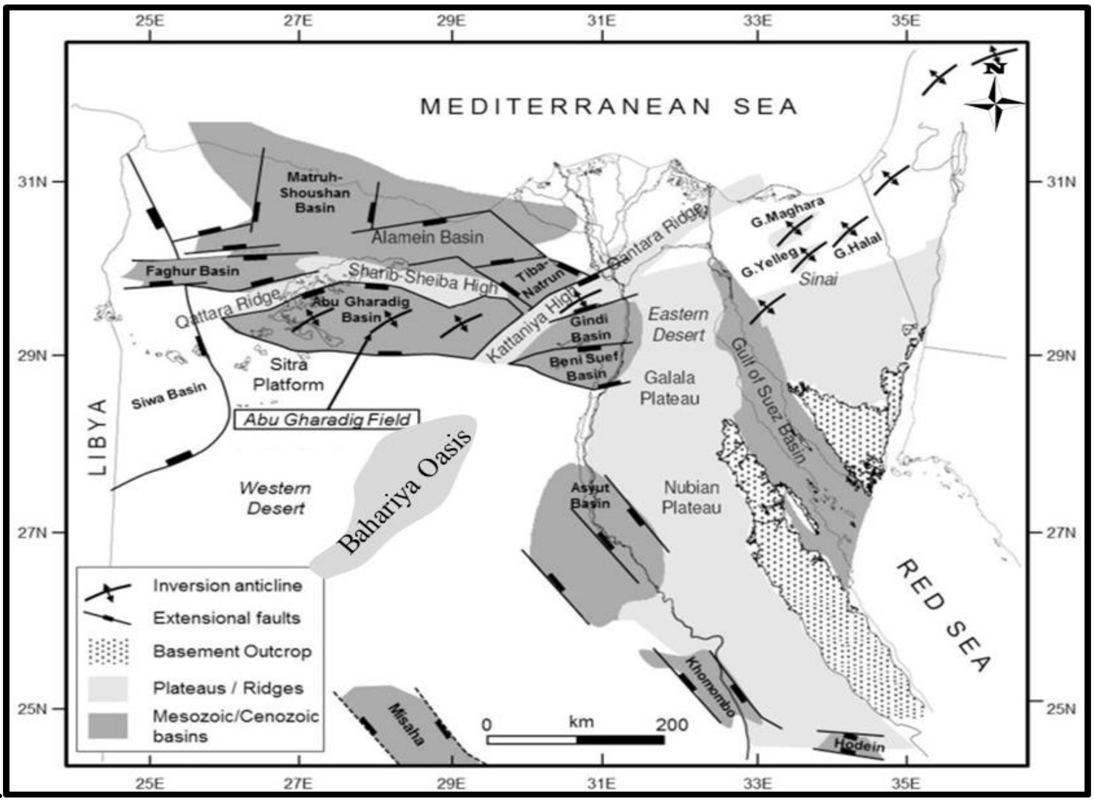

Figure (2): Mesozoic and Cenozoic basins with the main structural elements affecting in the Western Desert and Sinai (after Dolson et al., 2001).

Tectonic Evolution

The northern Western Desert has a long history of tectonic events started from the Ordovician age and extended to the Miocene. With a sequence of lifting up and subsidence, compressional and extensional, many of these events have a significant finger print tell nowadays, which result in a complicated structural regime in the study area. This part of the Western Desert province was affected by three different phases of deformations during the Mesozoic and Cenozoic (Fig. 2) time interval (Moustafa, 2008), These are:

1- Jurassic-Early Cretaceous rifting.

2- Late Cretaceous-early Tertiary positive structural inversion.

3- Miocene and Post-Miocene Extension.

The study area is a typical model of the tectonic situation of the northern part of the Western Desert, but the most effective event, which mainly formed the main structures of the area of study occurred by the end of Cretaceous. It is an important tectonic phase resulted in the elevation of the major portion of the basin along an east north east – west south west trend, which is known as the Syrian arc folding system and this phase continued till the Middle Eocene time. The Syrian arc folding system runs from Syria, Northern Sinai, crossing the Nile River and terminated at the south west of the area of study. During this phase, sets of faults with different directions developed in the area of study. The first Syrian arc basin inversion event occurred, which resulted in the folding, faulting, uplifting and subsequent erosion of the Santonian and older formations in the cores of the inverted anticlines, such as at Wadi Araba, on the western side of the Gulf of Suez (Moustafa, 2013).

Stratigraphy

The stratigraphic sequence of El Fayum area includes a sedimentary succession ranging in age from Cretaceous to Miocene (Fig. 3), the study area is characterized by the absence of the Paleozoic and Jurassic rocks, probably due to non-deposition. A thin section of the Lower Cretaceous sediments was deposited directly over the Precambrian basement rocks, and in turn covered by the Cenomanian and Turonian sediments.

A remarkably thin section of the Upper Cenomanian Khoman Formation was deposited over the Turonian rocks. The reduced thickness of the Khoman Formation is related to the uplifting of the area during the Late Cretaceous time. The area witnessed the deposition of shallow marine Paleocene to Middle Eocene carbonate rocks of the Apollonia Formation, which are currently exposed on the surface in the Fayum depression. The thickness of the individual rock units changes in different parts of the area, in response to the prevailing tectonics at the time of deposition, as will be indicated later (Abd El-Aziz, Moustafa and Said 1998).

Structural Regime

The eastern part of the northern Western Desert structures is dominated by faults, mostly it is normal faults and have a long history of growth. Most of these faults have affected by a sequence of tectonic events, from rifting by the extensional force, rejuvenated and tilting by the compressional force, even some of those faults has a strike-slip movement. The Strike-slip movements seem to have affected the orientation of many of the fold axes in this part of the Western Desert. The regional overview of El Fayum area, indicates two major sets of faults influencing the area, Northwest-Southeast and Northeast-Southwest. These trends are the typical trends of the northern part of the Western Desert of Egypt (EGPC, 1992).

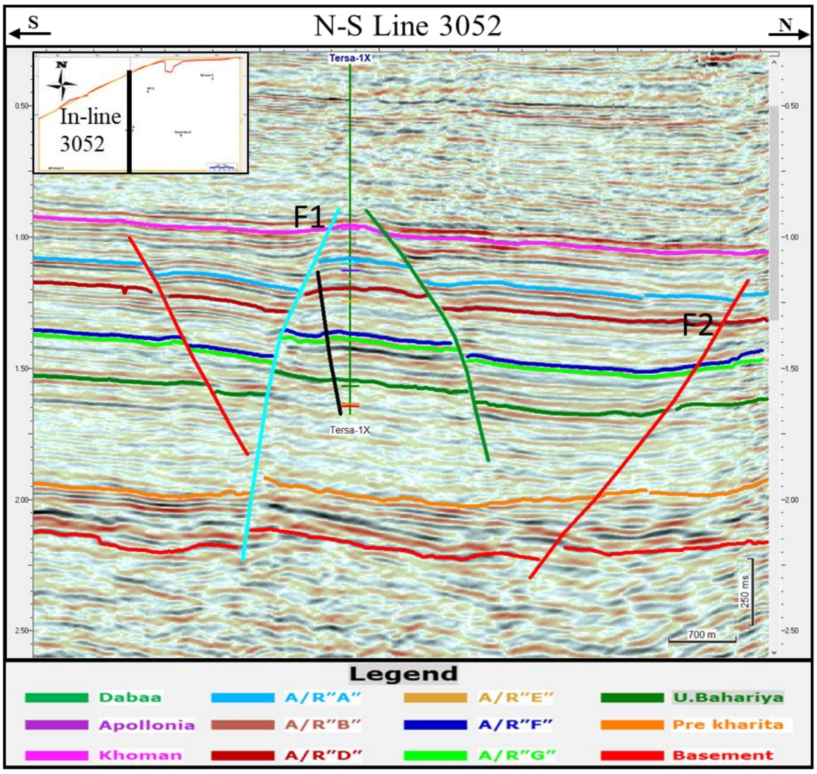

Figure (3): Seismic Section (In-line 3052) over the Tersa-1X Well.

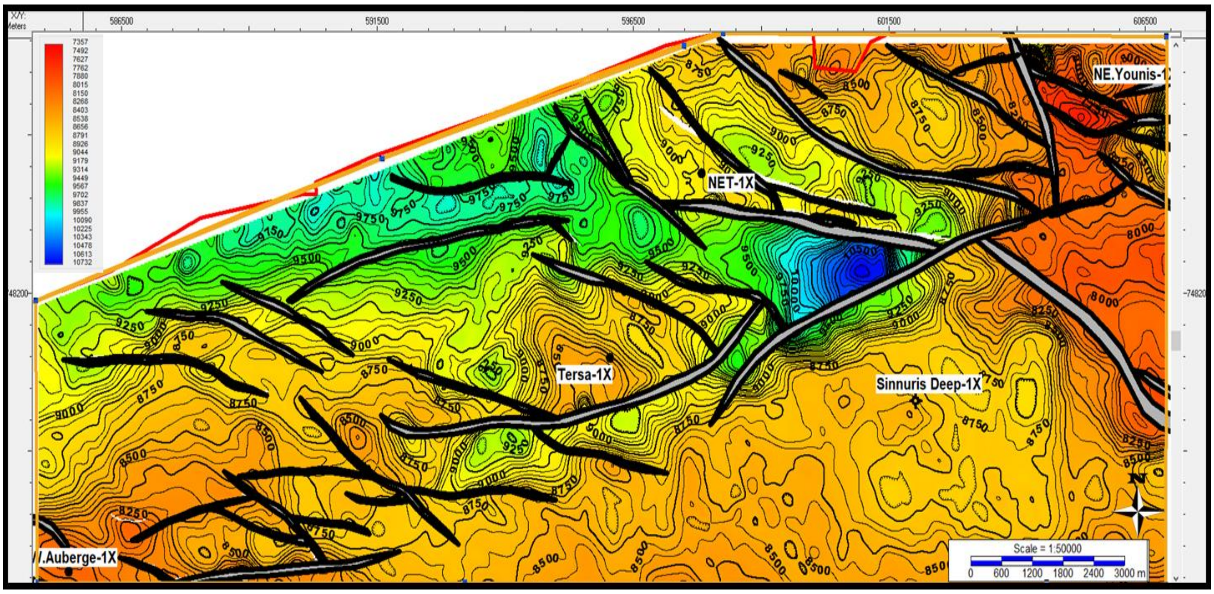

Figure (4): Upper Bahariya Formation Depth (ft) Structure Map.

Seismic Data Interpretation

Structural elements are considered as the main factor controlling the oil potentiality of any region, the delineation of these elements is the first step to evaluate the area for exploration from the basin scale to the reservoir scale. El Fayum 3D seismic data were acquired and processed in 2007, many discoveries were recorded, based on the structural interpretation model.

Pre-stack time migration (PSTM) data were used to evaluate the structural framework over Tersa field, 30 seismic sections varying between In-line (N-S) and X-line (E-W), in addition to 5 wells (Fig. 1) with the available well data used to identify the lithostratigraphic units over the area. Figure (3) shows a N-S seismic section passing through the main discovery well in the Tersa oil field (Tersa-1X) well, the section shows a horst block in the middle part, with antithetic normal fault in the South direction from the main fault (F1), forming a small graben block, with a normal deep fault (F2) affects the northern part of the section, creating another larger graben.

El Fayum area has multi-target reservoirs, one of the important productive reservoirs, the Upper Bahariya Formation, which belongs to the Cretaceous age. Many of the structural events affected the area are within that age, that usually developed at the Bahariya Formation level; older as same as the recent events. The Upper Bahariya Formation depth structure map (Fig. 4) reveals that, the effect of tectonism, that reached a high level of deformation.

3D Seismic Data Inversion

Seismic inversion involves extracting qualitative, as well as quantitative information from the seismic reflection data, which acquired in normal polarity. Inversion results showed high-resolution seismic data, that enhanced the interpretation and reduced the drilling risk (Pendrel, 2006). The original forward-modeling of the seismic data is bandlimited as a frequency content, and does not have the original low or high frequency data, unlike the well log data, Therefore; an initial model for the low frequency P-impedance is established, as generated from the well-log data and interpreted forward seismic model.

Convolution between the rock's reflectivity series and the seismic wave characteristics are controlling the propagation of the seismic wave and the reflection/ transmission coefficients, which affect the reflectivity pattern and the output traces:

$$S(t) = W(t) * R(t) + N(t) \quad (1)$$

where: S(t) is the recorded seismic trace, W(t) is the source wavelet, R(t) is the reflectivity series, and N(t) is the random noises.

The model-based inversion process aims to re-construct the earth's model and illustrates the physical properties of the layers rocks; which is a mathematical way of estimating and predicting the reflectivity series, that formed the forward model, Then Model-based inversion uses an iterative forward modelling and a comparison procedure (Veeken, 2004), in which the process aims to establish a realized reflectivity series model matching with the other available well log data.

Amplitude-Frequency Spectrum

A frequency spectrum of the amplitude for the 3D seismic data of El Fayum area shows the data content between 4 and 30 Hz, the frequency extended to reach the Nyquist frequency at 125 Hz (Fig. 5).

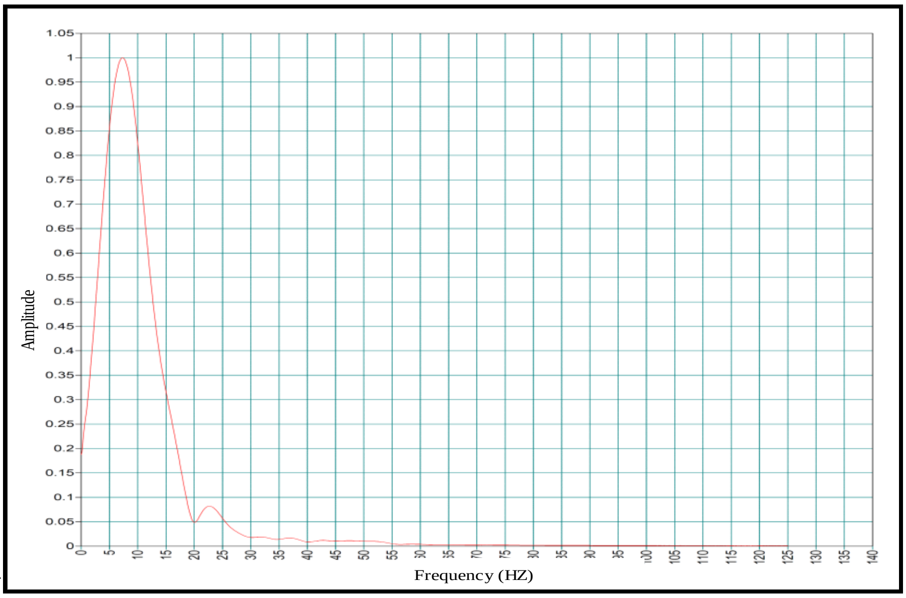

Figure (5): Amplitude-Frequency Spectrum for the 3D seismic data.

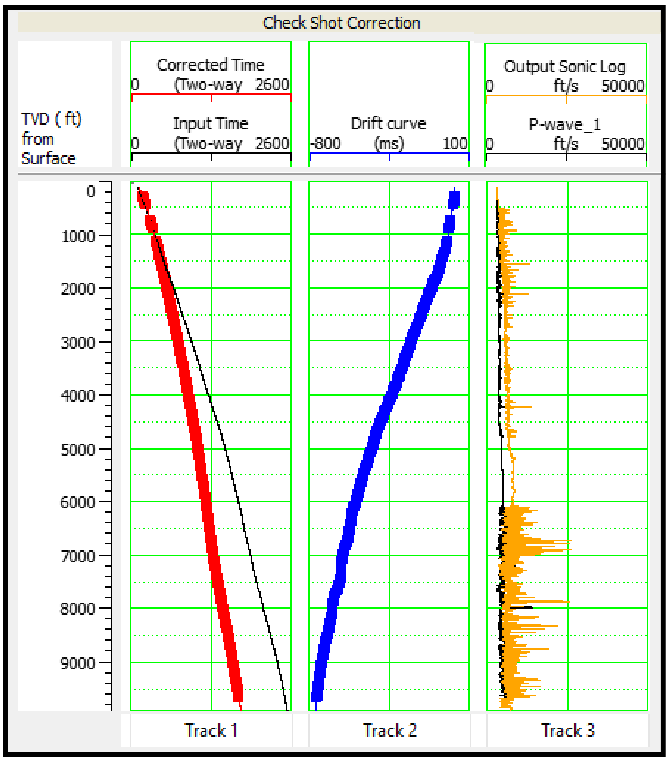

Figure (6): Sonic-Velocity matching for Tersa -1X well.

Sonic-Velocity Matching

This process is required to calibrate the vertical seismic profile (VSP) for Tersa-1X well, with the recorded sonic log (Δt P-wave) for the well, to establish the depth-time calibration. This will be used for generating the synthetic seismogram of such a well, for matching the surface 3D seismic with the recorded well data.

The well logs are recorded in the depth domain, while the seismic data are in the time domain. The velocity check shots are applied on the wells and seismic data to establish the depth-time calibration between the wells and seismic data (Freudenreich, 2004).

Sonic-Velocity matching for Tersa-1X well started, with conditioning the sonic log and de-spike. Figure (6) shows the matching process for Tersa-1X, track (1) is the input of the two-way time (TWT) in black color and the corrected displayed with red color. Track (2) shows the drift curve for the correction process, the curve represents the direction of the time correction.

Synthetic Seismograms

The depth-time relation, established through generating the synthetic seismogram, is considered as an important base for performing the 3D seismic data inversion process.

Figure (7) shows the generated synthetic seismogram along Tersa-1X well, track (1) shows the calibrated density log for the well, track (2) shows the corrected sonic log (P-wave) with the check shots (VSP) curve, track (3) shows the formation tops along the well and track (4) shows the generated synthetic seismogram. The blue traces on this display represent the synthetic traces calculated from the sonic and density logs, using the depth-time curve and the extracted wavelet, while the red traces are the average or "composite" traces extracted from the seismic data. Actually, all the red traces are supposed to be identical for a particular area or for the same seismic survey, since there is only a single composite trace. Track (5) shows the seismic data traces around the well locations.

Initial Model

The initial model starts with the interpolation of the well log curves, to construct the missing low bandwidth, a low pass-filter is applied to the log data, which allows the low frequencies to pass , to filling the frequency gaps of the low levels of the seismic, as same as the higher frequencies. The proposed filled data by default matched with well logs data that impeded with the low frequency model.

Figure (8) shows the N-S seismic section (3069) over Tersa-1X well, with the displayed data of the initial low frequency model. The represented p-impedance data show a great similarity with the lithologic rock units and the displayed section shows a good comparable structural pattern to the conventional seismic interpretation operation.

Figure (9) shows the N-S seismic section (2646) over the W.Auberge-1X well, with the displayed data of the initial low frequency model. The p-impedance data reflect the changes along the section, in addition to the changes in the horizontal direction. The section shows a quite stable p-impedance pattern around the well, with some localized high acoustic anomalies encountered through the well path toward the northern direction. On the other hand, the effect of the fault on the constructed model is observed.

Inversion Process

This analysis is performed to describe the matching between the inverted p-impedance (Zp), resulted from the initial model generation and the calculated p-impedance from the log data. However, the uncertainty is still propagating a minor error within the model built, the large variation in the amplitude and phase with the sensitive relation to the impedance property to other properties maybe the result of the uncertainty. The analysis is performed to adjust the inversion result by iterations, to reach a minim level of uncertainty.

Figure (10) shows the inversion process analysis results for Tersa-1X well. The first track shows the formation tops along the wellbore, track (2) displays the inverted p-impedance (Zp) in red color overlying the original p-impedance from log calculations in blue color with the analysis result in black line, which represents the mismatch and differences over this well. Track (3) displays the selected statistical extracted wavelet for the synthetic seismogram and track (4) shows the original seismic traces around the well overlying the inverted p-impedance traces, in color banded column.

Inversion Results and Discussion

Model-based inversion results, after accepting the analysis result and performing the required iterations, show a good matching between the calculated p-impedance from well data and the lithological content of the stratigraphic succession.

Figure (11) reveals the N-S seismic section (3069) over Tersa-1X well, which displays the data of p-impedance inverted model along the seismic section. The represented p-impedance data show a great similarity with the lithologic rock units and the picked horizon, as correlated to the specific trace of the computed p-impedance overlaid along the well path.

Figure (12) shows the seismic inversion results along the (2646) seismic section, as correlated with W.Auberge-1X well, with a good match, in which a local relative high p-impedance zone extended over top Abu Roash" B" observed.

Lower Abu Roash "G" Member reflects a high value of the p-impedance toward the western and eastern sides of the field, with local low relative values in between, which maybe a result of the distributed channel deposits at this level (Fig. 13).

Figure (14) displays a map view of the inverted p-impedance over the Upper Abu Roash "G" Member level. It reflects a concentration of the high acoustic impedance zone at the western side ,while the eastern side shows a concentration of the relative low impedance zone.

The inversion results indicate that, generally the western side of Tersa oil shows a higher acoustic impedance rather than the eastern side over Abu Roash "G" Member, while the lower acoustic impedance part is concentrated at the middle part of the field with extension to the southern direction.

Since discovering Tersa field, most production of the Upper Abu Roash Member flow through the western side through wells Tersa-1X and W.Auberge-1X, while the middle part is not sharing any production within this level. Also, the eastern side NE. Younes-1X well sharing with limited production at this level.

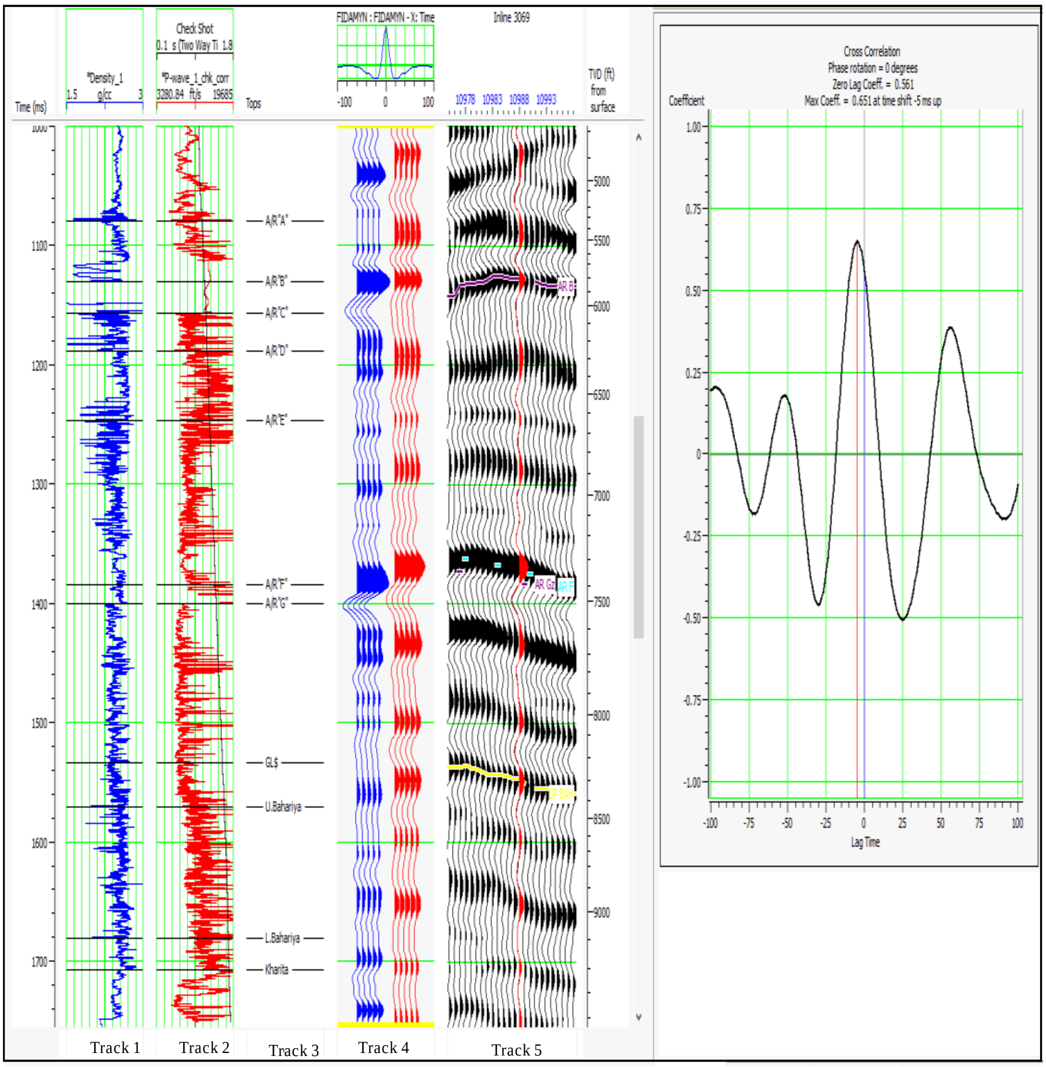

Figure (7): Synthetic seismogram for Tersa-1X well.

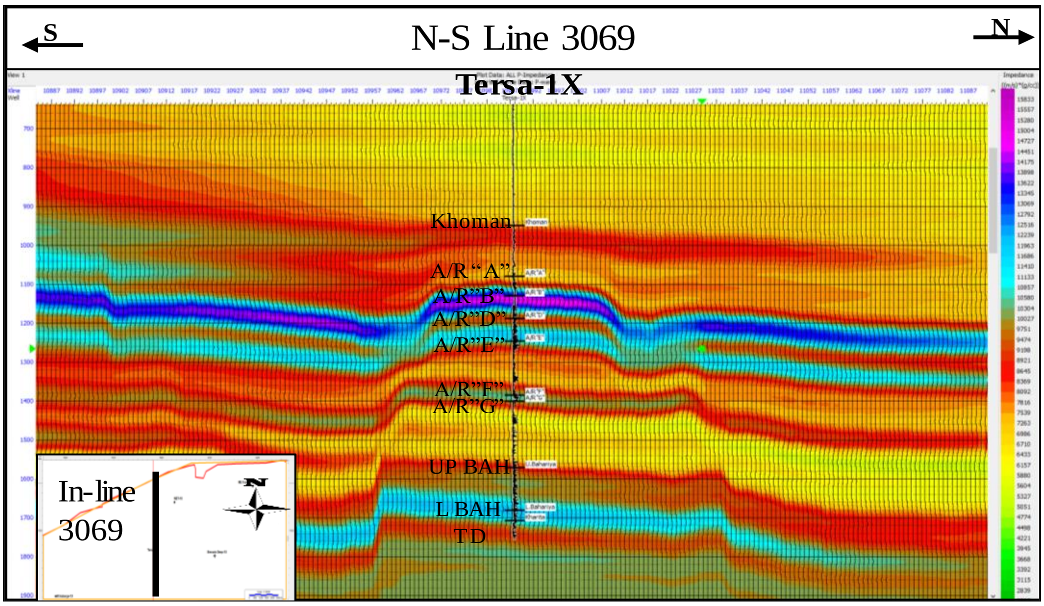

Figure (8): The initial model along the seismic section (3069) correlated, with Tersa-1X well.

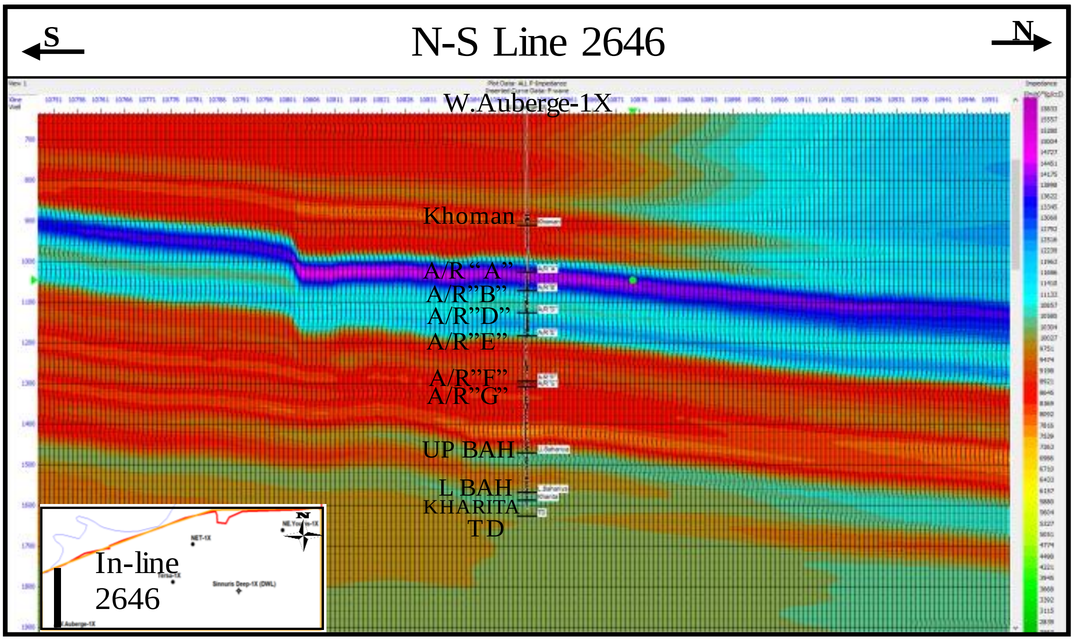

Figure (9): The initial model along the seismic section (2646) correlated, with W.Auberge-1X well.

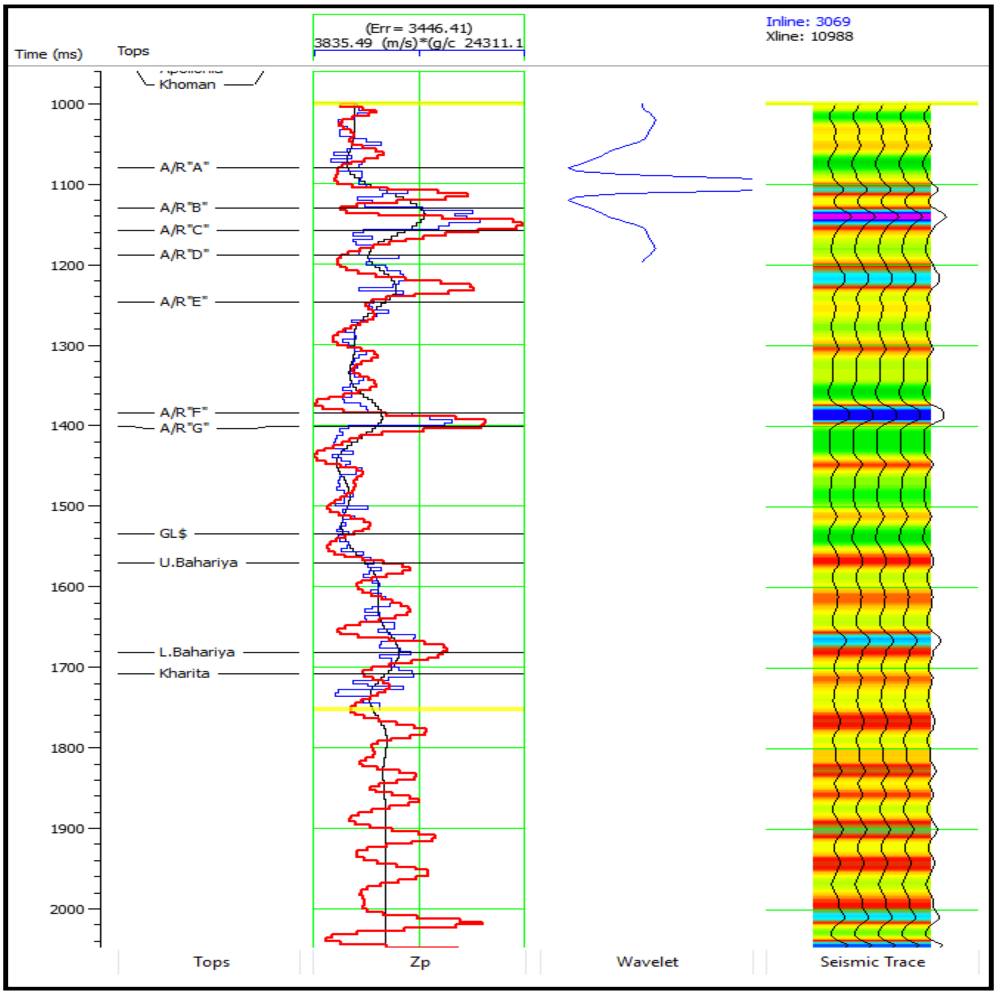

Figure (10): Inversion analysis results over Tersa-1X well.

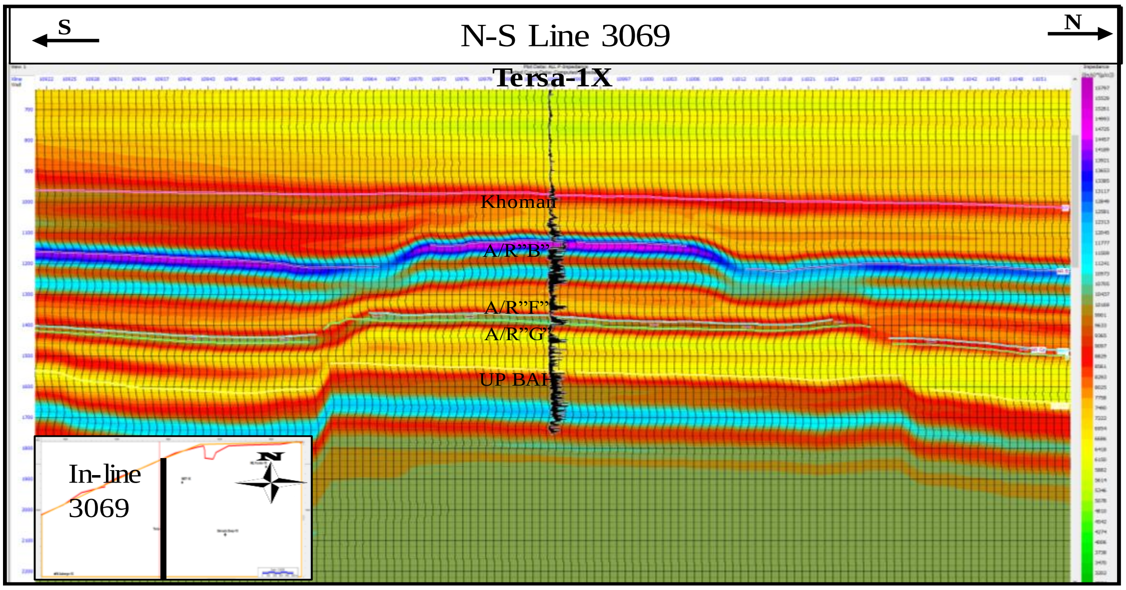

Figure (11): The final seismic inversion results along the seismic section (3069), as correlated with Tersa-1X well.

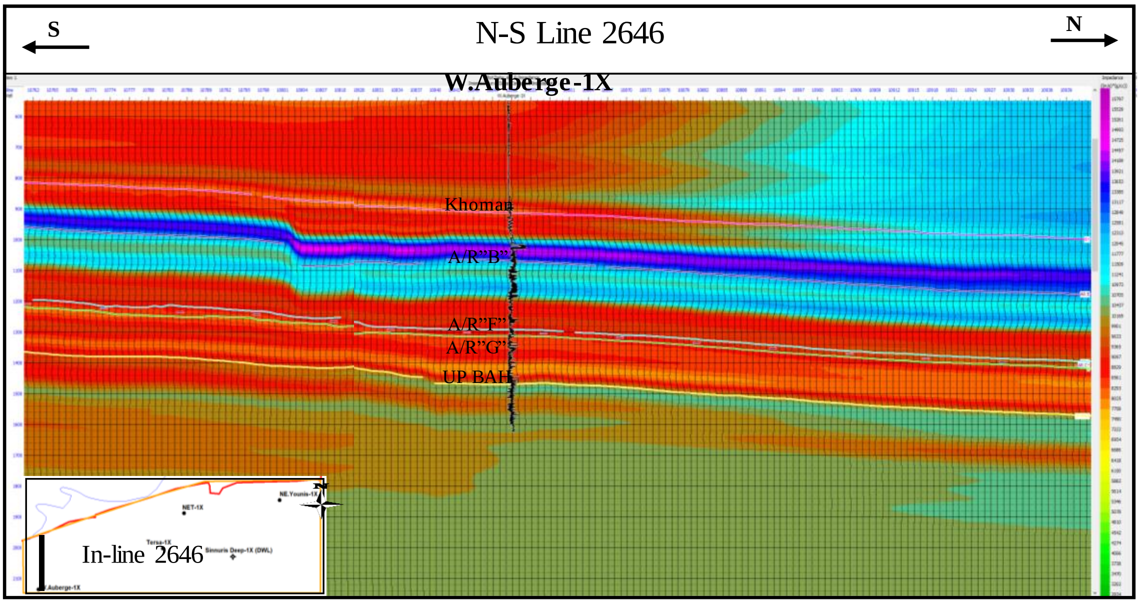

Figure (12): The final seismic inversion results along the seismic section (2646), as correlated with W.Auberge-1X well.

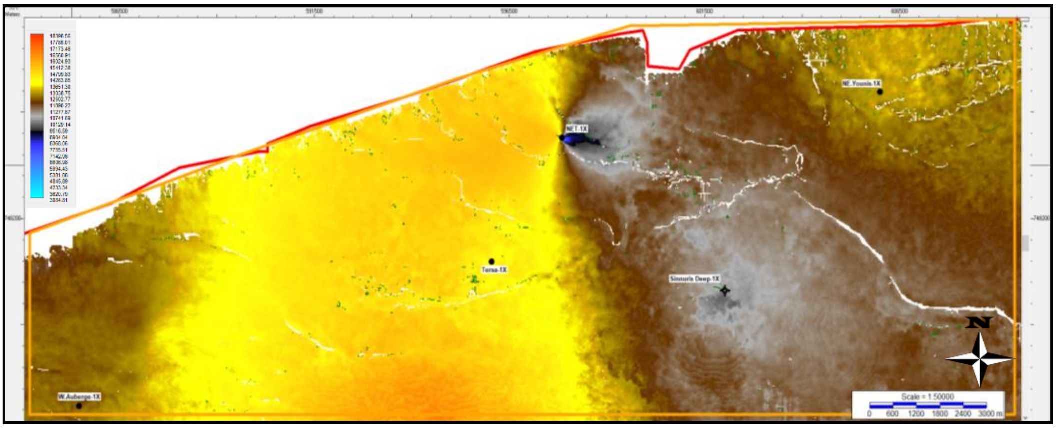

Figure (13): The inverted p-impedance map view over the Lower Abu Roash “G” Member.

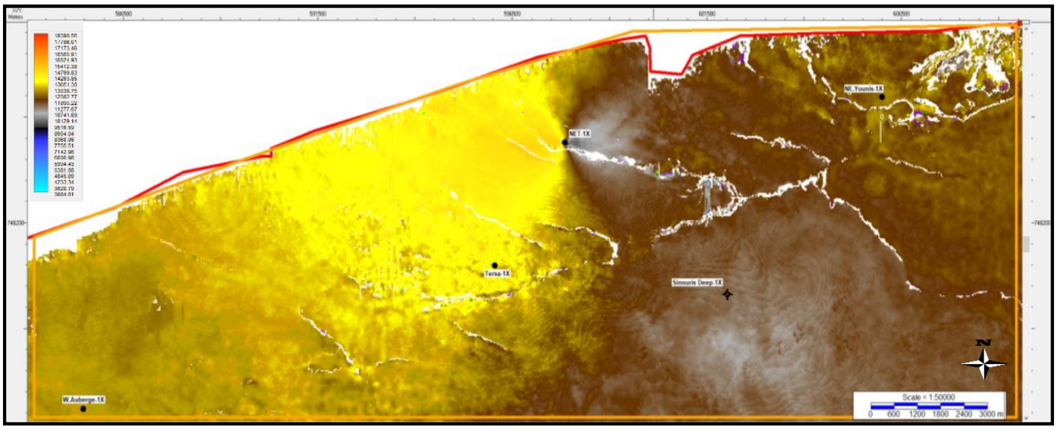

Figure (14): The inverted p-impedance map view over the Upper Abu Roash “G” Member.

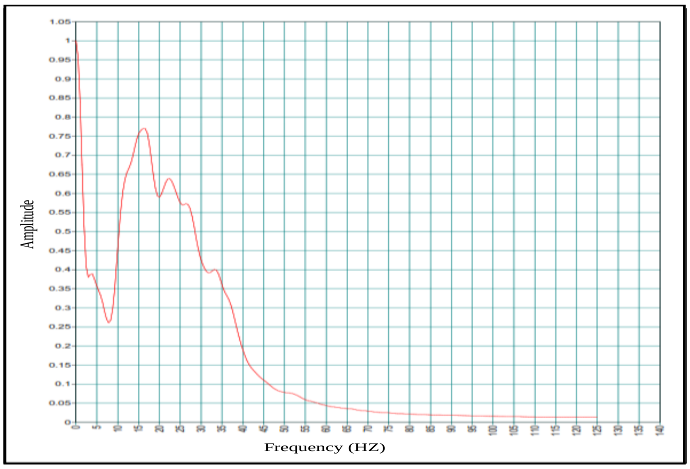

Figure (15): Amplitude-frequency spectrum for the inverted seismic data.

The lower zone of Abu Roash “G” Member has a production from NET-1X well at the middle part of the field, at the edge between the high and low acoustic impedance parts. After the drilling development wells in the same structure, the wells drilled toward the western direction, from the main well toward the high impedance shows developed reservoir parameter and enhanced recovery factor rather than the development wells toward the low impedance of the eastern side.

Amplitude-Frequency Spectrum of The Inverted Model

The inverted data have a modified frequency content, the new characteristic of amplitude-frequency spectrum (Fig 15) reflects the changes applied to the original data and reveals the effect of the inversion process. An extension of the lower frequencies till the zero with high amplitude observed, as same as the higher frequency extended to reach beyond the original upper limit.

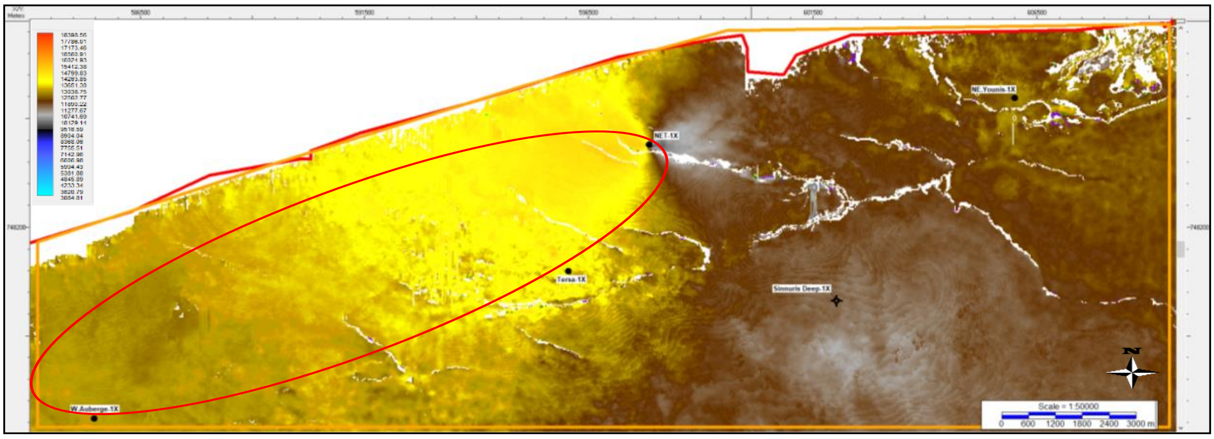

Figure (16): The inverted p-impedance map view over Upper Abu Roash "G" Member.

Summary, Conclusions and Recommendations

- Integration between the seismic structural analysis and the seismic inversion results over Tersa oil field offers a good development plan for the Upper Abu Roash "G" Member zone, for increasing the production, and explore the undiscovered potential with new concepts. Figure (16) shows the proposed promising exploration part, based on the presented work results and the productivity of the drilled wells in the field.
- Applying post-stack seismic inversion technique, even with no true amplitude data, may offer important information such as the presented study.
- Conditioning the well log data gives more accurate results, which will decrease the miss-match between these data and the seismic data.

Acknowledgement

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