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Reservoir Characterization and Quantitive Interpretation (QI) Using 3D Seismic and Well Logs Data of Mishrif Formation a Case Study Southern Iraq

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Abstract

Seismic reservoir property is one of the most important components of the seismic interpretation analysis. The research describes a successful use of a model-based seismic inversion tool and probabilistic neural network (PNN) to post-stack 3D seismic data for the identification of hydrocarbon reservoir zones within the Mishrif Formation. It represents an important formation in Iraq geologically and economically. The objective of this work is to evaluate reservoir characterization and increase the method to obtain better information about reservoir characterization by enhancement and assessment of petrophysical properties of Mishrif Formation such as (P-wave, effective porosity, density, and water saturation). Well logging data, well tops and 3D seismic were used as input to achieve the goal of this along with Petrel and Hampson Russel (The strata and emerge modules). Two horizons were picked in the Two-Way Travel Time (TWT) domain and converted to depth maps by using average velocity of wells. The TWT and depth maps of the Mishrif and near Ahmadi formations show highly developed structures in the southwest and southeast, with a N-S axis, and generally dipping toward the NW. The results of the acoustic impedance horizon units within the Mishrif Formation showed low acoustic impedance values, with higher values observed at the crest and on the northern sides of the N–S anticline axis, as well as in the southwestern part. The final results of the merged and horizon slices of P-wave data showed low velocity, high effective porosity, low water saturation, and low density within the reservoir units of the Mishrif Formation, with improved values observed at the crest, on the northern sides of the N–S anticline axis, and in the southwestern part. Two carbonate buildups within the Mishrif Formation were identified, and seismic attribute analysis was used to determine the boundaries of these buildups and to estimate their reservoir characteristics. The findings from the carbonate buildups and horizon slices revealed low acoustic impedance, low density, low P-wave velocity, high effective porosity, and low water saturation values. Based on all results and attribute analyses, it is recommended to drill an exploration well targeting the stratigraphic carbonate buildup located in the southwestern part of the 3D seismic survey area of the X Oilfield.

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Keywords: Seismic inversion, Acoustic Impedance, Probabilistic Neural Network (PNN), Reservoir characterization, carbonate buildup.

المواصفات المكمنية والتفسير الكمي باستخدام البيانات الزلزالية ثلاثية الابعاد وبيانات المجسات البئرية لتكوين المشرف دراسة حالة في جنوب العراق

الخلاصة

يعد تحديد خصائص المكامن الزلزالية احد اهم مكونات تحليل التفسير الزلزالي. يصف هذا البحث استخداما ناجحا في استخدام واعتماد موديل المعكوس الزلزالي و الشبكة العصبية الاحتمالية لتطبيقها على بيانات زلزالية ثلاثية الابعاد بعد النضد لتحديد مناطق المكامن الهيدروكربونية ضمن تكوين المشرف. ويمثل هذا التكوين احد التكوينات المهمة من الناحية الجيولوجية والاقتصادية. وترسب التكوين خلال العصر الطباشيري، ويعتبر من المكامن الكربوناتية المهة في وسط وجنوب العراق. يهدف هذا العمل الى تقييم تصنيف المكمن وتحسين الطريقة للحصول على معلومات افضل حول خصائص المكامن من خلال تعزيز وتقييم الخصائص البتروفيزيائية لتكوين المشرف مثل (سرعة الموجة الانضغاطية، الكثافة، و المسامية والتشبع المائي). في البحث الحالي تم استخدام بيانات المجسات البئرية، اعالي التكاوين، والبيانات الزلزالية ثلاثية الابعاد. تم استخدام برنامج Petrel and Hampson Russell لانجاز هذا العمل. تم التقاط عاكسين في المجال الزمني وتحويلها الى خرائط عمقية باستخدام السرع المعدلية للابار. الخرائط الزمنية والعمقية لتكوين المشرف وبالقرب من تكوين الاحمدي ارتفاع تركيبي في الجنوب الغربي والجنوب الشرقي مع محور تركيبي باتجاه شمال – جنوب، مع ميلان بالطبقات باتجاه الشمال الغربي. اظهرت نتائج شرائح الممانعة الصوتية للوحدات المكمنية ضمن تكوين المشرف قيم ممانعة صوتية قليلة وتحسن في المسامية في قمة وشمال جانبي محور التركيب باتجاه شمال جنوب وجزء الجنوب الغربي. النائج النهائية لتطبيق emerge والشرائح للسرعة الانضغاطية تظهر سرعة قليلة، ومسامية فعالية عالية، وتشبع مائي قليل و قيم كثافة قليلة ضمن الوحدات المكمنية لتكوين المشرف ووجود تحسن في قمة وشمال جانبي محور التركيب باتجاه شمال جنوب وجزء الجنوب الغربي. تم اكتشاف جسمين طباقيين بنائيين (كربوناتين) ضمن تكوين المشرف واستخدام التحليل والملامح الزلزالية لتحديد حدود هذا الاجسام وتقييم المواصفات المكمنية. حيث اظهرت النتائج الشرائح للاجسام الطباقية البنائية قيم ممانعة صوتية قليلة، وقيم كثافة قليلة، ومسامية فعالة عالية وقيم تشبع مائي قليل، ومن خلال جميع النتائج وتحليل السمات نوصي بحفر بئر استكشافي يستهدف البناء الطباقي الكربوناتي في جنوب غرب المكعب الزلزالي الثلاثي الابعاد لحقل X النفطي.

1. Introduction

The application of seismic inversion method for hydrocarbon exploration has been increasing in the last two decades. Seismic inversion with log data helps to extracts petrophysical properties such as elastic impedance, acoustic impedance, porosity, density, and volume of shale. Inversion method used to transform the seismic data into a velocity layer model which are used to yield petrophysical boundaries in the subsurface and make reliable geological interpretations [1]. The P and S impedance volume, porosity and density parameters are derived from this inversion method. These geophysical parameters provide information about the characterization of rock that forms the subsurface [2]. Seismic data can be transformed into rock properties by postulating relationships among key petrophysical properties. Changes in the reflection amplitudes of seismic waves from subsurface layers can then reveal significant information about the underlying materials and potential hydrocarbon accumulations. Seismic inversion

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utilizes reflection amplitudes correlated with well data to derive details that can be related to fluid saturation, porosity, lithology, and geomechanical parameters [3].

In the current study, well log data, well tops, and 3D seismic data were used to: (1) enhance the understanding of petrophysical properties within the Mishrif reservoir units; (2) perform seismic inversion of the data cube to derive acoustic impedance and predict various seismic attributes; and (3) apply the Emerge module to analyze seismic attributes, generate reservoir property volumes, and identify carbonate buildups within the Mishrif Formation.

2. Materials and Methods

2.1. Study area

X Oilfield is located in the eastern part of the Mesopotamian Zone within the Zubair Subzone. It is characterized by subsurface geological structures covered by Quaternary sediments. These structures are oriented in the NW-SE direction in the eastern part of the zone and in the N-S direction in the southern region, with some in the NE-SW direction [4].

The subsurface geological stratigraphy of Well_B has been selected to represent the stratigraphic column in X Oilfield. The total drilling depth of the geological column in Well_B is approximately 4,530 m, with the Mishrif Formation having a thickness of about 317 m. The well-top formations of three wells are shown in Table (1).

Table (1): Well tops formation of three well

Well Name	**Well_A**		**Well_B**		**Well_C**	
Formation Name	**Top (m)**	**Thick (m)**	**Top (m)**	**Thick (m)**	**Top (m)**	**Thick (m)**
Upper Fars	15	960	24	1016	24	939
Lower Fars	975	414	1040	396	963	339
Ghar	1389	216	1436	274	1302	183
Pabdeh	1605	83	1710	460	1485	113
Dammam	1688	225	/	/	1598	226
Um Radhuma	1913	214	/	/	1824	266
Shiranish	2127	215	2170	175	2090	236
Hartha	2342	275	2345	261	2326	289
Sadi	2617	79	2606	90	2615	71
Tanuma	2696	15	2696	11	2686	18
Mishrif	2711	322	2707	317	2704	316

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Ahmadi	3033	151	3024	151	3020	133
Mauddud	3184	187	3175	192	3153	200
Nahr Umr	3371	175	3367	188	3353	179
Sluaiba	3546	181	3555	198	3532	174
Zubair	3727	194	3753	171	3706	192
Ratawi	3921	102	3924	103	3898	114
Yamama	4023	395	4027	487	4012	148
Sulaiy	-		4514	16		
TD	4418		4530		4160	

2.2. Materials

In the current study, well logging data (all datasets), well tops, and 3D seismic (post-stack data) were used. The importance of seismic methods lies above all other geophysical methods in petroleum exploration.

The seismic data were first processed to increase the signal-to-noise ratio and then interpreted to determine subsurface geology. Seismic data result from a convolution operation between the earth's reflectivity and a source wavelet [5].

2.3. Methods and Software

2.3.1 Structural interpretation of seismic data

The Petrel software was used to construct two-way time (TWT) maps from the picked horizons (Mishrif top and near Ahmadi). Using seismic inversion, the results revealed a high structure in the southwest and southeast with an N-S axis and a general dip toward the NW (Figures 1A and 1B).

Depth maps were constructed using the velocity model, revealing structurally higher elevations in the southwestern and southeastern regions compared to the northeastern area, with an N-S axis and a general dip toward the NW (Figures 1C and 1D).

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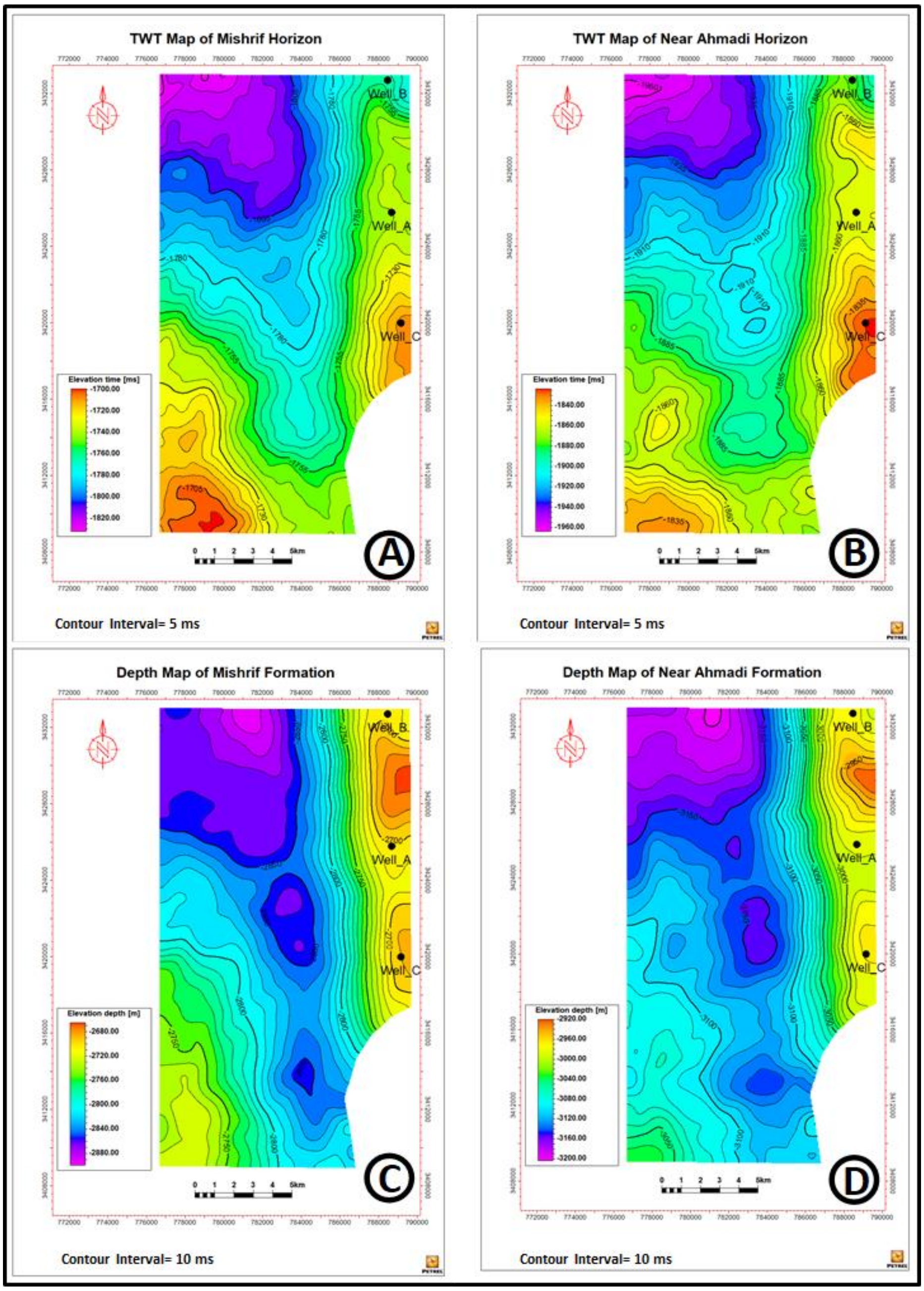

Fig. (1): TWT map of (A) Mishrif Fm. Horizon; (B) near Ahmadi Fm. Horizon; (C) depth map of Mishrif Fm.; (D) depth map of near Ahmadi Fm.

2.3.2 Model-based inversion workflow

Seismic inversion is a computational process that extracts subsurface geological structures and physical properties from seismic datasets. This method yields key parameters including compressional wave velocity (Vp), shear wave velocity (Vs), acoustic impedance, Poisson's

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ratio, density, and S-impedance volumes [6-8]. Figure (2) presents a flowchart outlining the main stages of the inversion process.

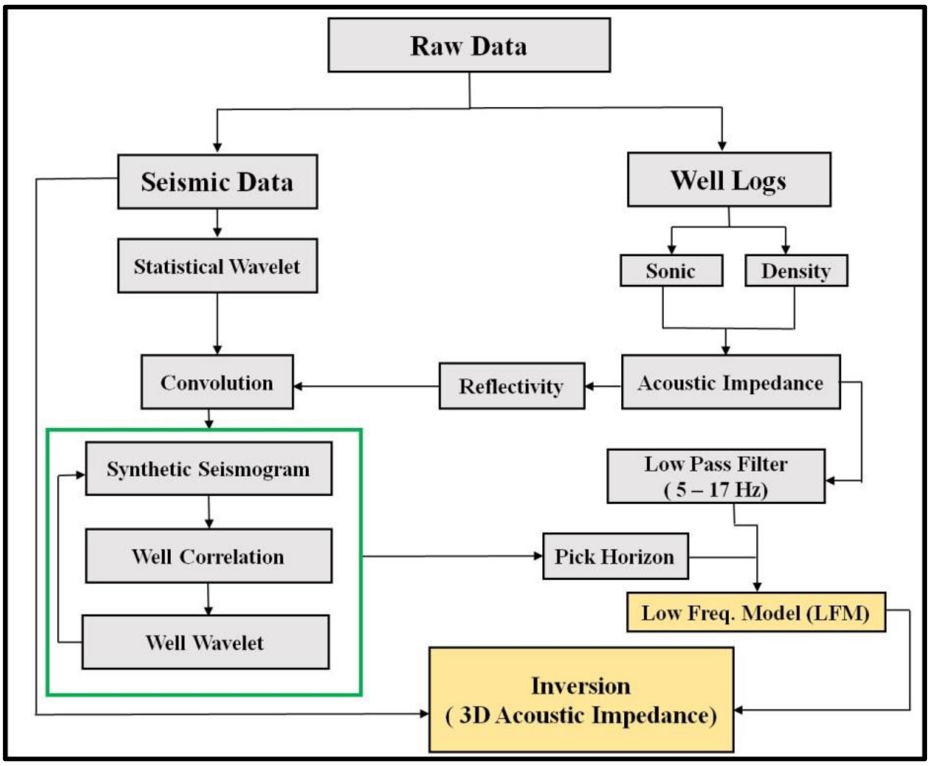

Fig (2): Flowchart of the main steps of seismic inversion.

The traditional approach to initiating any seismic interpretation project involves constructing a synthetic seismogram (seismic well tie) and correlating it with field seismic data. This process integrates well and seismic data to identify accurate reflections, enabling the extraction of stratigraphic, reservoir, and fluid information. Understanding the relationship between well log responses and seismic reflectors represents a critical stage in exploration and production workflows.

The seismic well tie methodology incorporates multiple data types, including well logs, geologic markers, check-shot surveys, and 2D/3D seismic interpretations [9]. In the current study, synthetic seismograms were generated for all wells and subsequently applied to define key reflectors, as illustrated in Figures (3) and (4).

An initial low-frequency model (LFM) of acoustic impedance is essential for successful seismic inversion. This model serves two critical functions: (1) it provides the low- and high-frequency components absent in seismic data, and (2) it helps mitigate solution non-uniqueness. Since seismic inversion alone yields only band-limited acoustic impedance estimates [10], the process

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requires compensation of low-frequency content through construction of a 2D or 3D geologic impedance model derived from well logs. This approach enables determination of absolute (rather than relative) impedance values [11], as demonstrated in Figures (5A and 5B).

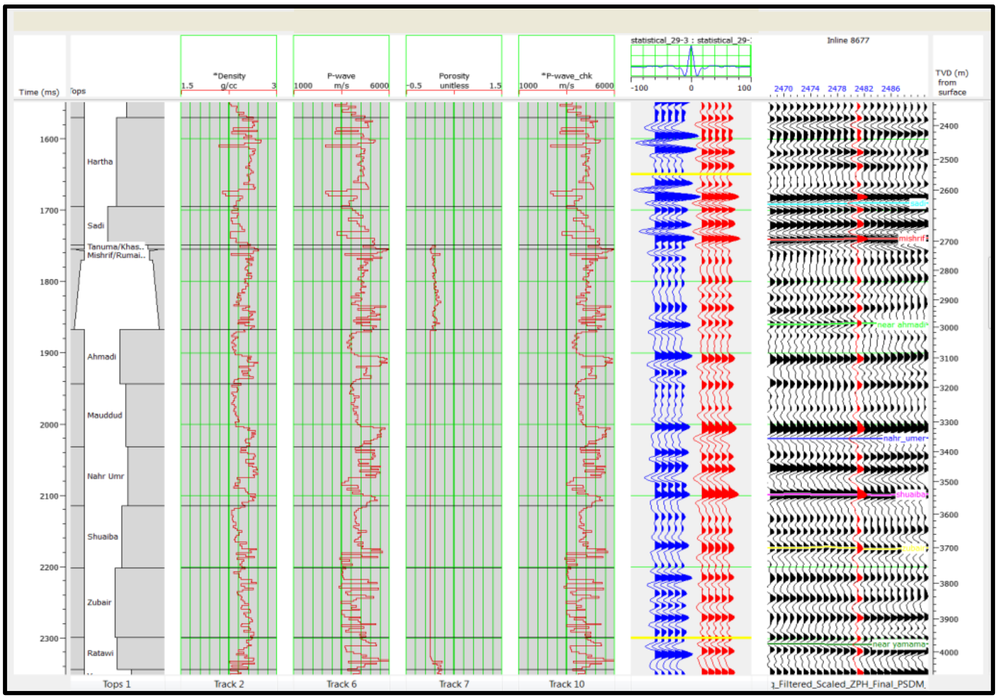

Fig. (3): Synthetic seismogram of well_A with maximum correlation 67%

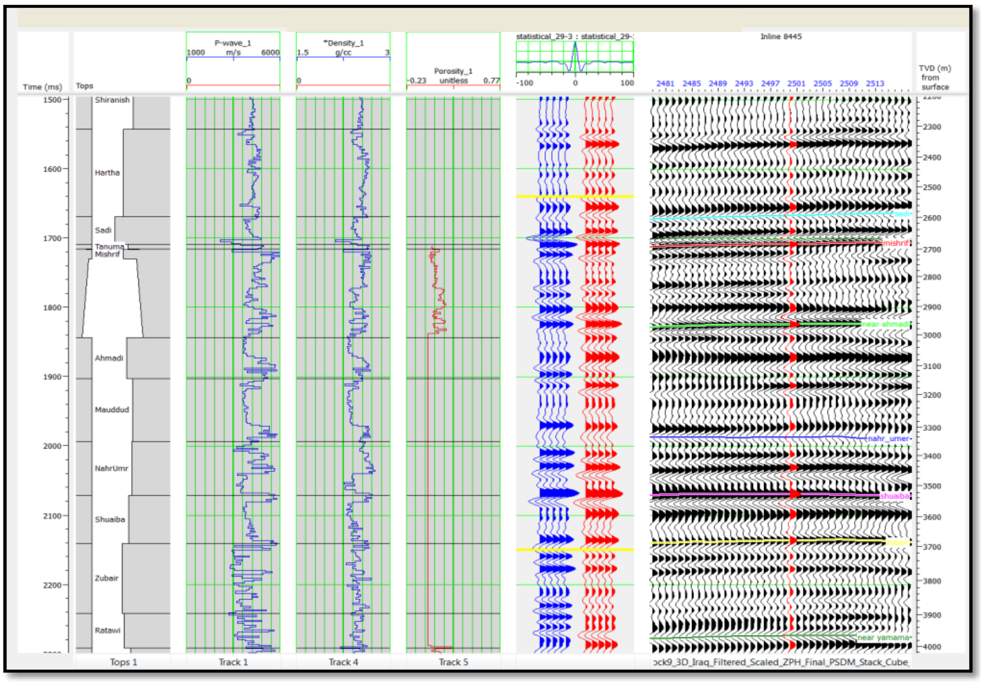

Fig. (4): Synthetic seismogram of well_ C with maximum correlation 80%

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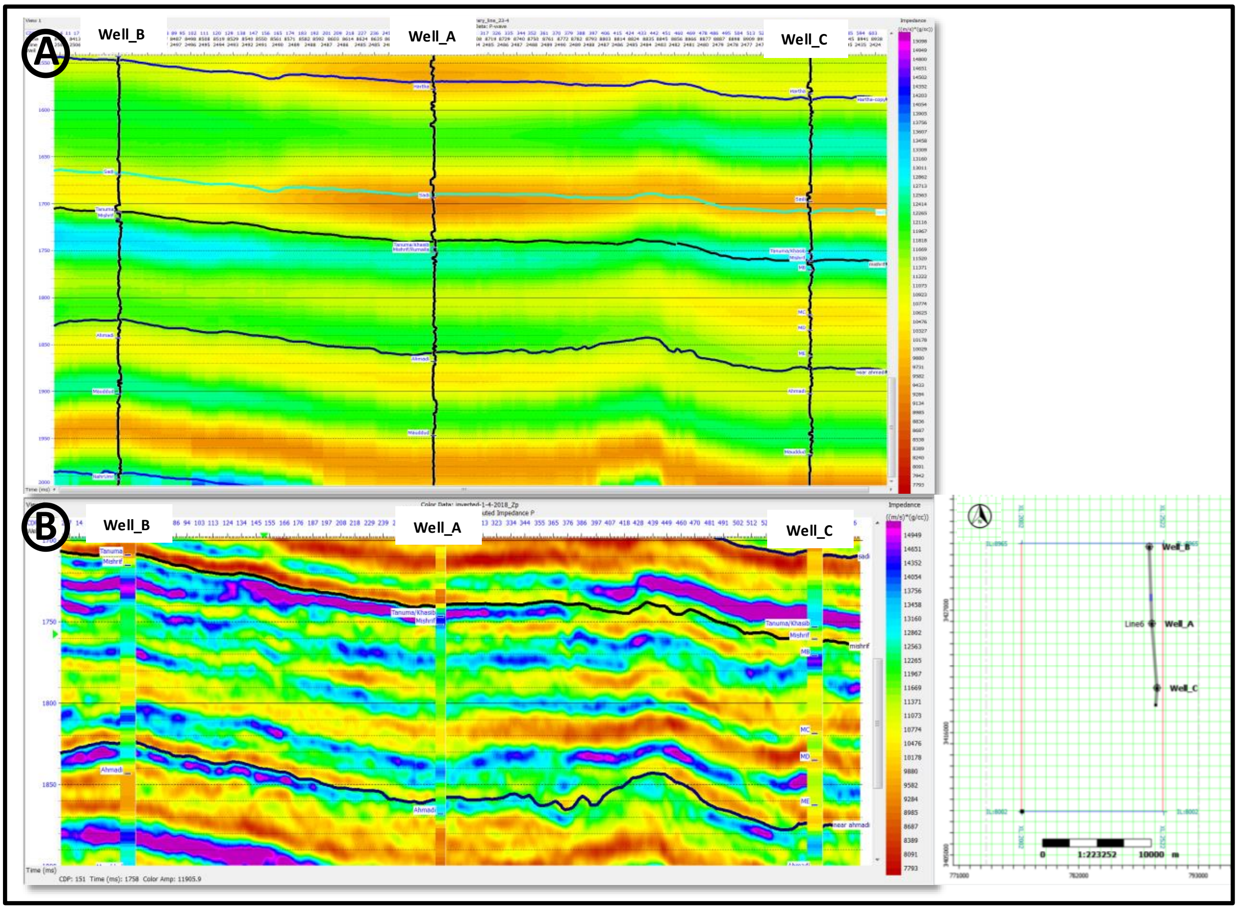

Fig. (5): Shows (A) arbitrary low-frequency model data passing in three wells; and (B) arbitrary inversion seismic data volume passing in three wells, with base map show well locations.

2.3.3 Emerge software analysis

The EMERGE™ module, developed by Hampson-Russell Software Ltd., performs integrated analysis of seismic data and well logs at well locations. This module evaluates various combinations of single seismic attributes, multiple attributes, and neural networks to establish relationships between seismic data and well logs.

By correlating seismic attributes with well and reservoir parameters, EMERGE™ enables the prediction of rock property volumes using both seismic and well data. The module's performance depends on two key factors: (1) the effectiveness of attribute selection in approximating log properties, and (2) the optimization of neural network training [12]. Examples of this workflow are illustrated in Figures (6) and (7).

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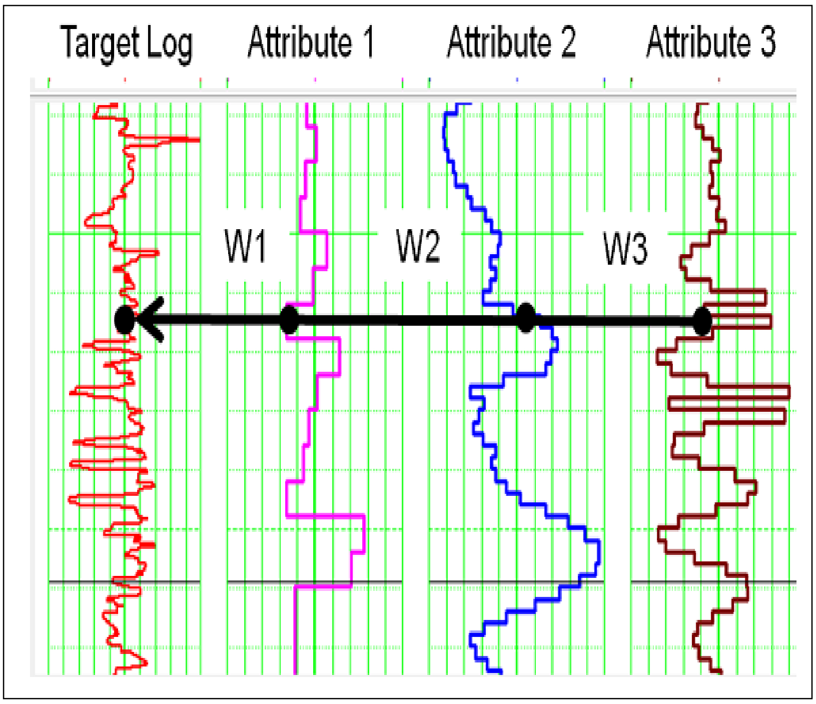

Fig. (6): Shows analytic window for target log and attributes at each point [12]

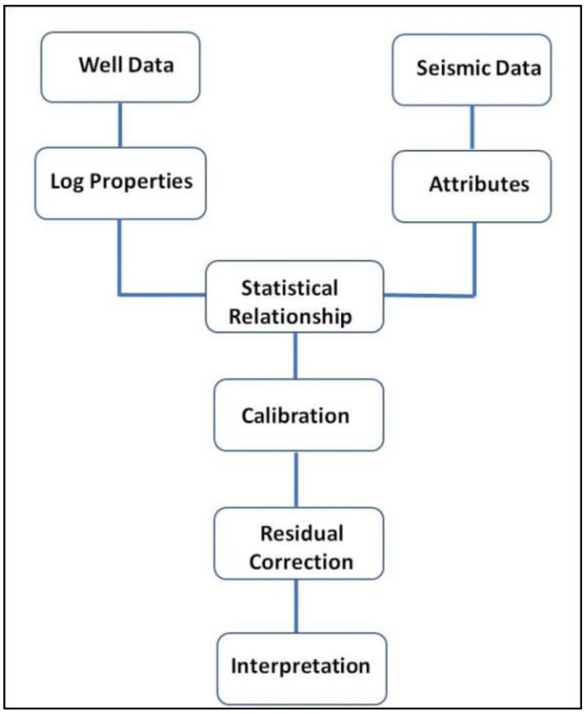

Fig. (7): Shows emerge workflow summarized

The EMERGE™ modeling process consists of two distinct stages. The first stage involves training, where statistical relationships between seismic attributes and well-log data are established. The second stage focuses on application, where these relationships are used to

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predict reservoir properties across the seismic volume. This two-phase approach ensures reliable property estimation throughout the field.

The EMERGE module enables simultaneous analysis of multiple seismic attributes to predict one or more reservoir variables. In the current study, we implemented a comprehensive multi-attribute analysis incorporating four key parameters: effective porosity, P-wave velocity, bulk density, and water saturation. These attributes were carefully selected to provide a robust characterization of reservoir properties within the Mishrif Formation.

For water saturation prediction in particular, we employed a neural network approach to transform seismic attributes into continuous log-scale water saturation volumes. This advanced methodology captures complex, non-linear relationships between seismic responses and reservoir fluid content. The results of this analysis are presented in Figures (8), (9), and (10), demonstrating the effectiveness of the EMERGE workflow for reservoir property prediction.

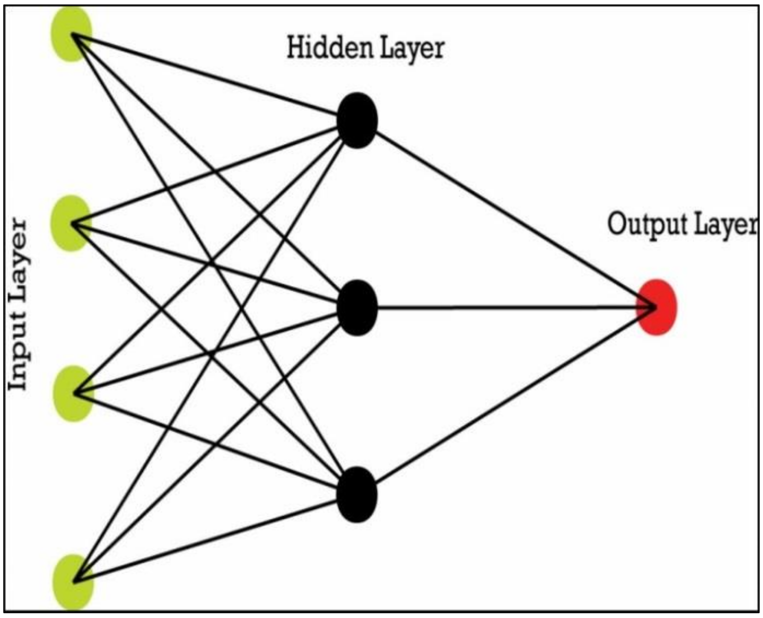

Fig. (8): Shows basic architecture of probabilistic neural network (PPN) [12]

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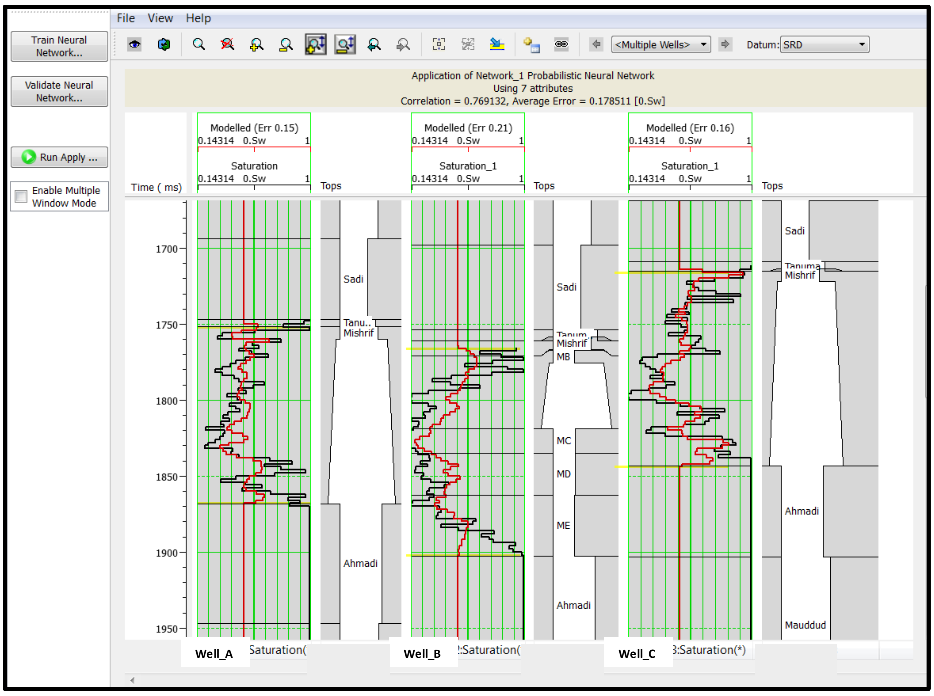

Fig. (9): Emerge application model of water saturation log using of probabilistic neural network (PPN)

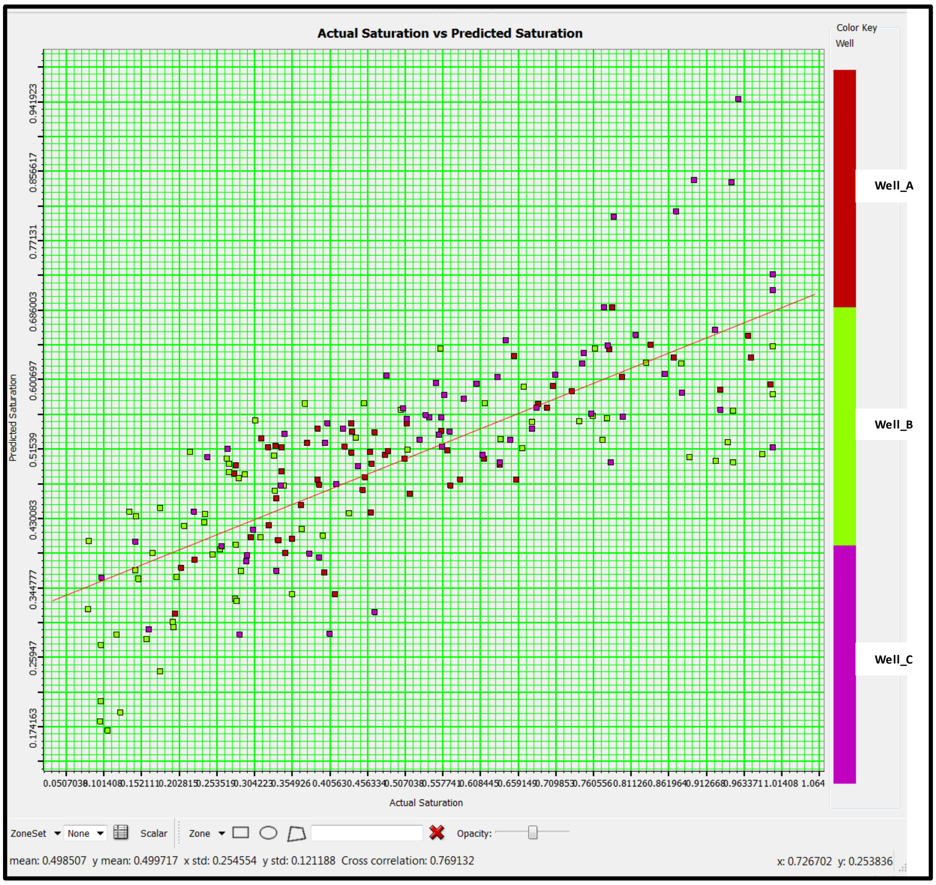

Fig. (10): Scheme between actual versus predicted saturation water property correlation coefficient 0.77 using neural network analysis.

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Two main types of data were available: well data and 3D seismic data. The 3D seismic data was first uploaded into Hampson-Russell software to tie the wells. The second dataset consisted of three wells (Well A, Well B, and Well C) that were scattered across the study area. Each of these wells contained various types of logs, including P-wave velocity, density, effective porosity, and water saturation. These logs were used to perform well correlation for the layers of the Mishrif Formation in the X Oilfield (Figure 11).

In the next step, the derived relationships were applied to the entire seismic volume to generate log values throughout the volume. Effective porosity, P-wave velocity, and water saturation were predicted using a neural network approach in the Emerge analysis. This analysis incorporated one external attribute—acoustic impedance—along with multiple internal attributes (Figures 12, 13, and 14). Additionally, density was estimated using a multi-attribute Emerge analysis that also used acoustic impedance as the external attribute and multiple internal attributes (Figure 15).

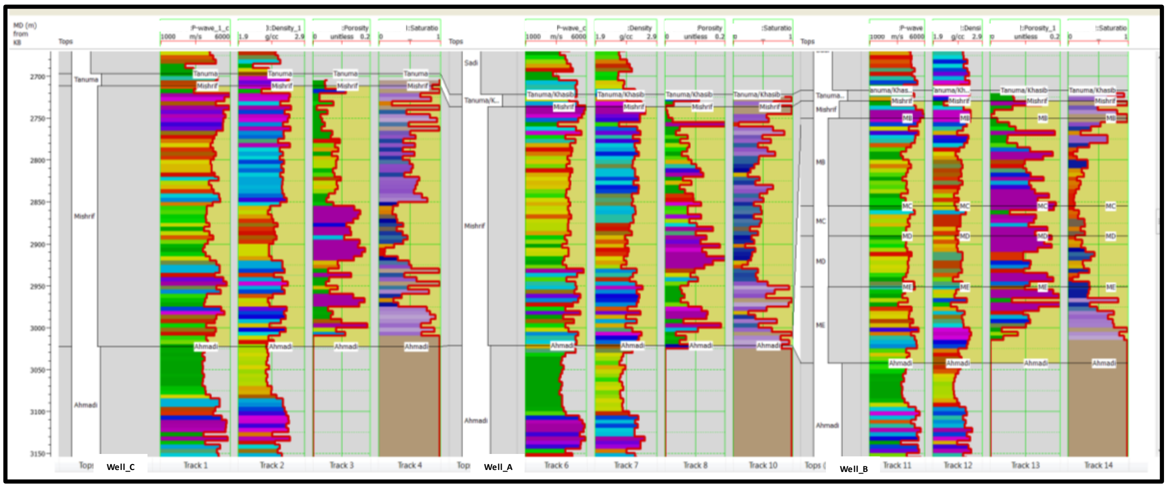

Fig. (11): Shows well log correlation between wells

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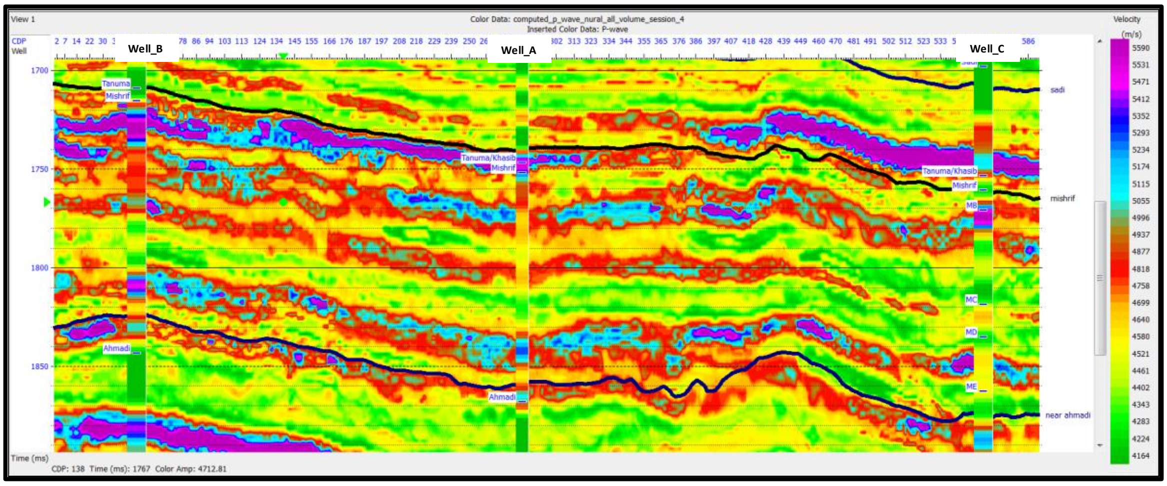

Fig. (12): Shows arbitrary p-wave velocity data volume passing in three wells

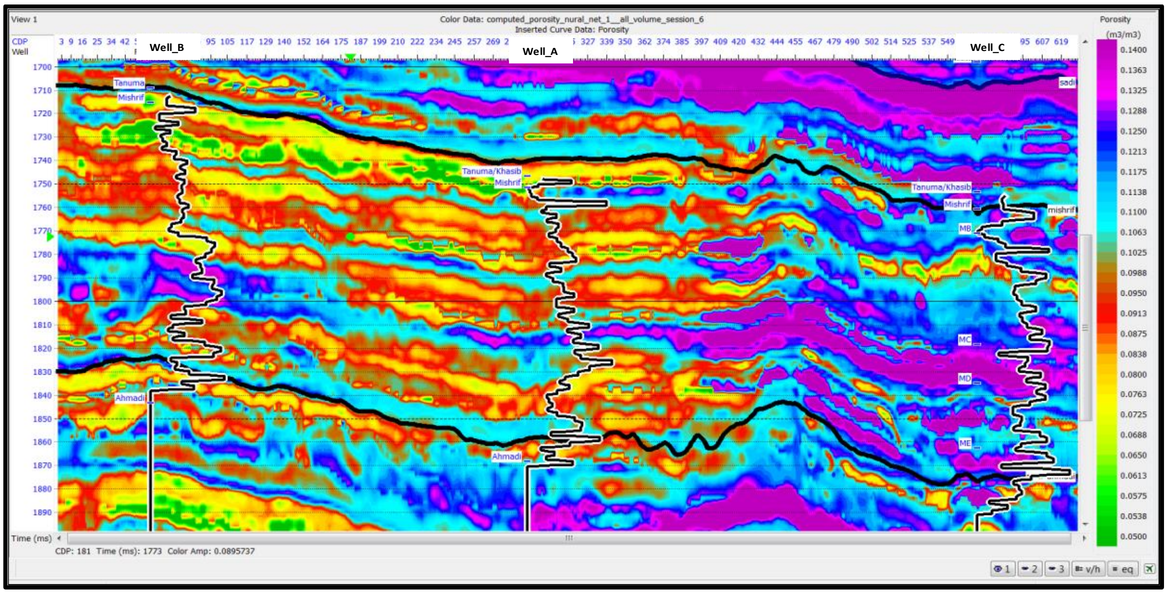

Fig. (13): Shows arbitrary effective porosity data volume passing in three wells

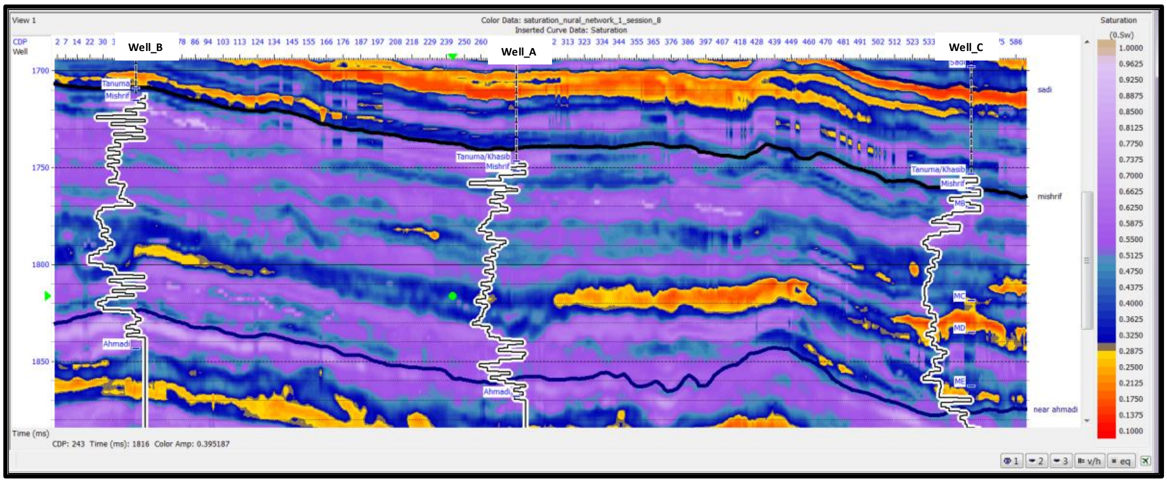

Fig. (14): Shows arbitrary saturation water data volume passing in three wells

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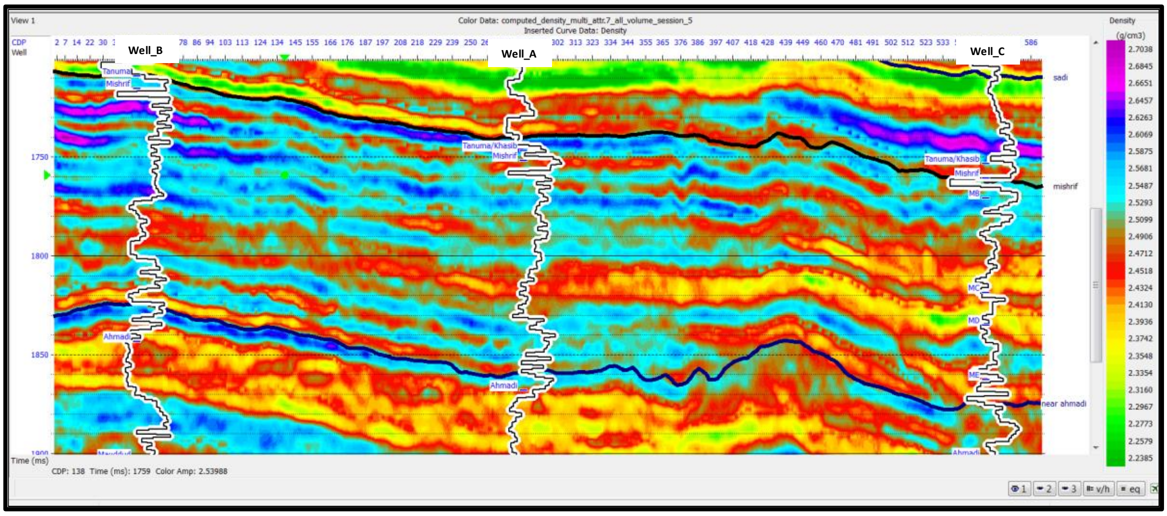

Fig. (15): Shows arbitrary density data volume passing in three wells

2.4. Carbonate buildup

Two carbonate buildups within the Mishrif Formation in the X Oilfield were identified. Seismic attribute analysis was used to define the boundaries of these buildups and to estimate reservoir properties such as P-wave velocity, effective porosity, density, and water saturation (Figures 16A and 16B, as well as Figures (17) and (18).

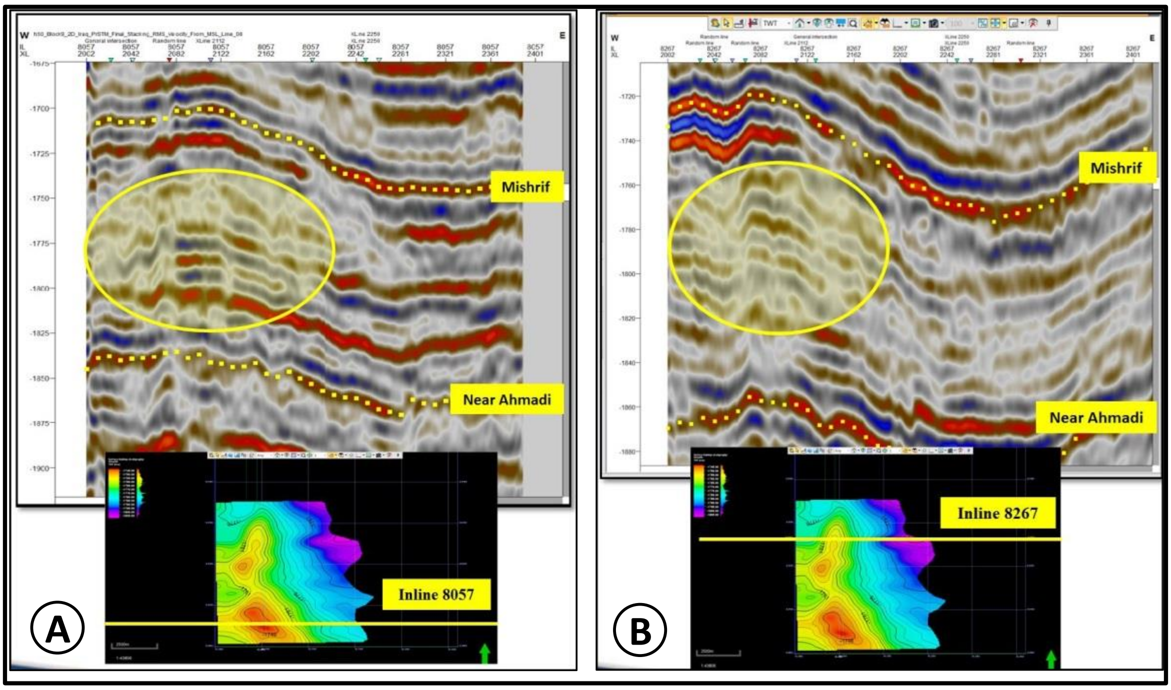

Fig. (16): Shows (A) first carbonate buildup on the seismic data inline 8057; and (B) Shows second carbonate buildup on the seismic data inline 8267

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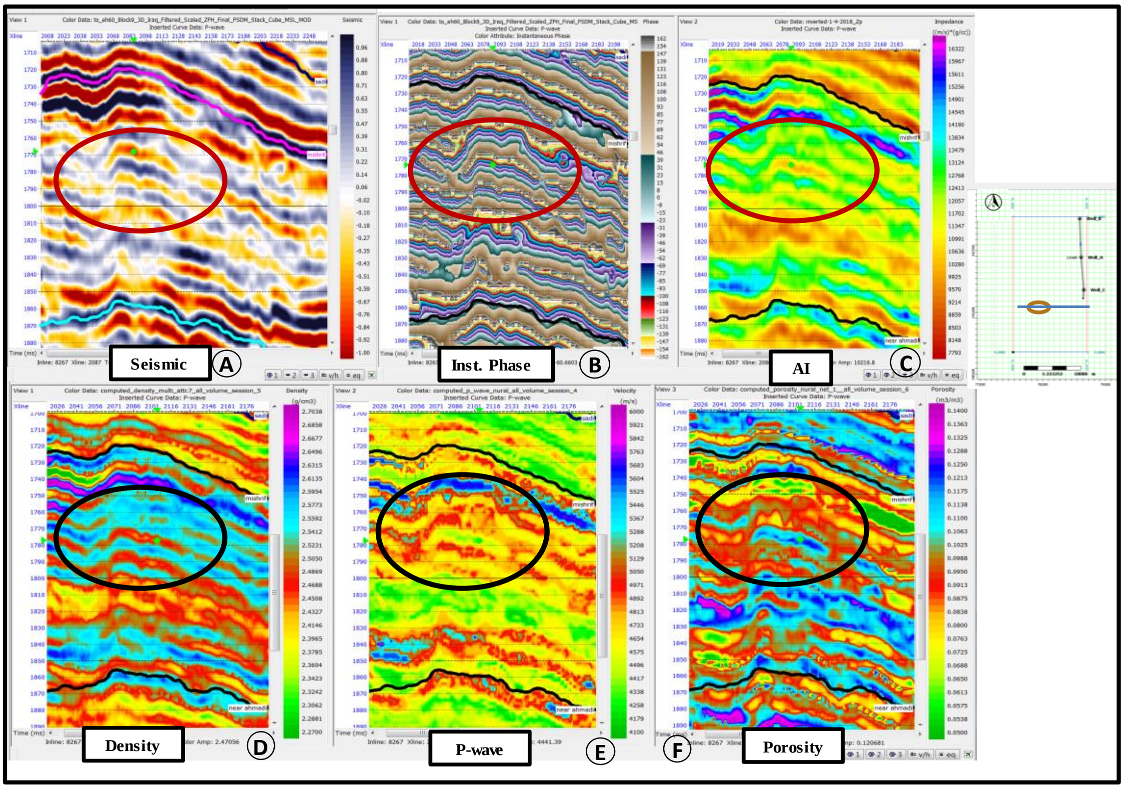

Fig. (17): Shows different attributes of second carbonate buildup inline 8267, A- seismic data, B- instantaneous phase, C- acoustic impedance, D- density, E- p-wave, and F- effective porosity.

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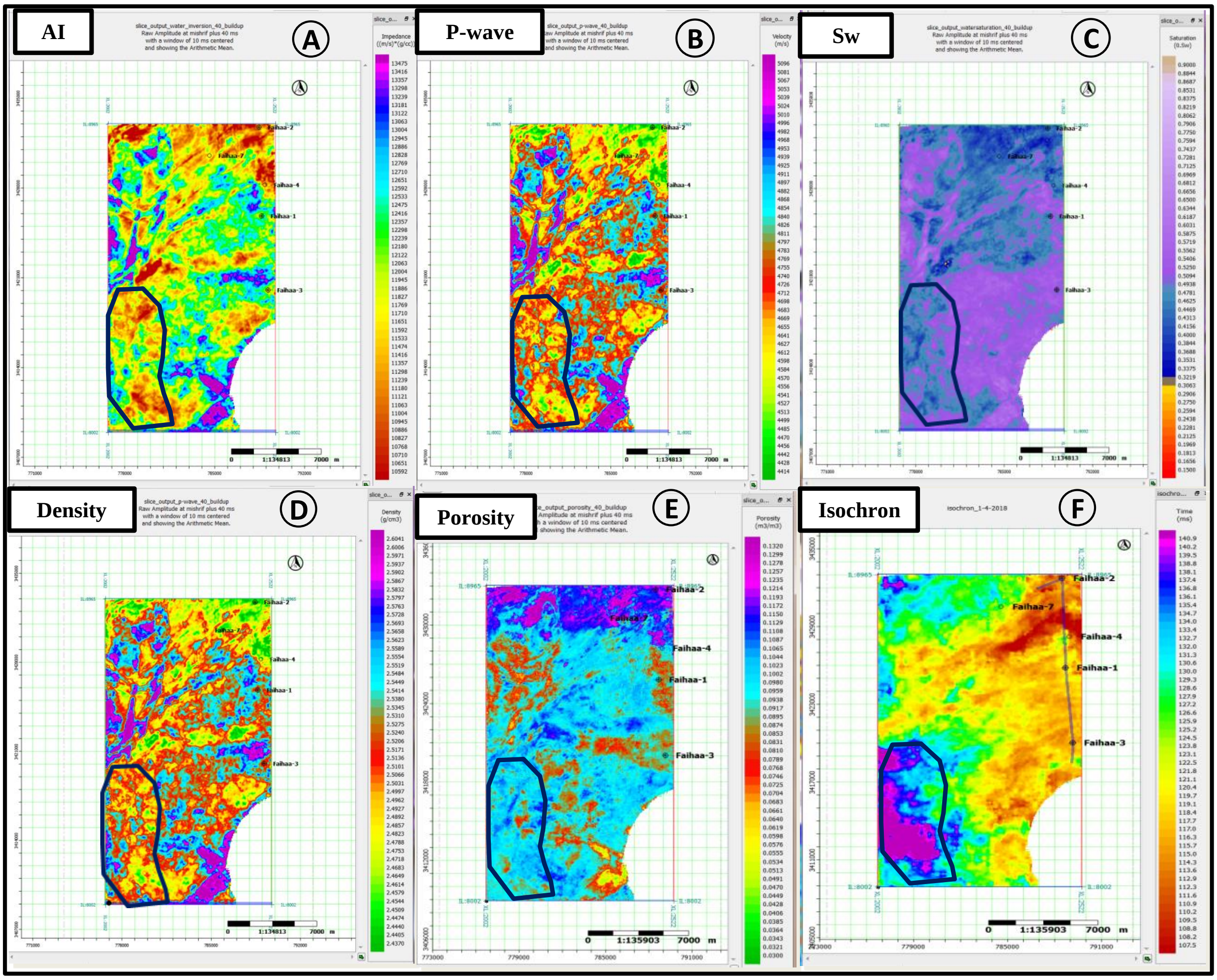

Fig. (18): Shows horizon slices of different attributes and enhancement in carbonate buildup reservoir characterization, A- acoustic impedance, B- p-wave, C- saturation water, D- density, E- effective porosity, and F- Isochron map.

3. Results and Discussion

TWT (Two-Way Time) maps of the Mishrif and near Ahmadi formations showed highly structured areas in the southwest and southeast, with a dominant N–S (north–south) axis and a general dip toward the northwest (Figures 1A and 1B). Depth maps were obtained by applying a velocity model to convert TWT data. These depth maps revealed that the southwestern and southeastern parts were structurally higher than the northern and northwestern areas, with the same N–S orientation and a general dip toward the northwest (Figures 1C and 1D).

The results of acoustic impedance inversion were compared with data from three wells (Well A, B, and C) to validate the inverted seismic data. Horizon slices of reservoir units within the Mishrif Formation showed low acoustic impedance, which improved at the crest and northern

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flanks of the N–S anticline and in the southwestern part of the study area (Figure 5B) and Figures (17 and 18).

The final results of the Emerge analysis were based on model-driven seismic inversion used as external attributes. Reservoir properties such as P-wave velocity, effective porosity, water saturation, and density were predicted using the Emerge module of the Hampson-Russell Software (HRS). The results and horizon slices of P-wave showed low velocity, high effective porosity, low water saturation, and low density values within the reservoir units of the Mishrif Formation. These properties improved at the crest and northern flanks of the N–S trending anticline and in the southwestern part of the study area (Figures 12, 13, 14, 15, and 18).

Two carbonate buildups were identified within the Mishrif Formation. Seismic attribute analysis was used to define the boundaries of these buildups and to estimate reservoir characteristics, including P-wave velocity, effective porosity, density, and water saturation. The results and horizon slices revealed low acoustic impedance, low density, low P-wave velocity, high effective porosity, and low water saturation values. Additionally, the isochron map showed increased thickness that corresponded with carbonate development (Figures 16A and 16B, 17, and 18).

4. Conclusions

A combined approach to reservoir characterization was applied in this study, starting from seismic data and including neural network modeling and seismic multi-attribute analysis to estimate log-like data from seismic data. A seismic inversion model-based method and attribute analysis were used to examine the relationship between reservoir unit structure, their acoustic response, and the distribution of reservoir properties in the X Oilfield. The results of acoustic impedance showed low values within the reservoir units, indicating high effective porosity. This analysis successfully distinguished between reservoir and non-reservoir units predicted from seismic data. Neural network methods proved to be an effective technique for this prediction, allowing for clear vertical separation of reservoir units and improved horizontal distribution mapping across the entire study area. All predicted results and horizon slices showed enhancement in reservoir properties within the Mishrif Formation. Based on the results and attribute analysis described above, it is recommended to drill an exploration well in the stratigraphic carbonate buildup located in the southwest portion of the 3D seismic survey area in the X Oilfield.

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