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Structural and Stratigraphic Interpretation of Zubair Formation (Lower Cretaceous) for the Area Between Halfaya, Noor, and Amara Oil Fields, Southeastern Iraq, Using 2D Seismic Reflection Data

Bakr Samar Al-Azzawi*, Kamal K. Ali
Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

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Abstract
The study area is located in the Missan governorate in southeastern Iraq including oilfields (Halfaya, Noor, and Amara). Each field was previously studied separately, it was found that the structures were anticline folds. In this study, the three oilfields and the area between them will be studied structurally in one study to find out the extension of the structural axis of these structures within the Lower Cretaceous period, using 2D seismic reflection data. Seismic data improvement was carried out by using some attributes (structural smoothing, second derivative, phase shift, and trace AGC) to increase the visibility, accuracy, and signal-to-noise ratio. Also, the mis-tie correction was performed to match the interpretation pick at the intersection points of the seismic section. Depending on the 2D seismic reflection interpretation, and based on the well velocity survey, sonic and estimated density logs were used to make a synthetic seismogram of well Am-2. Two horizons were identified and picked (top Zubair and top Ratawi formations) within the Lower Cretaceous period. Two-way time and depth maps (3D structural model) were conducted for the picked reflectors to show the structural model of the subsurface formations. The structural interpretation shows two structural axes in the study area. The first one is the Halfaya-Amara axis whose direction is WNW-ESE corresponding with Amara structure. Due to the tectonic effect on the Halfaya structure, this axis deviates in the southeast direction. Another tectonic force affected the Halfaya structure in the NW-SE direction leading to the appearance of a branch of a convex extension towards the north from the middle of the Halfaya structure as a nose and directed towards the Noor structure. The second axis of Halfaya-Noor is in the direction of NW-SE. Application of the instantaneous phase attribute detects the sag which represents a decrease in seismic velocity in addition to a flat spot representing the seismic response of hydrocarbon-water contact, and a bright spot in the seismic section is considered a (DHI).

Keywords: Structural interpretation, stratigraphic interpretation, Halfaya-Noor-Amara oil fields, Zubair Formation, direct hydrocarbon indicator (DHI).

* Email: bakr.samar.abdulwahhab@gmail.com

التفسير التركيبي والطباقي لتكوين الزبير (العصر الطباشيري الأسفل) للمنطقة الواقعة بين حقول نفط حلفاية ونور وعمارة، جنوب شرقي العراق، باستخدام بيانات الأنعكاس الزلزالي ثنائية الأبعاد

بكر سمر العزاوي* ، كمال كريم علي
جامعة بغداد، كلية العلوم، قسم علم الأرض، بغداد، العراق

الخلاصة

تقع منطقة الدراسة في محافظة ميسان جنوب شرق العراق وتشمل حقول نفط (حلفاية ونور والعمارة). تمت دراسة كل حقل على حدة سابقاً، وقد وجد أن التراكيب عبارة عن طيات محدبة. في هذه الدراسة سيتم دراسة الحقول الثلاثة والمساحة بينهم تركيبياً في دراسة واحدة لمعرفة امتداد المحور التركيبي لهذه التراكيب ضمن العصر الطباشيري السفلي، وذلك باستخدام بيانات الأنعكاس الزلزالي ثنائية الأبعاد. تم إجراء تحسينات على البيانات الزلزالية باستخدام بعض السمات الزلزالية (التنعيم الهيكلي، المشتقة الثانية، إزاحة الطور، وتتبع AGC) لزيادة الرؤية والدقة وزيادة نسبة الأشارة الى الضوضاء. أيضاً، تم إجراء تصحيح الخلل لمطابقة اختيار العاكس عند نقاط التقاطع في المقطع الزلزالي. اعتماداً على تفسير الأنعكاس الزلزالي ثنائي الأبعاد، واستناداً إلى بيانات سجلات الأبار والأثر الزلزالي المصنع للبئر Am-2. تم تحديد واختيار عاكسي (اعلى تكويني الزبير ورطاوي) في العصر الطباشيري السفلي. تم رسم الخرائط الزمنية والعمقية (نموذج تركيبي ثلاثي الأبعاد) للعواكس المختارة لإظهار الصورة التركيبية التحت السطحية. يبين التفسير التركيبي أن هناك محورين تركيبيين في منطقة الدراسة، الأول هو محور حلفاية – عمارة الذي يكون اتجاهه غرب شمال غرب – شرق جنوب شرق متطابق مع تركيب العمارة. بسبب التأثير التكتوني في تركيب حلفاية ينحرف هذا المحور إلى الأتجاه الجنوبي الشرقي. أثرت قوة تكتونية أخرى على تركيب حلفاية في الأتجاه شمال غرب – جنوب شرق مما أدى إلى ظهور تفرع من امتداد محدب بأتجاه الشمال من منتصف تركيب حلفاية كخشم بأتجاه تركيب نور. المحور الثاني حلفاية – نور بأتجاه شمال غرب – جنوب شرق. يكشف تطبيق الطور اللحظي عن الترهل (sag) الذي يمثل نقصان في السرعة الزلزالية بالإضافة إلى بقعة مسطحة (flat spot) تمثل الاستجابة الزلزالية للتلامس الهيدروكربوني مع الماء، ونقطة مضيئة (bright spot) في القسم الزلزالي الذي تعتبر (DHI).

1. Introduction

Seismic reflection exploration has been used to investigate the subsurface image of the oilfields since the turn of the 20th century [1]. The role of seismic investigation in petroleum studies is to provide the most accurate visual representation of the earth's subsurface and its geological structures, as it provides seismic section, time, and depth contour maps to determine the structural traps [2]. Numerous seismic investigations were carried out to look into the underlying geology of numerous oilfields in Iraq. Those who conducted the research came to the conclusion that the seismic reflection method offers a clear picture of the stratigraphy and structure of the subsurface, which aids in understanding subsurface geology and offers solid proof of oil accumulation [3-8]. The basic technique of seismic exploration consists of generating seismic waves by a near-surface explosion of dynamite, weight dropping, or vibrators and measuring the time required for the waves to travel from the sources to reflectors and back to a series of geophones. The arrival time of each reflection wave represents two-way travel time (TWT) [9]. This time provides information about the reflector's depth, and the intensity of the reflected signal provides information about any differences in the properties of the rocks at the interface [10]. Structural seismic interpretation aims to provide structural maps of the subsurface [11]. The seismic attributes technique enhances the results of seismic interpretation, knowing the reservoir characteristics and determining the location of the accumulation of hydrocarbons. In addition, the seismic attribute technique should allow us to increase the ability of geological interpretation of a formation [12]. Each field in the study area was studied separately in the previous studies [13-15], and it was found that the structures (Halfaya, Noor, and Amara) are anticline folds. Since the Cretaceous sequence in Iraq is the greatest-producing reservoir and holds over 80% of the country's oil reserves, much research has concentrated on this region [16]. This research aims to study the structural axes of the Zubair Formation for the area between Halfaya, Noor, and Amara oilfields in southeastern Iraq in one study, in addition, to detecting the seismic stratigraphy features that are considered direct hydrocarbon indicators (DHIs) in the Zubair Formation to increase the oil production in the area.

2. Location of the Study Area

The study area is located in southeastern Iraq in Missan Governorate as shown in Figure-1. The study area is about 966 km^2, and the Tigris River penetrates through it. The study area includes three oilfields; the Halfaya oilfield in the southeast, the Noor oilfield in the north, and the Amara oilfield in the west.

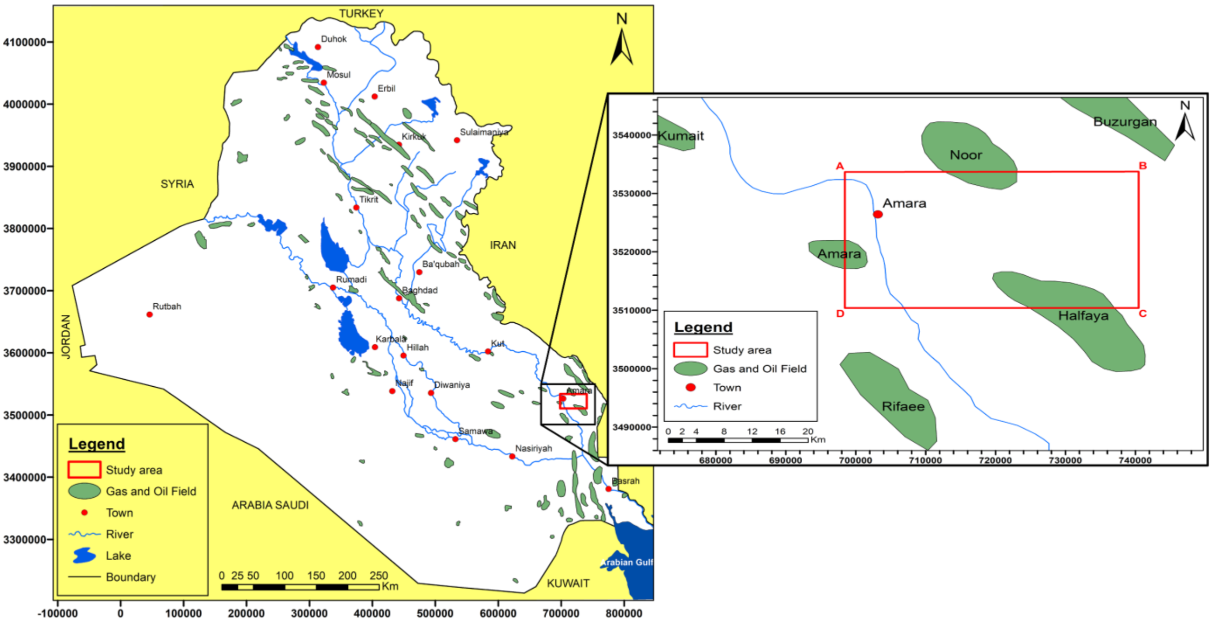

Figure 1: Map of Iraq, showing the location of the study area (modified from [17]).

3. Geology of the Study Area

Topographically, the area is nearly flat and it is covered with the Quaternary sediments represented by gravels, sands, silts, and clay [18]. The subsurface geology of the study area is identified from the data obtained from the Am-2 well drilled within the Amara oilfield, the Am-2 well reaches to Yamama Formation at a depth of 4692 m. This study is focused on the Zubair Formation, which represents the most important Lower Cretaceous clastic reservoir of oilfields in the study area. The depth of the Zubair Formation is 4124 m and its thickness is 191 m in Am-2 of the Amara oilfield; (Figure-2) [15]. Zubair Formation is the largest sandstone store in Iraq and is made out of fluvial-deltaic, deltaic, and marine sandstones. It is made out of alternating shales and sandstones with siltstones. In southeast Iraq, the Zubair Formation grades into offshore limestones and marly carbonates. Tectonically, the study area is located in the Unstable Shelf of the Mesopotamian Zone within the Tigris Subzone. In the Mesopotamian Zone, the Tigris Subzone is the largest and most mobile unit. It is characterized by two NW-SE trending groups of buried anticlines associated with longitudinal faults and an E-W transversal trend. The Zubair Formation represents a prograding delta composed of the products of erosion originating from the Arabian Shield. The sandstone of the formation suggests an influx of clastics from the NW in central Iraq and probably from the SW in S Iraq [19].

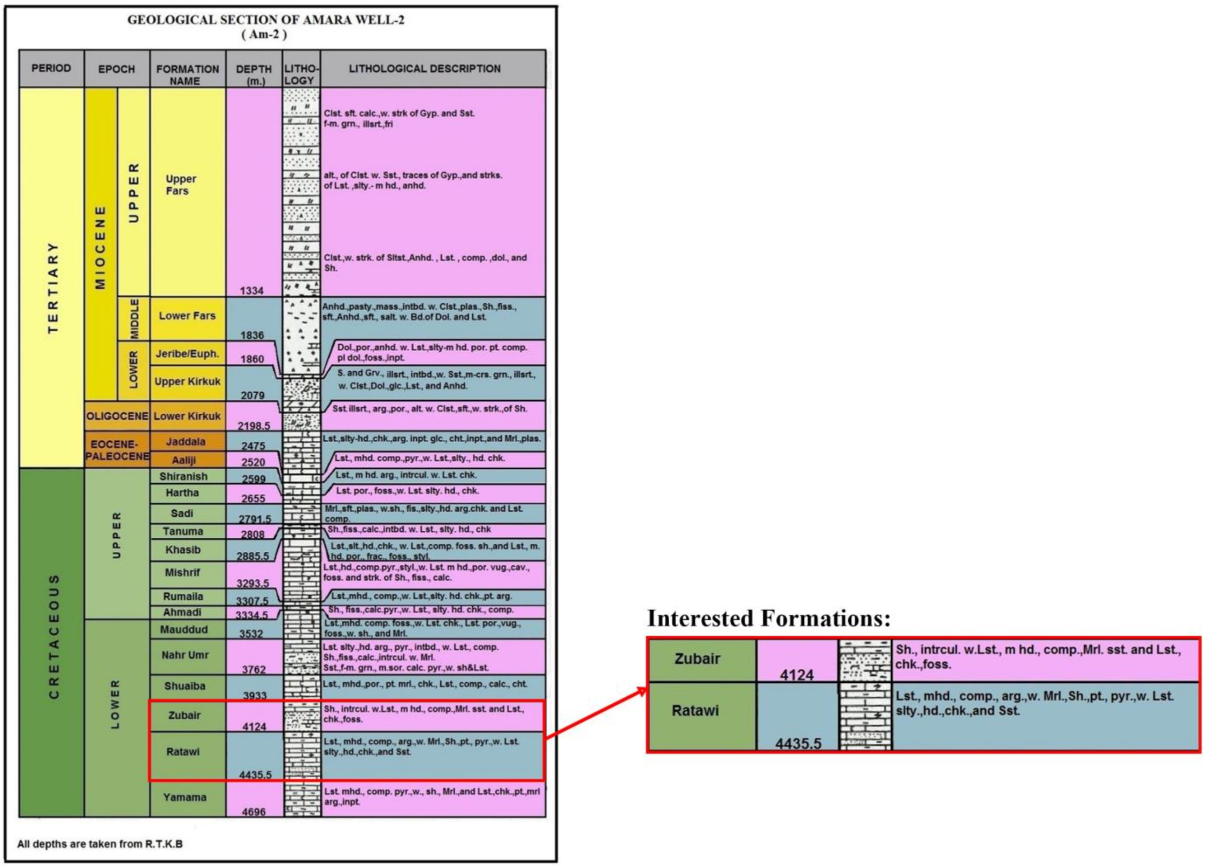

Figure 2: Stratigraphic column for Amara oilfield (Am-2 well) with a brief lithological description of the formations [15].

4. Database and Base Map Preparation

Three types of data were used in the current study (Obtained from the Iraqi Ministry of Oil, Oil Exploration Company), which include:

1- Well data: Including well tops, sonic log, and the coordinates of the well (Am-2) of the Amara oilfield in the study area.
2- Well velocity survey: Check-shot (One-way time) for well Am-2.
3- Seismic data: Twenty-six 2D seismic lines cover most of the study area.

The base map (Figure-3) was constructed using Petrel-18 software including the boundary of the study area, well, seismic lines, and oilfield with the geographic coordinates of the Universal Transverse Mercator (UTM).

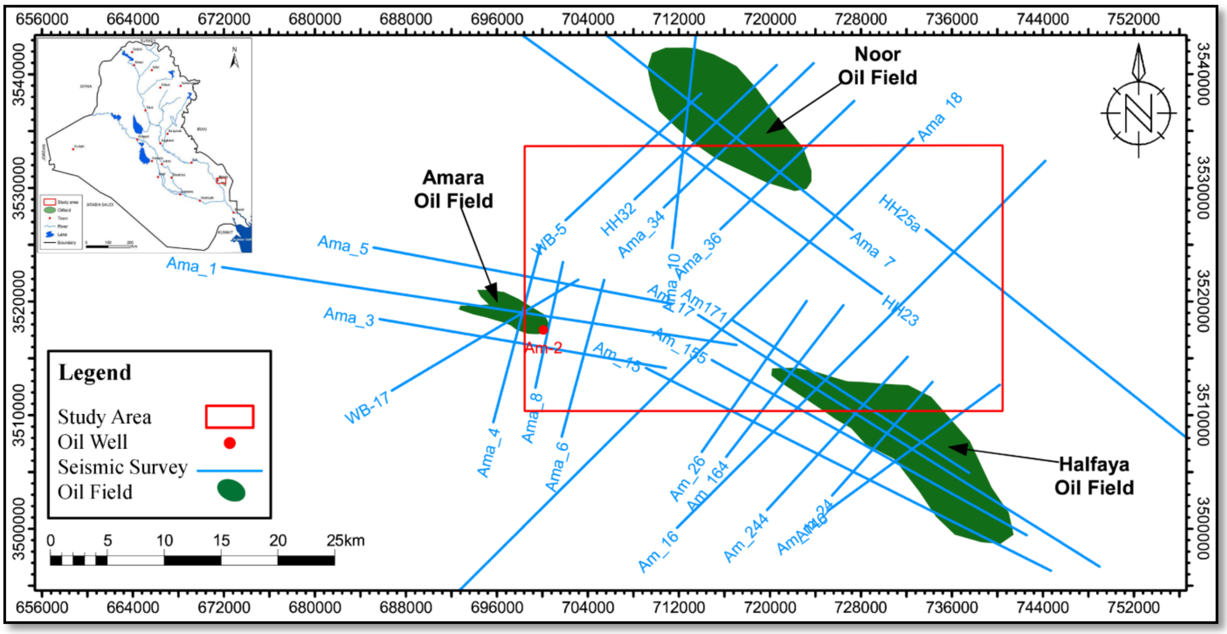

Figure 3: Base map of the study area shows the in-between area within the Halfaya-Noor-Amara oilfields.

5. Enhancement of the Seismic Data

Before the interpretation process, seismic data improvement was carried out by using attributes [20] in the following sequence:

a) Structural smoothing attribute: Smoothing of the input signal guided by the local structure to increase the continuity of the seismic reflectors and decrease noise.

b) Second derivative attribute: In the previous step, some unresolved events and overlapping may occur. This attribute can be used to help in picking the reflectors by providing continuity in areas where reflections are poorly resolved on the raw amplitude.

c) Phase shift attribute: As a result of the previous step, the calculated seismic data will be shifted (-180º phase). Hence, the phase shift attribute is applied to recover the original phase.

d) Source amplitude range recovery: Before the realization process and as a result of all previous steps, the seismic data will lose some of the amplitude range. So, we must re-inventory the original seismic section values.

e) Trace AGC (automatic gain control) attribute: This is the final step of enhancement, the trace AGC attribute is used for enhancing low-amplitude sections to improve horizon interpretation.

Figure-4 shows the steps of seismic data enhancement clarified by section (Ama_10). The yellow circles in the original seismic section in (Figure-4A) surrounded the areas of high noise where there were interruptions to the reflectors, while in (Figure-4B), after applying the structural smoothing attribute, the noise became less (by increasing the S/N ratio) in addition to increasing the continuity of the reflectors. In Figure-4C, when applying the second derivative attribute a phase shift is noticed (indicated by the red arrow) from peak to trough and trough to peak. The degrees of phase were returned to the original by applying the phase shift attribute as in Figure-4D. Afterwards, the source amplitude range recovery was applied (Figure-4E). Finally, the amplitude was increased by applying the trace AGC attribute as in Figure-4F.

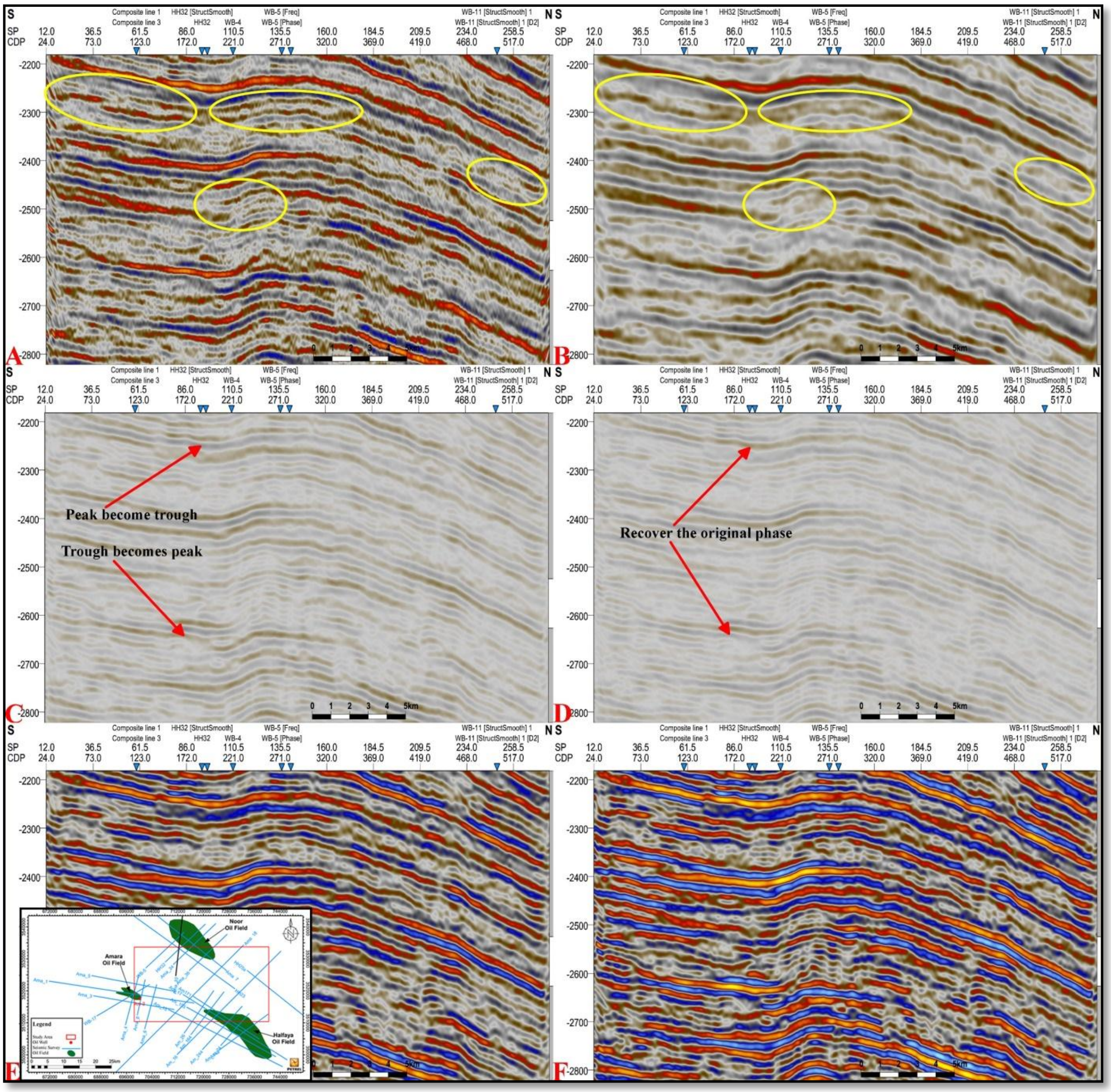

Figure 4: Seismic section (Ama_10) shows the stages of the enhancement: A: original seismic line, B: section with structural smoothing, C: section with second derivative, D: section with phase shift, E: section after recovering original phase, F: section with Trace AGC. The base map illustrates the location of the seismic section (black colored line) in the study area.

6. Seismic Sections Mis-tie

Mis-tie is a mismatch at the intersecting point of seismic lines. A situation in the interpretation of seismic data in which predicted and measured values differ, or when an interpreted reflection does not close, or tie when interpreting intersecting lines; or when interpreted seismic data do not match the results of a drilling well. In general, mis-tie occurs due to different reasons such as (different seismic surveys, differences in static correction values, differences between seismic sources and recording systems, variations in datum, different processing parameters, and other reasons) [21]. The Mis-tie between intersect points of the seismic section has caused great inconvenience to interpretation work. Therefore, we must minimize or eliminate it [22]. In this study, it was found that in most of the intersections of these surveys, there are mis-tie in the TWT. At each seismic line, by adding or subtracting the time difference between the seismic lines of observed mis-tie and its value of computed mis-tie, with care in considering the signs of the amplitudes, the estimated shift for the line is adjusted. Figure-5 shows the difference in TWT values between sections (Ama_3 and Ama_6) is (-15 ms). In this study we apply correction to intersections of 26 lines. After that, the intersection is greatly improved as shown in the composite section in Figure-6. After the mis-tie is corrected, horizon picking has taken place.

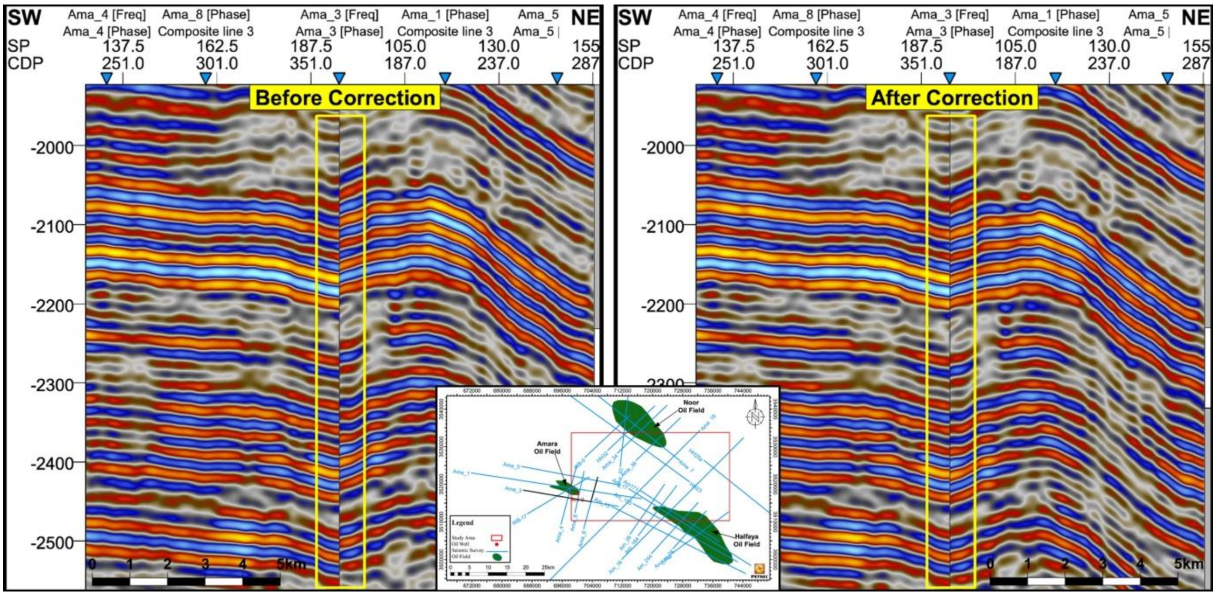

Figure 5: Mis-tie correction of seismic sections in the study area (Ama_3 to the left of the intersection and Ama_6 to the right of the intersection) where Ama_6 corrected by (-15 ms), the intersection between these sections in the base map is shown as black colored line.

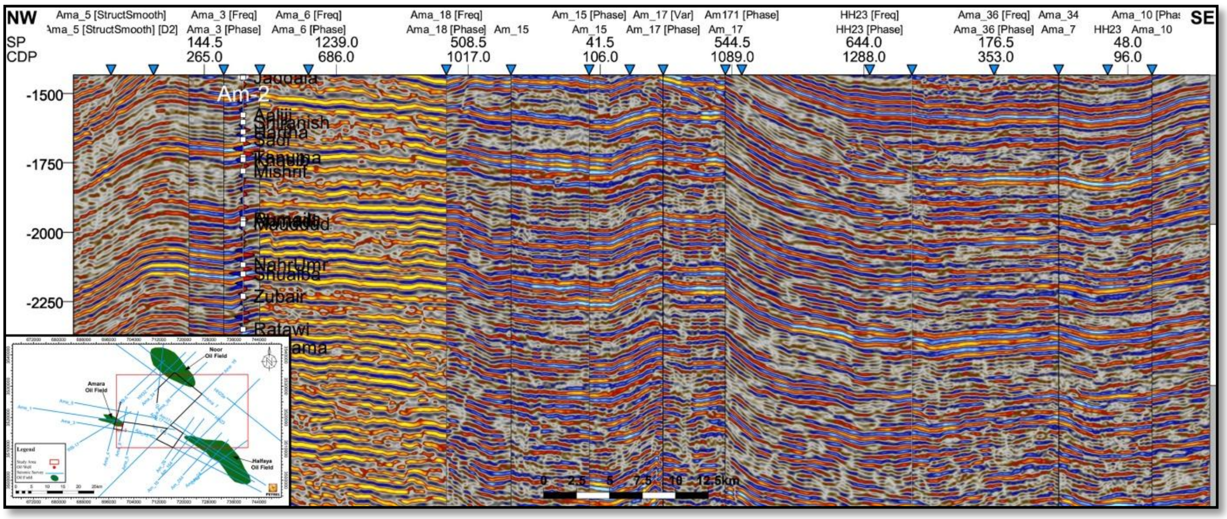

Figure 6: Composite section clarifies the correction of mis-tie in the study area, the composite line in the base map is shown as a black colored line.

7. Horizons Picking

The identification of the tops of Zubair and Ratawi (bottom Zubair) horizons in this study was carried out depending on well tops and the well seismic velocity survey data (check shot) of well Am-2 and by guiding a synthetic seismogram of this well as shown in Figure-7. A synthetic seismogram is generated in order to determine the reflectors more precisely on the seismic section at the well site to begin the process of horizon picking. A very good match was obtained between the synthetic seismogram and the seismic section (without any time shift). Horizon picking is marking the reflection on a seismic section. Identifying wiggles from the same reflection that appear on different traces is involved [23]. One then simply follows the path of that specific reflector on a set of seismic lines that cross orthogonally in planar view, producing a result that correlates on each line. By correlating specific horizons on a seismic line, a time map might then be created [24]. The picked reflectors appeared as follows: top Zubair is between the trough and peak (S-crossing) while top Ratawi corresponds to the peak. The top of Zubair Formation is an S-crossing because the rocks above and below the reflector are limestone and there is a slight difference between them. The top of Ratawi is peak because the upper layer represented by the lower part of Zubair Formation consists dominantly of sandstone which in turn has lower density compared with the limestone of the top Ratawi Formation.

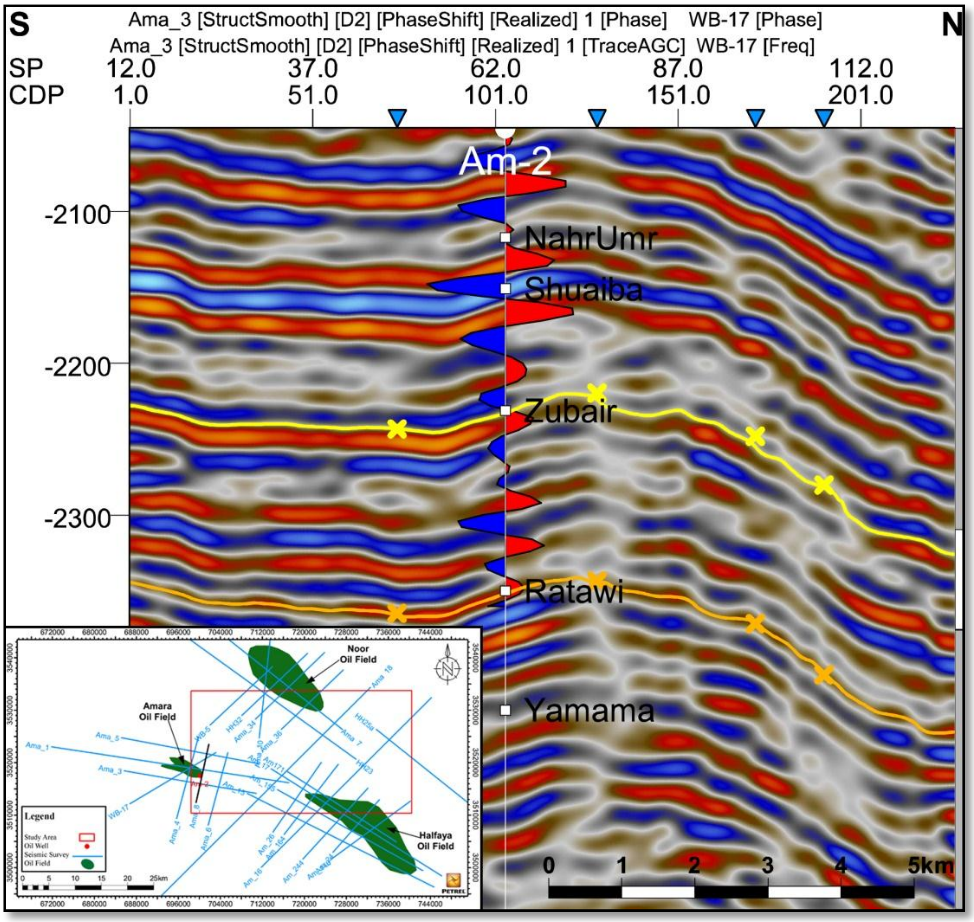

Figure 7: Ama_8 seismic section shows horizons picking from well Am-2, the base map (in the lower left corner) shows the location of the seismic line (black color) in the study area near Amara oilfield.

8. Result and Discussion

8.1 Two-Way Time (TWT) Maps

Two TWT maps were constructed for the picked horizons (top Zubair and top Ratawi formations) to show the values and changes on the map in the time domain. A contour interval of (10 ms) was used. Sea level is used as a reference datum for all maps. There is excellent correspondence between the two TWT maps of the two horizons regarding higher and lower values and the location of structural closures. All time maps show the lowest value of TWT in the southwest and southeast directions which represents an anticline folded structures extending out of the study area to the west of Amara structure and to the southeast of Halfaya structure, so the seismic wave reaches faster to the surface of the reflector, while the highest value of TWT in the northeast direction represents the depositional basin in the area. The increase in the TWT means the seismic wave took extra time to reach the surface of the reflector because the reflector is getting deeper. The general direction of these structures is NW-SE with a slight difference for each structure, Halfaya, Noor, and Amara structures appear as closures with their axes running along about N60˚W, N65˚W, and N75˚W respectively, these results correspond to the previous study [25]. In the study area, it was found that there are two structural axes as shown in Figures (8-9). The first is the Halfaya-Amara axis whose direction is WNW-ESE corresponding with Amara structure, and due to the tectonic effect at the Halfaya structure, this axis deviates to the southeast direction as explained by [26]. Another tectonic force affected the Halfaya structure in different geological times in the northwest-southeast direction leading to the appearance of a branch of a convex extension towards the north from the middle of the Halfaya structure as a nose and directed towards the Noor structure. The second axis of Halfaya-Noor is in the direction of NW-SE. Below is a detailed interpretation of all maps of interested formations.

8.1.1 Two-Way Time Map of Top Zubair Formation

The TWT map of the top Zubair Formation ranging between (2211 - 2651 ms) is shown in Figure-8. It appears that the lowest value of TWT is at the west and southwest (2211 ms) representing Amara structure, and at the southeast (2253 ms) representing Halfaya structure, while the highest value of TWT is at the northeast of the study area (2651 ms). In addition, the minimum value of TWT in Noor structure is (2467 ms) within the study area. The contour values of the structure enclosures are (2280, 2500, and 2280 ms) with closure amounts of (27, 33, and 69 ms) for Halfaya, Noor, and Amara respectively within the study area. The white polygons in the map represent the boundary of the three oilfields (Halfaya, Noor, and Amara) on the earth surface.

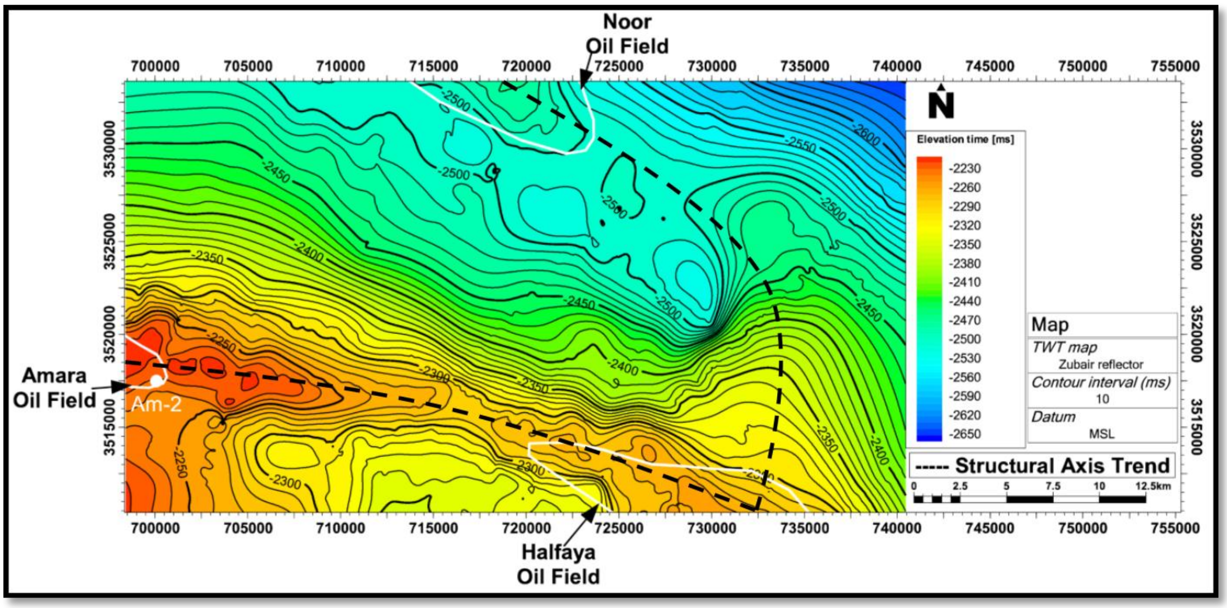

Figure 8: TWT map of the top of Zubair Fn. A dashed black line represents a structural axes.

8.1.2 Two-Way Time Map of Top Ratawi Formation

The TWT map of the top Ratawi Formation ranging between (2326 - 2812 ms) is shown in Figure-9. It appears that the lowest value of TWT is at the west and southwest (2326 ms) representing Amara structure and at the southeast (2384 ms) representing Halfaya structure, while the highest value of TWT is at the northeast of the study area (2812 ms). In addition, the minimum value of TWT in Noor structure is (2575 ms) within the study area. The contour values of the enclosures of the structure are (2400, 2590, and 2400 ms) with closure amounts of (16, 15, and 74 ms) for Halfaya, Noor, and Amara respectively within the study area.

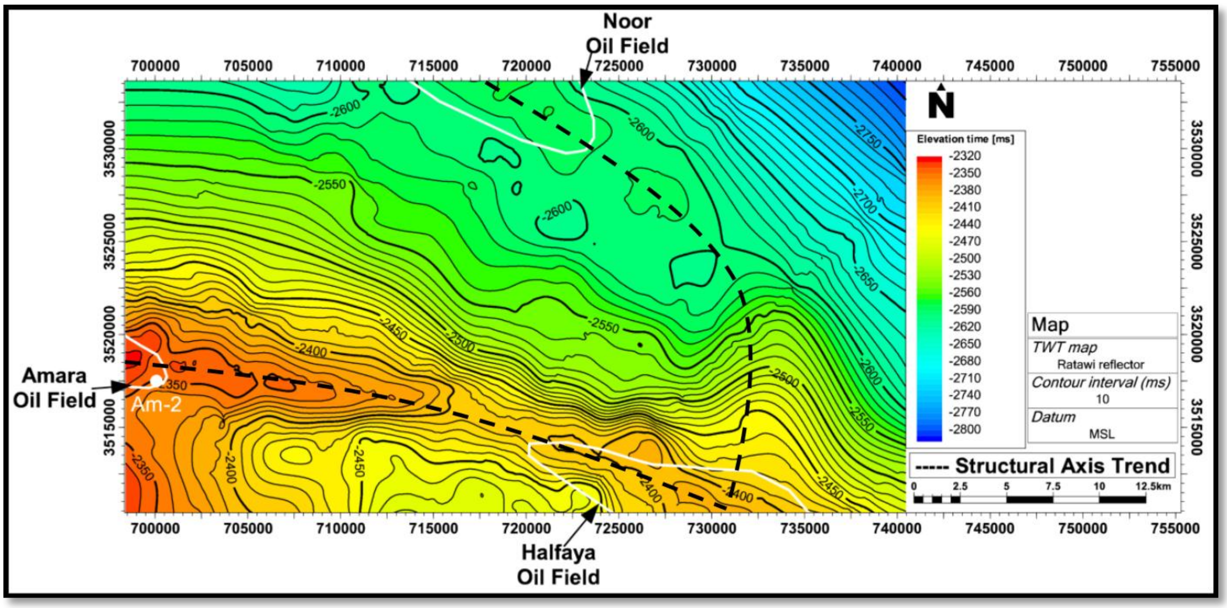

Figure 9: TWT map of the top of Ratawi Formation (bottom of Zubair Formation).

8.2 3D Structural Model in the Depth Domain

TWT maps are converted to depth maps by using the velocity model. The depth map reflects the same subsurface picture in the time domain. Thus, the shape of the depth map looks like a TWT map and shows the same picture of the studied formations. It is obtained by using the average velocity maps and one-way time (OWT) from the time map of the given reflector by dividing the values in the TWT map by two (to convert it to an OWT map, because the depth map is measured by one direction only). A contour interval of (15 ms) was used. Sea level is used as a reference datum. In this study, the simple grid model was prepared in the depth domain (Figure-10). The geological utilization for this model is to expose the high and low points of the area, the direction of the basin in the area, and illustrate the structure model more obviously in the study area [27]. Structurally, this model shows the lowest value of depth is located on the southwest and southeast side which represents an anticline folded structure extending out of the study area to the west of Amara structure and to the southeast of Halfaya structure while the highest value of depth on the northeast side represents the depositional basin in the area. The slope is steep on both sides of the anticline and then gradually decreases towards the NE. Halfaya and Amara structures are separated by a saddle. The general direction of the structures is NW-SE with a slight difference for each structure, Halfaya, Noor, and Amara structures appear as closures with the axis running along about N60˚W, N65˚W, and N75˚W respectively, these results correspond to the previous study [25]. This study found that there are two structural axes in the area (Figure-11). The first is the Halfaya-Amara axis whose direction is WNW-ESE at the Amara structure and due to the tectonic effect at the Halfaya structure, this axis deviates to the southeast direction as explained by [26]. The Halfaya-Amara axis coincides with both top formations. Another tectonic force affected the Halfaya structure in different geological times in the northwest-southeast direction leading to the appearance of a branch of a convex extension towards the north from the middle of the Halfaya structure as nose and directed towards the Noor structure. The second axis of Halfaya-Noor is in the direction of NW-SE. This axis is clearly observed in top Ratawi, where the influence is greater in Ratawi than in Zubair and gradually decreases towards the younger formations.

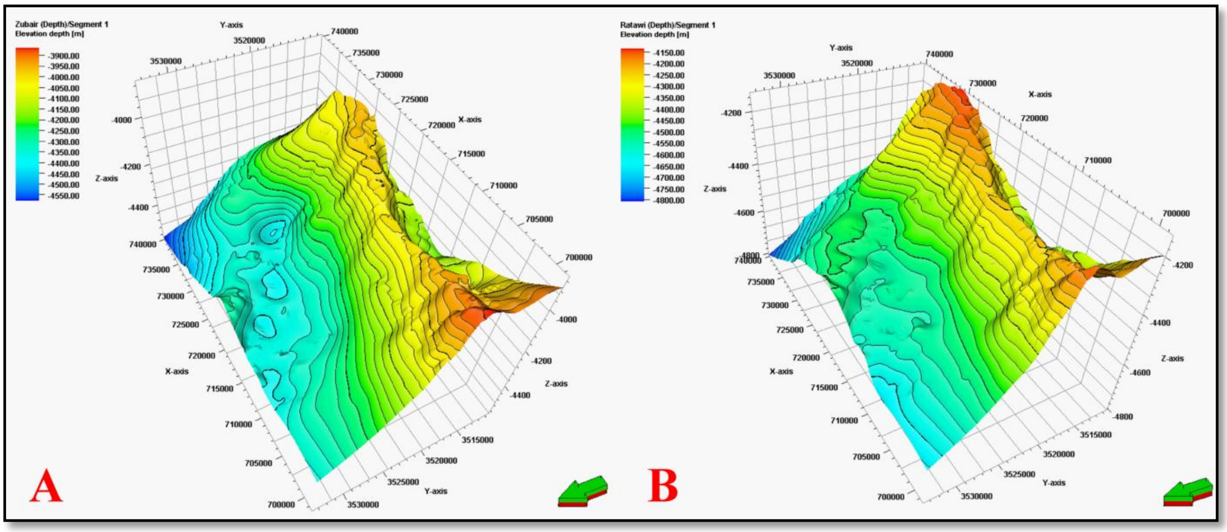

Figure 10: 3D structural models in depth domain for the top of (A) Zubair Formation and (B) Ratawi Formation. The depth values range is located in the top left of the model.

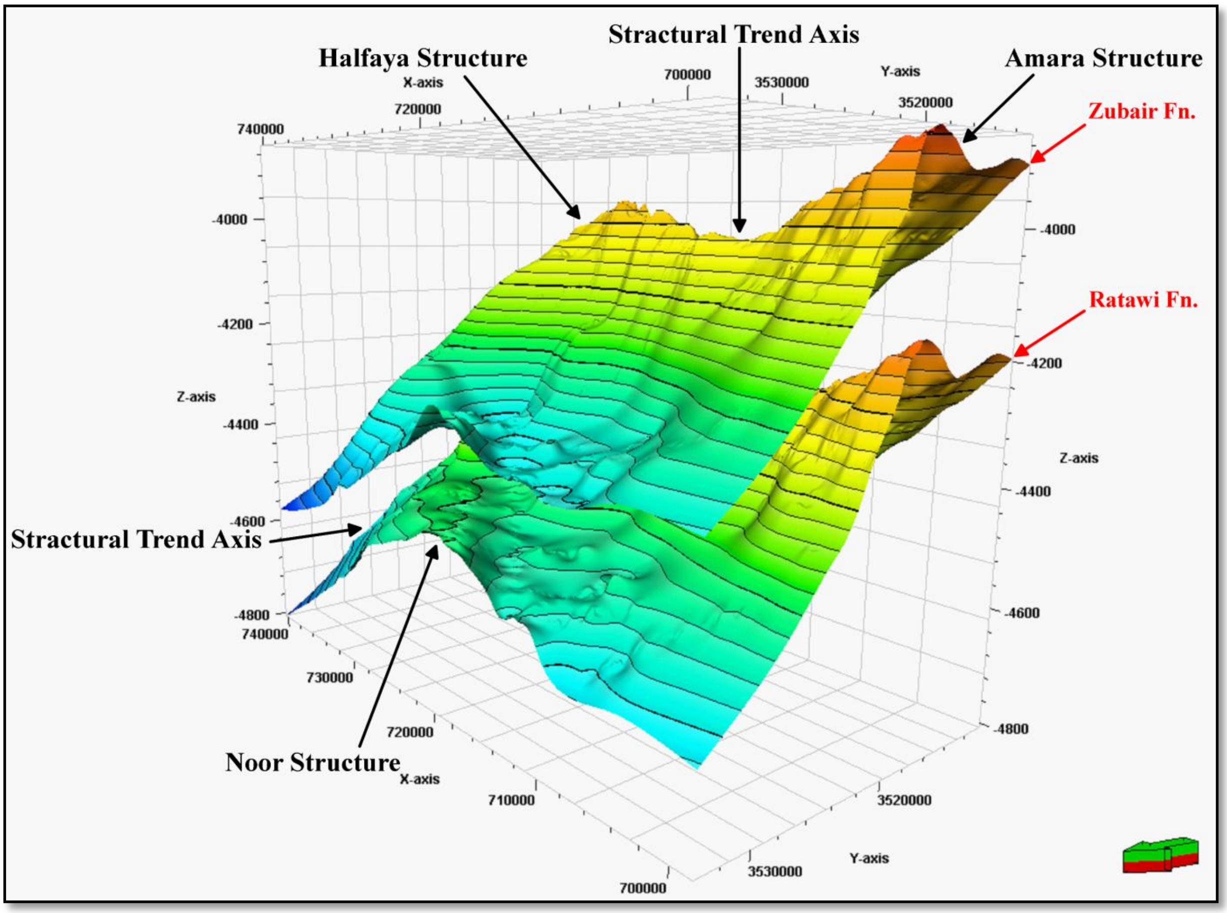

Figure 11: 3D structural model for the top of Zubair and Ratawi formations, this model shows the structural trend axes.

8.3 Seismic Stratigraphy Interpretation

Stratigraphical phenomena and hydrocarbon indicators have been identified on the seismic sections within the Zubair Formation depending on the geometry (or character) of reflections, their amplitudes, and their velocities. General examination of the seismic sections of the studied area gives us an indication of the important reflectors to be studied, their continuities over the area, the matching between the same reflector at the intersection points, concordance of the reflector, and the quality of the reflectors. The picked reflectors (top Zubair and top Ratawi (bottom of Zubair)) are described as very good. Seismic attributes carry useful information on certain physical properties of the medium traversed by the reflection wavelet. Instantaneous phase attribute was applied to the 2D seismic section of the study area, which is calculated in degrees (-π, π). The instantaneous phase is a good indicator of continuities, faults, pinch-outs, flat spots, mounds, bed interfaces, and sequence boundaries [28]. Figures (12-13) show the instantaneous phase section of seismic lines (Ama_5 and Am_17) respectively. These figures show the stratigraphic feature such as a flat spot (that appears in a horizontal form) within the Zubair Formation which may indicate oil-water contact. The sag is also noted in the same seismic sections which refers to a decrease in velocity which means an increase in travel time (time delay) due to the presence of hydrocarbons.

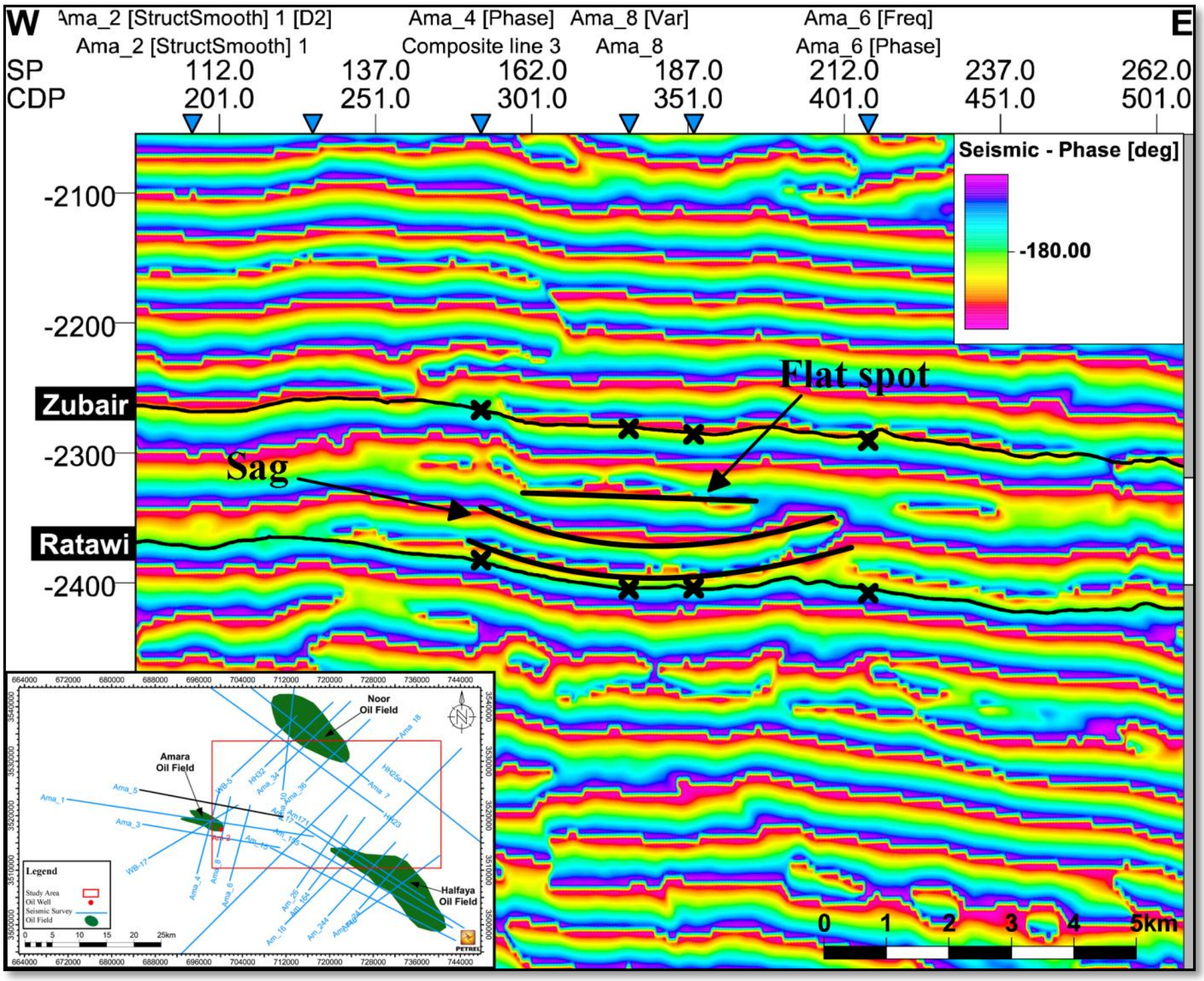

Figure 12: Instantaneous phase section for the Ama_5 section shows a flat spot and sag within Zubair Fn. which is indicated as a hydrocarbon indicator.

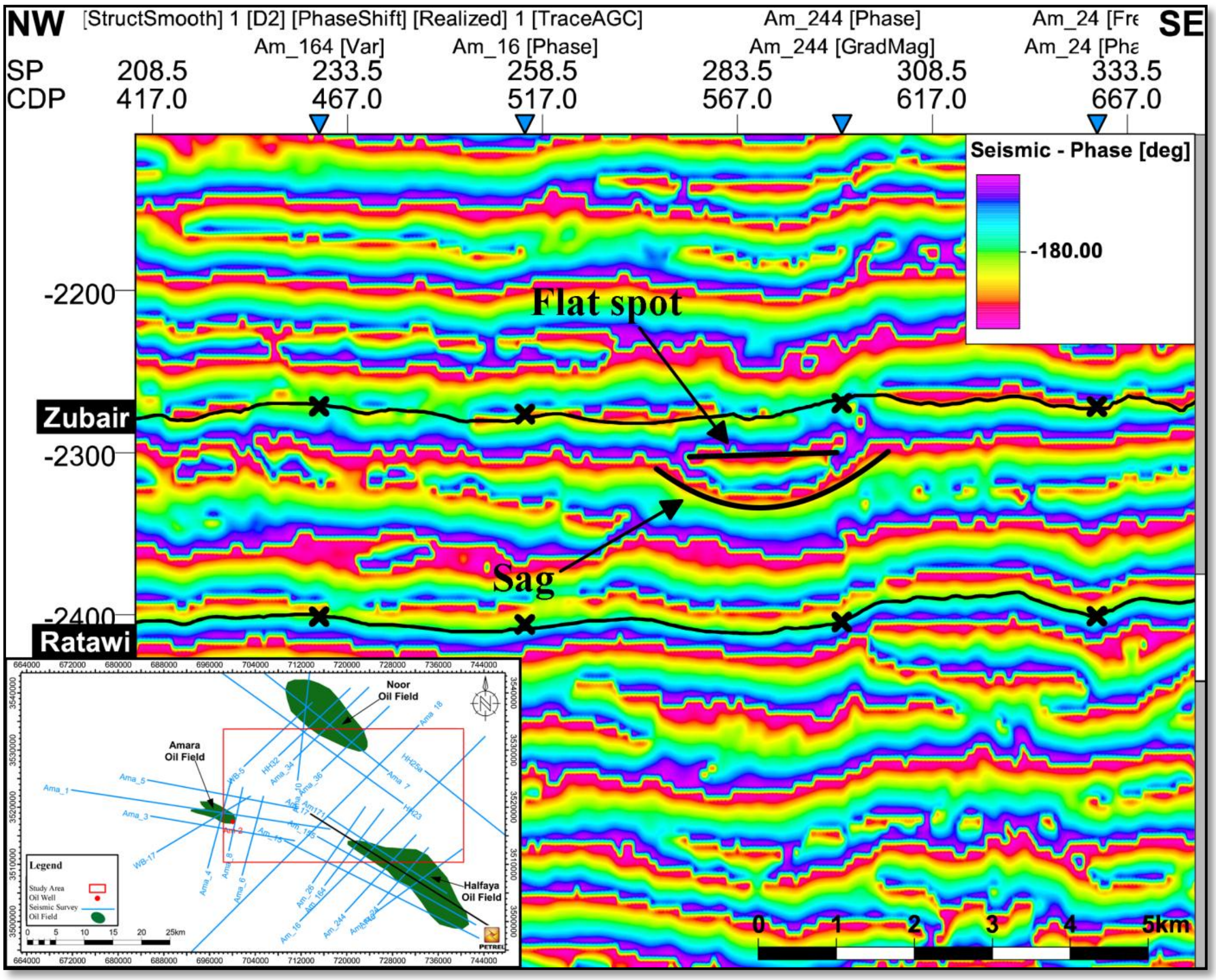

Figure 13: Instantaneous phase attribute for Am_17 section shows flat spot and sag feature.

Another type of direct hydrocarbon indicator detected in this study is the bright spot. A local high-amplitude seismic anomaly can indicate the presence of hydrocarbons. Bright spots result from large changes in acoustic impedance found across an interface [29]. In this study, Zubair Formation is composed of sandstone interbedded with shale, acoustic impedance is lower in the sandstone than in the shale. As hydrocarbons are added to pores spaces, the velocity and density of the sandstone decrease. Due to this, the acoustic impedance at the top of the sandstone increases, making the reflection stronger; thus, it becomes brighter [30]. Figure-14 shows the bright spots on seismic sections (HH25a, HH32, and AM_26).

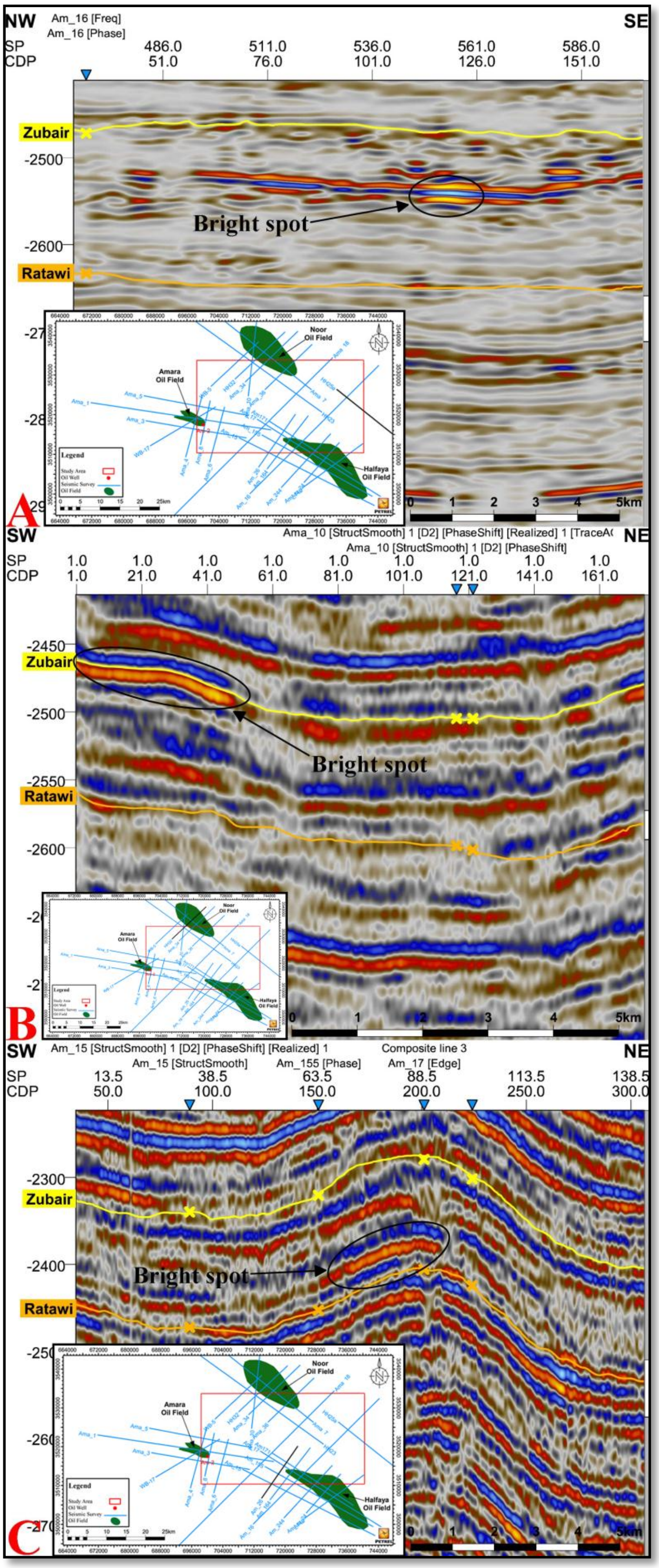

Figure 14: DHIs display bright spots on seismic sections (A) HH25a, (B) HH32, and (C) Am_26.

9. Conclusions

1- The current study showed three separate structures representing the three oilfields (Halfaya, Noor, and Amara) that have been influenced by various tectonic forces in different geological times and found two structural axes in the study area. The first one is the Halfaya-Amara axis whose direction is WNW-ESE at the Amara structure. Then this axis deviates in the southeast direction due to the tectonic effect on the Halfaya structure. Another tectonic force affected the Halfaya structure in the northwest-southeast direction leading to the appearance of a branch of a convex extension towards the north from the middle of the Halfaya structure as a nose and directed towards the Noor structure. The second axis of Halfaya-Noor is in the direction of NW-SE.

2- Studying the seismic sections and applying the instantaneous phase attribute, showed seismic stratigraphic features in the Zubair Formation, such as a flat spot representing the seismic response of hydrocarbon-water contact and sag which refers to a decrease in the velocity of seismic waves which means an increase in travel time due to the presence of hydrocarbons, in addition to the bright spots identified which are considered as Direct Hydrocarbon Indicators (DHIs).

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