



Seismic Interpretation of the Subsurface Structures for Delineating the Occurrence of some Reservoirs in the Main Abu El-Gharadig Oil Field, north Western Desert, Egypt



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THE OBJECTIVE of this study is to delineate and evaluate the subsurface structural features and to determine the hydrocarbon potentialities of the Abu El-Gharadig basin, Western Desert, Egypt, particularly in the Main Abu El-Gharadig oil field. The zones of interest of this study are Abu Roash “E” and Upper Bahariya reservoirs of the late Cretaceous age. 20 2D seismic reflection profiles were used to evaluate the study area’s structural framework and to construct structural contour maps. So, two horizons were interpreted and picked, by using seismic well tie, to link between the seismic data (in time domain) with the well log data (in depth domain) and to generate synthetic seismogram to create a wavelet which is then compared with the seismic traces and well location, and to determine the stratigraphic boundaries of interest. After that, structural contour maps are constructed, which reveal that, all the area are influenced by normal faults trending E-W and NW-SE directions. The Fault polygons of the two horizons generally indicate three-way dip closure tilted fault blocks and also two-way dip closures forming horst and graben blocks. Beside the two zones of interest, we found the Paleocene-Early Middle Eocene Appolonia “B” and “C” horizons in the north eastern part of the study area of high amplitude and has a bright spot, which is not continuous in any other location of the study area. Therefore, we applied some techniques of the seismic attributes, to indicate the presence of wedging or channeling of limestone rocks, which may indicate commercially hydrocarbon potential.

Keywords: Abu El-Gharadig Basin, Seismic Attributes, Hydrocarbon Potentiality, Subsurface Structural Features, Abu Roash E and Upper Bahariya Reservoirs, Appolonia “B” and “C” Horizons.

1. Introduction

The Western Desert stretches from Sudan’s boundaries in the south to the Mediterranean shoreline in the north, and from the Nile Valley in the east to Libya’s borders in the west. It occupies an area of about 681,000 Km², that is almost two thirds of the whole area of Egypt. The Western Desert is basically a plateau desert, with huge flat range of rocky ground and so many large deep depressions are located (Said, 1990). The north western desert formed mostly as a

result of vertical movement of basement blocks dominated by parallel, elongated, tilted fault blocks, resulting in horst and half-graben structures linked with the erosion of the upthrown blocks (Barakat, 2017)

The Abu El-Gharadig basin is a deep E-W oriented asymmetric graben in the north-central part of the Western Desert **Fig. (1)**. It occupies about 3.6 % of the Western Desert and stretches for about 300 km long and 60 km wide, with age ranging from Late

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Received: 15/07/2023; Accepted: 13/08/2023

DOI: 10.21608/EGJG.2023.218795.1051

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Jurassic to Early Cretaceous. The Main Abu El-Gharadig oil field is positioned in the Abu El-Gharadig basin's central part (EGPC, 1992 and Abdelmalek and Zeidan, 1994). The study area is located in the Abu El-Gharadig basin, between latitudes 29° 39' and 29° 45' N and longitudes 28° 24' and 28° 33' E **Fig. (1)**.

According to Barakat (1982), the structural elements discovered in the north Western Desert are frequently in the form of folds, faults, and subsurface ridges that separate the distinct sedimentary basins. The north Western Desert is subjected to two significant intersecting faults, one of which trends NE-SW associated to the Jurassic-Early Cretaceous rifting and the other of which trends NW-SE related to the Late Cretaceous-Early Tertiary rifting. The north Western Desert structures are dominated by faults. The majority of the faults are steep normal faults, with a long history of growth. During a period in their history, some normal faults experienced strike slip movements. The orientation of many of the fold axes appears to have been dislocated by the strike slip movements. The strike slip movements were most likely related to the African plate lateral movements within the Late Cretaceous (dextral) and Jurassic (sinistral) periods (Hantar, 1990).

There are three major fold trends of various ages in the north Western Desert, including the N-S trend, which is mostly represented in the subsurface and has a significant impact on the Paleozoic sediments. Surface structural features in Abu-Roash, Wadi El-Rayan, and Bahariya Oasis show a NE-SW trend, that was particularly active during the Late Cretaceous-Early Tertiary period (Syrian Arc system). Several Tertiary surface structures to the NE of Siwa, spanning between Moghra, Wadi El-Natrun and the Nile Delta, show a NW-SE trend. Faulting can be seen in the Lower Cretaceous rocks of the north Western Desert, with faults strike running parallel to the Syrian Arc System.

The Abu El-Gharadig basin is a part of geologic sequence in the north Western Desert (Abrams *et al.*, 2016), that includes rocks range in age from Pre-Cambrian to Quaternary **Fig. (2)**. Depending on lithology, the sedimentary succession in the north Western Desert can be split into three sequences: basal clastic group, from Cambrian to pre-Cenomanian, middle carbonate unit between, Cenomanian to Eocene, and top clastic section, from Oligocene to Recent. (Said, 1962). The Abu Roash Formation was deposited over a large shallow marine

shelf, throughout multiple sedimentary cycles, as the sea level changed. Limestone and shale sequences characterize transgressive phases, whereas clastic sequences characterize regressive phases. El Gezeery and Oconnor (1975) classified the Abu Roash Formation from bottom to top into seven members, (G, F, E, D, C, B and A). Fine clastics make up the Members A, C, E and G, while clean carbonates make up members B, D and F. The Mubarak Member (Abu Roash E) is a Middle Turonian shale and minor limestone bed, with fine glauconitic and pyritic sandstone, that was formed on a shallow marine shelf. This member sits on the top of Mansour Member (Abu Roash F) and beneath the Rakhm Member (Abu Roash D). Said (1962) was the first to use the name Bahariya Formation, stating that the type locality is Gebel El-Dist, Bahariya Oasis, with an overall thickness of 175 m. The age of this Formation is Early Cenomanian. It was identified as a transgressive marine environment in a marginal marine environment (Mohamed, 1994). The upper shaly section and the lower more sandy and silty section are the two primary lithologic units of the formation (Fawzy and Dahi, 1992). As a summary, the Abu Roash (D & E) and (Upper & Lower) Bahariya formations contain good reservoir zones, with varying lithologic compositions, that indicate various local depositional environments. Furthermore, both formations have high porosity, which supports oil and gas accumulation (El-Gendy *et al.*, 2022)

2. Materials and Methods

The seismic data used for this study comprise twenty 2D seismic lines, as shown in **Fig. (1)**. These 2D seismic lines are divided into 8 In-lines trending N-S, 9 Cross-lines trending E-W and 3 arbitrary lines as illustrated by the base map. All of these data were imported to Petrel Software (2017) to go through seismic interpretation.

2.1 Tying formation tops with the seismic lines via synthetic seismogram

The connection between seismic reflections and stratigraphy is one of the first important steps in analyzing seismic data. Sonic (DT) and formation density logs (RHOB) are available in some wells. It is easy to generate a synthetic seismogram from these logs, that display the seismic reflection response for comparison with the actual well data (Schlumberger, 2008). The link among the impedance logs, reflection coefficients and synthetic traces for AG-11 well is shown in **Fig. (3)**. The sequence of boundary reflections is shown to be consistent.

2.2 Picking horizons and faults to identify structural features and general fault trends

Interpreters can create horizons and faults on the in-lines, crosslines, random lines and slices. Horizons on vertical seismic displays and horizontal slice displays can be automatically tracked. Seismic-based interpretation maps can be created, using the improved horizon tracking algorithms paired with user interpreted faults and fault polygons. The reduction of reflection amplitude is a common indicator of faults on the seismic sections (Bjørlykke, 2010).

Schlumberger Inc.'s Petrel TM (Version 2017) was used for interpretation in this study. Four seismic signatures were chosen for the following horizons, that are: Top Abu Roash D, Top Abu Roash E, Top Upper Bahariya and Top Lower Bahariya. Some interpreted seismic lines are selected in order to show the picking of the horizons and the structural features in the study area **Figures (4 to 13)**. Five seismic sections are selected: three sections are in the in-line direction (N-S) and two are in the cross-line direction (E-W).

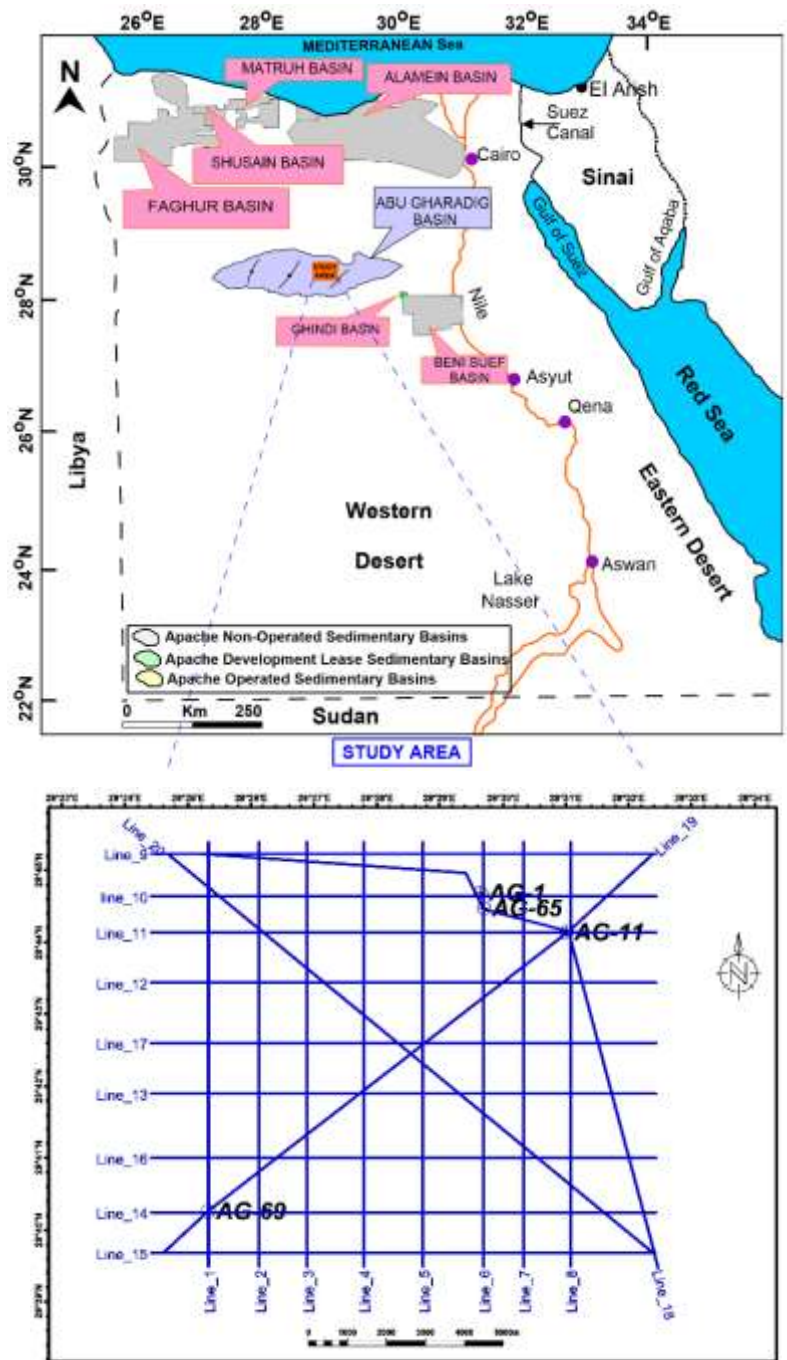


Fig. 1. Location map of the study area and a base map showing in-lines, cross-lines, arbitrary lines and well locations of the study area.

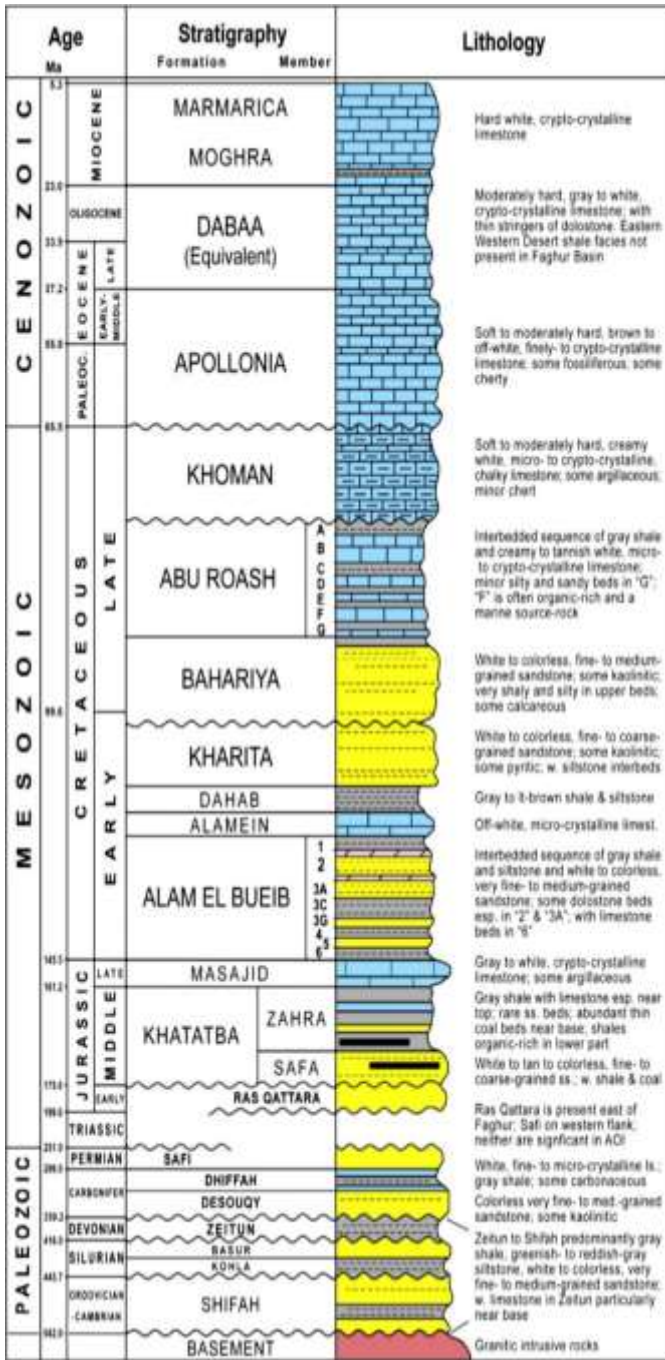


Fig. 2. The stratigraphic columnar section of the north Western Desert (Abrams et al., 2016).

The interpreted seismic section (in-line 3) is located in the central western part of the study area Fig. (5). It is oriented in the North-South direction. The faults of this section are all normal faults. The faults F2, F3, F4 & F7 striking through the area in NW-SE direction with a dip direction to the NE. The faults F1, F6 & F5 striking through the area in the NW-SE direction with a dip direction toward the SW, while F1 is dipping to the south. All the faults are dissecting the succession from Abu Roash "D" Member till Lower Bahariya Formation. The main fault F4 extends from the shallower rock units "Khoman A" till the top of Upper Bahariya Formation. The faults F1 & F2 and

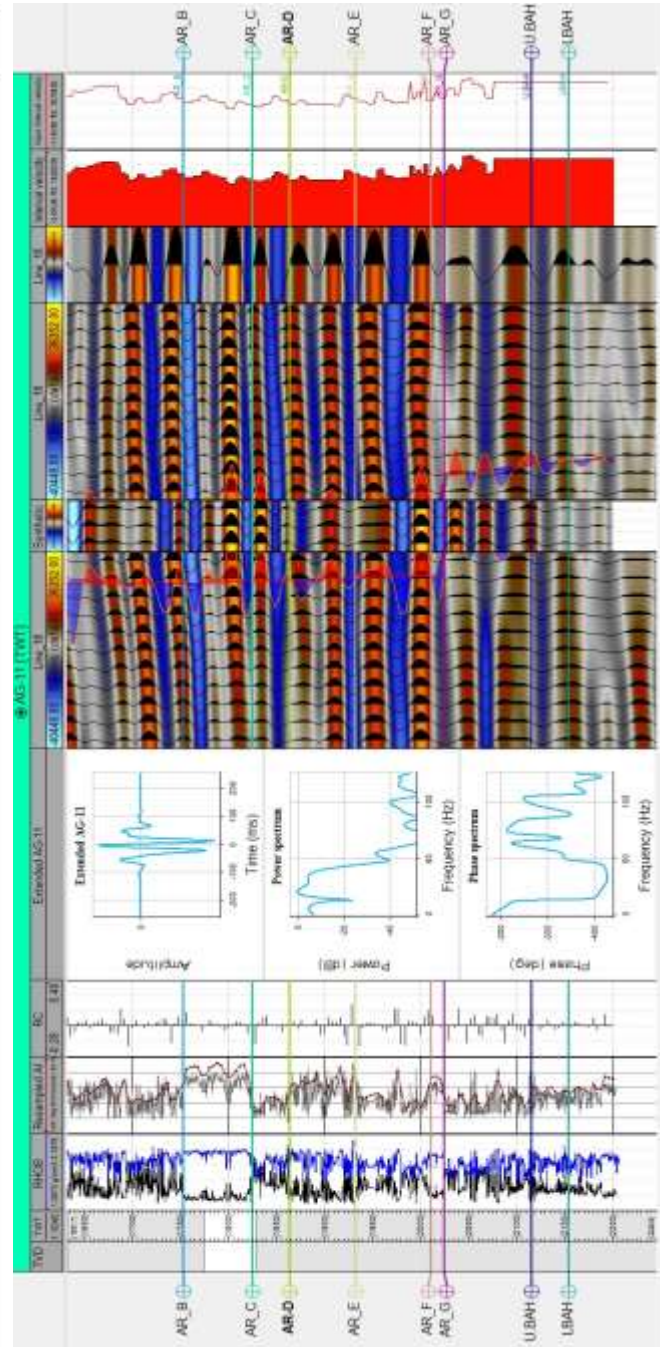


Fig. 3. Synthetic seismogram created for AG-11 well.

F6 & F7 are forming horst blocks, while the fault F3 and the fault F5 are forming graben block. The faults F2 & F3 and F6 & F5 are step-like faults.

The interpreted seismic section (in-line 6) is located in the central eastern portion of the study area Fig. (7). It is oriented in the N-S direction. The faults of this section are all normal faults. This section is showing the same structural regime, as the previous one, but with new fault trends, except the normal fault (F4) has appeared in the southern side of the section. The faults F4, F9, F10 & F12 are striking through the area in the NW-SE direction, with a dip direction to the NE, but

F12 is dipping to the north. The faults F8 & F11 are striking through the area in the NW-SE direction with a dip direction to the SW, while F11 is dipping to the south. All the faults are dissecting the succession from Abu Roash "D" Member till Lower Bahariya Formation. The faults F11 & F12 and F4 & F8 are forming horst blocks, while the fault F11 with the fault F10 are forming graben block. The faults F4 & F9 and F10 & F12 are step-like faults.

The interpreted seismic section (in-line 8) is located in the eastern portion of the study area **Fig. (9)**. It is oriented in the N-S direction. The faults of this section are all normal faults. This section is showing the same structural regime, as the previous one but, with some new fault trends, that are F13, F14 and F15. The faults F4, F9, F10, F12 & F15 are striking through the area in the NW-SE direction with a dip direction to the NE, except F12 is dipping to the north. The faults F11 & F13 are striking through the area in the NW-SE direction with a dip direction to the SW, while F11 is dipping to the south. All the faults of this section are dissecting the succession from Abu Roash "D" Member till the Lower Bahariya Formation, except the fault F12 is cutting through the Abu Roash Formation and stopping at the Bahariya Formation by the fault F14. The faults F12 & F13 are forming horst blocks while the fault F10 with the fault F13 are forming graben block. The faults F4, F9 & F10 and F12 & F15 are step-like faults.

The interpreted seismic section (in-line 10) is located in the northern portion of the study area **Fig. (11)**. It is oriented in the E-W direction. The faults of this section are all normal faults. This section is showing the same structural regime as the previous one, but with some new fault trends, that are F16 and other

minor faults, as explained in Figure 7. The fault F12 is appearing on this line as a listric fault, forming rollover anticline on the downthrown side of the fault. The fault F16 is striking through the area in the NW-SE direction with a dip direction to the NE. Some faults on this section are dissecting the succession from Abu Roash "D" Member till the Lower Bahariya Formation and the others are cutting through the Abu Roash or Bahariya formations.

The interpreted seismic section (in-line 13) is located in the central part of the study area **Fig. (13)**. It is oriented in the E-W direction. The faults of this section are all normal faults. This section is showing the same structural regime, like the previous fault trends, that explained above in the previous seismic sections.

2.3 Construction of Time Structure Contour Maps

The seismic data were primarily examined in terms of structural elements. Currently, this is accomplished by selecting seismic reflection horizons. According to Coffeen (1984), the major techniques in seismic interpretation include correlating seismic events, tying their times, closing their loops, posting their time values and fault segments, building the fault pattern, and contouring the arrival times.

To build a structural map at the Abu Roash E and Upper Bahariya horizons, the selected time values and the positions of fault segments are marked on the study area's base map **Figures (14 and 15)**. The two-way-times of Abu and Roash E and Upper Bahariya horizons vary from -1720 to -2570 ms and from -1880 to -2780 ms, respectively. These maps achieve their maximum values toward the north eastern and south western parts of the study area. The low relief parts are in the NW side of the study area.

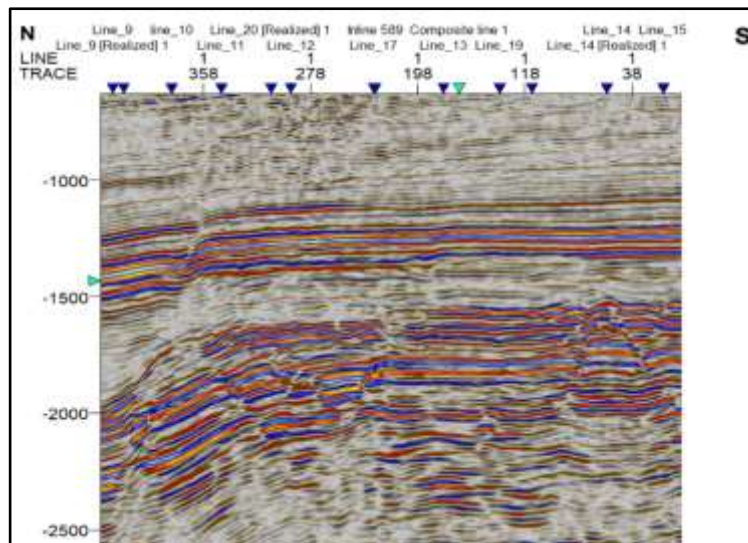


Fig. 4. Un-interpreted seismic line number 3.

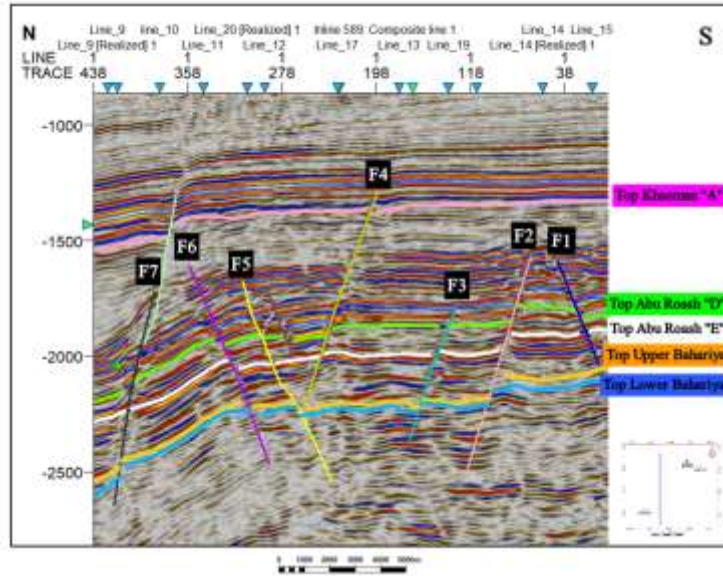


Fig. 5. Interpreted seismic line number 3.

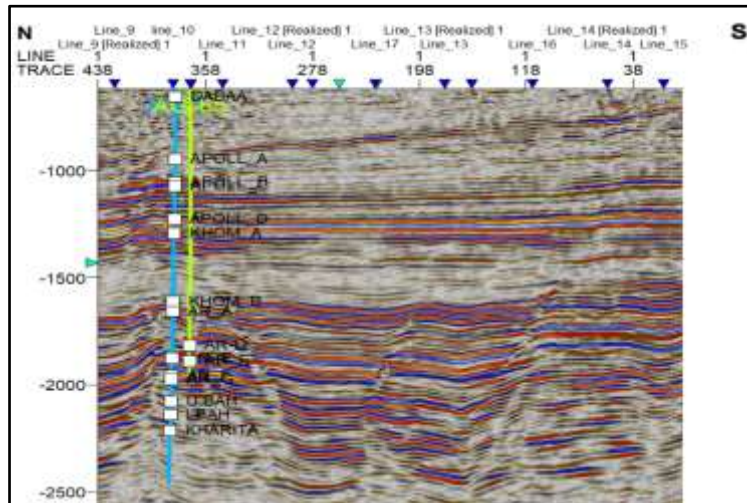


Fig. 6. Un-interpreted seismic line number 6.

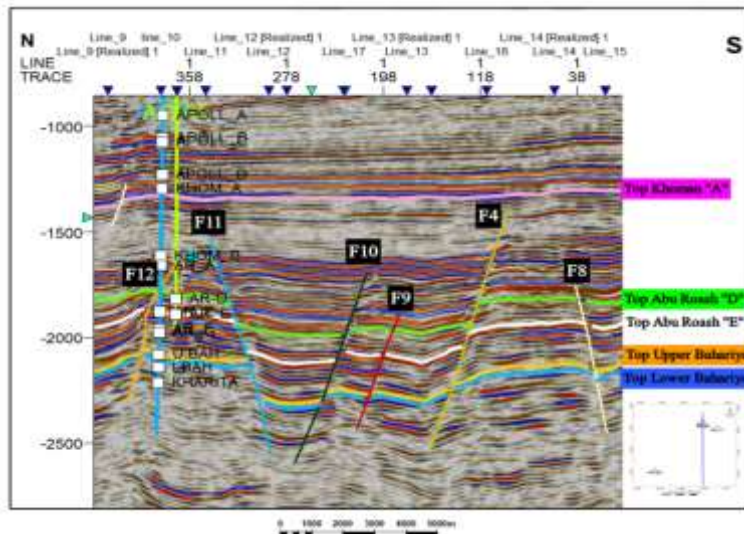


Fig. 7. Interpreted seismic line number 6.

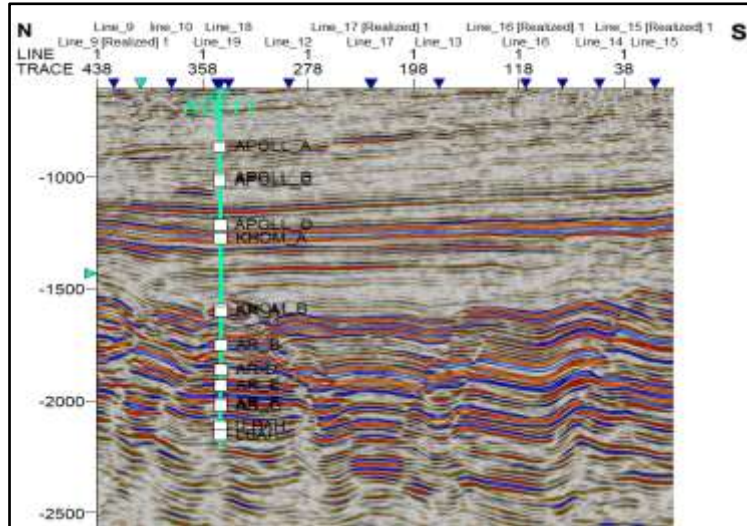


Fig. 8 Un-interpreted seismic line number 8.

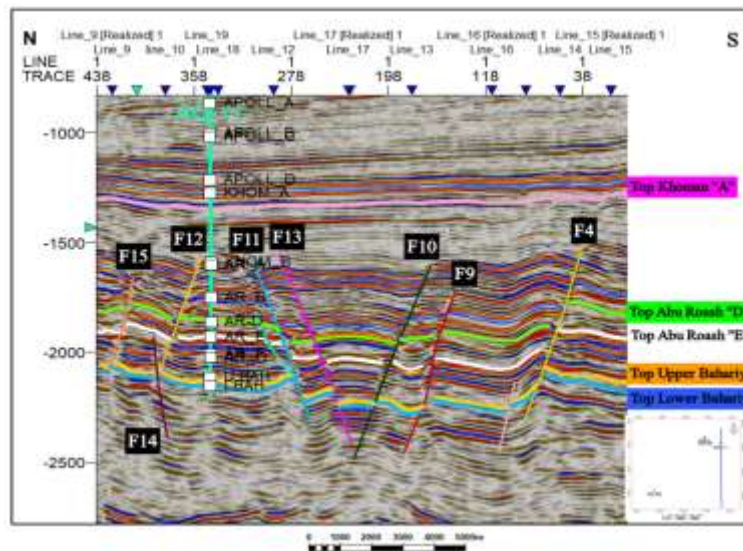


Fig. 9. Interpreted seismic line number 8.

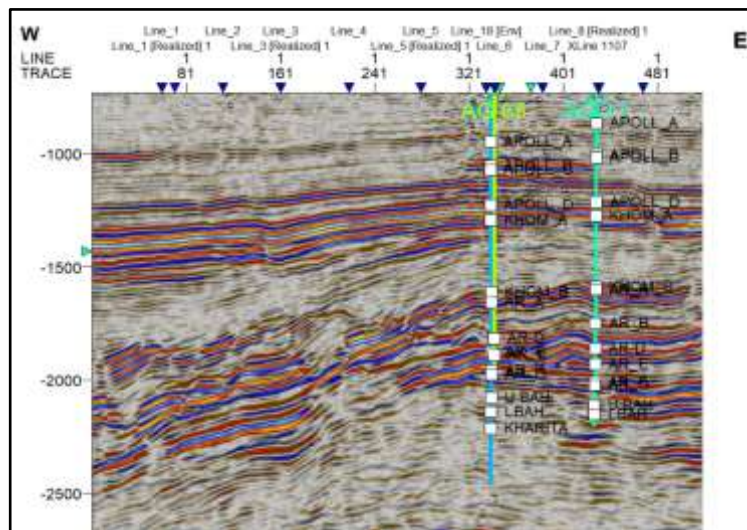


Fig. 10. Un-interpreted seismic line number 10.

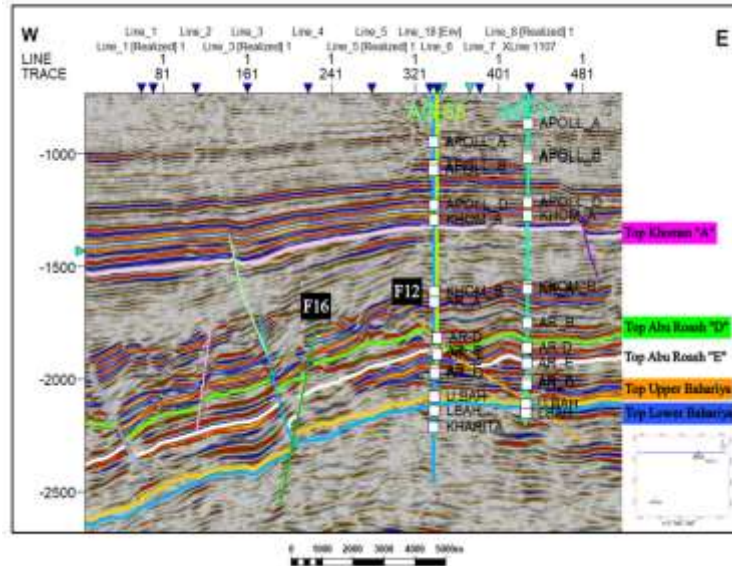


Fig. 11. Interpreted seismic line number 10.

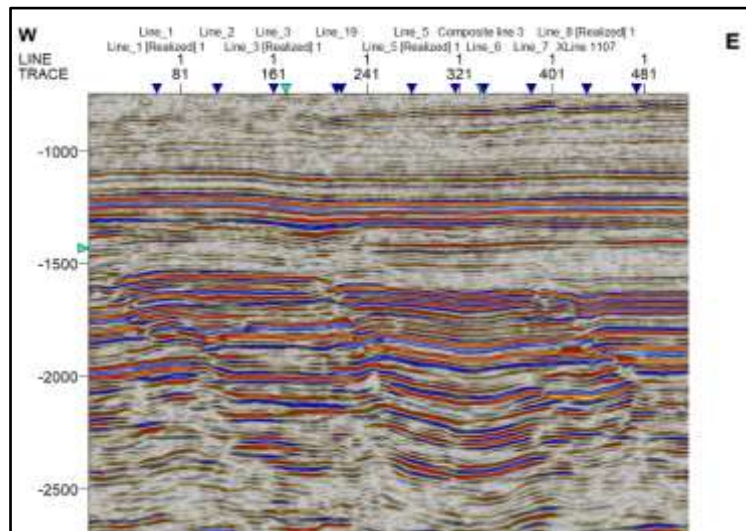


Fig. 12. Un-interpreted seismic line number 13.

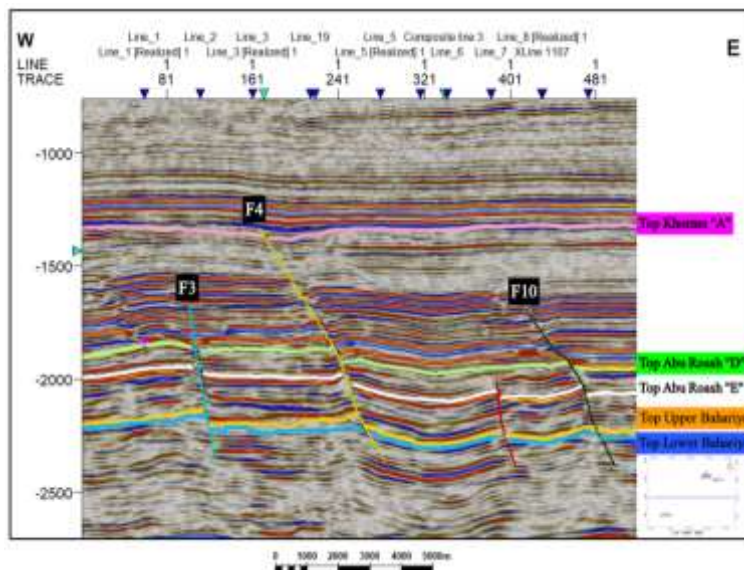


Fig. 13. Interpreted seismic line number 13.

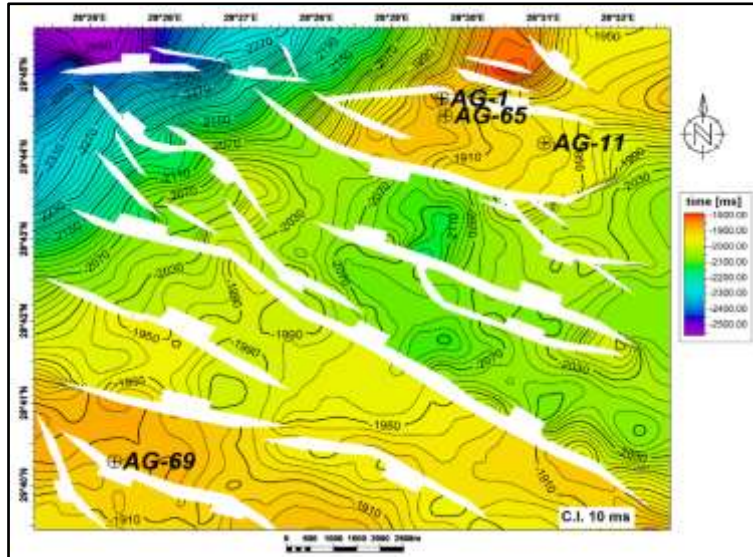


Fig. 14. Time structure contour map of Abu Roash “E” horizon.

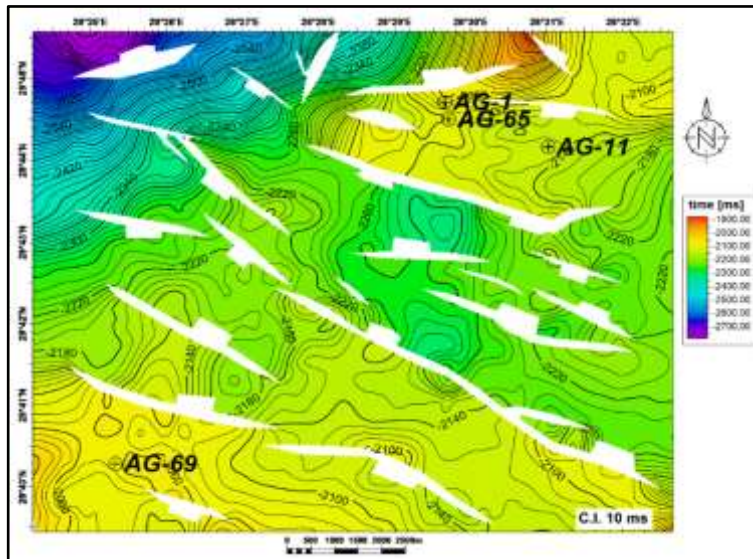


Fig. 15. Time structure contour map of Upper Bahariya horizon.

2.4 Construction of Average Velocity Maps

According to Dobrin (1976), the average velocity (V_{av}) is simply a velocity over a certain reflecting surface that is below the seismic reference datum.

$$V_{av} = Z/T$$

where;

Z = is the depth to the reflecting surface from the wells in ft, and

T = is the one-way transit time to the reflector from the same reference in ms

If (Z) represents the sum of the thicknesses of layers $Z_1, Z_2, Z_3...to Z_n$, the average velocity is defined as:

$$V_{av} = \frac{Z_1+Z_2+Z_3+\dots+Z_n}{T_1+T_2+T_3+\dots+T_n}$$

Figures (16 and 17) represent the average velocity maps of the Abu Roash E and Upper Bahariya horizons respectively. The velocity range at the Abu Roash E horizon is 4.54 to 4.87 ft/ms, where it increases toward the south eastern direction of the study area and declines toward the north western

direction **Fig. (16)**. The velocity range at the Upper Bahariya horizon is 4.70 to 4.99 ft/ms, where it increases toward the eastern direction of the study area and decreases toward the western direction **Fig. (17)**. These horizons' velocities show an increase toward the eastern part of the study area and a decrease toward the western part.

2.5 Construction of Depth Structure Contour Maps

The time structure and average velocity maps, are utilized to convert the reflection times into depths in order to construct the depth structure contour map. On the depth structural contour map, the structural elements are displayed in terms of depth rather than time. The projected horizons' positions would then show fault displacements across individual faults. **Figures (18 and 19)** show the depth structure contour maps for the investigated horizons.

The depth values of the Abu Roash E vary between 8175 and 11700 ft (TVDSS), while the depth values of the Upper Bahariya horizon vary between 9125 and 13100 ft (TVDSS). Maximum values (high relief) are found in the NE part of the study area, while the minimum values (low relief) are found in the NW part.

2.6 Utilizing seismic attributes to identify the limestone gas pocket in the Appolonia B and C horizons.

Figure (20) illustrates the location of the high amplitude body present in the study area. We found that, the appolonia "B" and "C" horizons has a bright spot in the north eastern part of the location map and not continuous in any other location of the study area. So, we applied three main types of attributes, which are the RMS (root mean square) amplitude attribute, Trace Envelope attribute and Instantaneous Phase attribute on the arbitrary seismic line 18, that passes

through AG-1X, AG-11 and AG-65 wells to see their influence on this location of the study area. **Figure (21)** indicates the arbitrary seismic line 18 before applying any type of seismic attributes.

3. Results and interpretation

3.1 Results of the depth structure contour maps

The depth structure contour maps reveal that, the entire area is influenced by normal faults trending E-W and NW-SE directions. The fault polygons of the two horizons generally indicate three-way dip closure tilted fault blocks and also two-way dip closure, forming horst and graben blocks. These maps will aid in the future development of the study area, as well as serve as a reference for future exploration plans. As a result, three new well proposed locations were chosen carefully, based on their good structural features.

Figures (22 and 23) indicate the recommended well locations on the depth structure contour maps. Location 1 is a promising development site near to the drilled well AG-69 for future hydrocarbon exploration, as this site is structurally high area located on a horst block. Locations 2 and 3 are also proposed exploration locations for future drilling plan and they are on a good structure closure, as they make three-way dip closure tilted fault block on the fault polygons 4 and 9, respectively and their high structural elements makes them good structural traps for hydrocarbon accumulation.

Figures (24 and 25) show the locations of the vertical proposed wells for the promising sites of the locations 1 till 3 on the interpreted seismic sections, which catch the two targeted zones of this study, that are the Abu Roash E and Upper Bahariya horizons.

3.2 Results of seismic attributes analysis

The result of the first seismic attribute RMS shows a high anomaly for gas on the seismic line, that matched with the mud log reading as illustrated in **Fig. (26)**.

The result of the second seismic attribute (Trace Envelope) is that, we found wedging or channeling of horizons on the seismic line, due to the presence of a limestone occurrence carrying a pocket of gas, and also matched with the mud log reading, as illustrated in Fig. (27).

The result of the third seismic attribute (Instantaneous Phase) is that, we discovered high amplitude, due to the presence of gas affecting the carbonate lithology of Appolonia “B” and “C”

horizons. As a result, we found a high anomaly on the seismic line, as illustrated in Fig. (28).

The results of the mud logs for AG-1X and AG-65 wells are that, we noticed high gas readings at depth 4300 m from C1, C2, C3, till C4, where the ditch gas analysis reading was 12.95%, as explained in Figures (29 & 30). The high gas reading influence matches the response on the seismic lines at this location of the study area.

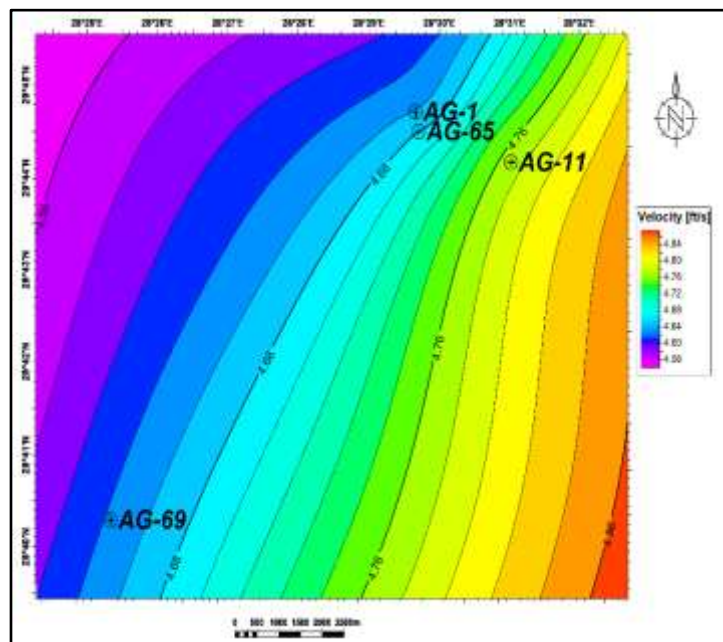


Fig. 16. Velocity map for Abu Roash “E” horizon.

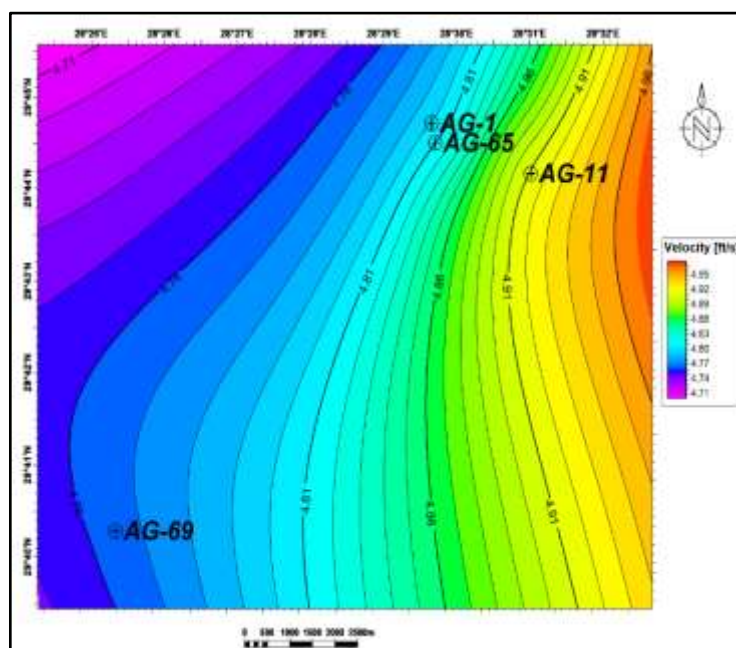


Fig. 17. Velocity map for Upper Bahariya horizon.

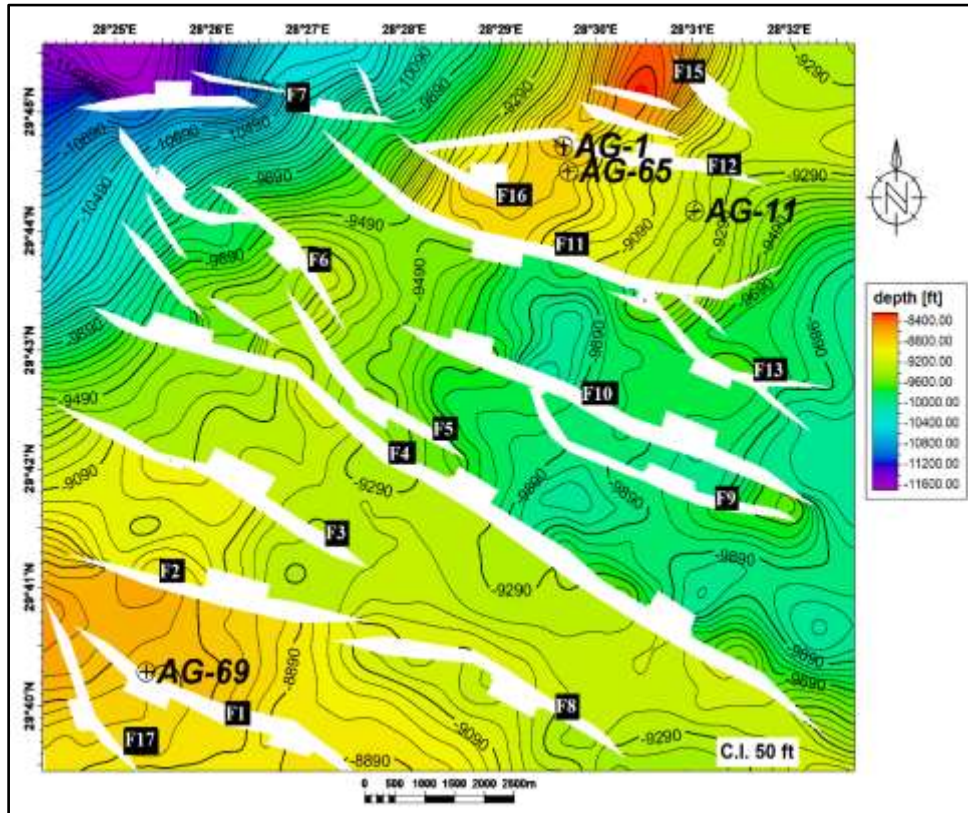


Fig. 18. Depth structure contour map of Abu Roash "E" horizon.

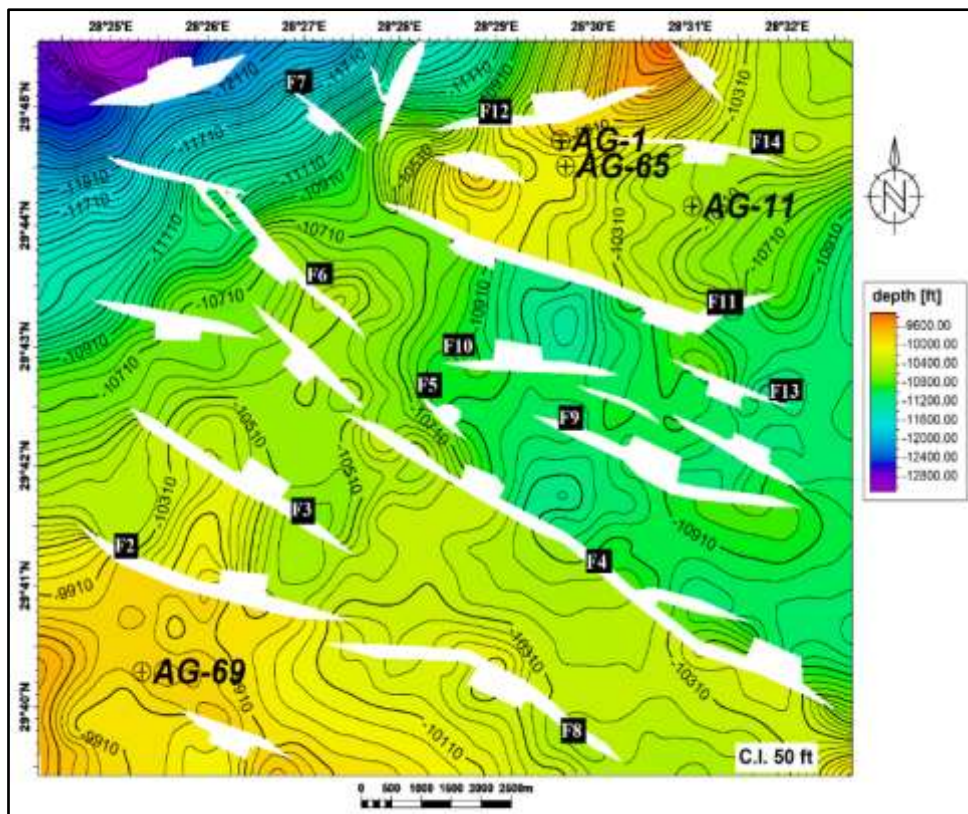


Fig. 19. Depth structure contour map of Upper Bahariya horizon.

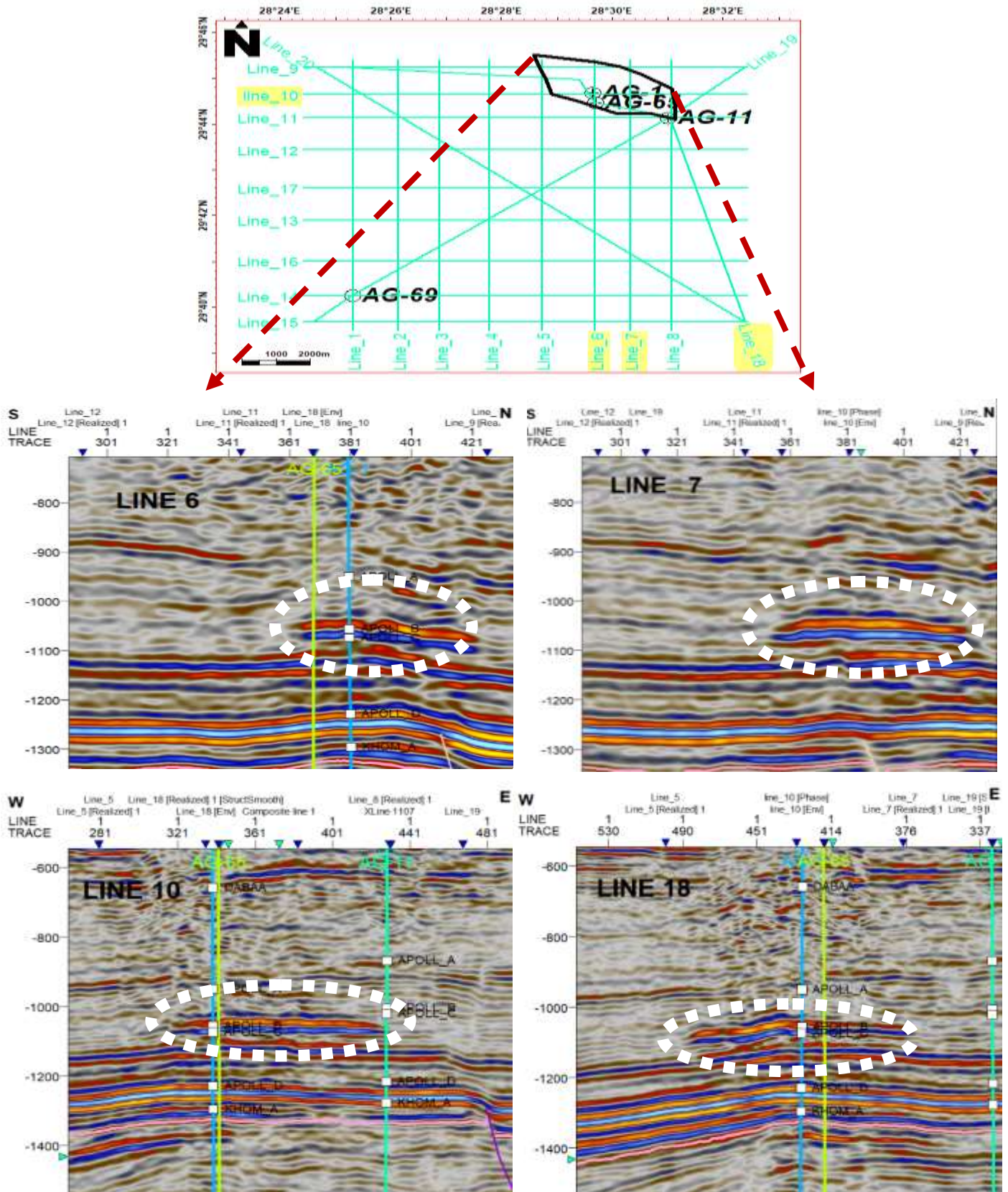


Fig. 20. The location of the high amplitude body in the study area and parts of some seismic lines matching this high anomaly for the Appolonia “B” and “C” units.

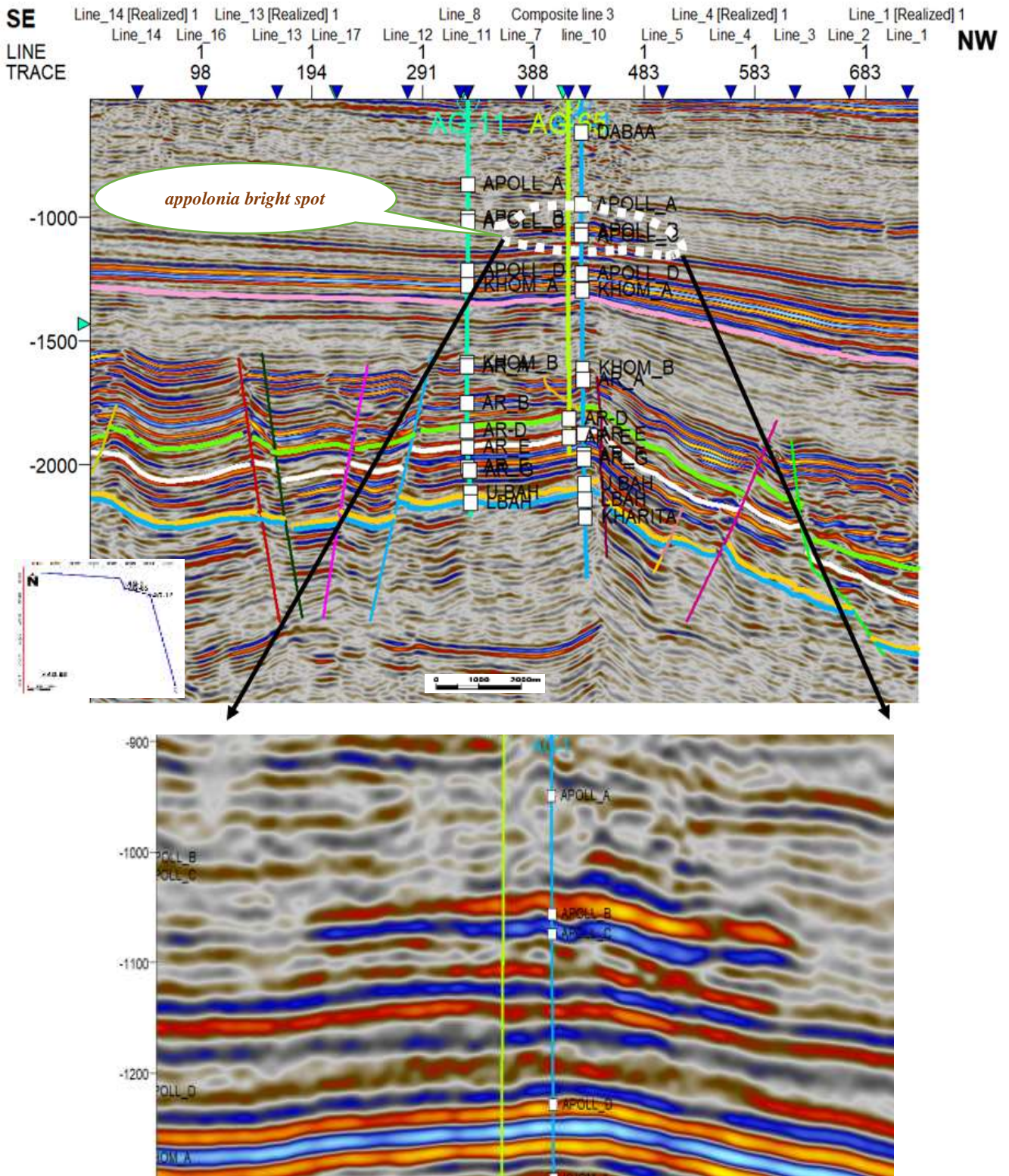


Fig. 21. Arbitrary seismic line number 18 passing through AG-1X, AG-11 and AG-65 wells and indicating the high anomaly for the Appolonia “B” and “C” units.

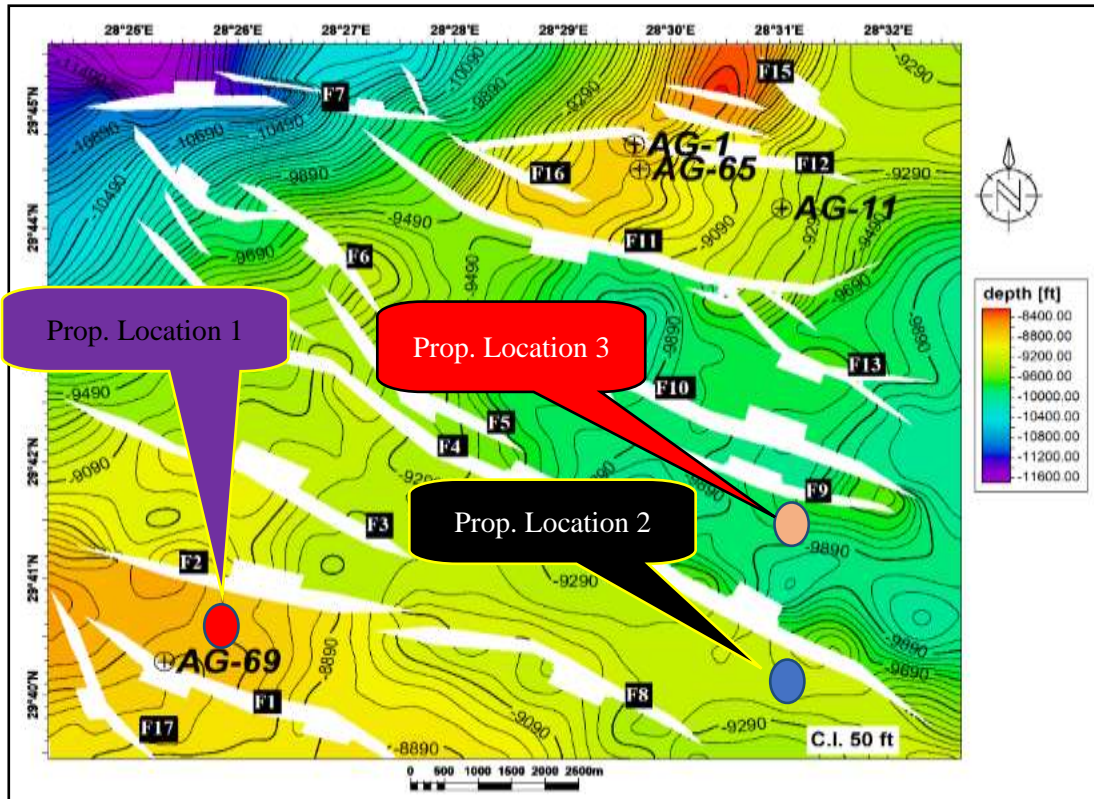


Fig. 22. Proposed well locations for Abu Roash "E" horizon.

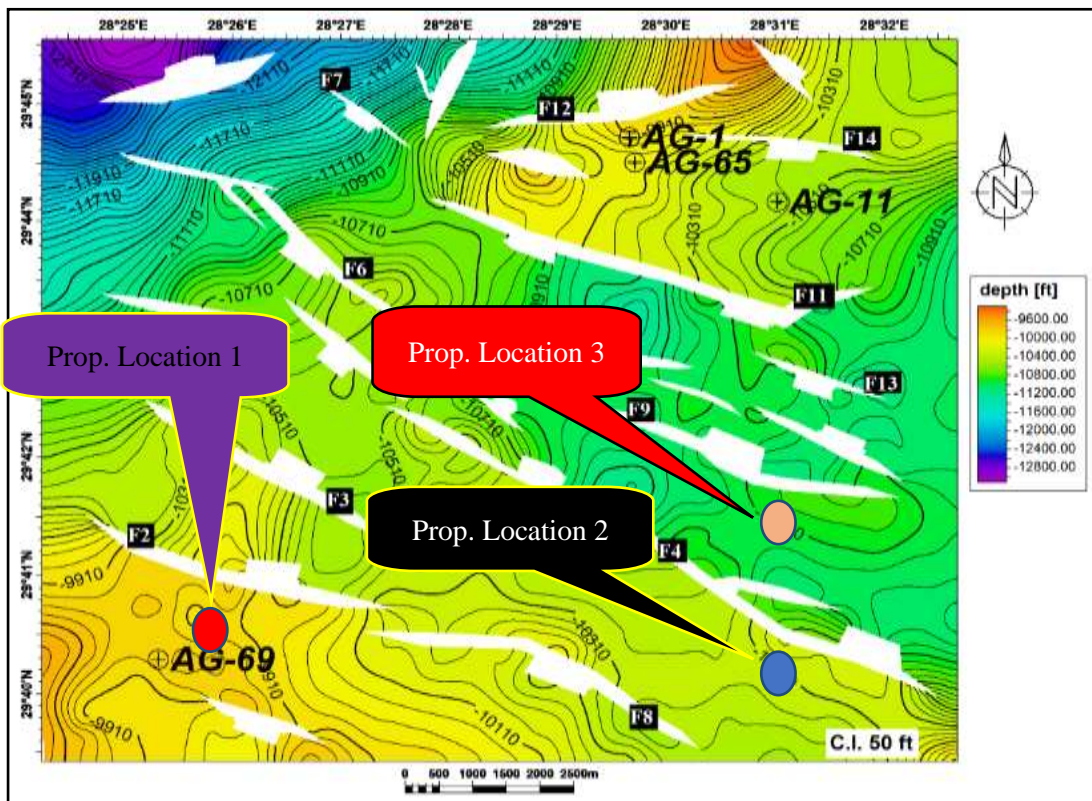


Fig. 23. Proposed well locations for Upper Bahariya horizon.

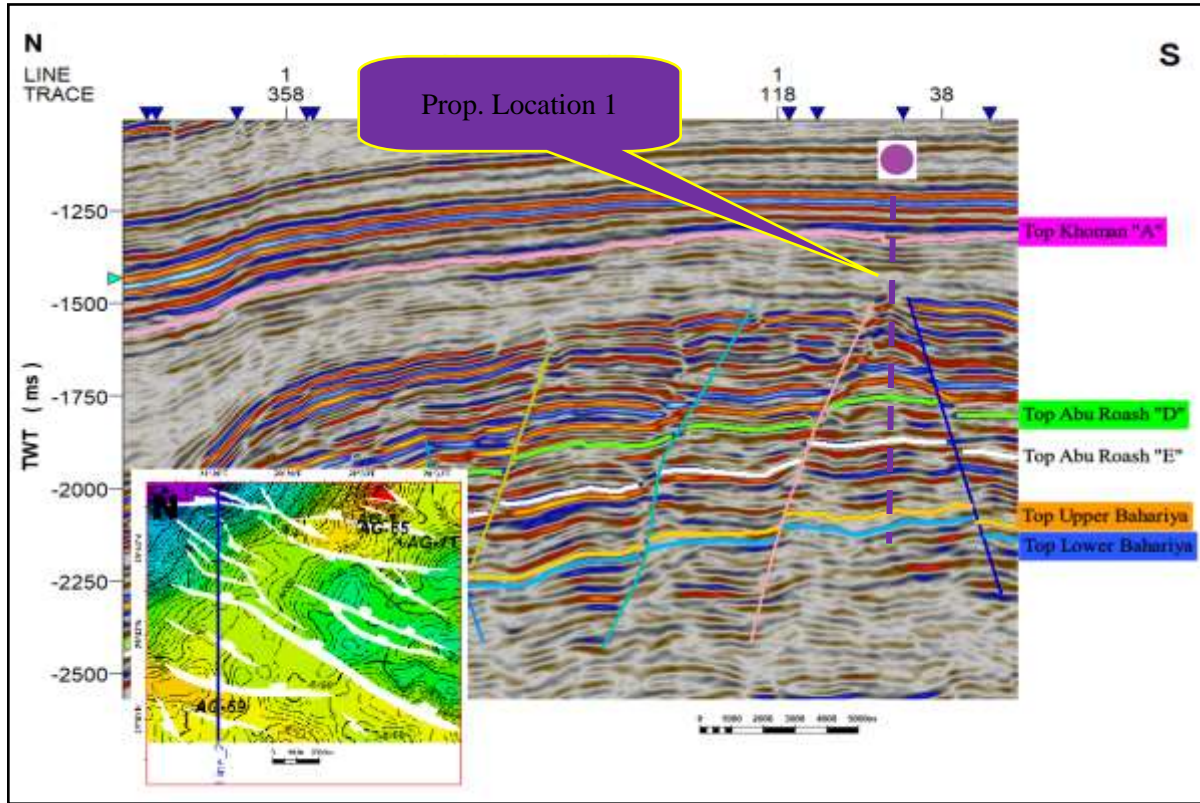


Fig. 24. Interpreted seismic line 2 reveals proposed well No.1.

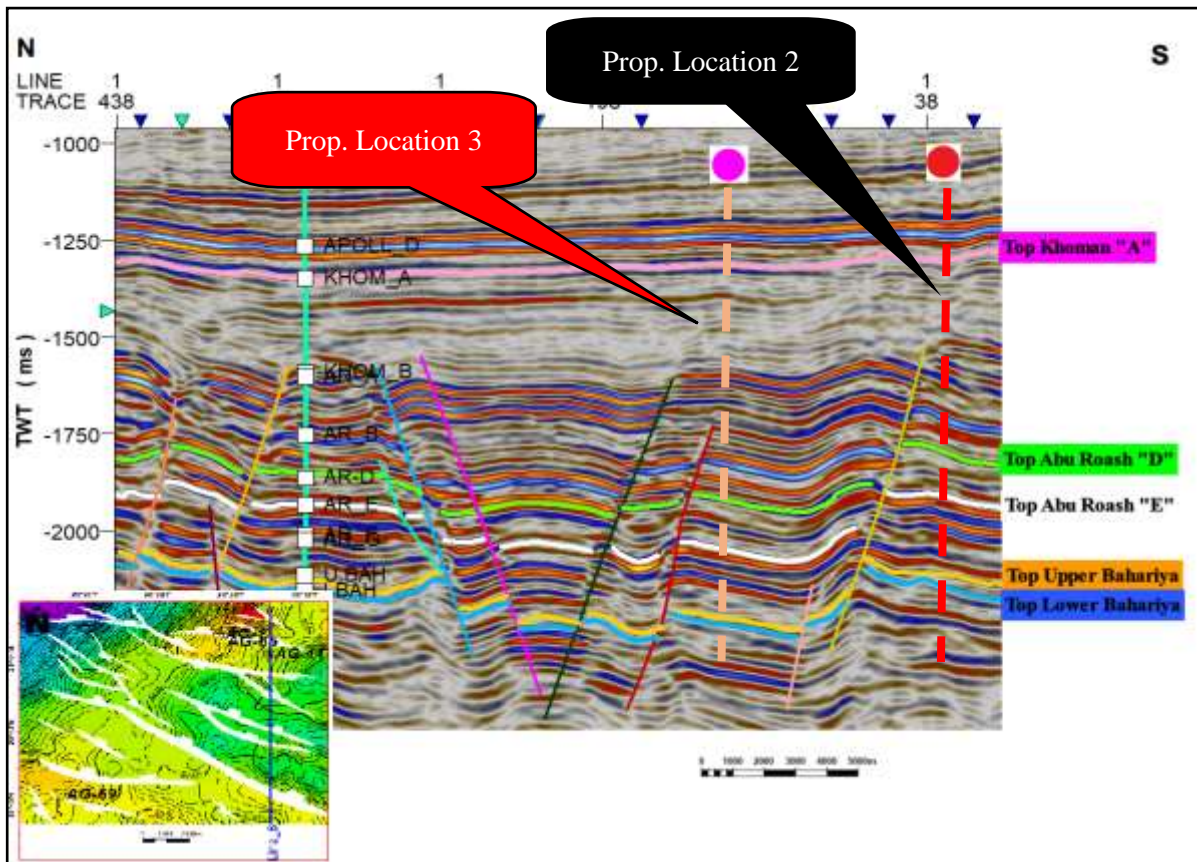


Fig. 25. Interpreted seismic line 8 reveals proposed well No. 2 & 3.

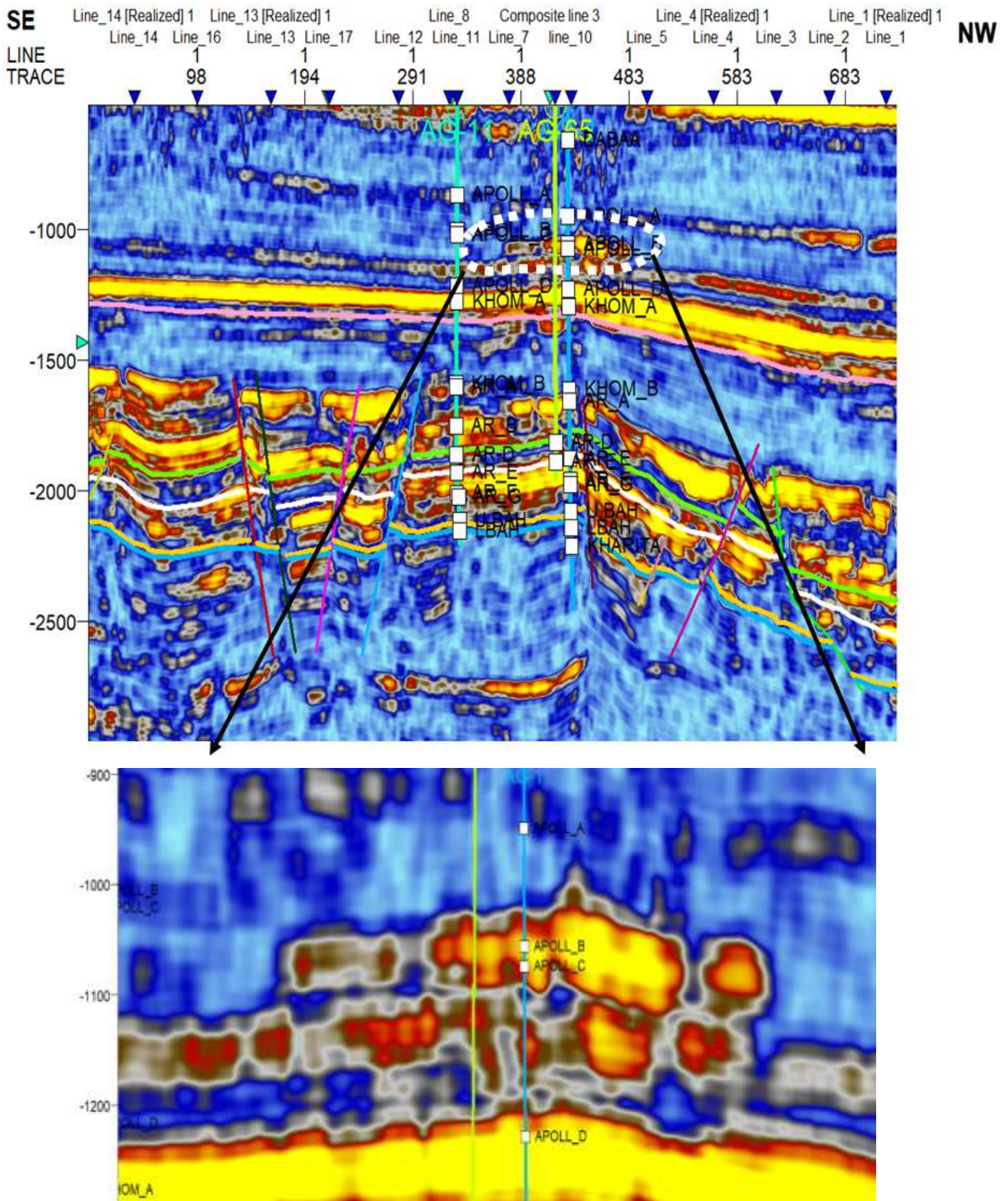


Fig. 26. Seismic line 18 pass through AG-1X, AG-11 and AG-65 wells after applying RMS (root mean square) attribute to present limestone channel lens.

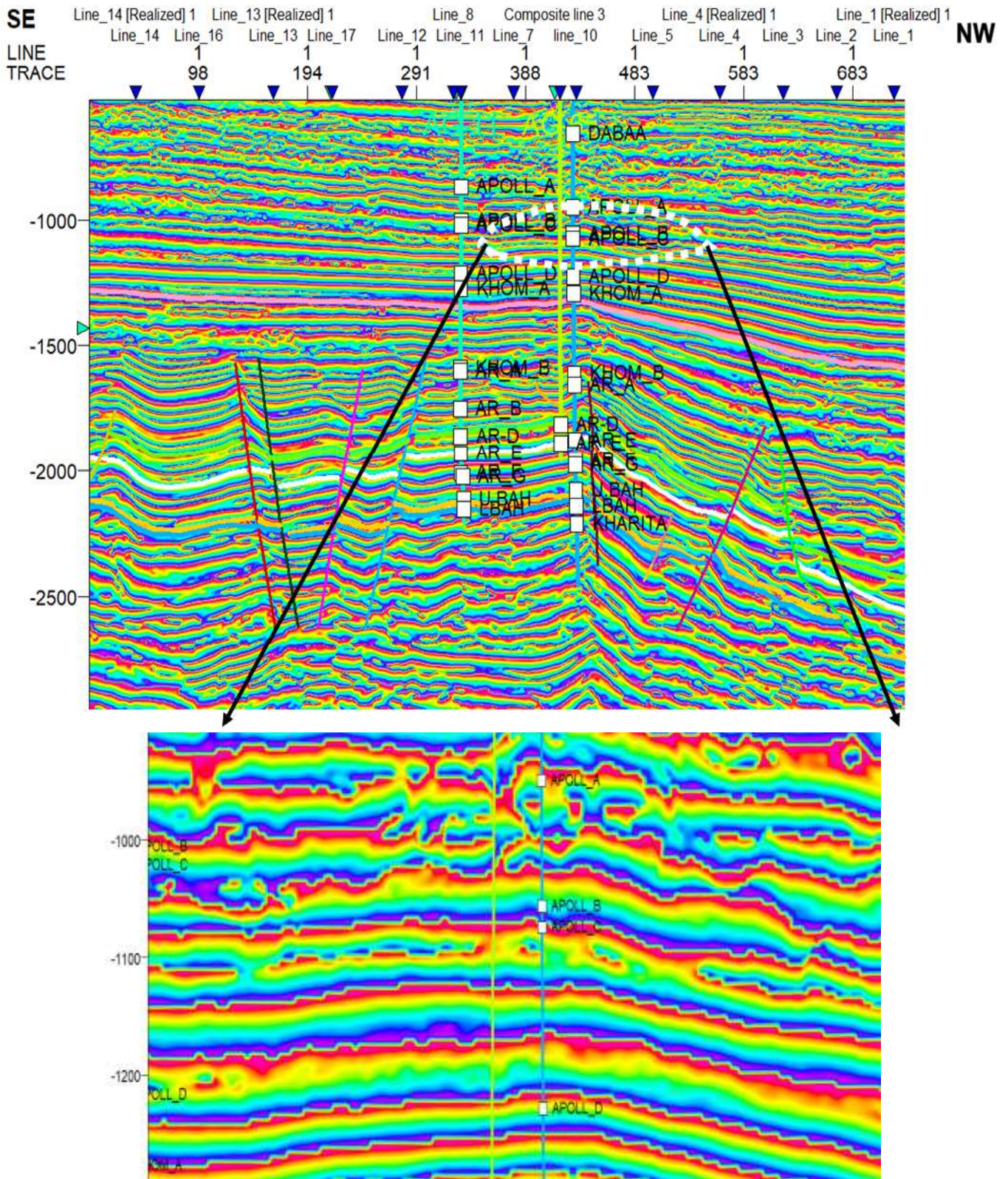


Fig. 27. Seismic line 18 passes through AG-1X, AG-11 and AG-65 wells, after applying the Trace Envelope attribute, to present the carbonate channel lens.

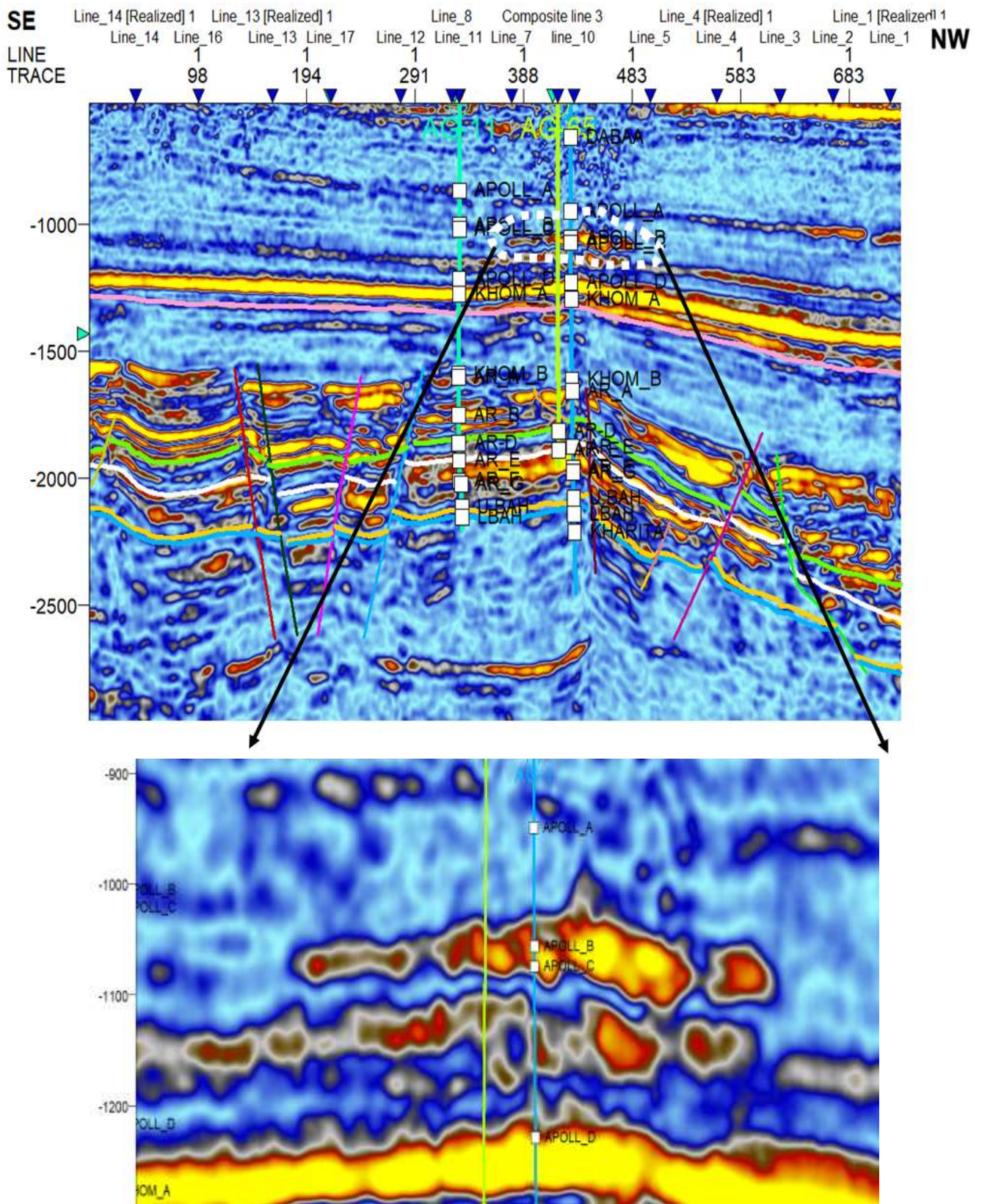


Fig. 28. Seismic line 18 passes through AG-1X, AG-11 and AG-65 wells, after applying the instantaneous phase attribute, to present the limestone channel lens.

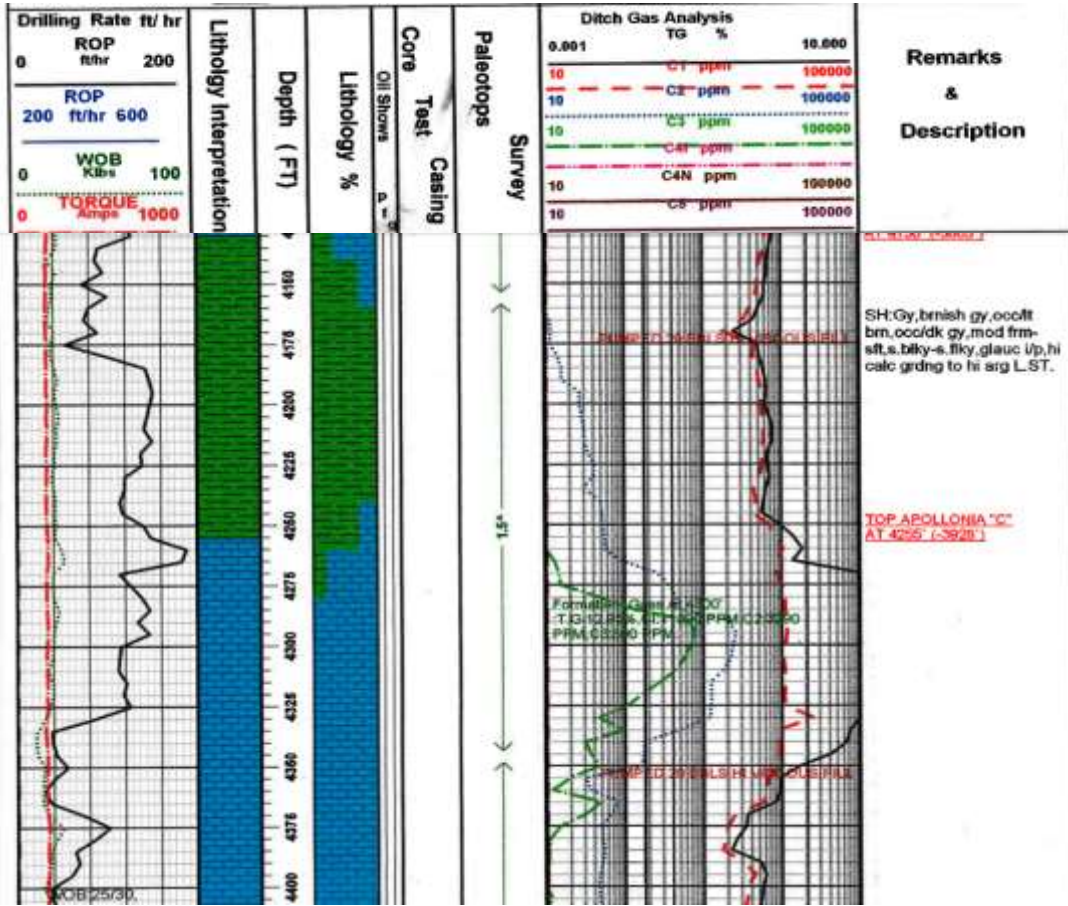


Fig. 29. A part of the AG-65 mud log indicating, the effect of gas pocket on the gas curves.

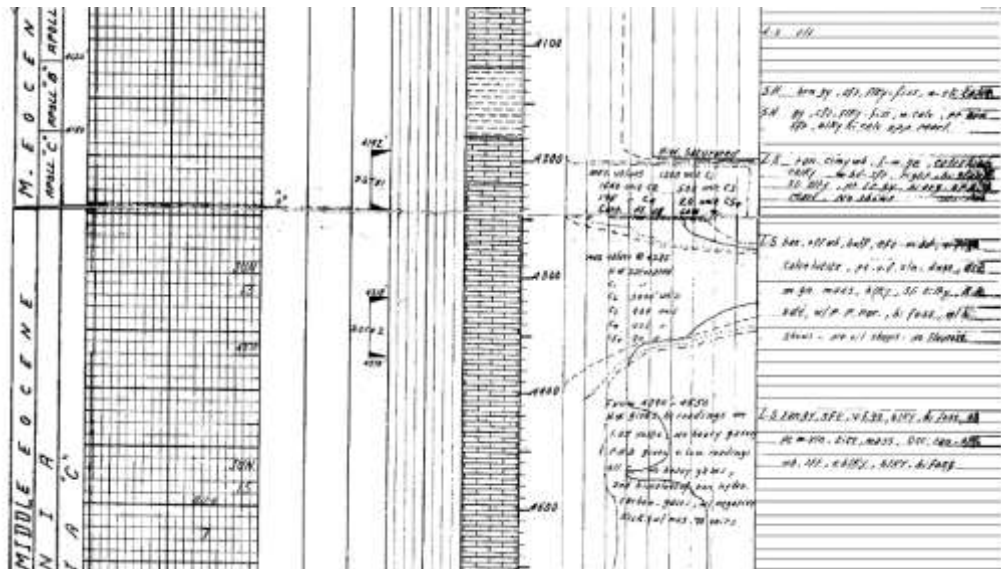


Fig. 30. A part of the AG-1X mud log, indicating the effect of gas pocket on the gas curves.

4. Conclusions

Seismic interpretation through the 2D seismic Reflection profiles of 20 lines serves this study, by providing good information about the structural features of the Abu Roash E and Upper Bahariya horizons and through the structure contour maps of the studied reservoirs. Also, through the stratigraphy of the Appolonia B and C horizons via utilizing the seismic attributes approach, to indicate the gas-bearing carbonate reservoir of this rock unit in the Main Abu El-Gharadig oil field. This work was achieved by the aid of Petrel 2017 Seismic Interpretation Software.

The structural features and geometry of the study area were indicated, by first picking five horizons, that are the Khoman A, AR/D, AR/E, U.BAH. and L.BAH., then construct both the time and depth structure contour maps, by the aid of velocity maps.

The depth structure contour maps reveal that, all the area are influenced by normal faults, trending E-W and NW-SE directions. The fault polygons of the two studied horizons generally indicate three-way dip closure tilted fault blocks and also two-way dip closures forming horst and graben blocks. Beside the two zones of interest, we found that the appolonia "B" and "C" horizons toward the north eastern part of the location map is high in amplitude and has a bright spot which is not continuous in any other location of the study area. So, we applied three techniques of seismic attributes, to indicate the presence of wedging or channeling of a limestone gas pocket, which may indicate commercially hydrocarbon potentials

Finally, three new well proposed locations were chosen carefully, based on their good structural features, which may help inform important operational, and field development and exploration decisions in the future.

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التفسير السيزمي للتراكيب تحت سطحية لتحديد تواجد بعض الخزانات في حقل نفط أبو الغراديق الرئيسي، شمال الصحراء الغربية، مصر

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تهدف هذه الدراسة الي تقييم الخصائص التركيبية تحت سطحية وتحديد الإمكانيات الهيدروكربونية لحوض أبو الغراديق، الصحراء الغربية، مصر، وخاصة في حقل نفط أبو الغراديق الرئيسي. أهم الخزانات التي تتناولها هذه الدراسة هي خزان أبو رواش "E" وخزان البحرية العلوي من العصر الطباشيري العلوي.

أستُخدم عشرون خط سيزمي انعكاسي لتوضيح السمات التركيبية تحت سطحية لمنطقة الدراسة وبناء الخرائط الكنتورية التركيبية باستخدام برنامج (Petrel, 2017) للتفسير السيزمي. لذلك، تم تأويل واختيار سطحين باستخدام رابط البئر السيزمي للمضاهاة بين البيانات السيزمية (في المجال الزمني) وبيانات سجل البئر (في مجال العمق) لإنشاء مخطط سيزمي تخليقي لإنشاء موجة لمقارنتها بعد ذلك بالموجات السيزمية المخلفة لتحديد مواقع أسطح الطبقات التي تتناولها الدراسة.

بعد ذلك، تم بناء الخرائط الكنتورية التركيبية، والتي تكشف أن كل منطقة الدراسة تتأثر بالصدوع العادية التي تتجه في اتجاهات E-W وNW-SE. تشير أنظمة الصدوع في منطقة الدراسة عموماً إلى كتل صدعية مائلة ثلاثية الاتجاه وأيضاً كتلا صدعية ثنائية الاتجاه والتي تشكل كتل سروج وأخاديد.

إلى جانب الخزانات التي تهتم بها الدراسة، وجدنا أن أعضاء "B" و"C" لتكوين الأبولونيا الذي ينتمي الي العصر الباليوسيني - أوائل العصر الأيوسيني في الجزء الشمالي الشرقي من منطقة الدراسة مرتفع السعة وبه نقطة مضبئة غير مستمرة في أي موقع آخر من منطقة الدراسة. لذلك، طبقنا بعض تقنيات السمات السيزمية للإشارة إلى وجود شكل عدسة أو قناة من صخور الحجر الجيري التي قد تحتوي على إمكانيات هيدروكربونية اقتصادية.