DOI: 10.24996/ijs.2022.63.12.23

ISSN: 0067-2904

Utilizing Seismic Attributes to Enhance Deduction of the subtle stratigraphic trap in Mishrif Formation at Dujaila oil field, Southern East of Iraq

Ahmed Muslim Attallah Khawaja*[1], Jassim Muhammad Thabit[2]

[1]Department of Applied Geology, College of Science, University of Babylon, Iraq

[2]Department of Geology, College of Science, University of Baghdad, Iraq

Received: 7/2/2022 Accepted: 1/6/2022 Published: 30/12/2022

Abstract

Three seismic instantaneous attributes (phase, frequency, and variance) were utilized on 3D-seismic poststack migrated data, covering 617.31 km^2, integrated with data of two wells (Du-1 and Du-2) in Dujaila oil field, southeast of Iraq. They gave good results in detecting reef buildups and confirmed the existence of the stratigraphic hydrocarbon trap that was not obvious in the conventional seismic amplitude sections. They display several seismic criteria in attribute sections for recognizing reef buildups and hydrocarbon accumulation, such as phase reversal, low frequency, and high amplitude variance. The seismic attributes emphasized that the stratigraphic trap of reef rudist buildups with hydrocarbon content is constricted in the upper part of the Mishrif Formation (Cenomanian-Early Turonian) the vicinity around productive well Dujaila-1. It is located at a time from -1730 ms in the Top Mishrif to underneath at a time -1775 ms, which has correspondent the depth 2825 m to 2887.5 m, respectively. This stratigraphic trap covered 70 km^2 (length is 10.0 km in direction N-S, and the width is about 7.0 km in the E-W direction). The enclosure of the stratigraphic trap extends about 7 km towards SW from the well Dujaila-1 and did not reach well Dujaila-2 (Du-2). That may explain why it was dry. As a result, the circular region around well Du-1 of a radius of about 4 km, and the area extended about 7 km toward SW from well Du-1 represent a zone of low risk-drill for new exploration wells.

Keywords: 3D-Seismic reflection, Seismic attributes, Seismic interpretation Mishrif Formation, Dujaila oil field, stratigraphic trap

استخدام الملامح الزلزالية لتعزيز استنتاج المصيدة الطباقية ذات السمك القليل في تكوين المشرف في حقل الدجيلة النفطي ، جنوب شرق العراق[1]

احمد مسلم خواجة[1], جاسم محمد ثابت[2]

[1]قسم علم الأرض التطبيقي, كلية العلوم, جامعة بابل, بابل ، العراق

[2] قسم علم الأرض, كلية العلوم, جامعة بغداد, بغداد، العراق

*Email: sci.ahmed.moslem@uobabylon.edu.iq

الخلاصة

استخدمت ثلاث ملامح زلزالية فورية (الطور، التردد، التباين) على البيانات الزلزالية ثلاثية الأبعاد المهجرة بعد التجميع, تغطي 617.31 كيلومتر مربع ، والمتكاملة مع بيانات بئرين (Du-1 و Du-2) في حقل دجيلة النفطي جنوب شرق العراق. لقد أعطت نتائج جيدة في الكشف عن تراكمات الشعاب المرجانية وأكدوا وجود المصيدة الهيدروكربونية الطباقية التي لم تكن واضحة في مقاطع السعة الزلزالية التقليدية. وذلك من خلال عرض العديد من الظواهر الزلزالية في مقاطع الملامح للتعرف على تراكمات الشعاب المرجانية وتراكم الهيدروكربونات مثل انعكاس الطور والتردد المنخفض والتباين العالي في السعة. أكدت الملامح الزلزالية أن المصيدة الطباقية لتراكم الشعاب المرجانية ذات المحتوى الهيدروكربوني محصورة في الجزء العلوي من تكوين مشرف (سينومانيان – تورونيان المبكر) بالقرب من البئر المنتج الدجيلة 1. يقع بين الزمن من −1730 مللي ثانية في أعلى المشرف إلى الزمن −1775 مللي ثانية، والذي يتوافق مع العمق من 2825 مترًا إلى 2887.5 مترًا، على التوالي. غطت هذه المصيدة الطباقية مساحة حوالي 70 km2 (الطول 10.0 km في اتجاه N-S، والعرض حوالي 7.0 km في اتجاه W-E). بالإضافة إلى ذلك ، أظهرت الملامح الزلزالية أن محيط المصيدة الطباقية يمتد حوالي 7 كم باتجاه الجنوب الغربي من بئر الدجيلة 1 ، ولم يصل إلى البئر الدجيلة 2 (Du-2). قد يفسر ذلك سبب جفافه. ونتيجة لذلك، فإن المنطقة الدائرية حول البئر Du-1 التي يبلغ نصف قطرها حوالي 4 كيلومترات ، والمنطقة الممتدة حوالي 7 كيلومترات باتجاه الجنوب الغربي من البئر Du-1 تمثل منطقة حفر منخفضة المخاطر لآبار استكشاف جديدة.

1-Introduction

Seismic attributes are important modern techniques used to understand the subsurface geological setting and predict reservoir characteristics from seismic data [1]. [2] concluded that seismic attributes provide a tie between reservoir characterizations and seismic data to detect reservoir distribution. [3] referred to that the seismic attributes are directly or indirectly related to rock properties and are directly measured from the seismic data. They helpful in seismic data interpretation by unrevealing the hidden features in reflection data through identifying certain physical wavelet parameters and by quantifying specific characterize. [4] pointed out that only seismic attributes have a physically justifiable relationship with the reservoir property when the wells in the study area are few numbers. Only seismic attributes can be considered effective predictors for pay zone characterizations. Attribute analysis is a vital facet in the interpretation of seismic reflection data for petroleum exploration and finds wide applications, from anomaly identification to features extraction to petrophysical prediction [5]. Seismic attributes represent physical parameters of reflected seismic wavelets, such as amplitude, phase, and frequency. They are directly affected by the petrophysical properties of layers passing through them. So, it in turn appears as an obvious change in section and/or horizontal slice of the individual physical parameter of seismic wavelets [6]. Whoever, the interpreter should correlate the different results using different attributes that display the feature of his interest to decrease the uncertainty in the results [7]. Porous carbonates associated with reefs, shoals, and isolated carbonate buildups usually compose suitable hydrocarbon reservoirs. They almost represent stratigraphic traps if sealed by impermeable rocks [8]. Carbonate-on-carbonate reflections, such as those resulting from the interface between a porous grainstone and a nonporous carbonate mudstone, generally create lower reflectivity and lower resolution than those made within siliciclastic sequences. Also, the dissolution and karstification digenesis processes within carbonates cause some modifications on the seismic reflector geometries. These reasons create significant problems for interpreters dealing with carbonate successions on seismic data [8], [9]. This study aims to utilize seismic attributes techniques to enhance the interpretation of the ambiguous 3D-seismic data, detect hidden sedimentary bodies, and predict the extensions of the hydrocarbon entrapment in the Mishrif Formation at the Dujaila oil field.

2- Location of the study area

The studied area is located in the southeastern part of Iraq in the Maysan Governorate, about 55 km NW of Amara city, situated between Kumiat and Abu-Amoud oil fields. It lies in the Unstable Mesopotamian Foredeep Basin of the outer platform of the Arabian Plate [10], as shown in Figure 1. The Dujaila field occupies a part of zone-38 of the Universal Transverse Mercator coordinate system (WGS-1984, UTM, Zone-38) [11].

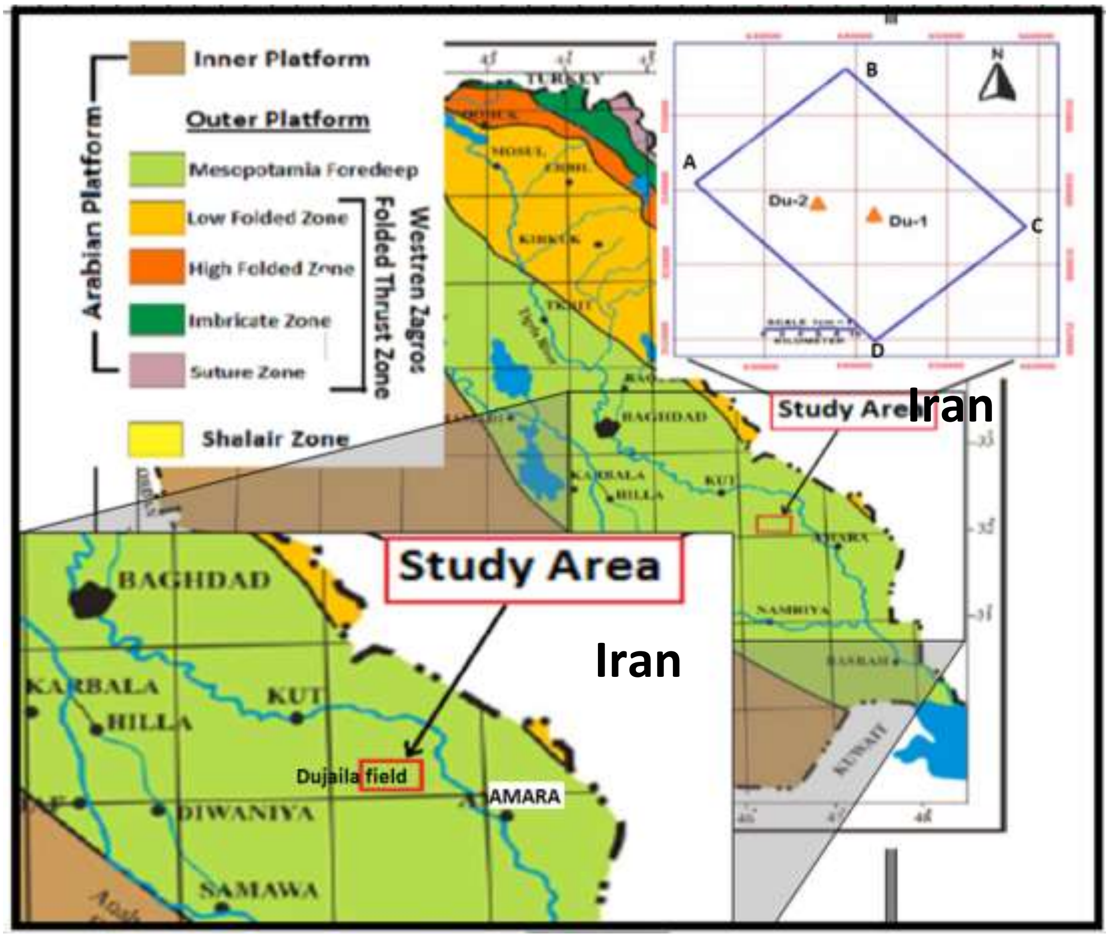

Figure 1: Location of the study area, posted on the tectonic map of Iraq [10]

3- Data Base

The current study is dependent on the integration between 3D-seismic post-stack time migration information, carried out in the Dujaila oilfield, covering 617.31 km^2 and data of two available wells to utilize seismic attributes in enhancing seismic interpretation. Only two wells, Dujaila-1 (Du-1) and Dujaila-2 (Du-2) have been drilled in the center of the field, and they penetrated the Mishrif Formation, a main oil reservoir in the studied oilfield. Well Du-1 produced oil from the upper part of the Mishrif Formation, while well Du-2 located about 7 km to the northwest of well Du-1, was dry [11].

The Mishrif Formation (Cenomanian-Early Turonian age) is one of the important carbonate reservoirs in the several productive oil fields surrounding the Dujaila field in middle and southern Iraq [12]. The Mishrif Formation represents a heterogeneous carbonate succession containing different carbonate facies deposited in various marine environments

[13]. The reefal facies is dominated in the Mishrif facies and consist of vast congregations of Rudist shells forming extensive biostromes. These congregations exist more localized (do not continue in all wells) and form the patch reef interbedded with related bioclastic units and have a primary porosity making it one of the best locations for hydrocarbon accumulation [14]. The formation forms from two regressive depositional cycles separated by a disconformity surface [15]. The lower contact of the formation is conformable with the underlying unit Rumaila Formation, whilst the upper contact is unconformable with the overlying Khasib Formation. The thickness of the Mishrif Formation in the study area is about 325 m which is occupied at a depth between 2825 to 3150 m, at a Two-Way-Time (TWT) ranging from -1725 to -1830 ms [15], [16].

The TWT seismic amplitude sections showed that seismic reflectors of the Mishrif Formation dis-concordant have several abrupt discontinuities and did not display a clear geologic structural setting, especially in the area around the two wells at its upper part [17], as shown in Figure 2. As a result, these conventional seismic data are difficult to interpret, leading to ambiguous conclusions and more confusion, and may be considered noise. Therefore, seismic instantaneous attributes were used to enhance the seismic interpretation's validity and to predict a reliable image of the subsurface geological setting.

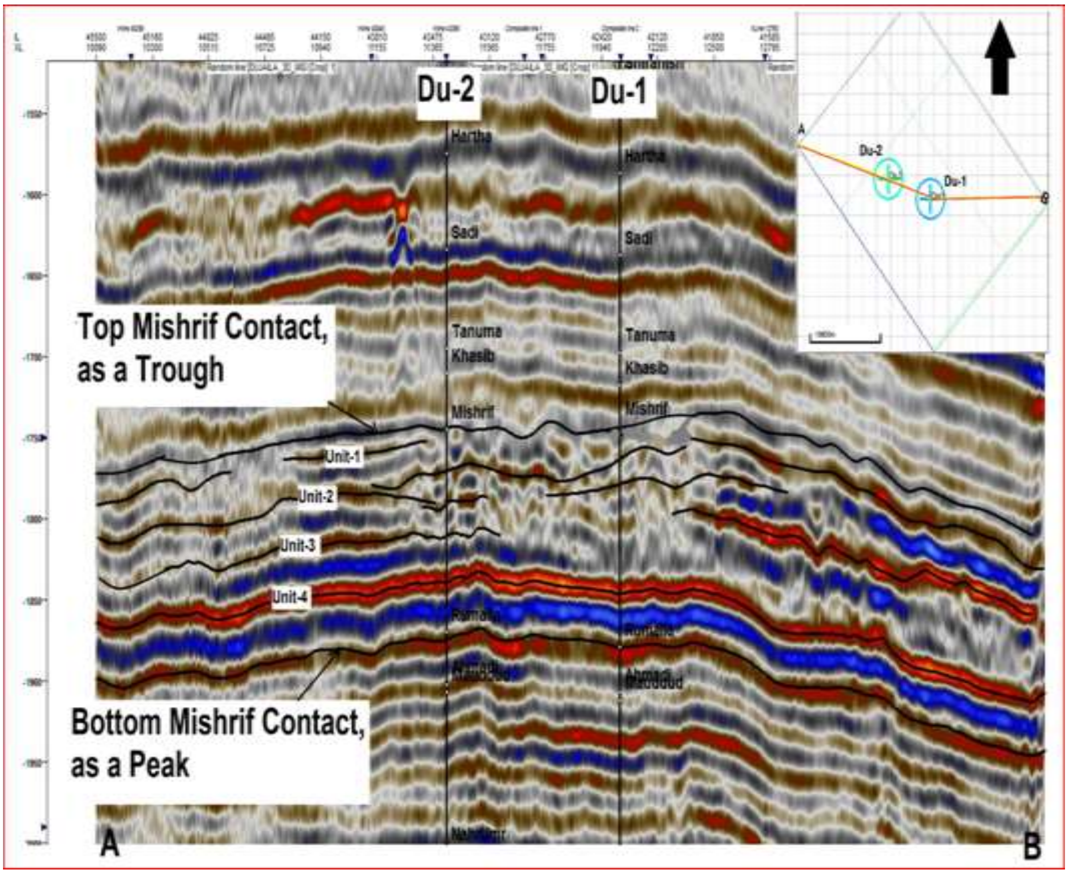

Figure 2: Two-Way-Time arbitrary seismic section passing through the two wells (Du-1& Du-2).

4- Theoretical Background

[18] pointed out that the seismic trace represents the real part of a complex wave function signal. They named the complex trace analysis results seismic attributes, and defined the seismic attributes as all the information extracted from analyzing the wavelet spectrum of the seismic data, either by direct measurement or by logic or experience-based reasoning and

displayed as colored sections or overlays for interpretational purposes. These attributes can be collectively termed instantaneous attributes since they concisely and quantitatively describe the seismic waveform parameters (frequency, phase and amplitude) at any sample point. So, they can be instrumental in correlating seismic events even for complex reflections. Based on the Hilbert transform, several seismic attributes were found. The Hilbert transform is a kind of filtering, which does not affect the amplitude of the spectral component, but it causes changes in the phases of these components by 90° degrees [19]. Whereby it gives access to the imaginary part of the seismic trace. Thus, the complex trace can be computed from the seismic trace. Accordingly, the recorded or real seismic trace (reflection amplitude) is present in a plane perpendicular to a plane of the calculated or imaginary trace [5], [18]. The amplitude is now a vector composed of two components: the real and imaginary part of the entire seismic trace. This is also known as the envelope or reflection strength. The complex seismic trace forms a corkscrew trace that rotates around the time axis [5], as shown in Figure (3).

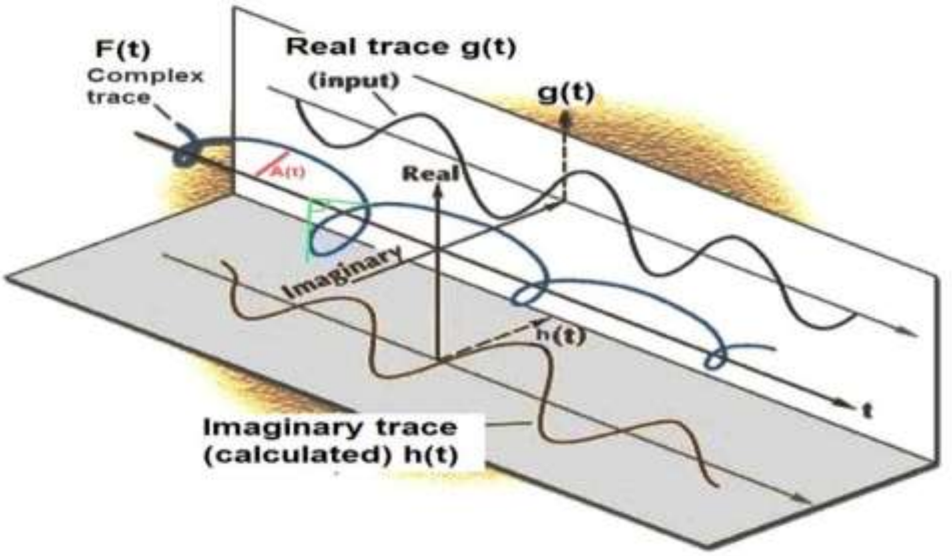

Figure 3: Complex seismic trace constructed from the real and imaginary traces, after [5].

Many types of seismic attributes can be used to interpret seismic events [20], [21]. The individual seismic attribute indicates geologic reservoir properties. Still, the real enhancement in predictive accuracy and reliability of results comes from combining multiple seismic attributes and solving the non-linear relationship between the seismic attributes and reservoir properties. Whereby Taner and Sheriff [5] referred that more information is obtainable by using a set of displays of different attributes synergetically than by interpreting them individually. The employment of multiple seismic attributes, rather than just amplitude, can allow the interpreter to detect subtle stratigraphic bodies better and predict accurate and reliable results [19], [22]. It is evident that the response of individual attributes is not a unique solution ; therefore utilizing many attributes in combination may help overcome these problems of non-uniqueness in results [8]. Thus, three seismic attributes (instantaneous phase, instantaneous frequency, and amplitude variance) will be used in this research to solve the problem and help to show hidden sedimentological features that are difficult to see in conventional seismic data.

5-Instantaneous Phase Attribute

The phase attribute is important to detect the termination of seismic reflectors and polarity reversals. It is an effective tool for revealing the reflection discontinuities, such as pinch out, angular unconformities, and faults resulting from abrupt lateral changes in petrophysical properties (lithology, porosity, permeability, and fluid content) of the adjacent rocks. Accordingly, the phase attribute sections and maps will show sudden changes in the phase angles or colors of the reflected wavelets, responding to the abrupt change in reservoir characterizes [23], [24]. In general, instantaneous phase sections view rotation in the phase angle from +180 to -180 degree, that through changes in colors vertically and laterally from green to pink, which corresponds to the sudden variations in petrophysical properties of the rocks [6].

The instantaneous phase attribute section, as in Fig. 4, clearly showed several discontinuities, polarity reversals, and direct hydrocarbon indicators in the reflectors of Units-1, 2, and 3, at the time between -1730 to -1800 ms, in the upper part of Mishrif Formation in the region surrounding the well Dujaila-1. Most of the seismic criteria for recognizing reef buildups and hydrocarbon accumulation are present in this section. They exhibit dome-shaped a reef mound, abrupt discontinuity, marginal onlap, polarity reversals, weak reflections or dim spots, and flat spots. This is manifested in the lateral change of color from green to pink due to rotation of the phase angle of the reflected wavelets, as outpointed inside the black elliptical shape constricted between two red arrows, which represent the approximate edges of the reef buildups reservoir. Meanwhile, these isolated reef buildups act as hydrocarbon stratigraphic traps with a trapping mechanism caused by reef dome shape and lateral changes in lithofacies. In addition, the phase attribute confirms the presence of hydrocarbon accumulation in the reefal reservoir occupying the region around the productive well Dujaila-1, where it extended about 10 km in the direction NE – SW, While it extended about 7 km toward SW from the well Du-1. Moreover, the instantaneous phase attribute section shows numerous discontinuities and vug (void) porosities in the layer over the reflector of the unit-4 in the time (TWT) -1805 ms, which refers to the presence of a disconformity surface that separates between two regressive depositional cycles that make up the Mishrif Formation.

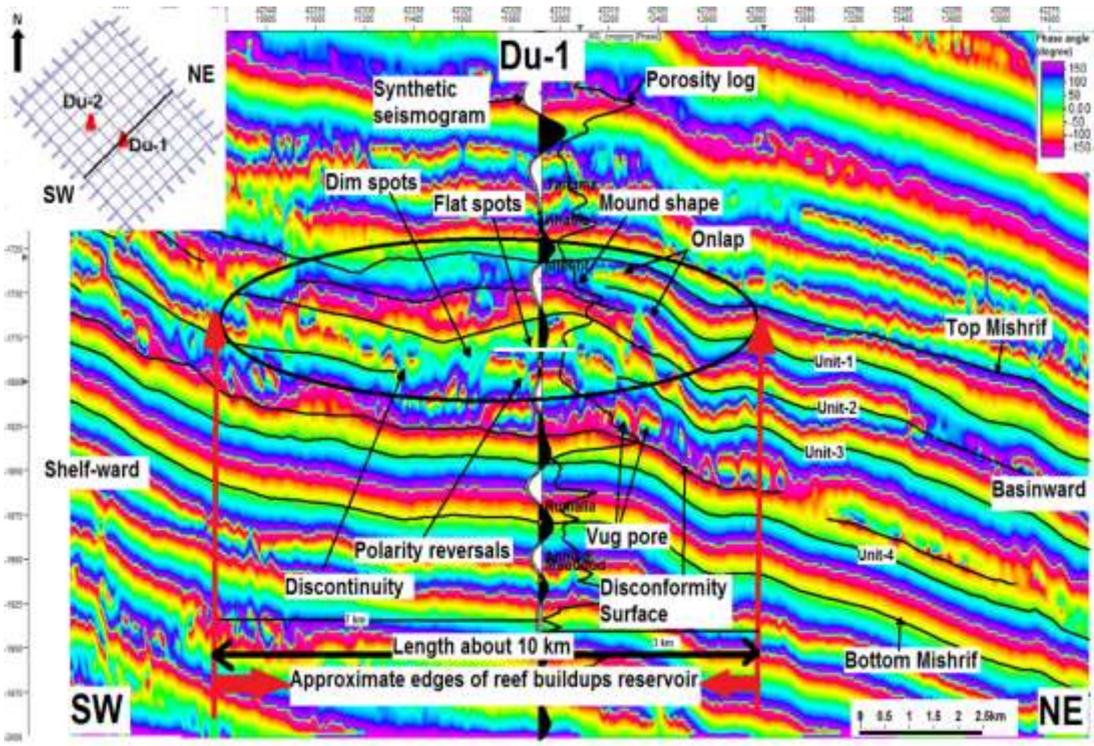

Figure 4: Instantaneous phase attribute section passing through the well Dujaila-1

Conversely, the instantaneous phase section passes through the well Du-2. Fig. 5, displays that most of the seismic phase reflectors had approximately continuous phases and did not exhibit characterizes referring to the presence of reef buildups, as in the well Du-1. This confirms that the reefal reservoir has not reached the well Du-2, which may explain why it was dry.

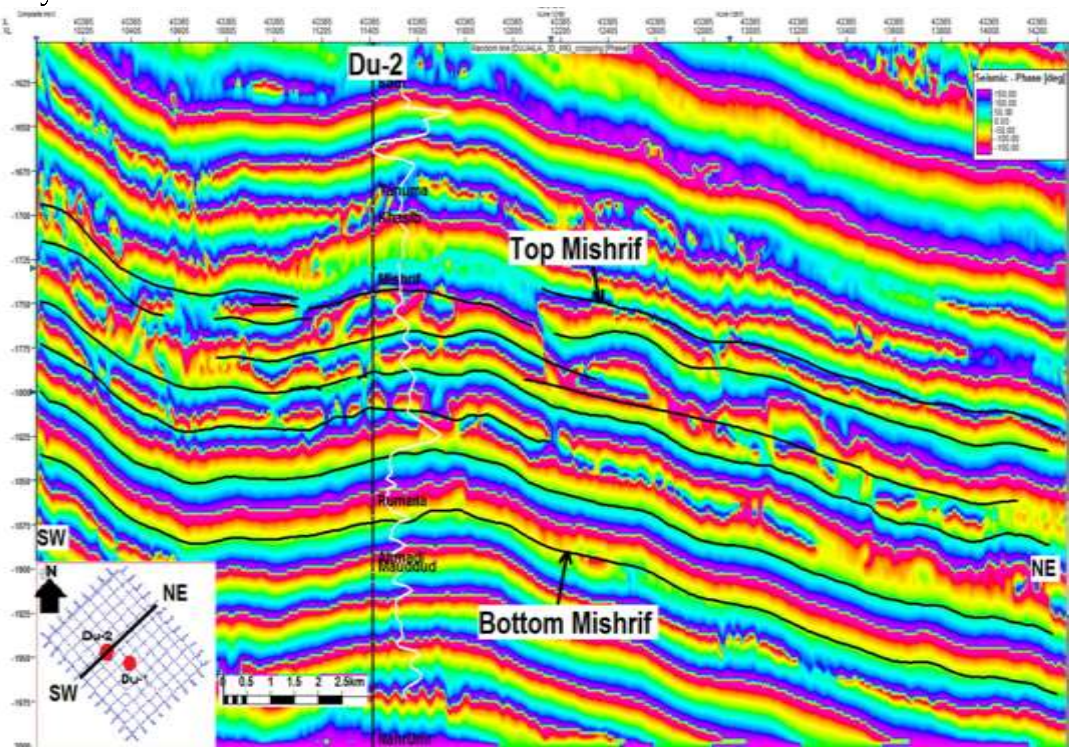

Figure 5: Instantaneous phase attribute section passing through well Du-2.

Figures 6 and 7 represent time slice maps of the instantaneous phase attribute at -1730 ms, and -1800 ms, respectively. They display a clear rotation in the phase angle through a change in color from green in the time slice at -1730 ms at Top Mishrif to the pink in time slice at -1800 ms beneath the Top Mishrif, particularly in the middle area where the two wells are located. This is related to vertical changes in the rock's physical properties due to reef buildups and hydrocarbon accumulation in the upper part and its absence in the time below -1800 ms and confirms that the Mishrif Formation is composed vertically of different lithofacies.

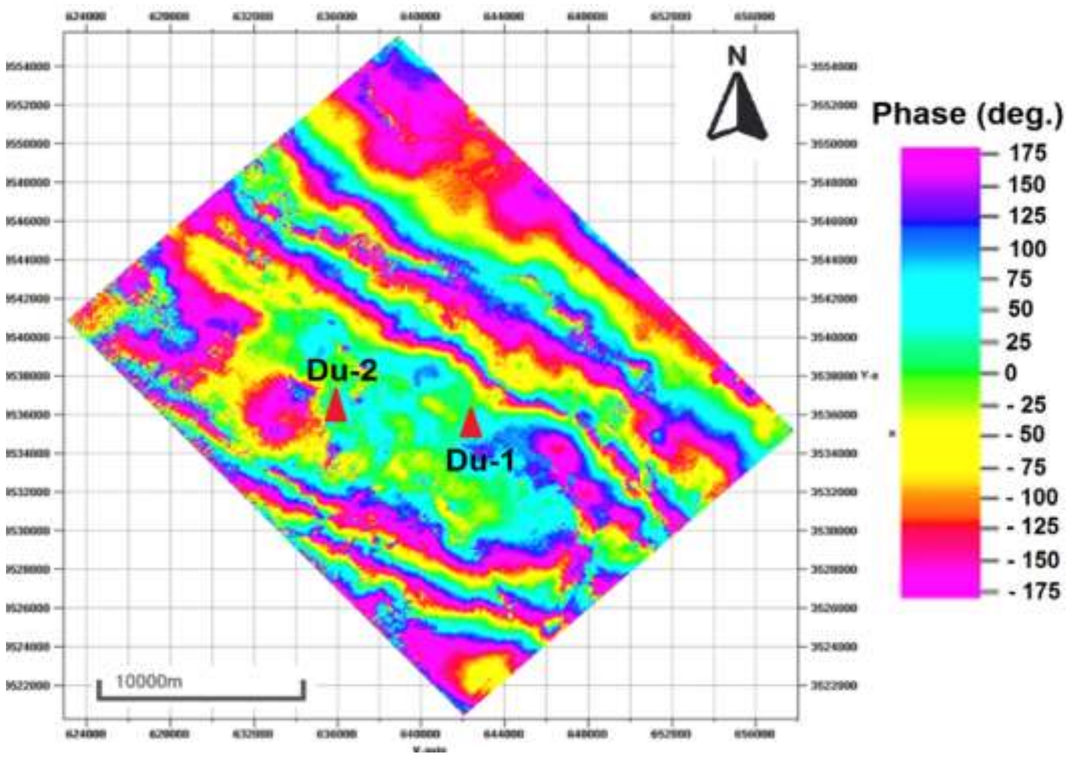

Figure 6: Instantaneous phase time slice at TWT -1730 ms in the Top Mishrif.

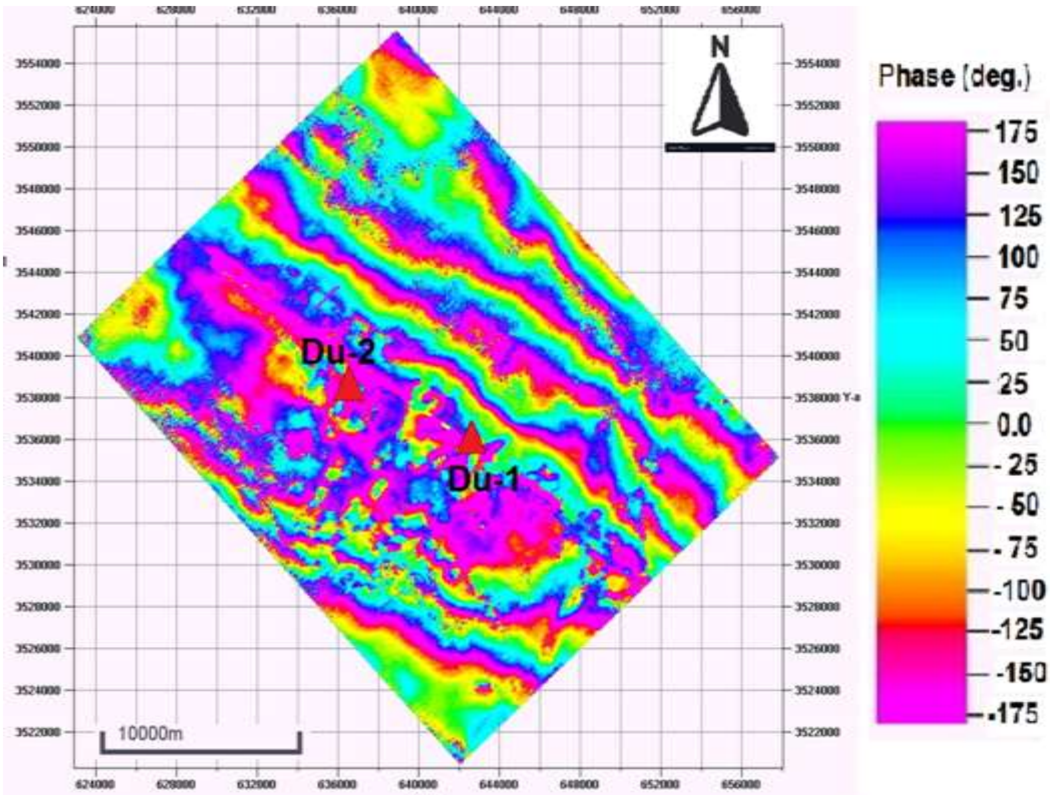

Figure 7: Instantaneous phase attribute time slice at TWT -1800 ms under the Top Mishrif.

6- Instantaneous Frequency Attribute

The instantaneous frequency attribute is one of the essential attributes of the seismic reflection wavelets that have a direct geological meaning and a reliable indicator to confirm the presence of hydrocarbon accumulations in the reservoir [25]. The seismic instantaneous frequency attribute map or section can show an abnormal low-frequency zone of the reflection events above the hydrocarbon-saturated regions and porous reef buildups due to its ability to absorb high-frequency wavelets [26].

Figures 8 and 9 represent instantaneous frequency attribute horizon slice and a 3D-model of the Top Mishrif reflector at time -1730 ms, respectively. These figures display that the zone of low frequency (red to the yellow color of 5 to 20 Hz) is constricted in the area around well Dujaila-1, extending to the south and southwest. It represents the porous carbonate of reef buildups and hydrocarbon accumulation and represents the main reservoir in the Dujaila oilfield. This result coincides with the location of reef facies that have been known from the results of the analysis of the instantaneous phase attributes and are compatible with the information of the two wells. Thus, this reef buildups mound acts as a stratigraphic trap with trapping mechanisms resulting from the dome shape of reef buildups and abrupt changes in the lateral and vertical lithofacies. In addition, the two figures clearly show that Du-2 is located in the high-frequency region (blue color, more than 45 Hz), indicating its presence in a dense limestone region devoid of porous reef facies. This may explain why it is dry despite being topographically higher than Du-1. Accordingly, the total surface area of the reservoir was measured using a polygon method in the Petrel software on the restricted area of a low frequency that appeared in the frequency attribute map (Fig. 8). It is about 70 km^2 (the length is approximately 10.0 km in direction N-S, and the width is about 7.0 km in the W-E direction).

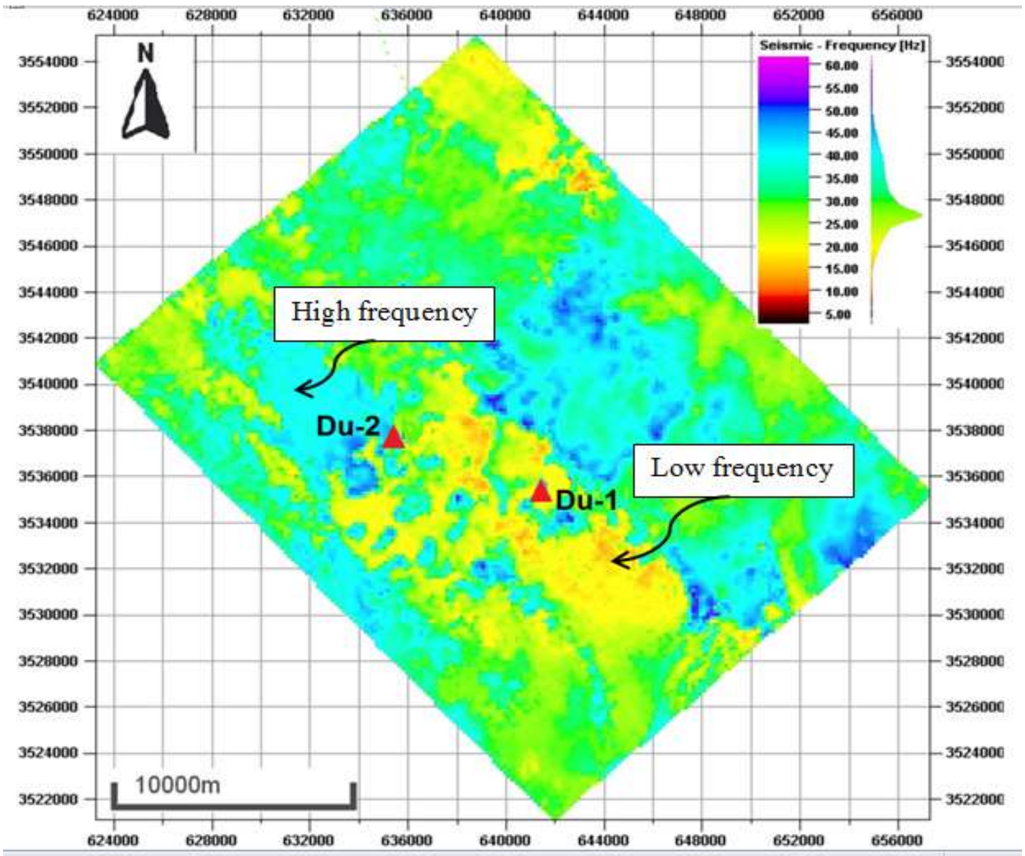

Figure 8: Horizon slice of an Instantaneous frequency attribute of Top Mishrif reflector.

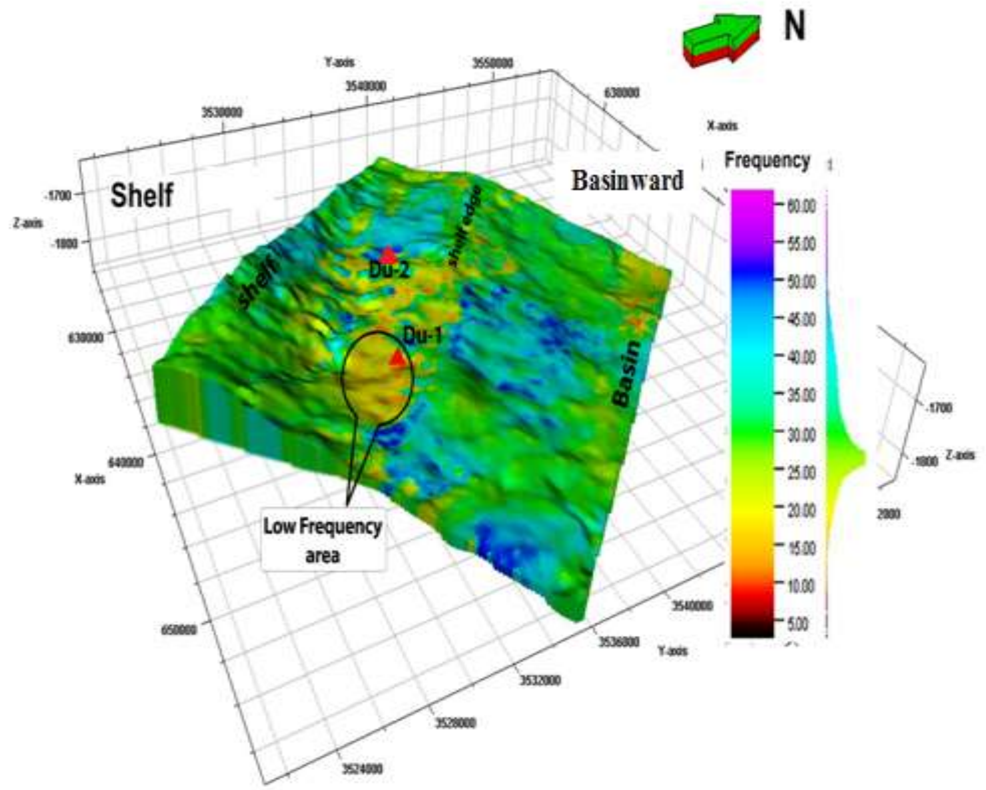

Figure 9: 3D- frequency attribute model of Top Mishrif reflector showing the position of a low-frequency area with supposed geologic interpretation

Figures 10 and 11 represent instantaneous frequency horizon slices and a 3D model of the Bottom Mishrif reflector (Top Rumaila Formation), respectively. They are showing that the frequency of the Bottom Mishrif is approximately uniform and has the same high-frequency value (green color, more than 30 Hz) throughout the layer. This indicates that the Bottom Mishrif layer consists of dense limestone deposited in the deep marine environment. This confirms that the Mishrif Formation is composed of two regressive depositional cycles separated by a disconformity surface located above the unit-4 in time -1800 ms approximately around well Du-1(Figure 4).

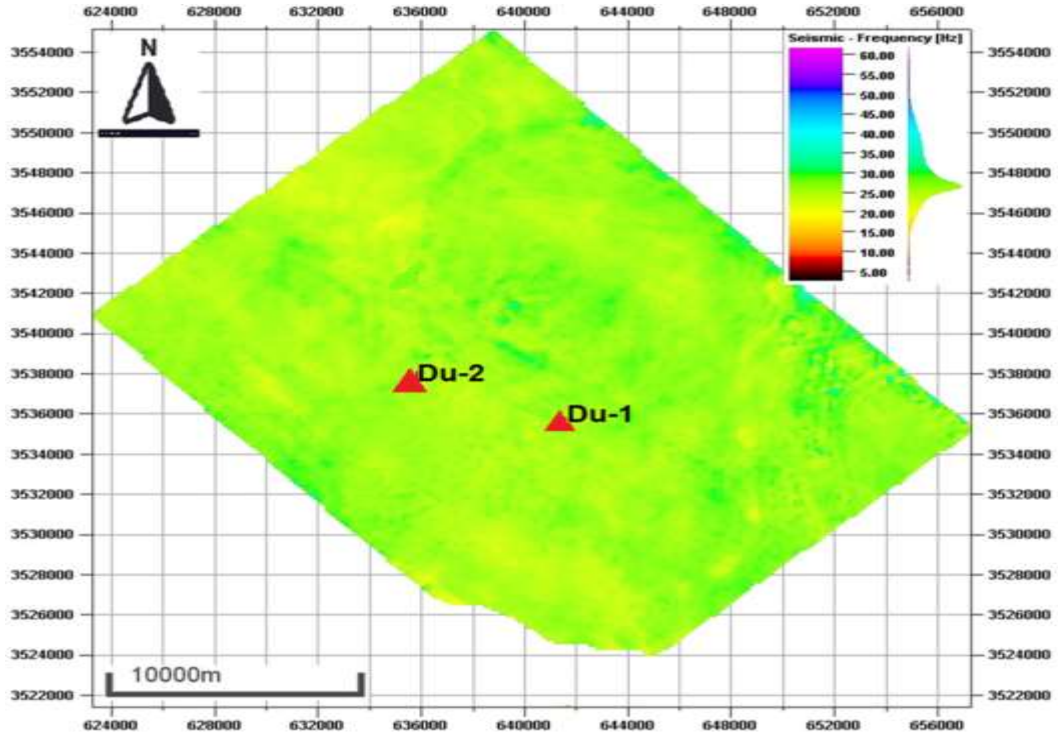

Figure 10: Instantaneous frequency attribute horizon slice of Bottom Mishrif reflector.

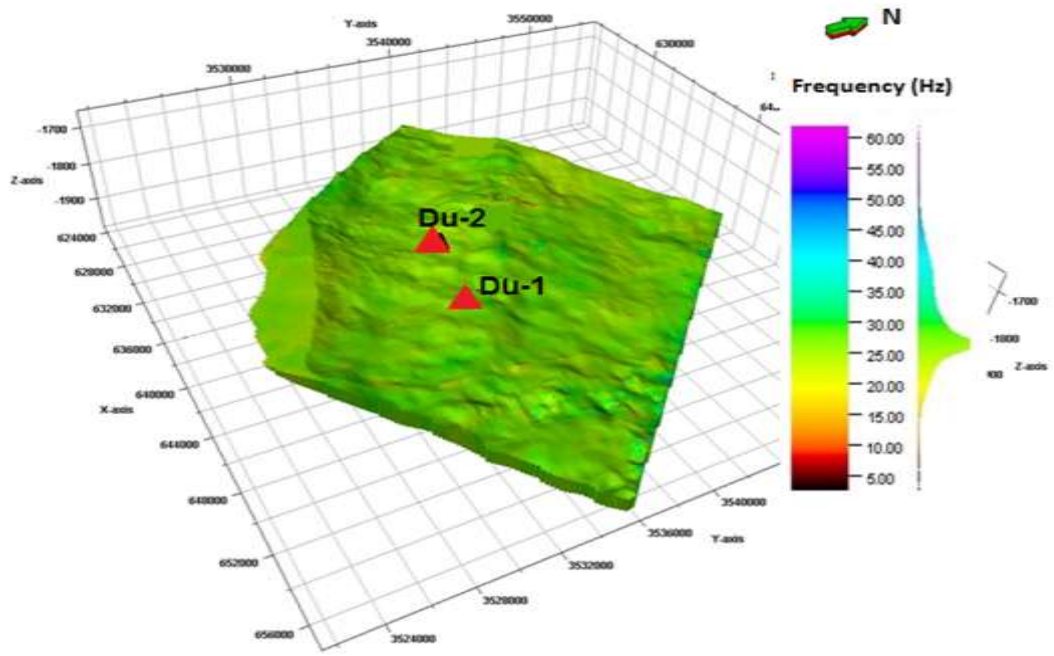

Figure 11: 3D- instantaneous frequency model of Bottom Mishrif

7- Amplitude Variance Attribute

The reflection amplitude variance attribute volume was created from 3D-seismic data of the Dujaila oil field by Petrel software. It represents the trace-to-trace (acoustic impedance) variability over a defined area. High amplitude variance indicates largely varying reflectivity produced from a high-energy depositional environment for good-quality data. In contrast, low amplitude variance indicates uniform reflectivity produced from a low-energy depositional environment [3]. The continuous seismic reflector of similar amplitude traces has a low variance attribute, while discontinuous reflectors appear to have a high variance attribute [26]. Variance attributes directly measure dissimilarity rather than the inferred similarity of seismic data, producing sharper and more distinct results [21]. The reef buildups, isolated sedimentological bodies, and faults create discontinuous reflections that can be easily detected by the variance attribute [8]. The acoustic impedance contrast increases at the reservoir borders, especially with hydrocarbon. It will appear in the variance attribute map with a high value as waves with sharp black edges [27].

Figure 12 represents an amplitude variance attribute horizon slice of the Top Mishrif reflector (at an approximate time of -1735). It displays a high reflection amplitude variance characterized by a black edge of the reflection wavelets. It is restricted in the vicinity of well Du-1, as marked by the red circle. This high amplitude variance in the limestone rocks indicates reef buildups in the region around the productive well Du-1, which is responsible for sudden lateral changes in acoustic impedance between the reef body and the surrounding dense limestone rock. In addition, it clearly shows that the reservoir is extended to the southwest of the well Du-1, and it does not reach the well Dujaila-2. This may explain why well Du-2 is dry. The time slice map for the variance attribute at a time of -1800 ms (under Top Mishrif) shows a low reflection amplitude variance attribute that is characterized by a white region of reflection wavelets in the area around the two wells marked by the red elliptical shape (Fig 14). This refers to that region consisting of homogenous limestone with the absence of reef buildups and termination of the vertical extension of the reservoir rocks. Moreover, that confirms the vertical heterogeneity in the Mishrif Formation lithofacies.

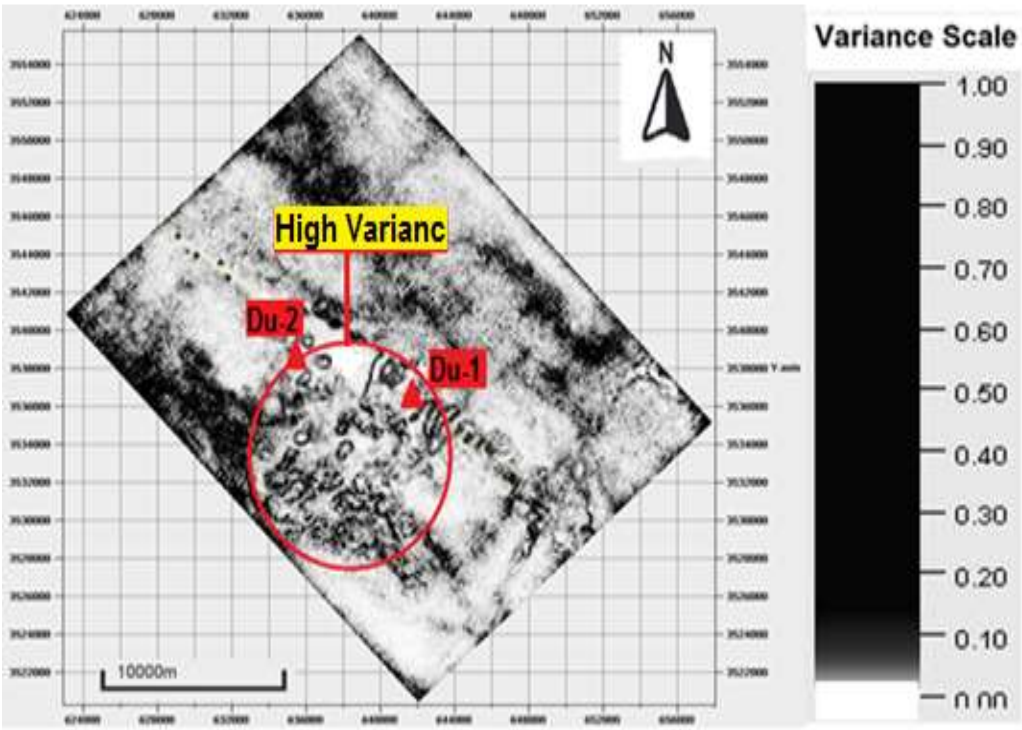

Figure 12: Amplitude variance attribute horizon slice for Top Mishrif.

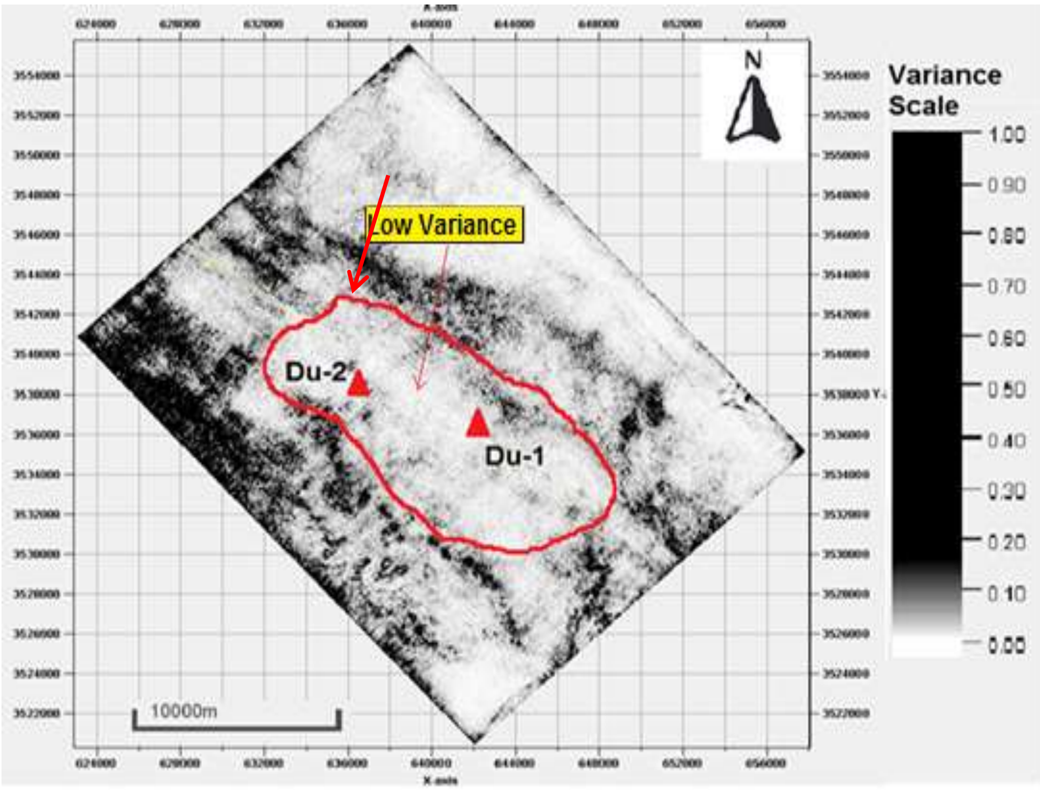

Figure 13: Variance attribute time slice at time -1800 ms under Top Mishrif reflector.

8- Conclusions

The important conclusion of this research is that seismic attributes are very effective tools for interpreting non-evident conventional 3D-seismic data. Three seismic attributes (phase, frequency, and variance) have been employed to enhance 3D-post stack seismic data interpretation. They gave good results in detecting the presence of isolated reef buildups in the upper part of Mishrif Formation in the region around the well Du-1, which acts as a stratigraphic trap for hydrocarbon accumulation. Furthermore, they showed the pay zone of the reservoir extending about 7 km toward SW from well Du-1 and did not reach well Du-2, which explains why it was dry. As a result, the circular region around well Du-1 has a radius of about 4 km, and the area extended about 7 km toward SW from well Du-1 represents a zone of low risk-drill for new exploration wells.

Acknowledgements

I sincerely thank the Interpretation Department, Oil Exploration Company, Iraqi Ministry of Oil for providing data and references and allowing using a computer with software. I greatly appreciate the help of the University of Babylon and the University of Baghdad for their efforts and for giving them time to implement and make this work worthwhile.

References

[1] T. Randen and L. Sønneland, "Atlas of 3D seismic attributes," in Mathematical methods and modelling in hydrocarbon exploration and, Berlin, Heidelberg, Springer, 2005, pp. 23-46.

[2] F. A. Neves and . H. Triebwasser, "Multi-attribute seismic volume facies classification for predicting fractures in carbonate reservoirs," The Leading Edge, vol. 25, no. 6, pp. 698-700, 2006.

[3] A. E. Barnes, Handbook of poststack seismic attributes, USA: Society of Exploration Geophysicists, 2016.

[4] C. T. Kalkomey, "Use of seismic attributes as predictors of reservoir properties—potential risks," in SEG Technical Program Expanded Abstracts , Society of Exploration Geophysicists, 1996, pp. 1789-1792.
[5] M. T. Taner and R. E. Sheriff, "Application of amplitude, frequency, and other attributes to stratigraphic and hydrocarbon determination: Section 2. Application of seismic reflection configuration to stratigraphic interpretation," in Seismic Stratigraphy--Applications to Hydrocarbon Exploration, American Association of Petroleum Geologists (AAPG), 1977, pp. 301-327.
[6] S. Chopra and K. J. and Marfurt, "Seismic attributes—A historical prospective," Geophysics, vol. 70, no. 5, pp. 3SO-28SO, 2005.
[7] M. A. Sarhan, "The efficiency of seismic attributes to differentiate between massive and non-massive carbonate successions for hydrocarbon exploration activity," Journal of Astronomy and Geophysics, vol. 6, no. 2, pp. 311-325, 2017.
[8] S. Chopra and K. J. Marfurt, K.J.,, Seismic attributes for prospect identification and reservoir characterization, Society of Exploration Geophysicists and European Association of Geoscientists and Engineers, 2007.
[9] A. R. Brown, Interpretation of three-dimensional seismic data, Society of Exploration Geophysicists and American Association of Petroleum Geologists, AAPG, 2011.
[10] S. F. Fouad, "Tectonic map of Iraq, scale 1: 1000 000,," Iraqi Bulletin of Geology and Mining , vol. 11, no. 1, pp. 1-7, 2015.
[11] OEC, "Detailed Interpretation of 3D-seismic Reflection Survey for Dujaila Oil Field,," Oil Exploration Company, Iraqi Oil Ministry, 2013.
[12] A. A. Aqrawi, J. C. Goff, A. D. Horbury A. D., and Sa and F. N. Sadooni, The Petroleum Geology of Iraq, Great Britain: Cambrian printers Aberystwyth, 2010.
[13] M. E. Nasser and N. T. Al-Itbi, "The Microfacies Analysis of Mishrif Formation in Gharraf Oil Field," Iraqi Journal of Science, vol. 54, no. 5, pp. 1129-1135, 2013.
[14] T. A. Mahdi, A. A. Aqrawi, A. D. Horbury and G. H. Sherwani, "Sedimentological characterization of the mid-Cretaceous Mishrif reservoir in southern Mesopotamian Basin, Iraq," GeoArabia, vol. 18, no. 1, pp. 139-174, 2013.
[15] T. Buday, The regional geology of Iraq, stratigraphy and paleogeography, Mosul, Iraq: Dar Al-Kutib Publishing House, 1980.
[16] A. M. Khawaja and J. M. Thabit, "A. Interpretation of 3D Seismic Reflection Data to Reveal Stratigraphic Setting of the Reservoir of Mishrif Formation in Dujaila Oil Field, Southeast of Iraq," Iraqi Journal of Science, vol. 62, no. 7, pp. 2250-2261, 2021.
[17] A. M. Khawaja and J. T. Thabit, "Predicting the Depositional Environments of Mishrif Formation from Seismic Isopach Map in the Dujaila Oil Field, Southeast-Iraq," Iraqi Journal of Science, vol. 62, no. 6, pp. 1943-1955, 2021.
[18] M. T. Taner, F. Koehler, F and R. E. Sheriff, "Complex seismic trace analysis," Geophysics, vol. 44, no. 6, pp. 1041-1063, 1979.
[19] D. A. Herron, First steps in seismic interpretation, Society of Exploration Geophysicists, 2011.
[20] R. E. White, "Properties of instantaneous seismic attributes," The Leading Edge, vol. 10, no. 7, pp. 26-32, 1991.
[21] A. E. Barnes, "Seismic attributes in your facies," CSEG recorder, vol. 26, no. 7, pp. 41-47, 2001.
[22] P. C. Veeken, Seismic stratigraphy and depositional facies models, Academic Press, 2013.
[23] Q. Chen and S. Sidney, "Seismic attribute technology for reservoir forecasting and monitoring," The Leading Edge, vol. 16, no. 5, pp. 445-448, 1997.
[24] B. Hart and M. A. Chen, "Understanding seismic attributes through forward modeling," The Leading Edge, vol. 23, no. 9, pp. 834-841, 2004.

[25] S. Koson, P. Chenrai and M. Choowong, "Seismic attributes and their applications in seismic geomorphology," Bulletin of Earth Sciences of Thailand, vol. 6, no. 1, pp. 1-9, 2014.
[26] S. Chopra, R. Kumar and K. J. Marfurt, "Seismic discontinuity attributes and Sobel filtering," in SEG Technical Program Expanded Abstracts, Society of Exploration Geophysicists, 2014, pp. 624-1628.
[27] J. Gao and B. Schrijver, "Creating Variance Cube from Seismic Data and Converting to Transmissibility Multiplier Pattern to Assist History Match," in SPE Reservoir Characterisation and Simulation Conference and Exhibition, Society of Petroleum Engineers, 2015, pp. 40-62.