Utilizing Direct Hydrocarbon Indicators on 3D-Seismic Data to Prove the Existence of Hydrocarbon Accumulation in the Subtle Stratigraphic Trap in the Mishrif Reservoir at the Dujaila Oil Field, SE of Iraq

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Abstract
The current study aims to utilize the Direct Hydrocarbon Indicators technique to identify the presence of hydrocarbons in the Carbonaceous Mishrif Formation (Late Cretaceous) from the 3D seismic data (post-stack) integrated with available information of two wells (Du-1 and Du-2). The 3D-seismic survey was carried out in 2010, covering 602.62 km², at the Dujaila oil field in Maysan, SE of Iraq. Distinct seismic features for hydrocarbon presence indicators were diagnosed and identified on both sections of seismic amplitude and instantaneous phase, such as dim spots, flat spots, and phase polarity reversals. They helped in direct detecting the presence of hydrocarbon accumulation in the stratigraphic trap, in the region around well Du-1 at the upper part of Mishrif Formation, which is located at a time (TWT) extending from -1730 ms in the top Mishrif to underneath at TWT -1775 ms that corresponded with depth 2825 m to 2887.5 m, respectively. Furthermore, based on the well-defined position of a flat spot, which represents oil-water contact; it helped to determine the length of the oil column was 56.8 m in the vicinity of productive well Du-1. It is close to the actual length of the oil column measured in the well was 49 m. As a result, the circular area with a radius of about 3 km around well Du-1 is more suitable for low-risk drilling in the future.

Keywords: Direct hydrocarbon indicators; 3D-seismic survey, Flat spots, Dim spots, Polarity reversals, Oil column

1. Introduction
In the last decades, much significant research has used Direct hydrocarbon indicators (DHIs) techniques and they have been successful in predicting the presence of hydrocarbons in many oil fields around the world (Nanda, 2021; Tai et al., 2009; Alsadi, 2017; Enachescu, 1990). In Iraq, a modest research effort has been presented to identify the suitability of the DHIs method as a new seismic tool for the detection of existing oil in Iraqi oil fields directly from seismic data. Therefore, this research may contribute to applying the DHIs technique to diagnose the presence of hydrocarbons in an untapped Dujaila oilfield, which may encourage using this tool in other explorative and productive oilfields. However, even in good-calibrated sedimentary sequences with seismic data, amplitudes do not always work well and that can show false positives anomaly of a bright spot. Therefore, the hydrocarbon-

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bearing reservoirs without much clear DHI support do not have enough evidence to prove the existence of hydrocarbons. Thus, there is a clear need to enhance our understanding of fluid-driven seismic responses and evaluate the potential for DHI support beyond the classic bright-spot anomaly (Blackburn, 1986; Clark, 1992).

DHI is seismic interpretation tools that use wavelet amplitude properties to achieve direct hydrocarbon detection from the surface seismic data (Brown, 2011). Veeken (2013) pointed out that the direct hydrocarbon detection method relies on the identification of an acoustic impedance contrast associated with the presence of hydrocarbon, which in turn depends on changes in the physical properties of the hosting and surrounding rocks. In general, DHIs are a response to the presence of hydrocarbons in the pores of sedimentary rocks, and their effect on the changing of the physical properties and a clear decrease in both velocity and density that lead to particular variation in wavelet amplitude properties. Therefore, good identification of DHIs in seismic data will provide a reliable basis for reservoir detection and mapping. In addition, it provides a reasonable estimate of a pay zone thickness (Backus and Chen, 1975). Consequently, these DHIs are a result of the corresponding changes in the reflection coefficient and amplitude values at the interface separating hydrocarbon-bearing rocks and the surrounding medium. These changes in the reflected wavelet amplitude can occur in several forms as a Bright spot, Amplitude Versus Offset (AVO), dim spot, flat spot, and wavelet polarity reversal (Downton, 2005; Sharma and Chopra, 2015). Our goal in the present study is using DHI's technique to verify its efficiency to reveal the presence of hydrocarbon accumulation in the subtle stratigraphic trap in the Mishrif Formation to avoid the risk of dry drilling.

2. Location and Geology of the Study Area

The studied field is located in the Maysan, about 55 Km northwest of Amara, and it is situated between Kumiat and Abu-Amoud productive oilfields (Fig. 1). Tectonically, it is sitting in the Mesopotamian Foredeep Basin zone of the unstable shelf of the Arabian Platform (Buday and Jassim, 1987), as shown in Fig.1. The Dujaila field is surrounded by many large oil fields that produce hydrocarbons from a Mishrif Formation by structural traps, such as Nasiriya, Kumiat, Abu Amoud, Amara, Rafidain, and Buzurgan oilfields (Aqrawi et al., 2010a; Al-Khafaji, 2015). The Mishrif Formation (Cenomanian-Early Turonian) is one of the important carbonate reservoirs in the several productive oilfields surrounding the Dujaila field in the middle of southern Iraq (Jassim and Goff, 2006). Mishrif Formation represents a heterogeneous carbonate succession containing different carbonate facies deposited in various marine environments. The reefal facies are dominated by Mishrif facies and consist of vast congregations Rudist shells forming extensive biostromes, these congregations exist more localized (do not continue in all formations) and form the patch reef interbedded with related bioclastic units and have a primary porosity making it one of the best locations to hydrocarbon accumulation (Mahdi et al., 2013). The formation forms from two regressive depositional cycles, separated by a disconformity surface. 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 (Buday, 1980). The thickness of Mishrif Formation in the study area, particularly in the region of the two wells, is about 325 m that is occupied a depth between 2825 to 3150 m, at a time (TWT) ranging from 1725 to 1830 ms respectively (Khawaja and Thabit, 2021a; Mahdi et al., 2013).
3. Materials and Methods

The current study is based on the 3D seismic post-stack time migration volume and available wells data to predict directly the presence of hydrocarbon from seismic data. Only two wells, Dujaila-1 (Du-1) and Dujaila-2 (Du-2) have been drilled in the middle of the survey area and they penetrated Mishrif Limestone Formation, the main oil reservoir in the studied oilfield. Du-1 Well was drilled in 1960 on what was thought to be the crest of the structural closure based on early surveys of gravity, magnetic, and seismic. The well reached 4124 meters deep into the Ratawi Formation. The well has produced oil from the upper part of the Mishrif Formation with a production rate that was estimated by a field test to be 2000 B/D. While, well Du-2, about 7 km to the northwest of well Du-1 was drilled in 1981 based on the interpretation results of the 2D seismic reflection survey, and reached to depth of 4589 m to the Sulaiy Formation. It was dry, despite it is structurally higher than the well Du-1. A 3D seismic reflection survey was carried out in the Dujaila oilfield, covering 602.62 km² in 2010 by the second Iraqi seismic surveying crew. They used special surveying parameters proportional to the geologic subsurface setting of the surveying area to achieve a more accurate survey and high signal to noise ratio.

Based on the 3D-seismic volume and two wells information, a seismic-well tie was made and synthetic seismogram had been created. The recorded seismic reflected traces adjacent wells Du-1 and
Du-2 were calibrated with the created synthetic seismogram traces, which exhibited a good matching. Accordingly, the upper contact of the Mishrif Formation was picked as a trough of wavelets due to the presence of an unconformity surface that consists of a thin layer of shale (Aqrawai et al., 2010a). It is separating between the Mishrif Formation and the overlying Khasib Formation and acts as an impermeable cap rock to the reservoir porous limestone unit in the Mishrif Formation. Whereas the lower contact of the Mishrif Formation was picked as a peak of wavelets on the entire 3D seismic volume due to conformable contact that separates continuous dense marine limestone between the Mishrif Formation and the underlying Rumaila Formation. Khawaja and Jassim (2021a) concluded that Mishrif Formation here consists of four layers that were picked and named unit-1, 2, 3, and 4 respectively, from top to the bottom, as in Fig. 2.

**Fig. 2.** Conventional seismic section passing through wells Du-1 and Du-2 (Khawaja and Jassim, 2021a).

The arbitrary seismic section passing through two wells (Fig. 2) shows these seismic reflectors of units 1, 2 and, 3 are disconcordant, have several abrupt discontinuities, and did not display a clear geologic structural setting, especially in the area around the two wells at the upper part of the Mishrif Formation. Khawaja and Thabit (2021b) interpreted these seismic settings as stratigraphic traps that is consisting of reefal buildup mounds. While the seismic reflector of unit 4 displays a continuous event on 3D seismic volume. The main challenge facing the interpreter of this 3D-seismic reflection data is to answer why the well Du-2 was dry, despite structurally being about 25 m higher than the productive well Du-1, and delineation the location of the central hydrocarbons pay zone. Thus, our task in this paper is to use the DHIs technique to identify the bearing zone and determine the length of the oil column. Meanwhile, this research may contribute to solving the main problem of the unexploited studied field by suggesting promising locations for low-risk drilling and avoiding dry wells in the future.

### 4. Theoretical Background of Direct Hydrocarbon Indicators (DHIs)

DHIs are amplitude anomalies of seismic reflection wavelets that include many distinct reflection amplitude characteristics such as bright spots, flat spots, dim spots, phase change at a projected oil or gas/water contact, and the AVO (Nanda, 2016). DHIs occurs at a potential reservoir level due to a change in the reflection response resulting from the variation in the physical properties (velocity, porosity,
density, and fluid contents) of the hydrocarbon reservoir rock. The existence of a hydrocarbon in the reservoir leads to a reduction in both velocity and density that would make a clear decrease of acoustic impedance (AI) (the product of velocity by the density) (Forrest et al., 2010). Kearey et al., (2004) pointed out that AI has a major influence on the strength and polarity of the reflected wavelets that are manifested by appearing special features of amplitude anomalies as DHI s in the seismic section. The following equations illustrate the theoretical principles of DHIs:

According to Alsadi (2017) and Herron (2011), the acoustic impedance of the rock is equal to:

$$AI = \rho \times v$$  \hspace{1cm} (1)

When the:
AI= Acoustic Impedance of rock reservoir
\rho= density of the rock
v= velocity of the waves in the rock

The reflection coefficient strength and its sign are dependent on AI contrast between the two materials situated on both sides of the reflection interface and are determined by the below equation.

$$R_c = \frac{AI_2 - AI_1}{AI_2 + AI_1}$$ \hspace{1cm} (2)

When the:
Rc= Reflection Coefficient
AI1 is the acoustic impedance of the first (upper) layer
AI2 is the acoustic impedance of the second (lower) layer

From equation 2 the Rc may have one of these signs = +, 0, -

If the AI2 > AI1, the Rc is positive (+), which leads to a high reflection of the positive amplitude polarity, so it appears as bright spots.

If the AI2< AI1, the Rc is negative (-), which leads to a high reflection of the reverse polarity amplitude, it appears as a polarity reversal.

If the AI2 = AI1, the Rc is zero, which leads to a dim or weak reflection, it appears as a dim spots.

Based on these theoretical principles, we can explain the reflection behavior of seismic wavelets to create DHIs features on the reef mound body.

The presence of hydrocarbon in the carbonate rock of the reef mound has a major effect to decrease the AI (reducing velocity and density). Figs. 3 and 4 show that dim spots or weak reflection events are created on the crest of the reef mound due to a decrease in acoustic impedance contrast at the interface between shale and the underlaying oil-saturated limestone of a low AI. As we go to both flanks, we can see a large positive amplitude of reflections due to a large AI contrast on the interface that separates between shale and tight limestone. Meanwhile, a flat spot of small positive amplitude reflections appears in the lower part of the reef mound due to low AI contrast on the horizontal oil-water contact that separates hydrocarbon and water in reef limestone.
In addition, there is another seismic phenomenon related to the presence of hydrocarbon is a polarity reversal of the amplitude of reflection events. It is one of the main DHIs characteristics that can be seen in the conventional seismic section. The presence of hydrocarbons in the reservoir leads to reduced AI in the bearing rock and a change in the reflection coefficient sign. This leads to reverse amplitude polarity from positive to negative, making an obvious polarity reversal in the reflected wavelet amplitudes. Thus, the polarity reversal will appear on the seismic sections as an abrupt change in the wavelet phase with a change in its color from red to blue (Brown, 2011).

The seismic hydrocarbon detector could be affected by many factors other than the hydrocarbon existence, so it happens that particular criteria may not be satisfied. Therefore, to have a reasonable diagnosis of the existence a hydrocarbon accumulation, the simultaneous presence of many DHIs is well recommended (Chen and Sidney, 1997) and (Forrest et al., 2010). In this research, we will employ three DHIs (dim spot, flat spot, and polarity reversal) to verify the presence of hydrocarbons in the reservoir. So, we will present a brief explanation to them as follows:
4.1. Dim Spot

The dim spot represents an area of a sharp decrease in the reflection strength as a result of a sudden drop in the acoustic impedance contrast on the part of the seismic reflector (discontinuity) due to a change in lateral physical properties due to existing the hydrocarbon accumulations in the pores of an underlying layer. Brown (2011) referred that dim spots occur where there are only small impedance contrasts between adjacent lateral lithofacies, especially when one of them is oil filled. The dim spot is an abnormally weak reflection zone or no reflection events that appear on the seismic amplitude sections, due to a reduction in the acoustic impedance contrast on the reflections at the interface (Barnes, 2001). Hart and Chen (2004) pointed out that the dim spot is a limited and weak reflection zone, indicating the reduced reflection contrast particularly observed in case of the presence of hydrocarbon, increase in porosity, or facies change. Thus, the dim spot is any distinctive weakness or loss of amplitude reflection that may manifest on the top of a geologic structure, which may be a significant indicator of hydrocarbon presence (Koson et al., 2014). In addition, Løseth et al. (2009) referred that dim spots commonly appear in the true amplitude seismic sections of carbonated rocks as a sign of porous reef buildups.

4.2. Flat Spot

A flat spot results from an increase in acoustic impedance contrast when a hydrocarbon-filled porous rock (with lower acoustic impedance) overlies a liquid-filled porous rock (with higher acoustic impedance). Therefore, it may stand out clearly in the seismic reflection section because it is flat and will contrast with surrounding dipping reflections (Backus and Chen, 1975). The flat spot is just a reflection of positive polarity flatter than the other reflections around it. It is usually disconformable with both top and base reflectors and it is more evident on a compressed horizontal scale. It is considered an important hydrocarbon indicator for any suggestion of an anomalous near–horizontal event in a possible trap location (Chen and Sidney, 1997). It is most likely a liquid contact, especially when it is associated with a structural height. In addition, the flat reflection (liquid contact or oil-water contact) is not necessarily to be strictly horizontal but relatively flat, and disconformable for some reasons related to the hydrodynamic forces or lateral change of velocity (Brown, 2011).

4.3. Polarity Reversals

The lowering of velocity due to present hydrocarbons in the reservoir leads to a change in the reflectivity coefficient sign at the top of a reservoir from positive to negative, making polarity reversal in the reflected wavelets (Nanda, 2016). Meanwhile, Barnes (2001) pointed out that the polarity reversals have resulted from a sudden change in the phase of reflected wavelets due to abrupt variations in the physical properties of neighboring lithofacies or by hydrocarbon presence.

5. Interpretation of the Seismic Section

Two of the DHIs criteria (dim spot and polarity reversals) and some of the reef buildup characteristics were clearly recognized in the seismic section that passes through Du-1 and Du-2 wells, as in Fig. 5. They had been observed at the upper part of the formation in the area around the two wells, as marked by a red circle, which may represent the approximate edges of the reef buildups (Fig. 5). These diagnosed seismic criteria have confirmed that the region around two wells is the main reservoir of the stratigraphic trap, which consists of an isolated Rudist reef mound.
Fig. 5. An arbitrary seismic section passing through Du-1 and Du-2 wells that shows many DHI features are identified in the area between the two wells.

Fig. 6 represents an inline seismic section passing through the Du-1 well that displays three distinguished DHI features (dim spot, polarity reversal, and flat spot) and reef mound structure in the upper part of formation at the area around well Du-1. They were well-identified and pointed out inside a red elliptical shape that may represent the approximate edge of reef buildups, as in Fig. 6. Therefore, the observed DHI features here have been confirming the existence of hydrocarbon accumulation in the circular area around the Du-1 well.

Fig. 6. Represent an inline seismic section passing through the Du-1 well that clearly shows three DHI features in the upper part of the formation at the circular area around well Du-1, as marked inside a red elliptical shape.
While the seismic section that passes through the Du-2 well displays no evidence of the presence of DHIs in the area around well Du-2. Besides, most formation layers showed a continuous extent and had no clear mound shape, as in Fig. 7. Thus, reasons confirm the absence of hydrocarbons in the region of the well Du-2 that may be due to lateral change in the lithofacies and/or the stratigraphic trap does not reach it so that was making Du-2 dry. As a result, this may explain why Du-2 was dry despite being structurally higher than the productive Du-1 well.

**Fig. 7.** Represents a seismic section passing through well Du-2 that obviously does not show evidence of the presence of DHIs in the region around well Du-2.

Furthermore, the instantaneous phase attribute seismic section that passes through Du-1 well, derived from 3D poststack seismic cube, also clearly shows many criteria of DHIs in the area around the Du-1 well, such as flat spot, dim spot, and polarity reversals as marked by a red ellipse in Fig. 8. Thus, the existence of these hydrocarbon indicators has confirmed the presence of hydrocarbon accumulations in the region around well Du-1 in the upper part of Mishrif Formation.

**Fig. 8.** Instantaneous phase attribute section passes through well Du-1. It shows many direct hydrocarbon indicators inside the red elliptical shape in the area around well Du-1.
Simm et al., (2014) referred that the flat spot is used to determine the length of the hydrocarbon column from seismic data when it is precisely defined. Depending on the accurate position identification of the flat spot (oil-water contact) at well Du-1, in both the seismic amplitude section and the instantaneous phase section, which they illustrated the flat spot is located at a time (TWT) 1780 ms in the lower boundary of the stratigraphic trap of the reef mound. While the upper edge of the pay zone in Du-1, approximately lies at a time (TWT) of 1745 ms, as shown in Fig. 9. The average velocity of the reef mound reservoir at well Du-1 (3250 m/s) as determined by Khawaja and Thabit (2021b) was used. Accordingly, the length of the oil column was calculated as follows:

Oil column length in TWT = 1780 – 1745 = 35 ms
One-way time = 35/2 = 17.5 ms,
Column length (m) = average velocity × Time (one way)
Oil Column length = 3250 m/s × 17.5/1000 s = 56.8 m

The calculated length of the oil column in this study is approximately 56.8 m, as in Fig. 9. It is close to the length of the actual oil column of the productive well Du-1, which is 49 m. This may provide a reasonable explanation of the increased length of the pay zone column compared to the reservoir structure volume that is due to the existence of stratigraphic trap from reefal buildups.

![Fig. 9](image.png)

**Fig. 9.** The instantaneous phase section illustrates the process of calculating the length of the oil column in the Du-1 well depending on the well-identified flat spot.

6. **Discussion**

A good probability for finding hydrocarbon accumulation by the seismic method is dependent on detecting some distinctive reflected amplitude criteria. These are directly related to the amount of acoustic impedance contrast between vertical and lateral adjacent rocks. Whereby, the variation in petrophysical properties (porosity, fluid content) between reservoir and neighboring rocks leads to produced distinct reflection amplitude events that proportion with the reflection coefficient strength, such as dim spot, flat spot and polarity reversal. Thus, identifying and finding DHIs features is significant work because they have the ability to prove the existence of hydrocarbons in subtle reefal buildup traps and help in delineation the location of new low-risk drilling exploratory wells.

7. **Conclusions**

Three direct hydrocarbon indicators (flat spot, dim spot and polarity reversals) have been clearly recognized in the 3D seismic data in the area around the well Du-1 in the upper part of the Mishrif Formation in the Dujaila oilfield. They helped to confirm the existence of hydrocarbon accumulation in
the subtle stratigraphic trap of the reef mound buildup. Conversely, the DHI characteristics in the region around Du-2 were not observed which referred to the absence of hydrocarbons and explains why it was dry. Furthermore, depending on the well-defined location of the flat spot had been calculating the length of the oil column of the pay zone in productive well Du-1 was about 56.8 m. It is close to the actual oil length of borehole about 49 m. This may provide a reasonable explanation for why increasing the length of the pay zone column compared with the reservoir structure volume is due to the existence of a reefal subtle stratigraphic trap. As a result, the circular area with a radius of about 3 km around well Du-1 is more suitable for low-risk drilling in the future.

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