

Original Article

An Amplitude Variation with Offset (AVO) Analysis of a Selected Profile of the Jeribe *Fn.* (Middle Miocene) In the Khashim Al-Ahmer Field in the Northeast of Iraq.

Yasir F. Shyaa

¹Seismic Processing, Oil Exploration Company (OEC), Baghdad, Iraq.

Corresponding Author : yasirfalih@com

Received: 12 August 2026

Revised: 16 September 2026

Accepted: 03 October 2026

Published: 21 October 2026

Abstract - Applying the Amplitude Variation with Offset (AVO) technique to the Jeribe Formation (Miocene) in the Khashm Al-Ahmar field. The field is located in Diyala Governorate in the northeastern part of Iraq. One well in the study area (Ka2) penetrated the required reservoirs within the Jeribi Formation (Middle Miocene). The synthetic seismogram was created to correlate well with the seismic data, which shows a good match using the extracted well waves. The Hampson-Russell HRS-9 technique was used for processing the 2D pre-stack seismic data, Common Depth Points (CDP). The log data of one well, Khashm Al-Ahmar 2 (Ka2) and 2D pre-stack seismic data were used. Initially, the petrophysical study of the well Khashm Al-Ahmar 2 (Ka2) was conducted to predict the gas zone in the reservoir at the well site. Then, the zones far from the well were predicted by correlating the seismic data with the well. The Jeribe reservoir model with saturation levels of 60% gas, 20% brine, and 20% oil was used to replace the in-situ fluid saturation level in the analysis of the Amplitude Variation with Offset (AVO) behavior. The result of this research shows that the Jeribe reservoir in the Khashm Al-Ahmar field contains Class-3 gas, according to the AVO response under the in-situ conditions.

Keywords - The Jeribe Gas Reservoir, AVO Analysis, Bright Spots, CDP Gathers, Class-III.

1. Introduction

The Jeribe Formation was first described by Damesin (Bellen, Dunnington, Wetzel, & Morton, 1959). Still, it was later defined by Bellen from the type locality near Jaddala Village in Jebel Sinjar Anticline and assumed to be of Early Miocene age. (Al-Kharsan, 1970) studied the Lower Oligocene and Lower Miocene stratigraphy of the eastern area of Khanaqin, Iraq. The Jeribe Formation is an important reservoir in many of Iraq's important oil fields (Aqrawi, Goff, Horbury, & Sadooni, 2010), such as the Kirkuk and Tawki oil fields (Abdula, 2010). (Kharajany, 2014) studied early middle Miocene formations in Ashdagh Mountain and stated that the Jeribe Formation consists of grey limestone, which is slightly marly, about 2 m thick, and contains Borelis melo curdica.

Knott and Zoeppritz did the theoretical work necessary for the Amplitude Variation With Offset (AVO) theory around 1900 (C. G. Knott, 2007). Considering the densities and velocities of the (P-wave) and (S-wave) in the two-bounding medium, they created formulas that expressed the amplitudes of plane-wave reflections in relation to incident angles. (KOEFOED, 1955), Outlined the connection between AVO and the variation in Poisson's ratio across a border. The

precise Zoeppritz equation served as the basis for Koefoed's findings. The current AVO interpretation is based on the conclusions made by Koefoed. (BORTFELD, 1961) Streamlined Zoeppritz's formula, facilitating a better understanding of the relationship between reflection amplitudes, incidence angles, and physical characteristics. When the reflecting layer is thick enough in comparison to the seismic wavelength, the reflections from the top and bottom of the layers are independent of each other. However, when the layer becomes sufficiently thin, the reflections begin to blend into one another. (Hamzah A. Almoghrabi, 1986) Found that the Amplitude Variation with Angle (AVA) response of a thin layer depends on the thickness of the layer and might differ significantly from the AVO response of a simple contact. The peak Frequency Variation with Offset (FVO) is also likely to be larger when the reflection is from a thin layer. An increasingly used method in the exploration business is analyzing seismic reflection data using Amplitude Variation With Offset (AVO) or Amplitude Variation with Angle (AVA). (Mazzotti, 1991), (Mitchell, 1991), given that reservoirs usually consist of gas-bearing sands with a low Poisson's ratio (low V_p/V_s) on top of high Poisson's ratio (high V_p/V_s) shale, Ava studies are particularly helpful for locating and mapping gas zones in the exploration sector. A



larger reflection coefficient will be observed at an increasing angle of incidence or offset in the case where the gas sand has a lower impedance than the shale layer above it. Even though the reflection coefficient is usually positive, it will exhibit similar increases in magnitude in different combinations of rock types, including shale over hard limestone. A negative polarity of the reflection and an increase in the absolute amplitude of are hence necessary conditions (Christopher Juhlin, 1993). The amplitude variation with offset, or AVO, approach measures how the distance between shot locations and receivers affects the amplitude of seismic reflection variations. Geophysicists can evaluate reservoir rock characteristics such as porosity, density, lithology, and fluid content more accurately by using AVO analysis (Feng, 2006). A plane-wave approximation serves as the foundation for the Zoeppritz equations, which are used in conventional Amplitude Variation With Offset (AVO) inversion analysis. Spherical waves, as opposed to plane waves, are a superior model for wave reflections since point sources produce actual seismic data. In fact, spherical reflection coefficients diverge from planar reflection coefficients in the vicinity of both the critical and post-critical angles. This suggests that, in the context of AVO analysis, angles that are close to critical reflection are not covered by the Zoeppritz equations (Jaimes-Osorio, Malcolm, & Gholami, 2020).

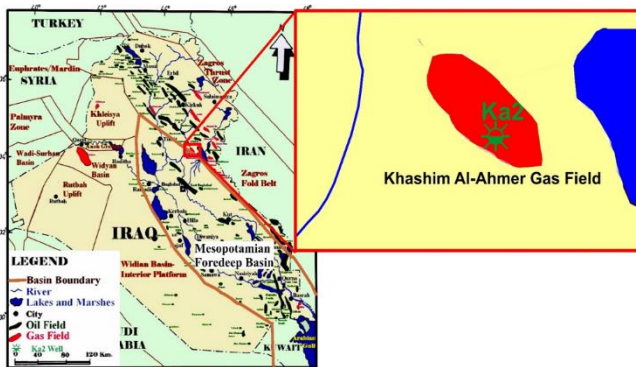


Fig. 1 Shows the location of the field geographically and administratively, its position in relation to the sedimentary basins, and its location concerning other oil and gas fields

2. Location of the Study Area

The study area of the Khashim Al-Ahmer Gas Field lies on the northern edge of the Mesopotamian Foredeep basin, between 33.8°N and 34.3°N latitude and from 44.2°E to 44.5°E longitude, in the north-eastern part of Iraq within Diyala Governorate (Figure 1). In addition, the area is inhabited, as the study area is surrounded by many agricultural villages and sub-district centers. Lake Himreen lies within the study area and extends to the east of it (Figure 1). Technically, the study area is located within the unstable shelf, within the foothill of the Hemrin-Makhul Subzone. The subzone was the depocenter of the Neogene molasse but has been a subsiding unit throughout the Mesozoic and Tertiary (Shyaa & Al-Rahim, 2021). The (Figure 1 shows the location of the field geographically and administratively, its position

in relation to the sedimentary basins, and its location concerning other oil and gas fields.

3. Theory of AVO

Seismic waves experience energy division at each layer boundary they encounter while traveling through the ground due to disparities in velocity and density. The process involves transforming some of the energy that comes from a compressional source into a shear wave. Afterward, the shear wave and the compressional wave only partially transmit and reflect at the boundary of each layer. The intensity of the reflected light is proportional to the angle of incidence. Plotting reflection amplitudes against incidence angle can sometimes reveal changes in Poisson's ratio or other lateral variations in the elastic properties of reservoir rocks. This may suggest a change in the fluid saturation of the reservoir rocks, which might be caused by an alteration in the ratio of P-wave velocities to S-wave velocities. An isotropic material's planar elastic wave equations can be derived and solved using the equations of motion and Hooke's law. Using Snell's law, one may determine the amplitudes of the P- and S-waves that are reflected and transmitted. Wave velocities, plane wave solutions, and the equations of continuity for the vertical and tangential components of stress and strain at a layer boundary are all connected by this law of propagation. The 2006 description by Feng and Bancroft of the propagation of compressible waves across a solid-solid interface is shown in Figure 2 (Feng, AVO Principles Processing and Inversion, 2006).

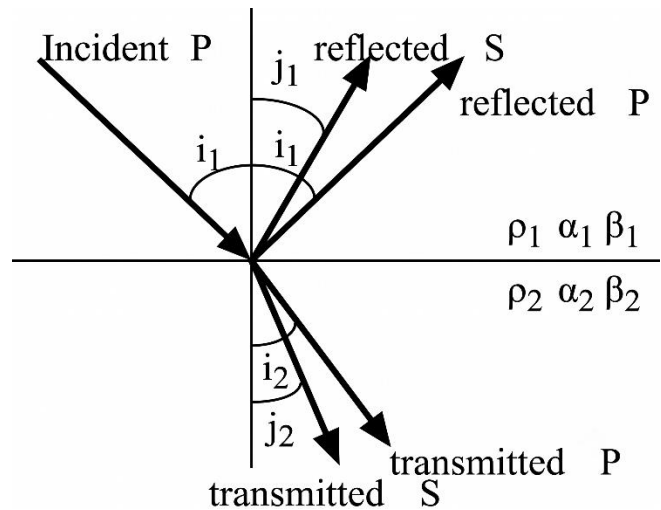


Fig. 2 Waves generated at an interface by an incident P-wave

The word "AVO" encompasses the correlation between seismic amplitude and offset, which is the distance between the source and the receiver. Conventional post-stack seismic data processing calculates the P-wave velocity and density in terms of acoustic impedance by assuming that the reflections come at nearly perpendicular angles onto the reflector. When considering the incidence angle, it is also important to evaluate the presence of S-waves (Figure 3). The Aki-

Richards equation, as demonstrated by the linearized Zoeppritz Equation 1, can be employed to simulate this occurrence. The AVO properties of intercept and gradient are denoted as A and B, respectively, in Equation 1. These can be seen as the primary AVO features from which additional elastic properties of rocks are derived (Buske, 2015).

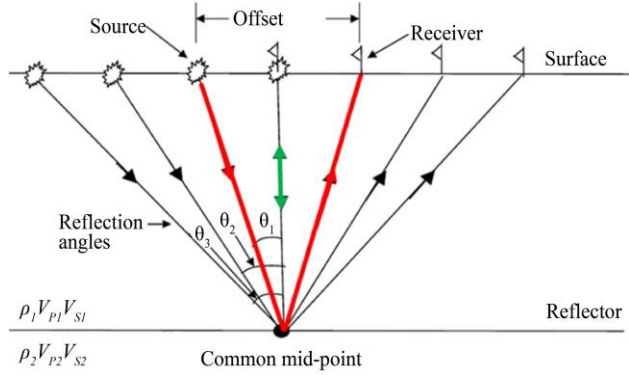


Fig. 3 Illustration of a normal incidence reflection (green) and a reflection with a non-zero incidence angle (red)

$$R(\theta) = A + B \sin^2 \theta + C \tan^2 \theta \sin^2 \theta \quad (1)$$

$$A = \frac{1}{2} \left[\frac{\Delta V_p}{V_p} + \frac{\Delta \rho}{\rho} \right]$$

$$B = \frac{1}{2} \frac{\Delta V_p}{V_p} - 4 \left[\frac{V_s}{V_p} \right]^2 - 2 \left[\frac{V_s}{V_p} \right]^2 \frac{\Delta \rho}{\rho}$$

$$C = \frac{1}{2} \frac{\Delta V_p}{V_p}$$

4. AVO Classification

The categorization of bright spot, phase reversal, and dim out during the 1970s is associated with the classification of reflection coefficient curves proposed by Rutherford and Williams, which has since been the prevailing standard in the industry, see Figures 4 and 5. A classification system was devised to classify reflections that originate from layers saturated with hydrocarbons. The curve representing the reflection coefficient for all classes exhibits a negative slope, as classified by Rutherford and Williams. The angle at which light hits a surface results in a reduction in the intensity of the reflected light. Nevertheless, the magnitude of the amplitude may rise in correlation with the angle at which the incident occurs, as demonstrated in the case of Class 2 and 3 abnormalities characterized by gas saturation. (Figure 4). The study conducted by Castagna & Swan, 1997) revealed that specific gas-saturated anomalies belonging to Class 3 might demonstrate a consistent decrease in magnitude as the offset gradually increases. The anomalies were categorized as Class 4 Affected Variables (AVO). Nevertheless, the primary characteristic that sets Class 4 anomalies apart is the significant magnitude attributed to hydrocarbons (Figures 4 and 5).

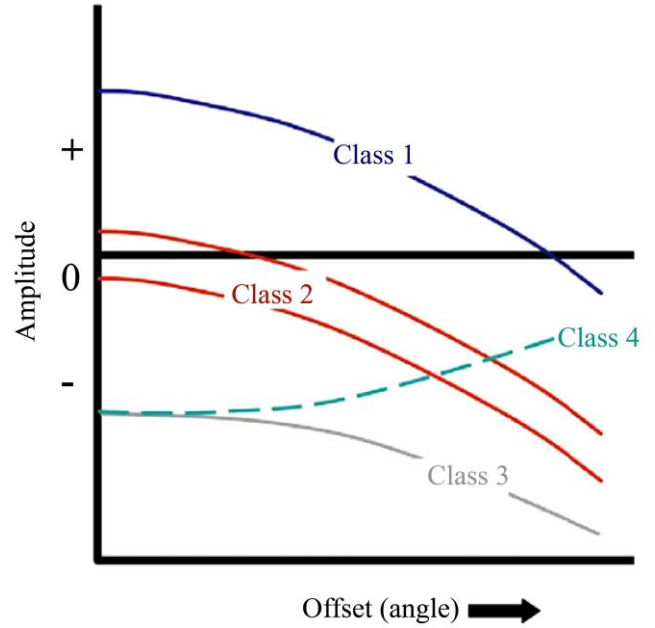


Fig. 4 The AVO responses are classified into four classes: Class 1, Class 2, Class 3, and Class 4, as defined by [17] (Rutherford & Williams, 1989).

AVO CLASSES REFERENCE GUIDE

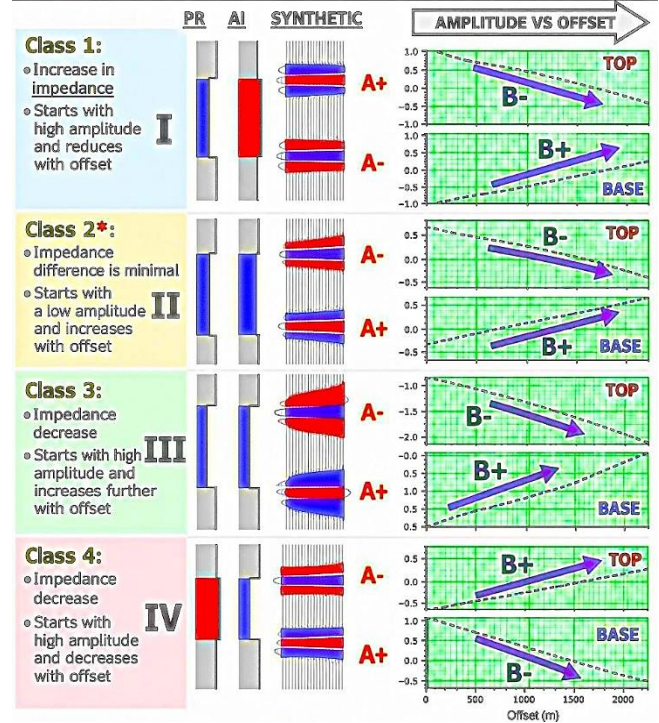


Fig. 5 illustrates the relation between acoustic impedance (AI) and CMP gathering and cross plotting reference to amplitude behavior for the AVO four cases.

5. Methodology

The following scheme would clarify the AVO workflow (Figure 6), starting from the CDP gathered to output AVO products.

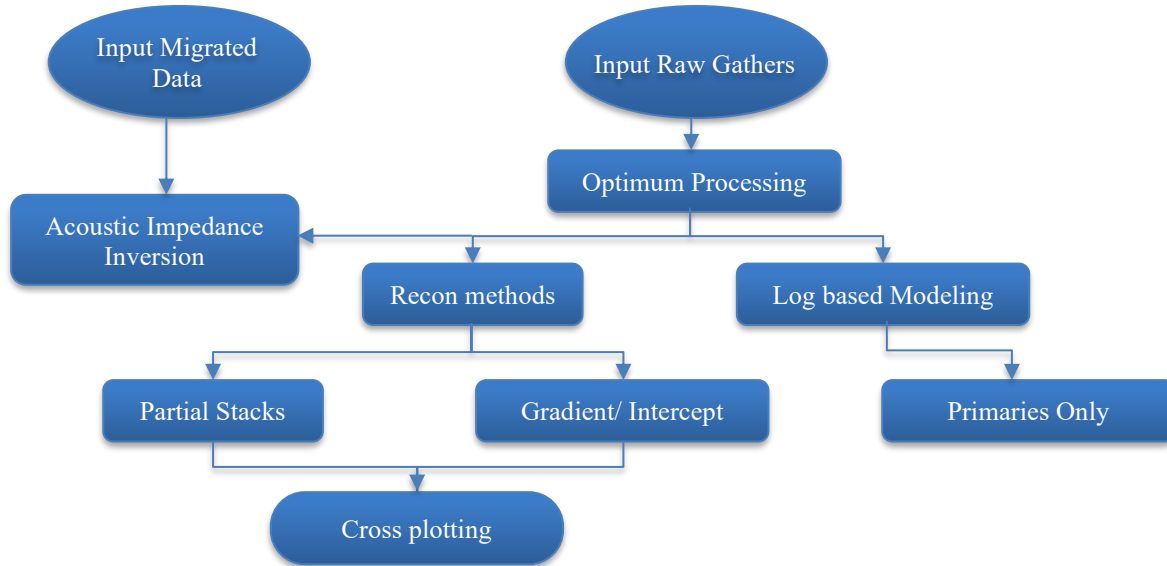


Fig. 6 The scheme would clarify the AVO workflow

Although there are some difficulties in conducting such studies over the Khashim Al-Ahmer field due to a lack of shear information (No dual sonic log DSI and/or VSP are available), poor 2D seismic CDP gathers Figure 7 and 8.

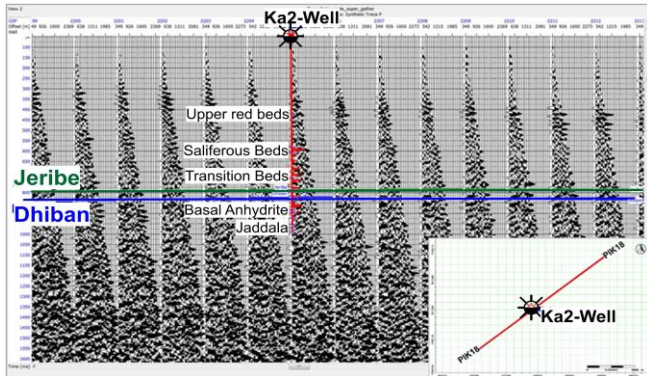


Fig. 7 PIK18 seismic line across migrated, NMO corrected CDP gathers cube shows the data quality

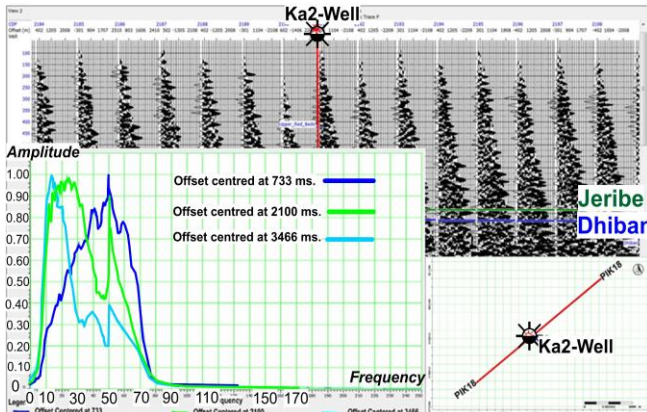


Fig. 8 PIK18 seismic line shows raw CDP gathers with amplitude spectrum measured at different offsets to show the frequency degradation at far offsets

Moreover, the nature of the lithology media is a carbonate, where AVO responses might not be presented at the CDP gathers. We decided to challenge such difficulties and conduct a data assessment and competency before commencing such AVO studies for Khashim Al-Ahmer. Hampson-Russell HRS-9 technology is used to precondition 2D CDP gathers, assess the available data for AVO modeling and analysis, and help to manage the risk of implementing such studies amongst the decision trees. Geological-driven 2D seismic processing sequence performed (surface consistent operators applied over the data, no trace-to-trace processing) to preserve the CDP gather's natural (relative) amplitudes; Yet, we had to prepare the data for AVO assessment and studies by applying a series of data conditioning such as outer mute, time-variant trim statics, super gathers stack, and parabolic radon transform.

5.1. Data Preparation

Migrated-NMO corrected CDP gathers, PSTM 2D seismic line, one well log and one check shot, and core data over Jeribe have been contributed to the studies; Log curves editing is just a minor de-spiking process besides a cross-check of its porosity readings with the porosity measurements from the Core plugs to validate the digitized curves. CDP gathers data conditioning, which has taken a tremendous amount of time to test and apply several processing parameters.

A series of CDP data processing was applied before screening CDP gathers for AVO responses; The Main objectives are to enhance the signal-to-noise ratio and its alignment, in particular at far offsets. Four process operators were selected and applied at the CDP gathers before commencing the study, namely outer mute, time-variant trim static, CDP super gather, parabolic radon transform and random noise remover (Figure 9).

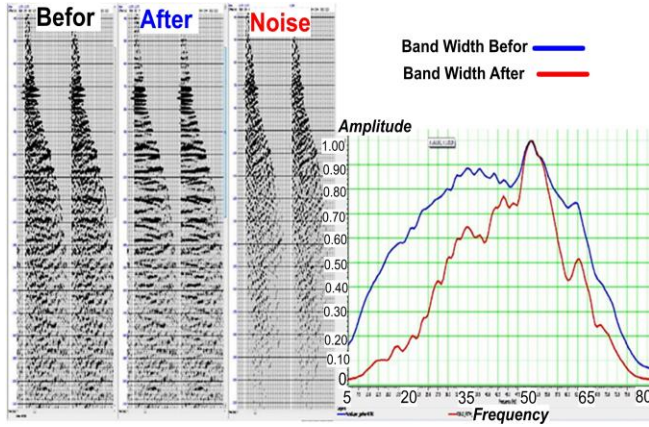


Fig. 9 shows the outcome of the CDP gather after applying the Super gather stack and Radon transform with the output noise trains. The amplitude Spectrum before and after (right) shows significant enhancement

Generally, the amplitude spectrum was measured before and after applying any process to make sure that the data bandwidth was improved for the entire time length (4 Sec). Parameter selections are based on a deterministic approach as well as data enhancement observation in the spectrum.

5.2. Data Assessment and Competency for AVO

After the completion of the AVO data pre-conditioning stage, data screening for hunting AVO responses was conducted. Real-time AVO responses coincided with the proven top of hydrocarbon (Figure 10), particularly with the gas caps at several spots around the control points. Meanwhile, the nature of the carbonate rock matrix in Khashim Al-Ahmer as a vuggy porous and random fractured media, for which the AVO response is similar to the clastic AVO response, strongly supports our justification to conduct the AVO studies by implementing the same algorithm, assumptions, and empirical relationships that are utilized with clastic media.

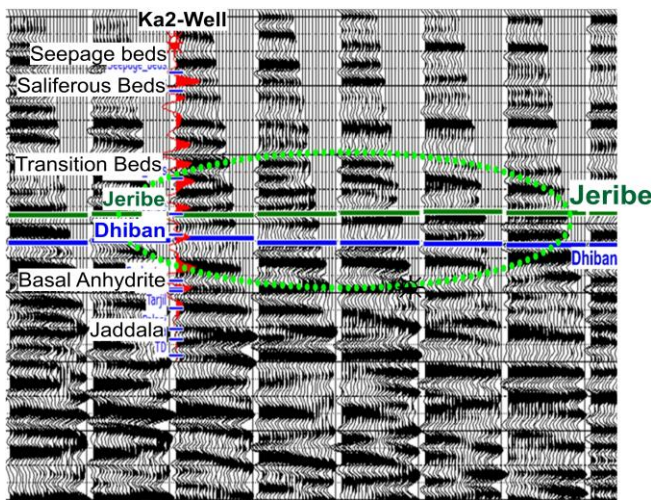


Fig. 10 Class-III AVO responses presented at top gas pay, Transition bed

5.3. AVO Modeling

The weakly stacked trace response and the high distant trace effect are confirmed by the AVO modeling and a close match with an observed gathering. The biot-Gassman Fluid Replacement Modeling technique is utilized to simulate different fluid behaviors within the Jeribe Formation. The flowchart (Figure 11) summarizes the common AVO modeling steps. Data inputs are well logs (measured P-log, Density, and estimated S-log and Poisson). Geological tops are inserted at the curves to bound the zone of interest, whereby Fluid Substitution Modeling (FSM) would be focused.

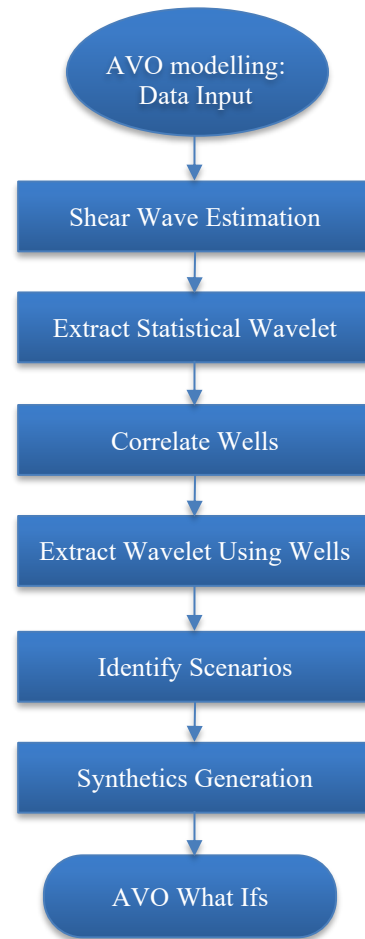


Fig. 11 The flowchart shows AVO modeling

5.3.1. Shear Wave velocity estimate

In the light of not having an in-situ shear wave vertical velocity V_s measurement, we had to empirically estimate it as a function of V_p as well as the fluid properties within a reservoir. Castagna mud rock line relation has been used to estimate V_s outside the reservoir zone (Jeribe interval) as ($V_s = -1172 + 0.8619 V_p$); (GREENBERG & Castagna, 1992) method was utilized to estimate V_s inside the reservoir matrix section in terms of mineral/fluid composition and coefficient according to Voigt-Reuss, Hill Average.

5.3.2. Well Logs to CDP gather Cross-Correlation

The log correlation method analyzes the existing depth-time conversion and adjusts it to ensure that the produced synthetic matches the seismic data in the best possible way. CDP conditioned gathers are used for correlation by computing a composite trace of CDP's surrounded borehole at one 2D seismic line (Figure 12) would illustrate the quality of well-seismic CDP gather cross-correlation around Ka2.

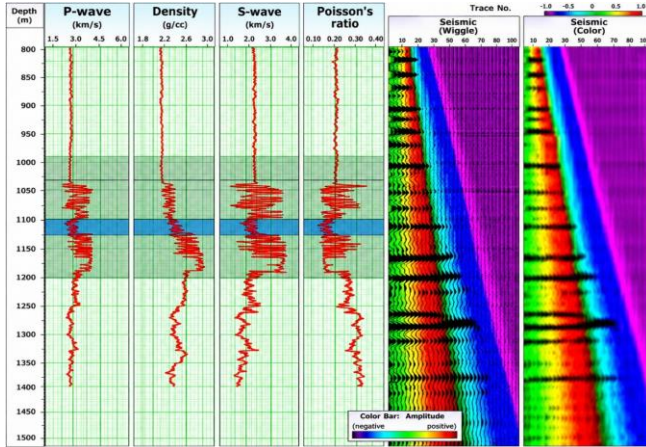


Fig. 12 Ka2 Correlation P-wave, Density, S-wave, and Poisson transform, CDP functioned of offset and colored incident angles

5.3.3. Wavelet estimation and AVO Synthetics Modeling

This step aims to extract a wavelet from the seismic volume that ensures an optimal match between the synthetic seismogram and the neighboring traces at a zero-lag time by modifying the depth-time transformation on the log while, at the same time, extracting a suitable wavelet. Initial wavelet estimates are based on the statistical approach by using seismic data only across a time window, mainly centered at the zone of interest; other options use the well to extract the wavelet corrected phase. Several offset-dependent wavelets have been estimated over the zone of interest in order to better present the model away from the control points (Figure 13).

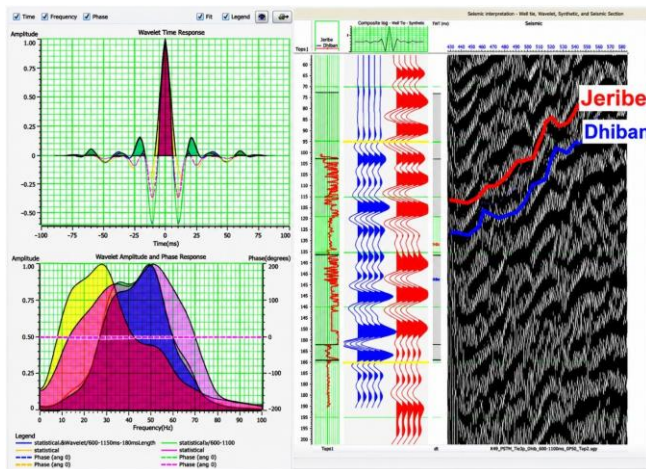


Fig. 13 Offset-dependent wavelets estimate at time window 650 to 1200ms, wavelet length 130 ms

5.3.4. Identify Fluid Charge Scenarios and Synthetic Generation

The steps for using the AVO technique are based on the flowchart (Figure 14),

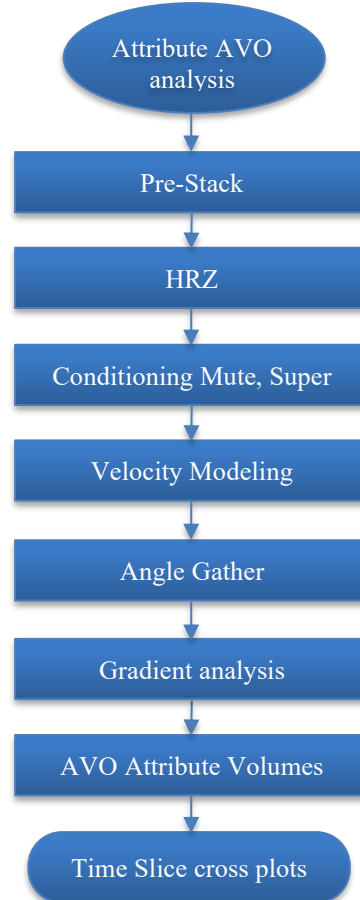


Fig. 14 The flowchart shows the AVO technique

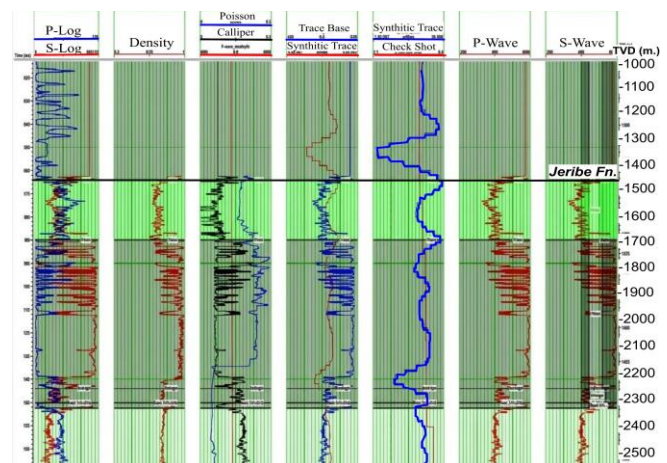


Fig. 15 Ka2 P-log, S-log, Density, and transformed Poisson overlaid by a synthetic trace to Quality Control (Qc) trends

After estimating the seismic wavelet, we need to simulate the geological conditions that we wish to model; a number of different fluid charge scenarios have been set up

at the Jeribe interval. At least one scenario is chosen, the in-situ scenario, which is present in the logs of Computer Processes Interpretation (CPI). (Figure 15) display the log curves quality at Ka2, namely P-log, S-log, Density, and transformed Poisson overlaid by a synthetic trace to Quality Control (Qc) the regional trends.

(Figure 16) shows a significant separation at P-log against Jeribe, whereby the charge simulated as 20% brine and 80% gas, which indicates that we should expect the same response at a high frequency seismic.

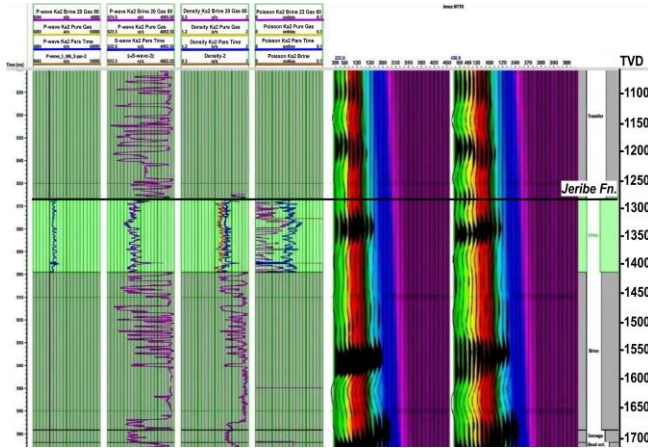


Fig. 16 ka2 well correlation, Acoustic Impedance (AI) One Dimension (1D) modeling for Gas and Brine charges, significant separation at Jeribe Formation

Zoeppritz ray tracing is used to calculate the multi-offsets synthetics. Offsets have been set to be consistent with the real Common Depth Point (CDP) gathered at around 2800 m, which displays the seismic synthetic with charge cases at Jeribe as 60% gas saturation, 20% brine, 20% oil. Class-III AVO is obvious against the Jeribe interval (Figure 17).

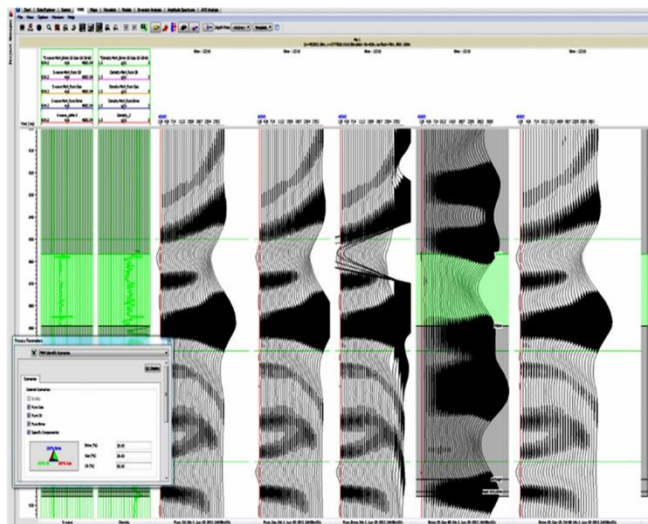


Fig. 17 AVO synthetic modeling over several charge scenarios, class-III AVO strongly presented at 60% gas charge at Jeribe (grey highlighted); Ka2

AVO Gradient Analysis

A large part of current industry practice in (AVO) analysis involves intercept/gradient analysis. This analysis is used in the gradient analysis function. These concepts are also used in the (AVO) attributes and volume functions.

"Intercept" is the result of comparing the signal's amplitude for a reflector (such as a horizon) with the trace's offset, or the computed angle at which the corresponding sound wave would hit the reflector. At this precise instant, the zero-offset line and the amplitude data meet.

In other words, it is the same as having a geophone positioned just close to the source and at a 90° angle to the reflector. Additionally, it produces the "Gradient," which represents the slope of the curve formed by the plotted points.

The Sum of three terms or differences of these gradients and intercept values can then be used for mapping AVO anomalies. Conventionally, the offset is represented by the square of the sine of the incident angle.

The crucial aspect is that the majority of occurrences exhibiting abnormal amplitude behavior may be easily identified for further, more meticulous examination. AVO qualities of a traditional nature are computed based on the Common Midpoint (CMP) gathers.

The preserved data includes a comprehensive set of statistical calculations, such as standard errors, for interpolated normal incidence amplitude and (AVO) gradient.

The utilization of quality control statistics, such as standard deviations for both intercept and gradient, has proven to be quite beneficial in the validation of identified (AVO) abnormalities. The flow chart in Figure 14 summarizes the overall workflow for (AVO) attributes production.

The usable incident angle for Khashim Al-Ahmer CDP conditioned gathers around the zones of interest (Jeribe & Transition beds) is hovering around 33 degrees, hence Aki-Richard two terms equation would be sufficient for extracting Intercept (I) and Gradient (G) attributes. (Figures 18 and 19) investigated the AVO responses at the top Jeribe to indicate class-III AVO.

Additionally, we found that the AVO curves suited us really well. (Figure 20) shows the completed gradient-versus-intercept cross plots; the small green and red squares represent the computed intercept/gradient for Jeribe, which agrees with the class-III (AVO) anomaly interpretation. Wet trends were associated with the other colored squares.

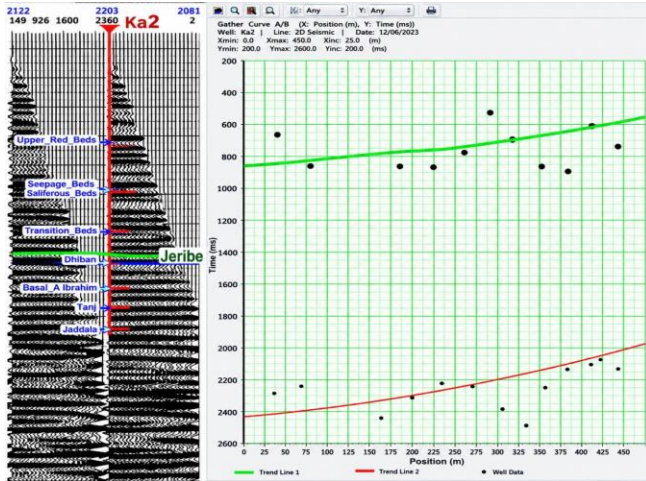


Fig. 18 CDP Intercept-Gradient analysis near Ka2, the green line follows the amplitude at the top of the Jeribe Formation

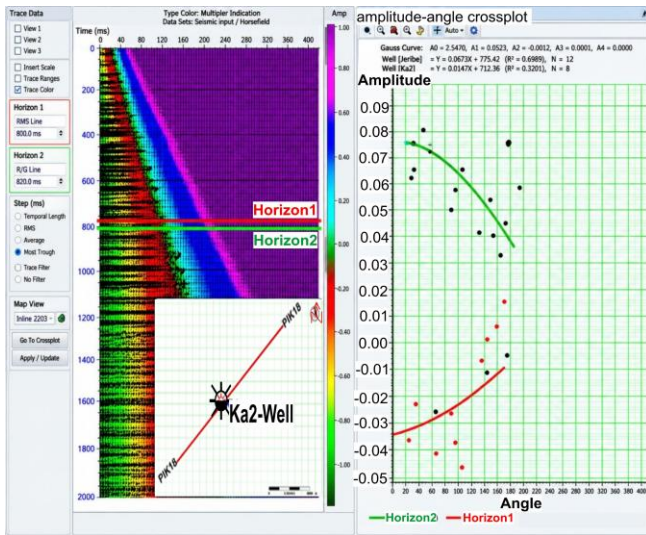


Fig. 19 CDP Intercept-Gradient cross plot around Ka2 well at top-based of the Jeribe indicated a wet trend

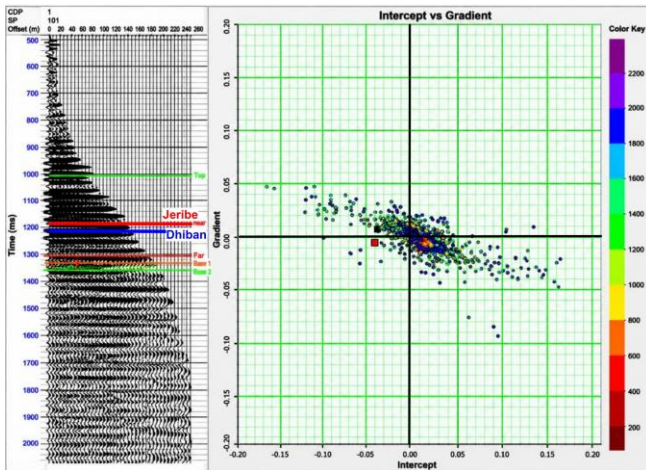


Fig. 20 CDP Intercept-Gradient cross plot around Ka2, red and green squares correspond to I/G, proving class-III (AVO) anomaly; the other colors dots are related to the wet trend

Angle Gather

Most (AVO) products would be performed at angle gathers; hence, we shall transform the offset gather to an angle gather by applying Root Mean Square (RMS) calibrated velocity last reliable incident angle at Jeribe is 33 degrees (Figure 21).

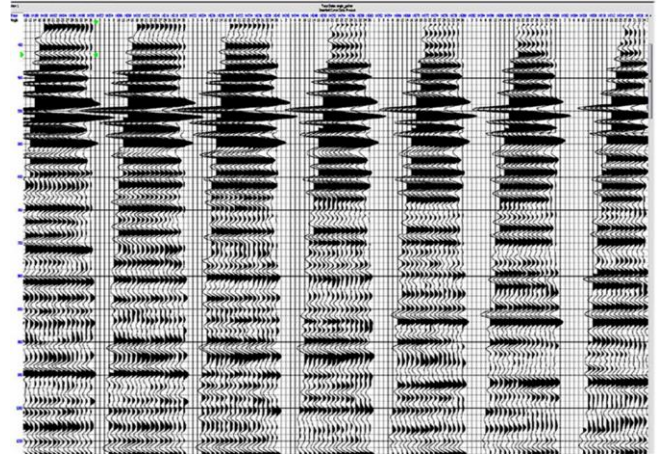


Fig. 21 shows the angle gather converted from the offset by using the RMS velocity

Partial Offset and Angle Stacks

Two offset stacks have been produced as near-offset sets from 200 to 1000m and a far-offset stack set from (1300 m.) to (2000 m.) (Figure 22). Bright spot anomalies are presented around (850 ms.) coincident with the top Jeribe. After concerting the CDP offset gather into incident angle gather, two angle stacks complied at ranges from 0 to 13 degrees and from 18 to 30 degrees to have corresponded to the near and far offset stacks respectively, (Figure 23) shows inline display crossing Ka2, cautions must be taken as we interpret the angle stacks as velocity pitfalls might mislead the interpretation as well as the sever deeping interfaces nearby the structure edges, optimum incident angle to hunt AVO anomaly is around 25 degree, (Figure 24).

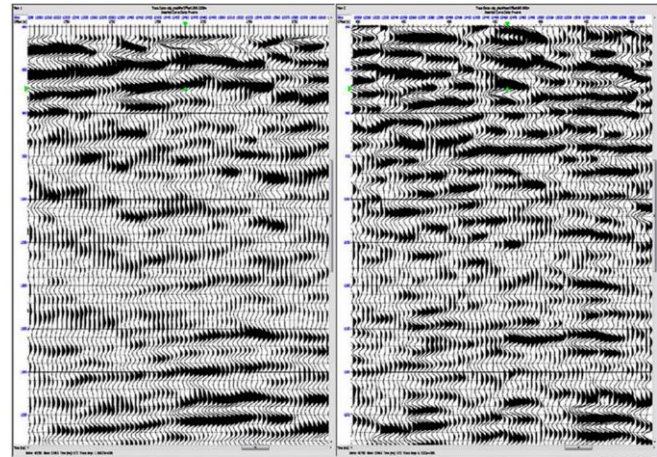


Fig. 22 Partial offset stack comparison, near 200-1000m (Right), Far 1300-2000m, shows an AVO anomaly around the top Jeribe

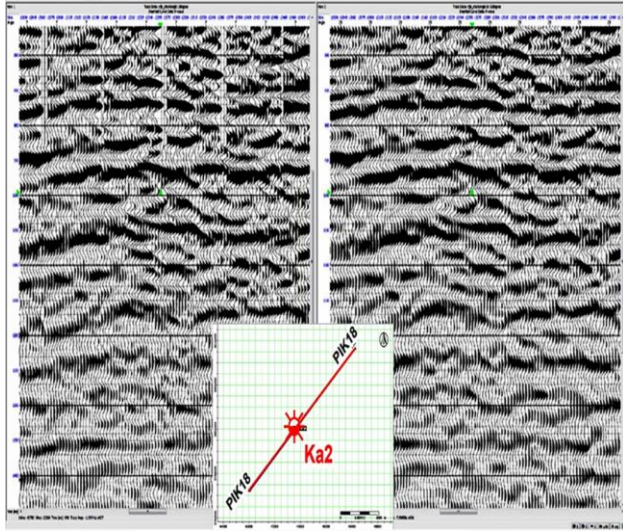


Fig. 23 Partial Angle stack comparison, 0-13 degrees (Left), 18-32 degrees (Right), shows the optimum angle to hunt AVO anomaly at 25 degrees

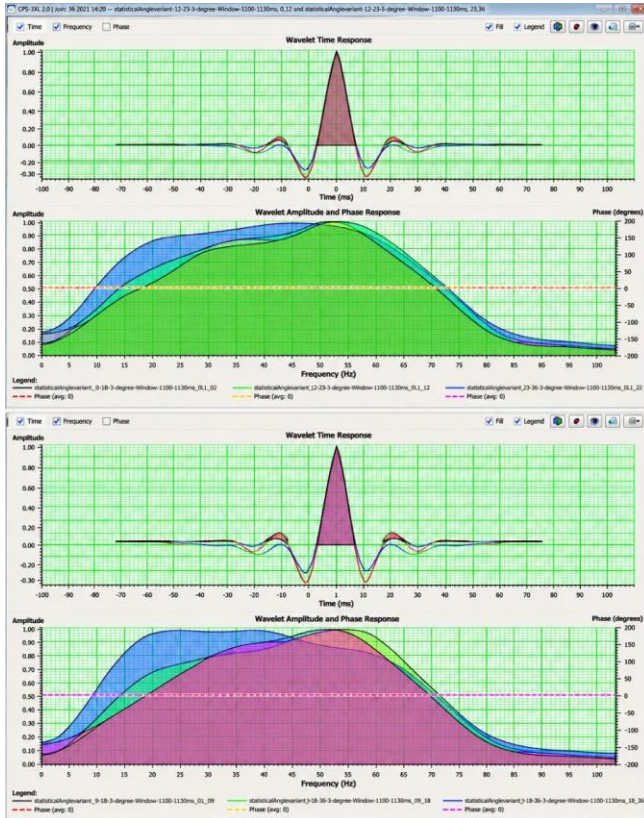


Fig. 24 150 ms.) (upper), 130 ms. angle variants statistical wavelets win 600 ms-1100 ms

6. Discuss the Results

By applying the AVO technology to the Khashm Al Ahmar field, the following facts became clear to us:

"Bright spots" can arise from lithological differences and the presence of gas sands. In response to this, geophysicists in the 1980s initiated the examination of pre-stack seismic

data. The amplitude exhibits an increase in response to the offset demonstrated in this study.

The so-called "bright spot" method was effective in the early 1970s in parts of the Gulf of Mexico (GOM) where gas-filled sands would correlate with light amplitudes.

However, as time went on, it became clear that this strategy was not foolproof. Drilling into what appeared to be gas sands revealed that several of the bright areas were really volcanic intrusions or other lithologies with far higher impedance contrast than the embedded shales.

Structure does not indicate the presence of gas sand on its own; this would have been a fortunate assumption. A geophysicist working in the 1970s would have used the presence of a "bright spot" on the seismic section as the foundation for the well.

Equations for elastic waves, two-term Aki Richards, and Zeoppritz have been added to these programs. We are able to select the optimal equation from the generated synthetic model. Compared to the elastic wave model, the real data model is better compatible with Zeoppritz, two-term Aki Richards's model.

7. Conclusion

The nature of the carbonate rock matrix in Khashim Al-Ahmer as a vuggy porous and random fractured media for which the AVO response is similar to the clastic AVO response strongly supports our justification to conduct the AVO studies by implementing the same algorithm, assumptions, and empirical relationships that are utilized with clastic media. Conventional AVO diagnostics on pre-stack data and look for anomalies—offset and fluid replacement modeling on the expected play types. Determination of the signal-to-noise ratios is required on the pre-stack data to see the AVO response modeled after 2D CDP gather data conditions. AVO responses around well locations proved Class-III existence, which gives high credibility for AVO's products. A Class-III anomaly occurs when there is a contrast between high-impedance shales and low-impedance uncompacted and unconsolidated gas sands. This contrast leads to significant negative amplitudes, which become larger as the angle of incidence increases.

Conflicts of Interest

There are no conflicts of interest regarding this manuscript, nor is there any financial funding; it is part of my master's thesis.

Funding Statement

There is no external financial funding; the cost of publication is covered by the author.

References

- [1] Rzger Abdula, "Petroleum Source Rock Analysis of the Jurassic Sargelu Formation," Northern Iraq: Master's thesis, Colorado School of Mines, 2010. [[Google Scholar](#)]
- [2] A.Z.H. Al-Kharsan, "Lower Oligocene and Lower Miocene Stratigraphy of the Eastern Area of Khanaqin Qadhafi," *Journal of the Geological Society of Iraq*, vol. 3, no. 1, pp. 97-98, 1970. [[Google Scholar](#)] [[Publisher Link](#)]
- [3] Adnan A.M. Aqrabi et al., *The Petroleum Geology of Iraq*, Beaconsfield, UK: Scientific Press, vol. 424, 2010. [[Google Scholar](#)]
- [4] R.C. van Bellen et al., *Lexique Stratigraphic International*, Paris: Asia, Fascicule 10a Iraq, vol. 3, 1959. [[Publisher Link](#)]
- [5] Roo Bortfeld, "Approximations to the Reflection and Transmission Coefficients of Plane Longitudinal and Transverse Waves," *Geophysical Prospecting*, vol. 9, no. 4, pp. 485-502, 1961. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [6] Cargill Gilston Knott, *Reflexion and Refraction of Elastic Waves, with Seismological Applications*, Classics of Elastic Wave Theory, 2007. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [7] John P. Castagna, and Herbert W. Swan, "Principles of AVO Crossplotting," *The Leading Edge*, vol. 16, no. 4, pp. 337-344, 1997. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [8] Christopher Juhlin, and Roger Young, "Implications of Thin Layers for Amplitude Variation with Offset (AVO) Studies," *Geophysics*, vol. 58, no. 8, pp. 1200-1204, 1993. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [9] Hong Feng, and John C. Bancroft, "AVO Principles Processing and Inversion," *CREWES Research Report*, pp. 1-19, 2006. [[Google Scholar](#)] [[Publisher Link](#)]
- [10] M.L. Greenberg, and J.P. Castagna, "Shear-Wave Velocity Estimation in Porous Rocks: Theoretical Formulation, Preliminary Verification and Applications," *Geophysical Prospecting*, vol. 40, no. 2, pp. 195-209, 1992. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [11] Hamzah A. Almoghrabi, and James Lange, "Layers and Bright Spots," *Geophysics*, vol. 51, no. 3, pp. 699-709, 1986. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [12] Ligia Elena Jaimes-Osorio, Alison Malcolm, and Ali Gholami. "Amplitude Variation with Offset Inversion using Acoustic-Elastic Local Solver," *Geophysics*, vol. 85, no. 3, pp. R251-R262, 2020. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [13] Soran O. Kharajany, "The Occurrence of Early and Middle Miocene Rocks (Euphrates, Dhiban and Jeribe Formations) in Ashdagh Mountain, Sangaw Area, Sulaimaniyah Vicinity, NE Iraq," *Iraqi Bulletin of Geology and Mining*, vol. 10, no. 1, pp. 21-39, 2014. [[Google Scholar](#)] [[Publisher Link](#)]
- [14] O. Koefoed, "On the Effect of Poisson's Ratios of Rock Strata on the Reflection Coefficients of Plane Waves," *Geophysical Prospecting*, vol. 3, no. 4, pp. 381-387, 1955. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [15] Alfredo Mazzotti, and S. Mirri, "An Experience in Seismic Amplitude Processing," *European Association of Geoscientists and Engineers*, vol. 9, no. 2, 1991. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [16] J. Mitchell, and A.B. Mitchell, "Seismic AVO Analysis of a Permian Gas Sand at Kerna Field, Cooper Basin, SA," *Exploration Geophysics*, vol. 22, no. 2, pp. 305-308, 1991. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [17] Steven R. Rutherford, and Robert H. Williams, "Amplitude-Versus-Offset Variations in Gas Sands," *Geophysics*, vol. 54, no. 6, pp. 680-688, 1989. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [18] Yasir F. Shyaa, and Ali M. Al-Rahim, "Updating Subsurface Image of Khashim Al-Ahmer Gas Field using the Interpretation for Anisotropic Velocity Model North-Eastern Iraq," *Iraqi Geological Journal*, vol. 54, no. 2F, pp. 110-119, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]