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Processing and interpretation of 3D seismic data of an oil field in central of Iraq using AVO techniques

Khalid S. Al Mukhtar , Anwar A. A. Alsayadi *
Department of Geology, College of science, Baghdad University, Baghdad, Iraq.

Abstract

In this research, a qualitative seismic processing and interpretation is made up through using 3D-seismic reflection data of East-Baghdad oil field in the central part of Iraq. We used the new technique, this technique is used for the direct hydrocarbons indicators (DHI) called Amplitude Versus Offset or Angle (AVO or AVA) technique. For this purposes a cube of 3D seismic data (Pre-stack) was chosen in addition to the available data of wells Z-2 and Z-24. These data were processed and interpreted by utilizing the programs of the HRS-9* software where we have studied and analyzed the AVO within Zubair Formation. Many AVO processing operations were carried out which include AVO processing (Pre-conditioning for gathers), AVO modeling and AVO analysis. Analyzing these variations in amplitude within offset or with angle (AVA), reveals the identification of one type of reservoir which is related to the fluid contents and lithology.

Keywords: Direct Hydrocarbons Indicators, Amplitude Versus Offset (AVO), AVO analysis, Rock physics.

معالجة وتفسير البيانات الزلزالية ثلاثية الابعاد لاحد الحقول النفطية في وسط العراق باستخدام تقنيات تغير السعة مع الازاحة

خالد شهاب المختار ، *انوار عبداللطيف آل قمر الصيادي
قسم علم الارض، كلية العلوم، جامعة بغداد ، بغداد، العراق.

الخلاصة

في هذا البحث ، تم اجراء دراسة نوعية في معالجة وتفاسير المعلومات الزلزالية وذلك من خلال استخدام بيانات الانعكاس الزلزالي الثلاثية الأبعاد لجزء من حقل شرقي بغداد النفطي والواقع في وسط العراق وضمن الحدود الإدارية لمدينة بغداد . من التقنيات الحديثة المستخدمة لاستكشاف الهيدروكربونات المباشر هي تقنية تغير السعة مع الازاحة (AVO) او مع زاوية السقوط للاشعة الانعكاسية (AVA). لهذا الغرض تم اختيار مكعب من البيانات الزلزالية الثلاثية الابعاد لمرحلة ماقبل النضد بالإضافة إلى بيانات لبئرين وهما (Z−2 و Z-24). وقد أجري هذا البحث باستخدام منظومة برامجيات HRS −9. ومن خلال الاستفادة من هذه البرامجيات قمنا بدراسة وتحليل تغير السعة مع الازاحة ضمن تكوين الزبير . في عملنا الحالي نفذنا العديد من عمليات AVO والتي تتضمن(معالجة البيانات ، عمل موديلات زلزالية وتحليل بيانات تغير السعة مع الازاحة او الزاوية. استنادا الى تغير السعة مع تغير الازاحة أو الزاوية وعلاقتها بمحتويات السوائل و الخصائص الصخرية اعتمادا على ذلك تم تحديد نوع الصنف للخزان النفطي.

Introduction

In classical interpretation, seismic interpreter prior to 1970 would have looked only at structure**,** since structure alone does not tell us that a gas sand is present. A geophysicist in the 1970's would have based

*Email: Anwarlateef828@yahoo.com

the well on the fact that there is a “bright spot” visible on the stacked seismic section, while the geophysicist in 1980′s look at pre-stack seismic data. Historically, attempts at practical application of amplitude versus offset (AVO) began in the end of seventies in last century. In 1984, 12 years after the bright-spot technology became a commercial tool for hydrocarbon prediction, Ostrander, 1984 published a break- through paper in geophysics [1]. He showed that the presence of gas in a sand capped by a shale would cause an amplitude variation with offset in pre-stack seismic data. He also found that this change was related to the reduced Poisson's ratio caused by the presence of gas. Consequently, Seismic interpretation has evolved over the years, from strictly structure interpretation, through "bright spot" identification, to direct hydrocarbon detection using AVO.

In reflection seismology the amplitude variation with offset (AVO) is the general term for referring to the dependency of the seismic attribute, amplitude change with distance between source and receiver. Amplitude variation with incidence angle is termed (AVA). As the angle of incidence is increased, the amplitude of the reflected wave changes.

The amplitude of a reflected seismic signal normally decreases with the increase of the distance between source and receiver. This decrease is related to the dependence of reflectivity on the angle at which the seismic wave strikes the interface, spreading, absorption, near surface effects, multiples, geophone planting, geophone arrays and instrumentation [2].

Variation in seismic amplitude with the increase in distance (AVO) between source and receiver is typically associated with changes in lithology facies and fluid content in rocks above and below the reflector, this is a good indicator for hydrocarbon accumulation especially gas spreading.

Amplitude changes as a function of those angles can indicate a change in P and S wave velocities at a geological boundary, hence providing information about the fluid content of reservoir rocks, and that the variation of P-wave reflected amplitude with angle of incidence or offset depends on Poisson's ratio and density contrast between layers. Consequently, the AVO response is dependent on the properties of P-wave velocity (V_P), S-wave velocity (V_S), and density (ρ) in a porous reservoir rock, and this involves the matrix material, the porosity, and the fluids filling the pores [3]. In other words, AVO response is closely linked to the rock physics of the reservoir.

Theoretical background

Many equations were used in the modeling of the amplitude changes as a function of angle for single layer. First of all, we should know some equations related to AVO technique where these equations used to model the amplitude changes and their usage is as following:

1. Zeoppritz's equations

It's one of the most famous equations which express the partition of the energy when a plane wave impinges on an acoustic impedance contrast are Zeoppritz equation. Reflection amplitude variations with angle of incidence (AVA) can be modeled using the Zoeppritz equations that describe the amplitudes of reflected and transmitted P and S waves. [4], the equations describing how the amplitudes of the reflected and transmitted P- and S-waves depend on the angle of incidence and the properties of the media above and below the interface were published by Zoeppritz, 1919; the amplitudes depend on the contrast in Poisson's ratio across the interface, as well as the acoustic impedance change.

The Zoeppritz equations explain a reflection from an interface that separates two isotropic elastic media with different values for V_P, V_S and density (ρ) for an incident plane wave on the interface, the equations explain the reflected and transmitted P-waves and S-waves, Figure-1.

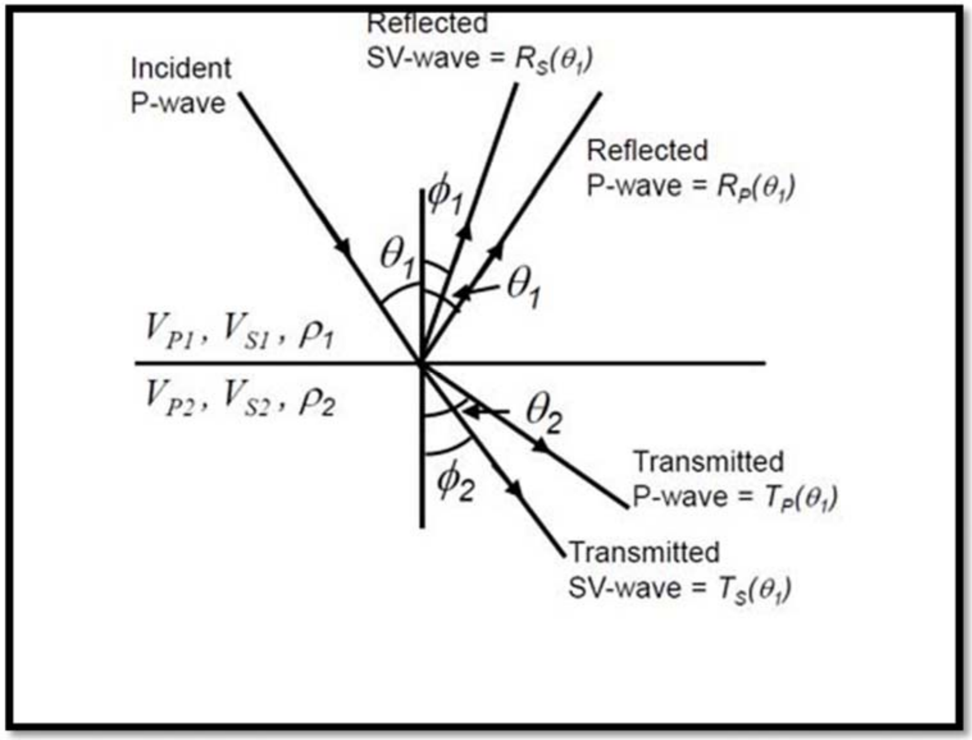

Figure 1-A diagram shows the partition of the incident P-wave.

$$\begin{bmatrix} R_P(\theta_1) \\ R_S(\theta_1) \\ T_P(\theta_1) \\ T_S(\theta_1) \end{bmatrix} = \begin{bmatrix} -\sin\theta_1 & -\cos\emptyset_1 & \sin\theta_2 & \cos\emptyset_2 \\ \cos\theta_1 & -\sin\emptyset_1 & \cos\quad\theta_2 & -sin\emptyset_2 \\ sin2\theta_1 & \frac{V_{P1}}{V_{S1}}\cos 2\emptyset_1 & \frac{\rho_2 {V_{S2}}^2 V_{P1}}{\rho_1 {V_{S1}}^2 V_{P1}}\sin 2\theta_2 & \frac{\rho_2 V_{S2} V_{P1}}{\rho_1 {V_{S1}}^2}\cos 2\emptyset_2 \\ -\cos 2\emptyset_1 & \frac{V_{S1}}{V_{P1}}\sin 2\emptyset_1 & \frac{\rho_2 V_{P2}}{\rho_1 V_{P1}} cos2\emptyset_2 & -\frac{\rho_2 V_{S2}}{\rho_1 V_{P1}}\sin 2\emptyset_2 \end{bmatrix}^{-1} = \begin{bmatrix} \sin\theta_1 \\ \cos\theta_1 \\ sin2\theta_1 \\ \cos 2\emptyset_1 \end{bmatrix} \ldots\ldots(1)$$

Although the Zoeppritz equations look intimidating, in the case of normal incidence (0 degrees) the equations give us the following simple values for the reflection and transmission coefficients.

$$T_P(\theta) = T_{P0} = \frac{2\rho_1 V_{P1}}{\rho_2 V_{P2} + \rho_1 V_{P1}} = 1 - R_{P0} \ldots\ldots \quad (2)$$

These equations tell us that there is no S-wave component at zero angle, and the reflection and transmission coefficients are related to changes in the acoustic impedance (P-velocity x density).

2- Aki-Richards

One approximation to the Zoeppritz equations was derived by Aki and Richards (1980) [5]. The Zoeppritz equations give us the exact amplitudes as a function of angle, the equations themselves do not lend themselves to an intuitive understanding of the AVO process for angles greater than zero degrees. For that reason, most AVO theory for analyzing real data is based on a linearized approximation to the Zoeppritz equations initially derived by Bortfeld (1961) [6] and then refined by Richards and Frasier (1976) [7] and Aki and Richards (1980) [5].

The following equation is a form of the Aki-Richards equation that was derived by Wiggins et al., 1983 [8]:

$$R_P(\theta) = A + Bsin^2\theta + Ctan^2\theta\, sin^2\theta \ldots\ldots(3)$$

A is the linearized zero-offset reflection coefficient and is called the intercept, B is the gradient, and C the curvature. This equation tells us that as the angle increases, so does the effect of S-wave velocity. Also A is identical to the linearized zero-angle reflection coefficient.

The Two-Term Aki-Richards Equation is below. It is common practice to use only 2 terms because: (1) It simplifies the analysis considerably (2) For angles less than about 45 degrees, the third term is not significant.

$$R(\theta) = A + Bsin^2\theta \ldots\ldots\ldots(4)$$

Where we have dropped the ***C*** term and define A and B as in equation (3).

3- Elastic Wave equation

The generated model include the computation of the full elastic wave solution (with optional an elastic effects), which includes primaries, converted waves, and multiples. Elastic Wave Modeling is the exact solution for a plane wave propagating through a series of layers. The theory has been available for a number of years and is described in [9].

AVO classification

The AVO or AVA responses are mondially classified into four main reservoir classes. The identification of the type of the classes is performed through analyzing of nature the amplitude variation and its relation to the fluid contents and lithology. The AVO effect depends on the combination of the petrophysical properties of overlying lithology and the reservoir rock (V_P, V_S and ρ). This is translated in terms of the impedance contrast over the top of reservoir interface which is considered the critical factor. The increases in acoustic impedance (or a hard kick) is represented by a positive peak on the seismic data.

Based on their amplitude behavior as a function of offset on a Common Depth Point (CDP) gather when filled with hydrocarbons, the top of reservoirs are categorized, as shown in Figure-2.

- Class 1 has a large positive R_0 amplitude that stays positive with offset (dimming of reflection on stack).
- Class 2 has small positive R_0 that is transitioned into negative amplitudes with offset (dimming/ brightening of reflection and polarity flip).
- Class 3 has Negative R_0 amplitude that becomes more negative with further offset (brightening of reflection).
- Class 4 have negative amplitude becomes less negative with offset (dimming of reflection on stack).

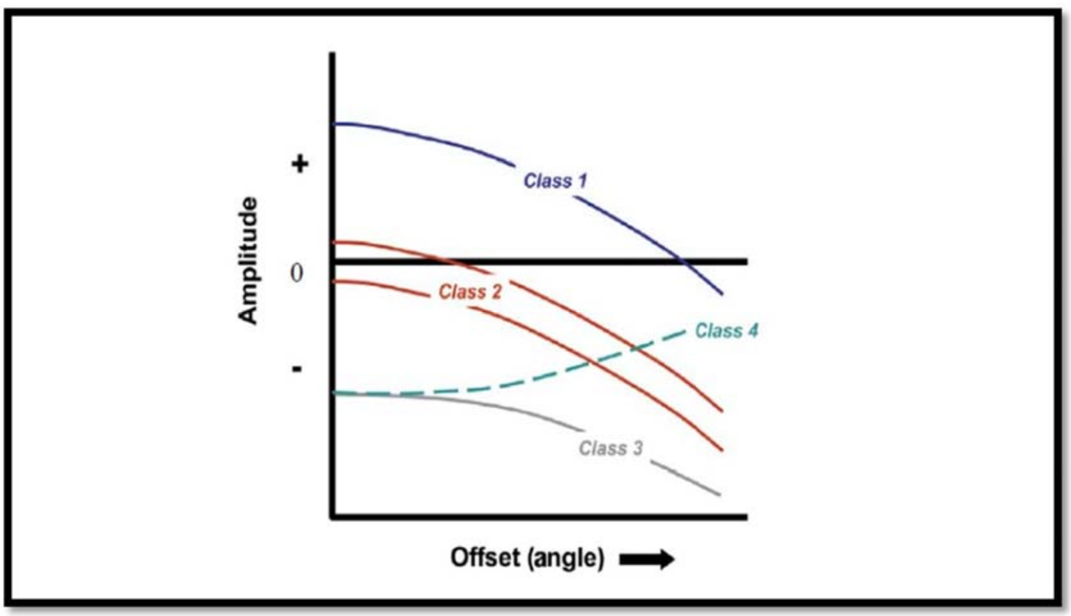

Figure 2- A plot of amplitude versus offset (angle), it shows the classification of AVO responses, (plot modified by [10]).

Materials and work

In the beginning, the data have been loaded as CDP gathers volume which will be used for AVO analysis. This data represents a part of south area (S1) of the studied field (Figure-3).

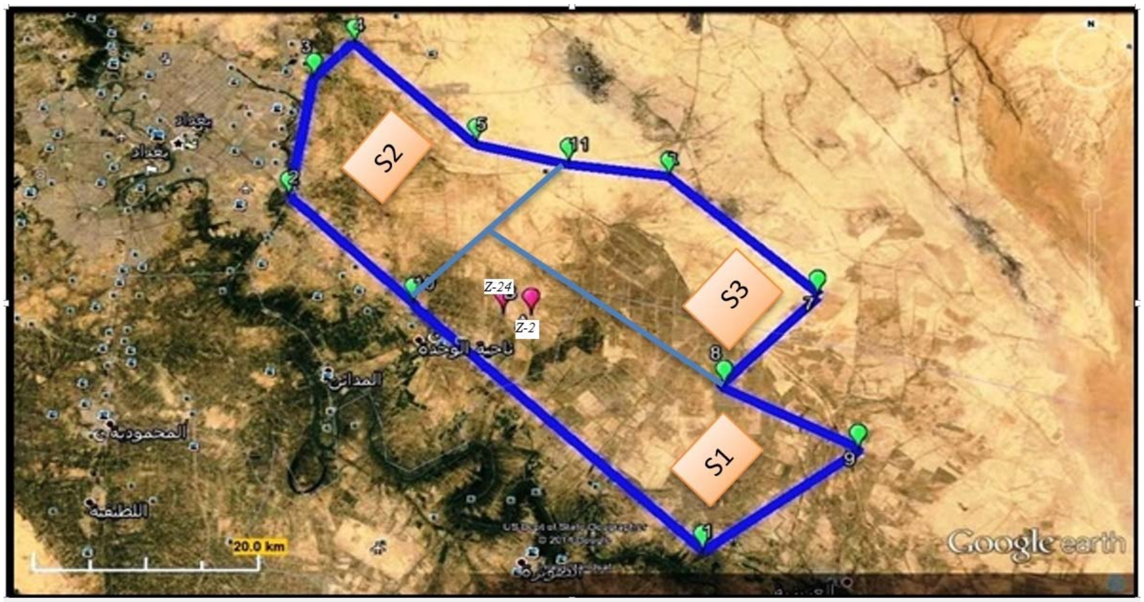

Figure 3- A map shows the partition of study area and the locations of wells marked as Z-2 and Z-24 on the study area.

AVO processes involve many aspects which are summarized in Table-1. These are:

1. AVO processing: It should preserve or restore relative trace amplitude within CDP gathers.
2. AVO modeling: One of the main tasks with the use of AVO is to generate a synthetic seismogram from a given earth model.
3. AVO analysis: The AVO analysis means bringing the data from the offset domain into the 'Amplitude versus Angle-of-incidence' domain (AVA), [11].

Table 1-The main aspects of AVO process.

AVO processing	**AVO modeling**	**AVO analysis**
Mute Super-gather process Time-variant trim statics Parabolic radon transform CDP stack	Using of algorthims of Zeoppritz, Aki and Richards equations and elastic wave equations to generate synthetic seismogram models.	Picking the horizons Super gather process Angale gather AVO gradient analysis. Partial stack

1- AVO processing (pre-conditioning CDP gathers)

Before doing any AVO processing operations, one must bear in mind the following points:

a. There are many factors cause changes in the amplitudes of seismic traces. Where the processing attempts are to compensate for or remove these effects.
b. The recuperation of true amplitude without Automatic Gain Control (AGC) is essential.
c. Processing must be applied to retain the broadest signal bandwidth.
d. Pre-stack amplitude must be applied to common reflection point gathers where the reflection point from a migrated section.

For the field seismic raw data, we have applied the following steps of processing:

1- Mute: It is used to exclude a part of the seismic data. Normally, it is applied in the early part of the trace that contains first arrivals and body waves, and also to remove the far offset amplitudes which are noisy.
2- Super Gather process: It is a very robust tool for reducing random noise and it is considered as a good tools for enhancement of signal to noise (S/N) ratio
3- Time-variant Trim Statics: The trim static is the process which attempts to correct for residual move-out errors and align the event on the gathers.
4- Parabolic Radon Transform: It is a process, we have used it for random noise suppression and coherent noise suppression.

5- CDP stack: firstly, common depth point (CDP) is the summation of traces which corresponds to the same subsurface reflection point but have different offset distances. The stacking process includes gathering of these CDP traces & then integrating all of these traces as one trace (Stacking). From all these processes, we have obtained CDP gathers which are suitable for AVO modeling and analyses.

2- AVO modeling

As previously explained, one of the main tasks in the use of AVO is to generate a synthetic seismogram from a given earth model. This seismogram may then be compared with a real data set and conclusions may be drawn from matching between them.

We have used three type of algorithms to generate synthetic seismogram model, and then applying AVO gradient analysis on these models to show which one has a good representation for the real data. These algorithms are The Zoeppritz equations and Aki-Richards equation with ray tracing, and full elastic wave equation. The Zeoppritz and Aki and Richards equations are used for modeled primary reflections, while elastic wave equation is used for primaries, multiples and converted waves. To generate these models, we have used the information of Z-2 and Z-24 well logs (sonic, density and the estimated S-wave log) and seismic, also making cross correlation between the wells and seismic data.

After the generation of synthetic seismogram models, we have made a gradient analysis for these models by taking an event, which is the top of Zubair Formation at TWT=1964 ms.

Figure-4, AVO analysis for the event 1964 ms. , shows that the real data event (marked in orange color line), the Zoeppritz model (in blue color) and Elastic wave in red color.

Examination of the synthetic models of Zeoppritz, real data and Elastic wave representation in Figure-4, indicates the similitude of the behavior of Zoeppritz data with the real data where they are practically lying neighbor to each other. Elastic model curve lies further away from the real data which is attributed to the effect of multiples and noise, whereas in Zoeppritz data the primary effect is only introduced. This confirms that the Zoeppritz model is a very good representation of the real response, and supports the idea which states that modeling can be very sensitive to the types of algorithm used.

The shape of curves indicates that, the AVO anomaly is of class 4 type. As previously explained and more specifically, Figure-2 explains that, class 4 means that the top reservoir classification gives negative values in amplitude and becomes less negative with increasing of offset.

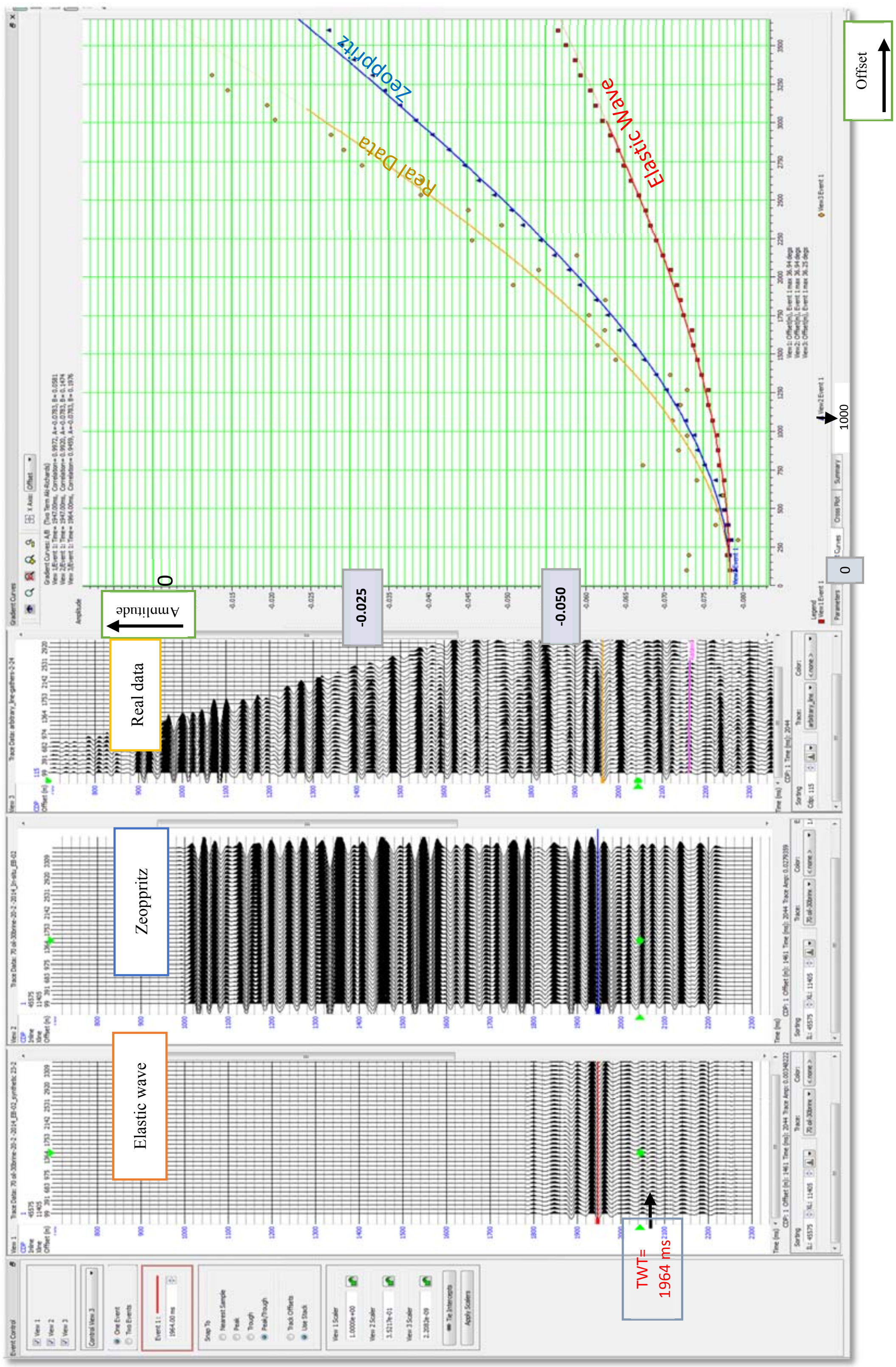

Figure 4-A display shows AVO Gradient Analysis for event TWT=1964 ms, using Zeoppritz, Elastic wave synthetics with real data modeling in the oil field. The first, second and third seismic sections on the left of figure is representing Elastic wave, Zeoppritz synthetic models and real data respectively.

3- AVO analysis

AVO analysis involves the analysis of the real seismic data which are pre-stack gathers to look for AVO anomalies, the analysis includes the following processes:

a. Picking the horizons

Since, the target zone is Zubair Formation, we have picked the top of it on the trough at time 1964 ms, and at the base on peak at time 2166 ms. Zubair Formation is of clastic type rocks, which has a low acoustic impedance (A.I) values overlained by high A.I carbonate rocks of Shuaiba Formation. Meanwhile, Zubair Formation is underlined by Ratawi Formation, which is composed of a high A.I carbonate rocks.

b. Super Gather Process

Super Gather is the process of forming average CDP's to enhance the signal-to-noise ratio. We do the averaging by collecting similar offset traces within adjacent CDPs and adding them together. This process reduces random noise, while maintaining amplitude versus offset relationships. Then we will display the range of incident angles in a color display and from it, we determine the maximum incidence angle at the zone of interest (1964-2166 ms) in Zubair Formation is around 30 degrees. This information is useful in determination of the used equation in AVO analysis, which is two term Aki-Richards equation because this equation used for angle less than 45 degrees.

c. Angle gather

In this step, the data is transformed from the offset to incidence angle domain, using the seismic velocity field. Here, we are transforming the volume super gather into the new volume angle gather.

d. AVO Gradient Analysis

The purpose of this process is to analyze the AVO behavior of one or more events at a particular CDP. This depends on offset and on an angle of incidence. To examine the behavior of amplitude with offset and angle of incidence (AVO and AVA), we can choose events on CDP gather for plotting a graph between offset or angle on x-axis and amplitude on y-axis.

In figures-5 & -6 the graphs of offset and angle gradient analyses are represented respectively. From the examination of these graphs, the event 1 represents top of Zubair at TWT=1964 ms. (in red color), while the green curve represents event 2 on a peak within Zubair Formation at TWT 2096 ms. The AVO response class is classified within class-4 type where AVO anomaly is characterized by decreasing of amplitudes for both the trough at the top of the sand (red) and the peak at the base of the sand (green).

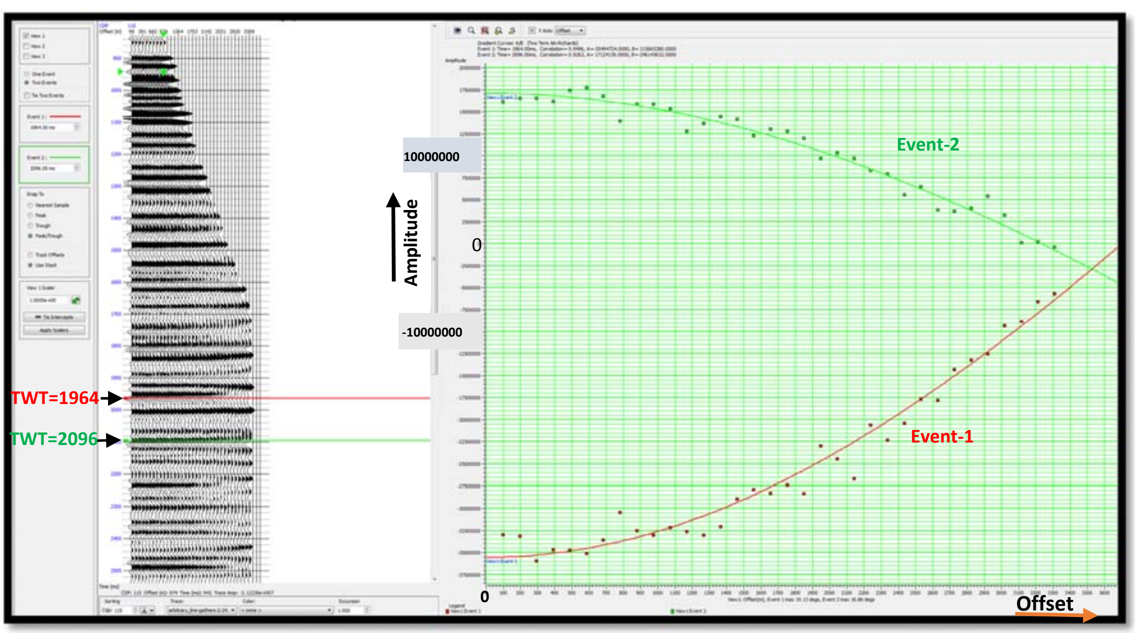

Figure 5-A display shows AVO Gradient analysis depend on offset and the AVO class is class 4.

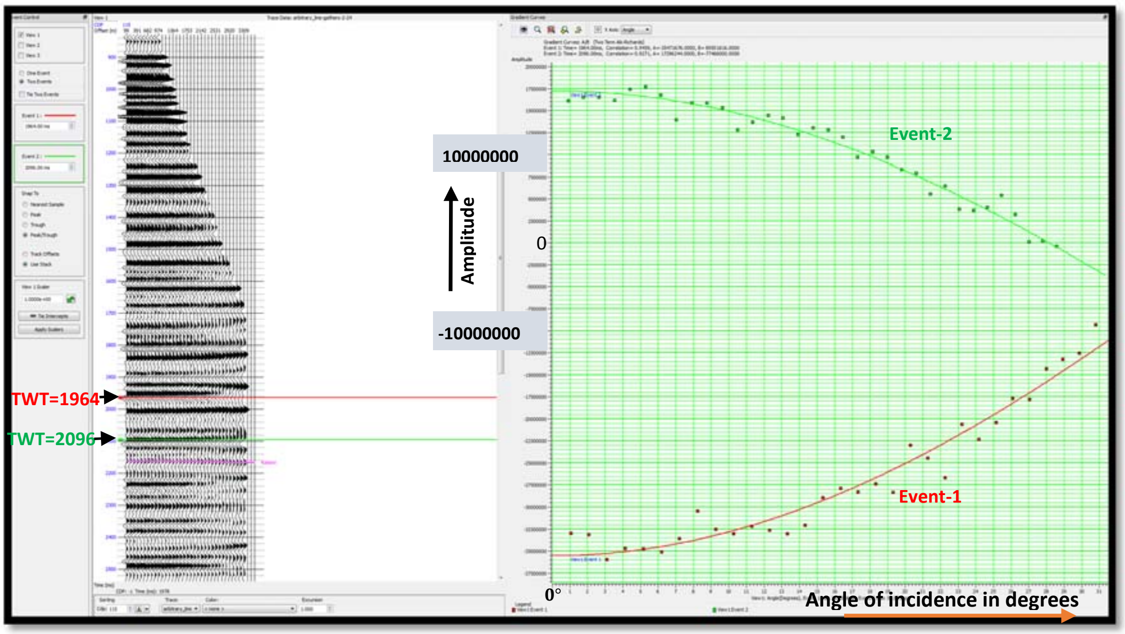

Figure 6- A display shows AVO Gradient analysis depend on angle, red curve represents event1 and green color represents event 2.

e- Partial stack

Partial stack is another method for AVO analysis. In the present work, we make angle stack section for angle gather. This angle stack is made up for three choices, the first for near (0°-8°), the second for intermediate (8°-18°) and the third for far angles (18°-34°).

As shown in Figure-7, the choices are displayed for the near angles, we can see on the top of Zubair reservoir that the amplitude is strong whereas in intermediate angles is stronger but for the far angle the amplitude becomes slightly weaker (dimming).

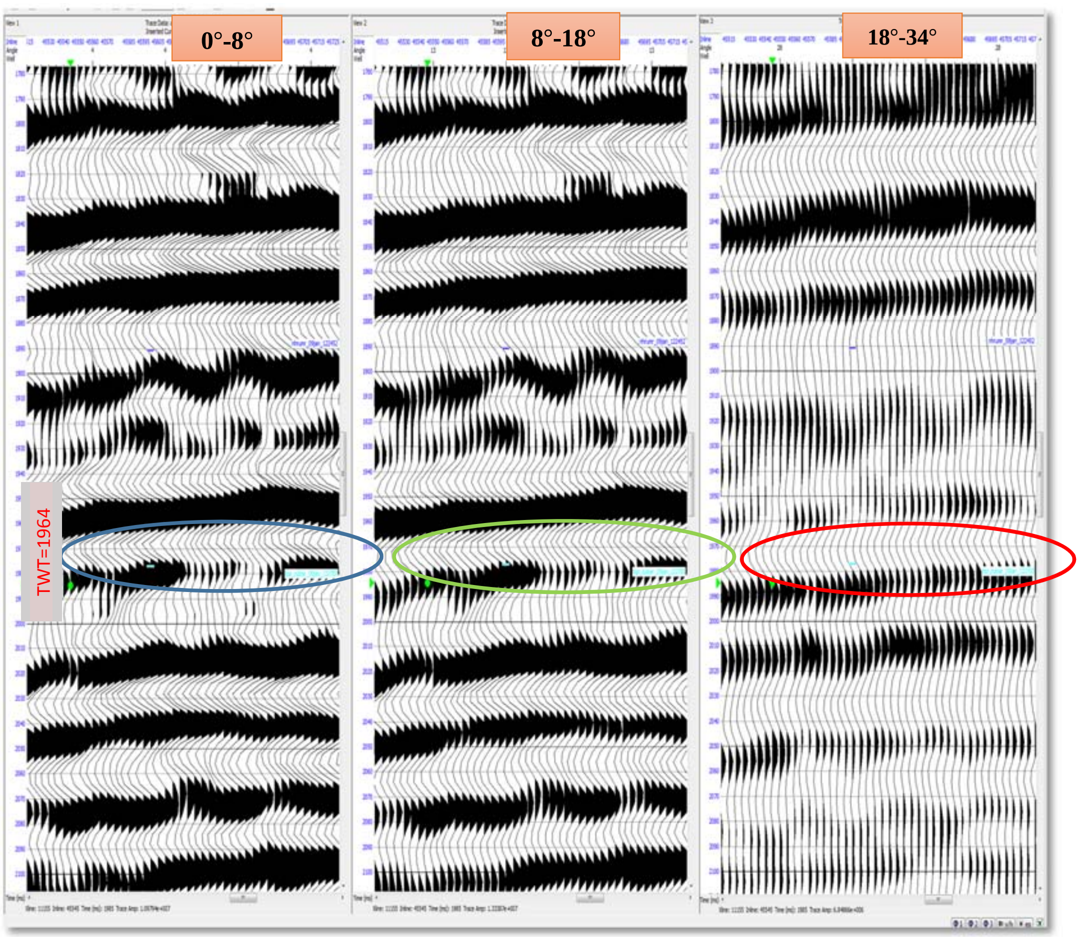

Figure 7-Showing the stack angle in near (0^0-8^0), intermediate (8^0-18^0) and far (18^0-34^0). From this range of angle, we show the AVO anomaly of class 4 in the third stack.

Conclusions

Based on the results and discussions the following conclusions may be drawn:

1- Concerning the AVO modeling, the amplitudes in a two-way time 1964 ms (top of Zubair Formation) has negative behavior and become less negative with offset. This behavior of AVO implies that reservoir classement lie within class-4. In addition, it was shown that Zeoppritz equation is a good representant of the real data response and better than Elastic wave equation.

2- AVO analysis has revealed that, the top of Zubair Formation is a trough, i.e. negative amplitude value. This is due to low acoustic impedance values of Zubair, which is overlained by the high acoustic impedance of Shuaiba Formation.

3- AVO gradient analysis has confirmed the dependence of AVO behavior on offset and the angle of incidence. For the top of Zubair event of TWT=1964 ms., the amplitude is negative and become less negative with increasing of offset and incidence angle. For the event within Zubair Formation of TWT=2096 ms., the amplitude values sign are positive which decrease with increasing of offsets and incidence angle. This behavior indicates a classement within AVO class-4, this classement is due to the position of sand which overlained by a very hard rock of *Shuiaba Fn*. (carbonate rocks).

4- Partial stack section shows slightly decrease in amplitude with far offset and this supports the classement of AVO anomaly within class-4.

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