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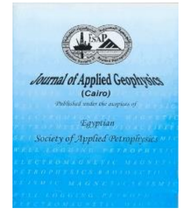

Original Article

Estimation of net-pay thickness, using seismic reflectivity and band-limited impedance approaches, Central Nile Delta, Egypt

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ABSTRACT

It is well-known that, the seismic amplitude scaling techniques are used to remove the tuning effect on seismic amplitude maps. Nonetheless, they are useful to predict the net-pay thickness in low impedance hydrocarbon-bearing sands. The aim of this paper is to address the prediction of the net-pay from seismic reflectivity compared to the band-limited impedance inversion techniques. The first step for the net-pay prediction from reflectivity consists in the plotting the amplitude extracted between top and bottom of the reservoir against the apparent thickness. Another approach to predict net-pay thickness is through colored inversion. Connolly and co-authors utilized the band-limited impedance of the colored inversion data rather than the conventional seismic amplitude. Connolly's method uses the average band-limited impedance and the apparent thickness values extracted between the zero-crossing picks. The results show that the Connolly's band-limited impedance technique shown a significant improvement over Brown's reflectivity-based techniques.

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1. Introduction

Egypt is one of the leading countries around the world for hydrocarbon investment having a long history in hydrocarbon exploration and production for more than a century. Nile delta cone considered one of the main hydrocarbon provinces in Egypt. Around 58 Tcf of gas reserves have been discovered until now in the Nile Delta province (Oil & Gas Journal, January 2008). Recently, the petroleum industry in Egypt has been flourished, and the production rates for hydrocarbons have been increased in an unprecedented way. In 2014, the great Nooros gas field had been discovered which located in Abu Madi West concession in the Nile Delta. Boosting estimated gas in place reserves at Great Nooros area to 4 Tcf. Nooros Field (Figs. 1&2) is an important gas discovery which encountered a thick gas bearing sandstone interval of Messinian age with excellent petrophysical properties. The development of Nooros discovery is challenged, because the locations of the development wells has to be chosen carefully. To locate a successful development well, some petrophysical properties have to be taken in considerations such as the reservoir net-pay thickness, porosity, permeability, and the structural position of the impact point of the new well. One of the most critical reservoir properties is the net-pay thickness, especially in case of fluvial depositional environment – as it is in our discovery – where the net-pay thickness may vary from position to another suddenly. So, our approach is to address the application of predicting the net-pay thickness from seismic reflectivity compared to band-limited impedance inversion techniques.

This case study has demonstrated that for net-pay estimation from seismic, the band-limited impedance technique is a significant improvement with respect to the reflectivity based technique. In fact, the cross plots of amplitude against apparent thickness resulted in estimating 70 meters of gas bearing sand. The result of the band-limited impedance was an estimation of 67 meters of net-pay sands. The actual thickness after drilling well was proved to be 65 meters.

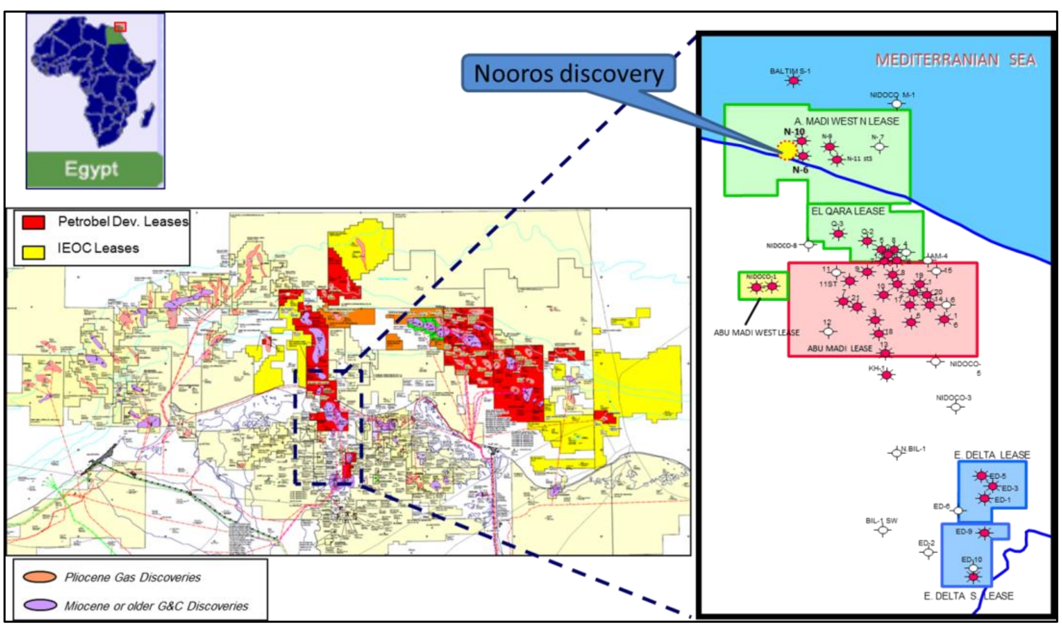

Fig. 1: Nooros Discovery Location Map.

2. Geologic setting

Since the Early Oligocene the Nile River sediments discharge formed a huge fluvio-deltaic to deep-marine wedge, lying on a transform continental margin, related to the oblique separation of the African and Arabian plates and the opening of the Red sea. The Nile Delta established in the Early Pliocene, above a regional transgression surface, on the top of Messinian sequence. The overall sedimentary pattern of the Plio-Pleistocene succession is characterized by a dominant progradation, with large scale clinoforms and an evident of northward migration of the shelf break, nevertheless some backstepping phases occurred.

Four main (Figure 3) depositional units have been traditionally recognized that from older to recent are:

- Abu Madi Formation (Missinian): Fluvial braided channel, mainly sand with shale intercalation.
- Kafr el Shikh Formation (Pliocene): Deep marine continental slope, shales interbeded to sand turbidities.
- El Wastani Formation (Plio-Plistocene): Sand/shale alternates deposited in a delta front/prodelta environment.
- Mit Ghamr Formation (Plistocene): Mainly sands deposited in a delta plain/delta front environment.

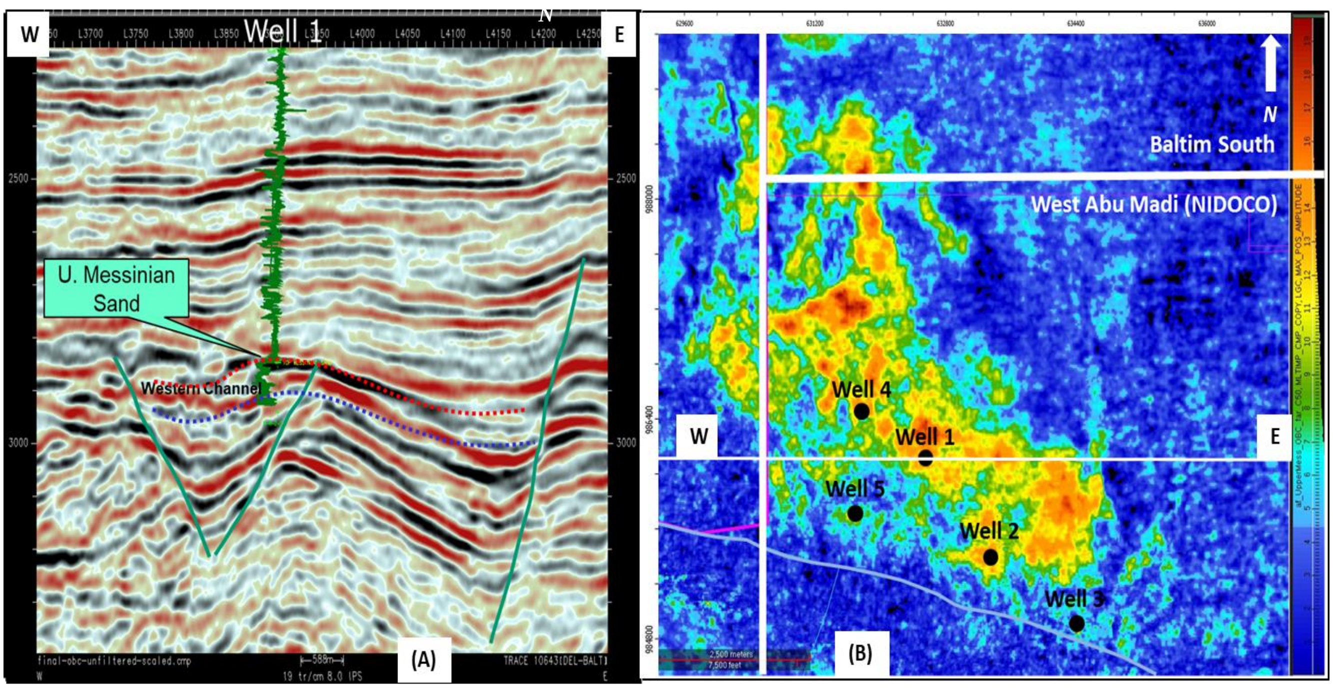

Fig. 1: nooros discovery, (a) e-w full-stacked seismic line passing through the discovery well 1 showing the target reservoir top and bottom, (b) far-stack amplitude map extracted between top and bottom of gas sand.

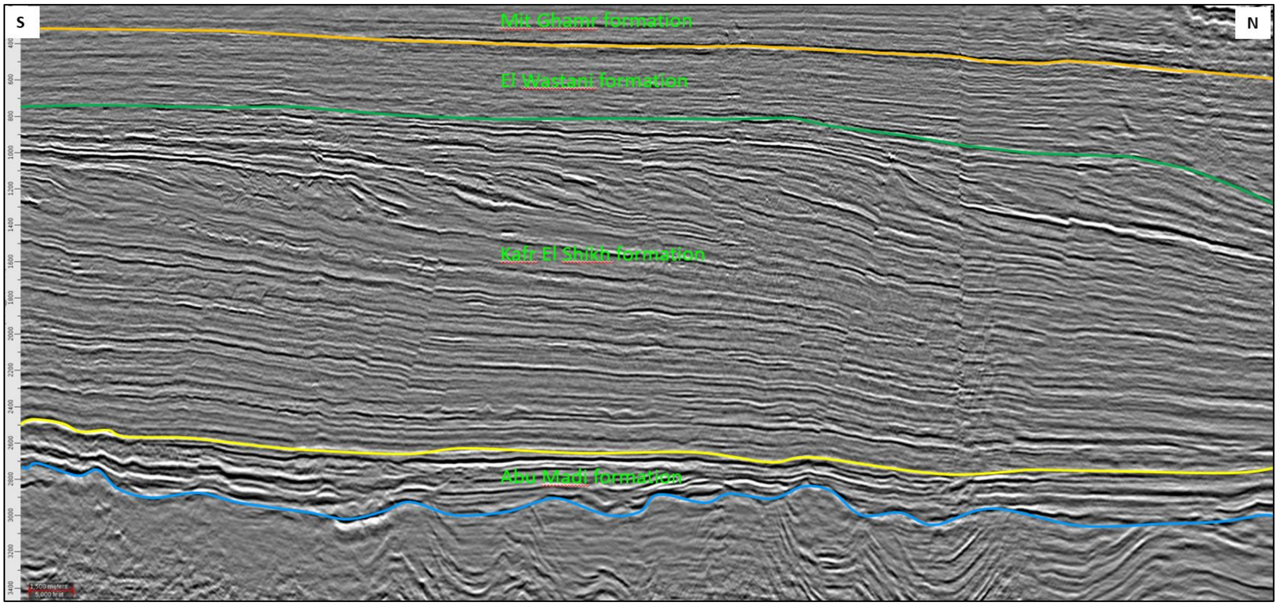

Fig. 2: N-S (2-D) Regional seismic Line across central Nile delta.

2.1. Net-pay estimation approach:

One of the most important parameters in the calculations of the original hydrocarbon in place is the *net-pay* thickness of the hydrocarbon bearing reservoirs. It is limited to calculate the net-pay thickness for the drilling of the wells, and it is critical also. While after the drilling of wells, May the net-pay thickness of the hydrocarbon bearing zone is not sufficient to consider that well as a commercial one. So, the interpreters need to estimate the net-pay thickness from the seismic before the drilling of wells in attempt to locate the best location for the well proposal, and this is what we are going to estimate through our work. The prediction of the net-pay from seismic will be carried out by both seismic reflectivity and band-limited impedance inversion techniques.

In 2009, Rob Simm presented a modelling study to estimate net-pay from seismic records by using reflectivity and band-limited impedance utilizing the basic theories of Brown (1986) and Connelly (2005, 2007). In this paper, the authors have used the algorithm which developed by Rob Simm of this modeling study to address the seismic net-pay for a real data in the study area.

2.1.1. ***Net-pay thickness from seismic reflectivity method***

Brown et al. (1986) proposed a method for estimating the reservoir's thickness from seismic reflectivity. They used the resemblance of the data cloud outline on a crossplot of the seismic amplitude reflectivity against the apparent seismic thickness (Fig. 4).

Figure (4) shows the tuning curve (red line) is placed to cover the bulk of points of the seismic amplitude that plotted against the apparent thickness. Also, a no-tuning baseline (blue line), easy to draw it above the tuning thickness and tends to the zero value below it. The area between the red and blue lines is the tuning values that are not corrected either seismic amplitude of apparent thickness. So, a scalar is applied to remove the effect of tuning values on the amplitude map (corrected amplitude map), and defined by the no-tuning baseline value (blue line) divided by the tuning curve value (red line). By multiplying the corrected amplitude map by the apparent thickness, net sand or net-pay can be computed (Brown A.R., et al. 1986). The most critical point in this method is the positioning of a tuning curve and the base line to represent a reflectivity of the clean sand together with the assumption that the ratio of an amplitude to the tuning curve amplitude is a measure of the N:G for any given apparent thickness (Simm R., 2009).

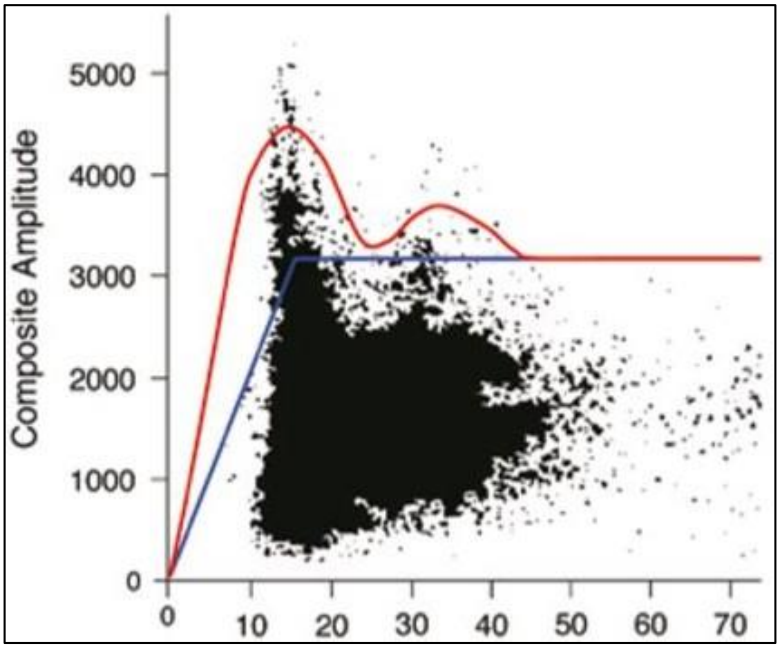

Fig. 3: Seismic crossplot example of thickness versus composite amplitude with simple tuning curve (red) and baseline (blue) (Brown A.R., et al. 1986).

2.1.2. Net-pay thickness from band-limited impedance method

Connolly (2005&2007) demonstrated a map-based amplitude scaling technique based on the band-limited impedance by using colored inversion (Lancaster and Whitcombe, 2000). They utilized the band-limited impedance of the colored inversion data rather than the conventional seismic amplitude. The conventional seismic amplitude reflectivity affected by the wavelet which causes – in some areas – wrong amplitude data. So, the utilizing of the inverted seismic data eliminates this effect of the wavelet on the seismic amplitude. Connolly's method uses the average band-limited impedance and the apparent thickness values extracted between the zero-crossing picks (Connolly, P., 2007).

3. Discussion

As mentioned before, our aim is to address the net-pay from the seismic in attempt to locate the optimum well proposal position. The net-pay estimation will be carried out through the seismic reflectivity method of Brown, and the band-limited impedance method of Connolly. Through Brown method, the amplitude extracted between the top and bottom of the reservoir is shown against the apparent thickness as the first stage in predicting net-pay thickness from reflectivity. Then, a scalar is used to adjust the amplitude map to remove the tuning effect (corrected amplitude map). Finally, the apparent thickness is then used with the corrected amplitude map to forecast the net-pay thickness.

Through Connolly method, extracting the apparent thickness and average band-limited impedance values between zero crossing picks are used in this method. The predicted net-pay thickness matches the net-pay in wells after a scalar function is applied to the average band-limited impedance and calibrated to well data.

The study area is located in Nidoco field, central Nile Delta of Egypt, near the costal line of Mansoura city. The acquired data is a 3-D seismic data, and five gas wells with good petrophysical parameters.

As a first step before estimating the net-pay, we need to know the vertical seismic resolution and tuning thickness of the seismic data. This can be obtained by either the mathematics equations or simple wedge model method.

3.1. Vertical seismic resolution calculation

Seismic resolution is a measure of minimum spatial or temporal separation between two reflection events so they can be distinguished and resolved separately. The acceptable threshold for vertical resolution generally is a quarter of the dominant wavelength ($\lambda/4$).

Seismic tuning thickness and vertical resolution calculations:

$$f = 1/T, (1)$$

$$v = \lambda f, (2)$$

Where: f is the predominant frequency, T is the periodic time (distance between two Consecutive peaks or troughs in milliseconds), v is the interval velocity of the reservoir, and λ is the wavelength. The minimum requirements to estimate the tuning thickness and the seismic vertical resolution are the periodic time and the interval velocity. Given $v = 3387$ (m/s) and $T = 38$ (ms), so $f = 26.31$ (Hz) and $\lambda = 128.71$ (ms).

$$\text{Tuning thickness (m)} = \lambda/4, (3)$$

$$\text{Tuning thickness (ms)} = \left(\frac{\textit{Tuning thickness (m)}}{v}\right) * 2000, (4)$$

$$\text{Seismic vertical resolution (ms)} = \left[\frac{1}{(2.31 * f)}\right] * 1000, (5)$$

$$\text{Seismic vertical resolution (m)} = \left[\left(\frac{\text{Seismic vertical resolution (ms)}}{2000}\right) * v\right], (6)$$

From the previous equations

$$\text{Tuning thickness} = 32.17\ m, = 19\ ms$$

$$\text{Seismic vertical resolution} = 16.45\ \text{ms}, \quad = 27.85\ m$$

Upon the previous calculations, in case of the reservoir thickness is less than 32.17 m, we cannot separate its top and base seismically due to the interference of reflected energy from top and base of theckness.

3.2. Wedge model

The simple wedge model is the interference effects related to the top and base of low-impedance sandstone encased in shale (Simm R., 2009). In other words, when the sand is very thin, estimating its thickness from the separation of trough and peak seismic loops will result in a significant overestimate. However, the thinning of the wedge does affect seismic amplitude (Widess, M.B., 1973). When the energy reflected from top and base of reservoir separated from each other, this is referred to as the 'tuning thickness.'

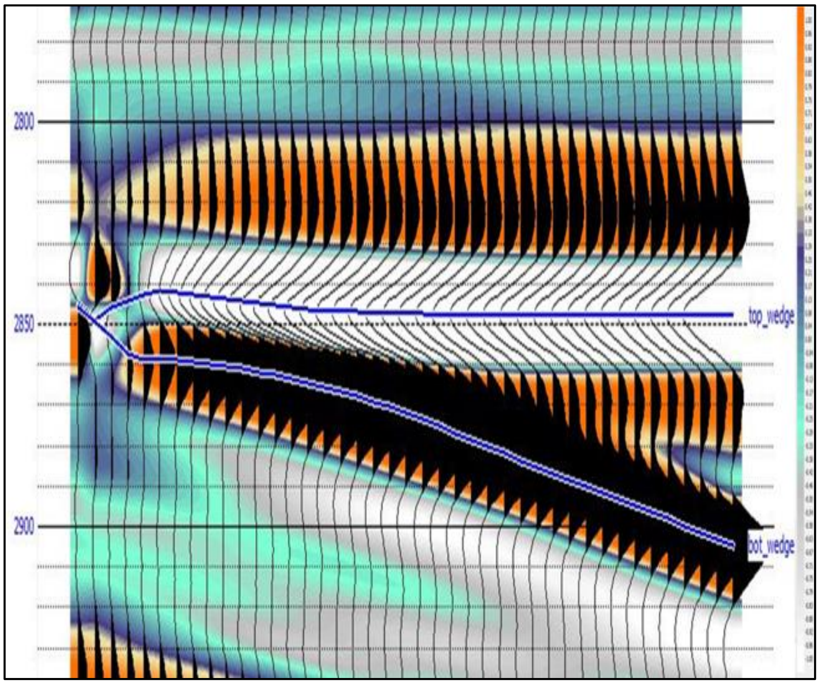

Figure 4: simple wedge model represents the reservoir.

Figure (5) shows the wedge model of the reservoir, where the tuning thickness is 20 *ms*. From the wedge model and the previous calculations results in the last section, we can see that there is no big change in the tuning thickness value between the two different methods. So the tuning thickness in our case is equal to 20 *ms* or 33 m.

3.3. Net-pay thickness from the reflectivity method

Brown introduced a technique which addresses the beds that thicker than tuning thickness (Brown A.R., et al. 1986). It is based on the crossplot of the composite amplitude between top and base of the reservoir versus the apparent seismic thickness.

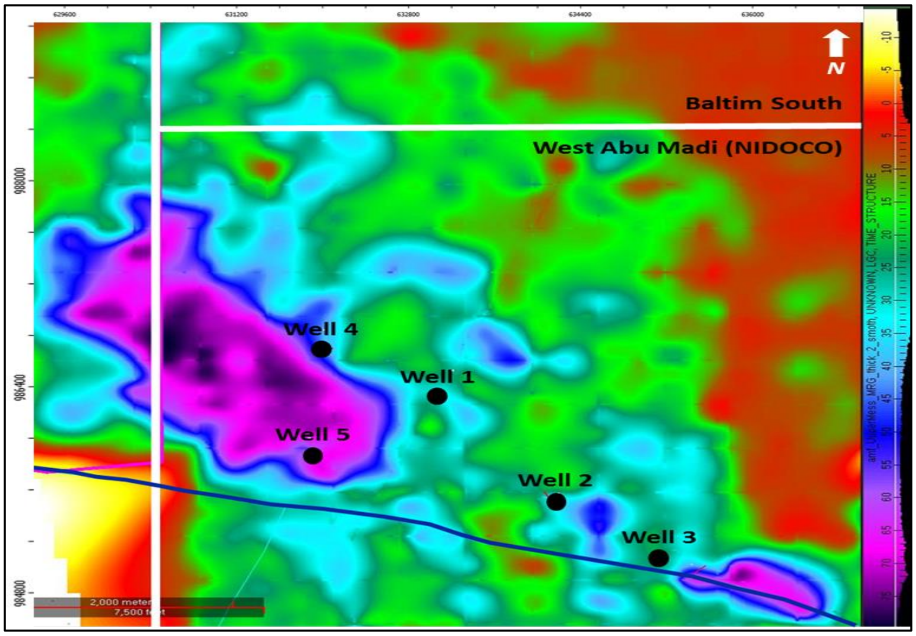

Figure 5: Seismic thickness between the top and bottom of the reservoir in (ms).

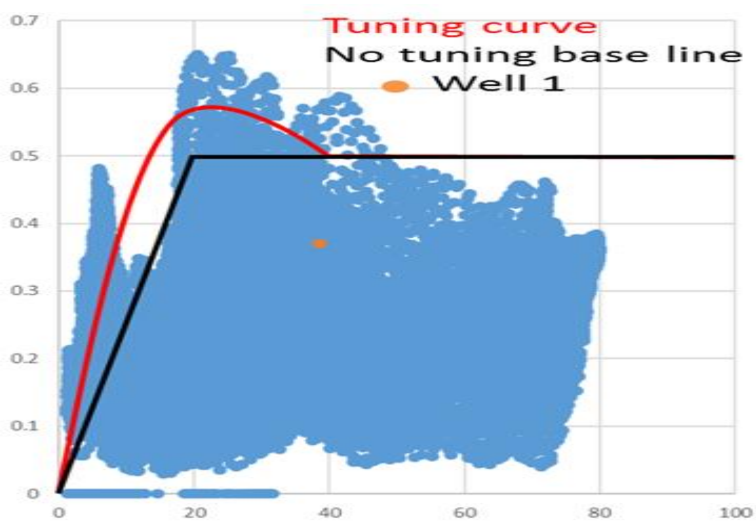

Figure 6: Nooros seismic crossplot of thickness versus composite amplitude with simple tuning curve (red) and baseline (black).

The main steps of this methodology are:

- Draw the top and bottom of the target reservoir (Figure 2A).
- Extract the seismic amplitude between top and bottom of the reservoir (Figure 2B).
- Calculate the apparent seismic thickness by subtracts the bottom values from the top values (Figure 6).
- Tabulate the data (thickness and amplitude) and create a crossplot (Figure 7) with the apparent thickness (ms) on the X-axis and the composite amplitude on the Y-axis.

The crossplot of reservoir seismic thickness versus amplitude extracted between top and base of the reservoir (Figure 7). By locating the amplitude value of the impact point of the new well on the crossplot, it is possible to estimate the apparent thickness of the reservoir.

The net-pay thickness is then estimated as the following equations:

For any given apparent thickness

$$N{:}G = \frac{\text{composite amplitude}}{\text{tuning amplitude}}, (7)$$

To remove the effect of tuning on a seismic amplitude map a scalar is applied, where

$$\text{Scalar} = \frac{\text{no tuning base line}}{\text{tuning curve}}, (8)$$

Then

$$\text{Corrected amplitede map} = \text{scalar} * \text{amplitude map}, (9)$$

Then, net-pay thickness can be calculated

$$\text{net} - \text{pay thickness} = \text{corrected amplitude map} * \text{apparent thickness}, (10)$$

The previous algorithm of Brown had been applied to five wells to obtain the net-pay. By knowing the actual net-pay of the wells, error can be calculated (Table 1). According to these results, we cannot consider the seismic reflectivity technique for net-pay estimation as a wide range of errors, (overestimated and underestimated) it ranges between 5-60%.

Neff stated that the method of Brown is not accurate to apply for the real data, as it considered being an oversimplification on the basis of these types of results (Neff, D.B., 1990a, 1990b, and 1993). He also said that the relationship between trough-to-peak amplitudes, isochrones, and reservoir characteristics can be complex, as well as vary dramatically amongst geological contexts (Simm R., 2009).

Table (1): Error percentage of calculated net-pay to actual net-pay by using the reflectivity method.

Well	Calibrated net-pay (ms)	Actual net-pay (ms)	Error	
			absolute	%
1	13.15	33	19.85	60
2	32.5	37.7	5.2	13.7
3	29.95	28.6	-1.35	-4.6
4	37.6	43.1	5.5	12.7
5	10.25	7.7	-2.55	-33

3.4. Net-pay thickness from the band-limited impedance method

Based on the band-limited impedance through colored inversion, Connolly developed a map-based amplitude scaling technique (Lancaster, S. and Whitcombe, D., 2000). This method utilizes the average band-limited impedance measured between zero-crossing picks and the apparent thickness (Connolly, P., 2005, 2007).

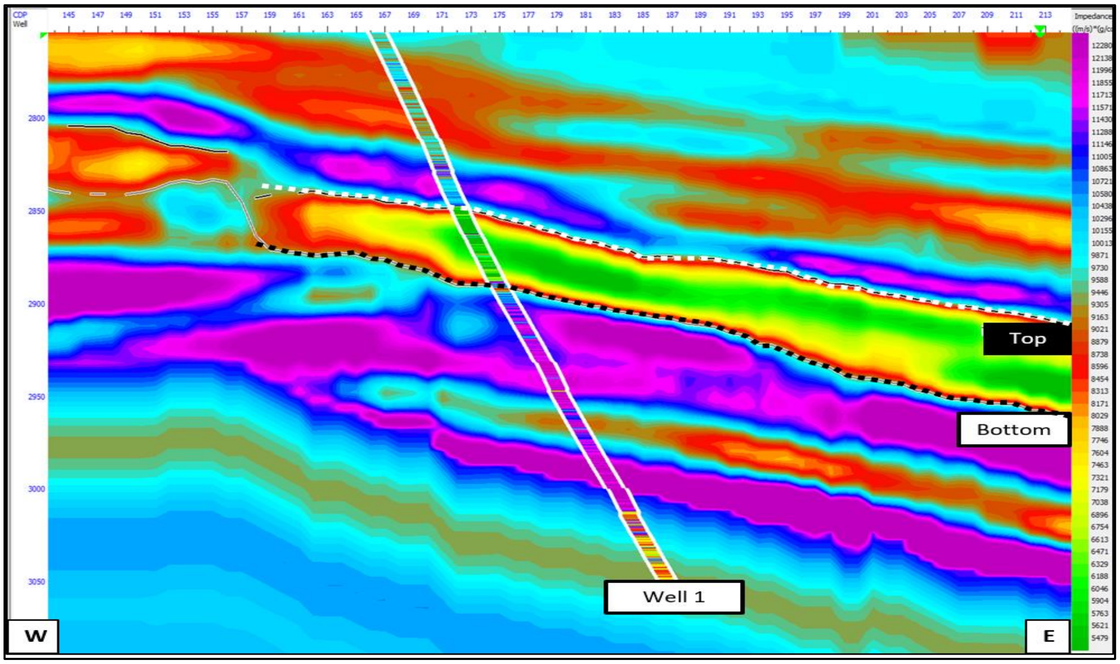

Figure 7: ABLI line passing through Well 1 with top and bottom of the reservoir.

Workflow summary:

- Draw the top and bottom of the reservoir on the zero-crossing of the band-limited impedance data (Figure 8).
- Extract the band-limited impedance values between top and bottom of the reservoir (Figure 9).
- Calculate the apparent thickness of the reservoir by subtracts the base values from the top values (Figure 10).
- Draw the detuning curve between the average band-limited impedance and the apparent thickness (Figure 11).
- Detune the average band-limited impedance using a detuning curve.
- Calculate net-pay using first-guess calibration.
- Calibrate the data by the drilled wells.

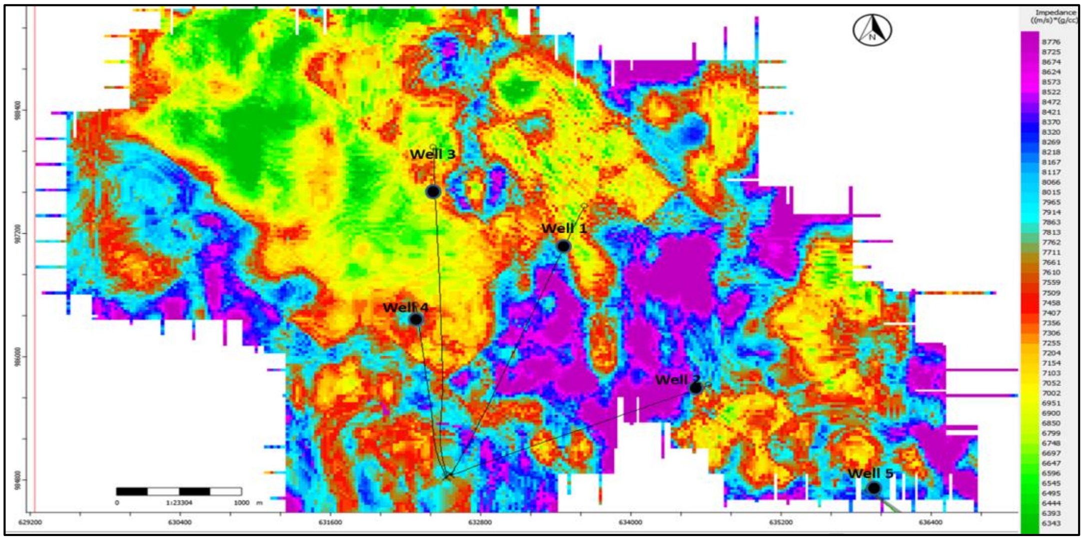

Figure 8: ABLI map extracted between top and bottom of the reservoir

Figure (8) shows the band-limited P-impedance of the reservoir. The inversion result exhibits a good match with the computed p-impedance from well logs. To estimate the net-pay thickness, follow the next equations after Rob simm (2009) and Connolly (2005, 2007).

Connolly's method started by the net-pay equation:

$$\text{net} - \text{pay thickness} = \text{N:G} * \text{gross thickness}, (11)$$

He presents the assumption of Seismic N:G, where:

$$\text{Seismic N:G} = \frac{\text{net–pay thickness}}{\text{apparent thickness}} (12)$$

So, the net-pay thickness formula in equation (11) becomes:

$$\text{net} - \text{pay thickness} = \text{seismic N:G} * \text{apparent thickness}, (13)$$

A relation between the Seismic N:G and the band-limited impedance is mandatory. After investigating a number of interval attributes, Connolly optioned that Seismic N:G varies linearly with the average band-limited impedance (ABLI) for a given apparent thickness (Simm R., 2009). Thus the net-pay equation becomes:

$$\text{net} - \text{pay thickness} = \text{scalar} * \text{ABLI} * \text{apparent thickness}, (14)$$

where: $\text{Scalar} = \frac{\text{seismic N:G}}{\text{ABLI}}$, (15)

Equation (14) can be used to estimate the net-pay thickness once the scalar is calibrated to the well data.

$\text{Scalar} = \frac{\text{apparent thickness}}{\text{constant}}$, (16) Consider the inverse of the scalar is the 'calibration amplitude' such that

$$\text{Calibration amplitude} = \frac{\text{constant}}{\text{apparent thickness}}, \quad (17)$$

Substituting Equations (16) and (17) into Equation (14) gives:

$$\text{net} - \text{pay thickness} = \frac{\text{ABLI}*(\text{apparent thickness})2}{\text{constant}}, \quad (18)$$

Equation (18) can be used to predict the net-pay at a certain well location.

Regarding to the data of the present case study, given the actual net-pay thickness of well 1 (57 m), scalar had been calculated as 0.000147954, and the constant is equal to 344700. Substituting the constant value, predicted net-pay thickness had been calculated for the other four wells and the error percentage are shown in Table (2). Referring to well 5's result; the relative increase in error percentage is due to the poor seismic data quality through this area.

Figure (12) shows the match of net-pay calculation by using ABLI approach and well results. Furthermore, two well locations (A) and (B) had been drilled after this study and they show a big match with study's result.

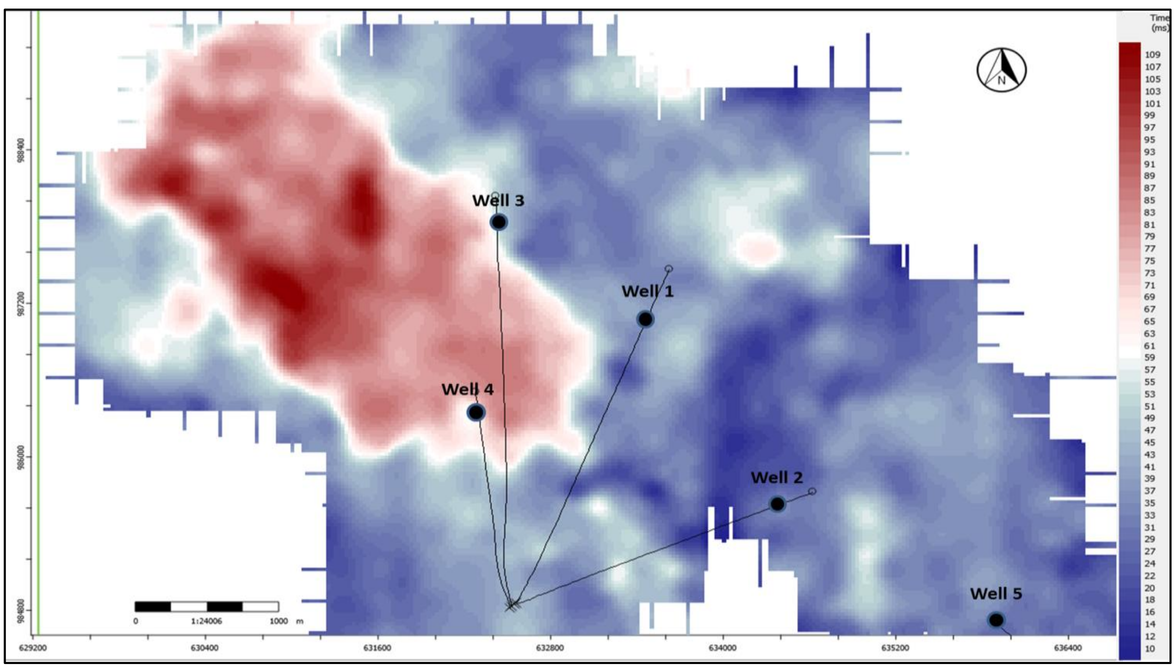

Figure 9: Apparent thickness map (Isochrone).

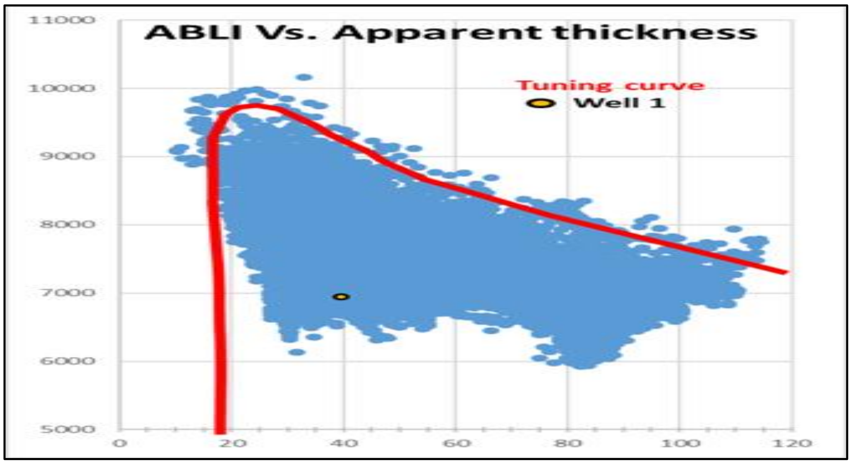

Fig. 10: Crossplot Plot of apparent thickness versus ABLI (detuning curve).

Table (2): Error percentage of the calculated net-pay thickness to actual net-pay thickness by using the ABLI approach.

Well	Predicted net-pay (m	Actual net-pay (m)	Error	
			absolute	%
2	66.5	64	-2.5	3.9
3	50	48.5	-1.5	3
4	74	73	-1	1.3
5	7	13	6	46

Simm (2009) states that, Connolly's approach will be successful in practice if a number of geological and data factors are met, the most important of which are:

1) The shales have higher impedance than the sands.

2) There is no any interference between the reservoir and events below or above.

3) The picking for the zero-crossing band-limited impedance is obvious (Connolly, P., 2007).

4) A single hydrocarbon phase exists.The relationship between the band-limited impedance and N:G is straightforward.

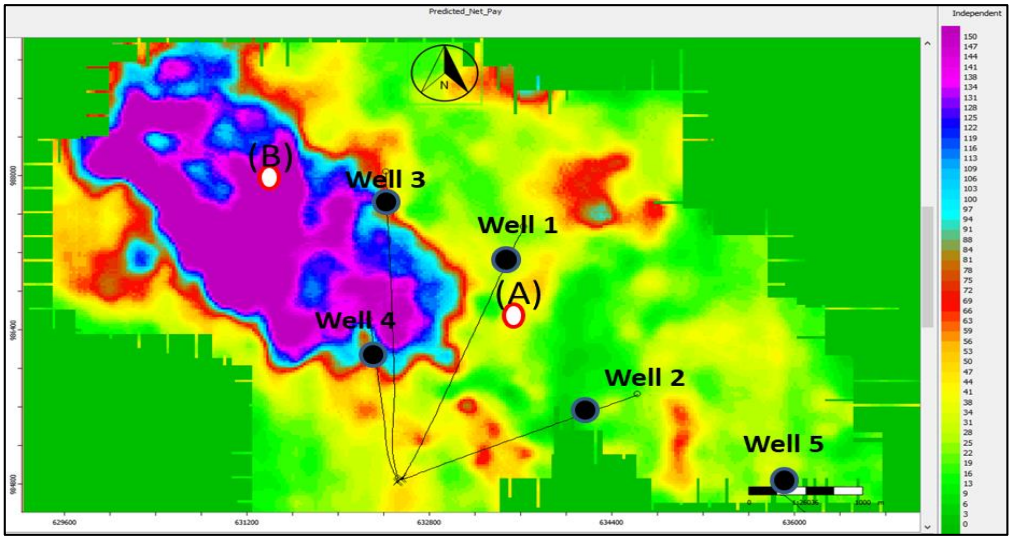

Fig. 11: Predicted net-pay map by using ABLI approach.

4. Conclusions

However, Brown's method is one of the earliest approach to estimate the net-pay from seismic reflectivity, it shows a wide range of error prone as it is depending on the conventional seismic amplitude which effected by the tuning amplitude. Besides it is difficult to positioning the tuning line and the base line.

Connolly's method is easier to apply and resulting in a good match with the actual data because of it is depending on the colored inversion of the seismic data which is more accurate than the conventional seismic data.

Upon the result of applying Brown's and Connolly's techniques for the same seismic data, and in terms of simple amplitude-scaling methodologies for estimating net-pay from seismic data, this work has shown that, Connolly's band-limited impedance technique shown a significant improvement over Brown's reflectivity-based techniques.

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