

Chi angle scan for investigating gas water contact of a Pliocene reservoir in the offshore East Nile Delta, Egypt

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Abstract

One of the main targets within the oil and gas industry is mainly the prediction of both fluids and lithology. Extended Elastic Impedance (EEI) technique is strongly recommended in facilitating reservoir characterization and in distinguishing between seismic amplitude anomalies caused by lithology and those caused by hydrocarbon. Chi angle scan range from 0° to 90° has been conducted to investigate a Pliocene prospect in the offshore East Nile Delta (ND), Egypt. The presence of a remarkable Gas Water Contact (GWC) in the study area helped in investigating the generated EEI volumes. The projections of Chi angles were either affected by lithology only or fluids only, or both lithology and fluids. The fluid volume was estimated at EEI35°, where the top of the gas sand is continuous because of the huge contrast with the overlaying shale and the high amplitude of the gas sand was shut off because of the variation of the fluid type from gas to water. This volume could clearly demonstrate the variation of different fluids with minimum lithology effect. The lithology volume with minimum effect of fluid was estimated at EEI90° (gradient volume), the bottom of the sand was shown on this volume regardless the type of the fluid. However, the base was challenging because of the insignificant contrast between the brine sand and the underlying shale. The findings of this study can help in better understanding the implication of EEI technique in investigating a Pliocene gas prospect and delineating possible recommended locations for drilling in this field. Moreover, the results show how the technique successfully discriminates between different lithology and fluids.

Keywords: Extended elastic impedance, Chi angle scan, litho projection angle, fluid projection angle, Pliocene, ND

1 Introduction

Extended Elastic Impedance (EEI) is a very interesting topic in geosciences. It is considered as a valuable seismic reconnaissance attribute. Moreover, it has the ability to discriminate between different types of fluids and lithology. The ability was successfully proven specifically within the interval, where low acoustic impedance contrasts between both gas sands and background shale. This technique helps in distinguishing between the seismic amplitude anomalies caused by the effect of lithology and those caused by fluid content (hydrocarbon, HC). The EEI is described as implement rotation of both acoustic and gradient impedances. It helps in investigating the physical properties and elastic parameters of reservoir (Gharaee Shari, 2013).

In this paper, Chi angle scan has been conducted over Gas Water Contact (GWC) of a Pliocene reservoir located in the offshore East Nile Delta (ND), Egypt. Different EEI volumes were generated by using Chi angle scan from 0° to 90° . This will help in determining the best angles to demonstrate and differentiate between lithology and fluids. The presence of a remarkable GWC in the study area confirms the presence of different fluids, which will help in estimating the optimum lithology and fluids angles. Therefore, the lithology and fluid volumes will be utilized in delineating the extension of the gas reservoir and determining the sweet spots in the study area.

EEI technique was successfully applied over different reservoirs in the ND. Hafez et al. (2014) calculated EEI logs by using different Chi angles over a field in West ND. These logs were correlated with the available petrographic logs; therefore, different EEI reflectivity cubes were generated based on the same Chi angles of the logs. In that study, Mu Rho -45° , Lamda Rho $+20^\circ$, volume of shale $+87^\circ$ and water saturation $+38^\circ$ volumes were obtained. Abuamarah et al. (2019) con-

ducted an integrated study of geological and petrophysical characterization of deep marine Oligocene gas reservoir in East ND. Habib et al. (2023) proved the ability of EEI technique in studying reservoir sands from those EEI techniques derived from petrophysical properties.

2 Theory of EEI

The \sin^2 term of Zoeppritz linear approximation limits the range of the reflectivity data (Gerlitz, 2004). Shuey's two term equation (Eq. 1) relies on the angle of incidence, as the seismic incident ray strikes the reflector (Shuey, 1985). The main concept is that the normal incident angle range of seismic data is normally from 0° to 30° . In theory, it could be extended over different range of angles, like -90° to $+90^\circ$ (Fig. 1). For the first time, Whitecombe (2002) presented the EEI as a method for lithology and fluid prediction (Eqs. 2 and 3).

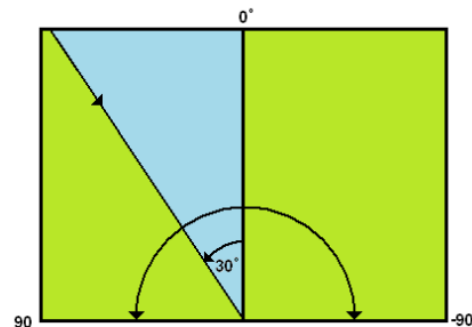


Figure 1. Range of incident angle versus Chi angle (Hampson and Russell, 2005).

Shuey's two term equation:

$$R_p(\theta) = A + B \sin^2\theta \quad (1)$$

Whitecombe (2002) equations:

$$R(x) = A + B \tan x \quad (2)$$

$$EEI = AI \cos x + GI \sin x ;$$

$$AI: \text{ when } x=0^\circ; GI: \text{ when } x=90^\circ;$$

$$EEI = -90^\circ \text{ to } 90^\circ \quad (3)$$

EEI is the procedure of angle rotation within the standard acoustic impedance by certain approximation. It is basically applied by projecting both the intercept and gradient together with different angles (Fig. 2) that emphasizes various features (Gharaee Shahri, 2013). The major

difference between both EEI and EI normalized version is the variable change. EI is directly related to θ (an angle of a physical experiment), while EEI is directly related to χ (an angle of an abstract construction) (Francis and Hicks, 2006). This means that EEI technique is more efficient than EI and is utilized to generate different outcomes more than the typical EI inversion workflow. It is important to monitor that the new variable (χ) permits the calculation of impedance value even beyond the normal range of

angle θ (more imaginary angles, which were not included in the gathers, will be considered) (Gharaee Shahri, 2013). However, the EEI log at $\chi=0$ is equal to EI log at $\theta=0$, which is basically the acoustic impedance (AI). Whitcombe and Connolly (2002) introduced a simple robust method to generate seismic impedance volumes, which are sensitive to both fluid and lithology. The EEI log at various Chi angles is proportional to other rock elastic parameters (Gharaee Shahri, 2013).

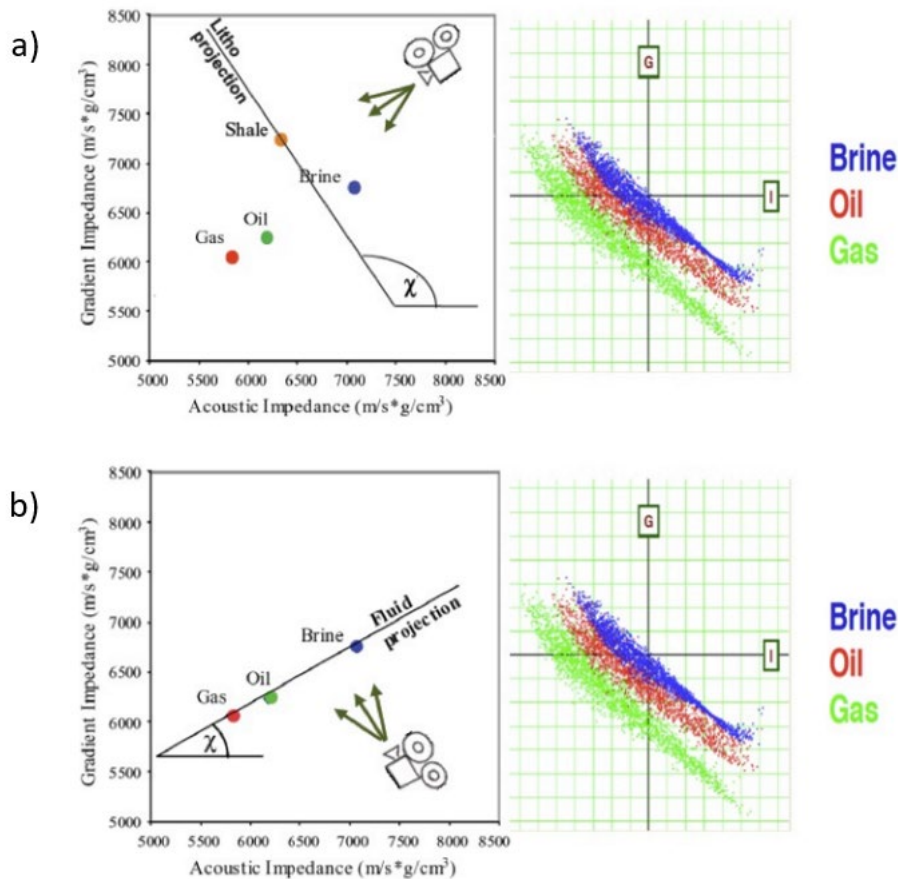


Figure 2. Intercept versus gradient cross plot (after Kemper and Huntbatch, 2012).
 (a) Lithology projection, (b) Fluid projection.

The last step is comprised of the application and the processing of EEI on seismic inverted data in addition to the interpretation of the EEI inverted results. This step involves generating different EEI volumes at various Chi angles to examine the main characteristics of the reservoir. This will assist in discriminating between different lithology and fluid content accu-

rately. The application of EEI technique to generate different EEI volume attributes was performed using Trace Math scripts tool on Hampson-Russell software (HRS 9-2013). Chi angle scan was conducted from angle 0° to 90° .

3 Study area

The ND is one of the main petroleum provinces within Egypt. The offshore part of the ND is an emerging gas and condensate province. It is one of the high potential areas of future petroleum exploration in northern Africa (Vandre et al., 2007). The study area is located around 75 km offshore in East ND, Egypt (Fig. 3). The ND is known as one of the world's great Tertiary deltas. Proven reservoirs in ND vary in age from Oligocene/Early Miocene to Pleistocene.



Figure 3. The location of the study area.

Trayner et al. (1988) divided the stratigraphic units of the offshore ND into three:

- 1) The Plio-Pleistocene unit which marks the main outbuilding phases of the delta and is dominated with shale. This unit is subdivided into Bilqas, Mit Ghamr, El-Wastani and Kafr ElSheikh (KES) Formation (Fm) (Fig. 4);
- 2) The Miocene unit which comprises a "sandwich" with two packages of sand (Abu Madi and Qawasim Fm are separated by Messinian Rossetta Anhydrite Fm);
- 3) The Middle-Lower Miocene unit is comprised of shales with stringers of sand and classified into Sidi Salem and Qantra (Moghra) Fms.

3-1 The Kafr ElSheikh (KES) Formation

The KES Fm is comprised of mudstone sequence with thin sandstone and lime-

stone interbeds. Extending within the Delta area (Younes, 2015), the KES Fm overlies the Abu Madi Fm and underlies the El Wastani Fm. It contains shale-clay intercalations with minor occurrences of siltstones, sands, dolomites, and argillaceous limestones. According to palaeontological (Barakat, 1982) and geophysical data (Badran, 1996), the KES Fm belongs to Early-Middle Pliocene. It is worth mentioning that during Early-Middle Pliocene, the Early Pliocene marine transgression extended over all the Mediterranean area (Azzam, 1994). Deibis et al. (1986) believed that the KES Fm was created at Early-Late Pliocene. Effat and Gezeiry (1986) assigned the same age for the Fm based on both lithology and wire-line logs. Rizzini et al. (1978) suggested that the upper part of this Fm is aged Middle Pliocene (Ismail et al., 2010).

The Pliocene gas play in this concession is primarily the KES Fm. Proven resources were found at depths ranging from approximately 1400-3700 m. The concession is located within the ND offshore Tertiary basin and the sediments range from Oligocene to recent. The Mesozoic platform along the southern edge of the ND basin has been in the form of a structural hinge zone since Late Oligocene time across which subsequent Tertiary sequences increased significantly in thickness. Structurally, the Pliocene productive trend encompasses the down-thrown side of expansion faults within the concession. This sub-province is distinguished by complex growth faults (Wigger et al., 1996).

Characterized by elongated shape, the reservoir is affected by Pliocene listric growth faults. The top of the pay zone is marked by continuous reflector on the seismic reflectivity data. However, the bottom of the reservoir is complicated by lithology variations and gas-water contacts. Seismic data demonstrates that the field has more than one GWC. At least two contacts were mapped. The regional

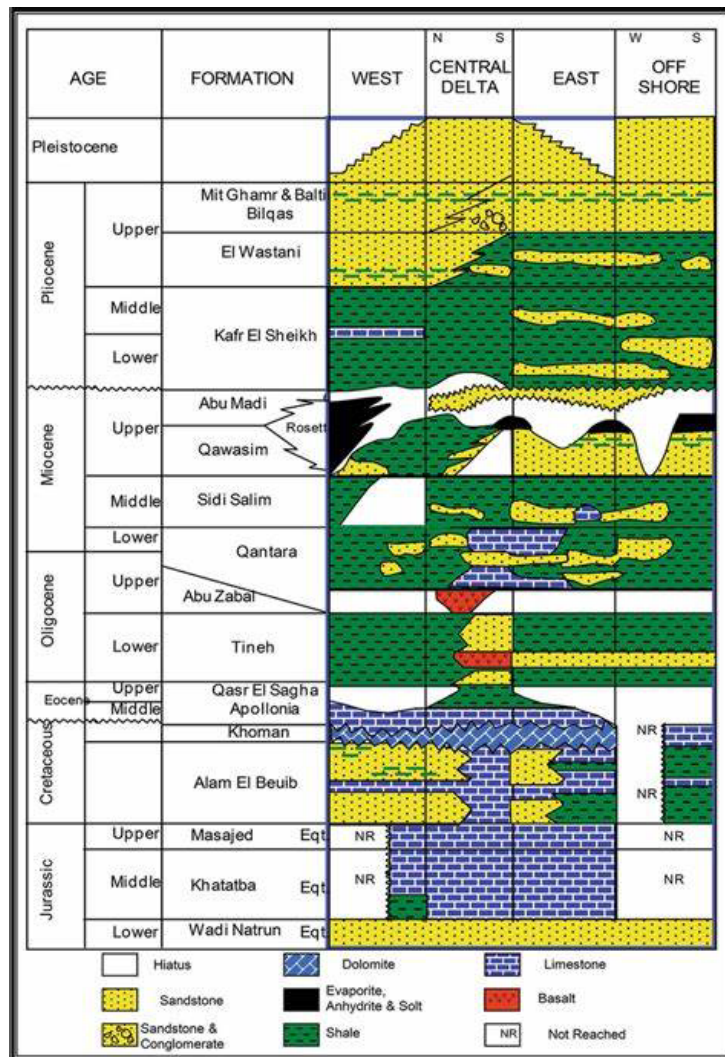


Figure 4. Lithostratigraphic column of ND Egypt (EGPC, 1994).

GWC was picked at around TVSS-1754M based on the flat spot and the amplitude conformance with depth. Another shallower GWC was picked at around TVDSS-1736 m to the northwest side of the field. The shallower nature of this lo-

cal GWC was suggested to be due to perched water effect. A model was formed with the combined surface of the two GWCs (Fig. 5) to demonstrate the different contacts in the field.

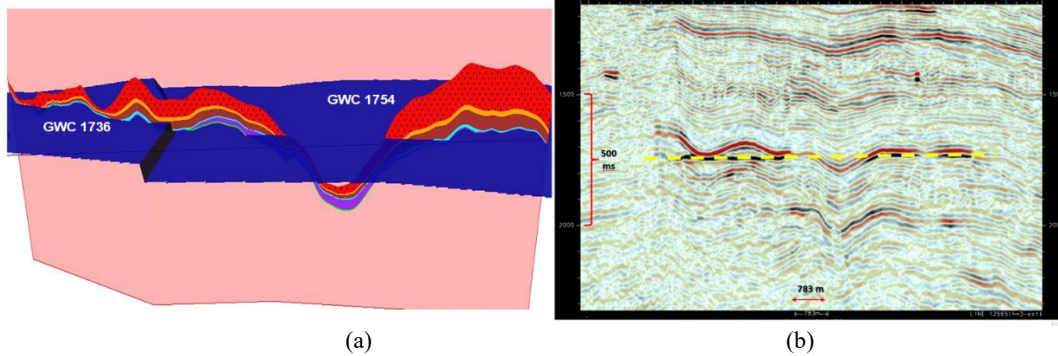


Figure 5. (a) Fence diagram across the study area illustrating the combined GWC. (b) Full stack seismic section showing one flat spot.

4 Application on the data

The main objectives are to investigate the sensitivity of EEI technique over seismic amplitude anomaly, highlighting the differences between both the reservoir and non-reservoir, and delineating HC bearing zones (Gharaee Shahri, 2013). This will help in indicating possible recommended drilling locations for developing this field (Samba et al., 2017). In addition to analyzing the extended elastic impedance (EEI), Chi angle scan

is conducted to find the best projection of Chi angles for demonstrating both lithology and fluid (Fig. 6). Fig. 6 expresses how the properties of the subsurface vary as the Chi angle is changing gradually from 0° to 90° . This is due to different projection angles which are either affected by lithology only or fluids only, or both lithology and fluids. The main objective is to determine which angle is the optimum angle for lithology with minimum effect of fluid and vice versa.

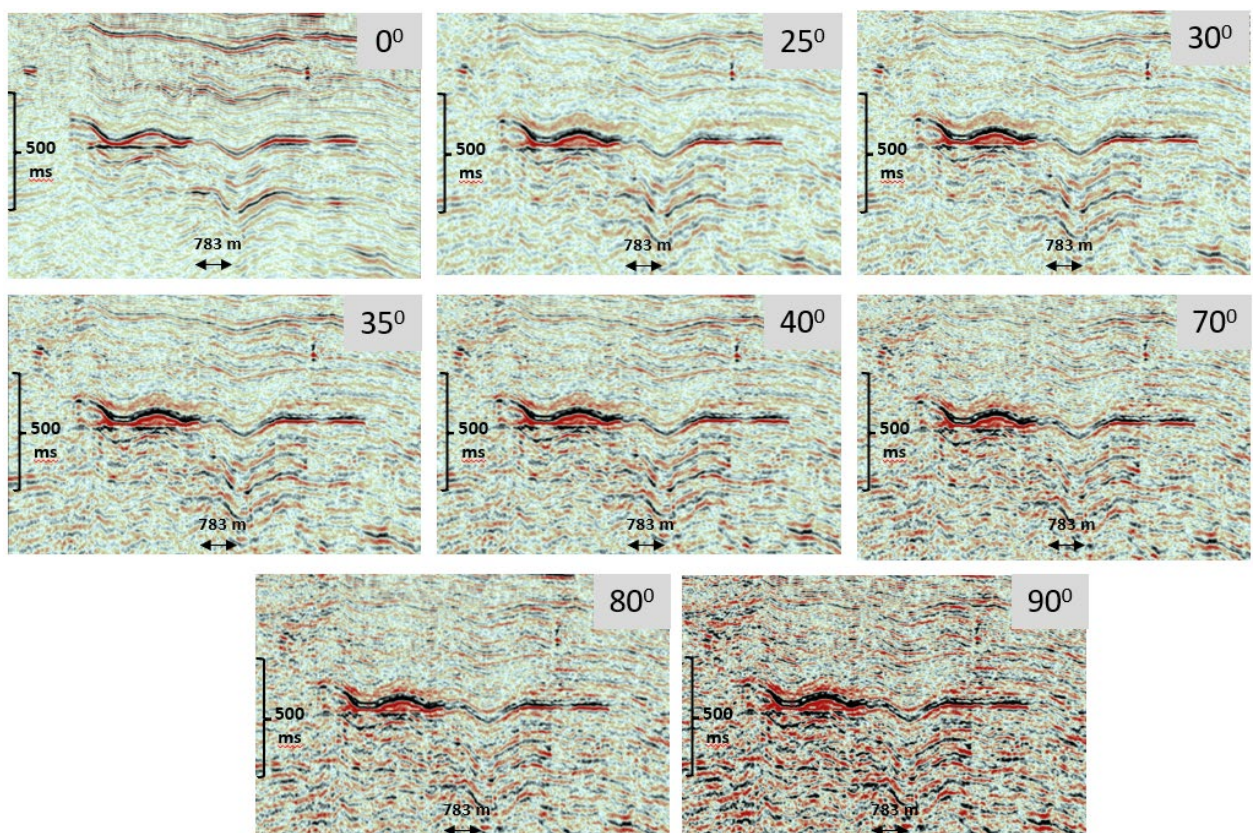


Figure 6. Chi angle scan EEI(0°) to EEI(90°) over the flat spot.

5 Results and Discussion

The presence of a significant GWC in the field was utilized to test the Chi angle scan and determine the best fluid and litho angles for two main reasons. The first reason is that the top of the reservoir is continuous because of the huge contrast between the overlaying shale and the gas sand. The second reason is the difficulty of mapping the base of the sand due to the insignificant contrast between the brine sand and the underlying shale.

Therefore, the presence of GWC (different fluids, gas and water) will help in QC the generated EEI volumes and will surely help in monitoring the best Chi angles for lithology and fluids.

The contrast in amplitude between the gas and brine sand has gradually increased from EEI 0° to 30° . The high amplitude of the gas sand was clearly shut off because of the variation of the fluid type at EEI 35° . Moreover, the difference between the reservoir and non-

reservoir is clearly obvious in this volume. Therefore, it is considered as the best projection of the Chi angle to discriminate between gas and brine sand, with minimum effect of lithology (Fig. 7).

Starting from EEI 40° to 90°, the effect of lithology began to dominate the effect of fluid. This is due to the projection of

Chi angle in the direction of lithology as Fig. 2. Besides the minimum effect of gas, the maximum effect of lithology is shown in EEI 90° volume. EEI technique could successfully be utilized in lithology/fluid discrimination, which will help in investigating the properties of the reservoir.

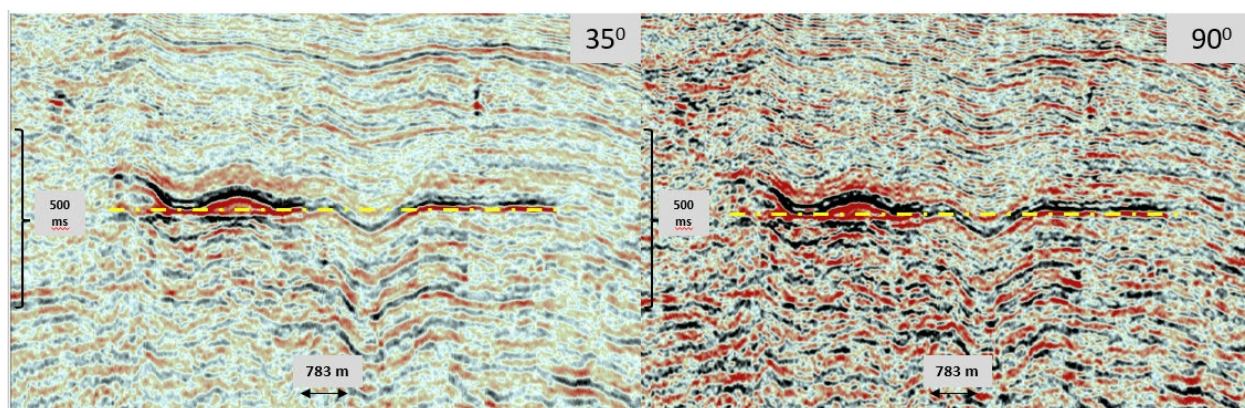


Figure 7. Fluid projection angle is 35° and Litho projection angle is 90°.

6 Conclusions

The ND is still in an immature exploration stage despite significant discoveries made during the last decade. In this paper, EEI technique could successfully discriminate between different lithology and fluids over a GWC of a Pliocene reservoir. Chi angle scan helped in determining the optimum angles to generate lithology and fluid volumes. These results indicate that this area has high potentiality of HC and can help in delineating possible recommended drilling locations in this field. The presence of well data will assure and validate the results by correlating the lithology and fluid logs such as volume of shale, water saturation and acoustic impedance logs with the generated volumes. However, one remaining question is whether this is commercial or residual gas. Therefore, more studies and further investigations should be done to reduce the risk.

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