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Application of AVO and Seismic Attributes Techniques for Characterizing Pliocene Sand Reservoirs in Darfeel Field, Eastern Mediterranean, Egypt

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Abstract

Mediterranean Sea considered as a main hydrocarbon province in Egypt as a huge reservoirs have been discovered till now. Port Fouad marine is a gas and condensate field located in Eastern Mediterranean Sea about 30 KM off Egyptian coast, in a water depth of about 30 m. The Concession is operated by PETROBEL on behalf of Petrosaid (Port Said Petroleum Company). The field was put on production on April 1996, from the Miocene turbidities sands of Wakar Formation plus Pilocene Kafr EL Sheikh Formation. Darfeel field is located within Port Fouad Concession, seven wells have been drilled till now and producing from Pliocene section (Kafr El Sheikh Formation). Pliocene is the main reservoir in Darfeel field which characterized by turbidities sand stone. The aim of this work is to identify the distribution of turbidities sand and characterize sand reservoirs using AVO (amplitude verses offset) and seismic attributes techniques. The workflow is starting from conventional seismic interpretation, maps (time, depth, and amplitude), depositional environments, and finally structure setting. In addition to use some of unconventional seismic interpretation such as seismic attributes. AVO analysis and attributes had been applied in a temp of differentiate between gas sand reservoirs and non-gas reservoirs. The final result aid to identify the reservoir distribution and characterization of sand reservoirs through the field. So, the use of different seismic techniques is powerful techniques in identifying reservoir distribution.

Keywords

AVO, Darfeel Field, Seismic Attributes, Wakar Formation, Kafr El Sheikh Formation, Turbidities

1. Introduction

Mediterranean Sea considered as a main hydrocarbon province in Egypt as a huge reservoirs have been discovered till now. Port Fouad marine is a gas and condensate field located in Eastern Mediterranean Sea about 30 KM off Egyptian coast, in a water depth of about 30 m. The Concession as shown below is operated by PETROBEL on behalf of Petrosaid (Port Said Petroleum Company) whose shareholders are EGPC (50%) and IEOC (50% as contractor) (**Figure 1**). The field was put on production on April 1996, from the Miocene turbidities sands of Wakar Formation plus Pliocene Kafr EL Sheikh Formation.

Darfeel field is located within Port Fouad Concession, seven wells have been drilled and producing from Pliocene section (Kafr El Sheikh Formation). Pliocene is the main reservoir in Darfeel field which characterized by turbidities sand stone.

Darfeel field is one of Pliocene reservoirs. It produces from four levels (An-1, An-2 An-2a, and An-3). The Reservoir is unconsolidated clean sand with high permeability with minor vertical barriers and high horizontal permeability. The most significant level for production was An-2. The cumulative production from the field is 284.925 BSCF. Started production in April 1997 and ended production in September 2008.

- **Stratigraphy:**

The whole surface of the Nile Delta region is almost covered by recent sediments (silt and clay), of a thickness reaching about few tens of feet. Therefore, the stratigraphy and structure of the area are mainly concealed under these surface sediments except some few outcropping areas Sarhan, M. and Hemdan, K. (1995) [1]. The oldest unites that crop out in the Nile Delta region at Abu Roash dome, west of Cairo, belongs to the cretaceous, However, older stratigraphic units have been generally encountered in several wells.

Regionally, the sedimentary succession is characterized by a sequence of Mesozoic and lower Eocene carbonates overlain by a northward thickening middle-late Eocene to Holocene mainly clastic deposits. The oldest sedimentary rock penetrated in the Nile Delta is of Jurassic age. According to the generalized stratigraphic column of the Nile Delta area, as shown in **Figure 1**, the sedimentary section of the Nile Delta ranges in age from Jurassic to Recent, where Jurassic section is resets uncomfortably on the basement.

- **Regional Tectonic and Structural setting:**

The structural pattern of the Nile Delta area is the result of a complex interplay among three main fault trends; The NW-SE (Temsah) fault trend, the NE-SW Qattara-Eratosthenes (Rosetta) fault trend and the E-W faults delineating the Messinian salt basin. These trends are parallel to the circum-Mediterranean plate boundaries (**Figure 2**), and seem to be old inherited basement faults that reactivate periodically throughout the development of the area.

The off-shore Nile Delta area is subdivided into five main structural domains these domains are eastern platform, western platform, inverted basin, diapiric

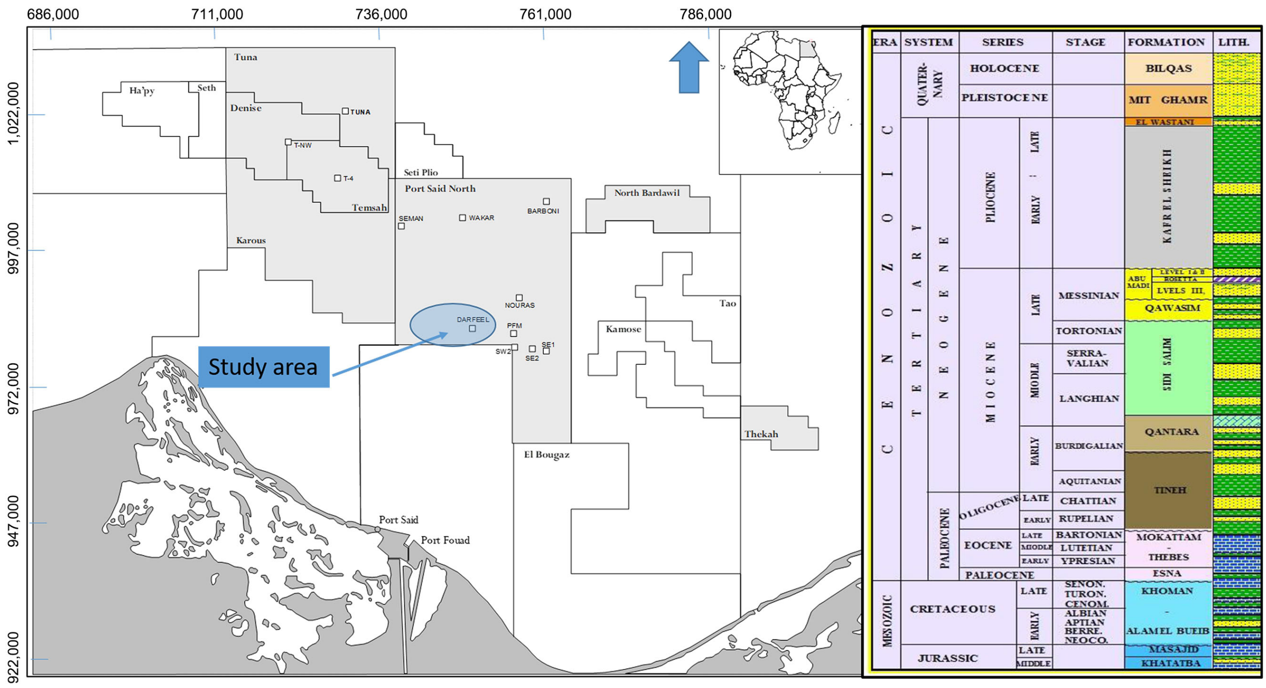

Figure 1. Location map & Seismic database, and generalized Stratigraphy column for Nile Delta [4].

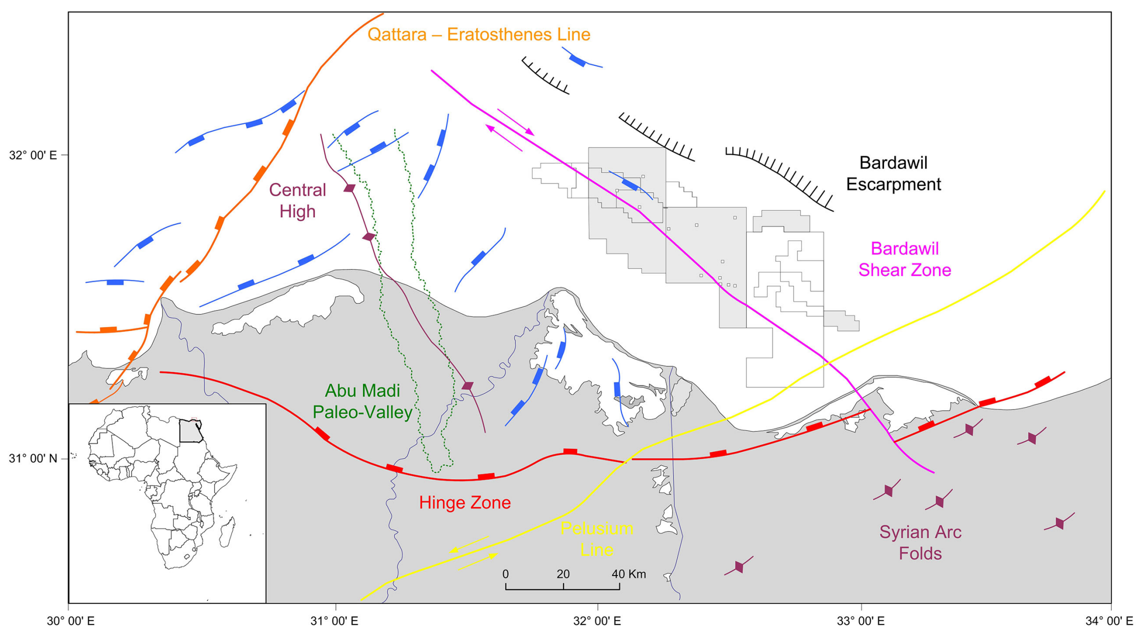

Figure 2. Mediterranean plate boundaries and their motion directions (Barsoum *et al.* 2004).

salt basin and rotated fault blocks, these five domains are separated from each other by major fault trends. The tectonic framework and structural setting of the area indicate five main structural domains (**Figure 3**) separated by major fault trends. Three main hydrocarbon play levels have been investigated the Pliocene turbidite system, the Miocene shallow marine system grading laterally into the salt province, and the presalt system. All have attractive hydrocarbon potential. Discoveries have been made within equivalent petroleum systems in the shallow water parts of the Nile Delta proper abdel aal, *et al.* (2000) [2]. The Pliocene contains slope-basin plain turbidites in the form of channel/channel levees and sheet sands.

2. Methodology and Workflow

The first part of this research is Well to seismic ties (synthetic seismogram) were carried out to make a match between the gas zones in the well log data and the seismic data. Then interpretation of the available seismic data to understand the different structures of anomaly 1, 2, and 3 (Kafr Elshekh Fm.) in the study area, and to identify the sand distribution by extracted seismic attributes. AVO gradient analysis is carried out to understand the AVO class of the gas proven anomalies and the prospective anomaly in the area. AVO attributes and cross plots also are created to comparing between the gas sands reservoirs and brine sands levels.

2.1. Synthetic Seismogram

A synthetic seismogram is the fundamental link between well data and seismic data, and it is the main tool that allows geological picks to be associated with reflections in the seismic data. The steps necessary to create a synthetic seismogram manually are described below:

1) Edit the sonic and density logs for bad intervals.
2) Calculate vertical reflection times.
3) Calculate reflection coefficients, Ro.
4) Combine the last two items to create a reflection coefficient time series.
5) Convolve the reflection coefficient series with the wavelet.

Well to seismic tie was performed using the available logs of Well darfeel-1 and seismic data to study the phase and polarity of seismic data. The seismic data has a zero phase and European polarity—increase in acoustic impedance represents by trough.

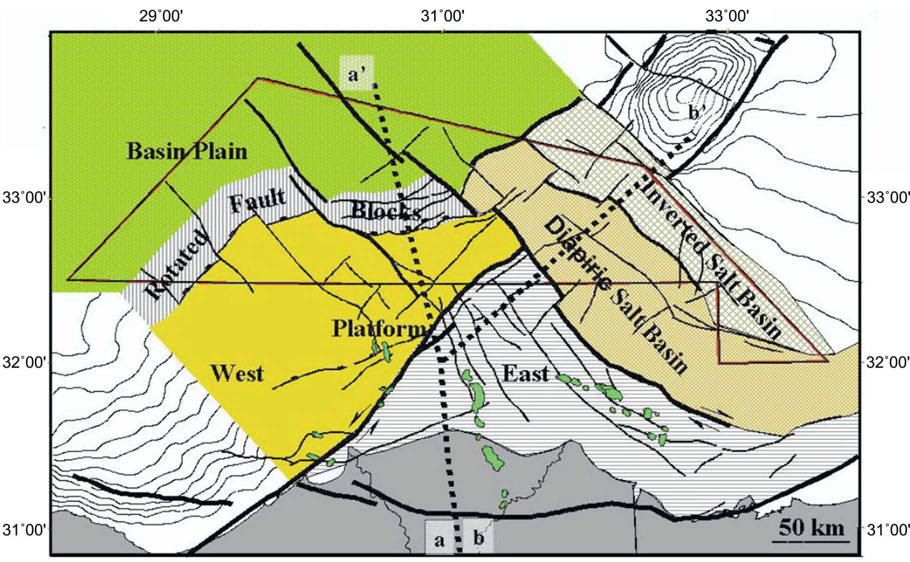

Figure 3. Geologic domain map of Nile Delta Cone and ultra Deepwater [11].

2.2. Seismic Interpretation

After performing well to seismic tie we start the conventional seismic interpretation, Picking faults and horizons to construct the two way time maps for the three horizons An-1, An-2, and An-3 (**Figure 4**), then we use the VSP data for well darfeel-1 to convert the time maps into depth maps (**Figure 5**).

Darfeel discovery is a 4-way dip closure as a structure setting drilled in 1996, four anomalies had been discovered, anomaly 1, 2, 2A, and 3. Seven wells had drilled to develop the discovery. Time and depth structure map of anomaly-1 showing the 4-way dip closure and all wells drilled on the crest of the closure as shown in (**Figure 6**).

2.3. Amplitude Maps

Seismic amplitude is a post stack attribute, which plays a major role in identifying lithology, geometry of sedimentary features and depositional setting. RMS (root mean square) amplitude extraction on angel stacks volumes (full, far and near volumes), a post-stack attribute that computes the square root of the sum of squared amplitudes divided by the number of samples within the specified window used Shuey (1985) [3] (**Figure 7**).

RMS amplitude maps extracted for the anomalies' top 1, 2, and 3 showing the difference in amplitude between partial angle stacks Castagna *et al.* (1998) [4]. Upon that, AVO class 3 had been expected as strong amplitude of far angle more than near one, so the comparison between far and near maps which extracted from the different anomalies is considered as a direct hydrocarbon indicator

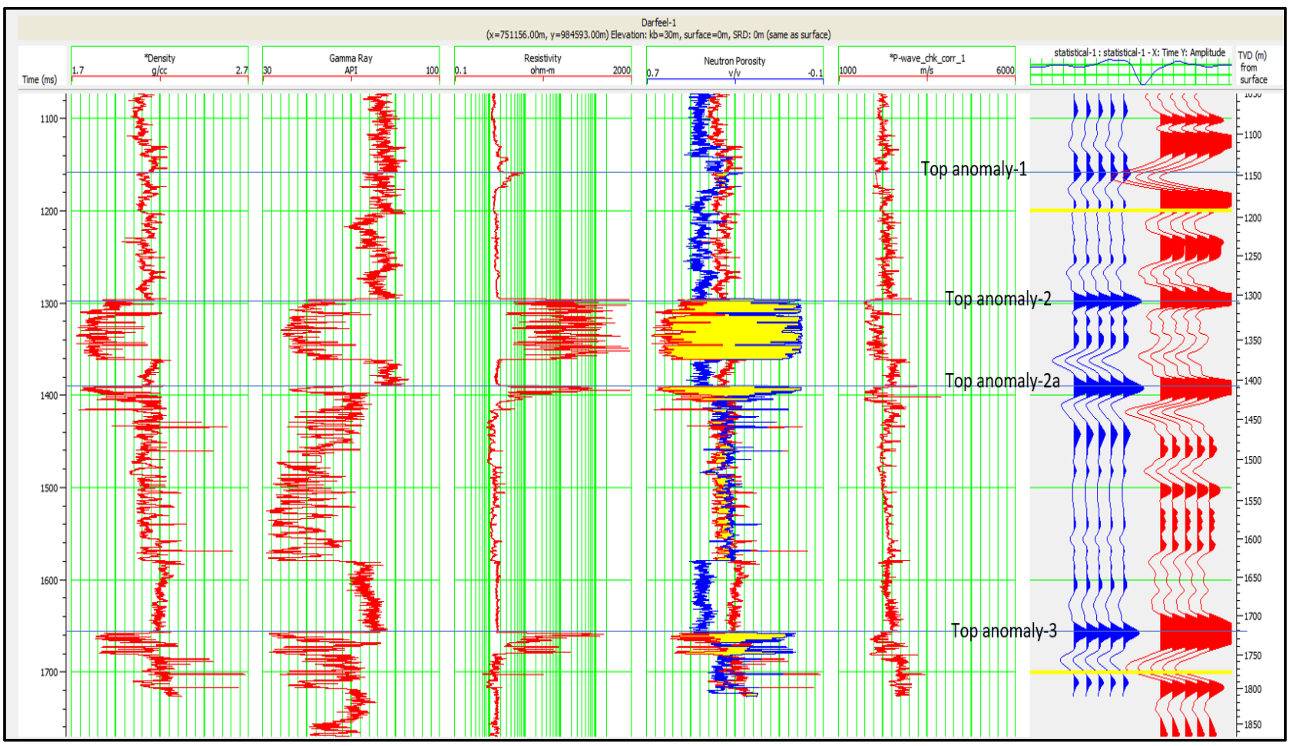

Figure 4. Well to seismic ties on well darfeel-1.

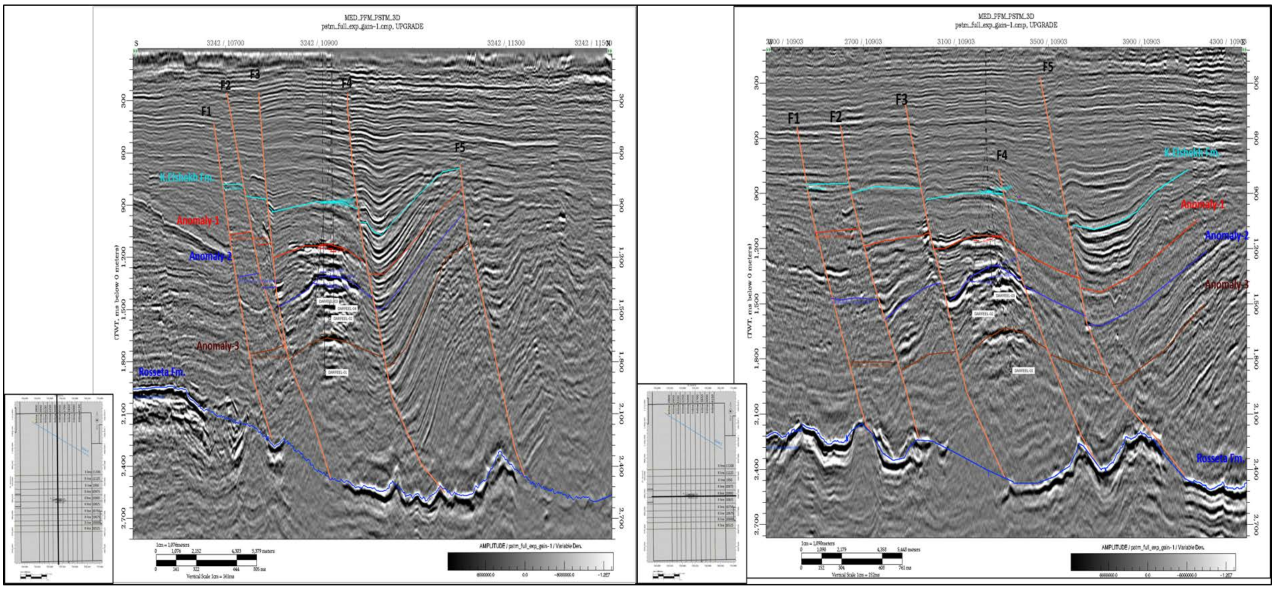

Figure 5. Regional S-N (Left) and W-E (Right) Seismic Lines.

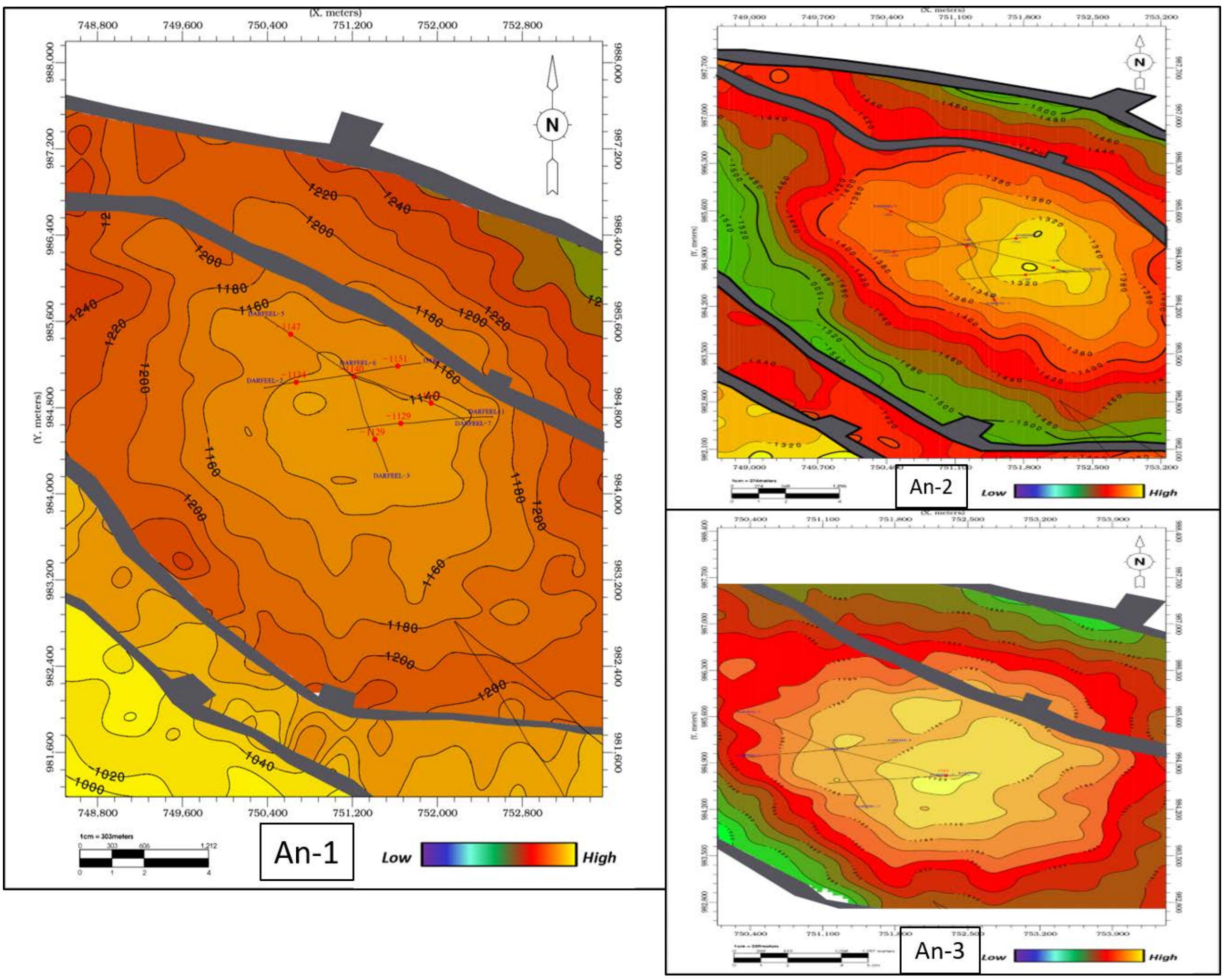

Figure 6. Structure contour maps for An-1, An-2 and An-3.

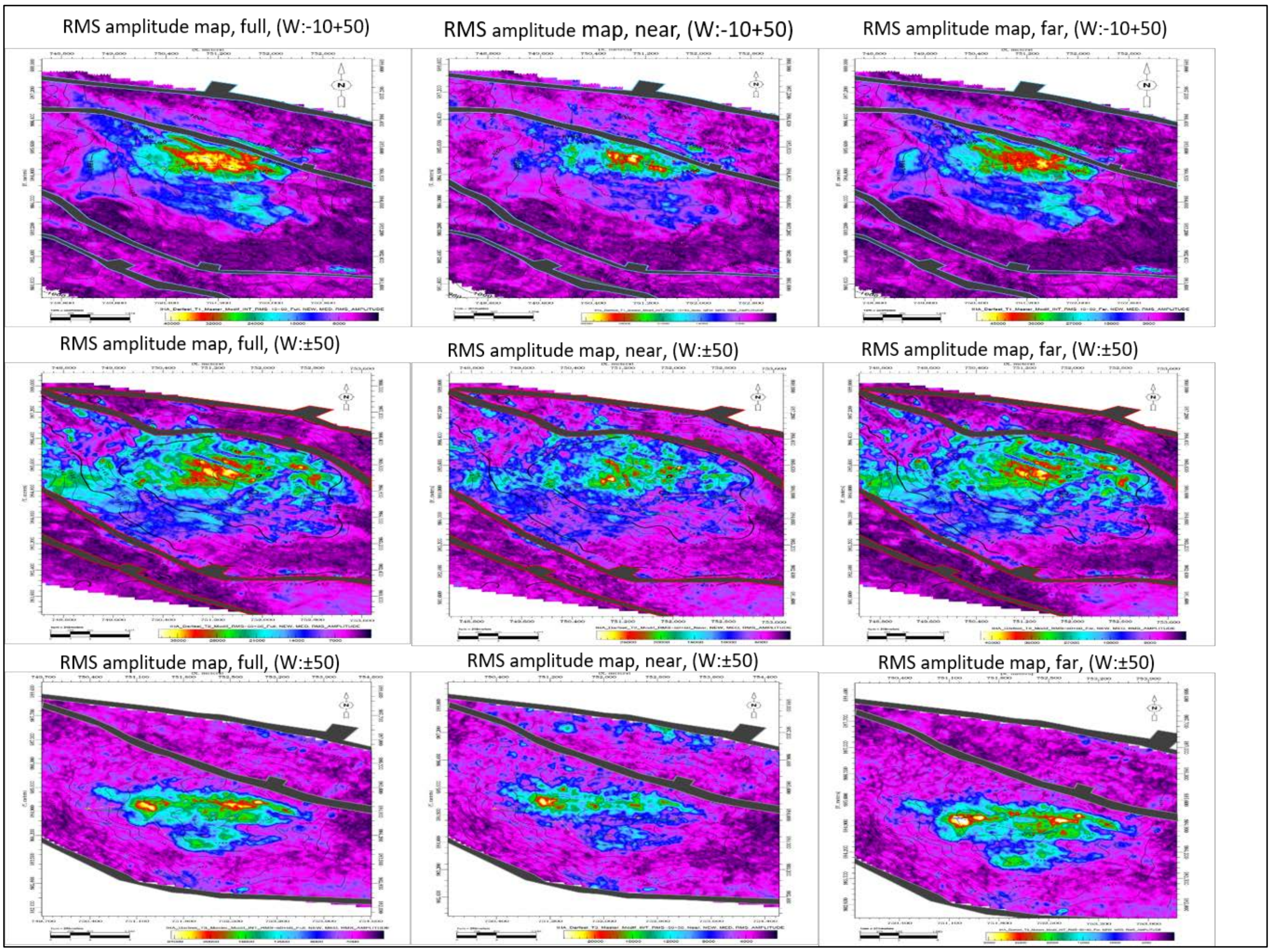

Figure 7. RMS structure amplitude maps for anomalies 1, 2 and 3 on full, near and far volume.

(DHI) which help in identifying the anomalies related to gas sand reservoirs. In addition, the full stack maps of the different anomalies declare the sand geometry in the field and to describing the depositional environment which are characterized as sand turbidities.

2.4. AVO Analysis

Amplitude verses offset (AVO) analysis was initially proposed as a technique for validating seismic amplitude associated with gas sands. Most of the time the gas sands that produces these amplitude anomalies have lower impedance than the encasing shales and have reflections that increase in magnitude with offset. This types of gas sands account for a large percentage of the AVO analysis being done in the industry. Since the early days of AVO analysis, geoscientists have learned that a wide range of AVO characteristics is possible for gas-sand reflections and that AVO analysis can be useful for analyzing reflections that do not necessarily correspond to bring "bright spots" on stacked seismic data.

The following formula is the two-term Shuey [5] [6] approximation to the Zoeppritz equations, which represents the angular dependence of P-wave reflection coefficients with two parameters: the AVO intercept (A) and the AVO gradient (B). In practice, the AVO intercept is a band-limited measure of the normal incidence amplitude, while the AVO gradient is a measure of amplitude variation with offset. Assuming appropriate amplitude calibration, A is the normal incidence reflection coefficient and B is a measure of offset-dependent reflectivity.

$$R(\theta) \approx A + B\sin^2\theta$$

where: θ is the incidence angle, $R(\theta)$ is the reflection coefficient at θ, A is the AVO intercept and B is the AVO gradient.

The seismic response is affected by the physical properties of pore fluids in a porous rock containing those fluids [7]. AVA analysis has become prominent in the DHI (Direct Hydrocarbons Indicator) aimed at characterizing the fluid content or the lithology of a possible reservoir and reducing the exploration drilling risk (Ismail *et al.*, 2020) [8].

2.5. AVO Reservoir Classification

Rutherford, S.R. and Williams, R. H., (1989) [9] classified reservoirs based on the amplitude behavior of the top reflection as a function of offset. Castagna and Swan (1997) [10] complemented the scheme with an additional fourth class [4] (**Figure 8**):

- Class 1: Large positive R0 amplitude that remains positive (dimming of reflection on stack).
- Class 2: Small positive R0 that is transformed into negative reflectivity with offset (dimming/brightening of reflection on stack and polarity flip).
- Class 3: Negative R0 amplitude that becomes more negative (brightening of reflection on stack).
- Class 4: Negative amplitude becomes less negative with offset.

AVA analysis for top and base of An-1, An-2 and An-3 shows class three where amplitude increases with angle. Gradient Vs intercept plot shows top (Red) and base (yellow) gas anomaly and the mud rock line (Green) as shown in (**Figure 9**).

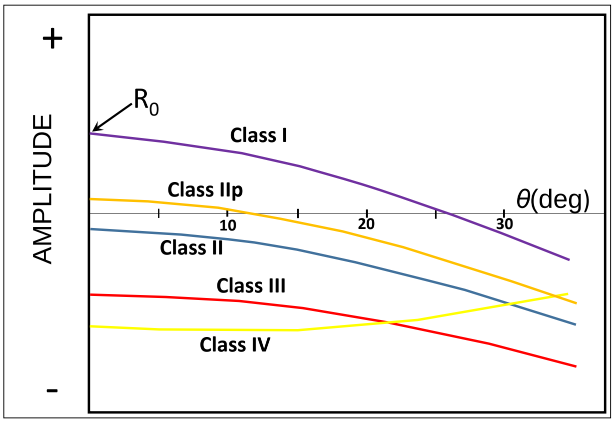

Figure 8. Shows the classes of AVO response, [10].

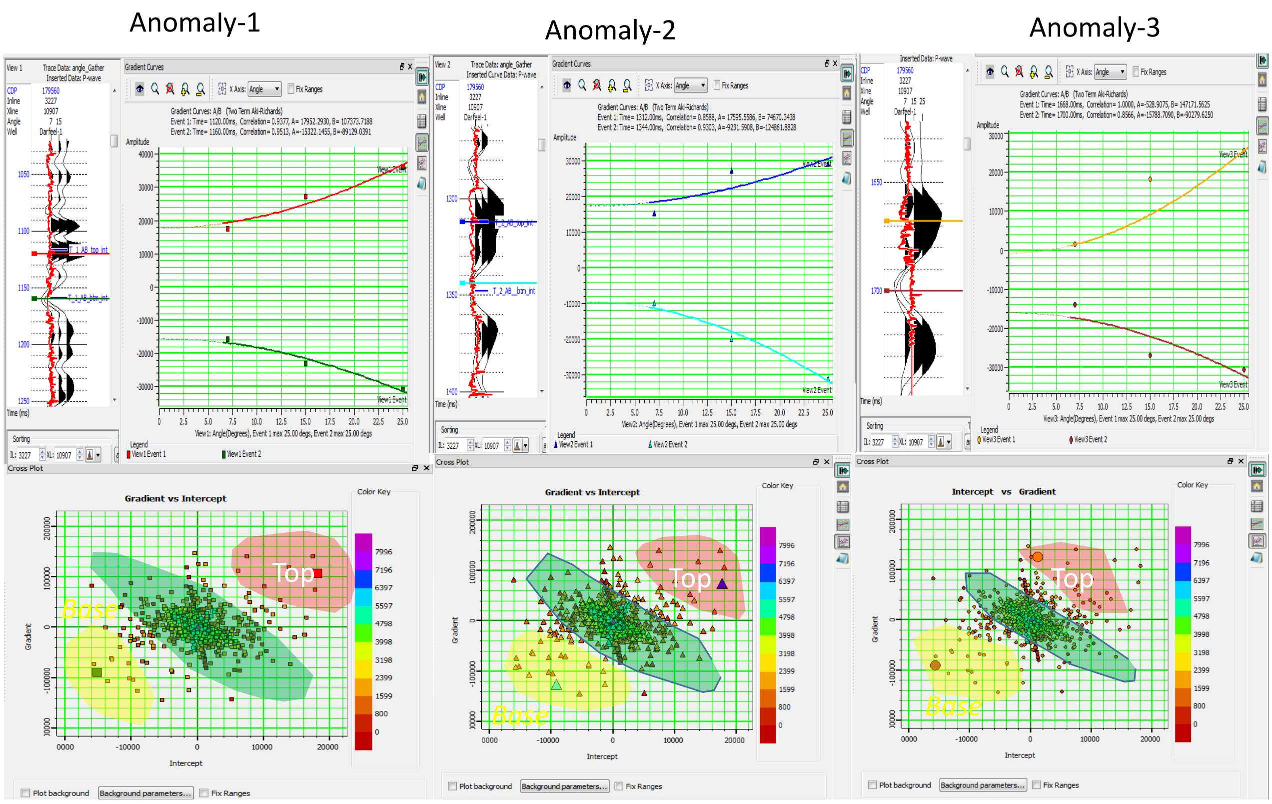

Figure 9. AVA analysis for top and base of An-1, An-2 and An-3.

2.6. AVO Attributes

- **Intercept and gradient attributes:**

The intercept yields the best reflectivity cross-sections. Here, the reflectivity that includes gas are identified with the polarities. **Figure 10** is the cross-section of intercept attribute. The gradient indicates amplitude variation ratio depending on an angle. Generally, although the amplitude variation dependence on an angle is not observed at other reflectors large amplitude variations are observed at gas sand reflectors (**Figure 10**).

Since the intercept, displays the P wave reflectivity and the gradient shows the amplitude variations depending on an angle. The Intercept * gradient which is the product of the two attributes indicates both the polarity and the angle dependence of the amplitude variations. The red color identified with this attribute correlates well with the gas anomaly determined from the other attributes (**Figure 11**).

- **Possion's ratio attributes:**

Poisson's ratio is one of the best indicators for the presence of gas saturated sands. Scaled poisons ratio AVO attribute shows variation based on the fluid content of the reservoir. Foster *et al.* (1993, 2010) [11] [12] described that sands can have higher or lower acoustic impedance than surrounding shale, but gas sands have a lower poisons ratio than shale or brine sands. Scaled Poisson's ratio attribute can aid in identifying the gas bearing anomalies of Darfeel -1 in (**Figure 12**). It is noticed that tops of gas reservoirs in positive values and bottom of reservoirs are negative.

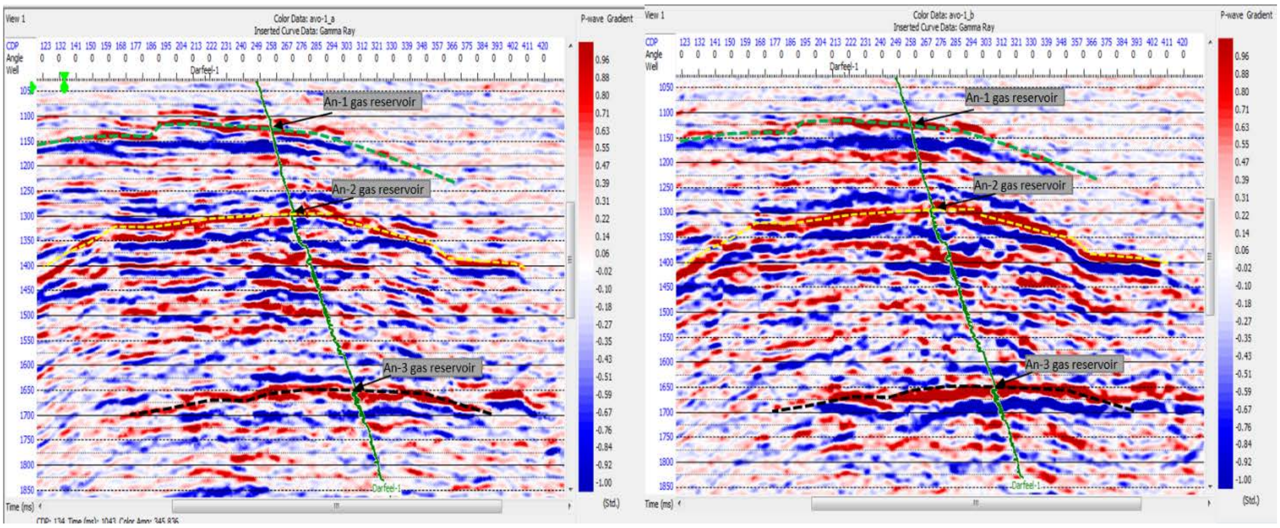

Figure 10. Intercept and gradient attributes shows the top (A and B are positive) and base (A and B are negative) of gas reservoir in red and blue reflectors respectively.

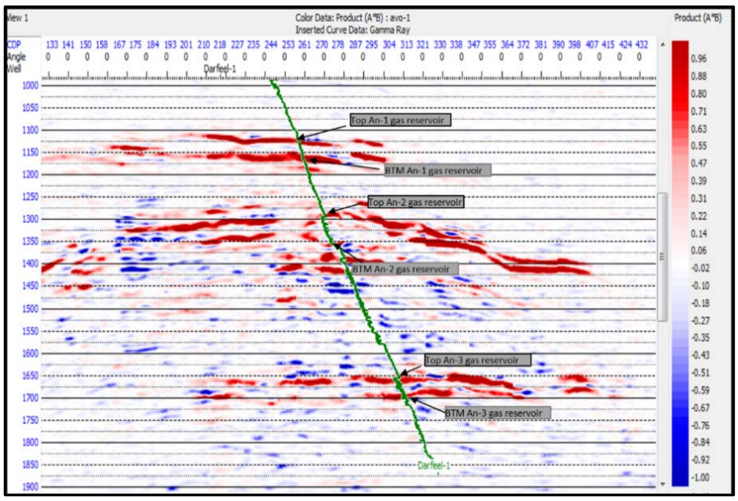

Figure 11. Intercept multiply by gradient attribute shows both top and base of gas reservoir in positive values.

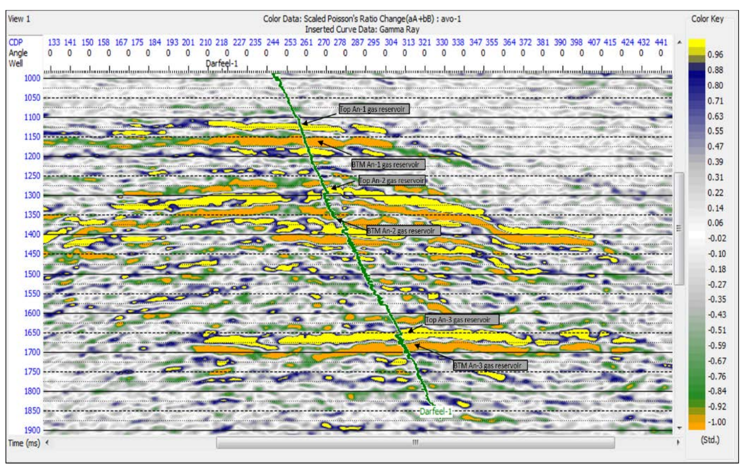

Figure 12. Scaled Poisson's ratio attribute.

3. Conclusion

Seismic attributes is considered as a direct hydrocarbon indicator (DHI) whereas amplitude maps can identify the sand deposits distribution which characterized by turbidities sandstone of the Pliocene section at Darfeel field. Sand anomalies of Level 1 & 2 & 3 are classified as AVA class III. In addition, AVA attributes and cross plots of intercept and gradient can be used to correlate the gas bearing sand anomalies with the prospective anomalies. Finally, integration between AVO analysis, AVO attributes and conventional seismic attributes has a good impact for characterizing the sand reservoirs in Darfeel field. Also, these techniques are considered as powerful techniques for increasing the POS (probability of success) of the next prospects. It is recommended to run such attributes on the anomalies before drilling.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Sarhan, M. and Hemdan, K. (1994) North Nile Delta Structural Setting and Trapping Mechanism. *Egypt EGPC 12th Petroleum Exploration and Production Conference*, **1**, 1-18.

[2] Abdel Aal, A., El Barkooky, A., Gerrits, M., Meyer, H., Schwander, M. and Zaki, H. (2000) Tectonic Evolution of the Eastern Mediterranean Basin and Its Significance for Hydrocarbon Prospectivity in the Ultra-Deepwater of the Nile Delta. *The Leading Edge*, **19**, 1086-1102.

[3] Shuey, R.T. (1985) A Simplification of the Zoeppritz Equations. *Geophysics*, **50**. https://doi.org/10.1190/1.1441936

[4] Castagna, J.P., Swan, H.W. and Foster, D.J. (1998) Framework for AVO Gradient and Intercept Interpretation. *Geophysics*, **63**, 984-956. https://doi.org/10.1190/1.1444406

[5] Russell, B. (2002) An AVO Primer, Search and Discovery. 1-3.

[6] (2004) Hampson-Russell Software Services Ltd AVO THEORY. *Internal Report*, Calgary, Canada, 2.

[7] Cardamone, M.J. (2007) Fundamental Concepts of Physics. Brown Walker Press.

[8] Ismail, A., *et al.* (2020) Identification of Gas Zones and Chimneys Using Seismic Attributes Analysis at the Scarab Field, Offshore, Nile Delta, Egypt. *Petroleum Research*, **5**, 59-69. https://doi.org/10.1016/j.ptlrs.2019.09.002

[9] Rutherford, S.R. and Williams, R.H. (1989) Amplitude-versus-Offset Variations in Gas Sands. *Geophysics*, **54**, 680-688. https://doi.org/10.1190/1.1442696

[10] Castagna, J.P. and Swan, J. (1997) Principles of AVO cross Plotting. *The Leading Edge*, **12**, 337-342. https://doi.org/10.1190/1.1437626

[11] Foster, D.J., *et al.* (1993) A Closer Look at Hydrocarbon Indicators. *SEG Technical Program Expanded Abstracts* 1993. *Society of Exploration Geophysicists*, 731-733. https://doi.org/10.1190/1.1822602

[12] Foster, D.J., Keys, R.G. and Lane, F.D. (2010) Interpretation of AVO Anomalies. *Geophysics*, **75**, 75A3-75A13. https://doi.org/10.1190/1.3467825