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The Interrelation between VpVs ratio, Acoustic Impedance and Gradient Impedance for Reservoir Characterization, Offshore East Nile Delta, Egypt

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DISCRIMINATING between different lithology and pore fluid is an essential phase in reservoir characterization. Crossplot technique is an important step in rockphysics analysis and in investigating the relationship between various elastic parameters. Studying the interrelation between VpVs ratio, acoustic impedance (AI) and gradient impedance can easily provide straightforward interpretation for gas detection, since the lithology and pore fluids have major effect on the reservoir analysis. This was successfully achieved at Pliocene gas reservoir situated at offshore East Nile Delta, Egypt. AI-VpVs ratio crossplot helped in grouping different lithology and pore fluid, where gas sand will cluster at low values within the crossplot. Therefore, Similar physical properties will group within the same cluster and hence different lithology and pore fluids will be discriminated. Moreover, AI versus gradient impedance could also differentiate between gas sand and shale. The gas sand will deviate from the background trend. Eventually, Rockphysics templates will help in providing information about the properties of the reservoir rather than normal well log interpretation.

Keywords: Rockphysics, VpVs ratio, AI, GI, Crossplots, Nile Delta.

1. Introduction

Offshore Nile Delta (ND) Egypt is one of the most famous Deltas around the world. It is a highly potential region for hydrocarbon, especially gas. During the last decade, many successful exploration activities were announced within the offshore gas fields of the ND. It has an important role for the future of petroleum exploration, not only in northern Africa but also in the global gas market. (El Gendy et al., 2023). It is a major gas province in Egypt (Vandre et al., 2007, Samuel et al., 2003). The study area is located at around 75 km offshore in East ND, Egypt (Figure 1).

Rockphysics is an essential tool for reservoir characterization like determining the physical properties of the reservoir, in addition to analyzing and discriminating between the lithology and fluid (Avseth et al, 2010). RockPhysics helps in understanding the theoretical tools which are required to improve all imaging and characterization solutions for the reservoir (www.rockphysicists.org). Well log data is key data for rockphysics, where different rock properties are measured within the subsurface. Generating crossplots with one attribute against the other will establish a relationship between these two attributes (Schlumberger 1989, Hampson Russell Software 2004, Dvorkin 2008). When appropriate pairs of attributes are plotted together, different lithology and fluids will cluster providing straightforward interpretation. In this paper, Rockphysics Templates (RPT) were selected for reservoir characterization of a Pliocene gas reservoir. Investigating the interrelation between VpVs ratio, acoustic impedance (AI) and gradient impedance (GI) will help in separating the gas reservoir from non-reservoir.

2. Geological Setting of ND:

2.1 Regional Tectonic and Structural setting

Offshore part of the African plate was formed by Mediterranean Ridge, Levant and Herodotus Basins, ND sedimentary pile, Eratosthenes Seamount and Rosetta Fault systems. While the onshore region is marked by Egyptian and Levantine coastlines. Northern Egypt was subdivided into three major areas: Western Desert, ND and North Sinai (Figure 2) (After Tassy et al. 2015). The tectonostratigraphy framework of the ND is mainly controlled by deep-seated basement structures and also by the interaction of the NW trending Misfaq-Bardawil (Temsah) and NE-trending Qattara- Eratosthenes (Rosetta) Fault Zones (Figure 3). The Misfaq-Bardawil zone fault is suggested to as a result of an oblique transpression tectonics. Fault zone Qattara-Eratosthenes marks a clear down-thrown thickening representing a post Miocene reactivation (Mosconi et al., 1996). The

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Rosetta fault is considered a major fault and it is suggested to be formed during the Pliocene deposition. Extensional to strike-slip fault with SW-NE orientation (Souilam et al., 2025).

2.2 Stratigraphy of ND

The ND is recognized as one of the world's major Tertiary deltas. The hydrocarbon reservoirs in ND are aged from Oligocene/Early Miocene to Pleistocene. The main outbuilding levels of the delta is Plio-Pleistocene, which is dominated with shale. This unit is comprised of Bilqas, Mit Ghamr, El-Wastani and Kafr Elsheikh (KES) formations (Fm). During the early Pliocene, the main transgression occurred. Thick marine prograding sequences were formed during the Pilo-Pleistocene (Ismail et al., 2020c).

2.3 KES FM

This formation consists of mudstone sequence with thin limestone and sandstone interbeds. It extends within the delta area (Figure 4) (Abdel-Aziz, 2015). This formation is located between Abu Madi Fm and El Wastani Fm (Figure 5). This formation is comprised of shale-clay intercalations with minor presence of sands, dolomite, siltstone and argillaceous limestone. According to the palentogical and geophysical data, KES Fm is considered Early Middle Pliocene Fm (Barakat 1982 and Badran 1996). While Deibis et al., 1986, Effat and Gezeiry 1984 mentioned that KES Fm is Early-Late Pliocene based on lithology and well log data. Rizzini et al. 1978 stated that the upper segment of KES Fm belongs to Middle Pliocene (Ismail et al., 2010). Azzam 1994 suggested that marine transgression extended over the Mediterranean area during the Early Pliocene.

3. Methology

Rockphysics is an essential tool for analyzing the reservoir properties such as lithology and fluid. It is highly recommended for enhancing and forming templates which characterize the reservoir (Avseth et al, 2010). Forming rockphysics model requires establishing a framework to determine the reservoir characteristics (Andersen et al., 2007). Rockphysics analysis can help in providing valuable information and discriminating between different lithology and fluids. The factors which control the reservoir analysis are the effect of lithology and the fluid content. The physical properties such as compressibility, stiffness and porosity are the most significant properties of the reservoir.

Well-1X is an offshore well, which has encountered Pliocene reservoir. Compressional and Shear Sonic logs, in addition to density log were utilized to estimate VpVs ratio, AI and GI. These elastic parameters have be crossplotted in order to investigate their interrelationship and confirm the presence of gas in this reservoir.

3.1 AI-VpVs ratio Crossplot

The integration of two main elastic properties, AI and VpVs ratio can easily determine the type of lithology and fluid (Odegaard and Avseth 2004, Avseth et al, 2005). AI and VpVs ratio crossplot is considered a prototype of rockphysics analysis in case of HC and brine sandstones, and shales (Avseth and Veggeland, 2015). AI-VpVs ratio crossplot plays an important role in understanding the interrelationship of these elastic parameters with other well log data such as gamma ray (GR) and Resistivity. This will provide information about the quality and characteristics of the reservoir (Avesth et al., 2010). Odegaard and Avseth 2003, presented figure 6a Showing different clusters in terms of lithology, fluid content, cementation, and pressure. Moreover, Russell in 2013 applied this RPT on well log data (Figure 6b). Figure 7 and Figure 8 shows that same RPT by using the well log data in the study area.

3.2 AI-GI Crossplot

Extended Elastic Impedance (EEI) is a powerful attribute, which is utilized in differentiating between various lithologies and fluids. The normal incidence angle within the seismic data usually ranges from angles 0° to 30°. However, this range can be extended from -90° to +90° (Figure 9). This is based on Shuey's two terms equation (eq. 1), which is known as Zoeppritz linear approximation (Gerlitz 2004 and Shuey 1985). The intercept and gradient crossplot (Figure 10) can easily facilitate interpretation. Since the values of brine sandstones and shales form a definite background trend, therefore HC zones will be deviated from this trend (Castagna and Swan, 1997). The gas sands will be the most well-deviated cluster due to the decrease in fluid's density (Hussein et al., 2020). Figure 11 shows the same RPT by using the well log data of the study area.

Shuey's Two Term equation,

$$R_P(\theta) = A + B \sin^2 \theta, \text{ (eq. 1)}$$

Whitecombe 2002 presented a technique for lithology and fluid prediction, equation 2 and 3.

$$R(x) = A + B \tan x, \text{ (eq. 2)}$$

$$EEI = AI \cos x + GI \sin x, \text{ (eq. 3)}$$

AI: When X=0°, GI: When X=90° , EEI= -90° to 90°

$$\text{Intercept} = Vp*\rho, \text{ Gradient} = V_p * V_s^{-8K} \rho^{-4K}, \quad K = (V_s/V_p)^2$$

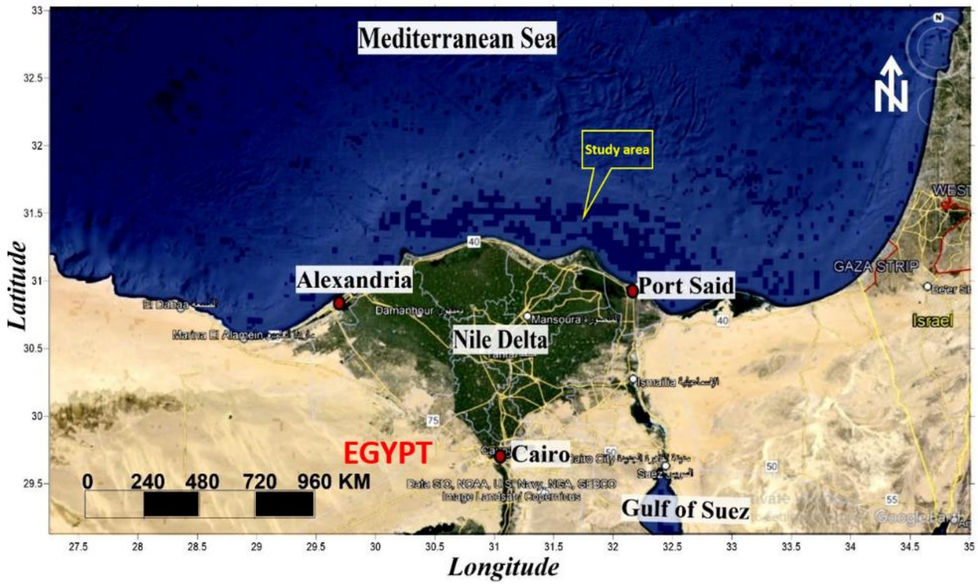

Fig. 1. The location of the study area, offshore East ND, Egypt (Google Earth).

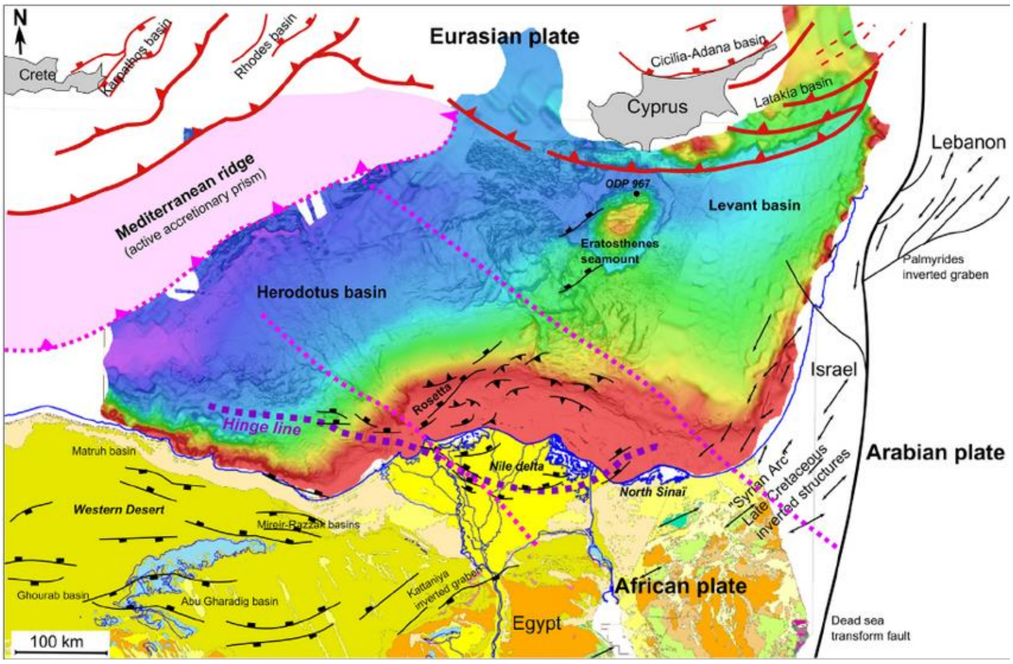

Fig. 2. Structural sketch of the East Mediterranean (after Tassy et al. 2015)

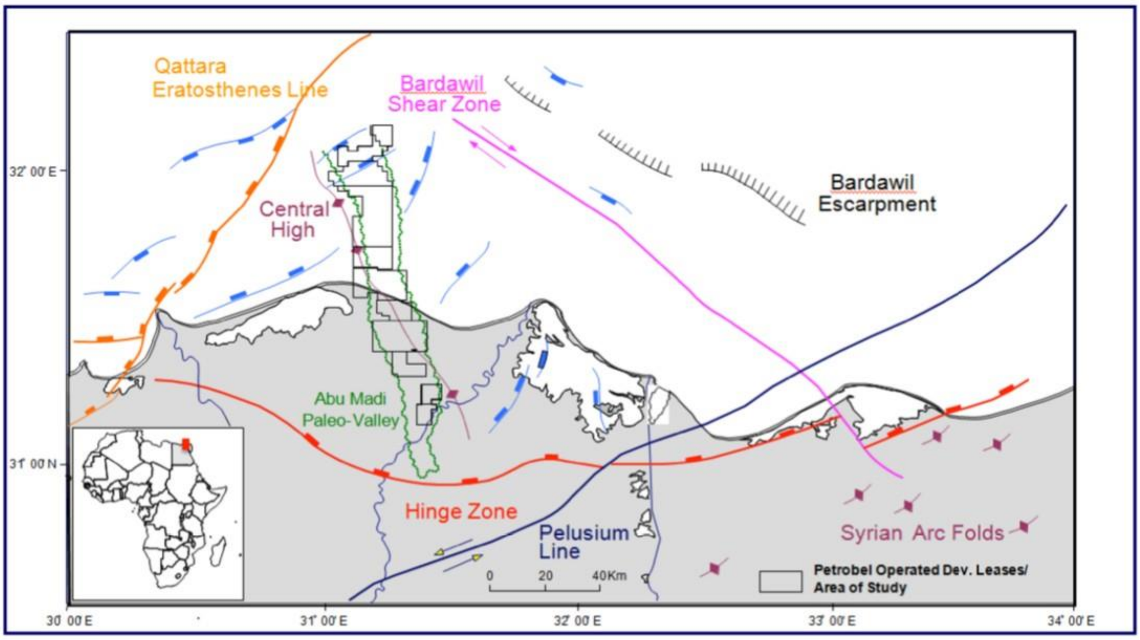

Fig. 3. Central Nile Delta Basin – Major structural elememts (after Matresu et al., 2013).

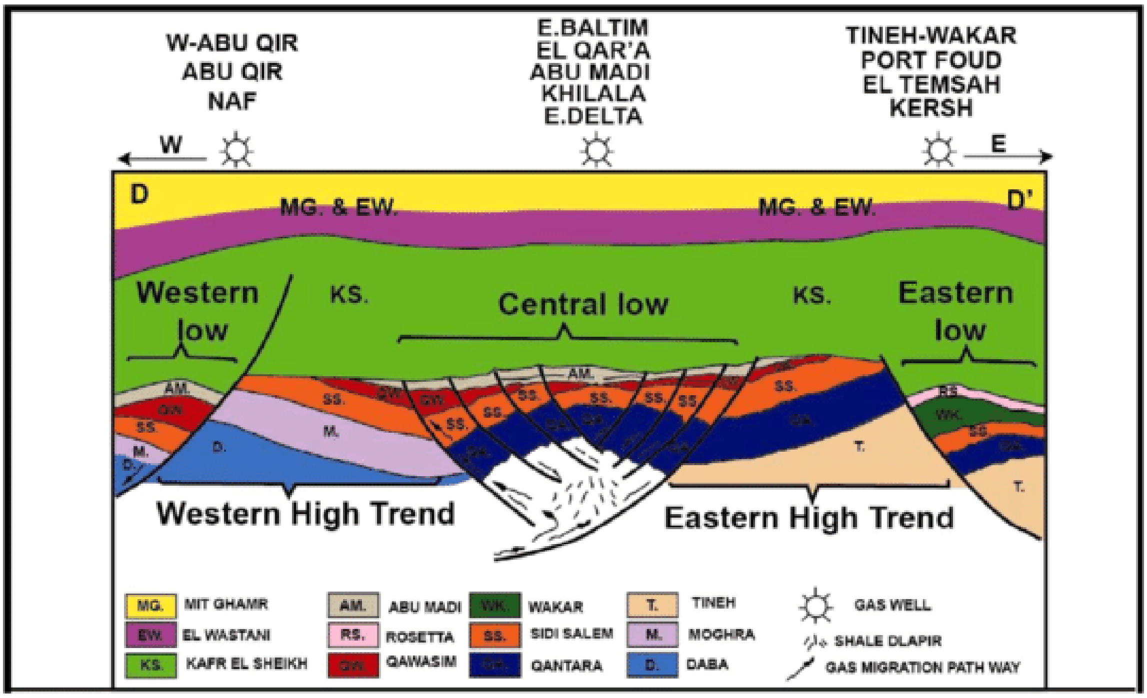

Fig. 4. Geological model for northern Nile Delta (after Sahran et al. 1994).

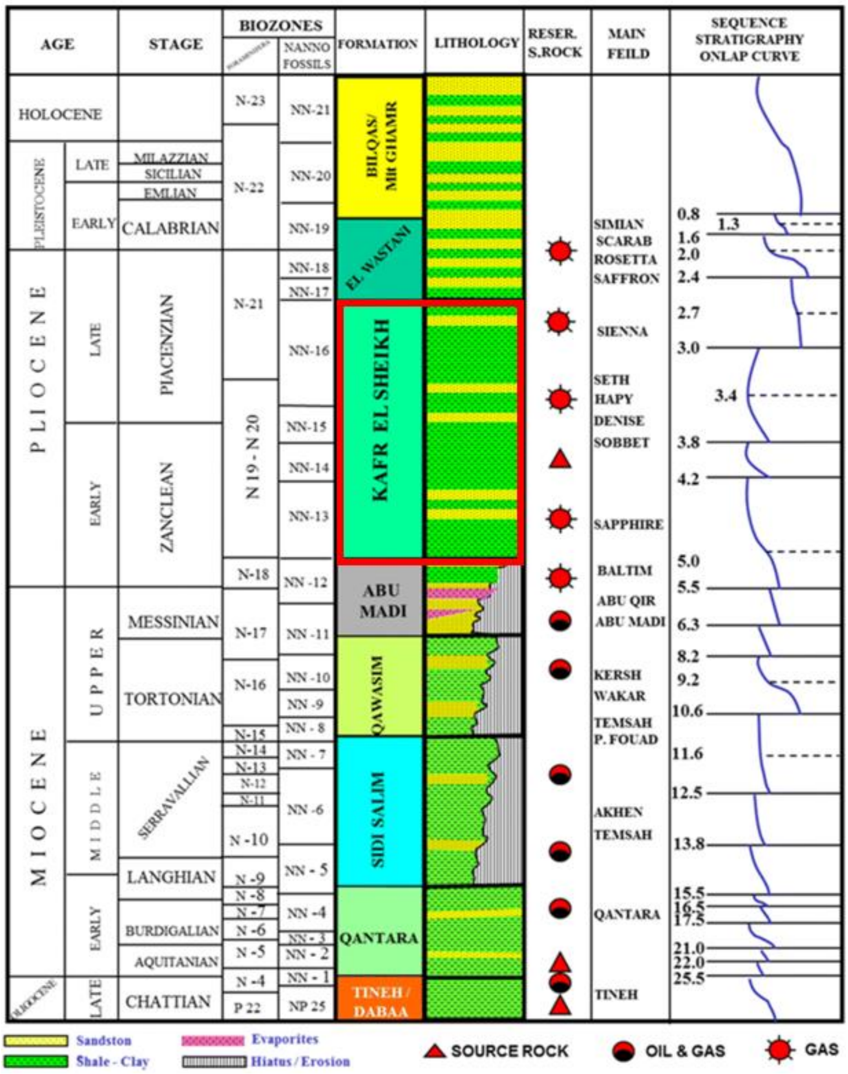

Fig. 5. Lithostratigraphic column of Nile Delta – KES Fm (After Othman et al. 2021).

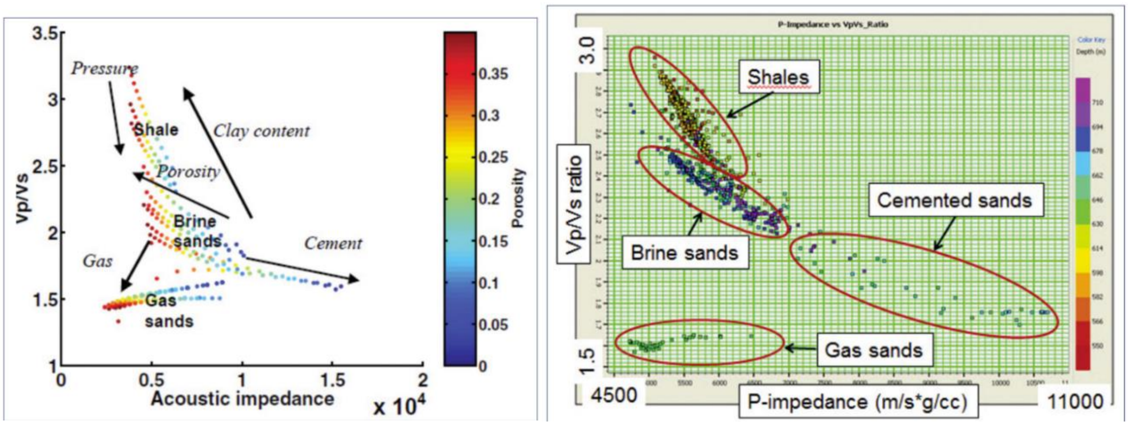

Fig. 6. a) Rockphysics template (After Odegaard and Avseth, 2003). b) AI-VpVs crossplot of well log data (after Russell, 2013).

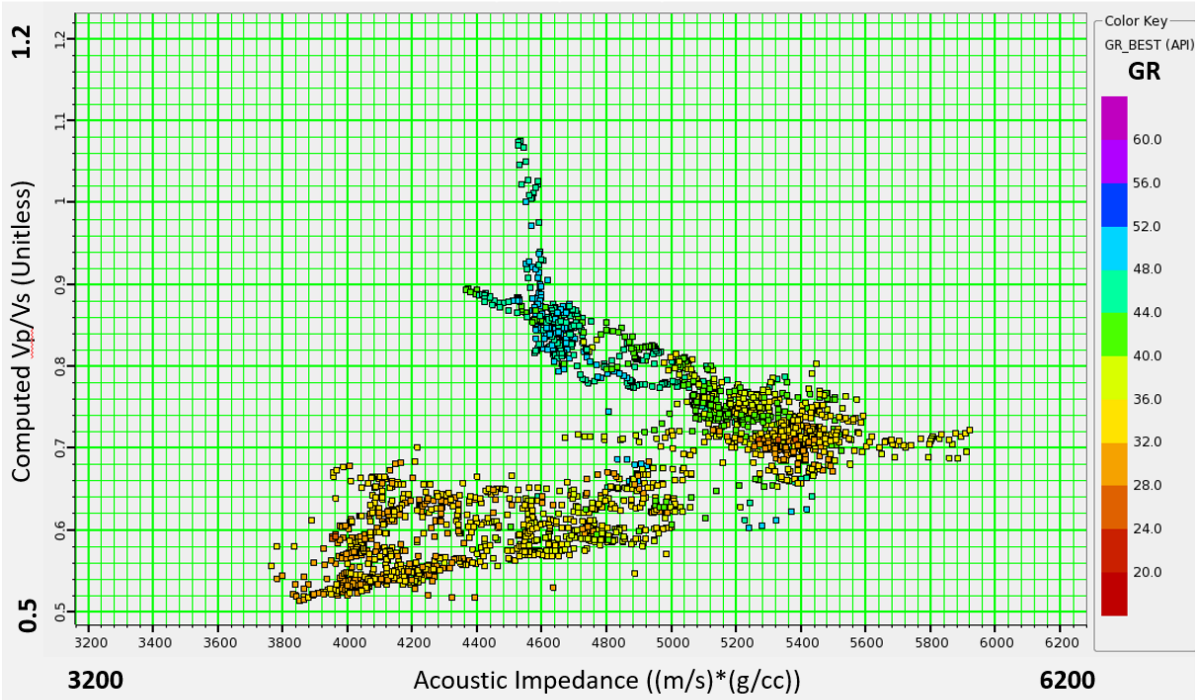

Fig. 7. AI versus computed Vp/Vs. GR log was utilized as color code.

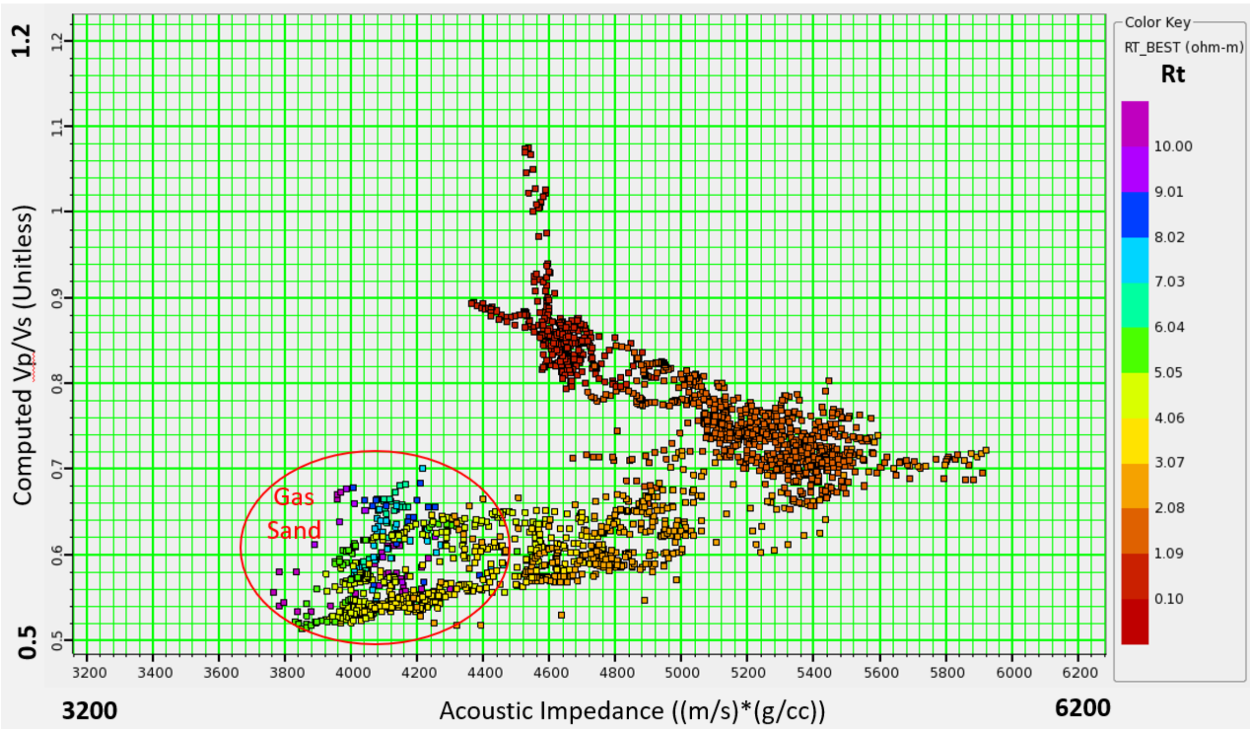

Fig. 8. AI versus computed Vp/Vs. Resistivity log was utilized as color code.

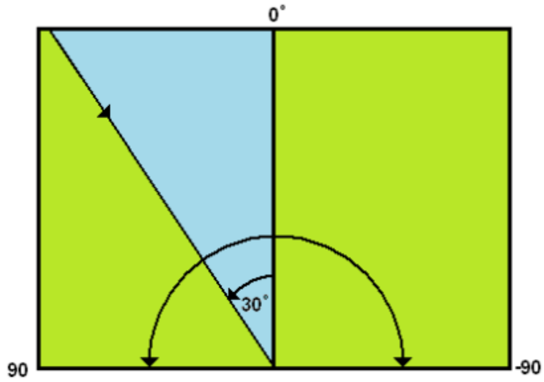

Fig. 9. Range of incident angle versus chi (Hampson and Russell 2005).

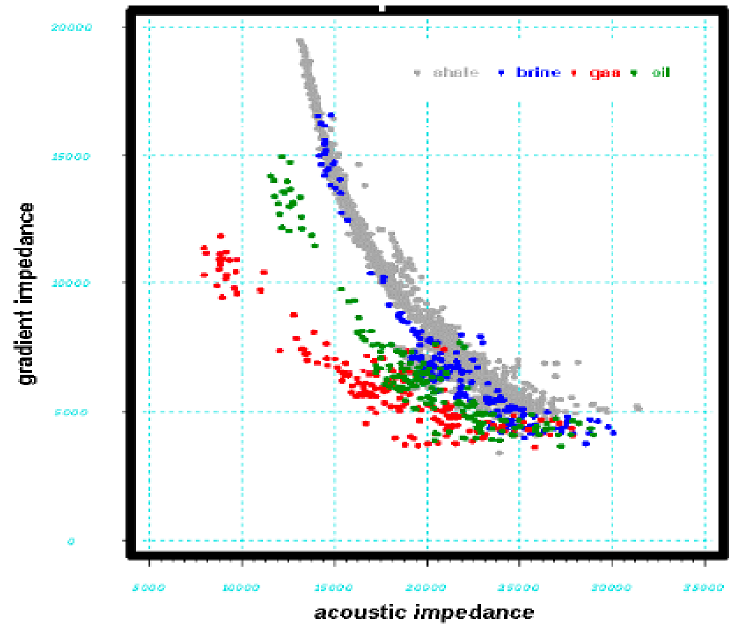

Fig. 10. Acoustic impedance versus gradient impedance crossplot. (Red-Gas Sand, Green-Oil Sand, Blue-Brine Sand, and Grey-Shale) (After Connolly et al. 2002).

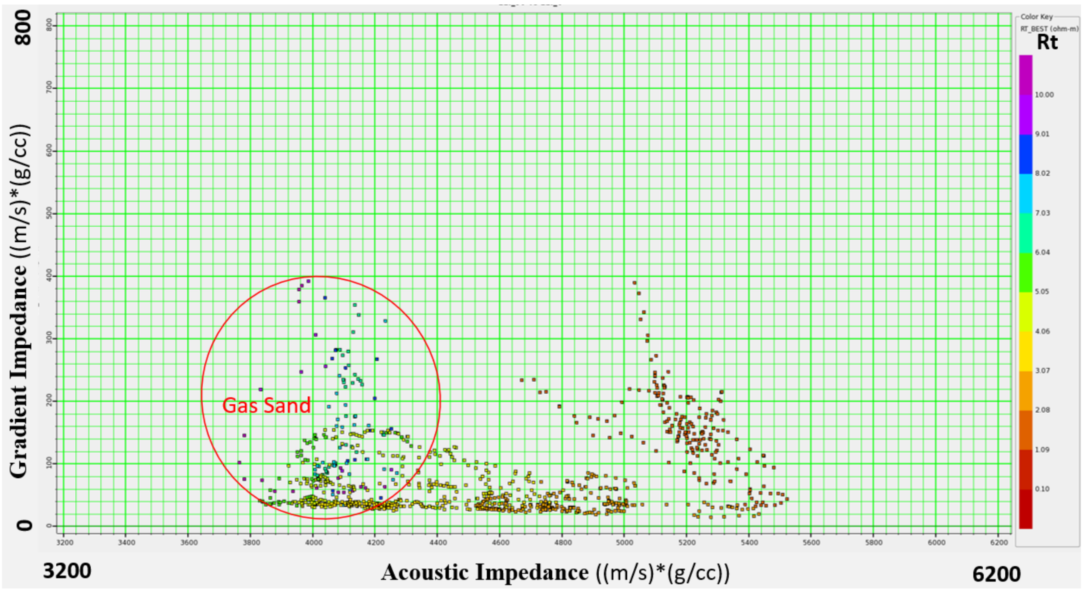

Fig. 11: Acoustic Impedance versus Gradient Impedance crossplot. Resistivity log was utilized as color code.

4. Results and Discussion

Different clusters within the crossplot resemble different lithology and fluids. These clusters can be marked by various colors, which reflect different values of the used attributes. These clusters will provide straightforward interpretation for different lithology and fluid content. The crossplot is a good technique in verifying the existence of hydrocarbon accumulation, especially gas. Rockphysics analysis relies on choosing appropriate model and geological information of the reservoir.

This paper is investigating the properties of a Pliocene reservoir, which is located offshore, East Nile Delta. This reservoir is low impedance gas sand. Therefore, AI versus VpVs ratio crossplot and AI versus GI crossplot could clearly discriminate between various lithology and pore fluids. This is due to the enormous difference between the elastic properties of this soft gas sand, brine sand and shales. Greenberg and Castagna 1992 stated that rock has higher VpVs ratio, while hydrocarbons have lower values than saline solutions. This is due to the sensitivity of P-wave velocity to fluid variations, unlike the S-wave. Therefore, AI versus VpVs ratio crossplot is a good indicator for lithology and fluids. This crossplot can help in distinguishing between different lithology and pore fluids. Moreover, Avseth and Veggeland, 2015 mentioned that this crossplot can differentiate between gas sand, brine sand and shale.

AI versus VpVs ratio crossplot (Figure 7) in this case study could successfully differentiate between different lithology when the GR log was utilized as color code. The sand of the reservoir is characterized by low AI and VpVs ratio values due to the presence of gas. Upon using the same crossplot but with Rt log as color code (Figure 8), this helped in discriminating between different fluids, where the gas sand is characterized by high resistivity. The low values of AI and VpVs ratio will signify the gas cluster, while the increase of AI and the decrease of VpVs ratio will signify the cement volume. Upon decreasing the AI and increasing VpVs ratio this will mark increasing in porosity values. Avseth and Wijngaarden in 2006 mentioned that different physical properties will cluster, differentiating between several lithologies and pore fluid.

AI versus GI crossplot (Figure 11) also helped in discriminating between different lithology and different pore fluids. This crossplot was consistent with the results of AI versus VpVs ratio crossplot. The soft gas sand will cluster further from the background shale trend, due to the significant contrast between their elastic properties.

Eventually, the integration of AI-VpVs ratio crossplot (Figures 7 and 8) and AI-GI crossplot (Figure 11) and studying the interrelationship between these elastic parameters, could successfully detect the presence of gas in the reservoir and separate it from the background shale, rather than systematic and conventional log interpretation.

5. Conclusions

Rockphysics application by investigating the interrelationship between VpVs ratio, AI and GI could successfully detect gas and cluster various lithological units of gas sands and shale. This was accomplished by using crossplotting technique of AI versus VpVs ratio, in addition to AI-GI crossplot. GR and resistivity logs were utilized to help in separating different lithology and fluids. The Pliocene reservoir is characterized by soft gas sand and huge contrast in the elastic properties from the brine sand and background shale. RPT helped in clustering various lithology and fluid types instead of regular log interpretation for the reservoir interval.

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6. References

Abdel-Aziz M., 2015, Natural Gas Geochemistry in the Offshore Nile Delta, Egypt, Advances in Petrochemicals - IntechOpen, Chapter 2.

Andersen, C.F., and Wijngaarden, (2007). Interpretation of 4D AVO inversion results using rock physics. Templates and virtual reality visualization. In: North Sea examples: 77th Annual International Meeting, SEG, Expanded Abstracts, 77: 2934–2938.

Avesth P., Mukerji T., Mavko M., and Dvorkin J., (2010). Rock Physics diagnostics of depositional A review of texture, diagenetic alterations, and reservoir heterogeneity in high porosity siliciclastic sediments and rocks-selected models and suggested workflows. Geophysics, 75: 5: A31-A47. DOI: 10.1190/1.3483770.

Avseth P, and Veggeland T., (2015). Seismic screening of rock stiffness and fluid softening using rock physics attributes. Interpretation 3:85–93. DOI:10.1190/INT-2015-0054.1

Avseth P. Wijngaarden A.J., Mavko G., and Johansen T.A., (2006). Combined porosity, saturation and net to-gross estimation from rock physics templates: 76th Annual Meeting, SEG, Expanded Abstracts: 1856–1860.

Avseth, P., Mukerji, T., and Mavko, G., (2005). Quantitative Seismic Interpretation-Applying Rock Physics Tools to Reduce Interpretation Risk. Cambridge University Press, 376p. DOI: 10.15413/ajsr.2018.0102

Azzam A., (1994). An integrated seismo-facies and seismo-tectonic study of the Nile Delta Egypt, utilizing common-depth seismic reflection data: Ph.D. Thesis, Geology department, Faculty of Science, Ein Shams University, Cairo, Egypt, 240 p.

Barakat M., 1982, General review of the petroliferous provinces of Egypt with special emphasis on their geological setting and oil potentialities: Geology department, Faculty of Science, Cairo University, Cairo, Egypt, 87 p.

Brian Russell B., (2013). A Gassmann-consistent rock physics template. CSEG RECORDER p.22-30

Castagna, J. P., Swan, H.W., 1997. Principles of AVO crossplotting. The Leading Edge, 16, 337-342.

Connolly P., Schurter G., and Davenport M., (2002). Imaging and Quantifying Turbidite Sand Systems in Deep-water Angola using Extended Elastic Impedance. Offshore Technology Conference OTC 14144 p.1-7.

Deibis S., Futyan A.R.T., Ince D.M., Morley R.J., Seymour W.P., Thompson S., 1986, The stratigraphy framework of The Nile Delta and its implications with respect to the region's hydro- carbon Potential. EGPC, Eighth Exploration Conference Centenary of first oil well, Nov. 7–23, 15 p.

Dvorkin J., (2008), Seismic reflections of rock properties: Stanford University – presentation, 1.1-1.16

Dvorkin J., (2008), Seismic reflections of rock properties: Stanford University – presentation, 1.1-1.16

Effat A., and El Gezeiry M., 1986, New aspects for Abu Qir stratigraphic and sedimentologic model: Wepco, P.O. Box 412, Alex., Egypt.

El-Gendy, N.H., El-Nikhely, A.H., Zakaria, A.H., Hellish, H.M., Nabawy, B.S., Barakat, M. Kh., 2023. Pre-Stack Imaging for the Messinian Sub Salt Sequences in the Levantine Basin of the East Mediterranean: A Case Study, Offshore Lebanon. The Iraqi Geological Journal (2023): 1-18

El-Shahat W., (2018). Characterization of the Upper Rudies Reservoir Rocks using Elastic Attributes and rock Physics Templates. Academia Journal of Scientific Research 6(4): 127-133.

Gerlitz K., (2004). Implementing Extending Elastic Impedance, Hampson Russell Software.

Greenberg M.L. and, Castagna J.P., (1992). Shear-wave velocity estimation in porous rock: theoretical formulation, preliminary verification and applications Geoph. Prosp. 40: 195-209.

Hampson Russell software services Ltd, (2004), Cross plots, 1-38, accessed on 22 Januray 2011ftp://ftp.hampson-russell.com/pub/manuals/xplot.pdf

Hampson, D. And Russell, B. (2005). AVO Fluid Inversion, Uncertainty In AVO: How Can We Measure It? Hampson Russell Software, Calgary.

Hampson, D. And Russell, B., (2005). AVO Fluid Inversion, Uncertainty In AVO: How Can We Measure It? Hampson Russell Software, Calgary. http://dx.doi.org/10.1017/ CBO9780511600074.

Hussein M., Abu El-Ata A., El-Behiry M, (2020). AVO analysis aids in differentiation between false and true amplitude responses: a case study of El Mansoura field, onshore Nile Delta, Egypt. Journal of Petroleum Exploration and Production Technology. Vol.10, 969-989.

Ismail, A., Ewida, H. F., Al-Ibiary, M. G., Gammaldi, S., & Zollo, A. (2020). Identification of gas zones and chimneys using seismic attributes analysis at the Scarab field, offshore, Nile Delta, Egypt. Petroleum Research, 5(1), 59-69.

Matresu J., Talaat A., El Belasy A., El-Meadawy M., (2013). Pre-Messinian Extensional Tectonics and Exploration Potential of Related Structures in Central Nile Delta Basin, Egypt. SPE North Africa Technical Conference and Exhibition, Cairo, Egypt. 15-17 April 2013.

Mosconi A., Rebora A., Venturino G., Bocc P., Khalil H., (1996). Egypt-Nile Delta and North Sinai Cenozoic Tectonic Evolutionary Model a proposal. Egyptian

General Petroleum Corporation, 13th Exploration Seminar 1: 203-223.

Nssir N.,Al-Banna A., Al-Sharaa G., (2020). The Using of Vp/Vs Ratio and P-Impedance for Differentiate Both Fluid Sand Lithology Depending on Rock Physics Templates Model of Mishrif and Nahr Umr Formations in Kumait and Dujaila Oil Fields Sothern Iraq. Bulletin of Pure and Applied Sciences, Vol.39F, No.2, P.285-300. DOI: 10.5958/2320-3234.2020.00025.6

Odegaard E. and Avseth P., (2004). Well log and seismic data analysis using rock physics templates. First Break. Volume 23, p.37-43.

Odegaard, E. and Avseth, P., (2003). Interpretation of Elastic Inversion Results UsingRock Physics Templates: EAGE, Expanded Abstracts, E17.

Othman A., Fathy M., Ali I., (2021). Application of Artificial Neural Network in seismic reservoir characterization: a case study from Offshore Nile Delta. Earth Science Informatics 14(2) DOI:10.1007/s12145-021-00573-x

Rizzini A., Vessani F., Cococetta V., and Milad G., 1978, Stratigraphy and sedimentation of Neogene-Quaternary section on the Nile Delta area – Marine

Samuel A., Kneller B., Raslam S, Andy S., Parsons C.,2003, Profilic Deep-marine Slope Channels of the Nile Delta, Egypt. AAPG (American Association of Petroleum Geology). Bull. 87, 541-560.

Sarhan M., Hemdan K., (1994). North Nile Delta structural setting and trapping mechanism, 12th Petroleum Exp. & Prod. Conf., 1, 18.

Schlumberger, (1989), Log interpretation principles/applications, Seventh printing 1998, 1.1 – 13.19

Shuey R., (1985). A simplification of the Zeoppritz equations: Geophysics, Vol. 50, No.4, 609-614.

Souilam N., El-Nagar A., Ali A., Shehab, S, (2025). Integrating petrophysical characterization and reservoir evaluation of the Kafr ELSheikh formation in Sapphire field, Nile Delta, Egypt. Scientific Reports volume 15, Article number: 4555.

Tassy A., Crouzy E., Jean-Loup G., (2015). Egyptian Tethyan margin in the Mesozoic: Evolution of a mixed carbonate-siliciclastic shelf edge (from Western Desert to Sinai). Marine and Petroleum Geology 68, 565-581 DOI:10.1016/j.marpetgeo.2015.10.011

Vandre C., Cramer B., Gerling P., and Winsemann J., (2007). Natural gas formation in the western Nile delta (Eastern Mediterranean), Thermogenic versus microbial: Science Direct – ELSEVIER, Vol. 38, 523-539.

Whitecombe, D. (2002). Elastic Impedance Normalization. Geophysics, 67(1), 60-62. www.Rockphysicists.org Rock physics introduction, accessed on 17 December 2011;

العلاقة بين نسبة السرعات، المقاومة الصوتية، المقاومة المتدرجة لتحديد صفات الخزان، الجزء البحري، شرق دلتا النيل، مصر

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تعتبر مرحلة الفصل بين الصخور والموائع المختلفة مهمة في توصيف الخزان. تقنية رسم البيانات هي خطوة أساسية في تحليل فيزياء الصخور ودراسة العلاقة بين المعاملات المرنة المخلتفة. ساعدت دراسة العلاقة بين نسبة سرعات الموجات، الممناعة الصوتية والممناعة المتدرجة في التفسير المباشر لتحديد الغاز، حيث أن الصخر والموائع لهم تأثير كبير على تحليل الخزان. تم تحقيق هذا بنجاح على خزان كائن على الساحل الشرقي في دلتا النيل، مصر. ساعد الرسم البياني للمناعة الصوتية ونسبة السرعات لفصل الصخور والموائع، حيث أن الطبقة الرملية المشبعة بالغاز سوف تتكتل في الجزء ذو القيم القليلة في الرسم البياني. تجتمع السمات الفيزيائية المتشابهة سوياً في مجموعات موحدة، وذلك سوف يساعد في عملية فصل الصخور والموائع. أستطاع أيضاً الرسم البياني للممناعة الصوتية والتدريجية للفصل بين الطبقة الرملية المشبعة بالغاز وطبقة الطفلة، حيث أن الطبقة الرملية المشبعة بالغاز ستحيد عن إتجاه الطفلة. أخيراً، تساعد نماذج فيزياء الصخور في توفير معلومات عن صفات الخزان بدلاً من الطرق التقليدية لتفسير تسجيلات اللآبار.