The Dhaka University Journal of Earth and Environmental Sciences, Vol. 11 (2): 2022

Characterization of The Reservoir Hydrocarbon Zones in Offshore Angola Field Using Well Log Data

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Manuscript received: 17 January 2023; accepted for publication: 06 April 2023

ABSTRACT: The study uses data from the Girassol-1 and Girassol-2A wells, which have been utilized to describe the reservoir hydrocarbon zones in the offshore Angola field, to characterize the reservoir via formation evaluation. In petrophysical analysis, the physical characteristics of the subsurface formation and how they interact with the fluid content are often of utmost importance. The main factors employed in reservoir characterization include lithology, porosity, permeability, shale volume, water saturation, reservoir geometry, and reservoir heterogeneity. The pay zones of the reservoir are identified, and their petrophysical characteristics are described using publicly available well-log data from the prolific hydrocarbon province Girassol of offshore Angola. The net-to-gross thickness ratio of the reservoir ranges from 77% to 94%. The effective porosity of the pay zones varies from 26% to 29%, whereas the permeability ranges from 278-471mD. The shale volume ranges from 9%-17%, and the overall water saturation ranges from 17% to 45%. The general petrophysical properties reveal that the Girassol Field contains excellent reservoirs. Water saturation estimates are indicative of hydrocarbon charges throughout the pay zone. The findings, including reservoir characteristics of offshore Angola, may help take strategy for further development, enhanced production, and exploring yet-to-find gas reserves in this area in general and implementing the acquired knowledge in hydrocarbon exploration of Bangladesh in particular.

Keywords: Reservoir Characterization; Shale Volume; Net-to-Gross; Pay Zone; Offshore Angola

INTRODUCTION

In recent years, there has been an increase in the "energy demand" of the world due to industrial development and population growth. An energy crisis is inevitable due to a significant gap between an ability of a nation to supply and its demand to meet economic growth. Girassol is one of the largest offshore complex turbidite reservoirs of Angola (Roggero et al., 2007). With an estimated daily production of 1.55 million barrels of oil and 17,904,5 million cubic feet of natural gas, Angola has been the second-most compliant member of OPEC. Exploration wells have found numerous reservoirs in the deepwater turbiditic sands of Angola (Davenport, 2004). Fifty blocks make up the oil-rich continental shelf off the coast of Angola. Block 17 is called a "Golden Block" because its highly productive oil fields represent the third largest prolific block of Angola (Lefeuvre et al., 2003). There are ten discoveries in Block 17, and the studied field Girassol is one of them. The total proven reserves of the Girassol oil field are around 700 million barrels, and the production is approximately 200,000 barrels per day from 8 wells.

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DOI: https://doi.org/10.3329/dujees.v11i2.68864

However, oil fields are becoming more mature and rapidly approaching depletion in Angola. In its 2018 Oil Report, the International Energy Agency warned that things would get increasingly more accessible with more funding for fresh discoveries. Over the coming five years, the oil production capacity of Angola will decrease to just 1.29 million BPD if no action is taken to encourage new investment. Excellent seismic and log data can build a strong foundation for hydrocarbon exploration of offshore Angola (Bhuiyan, 2009). Therefore, it is crucial to analyze the reservoir to find further potential to extend the life of the hydrocarbon fields. The research aims to evaluate the reservoir characteristics by utilizing petrel software to analyze the wireline log data available for the Girassol-1 and Girassol-2A wells.

METHODOLOGY

Study Area

Offshore Angola Girassol Field, discovered in 1996, is located at the southwest corner of Block 17, situated in the lower Congo Basin of Angola. And 90km away from the coastline of Angola (Angolan Coastline). The prospect area is a large NNW-SSE basin characterized by a deep marine turbidite sequence (Roggero et al., 2012) and an allochthonous salt of the Aptian age. The reservoir is a faulted turtleback anticline within a regional closer (Gonzalez-Carballo et al., 2006). The average seafloor depth is 1350m. This is the first field to produce 17 deepwater blocks of Angola. The oil field is operated and owned by Total Fina Elf SA. Girassol came on stream in December 2001 and reached production in 2002.

Evolution driven by gravity tectonic and hallotectonic forces governs the Girassol Oligocene structure. (Delattre et al., 2004). Three rifting periods between around 145 and 113 million years ago, from the Jurassic to the Cretaceous, can be used to categorize the development of the Angola Basin. The preexisting bedrock is covered in salt after the rifting, and the vast levels of salt in the majority of the basin make it challenging to identify the structures and sedimentary deposits underneath it. Large-scale anoxic episodes that produced organic-rich shales caused the carbonate layer to form roughly 112 million years after the salt layer was first laid down. As the Cretaceous epoch concluded, the Congo River flooded the basin with terrigenous sediments, distinguished by many turbidite formations that mostly supplanted the carbonate deposits. The Walvis Ridge, which stretches hundreds of kilometers into the Atlantic Ocean and the Congo River off the coast of Africa, has significantly impacted much of the sediment from the beginning of the Quaternary to the present day.

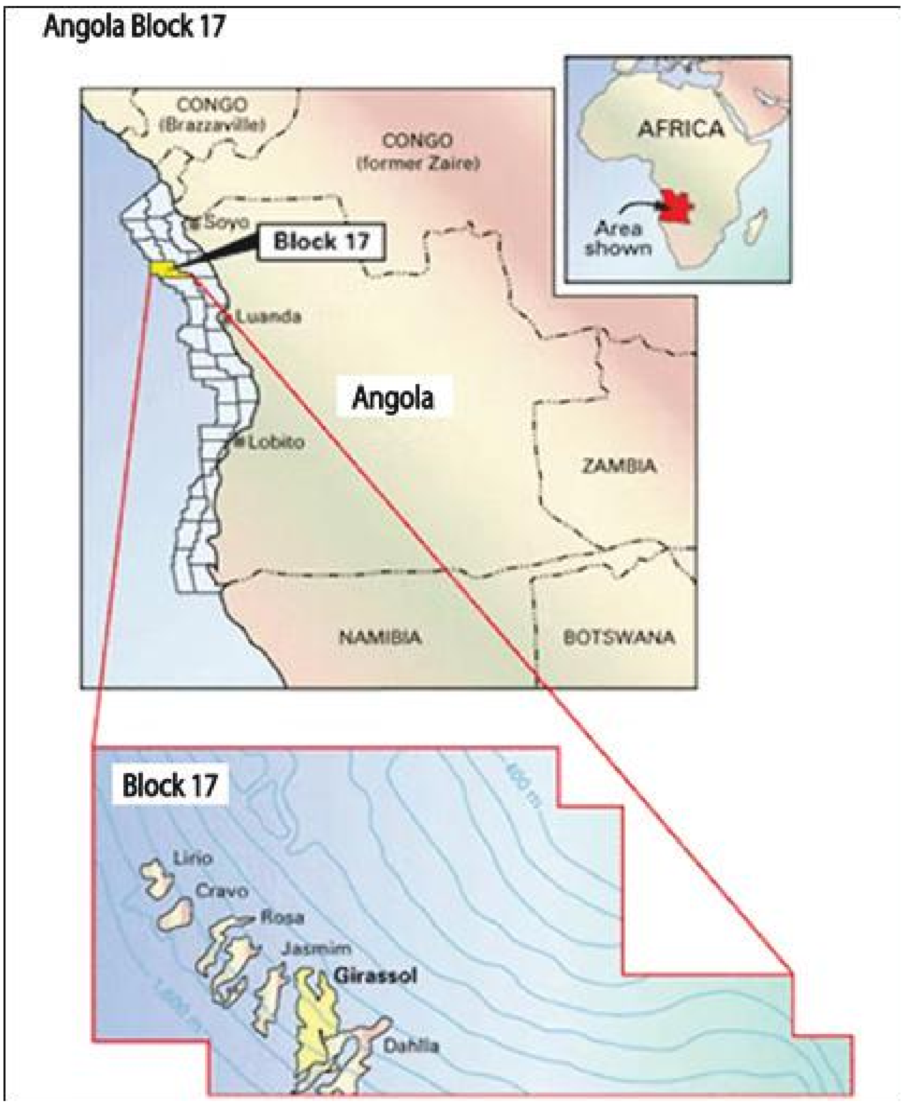

Figure 1: The Location Map of Girassol Gas Field in Angola Shows a Field Located in Block-17. Block-17 is Cropped, and the Position of the Girassol Gas Field is Shown Separately

The two sub-basins are the Lower Congo Basin in the northern section and the Kwanza Basin in the lower portion of the Angola Basin (Bhuiyan, 2009). The Lower Congo Basin, which the Congo River feeds, is chiefly identified by a sedimentary fan covering 300,000 km². The Kwanza Basin can be divided into the inner and outer Kwanza Basins, where the stratigraphic record lacks or only contains a very thin coating of the distinctive salt.

The geography of the Angola Basin is significantly impacted by a large deposit of evaporites known as the "Aptian Salt Basins" (Valle et al., 2001), and a prime illustration of how salt tectonics regulates future sedimentation and reservoir construction is the Angolan margin. The region can be seen from west to east in a profile, with grabens in the east created by listric faults detaching in the salt layer. These structural zones have a northwest-southeast trend, and most salt has been ejected from this area. Salt pods start to form on the high-level listric faults in the middle and may become detached from the triangular salt pedestals beneath them (Valle et al., 2001). Last but not least, salt domes grow in the southwest from the original salt layer up to shallow levels, but significant listric faulting continues to determine where they appear (Guevara et al., 2009).

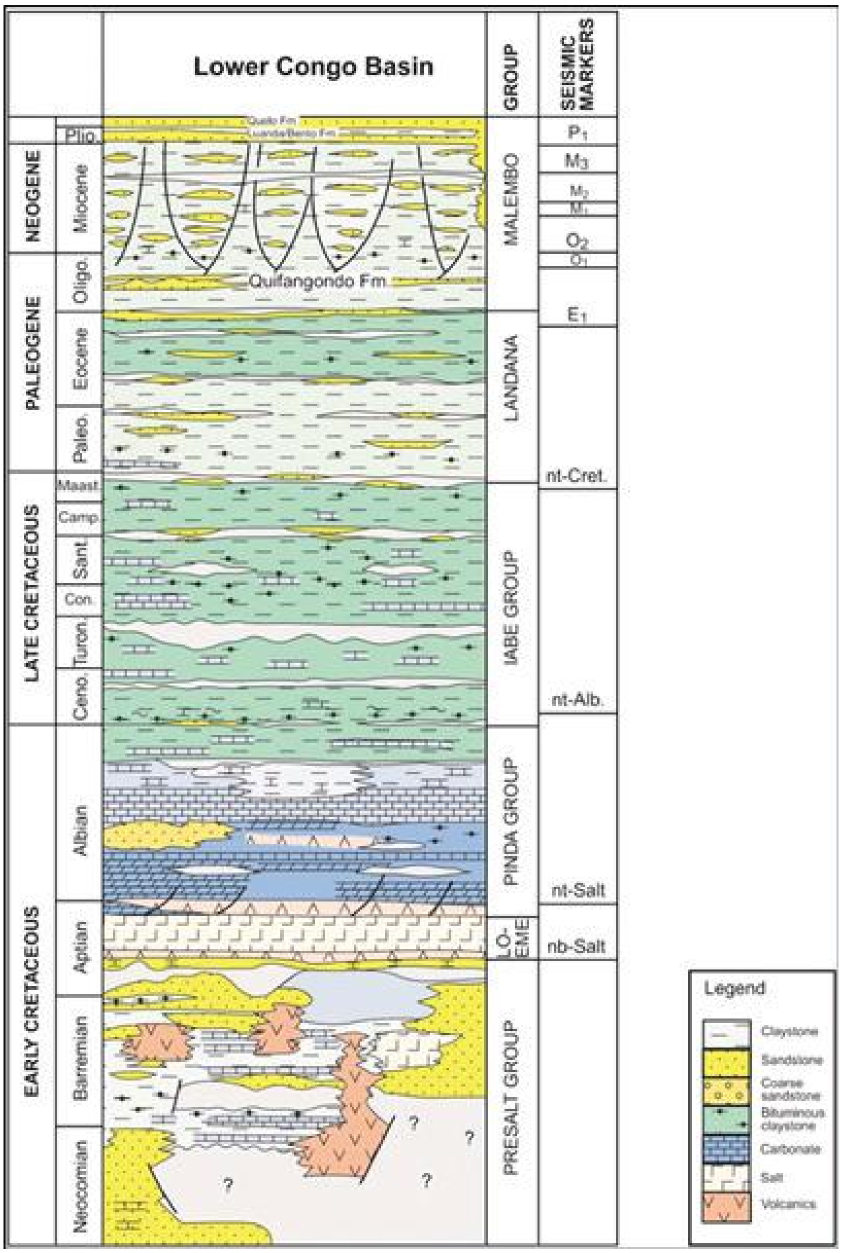

Figure 2: Stratigraphy of Lower Congo Basin of Angola Basin. The Geological Time Records are Shown in the Left Column of the Table, Followed by a Lithological Description, Groups, and Seismic Markers. Different Symbols Display Lithological Descriptions in the Lower Right of the Figure (Valle et al., 2001)

Conglomerate sediment packages, alluvial sandstones, and potentially shallow marine shales have been deposited above the breakup unconformity. These sediment packages have an overall transgression character reflecting marine invasion and are immediately buried beneath heavy salt deposits (Marton et al., 2000). Early drift was characterized by thermal subsidence, which created shallow marine shelf conditions that eventually gave rise to a carbonate platform, and these carbonates make the primary reservoir rock. Sporadic anoxic bottom water conditions occurred when a good source rock interval was produced during the Early-Mid Aptian. Erratic anoxic bottom water conditions occurred when a good source rock interval was created during the Early-Mid Aptian (Tuenza Fm, Kwanza Basin, Gjelberg and Valle, 2003). A regional unconformity marks the transition from the Eocene to the lower Oligocene, and between the Oligocene and the Miocene, there were multiple occurrences of regional pause. Calcareous to non-calcareous claystone, siltstone, mudstone, and sandstone comprise most sedimentary sequences from the Oligocene, Miocene, and Pliocene. The extensive tilting of the Oligocene of the basin bottom and reactivated raft tectonics produced highly sinuous deep marine channels loaded with turbidites and debris flow. Several dense turbidite sands are vital reservoirs (Valle et al., 2001).

Datasets

In evaluating a petroleum reserve, it is necessary to accurately determine the specific petrophysical properties of the reservoir rock. The Girassol gas field log data have been used for this research, and well logs are correlated for identifying the zone of interest. The well-log analysis evaluates parameters such as; lithological units, net-gross ratio, fluid contact, porosity, permeability, water saturation, shale volume, etc. Then petrophysical properties of the reservoir were calculated. Petrel software provided by Schlumberger Inc. is used for this study.

The study has been carried out by using secondary data. Well-log data were in LAS format, and wellhead data were in ASCII format. Data analysis was initially performed in NTNU as part of the MS and Ph.D. of the first Author's thesis works in 2002 and 2010 and, after that, recently in the Department of Geology, University of Dhaka. Wireline log data available for study include Gamma ray logs, sonic logs, Caliper logs, Deep Resistivity logs, and Porosity logs (neutron and density logs). Wellhead data has been prepared according to the format by including the names Y (northing), X (easting), Kelly Bushing (KB), and TD in Measured Depth (MD) of the wells. Wellhead data are created with an Excel sheet in space delimited format (ASCII) and are imported as wellhead. AS Girassol-1 and 2A are vertical wells, there were no uses of deviation data. The available conventional logs stated earlier have been interpreted in petrel software, and the volume of shale, porosity, permeability, and water saturation has been calculated. Together with the conventional logs, these properties have been interpreted into petrel in 'ASCII' format.

Well-log analysis was carried out by lithology identification, well-to-well correlation, hydrocarbon-bearing zone identification, and petrophysical property calculation. In this study, a well correlation is done between two wells of the Girassol field (Fig. 3).

Using petrophysical calculations, the rock and fluid parameters of reservoir sands are ascertained from well logs (Archie, 1942; Darling, 2005; Asquith, 2004).

RESULT AND DISCUSSION

Well Log Analysis

Since thorough coring and core analysis of the entire pay zone is impracticable, critical information and necessary qualities are obtained through well-log interpretation. Among eight wells of the Girassol field, data were available for two wells, Girassol 1 and Girassol 2A. Five Pay sands (A, B, C, D, E) are encountered in Girassol 1, and four (A, B, C, E) are located in Girassol 2A (Fig. 5). The petrophysical analysis is done for Girassol 1 and Girassol 2A. Finally, average petrophysical properties are calculated.

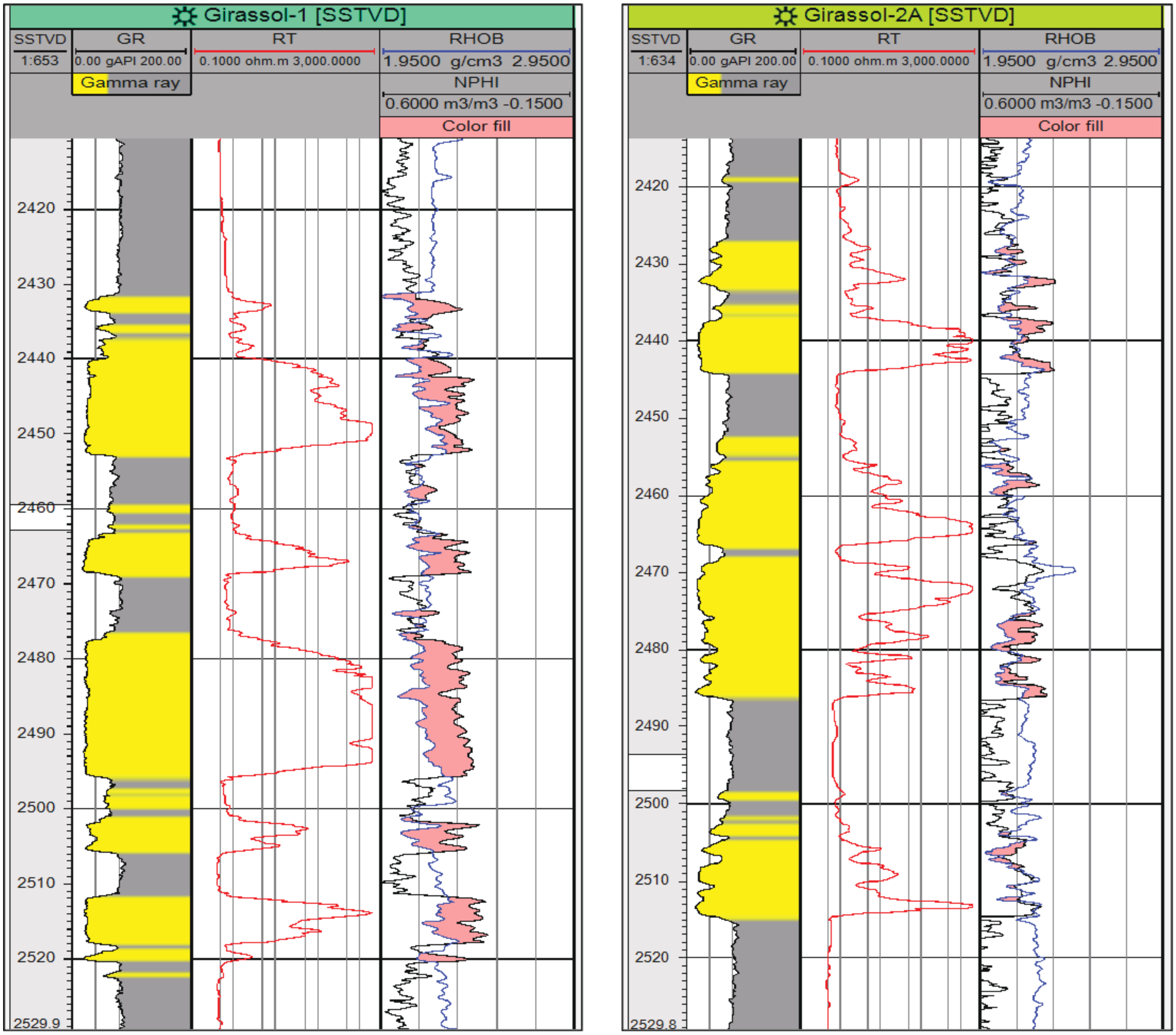

Figure 3: Well-log Data of Girassol-1 and Girassol-2A of Angola Field. The Vertical Thickness is Shown in Meters in the Left Columns of the Figure. The Gamma-ray Logs are Shown in the Second-most Left Columns, Which Characterize the Lithological Variations by Contrast in Color. The Third Column from the Left Displays the Resistivity Log by the Red Curve Lines. The Right-most Column Hows the Cross Plot of the Density Log and Neutron Porosity Log, Demonstrated by Blue and Black Curved Lines, Respectively. The Decrease in Density and Neutron Porosity Logs Indicates Negative Separations Filled with Colors for Better Visualization

Lithology Identification

Neutron-Density logs were plotted on the Y and X axis (Fig. 4), respectively, and gamma-ray on the third axis for the lithology identification. Three types of lithologies had found in the study area. In Well-1, sands with low density-low gamma ray value are separated from shale with higher density and higher gamma ray value in the northeastern part of the cross plot. Comparatively, low porosity and low-density value in the middle part indicate pay sand. By analyzing the wireline log, it was found that gas sand shows a GR range of around 20-60API, 2.1-2.4gm/cc density, while wet sand shows similar GR, but higher density values range 2.4-2.7gm/cc (Fig. 4).

In Well-2A, in the middle of the figure, low-density, low-GR sands are separated from the comparatively high-density, high-GR shale. At the same time, pay sands in Well-2A are indicated by poor porosity and a low-density cluster in the southwest corner of the plot. GR ranges around 20-62API, and density values at 1.92-2.07gm/cc are observed in pay sands.

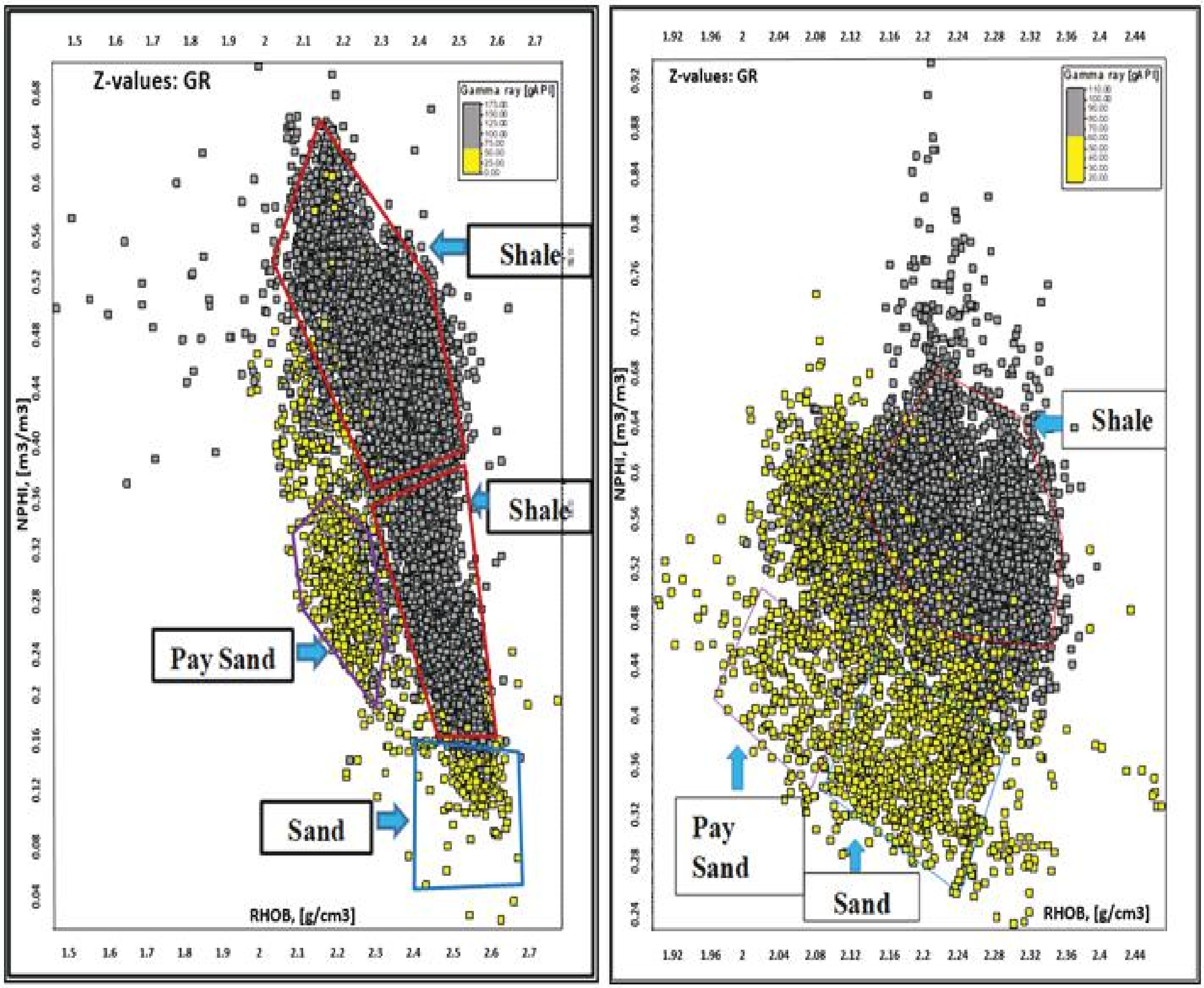

Figure 4: Cross Plot of Girassol-1 and Girassol-2A Wells Using Neutron Log Along the Y-axis, Density Log Along the X-axis, and Gamma-ray Log Along the Z-axis. The Distinct Lithological Variations Helped to Differentiate the Shale and Sand Portions and the Pay Sand Zones

Hydrocarbon Bearing Zone Identification

Gamma (GR), resistivity (RT), neutron (NPHI), and density (RHOB) logs were used to determine the hydrocarbon-bearing zones of Girassol-1 and 2A based on the extremely high values of the deep resistivity logs compared to water-bearing zones, low values of GR log, very low density, and neutron log response. Oil has stood out in the neutron-density combination, producing a significant negative separation as the neutron log indicates limited porosity due to the presence of hydrocarbon.

Five hydrocarbon-bearing zones are identified in Girassol-1 at the depth ranging from 2431.71-2452.83m; 2463.29-2468.89m; 2476.39-2495.77m; 2501-2505.62m; 2511.55-2520.40m, respectively (Fig. 5).

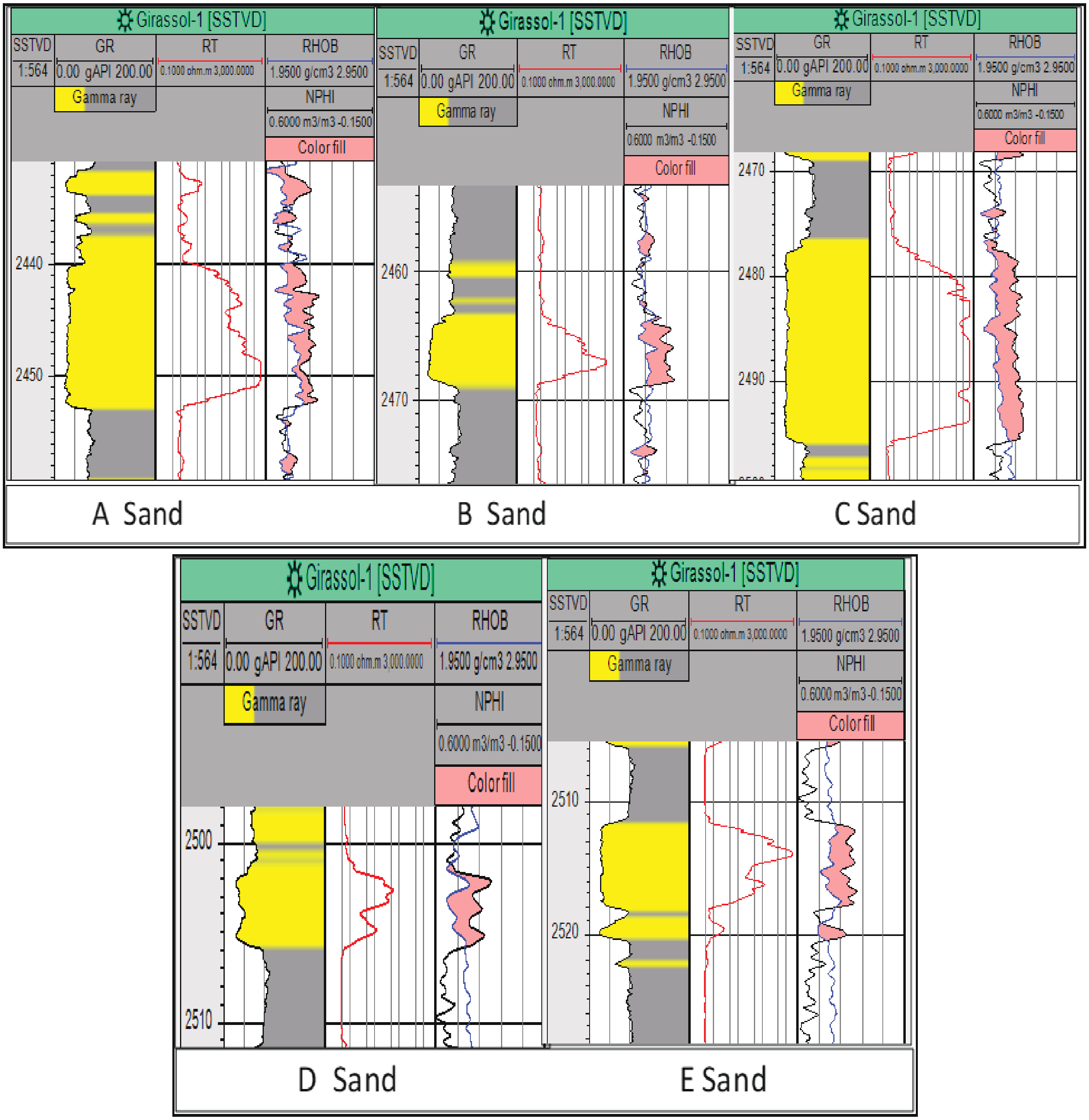

Figure 5: Hydrocarbon Bearing Zones of Girassol-1 Well. The Sand Units are Displayed Separately as A, B, C, D, and E Sands Characterized by the Gamma-ray Log (In the Second Left Columns) for Better Understanding. The Vertical Thickness is Shown in Meters in the Left Columns of the Figures. The Third Column from the Left Shows the Resistivity Log Displayed by the Red Line. The Right-most Column Shows the Cross Plot of the Density Log and Neutron Porosity Log Displayed by Blue and Black Curved Lines, Respectively. The Decrease in Density and Neutron Porosity Logs Indicates Negative Separations Filled with Colors for Better Visualization

Four hydrocarbon-bearing zones are identified in Girassol-2A at the depth ranging from 2427.20-2444m, 2452.83-2466.72m, 2467-2486m, and 2501-2515m, respectively (Fig. 6). Here D sand is absent in Well-2A. The different depositional environments could cause the absence of D sand in this well.

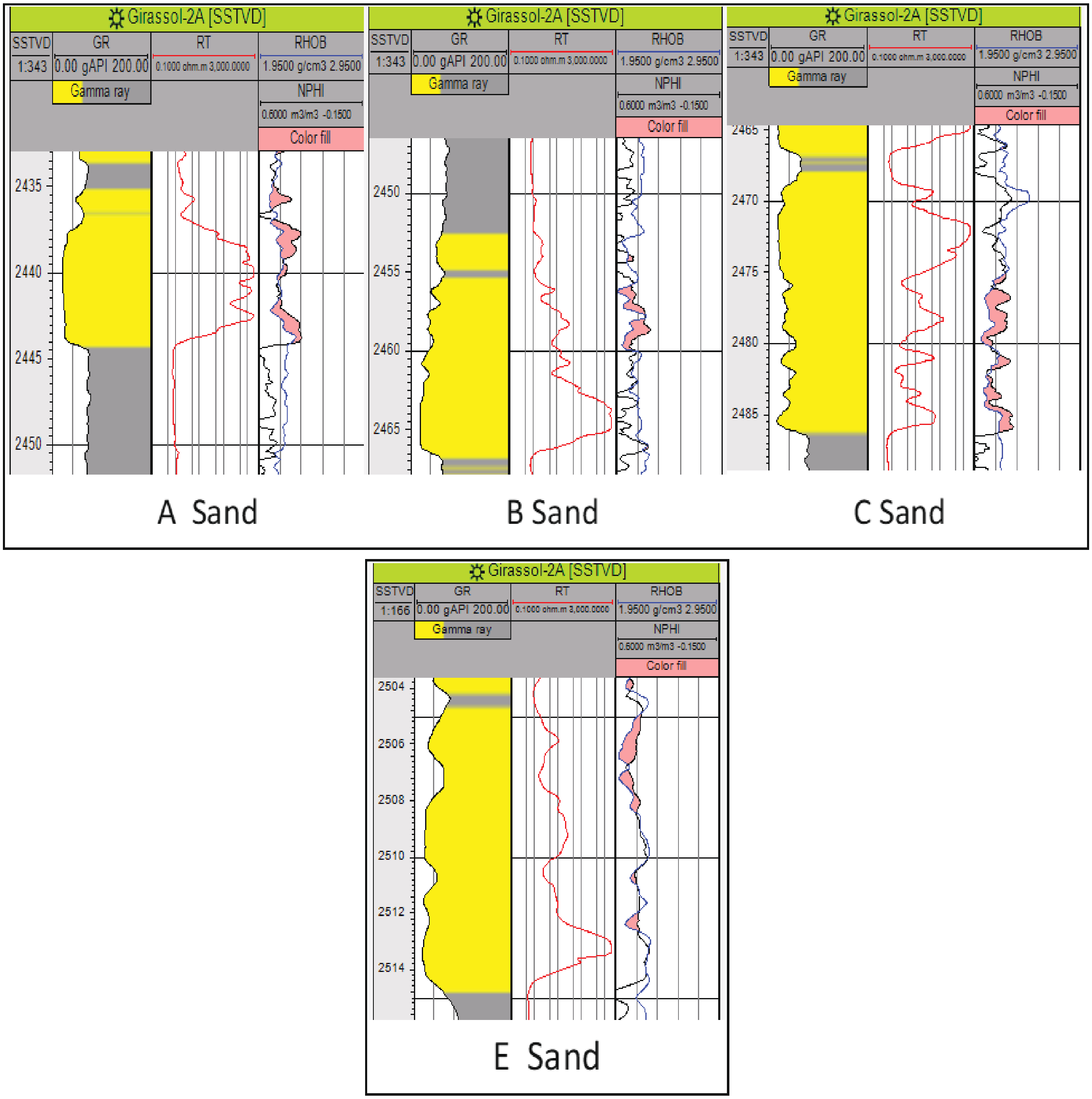

Figure 6: Hydrocarbon Bearing Zones of Girassol-2A Well. The Sand Units are Displayed Separately as A, B, C, D, and E Sands Characterized by the Gamma-ray Log (In the Second Left Columns) for Better Understanding. The Vertical Thickness is Shown in Meters in the Left Columns of the Figures. The Third Column from the Left Shows the Resistivity Log Displayed by the Red Line. The Right-most Column Shows the Cross Plot of the Density Log and Neutron Porosity Log Displayed by Blue and Black Curved Lines, Respectively. The Decrease in Density and Neutron Porosity Logs Indicates Negative Separations Filled with Colors for Better Visualization

Well Correlation

Well correlation has been made from available log data. The gamma-ray log is the primary tool to identify lithology. Resistivity log, Neutron density negative separation were also used to correlate two wells of the Girassol field. Well correlation is carried out from SW direction to NE direction. Well-1 was drilled in the South Western part, whereas Well-2A was in the North Eastern region.

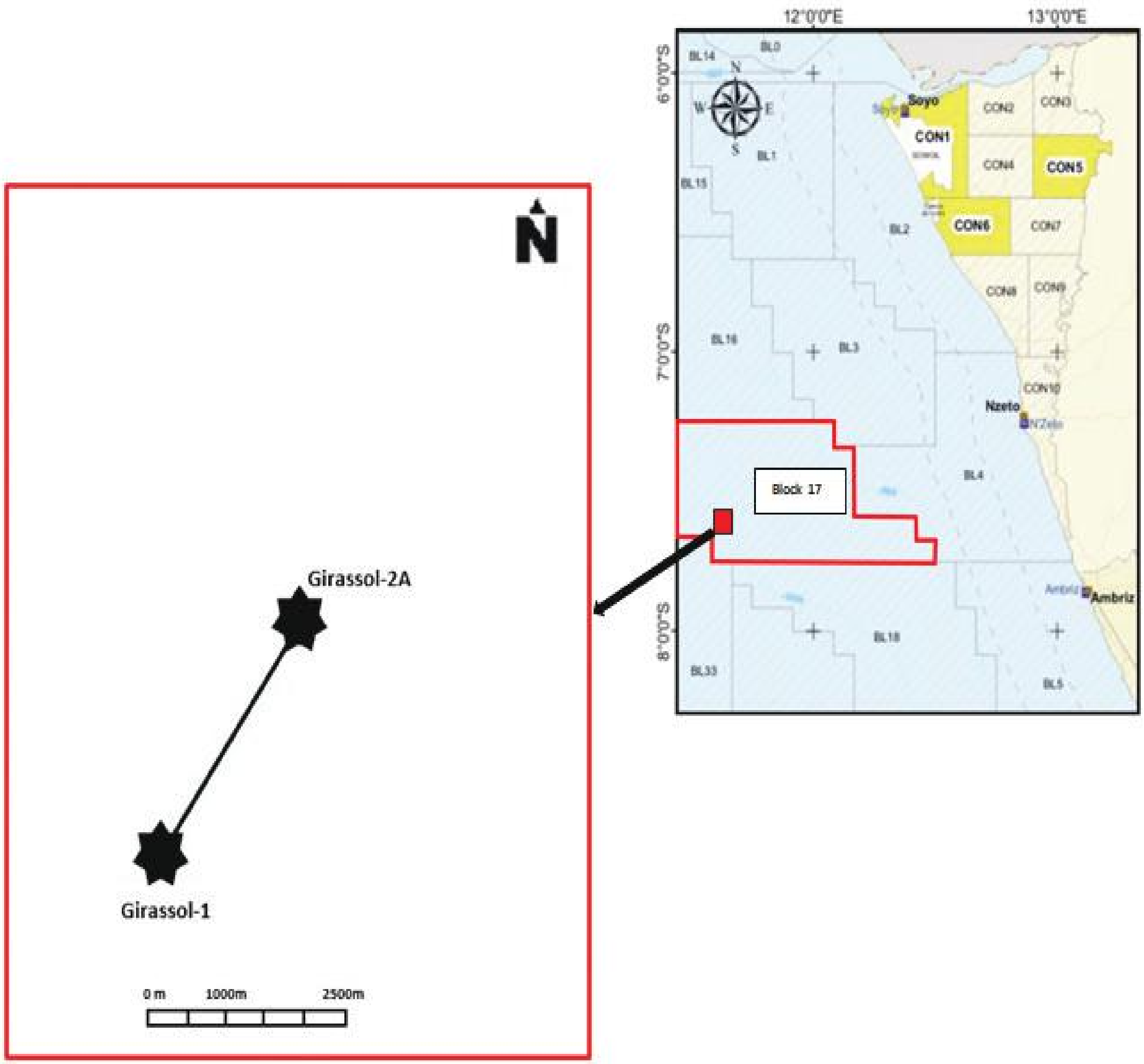

Figure 7: Location Map of Girassol-1 and Girassol -2A Showing Correlation Direction from S-N. The Image on the Right Shows the Offshore Angolan Blocks, While the Image on the Left Shows the Locations of the Girassol-1 and Girassol-2A Wells

Correlation of Pay Sands

The depth interval of the pay sands of two wells is given in Table 1. As mentioned earlier, five zones have been identified.

Table 1: The Depth Interval of Pay Sand of Girassol-1 and Girassol-2A Wells. The Depth Values in the Meter are SubSea True Vertical Depth (SSTVD). The Top and Base Values Determine the Thickness of the A, B, C, D, and E Pay Sands in the Girassol-1 Well and the A, B, C, and D Pay Sands in the Girassol-2A Well

Well	Girassol-1		Girassol-2A	
	SSTVD m		SSTVD m	
Pay Sand	**Top**	**Base**	**Top**	**Base**
A	2431.71	2452.83	2427.20	2444
B	2464.29	2468.89	2455.55	2466.83
C	2476.39	2495.77	2468	2486.29
D	2501	2505.62		
E	2511.65	2518.23	2504.78	2514.66

Markers were found by identifying high GR and low resistivity, then pay sands were determined for all producing wells. The total depths of Well-1 and Well-2A are 2110m and 900m, respectively. The absence of D sand in Well-2A can be interpreted as that a tiny channel might cut D sand in Well-2A, and further, this channel was filled with clay (Fig. 8).

Structural Correlation

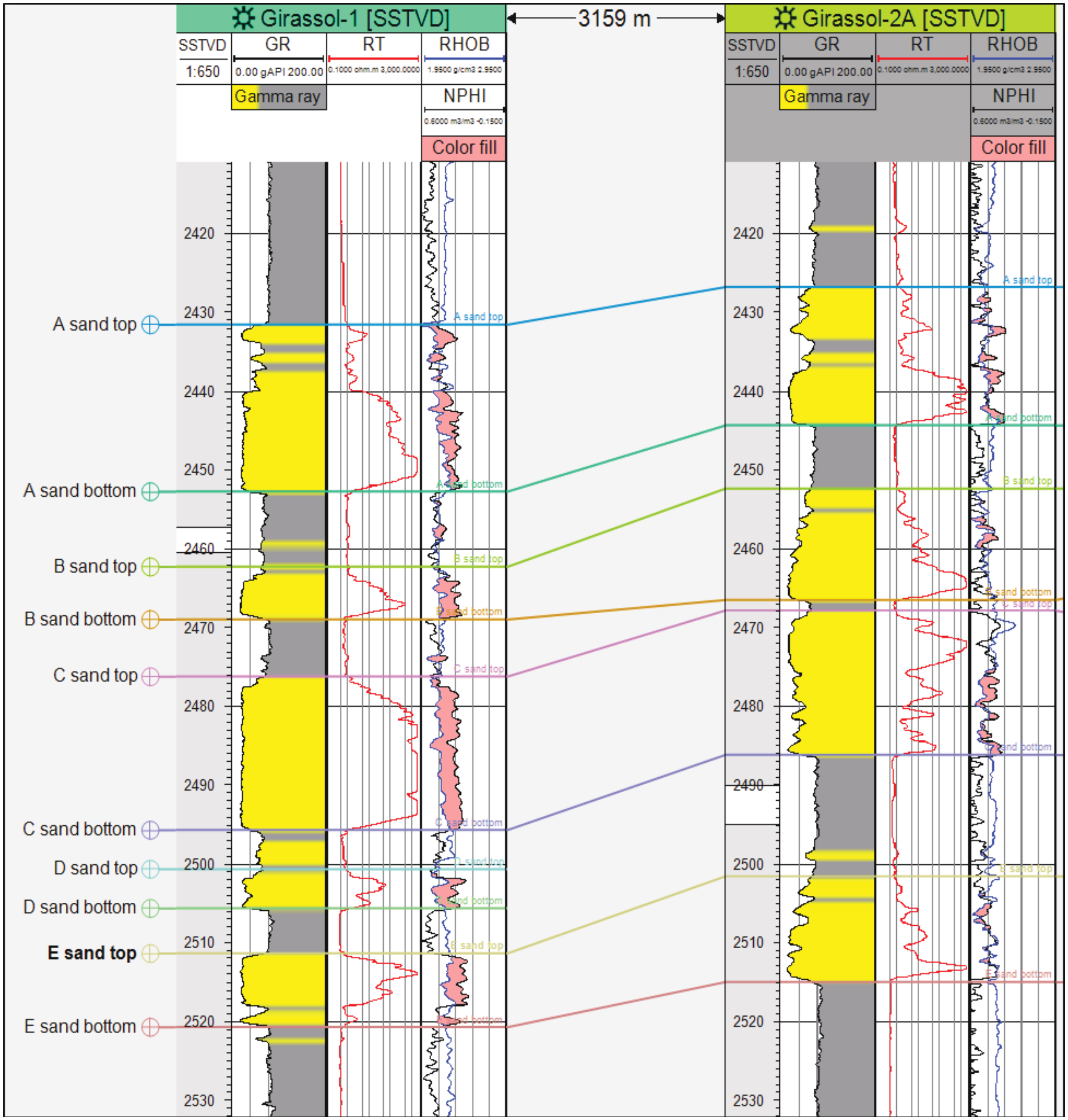

Figure 8: Structural Correlation Among Pay Sands between Well Girassol-1and Girassol-2A. The Sand Tops and Bottoms of A, B, C, and E Pay Sand Zones of Girassol-1 are Correlated with Those of A, B, C, and E Pay Sand Zones of Girassol-2A

Pay sands correlation (Fig. 8) shows that A and C pay sand thicknesses are more or less similar in the two wells. A thick shale layer is observed between C and E sand, which might cause the absence of D sand in

Well-2A. Sand B and E are comparatively thick in Well-2A. The variation of B and E in two wells indicates that pay sands are thinning from NE- SW direction, suggesting that they might be deposited in two different depositional environments.

Petrophysical Analysis of Girassol-1

By analyzing geophysical log data, petrophysical property logs were created to calculate the petrophysical properties of the pay zones of the well.

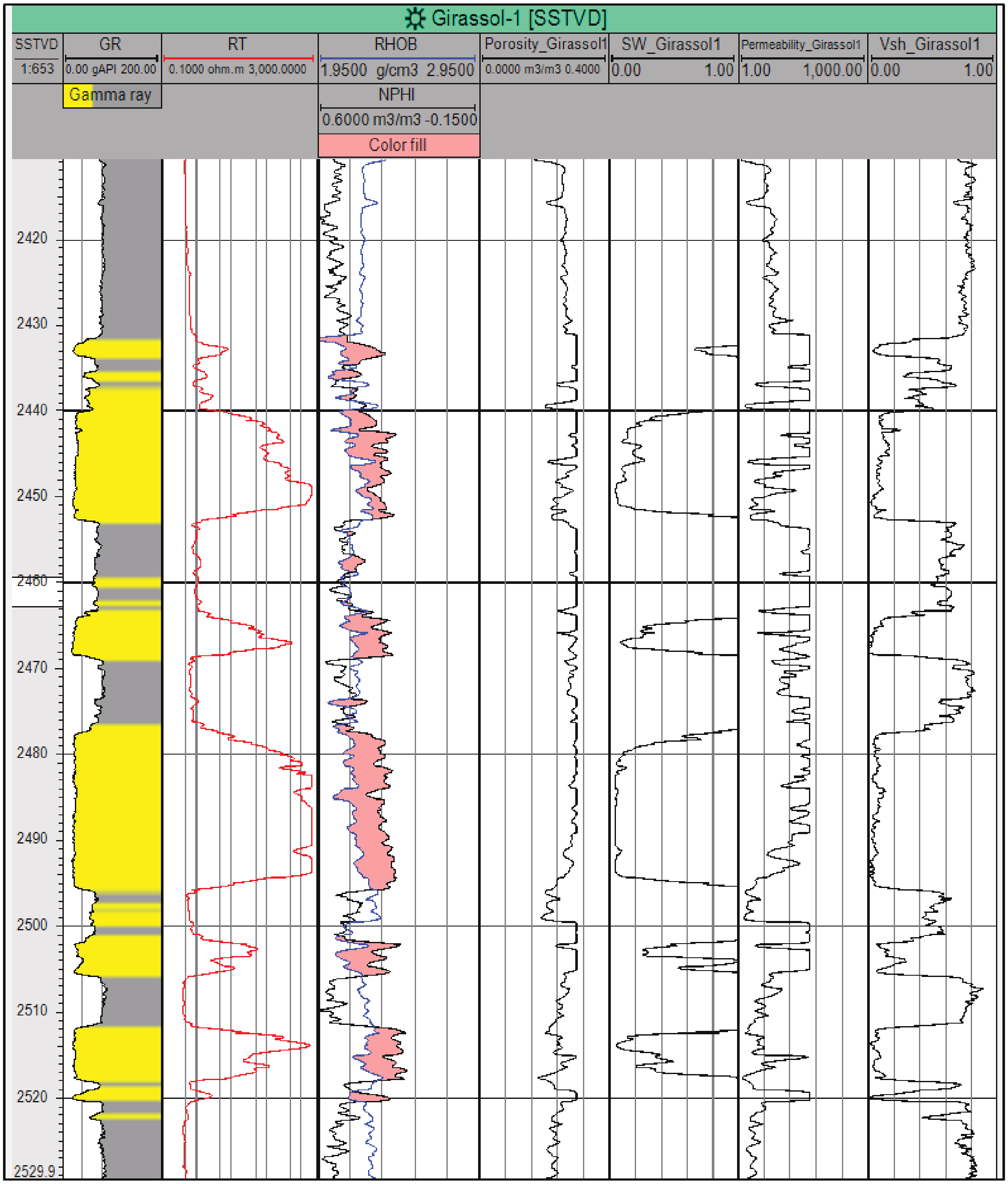

Figure 9: Composite Log Response and Petrophysical Properties of Pay Sands of Girassol-1. From Left to Right, the Columns Display Thickness in Meters, Gamma Ray Log Response, Resistivity Log, the Cross Plot of Density and Neutron Porosity Log, Porosity, Water Saturation (SW), Permeability, and Shale Volume (Vsh), Respectively. The Gamma-ray Logs Characterize the Lithological Variations by Contrast in Color. The Red, Blue, and Black Curve Lines Display the Resistivity Log, Density Log, and Neutron Porosity Log

Porosity

The porosity ranges from 24%-29%, with an average value of 27% in Girassl-1 (Fig. 10). The histogram shows that the maximum porosity of A, B, C, D, and E sands are 31%, 31%, 30%, 31%, and 30%, while minimum porosity is 20%, 23%, and 21%, respectively 23% and 18%. Maximum porosity is shown by B, C, and D sand, and the minimum is shown by E sand. Percentages shown in the ordinates of the figures represent sand portions with their respective porosities.

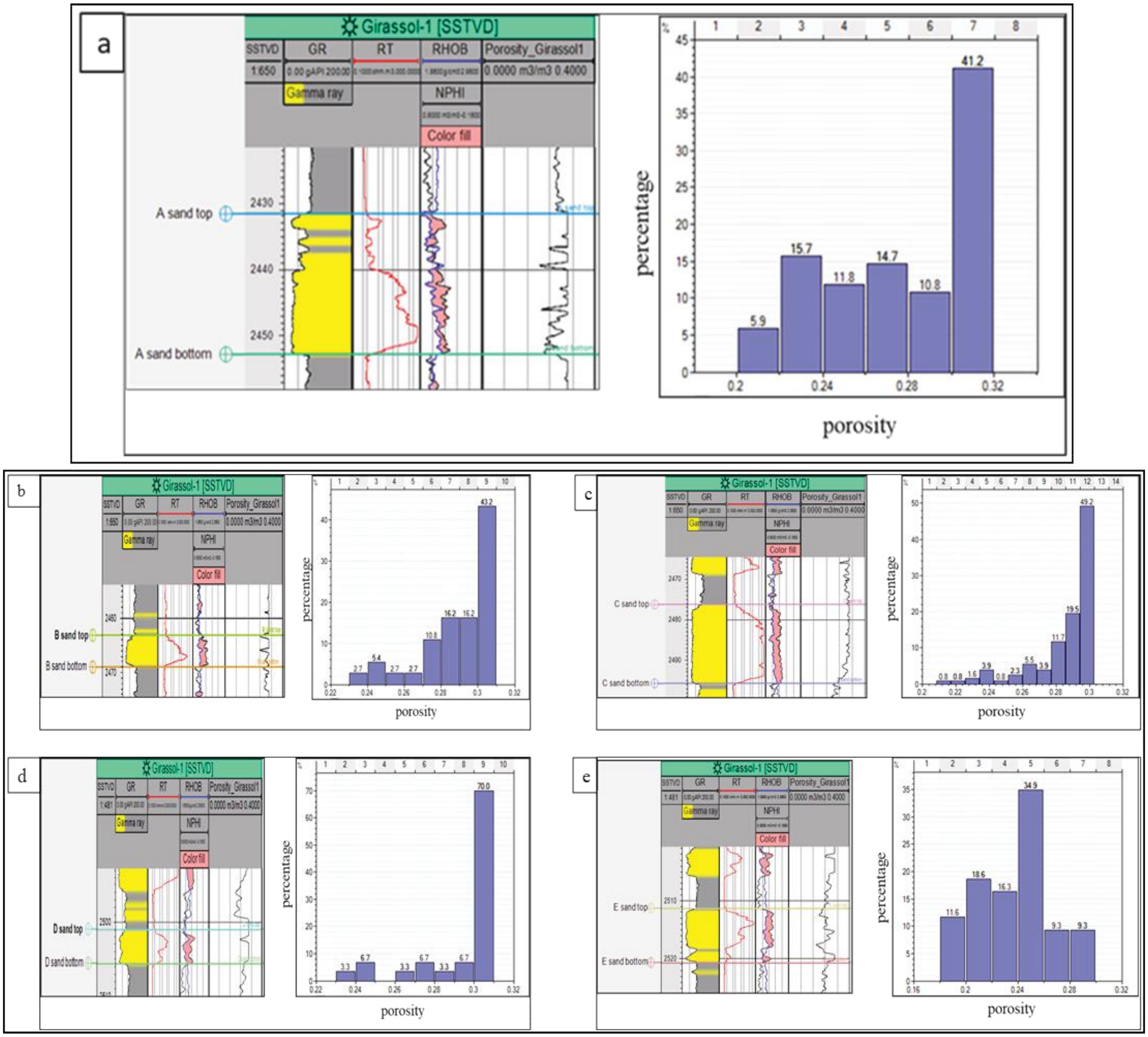

Figure 10: Porosity of A, B, C, D, and E Pay Sand Zones in Girassol-1 is Shown in a, b, c, d, and e in Percentage. The Corresponding Histograms of the Porosity Values are Displayed Beside the Logs

Permeability

Permeability ranges from 167-471mD and shows a good correlation with porosity in the sandstone of Girassol-1. The histogram shows maximum permeability of A, B, C, D, and E sands are 595mD, 598mD, 600mD, 597mD, and 590mD, respectively, while the minimum permeability is 12mD, 100mD, 15mD, 100mD, 11mD, respectively. The maximum value is shown by D sand, and the minimum is shown by E sand (Fig. 11).

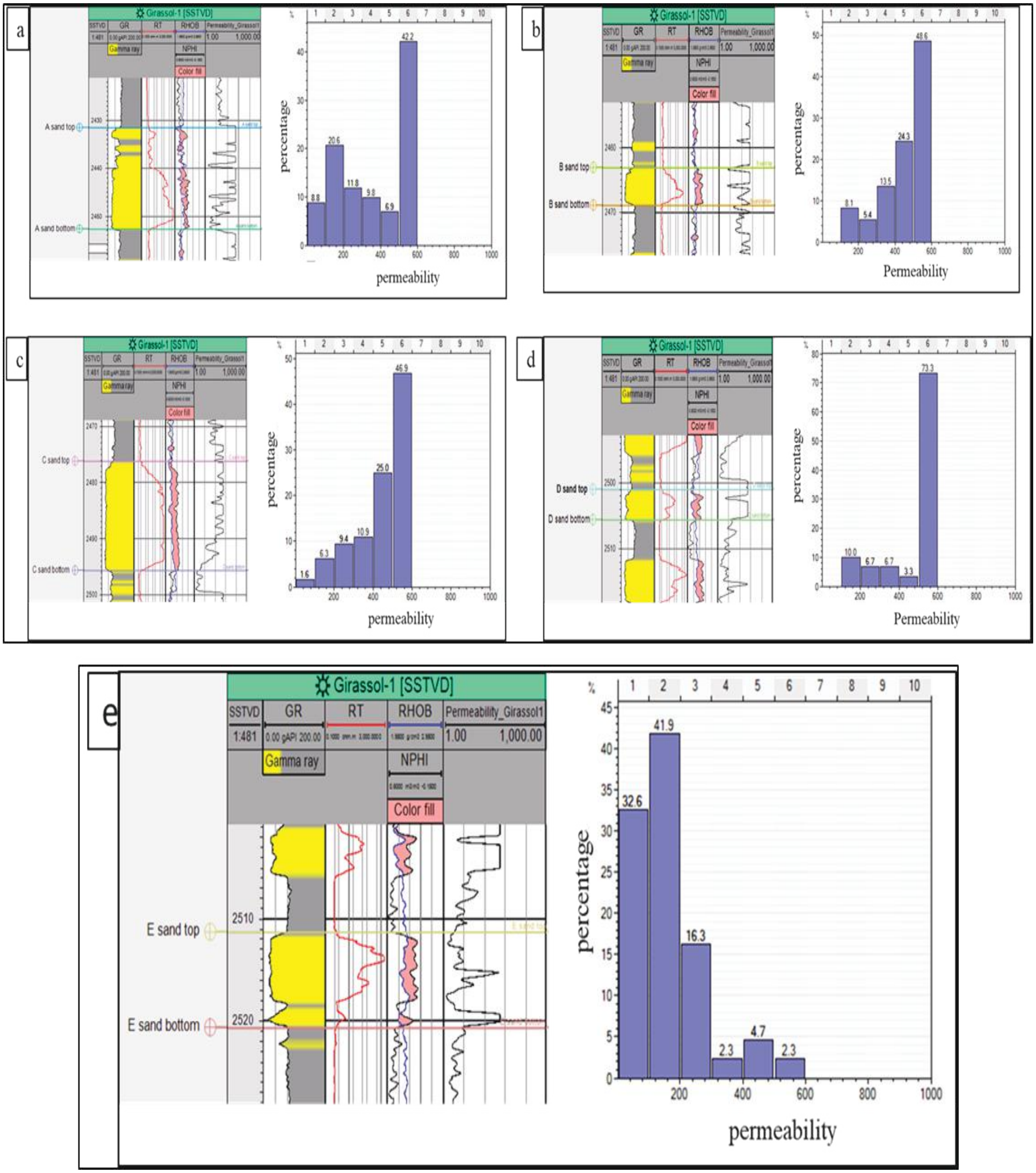

Figure 11: Permeability of A, B, C, D, and E Pay Sand Zones in Girassol-1 is Shown in a, b, c, d, and e in mD (Millidarcy). The Corresponding Histograms of the Permeability Values are Displayed Beside the Logs.

Water Saturation

Water saturation varies from 9%-34% in well Girassol-1 and correlates pretty well with porosity. The histogram shows maximum saturation of A, B, C, D, and E sands are 5%, 3%, 4%, 22%, and 6%, respectively, while minimum saturation is 40%, 39%, 40%, 59%, and 22%, respectively. The maximum is shown by D sand, and the minimum is shown by E sand (Fig. 12).

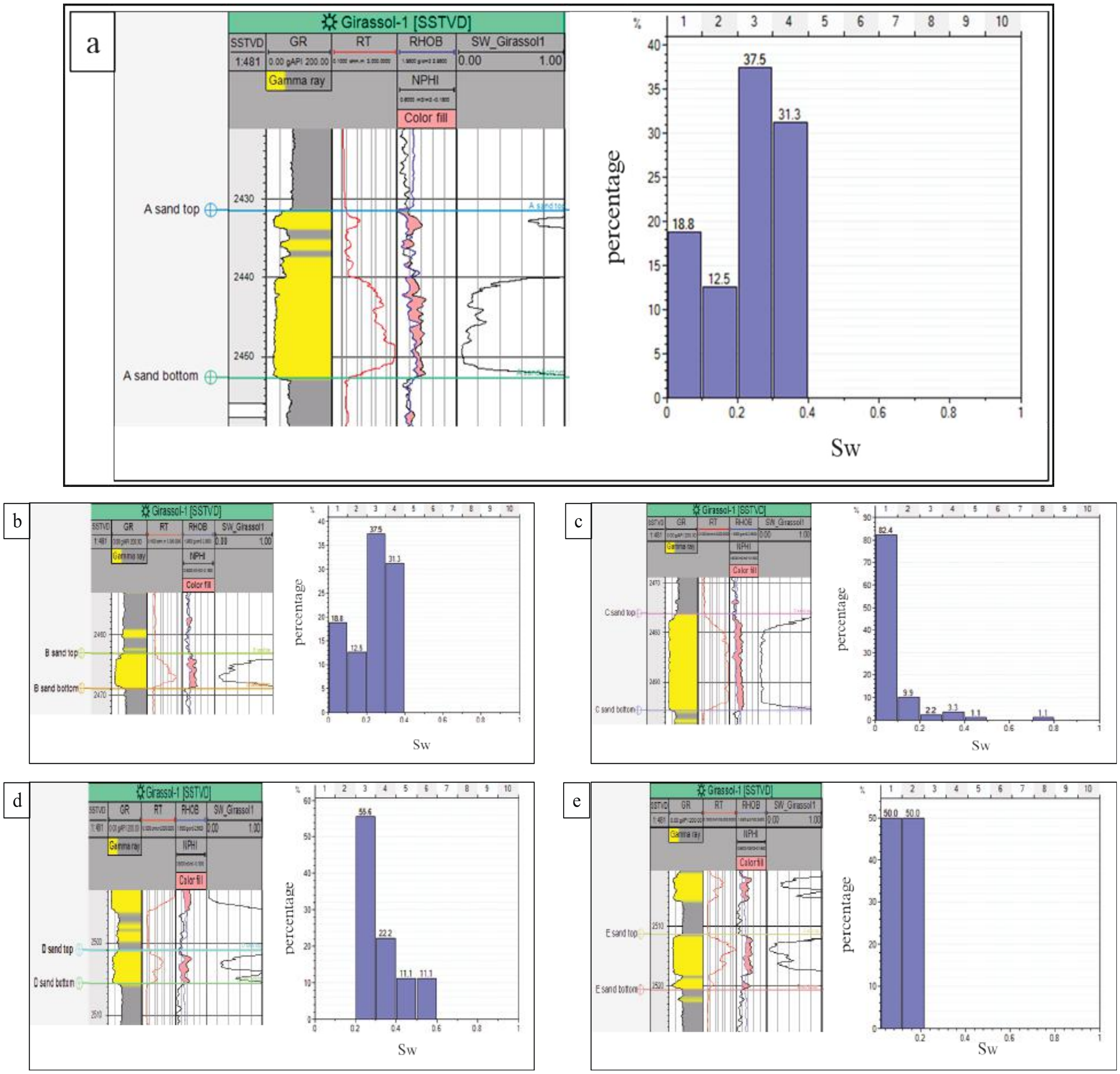

Figure 12: Water Saturation of A, B, C, D, and E Pay Sand Zones in Girassol-1 is Shown in A, B, C, D, and E in Percentage. The Corresponding Histograms of the Water Saturation (Sw) Values are Displayed Beside the Logs

Hydrocarbon Saturation and Volume of Shale

Hydrocarbon saturation values for the five zones are estimated as 84%, 76%, 91%, 66%, and 89%, respectively. The resultant shale volume of pay zones in Girassol-1 varies from 8%-17%, indicating lower clay content in the pay sands. The histogram shows that minimum shale volumes of A, B, C, D, and E sands are 3%, 2%, 3%, 6%, and 2%, respectively, while maximum shale volumes are 6%, 49%, 58%, 48%, and 60%, respectively.

Shale Volume Calculation

Volume shale is used to characterize the shale distribution of a reservoir. The shale volume of a reservoir also indicates the lithology of rock types. Shale volume was calculated using the Vsh equation of Larionov (Adepehin et al., 2022). The resultant shale volume of pay zones in Girassol-1 varies from 8%-17% (Figs. 12 & 13, Table 2), indicating lower clay content in the pay sands.

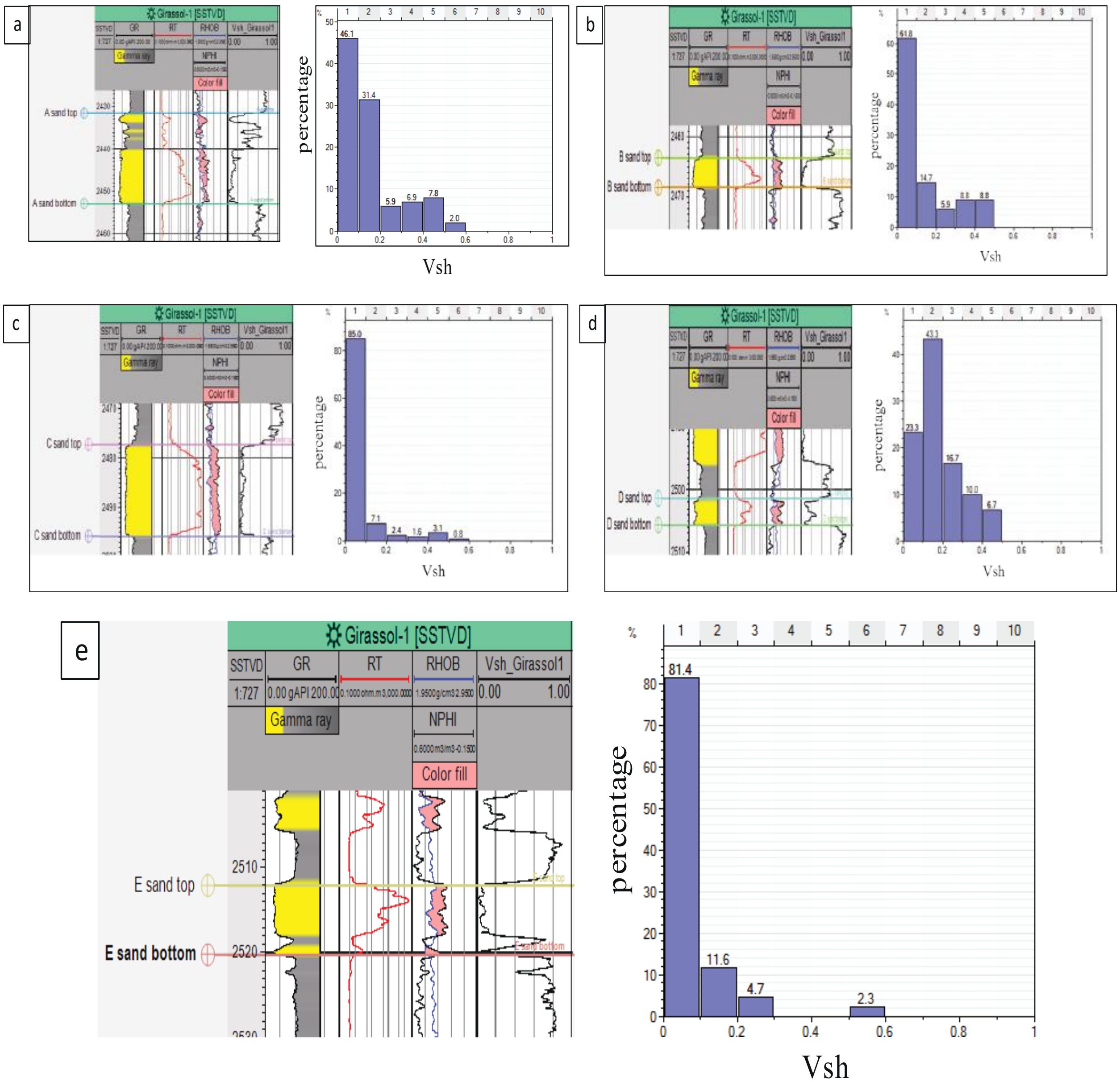

Figure 13: The Shale Volume of A, B, C, D, and E Pay Sand Zones in Girassol-1 is Shown in a, b, c, d, and e in Percentage. The Corresponding Histograms of the Shale Volume (Vsh) Values are Displayed Beside the Logs.

Net to the Gross Calculation of the Oil-bearing Zone of Girassol

Table 2: Net to the Gross Calculation of the Oil-bearing Zones (A, B, C, D, and E) of the Girassol-1 Well. The Left to Right Columns Shows the Oil-water Contact (OWC) Depths, Gross Thickness, Net Thickness, and Net to Gross. The Thickness Values are Given in the Meter (m) Unit.

Zone	OWC (m)	Gross thickness (m)	Net thickness (m)	Net to Gross (m)
A	2450.84	20.82	16.66	0.80
B	2467.72	6.7	5.04	0.75
C	2493.69	19.36	17.13	0.88
D	2505.35	5.3	4.55	0.85
E	2520.15	8.85	7.36	0.83

Petrophysical Analysis of Girassol-2A

By analyzing geophysical log data, petrophysical property logs were created for Girassol-2A to calculate the petrophysical properties of the pay zones of the well. Following petrophysical parameters are estimated for this well that helps evaluate pay zones encountered from the well data.

Effective Porosity

The calculated effective maximum porosity of A, B, C, and E sands is 30%, while the minimum porosity of these zones is 22%, 24%, 11%, and 22%, respectively. The porosity varies from 27%-29% in Well-2A, with an average value of 28%. The maximum is shown by A and B sand, while the minimum is shown by C sand. The overall porosity value of the well is very good to excellent. A high porosity value generally indicates the good textural value of the deposits, exceptionally moderate to good sorting, and possibly medium to coarse sand. Seismic data indicate amalgamated channel sands of the Girassol fields (Bhuiyan, 2009), which correspond well with the porosity estimated in this study.

Permeability

The calculated maximum permeability of A, B, C, and E sands are 546mD, while the minimum permeability of these zones is 79mD, 127mD, 116mD, and 96mD, respectively. The permeability varies from 390mD to 492mD in Well-2A, with an average value of 462mD. The maximum value is shown by B sand, while the minimum is by E sand. Overall permeability of the pay zones of the well is very good to excellent. The estimated permeability corresponds well with the estimated porosity of this well and reflects textural maturity with good sorting, reflecting very good to excellent reservoir quality.

Water Saturation Calculation

The estimated maximum water saturation of A, B, C, and E sands are 13%, 56%, 89%, and 40%, while the minimum value of these zones is 2%, 3%, 4%, and 23%, respectively. Calculated results are given in Table 2. So, the water saturation varies from 3% to 33% in Well-2A, with an average value of 22%. The porosity-permeability values indicate excellent reservoir quality with high hydrocarbons (with low water saturations) observed in this well. Low water saturation and very good to excellent poro-perm values indicate favorable conditions for further development in this structure. Since channel sands are encountered in this field (Bhuiyan, 2009), lateral and vertical facies changes might be the lithological scenario. Therefore, petrophysical estimates would vary laterally and vertically for such a depositional setting. Multicomponent data would help find detailed subsurface geological models and petrophysical data for hydrocarbon development and enhanced production from offshore Angola Girassol and other structures.

Shale Volume Calculation

The calculated maximum shale volume in A, B, C, and E sands is about 52%, 53%, 53%, and 51%, while the minimum value of these zones is 5%, 2%, 3%, and 4%, respectively. Table 3 is used to show the estimated results. So, the volume of shale varies from 3% to 33% in Well-2A, with an average value of 22%. The average shale volume of the pay zones varies. Varying shale volume indicates the heterolithic composition of the reservoir. The relatively high average value of shale volume suggests (33%) low N/G value of the reservoir, which might be due to the heterolithic lithology of the reservoir, and hence the pay zones. However, low average shale volume (3%) indicates clean reservoir and pay zones.

Net-to-Gross Calculation

Table 3: Net to the Gross Calculation of the Oil-bearing Zones (A, B, C, D, and E) of the Girassol-2A Well. The Left to Right Columns Shows the Oil-water Contact (OWC) Depths, Gross Thickness, Net Thickness, and Net to Gross. The Thickness Values are Given in the Meter (m) unit

Zones	OWC (m)	Gross thickness (m)	Net thickness (m)	Net/ Gross (m)
A	2442.98	17.17	12.62	0.74
B	2465.45	13.89	11.85	0.85
C		18.29	18.29	1
E	2513.76	13.13	11.14	0.85

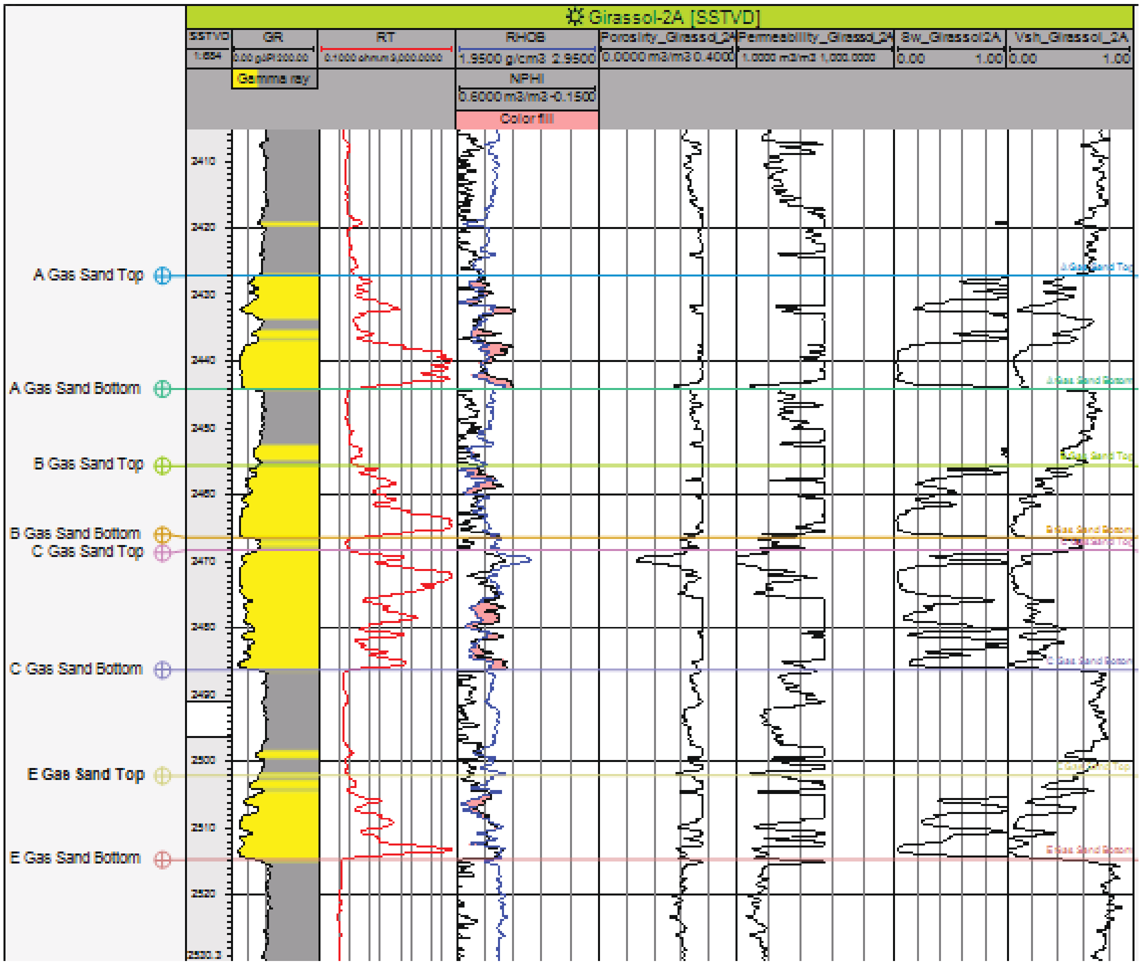

Figure 14: Composite Log Response and Petrophysical Properties of Pay Sands of Girassol-2A. From Left to Right, the Columns Display Thickness in Meters, Gamma Ray Log Response, Resistivity Log, the Cross Plot of Density and Neutron Porosity Log, Porosity, Water Saturation (SW), Permeability, and Shale Volume (Vsh), Respectively. The Gamma-ray Logs Characterize the Lithological Variations by Contrast in Color. The Red, Blue, and Black Curve Lines Display the Resistivity Log, Density Log, and Neutron Porosity Log

Average Petrophysical Properties

The average estimated effective porosity ranges from 26% to 29%. The result shows that the porosity increases from A to B and then decreases to C, D, and E sands. The maximum porosity is found in B (29%), whereas the minimum porosity is shown in E sand (26%). The range of average permeability varies from 278mD to 471mD. The histogram shows that average permeability increases from A to D sand and decreases to E sand. The maximum value is found in D sand (471mD) and the minimum in E sand (278mD).

The estimated average water saturation ranges from 17% to 34%. The results show that average water saturation increases from A to B sand and decreases to C sand. Again, higher in D sand and reduced in E sand. The maximum value of average water saturation is shown by D sand (34%), whereas the minimum is shown by C (9%). The average water saturation value of D sand is higher (above 30%) than the other zones.

The average shale volume of the pay zone ranges from 11% to 17%. The output shows an increasing trend from A to B, then decreasing to pay zone C and E, but increasing toward D. Sand A represents a lower value, and sand D represents the higher value of water saturation and thus hydrocarbon saturation vice-versa. The average net-to-gross ratio of the pay zone varies from 77% to 94%. The estimated maximum ratio is shown by C sand, and the minimum value is established by B sand.

CONCLUSIONS

The research attempted to characterize the reservoir hydrocarbon zones of the Offshore Angola Field to evaluate the formation. Lithology, porosity, permeability, shale volume, water saturation, reservoir geometry, and reservoir heterogeneity are the primary variables used in the petrophysical investigation of the Girassol-1 and Girassol-2A wells. The net-to-gross thickness ratio of the reservoir, the effective porosity of the pay zone, the permeability of the shale volume, and the overall water saturation can all be determined using publicly available well-log data, demonstrating that the Girassol Field has top-notch reservoirs. From this study following outcomes have been obtained:

- Five pay zones have been identified and characterized in the Girassol Field.
- All the pay zones show excellent reservoir quality with high net-to-grass value, porosity, permeability, and hydrocarbon saturation.
- From these results, undrained compartments, if any, could produce more hydrocarbons.

The observations, which include the reservoir characteristics of offshore Angola, may aid in formulating a strategy for further advancement, improved efficiency, and exploring yet-to-discover oil/gas reserves in this region. A thorough well-log analysis of the Offshore Angola Girassol field has been established in this work to anticipate and identify economic hydrocarbon accumulations and apply the learned skills in hydrocarbon exploration of Bangladesh specifically.

A similar methodology can be implemented to identify and characterize the hydrocarbon pay zone of the mature gas fields in Bangladesh.

ACKNOWLEDGMENTS

The work was performed at the Department of Petroleum Engineering and Applied Geophysics, NTNU, under Professor Martin Landrø and Ståle Johansen, Department of Petroleum Engineering and Applied Geophysics. Petrophysical analysis was performed at the Department of Geology, University of Dhaka.

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