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Integration Of Core-Derived Facies Analysis And Well-Log Petrophysical Evaluation For Reservoir Characterization In The GABO Field, Onshore Niger Delta Basin

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Abstract:
An integrated analysis of core-derived facies and well-log petrophysical data was carried out to characterize the reservoir architecture of the GABO Field in the onshore Niger Delta Basin. Detailed core descriptions were used to identify lithofacies based on grain size, lithology, and sedimentary structures. Six lithofacies were recognized, including trough cross-bedded sandstone, planar cross-bedded sandstone, ripple-laminated sandstone, horizontally laminated sandstone, heterolithic sand–mud facies, and laminated mudstone. These facies reflect a range of depositional processes from high-energy traction currents to low-energy suspension settling. Well-log correlation across the three wells (GABO-12, GABO-13, and GABO-20) used for the study reveals twelve laterally correlatable reservoir zones (A1–A12) characterized by low gamma-ray responses and relatively high resistivity signatures typical of clean sandstone reservoirs. Although these reservoirs display overall lateral continuity, variations in thickness and shale content suggest facies-controlled heterogeneity within the field. Petrophysical evaluation of the correlated reservoir zones in the three wells indicates that the reservoir sandstones exhibit generally favorable properties, with porosity values ranging from approximately 0.24 to 0.33 and permeability values varying from about 130 mD to more than 1100 mD. Hydrocarbon saturation values reaching up to about 0.97 indicate the presence of productive hydrocarbon-bearing intervals. The integrated results indicate that the reservoirs were deposited within a tidally influenced deltaic system characterized by stacked sandstone bodies separated by shale layers that act as vertical seals or internal flow barriers. This study demonstrates that combining core sedimentology with petrophysical analysis and well-log correlation provides a more reliable understanding of reservoir architecture and heterogeneity in complex deltaic systems such as the Niger Delta Basin.
Key Word: *Facies analysis; Reservoir characterization; Petrophysical evaluation; Tidal deltaic deposits; Core–log integration; Niger Delta Basin.*

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I. Introduction

Understanding the distribution and quality of subsurface reservoirs remains one of the most important challenges in petroleum geology [1, 2]. Reservoir characterization seeks to describe the geometry, physical properties, and fluid distribution of reservoir rocks in order to improve exploration success and optimize hydrocarbon recovery [3, 4]. In clastic sedimentary systems, reservoir quality is strongly influenced by depositional processes that control grain size distribution, sorting, clay content, and pore structure. These parameters ultimately determine the storage capacity and fluid flow characteristics of the reservoir [5, 6].

Since depositional processes play such a critical role in reservoir quality, sedimentological analysis has become a central component of reservoir characterization studies. Core data provide direct observations of lithology, sedimentary structures, grain size variation, and depositional textures that cannot always be resolved from geophysical logs alone [7]. Through detailed facies analysis, it becomes possible to reconstruct the depositional environment and identify the sedimentary processes responsible for the formation of reservoir units [8]. These interpretations provide an important framework for understanding the spatial distribution of reservoir and non-reservoir facies within sedimentary basins.

While core analysis provides detailed geological information, it is often limited in spatial coverage because cores are available only from selected intervals within a few wells. For this reason, petrophysical evaluation derived from well logs is commonly integrated with sedimentological analysis to obtain quantitative estimates of reservoir properties such as porosity, permeability, shale volume, and fluid saturation. Well logs provide continuous subsurface data that allow the correlation of reservoir units between wells and the evaluation of reservoir quality across the field [9, 10]. When combined with facies analysis, petrophysical data can be used to establish relationships between depositional facies and reservoir properties, thereby improving predictions of reservoir heterogeneity and hydrocarbon distribution [11].

Integrated approaches that combine sedimentological observations with petrophysical analysis have increasingly been applied in reservoir studies around the world [12, 13]. Such multidisciplinary methods help reduce uncertainty in reservoir interpretation and improve the understanding of reservoir architecture. In many clastic reservoirs, the integration of well log data with sedimentological observations has been shown to significantly improve the identification of reservoir units and the prediction of hydrocarbon-bearing intervals [14, 15]. Recent studies have emphasized that combining petrophysical evaluation with geological analysis provides a more reliable framework for reservoir characterization and field development planning.

The Niger Delta Basin is one of the most prolific hydrocarbon provinces in the world and represents the principal petroleum-producing region in Nigeria. The basin formed as a large regressive clastic wedge along the continental margin of the Gulf of Guinea and contains sediment thicknesses exceeding several kilometers. The stratigraphic succession of the basin is commonly divided into three major lithostratigraphic units: the Akata Formation, the Agbada Formation, and the Benin Formation [16-18] . Among these units, the Agbada Formation contains the majority of hydrocarbon reservoirs and consists of alternating sandstone and shale sequences deposited in deltaic and shallow marine environments.

Sedimentation within the Niger Delta was controlled by a complex interaction of fluvial discharge, wave action, and tidal processes [18]. These processes produced a wide range of depositional environments including distributary channels, mouth bars, tidal flats, and shallow marine deposits. As a result, the resulting sedimentary architecture is highly heterogeneous and often exhibits significant lateral and vertical variability in reservoir properties. This heterogeneity poses challenges for reservoir prediction and hydrocarbon production, particularly in fields where sand bodies are compartmentalized by shale layers or heterolithic deposits [18, 19].

In recent years, several studies have highlighted the importance of integrated sedimentological and petrophysical approaches for reservoir characterization within the Niger Delta Basin [20-22]. Petrophysical evaluation of well logs has been widely applied to identify reservoir sands, estimate reservoir properties, and determine hydrocarbon saturation in various Niger Delta fields [23-25]. Similarly, integrated analyses involving well logs, seismic data, and facies interpretation have been used to evaluate reservoir continuity and depositional environments within onshore and offshore fields in the basin [26, 27]. These studies demonstrate that linking sedimentological facies with petrophysical parameters significantly improves the understanding of reservoir heterogeneity and hydrocarbon potential.

Despite these advances, many reservoirs in the Niger Delta remain incompletely characterized due to the complex depositional architecture of the basin. A clearer understanding of how depositional facies influence reservoir quality is therefore essential for improving hydrocarbon exploration and production in the region.

The present study therefore aims to integrate core-derived facies analysis with well-log-derived petrophysical evaluation in order to characterize the reservoir units within the GABO Field, onshore Niger Delta Basin. Detailed core descriptions are used to identify lithofacies and interpret depositional processes, while petrophysical parameters obtained from well logs are used to evaluate reservoir quality and hydrocarbon saturation. By integrating these datasets, the study seeks to establish the relationship between depositional facies and reservoir properties, delineate reservoir units, and provide a clearer understanding of the depositional environment and reservoir architecture within the field.

II. Material And Methods

This study applies an integrated sedimentological and petrophysical workflow to characterize the reservoir units in the GABO Field, located in the onshore Niger Delta Basin. The approach combines detailed core examination with well-log petrophysical evaluation in order to understand the depositional environment, reservoir architecture, and variations in reservoir quality within the field. By integrating direct geological observations from cores with quantitative measurements derived from well logs, it becomes possible to relate depositional facies to reservoir properties such as porosity, permeability, and hydrocarbon saturation. The workflow for this research work is shown in Figure 1.

Data Sources

The data used in this study consist of conventional core descriptions obtained from three cored intervals as well as petrophysical data derived from well logs of wells GABO-12, GABO-13, and GABO-20.

Three core samples (Figure 2) were taken from GABO-20 at different depths; Core 1 was recovered between 2597.00 and 2624.00 m/RT, Core 2 between 2686.50 and 2713.50 m/RT, and Core 3 between 2886.50 and 2904.50 m/RT. The percentage of material recovered from each interval is presented in Table 1. The core data include information on lithology, grain size, sedimentary structures, and bedding characteristics observed within the reservoir interval. These observations provide the basis for identifying lithofacies and interpreting depositional processes.

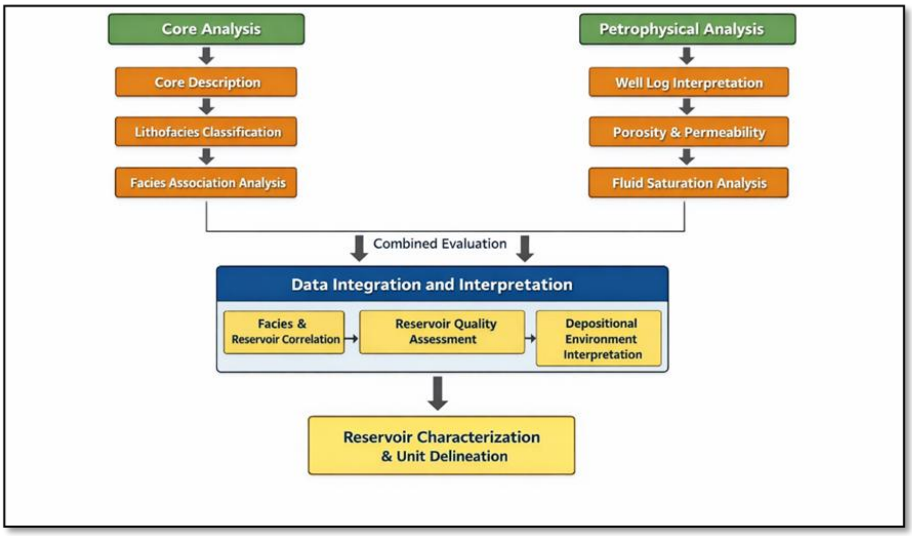

Figure 1: Integrated workflow for reservoir characterization in GABO field

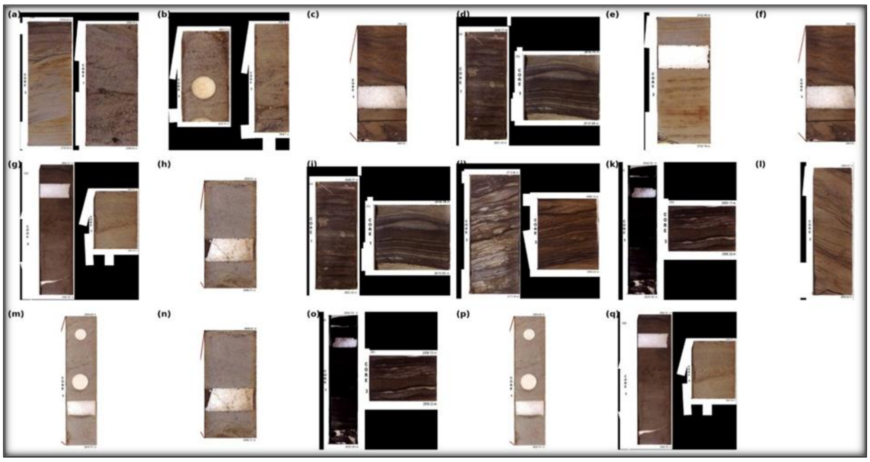

Figure 2: Core photographs showing representative lithofacies from Core 1 (a–e), Core 2 (f–k) and Core 3 (l–q)

Table no 1: Core data interval in GABO-20

Core no.	Top (m/RT)	Base (m/RT)	Provisional core length (m)	Recovered length (m)	Recovery (%)
1	2597	2624	27	26.15	97
2	2686.5	2713.5	27	25.26	94
3	2886.5	2904.5	18	17.9	99

The petrophysical dataset includes calculated parameters such as porosity, permeability, shale volume, water saturation, hydrocarbon saturation, and net-to-gross ratio. These parameters were derived from standard well-log interpretation techniques and were used to evaluate reservoir quality within the identified sandstone units. Similar integrated approaches have been widely applied in reservoir characterization studies because they allow geological observations to be directly linked with reservoir properties [9, 11].

Core Description and Sedimentological Analysis

The available cores were examined in detail in order to document lithologic variations and sedimentary structures within the reservoir succession. Each core interval was carefully described based on grain size, sediment composition, sedimentary structures, and vertical changes in bedding characteristics. Particular attention was given to features such as cross-bedding, ripple lamination, horizontal bedding, and the presence of mud drapes or heterolithic layering. These features provide important clues about the depositional processes responsible for the formation of the sediments.

The description of the cores was carried out systematically from the base to the top of each core interval, allowing changes in lithology and sedimentary structures to be identified with depth. The vertical stacking patterns of the sediments were also recorded because they help reveal changes in depositional energy and sediment transport conditions during sediment accumulation.

Lithofacies Identification and Classification

Lithofacies were identified from the core descriptions using a combination of grain size, lithology, and sedimentary structures. The classification scheme adopted in this study follows the widely used lithofacies coding system originally developed for siliciclastic deposits by Miall [28-30] and later applied in numerous sedimentological investigations of fluvial and deltaic systems [31-33]. In this system, lithofacies are represented by two-letter codes that describe the dominant sedimentary structure and lithology.

Using this approach, six lithofacies were identified within the studied cores: trough cross-bedded sandstone, planar cross-bedded sandstone, ripple-laminated sandstone, horizontally laminated sandstone, flaser-bedded heterolithic deposits, and laminated mudstone. These facies reflect different depositional processes ranging from high-energy traction currents responsible for cross-bedded sandstones to low-energy suspension settling responsible for mudstone deposition.

The lithofacies classification used in this study is summarized in Table 2.

Table no 2: Lithofacies classification used in this study.

Facies Code	Lithofacies	Description	Depositional Interpretation	Reference
St	Trough cross-bedded sandstone	Medium to coarse sandstone with trough cross-stratification	Migration of three-dimensional dunes under strong currents	Miall [29]
Sp	Planar cross-bedded sandstone	Medium to coarse sandstone with planar cross-bedding	Migration of two-dimensional dunes and sand bars	Miall [29]
Sr	Ripple laminated sandstone	Fine sandstone with ripple cross-lamination	Lower flow regime traction deposition	Miall [29]
Sh	Horizontally laminated sandstone	Parallel laminated sandstone	Upper plane-bed flow conditions	Miall [29]
Fl	Flaser or wavy-bedded heterolithics	Alternating sand and mud laminae	Deposition under fluctuating tidal currents	Miall [29]
Fm	Mudstone/shale	Laminated mudstone with minor silt lenses	Suspension settling in low-energy environment	Miall [29]

Facies Association Analysis

After identifying the individual lithofacies, they were grouped into facies associations based on their vertical stacking patterns and depositional characteristics. Facies associations represent groups of genetically related lithofacies that formed under similar environmental conditions. This step helps to simplify the interpretation of complex sedimentary successions and provides a clearer understanding of the depositional environments represented within the cores.

The facies associations identified in this study were interpreted by examining changes in grain size, sedimentary structures, and lithologic transitions observed in the cores. Similar approaches have been widely used in sedimentological studies to reconstruct depositional environments and to link sedimentary facies with reservoir architecture [34-36].

Well Log Correlation and Petrophysical Analysis

In order to identify potential reservoirs of interest within the study area, a well log correlation was carried out using the available well logs. This was achieved by comparing the signatures of the gamma ray log and the resistivity logs, with low gamma ray and high resistivity indicative of the presence of a sand body containing a hydrocarbon.

Furthermore, petrophysical analysis was carried out in the potential reservoirs by extracting datasets from the available well logs. The gamma ray index (I_{GR}) was estimated from readings from gamma ray log (GR_{log}) relative to the maximum and minimum values (GR_{max} and GR_{min}) on the gamma ray track for each well, as seen in equation (1). The volume of shale (V_{Sh}) was then estimated from the gamma ray index by applying Larinov's relationship for Tertiary sandstones, equation (2), as described by Asquith et al. [9]. Porosity (ϕ) was estimated from measures read from density logs relative to the formation bulk density (ρ_b), density of the formation fluid (ρ_{ma}) and density of the formation matrix (ρ_{ma}) using Asquith and Gibson [37] equation (equation (3)). Furthermore, water saturation (S_w) was estimated using Archie's [38] model relative to measures of formation resistivity (R_t) as read from the resistivity log, formation water resistivity (R_w), tortuosity factor (a), cementation factor (m) and Archie's saturation exponent (n), as shown in equation (4). Permeability (k) was also estimated relative to the estimated porosity and irreducible water saturation (S_{wirr}), which was taken as the minimum value of the estimated water saturation in the reservoir zone, by applying a version of Tixier's model, equation (5) as seen in Asquith et al. [9]. Finally, the net-to-gross ratio (NTG) was estimated using equation (6).

$$I_{GR} = \frac{GR_{log} - GR_{min}}{GR_{log} - GR_{min}} \quad \text{Eq (1)}$$

$$V_{sh} = 0.083(2^{3.7 I_{Gr}} - 1) \quad \text{Eq (2)}$$

$$\phi = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}} \quad \text{Eq (3)}$$

$$S_w = \left(\frac{aR_w}{R_t \phi^m}\right)^{1/n} \quad \text{Eq (4)}$$

$$k = 250 \frac{\phi^3}{S_{wirr}^2} \quad \text{Eq (5)}$$

$$NTG = \frac{Net\ Reservoir\ Thickness}{Gross\ Thickness} \quad \text{Eq (6)}$$

After calculating the petrophysical parameters along the well logs, average values of porosity, water saturation, shale volume, permeability, and net-to-gross ratio were determined for each reservoir interval. These averaged parameters were used to characterize the reservoir quality and hydrocarbon potential of the identified reservoir zones.

Integration of Sedimentological and Petrophysical Data

The final stage of the analysis involved integrating the results from the core sedimentological study with the petrophysical parameters derived from the well logs. This integration allows the relationship between depositional facies and reservoir properties to be evaluated. By comparing lithofacies distribution with variations in porosity, permeability, and shale content, it becomes possible to identify the facies that form the most effective reservoir units within the succession.

This integrated workflow provides a more complete understanding of reservoir architecture because it combines direct geological observations with quantitative reservoir measurements. Such approaches are widely regarded as essential for reservoir characterization in complex clastic systems such as those found in the Niger Delta Basin.

III. Result

The results from the facies analysis (Table 3), well log correlation (Figure 3) and petrophysical analysis (Tables 4, 5 and 6) are shown below

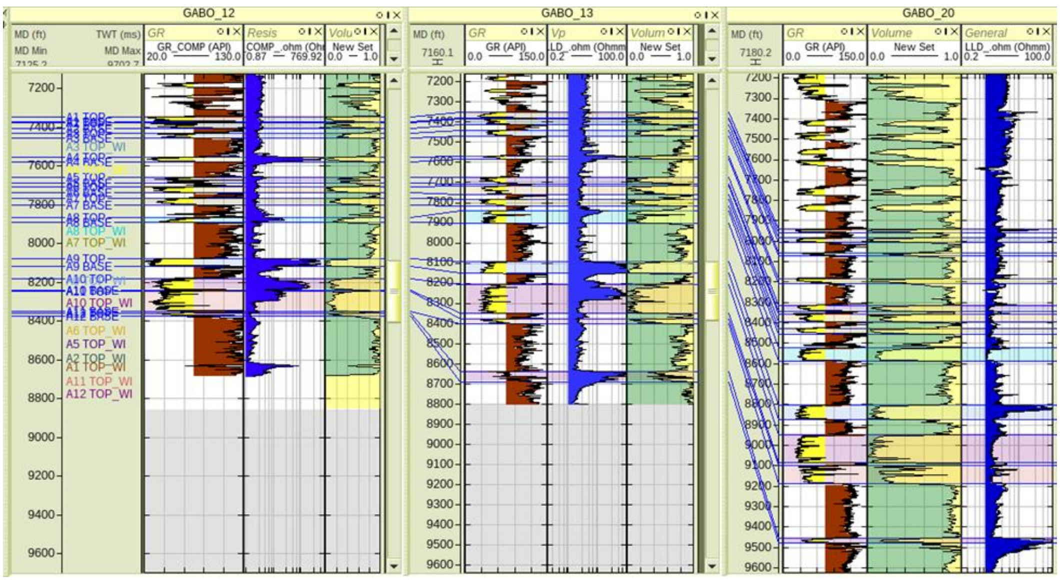

Figure 3: Correlation panel for the potential reservoir units in GABO-12, GABO-13 and GABO-20

Table no 3: Summary of Core-Derived Lithofacies and Depositional Interpretation

Core	Depth Interval (m)	Facies Code	Lithologic Description	Sedimentary Structures	Depositional Interpretation
Core 1	2597.00 – 2599.12	Sp, St	Medium to coarse-grained sandstone	Planar and trough cross-bedding	Migration of dunes in high-energy channels
Core 1	2599.12 – 2600.10	Sr, Sh	Fine to medium-grained sandstone	Ripple lamination and horizontal bedding	Lower-energy sand flat deposition
Core 1	2600.10 – 2614.03	St, Sp	Coarse-grained sandstone with quartz granules	Planar and trough cross-bedding	Channelized sand deposition
Core 1	2614.03 – 2619.34	Sr, Fl	Very fine- to fine-grained sandstone with shale drapes	Ripple lamination, flaser bedding	Tidal sand flat deposits
Core 1	2619.34 – 2623.15	Fm	Laminated shale with siltstone lenses	Lenticular bedding	Suspension settling in low-energy setting
Core 2	2686.50 – 2695.30	St, Sp	Medium to very coarse sandstone	Planar and trough cross-bedding	Channelized sand bodies
Core 2	2695.30 – 2701.00	St	Coarse sandstone with mud clasts	Trough cross-bedding	High-energy channel deposition
Core 2	2701.00 – 2703.00	Sr, Sh, Fl	Fine-grained sandstone and siltstone	Ripple lamination and flaser bedding	Tidal sand flat
Core 2	2703.00 – 2706.06	Sr, Fl	Very fine-grained sandstone with shale drapes	Ripple lamination	Lower-energy tidal deposits
Core 2	2706.06 – 2711.76	Fl, Fm	Heterolithic sand-mud alternations	Flaser and lenticular bedding	Tidal flat / lagoonal deposits
Core 3	2886.50 – 2888.63	Sr, Fl	Fine-grained sandstone with shale drapes	Ripple lamination	Sand flat deposition
Core 3	2888.63 – 2893.12	Sr	Ripple-laminated fine sandstone	Wave and current ripples	Moderate-energy sand deposition
Core 3	2893.12 – 2894.70	Sr, Fl	Very fine-grained sandstone	Ripple lamination with mud drapes	Tidal flat environment
Core 3	2894.70 – 2895.00	Sh	Fine sandstone	Horizontal lamination, HCS	Storm-influenced deposition
Core 3	2895.00 – 2899.12	Fl	Sand-mud alternations	Flaser bedding	Intertidal deposits
Core 3	2899.12 – 2904.10	Fm	Laminated shale	Lenticular bedding	Low-energy offshore/lagoon

Table no 4: Summary of some estimated petrophysical parameters from the reservoir intervals in well GABO 12

Reservoir Zones	Top depth (m)	Bottom Depth (m)	Gross Thickness (m)	Net to Gross (NTG)	Water Saturation (frac)	Hydrocarbon Saturation (frac)	Porosity (frac)	Volume of Shale (frac)	Permeability (mD)
A1	2239.07	2246.30	7.22	0.08	0.207	0.793	0.278	0.078	151
A2	2248.59	2257.46	8.86	0.30	0.198	0.802	0.267	0.300	166
A3	2265.66	2272.58	6.91	0.31	0.229	0.771	0.267	0.308	237
A4	2302.47	2309.95	7.47	0.18	0.075	0.925	0.287	0.177	219
A5	2334.82	2343.14	8.32	0.34	0.231	0.769	0.258	0.342	141
A6	2349.09	2358.71	9.62	0.18	0.247	0.753	0.267	0.183	264
A7	2366.90	2377.22	10.32	0.23	0.270	0.730	0.245	0.233	545
A8	2396.44	2405.34	8.90	0.37	0.151	0.849	0.282	0.370	433
A9	2461.57	2474.03	12.46	0.12	0.035	0.965	0.310	0.116	208
A10	2493.26	2511.49	18.23	0.17	0.060	0.940	0.290	0.172	292
A11	2513.62	2544.81	31.19	0.17	0.193	0.807	0.249	0.173	164
A12	2547.44	2552.80	5.36	0.21	0.115	0.885	0.290	0.210	130

Table no 5: Summary of some estimated petrophysical parameters from the reservoir intervals in well GABO 13

Reservoir Zones	Top depth (m)	Bottom Depth (m)	Gross Thickness (m)	Net to Gross (NTG)	Water Saturation (frac)	Hydrocarbon Saturation (frac)	Porosity (frac)	Volume of Shale (frac)	Permeability (mD)
A1	2241.09	2248.93	7.84	0.15	0.207	0.793	0.256	0.150	130
A2	2251.11	2259.55	8.44	0.26	0.194	0.806	0.269	0.259	330
A3	2267.69	2276.28	8.58	0.31	0.206	0.794	0.269	0.305	244
A4	2306.72	2311.68	4.96	0.24	0.083	0.917	0.251	0.239	387
A5	2339.23	2348.60	9.37	0.22	0.214	0.786	0.281	0.217	311
A6	2352.46	2364.40	11.94	0.21	0.236	0.764	0.266	0.208	206

A7	2372.67	2382.03	9.37	0.15	0.249	0.751	0.267	0.152	451
A8	2389.71	2408.64	18.94	0.22	0.190	0.810	0.263	0.215	685
A9	2466.95	2484.70	17.74	0.14	0.057	0.943	0.266	0.136	774
A10	2500.80	2545.15	44.36	0.14	0.157	0.843	0.251	0.136	808
A11	2553.03	2560.79	7.76	0.29	0.255	0.745	0.277	0.290	1083
A12	2633.18	2648.87	15.69	0.26	0.092	0.908	0.270	0.259	568

Table no 6: Summary of some estimated petrophysical parameters from the reservoir intervals in well GABO 20

Reservoir Zones	Top depth (m)	Bottom Depth (m)	Gross Thickness (m)	Net to Gross (NTG)	Water Saturation (frac)	Hydrocarbon Saturation (frac)	Porosity (frac)	Volume of Shale (frac)	Permeability (mD)
A1	2420.54	2425.11	4.58	0.12	0.185	0.818	0.242	0.124	251
A2	2433.33	2439.68	6.35	0.11	0.233	0.766	0.287	0.111	266
A3	2456.39	2460.32	3.92	0.34	0.248	0.751	0.281	0.335	337
A4	2494.39	2501.97	7.57	0.17	0.262	0.737	0.292	0.168	908
A5	2533.83	2542.97	9.14	0.20	0.285	0.714	0.287	0.204	1183
A6	2547.15	2559.43	12.27	0.23	0.300	0.699	0.279	0.234	668
A7	2568.31	2576.98	8.67	0.16	0.313	0.686	0.256	0.163	319
A8	2597.65	2617.52	19.87	0.22	0.332	0.667	0.280	0.221	241
A9	2683.13	2704.49	21.35	0.14	0.160	0.839	0.309	0.140	364
A10	2726.97	2769.17	42.20	0.14	0.307	0.692	0.257	0.139	433
A11	2773.86	2800.76	26.89	0.29	0.277	0.722	0.287	0.289	208
A12	2882.18	2889.37	7.19	0.31	0.076	0.923	0.329	0.308	164

IV. Discussion

Core Sedimentological Characteristics

The core descriptions provide important insight into the depositional processes responsible for the reservoir succession in the GABO Field. The vertical stacking pattern observed in the cores shows a transition from sand-dominated intervals to heterolithic deposits and mudstone layers. Such vertical facies transitions are typical of deltaic successions where variations in depositional energy control sediment distribution (Reading, 1996; Boggs, 2012).

The presence of cross-bedded sandstone facies indicates deposition under relatively high-energy conditions where traction currents were capable of transporting coarse sediment and forming subaqueous dunes. In contrast, ripple-laminated sandstone and heterolithic facies reflect lower-energy conditions where alternating sand and mud deposition occurred due to fluctuating current velocities. These facies transitions suggest a gradual reduction in depositional energy upward within the studied intervals, which is characteristic of deltaic and shallow-marine depositional systems [29, 34].

The occurrence of mudstone and heterolithic deposits in the upper sections of the cores further supports deposition in relatively quiet water environments such as tidal flats or lagoonal settings where suspension settling dominates sediment accumulation. Similar sedimentary successions have been reported in several reservoirs within the Niger Delta Basin where channel sandstones are overlain by tidal and shallow marine deposits [18, 39].

Lithofacies Distribution and Depositional Implications

The lithofacies identified in this study correspond closely to the standard facies associations commonly observed in siliciclastic depositional systems. Trough cross-bedded sandstone (St) and planar cross-bedded sandstone (Sp) facies are typically associated with high-energy depositional environments such as distributary channels and mouth-bar deposits. These facies are commonly characterized by relatively good sorting and high sand content, which favor the development of good reservoir properties [29, 40].

Ripple laminated sandstone (Sr) and horizontally laminated sandstone (Sh) facies represent lower flow regime conditions where sediment transport occurs primarily by traction currents. These deposits commonly occur in sand-flat environments or lower-energy portions of distributary channels. In contrast, the heterolithic facies (Fl) and mudstone facies (Fm) indicate alternating traction and suspension processes that are typical of tidal environments where periodic changes in current velocity produce alternating sand and mud layers [41].

The vertical succession of these facies therefore reflects a shift from relatively high-energy channel deposition to lower-energy tidal or shallow marine environments. Such depositional patterns are widely documented in the Niger Delta Basin where fluvial sediment supply interacts with marine and tidal processes to produce complex facies architectures [18, 42].

Facies Associations and Reservoir Architecture

Grouping the lithofacies into facies associations provides further insight into the depositional environment and reservoir architecture within the GABO Field. The cross-bedded sandstone facies form thick sand bodies that likely represent channelized deposits or mouth-bar accumulations within a deltaic system. These sand bodies typically constitute the primary reservoir units because they contain the highest sand content and lowest shale volume.

Above these sand-dominated units, the occurrence of ripple laminated sandstones and heterolithic deposits suggests deposition within sand-flat or tidal environments where energy conditions were more variable. These deposits often act as transitional facies between channel sandstones and mud-dominated environments. The upper mudstone intervals represent low-energy environments where fine-grained sediments accumulated through suspension settling.

Such facies relationships are consistent with depositional models proposed for many Niger Delta reservoirs where stacked channel sand bodies are interbedded with tidal or shallow marine deposits that influence reservoir connectivity and heterogeneity [17, 43].

Well Log Correlation Interpretation (GABO-12, GABO-13, and GABO-20) and Petrophysical Characteristics of the Reservoir Units

The well-log correlation of wells GABO-12, GABO-13, and GABO-20 reveals a series of laterally correlatable reservoir intervals labelled A1–A12, which display generally consistent stratigraphic signatures across the field. These units are characterized by relatively low gamma-ray responses, indicating sandstone-dominated lithologies with reduced shale content, while several intervals show elevated resistivity values, suggesting the presence of hydrocarbon-bearing formations. Although the reservoirs can be correlated between wells, noticeable variations in thickness and log character indicate lateral facies variability within the sandstone bodies. Such variations likely reflect changes in depositional energy and sediment supply within a deltaic depositional system, where channel or mouth-bar sand bodies may thin or grade laterally into heterolithic or shale-rich deposits. The intervening shale intervals observed between the sandstone units probably act as vertical seals or internal baffles, influencing reservoir connectivity and fluid flow. This stratigraphic architecture is typical of stacked deltaic reservoirs in the Niger Delta Basin, where multiple sandstone bodies occur within alternating sand-shale successions that control reservoir heterogeneity and hydrocarbon distribution [18, 42].

Petrophysical evaluation of wells GABO-12, GABO-13, and GABO-20 provides quantitative evidence of the reservoir quality within the sandstone units. The porosity values obtained from the analyzed intervals range from approximately 0.24 to 0.33, indicating relatively good pore space within the reservoir rocks. Such porosity values are typical of moderately to well-sorted deltaic sandstones within the Niger Delta Basin [11].

Permeability values within the reservoir intervals vary widely from about 130 mD to more than 1100 mD, reflecting variations in grain size distribution, sorting, and clay content within the sandstone units. Higher permeability values observed in some intervals suggest relatively clean sandstones with well-connected pore networks, whereas lower permeability values may reflect the influence of shale interbeds or heterolithic layering. These variations in permeability are consistent with the facies-controlled heterogeneity commonly observed in deltaic reservoirs [18, 44].

Water saturation values generally range between approximately 0.035 and 0.332, while hydrocarbon saturation values range between about 0.67 and 0.97, indicating that several intervals within the studied wells contain significant hydrocarbon accumulations. For example, hydrocarbon saturation values exceeding 0.90 are observed in several reservoir zones, suggesting the presence of highly productive hydrocarbon-bearing sandstones within the reservoir system.

Net-to-gross ratios within the reservoir intervals vary between approximately 0.08 and 0.37, indicating significant variation in sand content across the different reservoir zones. Lower net-to-gross values are typically associated with heterolithic or mud-rich intervals, while higher values correspond to cleaner sandstone units with better reservoir potential.

Integration of Sedimentological and Petrophysical Data

The integration of core sedimentological observations with petrophysical analysis provides a clearer understanding of the reservoir architecture within the GABO Field. The cross-bedded sandstone facies identified in the cores correspond closely with intervals that exhibit relatively high porosity and permeability values in the petrophysical dataset. This relationship confirms that depositional facies exert a strong control on reservoir quality.

Similarly, intervals characterized by heterolithic facies and mudstone layers tend to exhibit higher shale volumes and reduced permeability, indicating poorer reservoir quality. These intervals likely act as internal baffles that may compartmentalize the reservoir and influence fluid flow during hydrocarbon production.

Overall, the combined sedimentological and petrophysical evidence suggests that the reservoir system in the GABO Field was deposited within a tidally influenced deltaic environment where stacked channel sand bodies form the primary hydrocarbon reservoirs. The presence of heterolithic tidal deposits introduces variability in reservoir quality and may affect reservoir connectivity. Integrated reservoir characterization approaches such as the one applied in this study are therefore essential for improving the understanding of reservoir heterogeneity and guiding hydrocarbon development strategies in complex deltaic systems.

V. Conclusion

This study integrated core sedimentological analysis, well-log petrophysical evaluation, and stratigraphic correlation to characterize the reservoir architecture of the GABO Field in the onshore Niger Delta Basin. Core descriptions identified six lithofacies that record depositional processes ranging from high-energy channel deposition to lower-energy tidal and suspension-dominated environments. These facies relationships indicate deposition within a deltaic system influenced by variable hydrodynamic conditions. Well-log correlation across wells GABO-12, GABO-13, and GABO-20 reveals twelve reservoir units (A1–A12) that can be traced laterally across the field. These units are characterized by low gamma-ray responses and relatively high resistivity values, consistent with sandstone reservoirs containing hydrocarbons. Although the correlated intervals show general stratigraphic continuity, noticeable variations in thickness and log character indicate lateral facies changes typical of deltaic depositional environments. Petrophysical evaluation in the reservoir units within the three wells shows that the sandstone reservoirs generally possess good reservoir quality. Porosity values range between approximately 0.24 and 0.33, while permeability values vary from about 130 mD to more than 1100 mD. Hydrocarbon saturation values approaching 0.97 in several reservoir zones indicate effective hydrocarbon accumulation within the sandstone units. However, variations in shale volume and net-to-gross ratios indicate the presence of heterolithic intervals that locally reduce reservoir quality. The integrated interpretation suggests that the reservoirs in the GABO Field form a stacked sandstone system deposited within a tidally influenced deltaic setting. Channel or mouth-bar sand bodies constitute the primary hydrocarbon reservoirs, while intervening shale layers act as vertical seals or internal baffles that influence reservoir connectivity. Understanding this facies-controlled reservoir architecture is essential for predicting reservoir behavior and improving hydrocarbon development strategies within the field.

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