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DETERMINATION OF THE DEPOSITIONAL ENVIRONMENT OF THE RESERVOIR ROCK IN “SCOJAS -43” WELL USING CORE SAMPLES

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Abstract

The aim of this study is to carry out Sedimentological core description in order to characterize the different depositional environments of the reservoir sandstones in “SCOJAS” -43 well. The depositional environments were used to define the geometry of the hydrocarbon reservoir. Detailed Sedimentological core description and interpretation yielded the different depositional environments. Sedimentological studies of four hundred and eleven feet (411ft) length of core covering 6233.2 metres to 8773.2 metres from “SCOJAS” -43 well was carried out using slabbed core samples with the aim of determining lithofacies association. Thirteen (13) Lithofacies units were identified within the cored interval. They include, Massive-Laminated Sideritic Mudstone, Fossiliferous Sandstone, Fossiliferous Mudstone, Bioturbated Muddy Heterolith, Massive-Parallel Laminated Sandstone, Planar Laminated Sandstone, Massive-Laminated Mudstone, Current Rippled Sandy Heterolith, Hummocky/Swaley Cross Stratified Mudstone, Cross-Bedded Medium-Fine Grained Sandstone, Cross-Bedded Coarse-Gravelly Grained Sandstone, Bioturbated Medium-Fine Grained Sandstone and Current Rippled Sandstone. Seven (7) Lithofacies Associations were identified within the cored interval; they include Marine Shales, Bioturbated Channel Heterolithic, Stratified Channel Heterolithic, Tidal Channel Heterolithic, Proximal Lower Shoreface Heterolithic, Fluvial Channel Sandstone and Coastal Plain Sandstone. These lithofacies associations can be further categorized using the three major types of depositional environments. Fluvial Channel Sandstone and Coastal Plain Sandstone are continental, Bioturbated Channel Heterolithic, Stratified Channel Heterolithic and Tidal Channel Sandstone are transitional while Marine Shales and Proximal Lower Shoreface Heterolithic are marine. This study was able to reconstruct the environment of deposition of “SCOJAS” -43well, which will be very useful for reservoir modelling.

Keywords: Core Description, Depositional Environments, Lithofacies, Lithofacies Associations, Niger Delta, Paleoenvironment, Reservoir, Sandstones.

Introduction

Sedimentology is the study of the processes of formation, transport and deposition of materiasl that accumulates as sediment in continental and marine environments and eventually forms sedimentary rocks.Most of the rocks that cover the Earth surface are of sedimentary origin. Most of the information about earth’s history was deciphered from sedimentary rocks. The fact that several events taking place in the earth today are very similar to those that have occurred in the past plays a key role in reconstruction of ancient environments.The nature of subsurface exploration requires obtaining the downhole rock samples that provide a wealth of information, an unweathered and undisturbed, sequence of rock properties (Efemena and Maju-Oyovwikowhe, 2022).

Core analysis can be defined as the laboratory measurement of the physico-chemical properties of samples of recovered core, for purposes of multiple disciplines, it is the name given to the test procedures and data collected on core samples. A geologist, for example, needs core analysis for facies analysis, mineral identification or to obtain depositional information and build static reservoir models. A reservoir engineer uses core analysis for comprehensive interpretation of fluid flow characteristics in field applications in order to design and optimize the recovery processes. Though, drilling and recovering of core samples is an expensive business, it is the only way to determine the rock forming properties of the reservoir in which one is interested, so core material is of prime significance. As such, interpreting results from analyses on core material has long been one of the exploration geoscientists’ most important tasks. Although the concept has expanded to encompass well log data acquisition and interpretation, core analysis remains as an important element within the domain of Petrophysics. Core analysis is the fundamental foundation of reservoir characterization and it provides the only direct and quantitative measurement of the “intact” reservoir properties, and should provide the foundation upon which formation evaluation rests.

A number of generally accepted sampling and analytical techniques have been developed for evaluating core samples. The choice of technique depends on the type of core recovered, its lithology, and the nature of the pore system. Core analysis can be divided into conventional or plug analysis, sidewall core analysis, and whole core analysis.

Conventional or plug analysis employs a small sample to represent an interval of core and produces acceptable results when the pore system is relatively homogeneous. Conventional core analysis plugs are usually collected once per foot or three to four times per meter. Sidewall core analysis is performed on cores recovered by any of the sidewall coring techniques. Percussion sidewall cores from hard, well-cemented formations are badly altered during the coring process and generally fail to produce suitable measurements of mechanical and petrophysical properties. Sample alteration may be reduced through the use of sidewall coring or a hydraulic press to collect sidewall core samples. Sidewall cores and analysis produce acceptable results when suitable formations, such as soft sandstones are sampled in adequate detail. Data quality in wells where only sidewall cores are available can be improved by developing correlations between conventional and sidewall core values. This requires that conventional cores and sidewall cores be collected from the same interval in selected wells. Whole core analysis examines the complete length of full-diameter core in the interval being tested and affords the maximum possible sample size. Large samples are mandatory in heterogeneous formations in which most of the porosity and permeability are due to fractures, solution vugs, or erratically developed pore systems. In these cases, the volume of individual pore spaces may be large in relation to the size of conventional core analysis plug samples. A variation of whole core analysis, called full-diameter analysis, utilizes selected lengths of a core rather than the entire core. Whole core analysis was used for this study.

A depositional environment describes the combination of physical, chemical and biological processes associated with the deposition of a particular type of sediment and therefore the type of rock that forms after lithification. Therefore, environment at any point on the land or under the sea can be characterized by the physical and chemical processes that are active there and the organisms that live under those conditions at that time. (Maju-Oyovwikowhe and Lucas, 2019a).

In the description of sedimentary rocks in terms of depositional environments, the term 'facies' is often used. A rock facies is a body of rock with specified characteristics that reflect the conditions under which it was formed (Reading, 1996). Describing the facies of a body of sediment involves documenting all the characteristics of its lithology, texture, sedimentary structures and fossil content that can aid in determining the processes of formation. By recognizing associations of facies, it is possible to establish the combinations of processes that were dominant; the characteristics of a depositional environment are determined by the processes that are present, and hence there is a link between facies associations and environments of deposition. (Maju-Oyovwikowhe and Lucas, 2019a).

Lithofacies represents a body of sediment/rock with specific lithologic and organic characteristics like grains size, sorting and sedimentary structures imparted by a particular set of energy within an environment of deposition (Maju-Oyovwikowhe and Lucas, 2019b). Lithofacies identification and interpretation helps in understanding the sedimentological characteristics of a reservoir rock such as grain sizes, shapes, degree of sorting, colors, textures, sedimentary structures (physical, chemical and biological structures), etc. This will enable proper interpretation of reservoir rocks as well as in the determination of their depositional environments (Nichols, 2009).

Lithofacies Associations represents groups of lithofacies within a Genetic unit with environmental significance, consistent range of reservoir properties, consistent external geometry consistent set of Log properties, and upscaling from micro to meso scale for reservoir modelling purposes (Maju-Oyovwikowhe and Lucas, 2019b).

The aim of this study is to use Sedimentological analysis to determine environment of deposition. The objectives of this study are to carry out Sedimentological description of the interval of the well and to determine depositional environment (facies association), vertical sequence of facies and sedimentary structures (ripples, cross bedding, lamination etc.) using core data.

Location of Study Well

The study area is situated within the Greater Ughelli Depobelt of Niger Delta province (Fig.1). The Niger Delta sedimentary basin is located in the Southern part of Nigeria, bordering the Atlantic Ocean between latitudes 4^0 and 6^0N, and longitudes 3^0 and 9^0E (Nwachukwu and Chukwura, 1986). It is bounded in the South by the Gulf of Guinea and to the North by the Anambra basin, Abakaliki uplift and Afikpo syncline (Ejedawe, 1981).

Fig.1: Location of 'SCOJAS-43' well

The megatectonic setting of the Niger Delta was discussed by Stoneley (1996). He described the major fault bearing structures as they developed during the evolution of the Delta. Doust and Omatsola (1989) carried out a comprehensive study of the Niger Delta depobelts and defined them in terms of the age of their paralic sequences. Nwachukwu and Chukwura (1986) carried out an organic matter survey on the Agbada Formation in an attempt to investigate the hydrocarbon source rocks in the Niger Delta. They concluded that the shales of the Agbada Formation are mature and contain Type III organic matter that is capable of generating hydrocarbons. Ejedawe (1981) discussed the evolution of oil generative windows and the occurrence of oil and gas in the Niger Delta. Weber and Daukoru (1975) discussed the sedimentological aspects of the Niger Delta basin with respect to the evolution of the

Delta. They described the evolution of the basin in three phases, which are the Santonian basin evolution, the Santonian-Paleocene evolution and the Eocene-Recent delta phase. Short and Stauble (1967), identified three lithostratigraphic subdivisions for the Niger Delta subsurface, comprising of the Akata Formation, Agbada Formation, and Benin Formation in ascending order. These authors observed that the units which are strongly diachronous and represent marine, paralic and continental facies of the Niger Delta respectively.

Reservoir description studies and characterization based on sequence stratigraphic model have been carried out by various workers like Reijers et al., (1996) and Shanmugam, (1997). Ozumba (1995) observed that the mode of hydrocarbon trapping in the Niger Delta is a combination of structural and stratigraphic trapping. They also maintained that the Opuama sedimentary infill forms part of the Niger Delta stratigraphic succession and exhibits itself as a clay plug set within the paralic Agbada Formation. The geology of Southern Nigeria and South-Western Cameroon delineates the onshore portion of the Niger Delta Province (Fig.2).The province covers 300,000km^2 and includes the geologic extent of the Tertiary Niger Delta (Akata-Agbada) petroleum system which is the only petroleum system which has been identified in the Niger Delta basin.

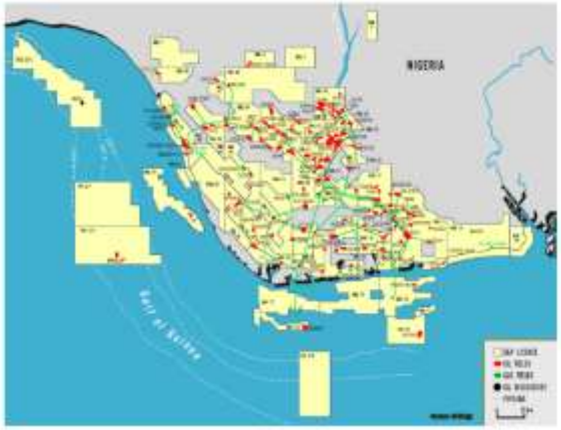


Fig. 2: Map of Niger Delta basin showing oil and gas fields. [Modified after Lucas and Odedede ,2013]

Sedimentation

The Niger Delta basin has been a site of cyclic sedimentation. Regionally, sediment dispersal was controlled by marine transgressive/regressive cycles related to eustatic sea level changes with varying duration (Table1). Differential subsidence locally influenced sediment accumulation. The tertiary paralic sediments are composed of several depositional cycles with thickness ranging from 50-300ft, although cycles exceeding is less common. The complete cycle consists of thin fossiliferous transgressive marine sand followed by an offlap sequence of marine shale and laminated fluviomarine sediments (Weber 1971).

Table 1: Classification of main sub-environment of depositions and corresponding facies by Weber and Daukoru (1975)

SUB-ENVIRONMENT	DEPOSITS
Holomarine	Transgressive marine sands (onlap) Marine shales (offlap)
Barrier foot	Laminated barrier foot sands(offlap)
Barrier bar	Barrier bar sands (offlap)
Tidal coast plains	Point bars and Tidal channel deposits (offlap)
Low deltaic flood plain	Fluviatile backswamp deposits (offlap)

Depobelts

The sediment fill of the Niger Delta basin is characterized by three major Depobelts. These three cycles show that the basin experienced an overall regression throughout the time as the sediments go from deep sea mud sized grains to fluvial denser sand sized grains. Deposition of the three formations occurred in each of the five offlapping siliciclastic sedimentation cycles that comprise the Niger Delta. These cycles (depobelts) are 30-60 kilometers wide, prograde southwestward 250 kilometers over oceanic crust into the Gulf of Guinea (Stacher, 1995), and are defined by synsedimentary faulting that occurred in response to variable rates of subsidenceand sediment supply (Doust and Omatsola, 1990). The interplay of subsidence and supply rates resulted in deposition of discrete depobelts--when further crustal subsidence of the basin could no longer be accommodated, the focus of sediment deposition shifted seaward, forming a new depobelt (Doust and Omatsola, 1990). Each depobelts (Fig. 3) is a separate unit that corresponds to a break in regional dip of the delta and is bounded landward by growth faults and seaward by large counter-regional faults or the growth fault of the next seaward belt (Evamy et.al., 1978; Doust and Omatsola, 1990). Five major Depobelts are generally recognized, each with its own sedimentation, deformation, and petroleum history;

- Northern Delta
- Greater Ughelli
- Central Swamp
- Coastal Swamp (Most productive depobelt in terms of petroleum)
- Offshore

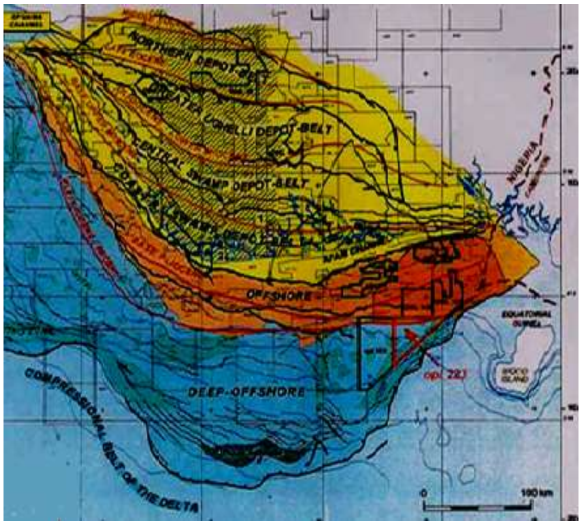


Fig. 3: Depobelts in Niger Delta (Nwozor *et al*., 2013)

Materials and Methods

This study was carried out on core samples recovered from ‘SCOJAS-43’ well. Slabbed core samples were used from between 6233.2 metres and 8773.2 feet for the study.

Coring and Core Recovery

A core is an unbroken cylindrical section of the subsurface taken as a well is being drilled (Fig. 4).

The coring of ‘SCOJAS-43’ well was done using the method described by Maju-Oyovwikowhe and Lucas, 2019b. Except for intervals that were unconsolidated and resulted in low to moderate resin inversion, core recovery (Fig.4) at retrieval was good, and cores were generally in acceptable condition. In general, there was a good to moderate recovery.

Fig. 4: Whole core (SPDC Reservoir Geology Atlas)

The core sections were slabbed after plugging, using a masonry saw, to provide a clean surface for detailed description and for photography. Slabbing is essential for adequate reservoir description, as it allows detailed observation of sedimentary structures poorly displayed in the rough outer surface of the core. The biscuit slab (Fig.5) is normally preserved by resination in which the slab is immersed to just below its top surface in epoxy resin. Slabbing was performed parallel to maximum apparent dip.

Fig. 5: Slabbed core

Sedimentological Studies

Procedures used for describing the cores in this study are, in general, similar to those used in previous studies published by the Antarctic Research Facility (Kaharoeddin *et al*., 1988;).Detailed Sedimentological data was used to model the Geology and environments of deposition of the reservoir and include the following as a function of depth:

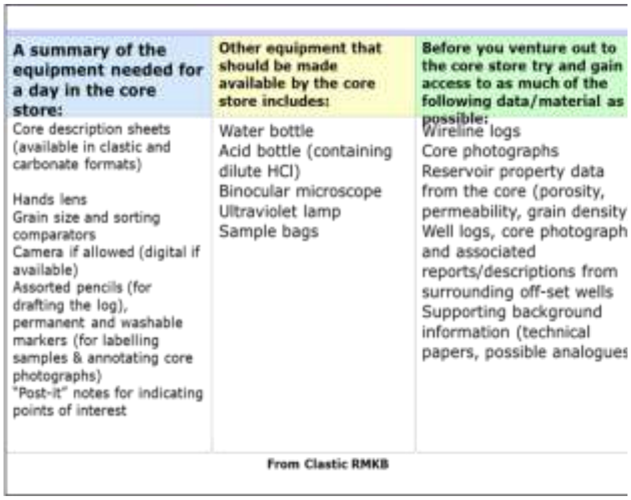
1) Grain size profile
2) Bioturbation
3) Sand/shale ratio
4) Sedimentary structures
5) Cementation
6) Oil stain
7) Environments of deposition

The geological description of core material was performed on slabbed clean core which has been photographed (Fig.5). The descriptions were performed on one section (slab or resinated cut) whilst all plugging and sampling was done on the alternate cut (which was kept in storage). The core description for geological purposes and this present study was split into two categories: macroscopic and; microscopic. These were performed side by side. The macroscopic core description was used for the characterization of lithofacies and the interpretation of depositional setting. The description followed an extensive schedule of items to be recognized, described, commented on and entered on a core description form as presented in Tables 3 and 4. The coding/abbreviations and symbols laid down in the Standard Legend Exploration and Production Departments (1976) and summarized for geological core descriptions in the Guide for Lithological Descriptions of Sedimentary Rocks ("Tapeworm") by E.H.K. Kempter, Shell Gabon, 1966 version was used for this study.

Essential equipment and supporting data

The various equipment and supporting data that was used for this study is given in Table 2. Including grain size comparator (Fig.6) GSA rock color chart, Ichnofacies manual, hand- held magnifying lenses, measuring tape, distilled water, dilute HCL, and brush.

Table 2: Equipments and supporting data used for sedimentological core description.



A summary of the equipment needed for a day in the core store:	Other equipment that should be made available by the core store includes:	Before you venture out to the core store try and gain access to as much of the following data/material as possible:
Core description sheets (available in clastic and carbonate formats) Hands lens Grain size and sorting comparators Camera if allowed (digital if available) Assorted pencils (for drafting the log), permanent and washable markers (for labelling samples & annotating core photographs) “Post-it” notes for indicating points of interest	Water bottle Acid bottle (containing dilute HCl) Binocular microscope Ultraviolet lamp Sample bags	Wireline logs Core photographs Reservoir property data from the core (porosity, permeability, grain density Well logs, core photograph and associated reports/descriptions from surrounding off-set wells Supporting background information (technical papers, possible analogues

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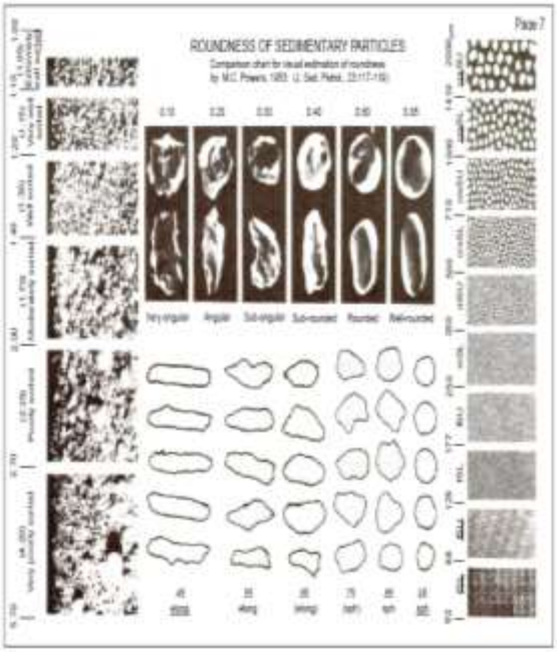


Fig. 6: Example of grain sizes comparator by M.C. Powers, (1953)

Geological Mapping – Description Attributes

The Sedimentological description of the cores for the study was done using the description attributes below.

- ✓ Lithology
  - ○ Main
    - ▪ Sandstone, Shale, Coal, Heterolithics
  - ○ Subordinate
    - ▪ Silty, clayey
  - ○ Colour
- ✓ Sedimentology
  - ○ Textures, bioturbation, grain size, hydrocarbon testing, petrography, accesory minerals, Ichnofacies etc
- ✓ Sedimentary Structures
- ✓ Lithofacies
- ✓ Lithofacies Associations (Genetic Units)

Textural description was done in the order below.

- ✓ Grains Size
  - ○ Coarse, medium or fine
- ✓ Sorting
  - ○ Very well to Poor
- ✓ Roundness
  - ○ Rounded to subrounded
- ✓ Grading

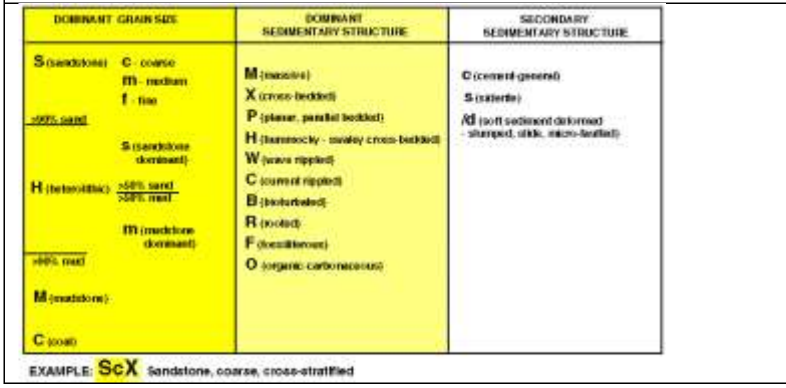
Other features that were described are

- ✓ Hydrocarbon
  - ○ Oil staining, patches, smell
- ✓ Core Condition
  - ○ Rubble zones, mud invasion
- ✓ Sample Location
- ✓ Cementation
  - ○ Carbonate (test by Hcl), Silica, ferruginous
- ✓ Quantitative porosity and permeability
  - ○ Tested by water

Lithofacies

Lithofacies represents a body of sediment/rock with specific lithologic and organic characteristics like grains size, sorting and sedimentary structures imparted by a particular set of energy within an environment of deposition. Uniform physical characteristics mean uniform reservoir properties. Lithofacies constitute the smallest building block in reservoir geology because the unique physical characteristics of a particular lithofacies type (e.g. planer/parallel-bedded fine-medium sandstone) mean that they possess uniform reservoir properties. The SIEP (Davies *et al*. 1997) Lithofacies Scheme – SPDC Practice) was used for this study. It is based primarily on lithology, dominant grain size, dominant sedimentary structure and diagenetic modifications. (Table 3) and studied in relation to the Niger Delta Lithofacies scheme (Table 4)

Table 3: Recognized SPDC Lithofacies Scheme



DOMINANT GRAIN SIZE	DOMINANT SEDIMENTARY STRUCTURE	SECONDARY SEDIMENTARY STRUCTURE
S (sandstone) c - coarse m - medium f - fine >90% sand s (sandstone dominant) H (heterolithic) >50% sand / >50% mud m (mudstone dominant) >90% mud M (mudstone) C (coal)	M (massive) X (cross-bedded) P (planar, parallel bedded) H (hummocky - swaley cross-bedded) W (wave rippled) C (current rippled) B (bioturbated) R (rooted) F (fossiliferous) O (organic carbonaceous)	C (cement-general) S (siderite) /d (soft sediment deformed - slumped, slide, micro-faulted)

EXAMPLE: ScX Sandstone, coarse, cross-stratified

The SIEP (Davies *et al*. 1997) Lithofacies Scheme – SPDC Practice)

Table 4: Niger Delta Lithofacies

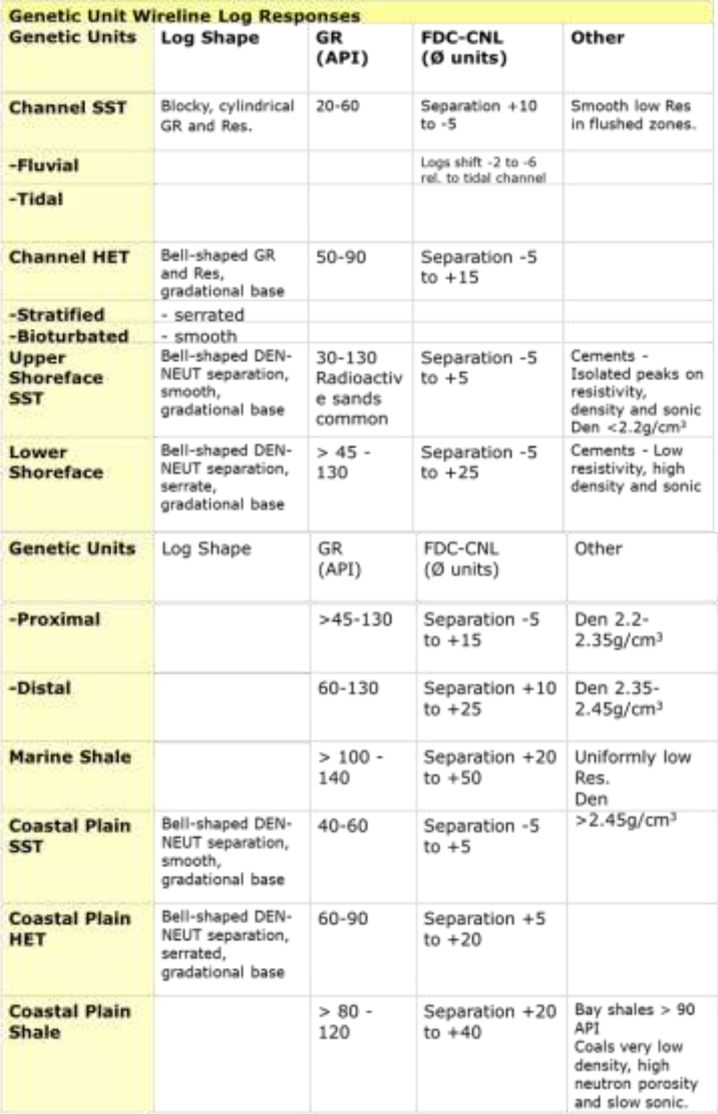
Mudstones	Coal
MASSIVE-LAMINATED MUDSTONE (MP)	COAL (C)
MASSIVE-LAMINATED SIDERITIC MUDSTONE (MPs)	
CARBONACEOUS MUDSTONE (MD)	
ROOTED MOTTLED MUDSTONE (MR)	
FOSSILIFEROUS MUDSTONE (MF)	

Genetic units/Lithofacies Associations

Genetic reservoir units are the result of a practical subdivision of a reservoir into components which have a consistent range of reservoir properties, a consistent external geometry, and a set of log responses (electrofacies) by which they can be consistently recognised (Table5). This up-scaling step from lithofacies to genetic reservoir unit (micro- to meso-scale) is a key stage in the reservoir geological modelling process. It provides the link which ensures that the reservoir property data measured from core is properly incorporated into the volume cells (voxels) used in reservoir modelling (SPDC reservoir Geology Atlas).Electrofacies refers to groups of rocks which have similar physical properties as measured by petrophysical logging tools. The various Genetic units/Lithofacies Association described by SPDC and used as a guide for this study is highlighted below;

1) Channel Sandstone
  I. Fluvial Channel Sandstone
  II. Tidal Channel Sandstone
2) Channel Heterolithic
  I. Stratified Channel Heterolithic
  II. Bioturbated Channel Heterolithic
3) Upper Shoreface Sandstone
4) Lower Shoreface Heterolithic
  I. Proximal Lower Shoreface Heterolithic
  II. Distal Lower Shoreface Heterolithic
5) Marine Shale
6) Coastal Plain Sandstone
7) Coastal Plain Heterolithic
8) Coastal Plain Shale

Table 5: Genetic units and their wireline log responses



Genetic Unit Wireline Log Responses				
Genetic Units	**Log Shape**	**GR (API)**	**FDC-CNL (Ø units)**	**Other**
Channel SST	Blocky, cylindrical GR and Res.	20-60	Separation +10 to -5	Smooth low Res in flushed zones.
-Fluvial			Logs shift -2 to -6 rel. to tidal channel	
-Tidal				
Channel HET	Bell-shaped GR and Res, gradational base	50-90	Separation -5 to +15	
-Stratified	- serrated			
-Bioturbated	- smooth			
Upper Shoreface SST	Bell-shaped DEN-NEUT separation, smooth, gradational base	30-130 Radioactive sands common	Separation -5 to +5	Cements - Isolated peaks on resistivity, density and sonic Den <2.2g/cm³
Lower Shoreface	Bell-shaped DEN-NEUT separation, serrate, gradational base	> 45 - 130	Separation -5 to +25	Cements - Low resistivity, high density and sonic
Genetic Units	Log Shape	GR (API)	FDC-CNL (Ø units)	Other
-Proximal		>45-130	Separation -5 to +15	Den 2.2-2.35g/cm³
-Distal		60-130	Separation +10 to +25	Den 2.35-2.45g/cm³
Marine Shale		> 100 - 140	Separation +20 to +50	Uniformly low Res. Den
Coastal Plain SST	Bell-shaped DEN-NEUT separation, smooth, gradational base	40-60	Separation -5 to +5	>2.45g/cm³
Coastal Plain HET	Bell-shaped DEN-NEUT separation, serrated, gradational base	60-90	Separation +5 to +20	
Coastal Plain Shale		> 80 - 120	Separation +20 to +40	Bay shales > 90 API Coals very low density, high neutron porosity and slow sonic.

Precautions

In order to obtain valid and correct results and ensure safety during the processing stage of a core analysis programme, the following precautions were adhered to;

- Various samples were prevented from exposure to chemicals and air until tests had been completed.
- Proper labelling of containers used for storage of various chemicals.
- Laboratory protective jacket, hand gloves, protective eye glasses and respiratory masks were used to ensure body protection.

Results and Discussion

. The various lithofacies encountered during the study are shown in Fig.7.

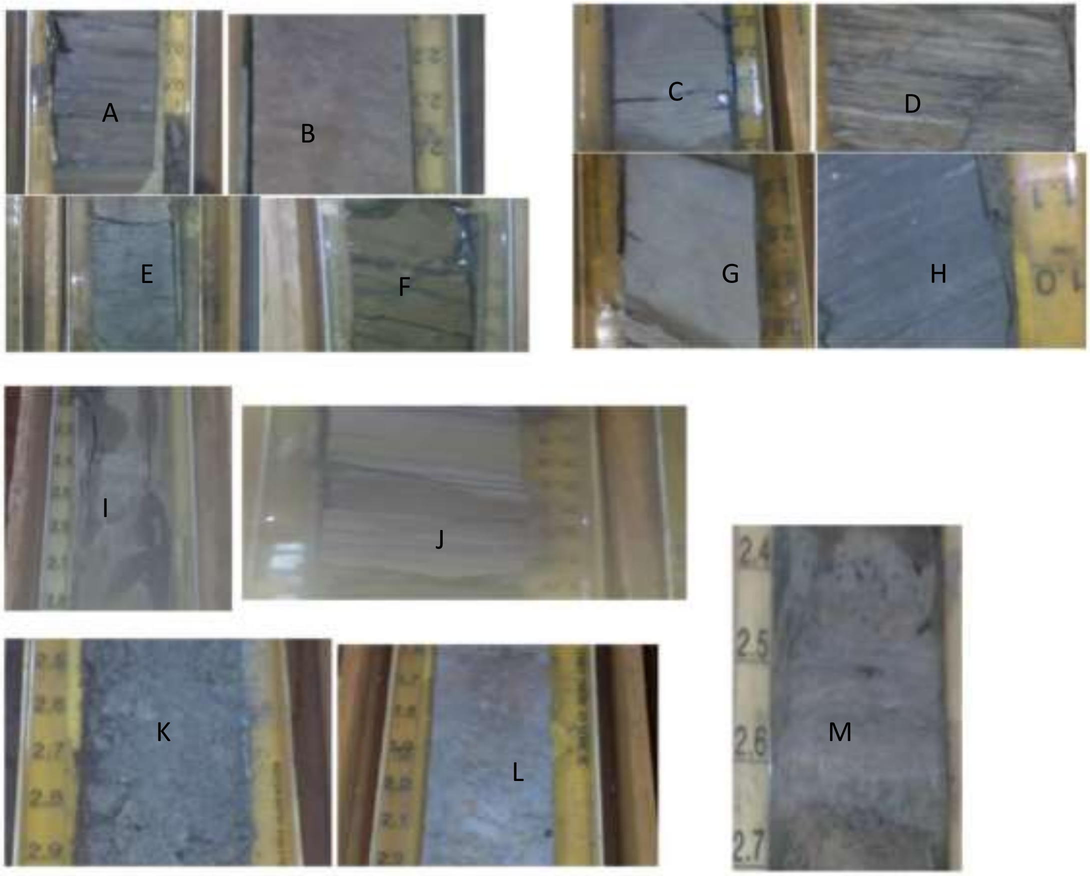


Fig.7: Core samples in the study well showing the different lithofacies
(A)Massive-Laminated Sideritic Mudstone (MPs), (B) Fossiliferous Sandstone (SF), (C) Current Rippled Sandstone (SC), (D)Bioturbated Muddy Heterolith (HmB), (E) Fossiliferous Mudstone (MF), (F) Cross-Bedded Medium-Fine Sandstone (SmX), (G) Hummocky/Swaley Cross Stratified Sandstone (SH), (H)Massive-Laminated Mudstone (MP), (I) Planar Laminated Sandstone (SP), (J) Current Ripple Sandy Heterolith (HsC), (K) Cross-Bedded Coarse-Gravelly Sandstone (ScX), (L) Bioturbated Medium-Fine Sandstone (SmB, (M) Planar Laminated Sandstone (SP[2])

Table 6: Summary of Lithofacies Sedimentological Description of ‘SCOJAS’-43 Well

	DEPTH				
S/N	BOTTOM	TOP	**LITHOTYPE/ LITHOLOGY**	**LITHOFACIES**	**CODE**
1	6233.2	6230	SHALE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
2	6238	6233	SANDSTONE	FOSSILIFEROUS SANDSTONE	SF
3	6238.5	6238	SHALE	FOSSILIFEROUS MUDSTONE	MF
4	6239	6238.5	SANDSTONE	FOSSILIFEROUS SANDSTONE	SF
5	6243.3	6239	HETEROLITH	BIOTURBATED MUDDY HETEROLITH	HmB
6	6251.7	6243	SANDSTONE	MASSIVE-PARALLEL LAMINATED SANDSTONE	SP
7	6253	6252	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
8	6253.7	6253	SANDSTONE	PLANAR/PARALLEL LAMINATED SANDSTONE	SP
9	6255.4	6254	MUDSTONE	MASSIVE-LAMINATED SIDERITIC	MPs

				MUDSTONE	
10	6258.2	6255	SANDSTONE	PLANAR/PARALLEL LAMINATED SANDSTONE	SP
11	6259	6258	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
12	6260.5	6259	SANDSTONE	PLANAR/PARALLEL LAMINATED SANDSTONE	SP
13	6265.1	6261	SANDSTONE	PLANAR/PARALLEL LAMINATED SANDSTONE	SP
14	6266	6265	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
15	6267.4	6266	SHALE	MASSIVE-LAMINATED MUDSTONE	MP
16	6267.9	6267	SANDSTONE	FOSSILIFEROUS SANDSTONE	SF
17	6269	6268	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
18	6273.1	6269	SANDSTONE	PLANAR/PARALLEL LAMINATED SANDSTONE	SP
19	6281	6273	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
20	6294	6282	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
21	6300.5	6294	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
22	6302.6	6301	SANDSTONE	HUMMOCKY/SWALEY CROSS STRATIFIED SANDSTONE	SH
23	6312.6	6303	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
24	6326.4	6324	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
25	6347.9	6327	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
26	6350.5	6349	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
27	6359.5	6358	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
28	6362	6360	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
29	6362.5	6362	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
30	6369.2	6363	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
31	6373	6369	SHALE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
32	6376.5	6373	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
33	6378	6377	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
34	6378.5	6378	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
35	6391.7	6389	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
36	6393.5	6392	SHALE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
37	6396.7	6396	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
38	6428.6	6420	MUDSTONE	MASSIVE-LAMINATED SIDERITIC MUDSTONE	MPs
39	6429.8	6428.6	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
40	6770	6767	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
41	6795.6	6770	SANDSTONE	CURRENT RIPPLED SANDSTONE	SC
42	6797.6	6796	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
43	6812	6798	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX

44	6813.1	6812	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
45	7043	7041	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
46	7046	7043	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
47	7070.4	7046	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
48	7104	7101	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
49	7107	7104	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
50	7110	7107	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
51	7113	7110	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
52	7114.5	7113	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
53	7122	7115	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
54	7127.4	7122	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
55	7138	7128	SANDSTONE	CROSS-BEDDED MEDIUM-FINE SANDSTONE	SmX
56	7159	7138	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
57	8686	8683	SHALE	MASSIVE -LAMINATED MUDSTONE	MP
58	8686.3	8686	SANDSTONE	FOSSILIFEROUS SANDSTONE	SF
59	8687.4	8686	SHALE	MASSIVE-LAMINATED MUDSTONE	MP
60	8689	8687	SANDSTONE	BIOTURBATED MEDIUM-FINE GRAINED SANDSTONE	SmB
61	8699.2	8689	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
62	8710	8699	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
63	8712.6	8712	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
64	8718.9	8713	HETEROLITH	CURRENT RIPPLED SANDY HETEROLITH	HsC
65	8740.4	8719	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
66	8743.1	8741	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
67	8746.5	8746	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
68	8748	8747	MUDSTONE	MASSIVE -LAMINATED MUDSTONE	MP
69	8750	8748	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
70	8751	8750	MUDSTONE	MASSIVE-LAMINATED MUDSTONE	MP
71	8755.5	8751	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
72	8755.7	8756	MUDSTONE	MASSIVE-LAMINATED MUDSTONE	MP
73	8755.9	8756	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
74	8756.1	8756	MUDSTONE	MASSIVE -LAMINATED MUDSTONE	MP
75	8761.3	8756	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
76	8763.4	8761	SANDSTONE	PLANAR/PARALLEL LAMINATED SANDSTONE	SP
77	8772.6	8763	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX
78	8775	8773	SANDSTONE	CROSS BEDDED COARSE-GRAVELLY SANDSTONE	ScX

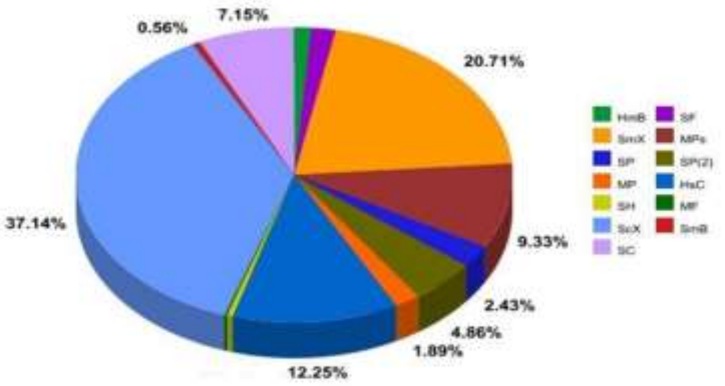


Fig. 8: Pie Chart Showing Lithofacies Distribution of 'SCOJAS' -43 Well

Table 7: Summary of Lithofacies Association of 'SCOJAS' -43 Well

	DEPTH		
S/N	BOTTOM	TOP	**LITHOFACIES ASSOCIATION/DEPOSITIONAL ENVIRONMENT**
1	6233.2	6230	MARINE SHALE
2	6243.3	6233.2	BIOTURBATED CHANNEL HETEROLITHIC
3	6273.1	6243.3	MARINE SHALE
4	6302.6	6273.1	STRATIFIED CHANNEL HETEROLITHIC
5	6347.9	6302.6	TIDAL CHANNEL SANDSTONE
6	6359.5	6347.9	MARINE SHALE
7	6369.2	6359.5	TIDAL CHANNEL SANDSTONE
8	6373	6369.2	MARINE SHALE
9	6391.7	6373	TIDAL CHANNEL SANDSTONE
10	6428.6	6391.7	MARINE SHALE
11	6797.6	6428.6	PROXIMAL LOWER SHOREFACE HETEROLITHIC
12	7070.4	6798	FLUVIAL CHANNEL SANDSTONE
13	7104	7101	TIDAL CHANNEL SANDSTONE
14	7107	7104	FLUVIAL CHANNEL SANDSTONE
15	7114	7107	COASTAL PLAIN SANDSTONE
16	7122	7114	FLUVIAL CHANNEL SANDSTONE
17	7138	7122	TIDAL CHANNEL SANDSTONE
18	7159	7138	FLUVIAL CHANNEL SANDSTONE
19	8689	8683	MARINE SHALE
20	8699.2	8689	FLUVIAL CHANNEL SANDSTONE
21	8719	8699.2	PROXIMAL LOWER SHOREFACE HETEROLITHIC
22	8750	8719	FLUVIAL CHANNEL SANDSTONE
23	8751	8750	MARINE SHALE
24	8775	8751	FLUVIAL CHANNEL SANDSTONE

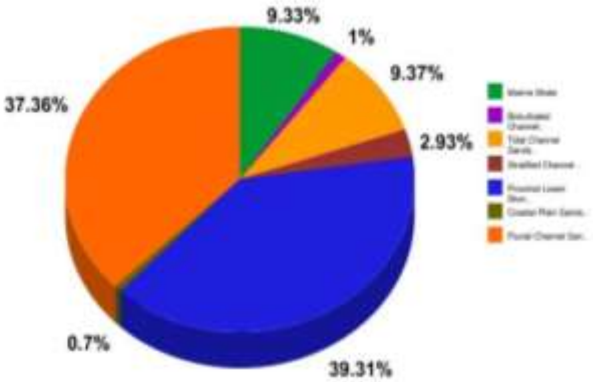


Fig. 9: Pie Chart Showing Distribution of Lithofacies Association in 'SCOJAS' -43 Well

Lithofacies Description

Massive-Laminated Sideritic Mudstone (MPs)

This lithofacies constitutes **9.33%** of the cored interval with colour ranging from medium to dark brown. The facies consist of shales and streaks of silty shales and streaky laminae. It is massive in appearance to weakly laminated and moderately fissile. Physical sedimentary structure is limited to the occurrence of thin, horizontally bedded siltstones and very fine sandstones. This facies is characterized by mm scale thick nodules of orange-brown siderite. The fine grained nature of this facies suggests deposition under low hydraulic energy conditions primarily by suspensions fallouts. The rare sand and silty laminae are indicative of energetic events.This sandstone constitutes **1.77%** of cored interval. It is made up of light brown to light grey sandstones and marked by its abundance of fossils which tend to obliterate the original sedimentary structures. Grain size ranges from fine to medium with sparsely dispersed coarse grains. The lithofacies commonly exhibit high organic content. On the basis of high fossil content, deposition in low energy marine setting in which sorting was achieved by tidal currents can be suggested.

Fossiliferous Mudstone (MF)

This facies constitute **0.17%** of cored interval. It is primarily medium to light grey in colour and characterized by its abundance of fossils. Abundance of fossils and relatively fine grains indicate deposition in a wide range of shallow marine setting.

Bioturbated Muddy Heterolith (HmB)

This facies make up **1.2%** of cored interval and consists of intensely bioturbated sandy claystones and planar laminated sandstones and shales with abundance of trace fossil assemblage. The heterolithic nature of this facies and intense bioturbation indicates deposition in a low energy, shallow-deep marine setting characterized by alternating bedload and suspension fallout.Heterolith, muddy, light to dark grey, fine to very fine grained, well sorted sandstone and claystones, interbedded sand laminae, clay greater than 65%, highly bioturbated.

Massive-Parallel Laminated Sandstone (SP)

This lithofacies constitute **2.43%** of cored interval. It consists of parallel laminated sandstone which is massive in some parts. Sandstones are medium-fine grained and are usually moderately well to well sorted. Bioturbation and fossils are rare. Well-developed sorting and low fossil content is indicative of wave sorted sand, deposited in high energy, shallow marine environments.

Fossiliferous sandstone (SF)

This lithofacies type constitutes **4.86%** of the cored interval. It consists of amalgamated planar to parallel laminated, medium to fine grained sandstone, with a dominance of medium grained sandstones. The deposits are moderately well to well sorted, subrounded to subangular. Bioturbation is rare to moderate. The well-developed sorting and restricted marine ichnofaunal assemblages found in this facies are indicative of wave-sorted sand that was deposited in a high energy, shallow marine environment.

Massive-Laminated Mudstone (MP)

This facies constitute **1.89%** of the cored interval, with colour ranging from medium-dark brown. The facies consist of shales and streaky of silty shales and sand laminae. It is usually massive to weakly laminated in appearance. Fine grained nature of this facies suggests deposition under low energy conditions primarily by suspension fallouts.

Current Ripple Sandy Heterolith (HsC)

This lithofacies makes up **12.25%** of cored interval. It consists of heterolithic mix of sand, silt and claystones and is characterized by current rippled laminated fine grained sandstones interbedded with mm scale thick shale laminations. Bioturbation is generally rare with dm scale discrete spotty appearance. The rare bioturbation and heterolithic fabric of this facies indicates deposition in a low energy, shallow marine setting characterized by alternating bedload and suspension fallout.

Hummocky/Swaley Cross Stratified Sandstone (SH)

This facies constitutes **0.45%** of cored interval. Sandstone of this facies are usually grey to light brown in colour. This facies is characterized by a series of smile-like shapes, crosscutting each other. The hummocky cross stratification structure is indicative of formation at depth of water below fair-weather wave base and above storm-weather wave base.

Cross-Bedded Medium-Fine Sandstone (SmX)

This lithofacies constitutes **20.71%** of the core interval. The lithofacies consists of moderately sorted, fine to medium grained sandstones with unidirectional stratifications and rarely preserved reverse cross stratifications. On account of its good sorting, the uni- to bi- directional cross stratification indicate marine sourced sand sorted by tidal/wave processes in a lower flow regime current and was interpreted to be deposited in tidal channels with marine influence.

Cross-Bedded Coarse-Gravelly Sandstone (ScX)

This lithofacies constitutes **37.14%** of cored interval. It is composed of interbedded granular sandstones with very fine grained laminae. This lithofacies is characterized by pebbles and granules which commonly form lags at the bases. This facies exhibits tabular to low-angled cross stratifications. Bioturbation is mostly absent to rare. The coarse grained, poor sorting, cross beddings and sharp erosive bases reflect a high energy flow regime characteristic of a fluvial depositional system and restricted ichnofacies is suggestive of coastal environment. About 2cm bed of silty sand with greater than 35% clay and rich amount of carbonaceous matter within the cross bedded coarse to gravelly sandstone

Bioturbated Medium-Fine Sandstone (SmB)

Sandstone, light grey to light brown, medium to fine grained, well sorted, clay 5-15%, Highly consolidated, few calcareous shell debris, ichnofossil, highly bioturbated. The lithofacies constitutes **0.56%** of cored interval. It is composed of light brown to light grey sandstones and marked by its high degree of bioturbation which has destroyed the original sedimentary structures. Grain size ranges from very fine to medium with sparsely dispersed coarse grains, poorly to moderately sorted and unconsolidated. This lithofacies commonly exhibits high organic content. On the basis of its moderately-poor sorted nature, the presence of argillaceous laminae and the pervasive bioturbation are suggestive of deposition in a low energy marine setting in which sorting was achieved by tidal currents.

Current Rippled Sandstone (SC)

The current rippled sandstone lithofacies makes up 7.15% of the lithofacies described in the study. The sandstones are mostly light grey to dark grey, medium to fine grain, well to moderately sorted, sedimentary structures are current ripples, clay is less than 10%, wavy beds, mud drapes and carbonaceous plant debris forms organic rich laminae. Highly consolidated, bioturbation is absent, sharp contact with a ScX lithofacies.

Lithofacies Association Description

Marine Shale

This lithofacies association makes up **9.33%** of the cored interval. These units mostly comprise of succession of silty shales (MP) in which siderite cement is common (MPs). They are characterized by low levels of bioturbation and may contain streaks and lenses of very fine sand and coarse units. Biostratigraphical analysis shows that the marine clays were deposited in middle neritic to bathyal environment.

Bioturbated Channel Heterolithic

This lithofacies association makes up **1%** of cored interval. This unit includes the only Bioturbated Muddy Heterolith (HmB) in the sequence overlain by fossiliferous facies (SF and MF). From the abundance of fossils present and intense bioturbation, it can be inferred that deposition probably occurred in neritic environment.

Stratified Channel Heterolithic

This lithofacies association makes up **2.93%** of cored interval. This unit is characterized by of Current Rippled Sandy Heterolith (HsC) with underlying Massive Laminated Sideritic Mudstone (MPs)

Tidal Channel Sandstone

This lithofacies association makes up **9.37%** of cored interval. This unit is characterized by medium scale cross stratified strata developed in well to very well sorted medium-fine grained sandstone (SmX). The cross strata are predominantly unidirectional with tidal influence rarely indicated by opposing sets of cross-strata. They are characterized by the occurrence of restricted marine burrow assemblages

Proximal Lower Shoreface Heterolithic

This lithofacies association makes up **39.31%** of core interval. These are sandstones dominated heterolithic successions comprising medium-bedded fine grained sandstones interbedded withy thin heterolithic intervals. Bioturbation levels range from rare to moderate, being more in heterolithic strata. There is typically a diverse open marine trace fossil suite.

Fluvial Channel Sandstone

This lithofacies association makes up **37.36%** of cored interval. The internal structure of this unit is characterized by unidirectional, medium scale cross strata developed in poorly sorted, granular to coarse grained sandstones of the of ScX lithofacies. The coarse grain size and poor sorting of the sands reflect fluvial dominance. Also, the rare presence of restricted marine trace fossil assemblages indicates deposition in marine setting. Tidal influence is inferred from the argillaceous laminae and rhythmic alternations of granular and coarse grained strata.

Coastal Plain Sandstone

This lithofacies association makes up **0.7%** of cored interval. This unit is composed of coarsening-upward successions of moderately well sorted fine to medium grained sandstone dominated by interbedded planar bedded sandstone (SP). The unit possesses gradational bases and bioturbation levels range from rare to moderate.

Conclusion

Geological core analysis is the first step in a long chain of investigations and measurements involving core material. The geological analysis of core material provides a framework of understanding of the cored hydrocarbon reservoir to which the various stratigraphical, geochemical and petrophysical analyses can be attached. The vertical succession of texture and sedimentary structures help define the depositional facies of the sequence. The depositional facies define the geometry of the potential hydrocarbon reservoir. For reservoir modeling, it is important to note that the differentiation of Fluvial Channel and Upper Shoreface sands in reservoir units is necessary as they both share the same dominant lithofacies. Channel heterolithic units, will not form intra-reservoir barriers due to the absence of non-reservoir shale layers but may form localized flow baffles and potential barriers within fluvial channel dominated reservoirs as a result of their reduced permeabilities. The accurate description of the reservoir is essential to field development.

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Conflict of Interest
The authors declare no conflict of interest

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