Journal of Scientific Research & Reports

26(1): 93-103, 2020; Article no.JSRR.54492
ISSN: 2320-0227

Interpretation of Depositional Environment of Rho Field Using Sequence Stratigraphic Analysis, Shallow Offshore Depobelt, Niger Delta

Okoli Emeka Austin[1*], Acra Jones Edward[2] and Ehirim Chukwuemeka Ngozi[2]

[1]Federal University of Technology, Owerri, Nigeria.
[2]University of Port Harcourt, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author OEA acquired the data, performed the correlation across the wells, the sequence stratigraphic analysis from biostratigraphic data in the wells and developed the initial write-up of the paper. Author AJE QCed the correlation across the wells, developed the depositional environment model from the correlation across the wells, analyzed the biostratigraphic data for sequence stratigraphic analysis, justified the sequence stratigraphic interpretations and proof-read the write up. Author ECN proof read the paper and corrected and edited the grammatical errors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2020/v26i130217
Editor(s):
(1) Dr. R. Pandiselvam, Department of Agricultural Process Engineering, ICAR-Central Plantation Crops Research Institute, India.
Reviewers:
(1) Kasturi Bhattacharyya, Indian Institute of Technology, India.
(2) Jasenka Sremac, University of Zagreb, Croatia.
Complete Peer review History: http://www.sdiarticle4.com/review-history/54492

Original Research Article

Received 10 December 2019
Accepted 15 February 2020
Published 21 February 2020

ABSTRACT

Candidate Maximum Flooding Surfaces (MFS) identified on Rho-1, Rho-2 and Rho-3 were the basis of correlation across the wells for sequence Stratigraphic analysis in the field. Three (3) candidate MFS which include MFS-1, MFS-2 and MFS-3 were identified using the method adopted by Okoli [1]. Erosional surfaces were also delineated in wells from the observed stacking pattern between a sequence from Galloway model (1989) leading to the correlation of SB-1 and SB-2 across the wells. Using the Galloway model, four (4) depositional sequences were inferred SEQ (1-4). In the first sequence (SEQ 1), deposition occurred in a transgressive episode. Depositional environment was interpreted from electrofacies and revealing stacked sequences of reservoirs predominantly composed of fluvial channels which incised the Upper and Lower Shorefaces on a delta front system. In SEQ 2, looking at the aggradational pattern of the sequence, the formed channels were under the influence of both tidal and fluvial systems. In SEQ 3 and 4, based on

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*Corresponding author: E-mail: ebukasean09@yahoo.com;

electro-facies, the stacked reservoir sands were deposited predominantly in a shoreface/delta front environment and channel incisions in a wave subjugated high energy deltaic setting.

The entire well section showed deposition in a regressive phase. Proposed conceptual models were generated using Petrel software and could be used as an input reconstruction of subsurface geological models. Indicating correct orientation of geo-bodies and facies belts (pinch outs of sands and shales), depositional dips and gross permeability architecture.

Keywords: Electro-facies; gross permeability; depositional environment; sequence stratigraphy.

1. INTRODUCTION

Sequence stratigraphic perceptions for sediment accumulation and conservation inclinations within the basin fills are highly successful exploration tool in the search for hydrocarbon resources. Basin's sedimentary fill hooked on stratigraphically constrained depositional packages is an imperious in extrication basin progress and essential hydrocarbon capacities. Sequence stratigraphic perception is progressively finding new and unique applications in the reverting siliciclastic deposits of the Niger Delta Basin.

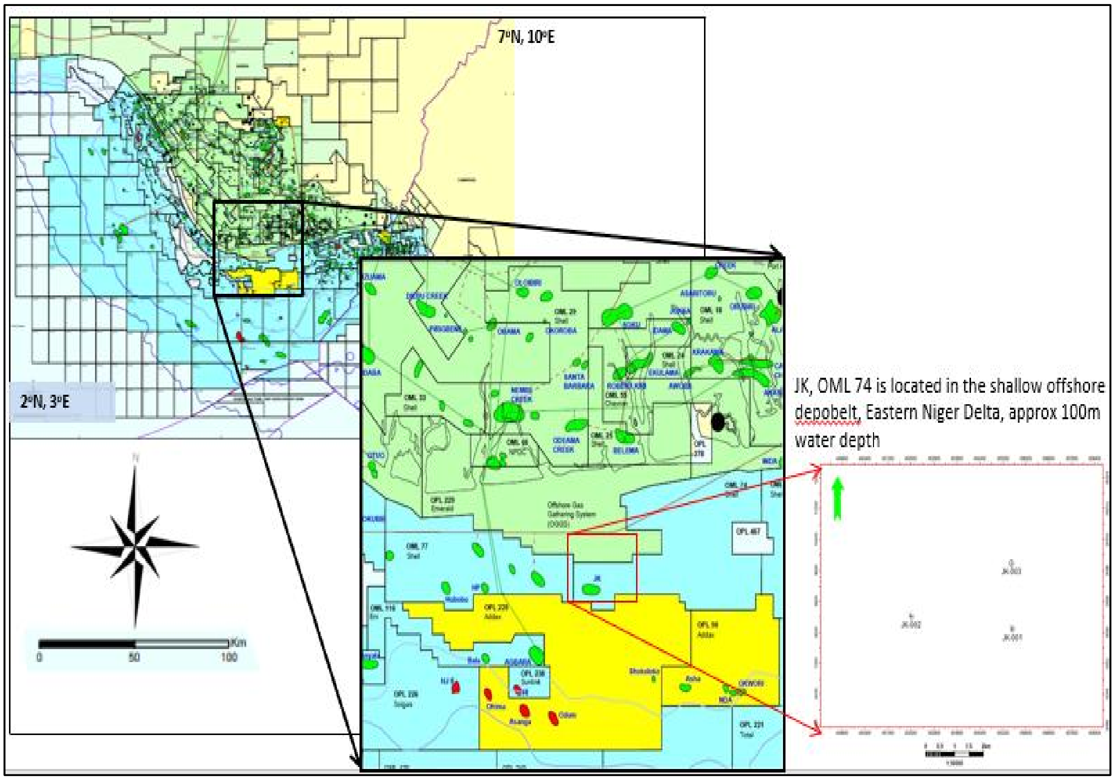
Hydrocarbons are within the subsurface, they cannot unwarily spurt to the surface when infiltrated by a production well [2]. On the divergent, most reservoir hydrocarbons exist in the microscopic pore galaxies or exposed fractures of sedimentary rocks like sandstones. Through their exploitation, thorough geological, and petrophysical information and data are required to guide the placement of production podiums and well pathways [3]. This can subsequently help to enhance hydrocarbon retrieval, and to expand estimates of the reservoir recital. Well-log sequence stratigraphy on the other hand, being an essential part of well-log seismic sequence stratigraphy permits the geoscientists to divide a rock segment into sequences of genomic units restricted by abbreviated segment and their allied extreme flooding surface by means of wire line log patterns [4,5,6]. Each sequence can be sub-divided into minor deposits packages called systems tracts on the basis of distinctive well-log patterns [7]. Sequence analysis and system tract study permits the estimate of the depositional setting and this can be linked to the petrophysical property values gotten. The study is intended at unravelling the expectations that stems from relating reservoir stratigraphy with rock assets. The main impartial of this work is the valuation of hydrocarbon potential in the field by petrophysical interpretation and scrutiny, and afterward in the identification of depositional environments to deduce associations between petrophysical values and the depositional environment of the area. Through this, the cross disparities in petrophysical values may be clarified, and there would be a better considerate of the implication of petrophysics to exploring hydrocarbon in topography similar to the study area.

Numerous works have been carried out in relative to the sequence stratigraphy of diverse parts of the Niger Delta. These include [8], who recognized an cohesive geologic outline of the Niger Delta slope, by smearing recognized sequence stratigraphic notions on a seismic data set of the Niger Delta along with the biostratigraphic data. Stacher [9] fashioned a delta wide framework of chronostratigraphic surfaces, and a sequence stratigraphic chart for the Niger Delta using alphanumerically deposited biostratigraphic data. Krusi and Idiagbor [10] associated some types of stratigraphic traps to carved valley fills and low stand fans. Thus, they were able to advance the identification of stratigraphic plays in the eastern Niger Delta. Ozumba [11] established a classification stratigraphic context of the western Niger Delta, by means of foraminifera and wireline log data gotten from the coastal and central swamp depobelts. He resolved that the late Miocene sequences were denser than the Middle Miocene sequences.

2. STRATIGRAPHY AND GEOLOGICAL SETTING

The Niger Delta is located in the Gulf of Guinea and spreads through the Niger Delta domain. The delta has prograded southwestwards establishing depobelts that characterize the utmost vigorous slice of the delta at each stage of its progress [12].

The Niger Delta is one of the utmost inexhaustible deltaic hydrocarbon provinces in the flora and fauna. While it is extensively supposed that the Niger Delta encompasses only one recognized petroleum system [9,13]. Haack et al. [14] acquiesced that the Niger Delta is essentially made up of three discrete petroleum systems.



JK, OML 74 is located in the shallow offshore depobelt, Eastern Niger Delta, approx 100m water depth

Fig. 1. Map showing the study area

These are: Lower Cretaceous (lacustrine), Upper Cretaceous – Lower Paleocene (marine), Tertiary (deltaic).

Nevertheless, it is commonly alleged that the prime spring of oil and gas in the Niger Delta is the Tertiary deltaic petroleum systems involving of types II, II-III, and III kerogens [12,14,15]. Short and Stauble [16], Doust and Omatsola [12], Reijers et al. [13] providing evidence on the depositional sequences in Southern Nigeria.

The Niger Delta is a bulky arcuate Tertiary prograding alluvial multipart placed below provisional marine, deltaic and interior environments subsequently the Paleocene in the north to Recent in the south. It covers an expanse of about 75,000 Km² from the Calabar Flank and Abakaliki Trough in eastern Nigeria to the Benin Flank in the west. It releases to the Atlantic Ocean in the south where it obtrudes into the Gulf of Guinea as an allowance from the Benue Trough and Anambra Basin provinces. It is categorized by abrading upward reverting sequences which spreads a extreme thickness of 30,000 to 40,000 feet [17]. The general reverting sequence of clastic sediments was placed in a series of offlap sequences that were intermittent by stages of the sea level alteration. The operational formation and the stratigraphy of the Niger Delta have been measured by the interaction amid rates of sediment supply and subsiding [12,17].

3. METHODOLOGY

The dataset comprises: 3D seismic data, unconventionality surveys, check shot data and complements of well logs for three wells. The three dimensional (3-D) seismic replication data used for this study comprise in-lines and cross-lines. Well log data contain gamma ray, caliper, resistivity, spontaneous potential, bulk density and sonic.

The workflow used in this study is presented in Fig. 2.

A complement of well logs, were gotten from three wells namely; Rho-1, Rho-2 and Rho-3, penetrated inside the Rho- Field in the western Niger Delta.

A thorough investigation and explanation of the complement of well logs was carried out,

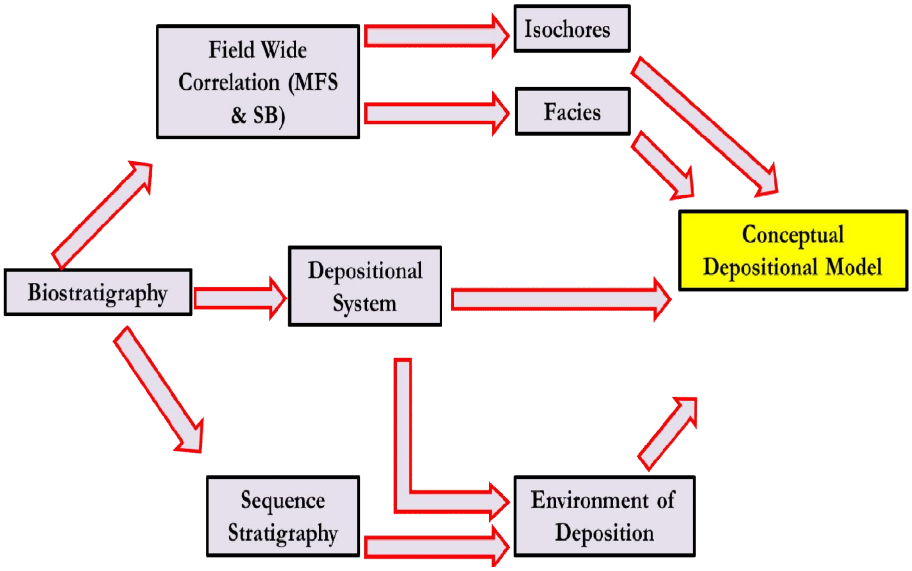


Fig. 2. Workflow for the study

followed by biostratigraphic interpretation of data. The numerous estimates were unified and interpreted to infer a sequence stratigraphic outline of the Field.

The recognition of sequence boundaries (SB) in this study was grounded on the notion of [18]. The sequence boundaries were recognized by sand-rich facies, within a roughening ascendant sequence. These are habitually located amid the two maximum flooding surfaces and are predictable by an erosional surface amongst a low- stand and a high stand system tract.

Schlumberger Petrel software was used for the analysis of seismic and well data. In-lines, crossline and time slices were produced and quality control performed on them. Well header information file encompassing co-ordinates was loaded into the Petrel software before the well logs were loaded in order to parade the wells within their appropriate co-ordinates. Unconventionality surveys were also introduced into the Petrel software. The unconventionality survey dealings the unconventionality of the wells from upright.

Well log data were imported after appropriate quality control was carried out on the data. A base map (Fig. 3) of the study area was produced after loading the numerous data types reckoned above.

Posamentier and George [19] acknowledged the first stage in sequence stratigraphic explanation as fortitude of the overall paleogeographic setting for the database in question.

Resolve of physiographic setting for this dataset was skilled using 2-D and 3-D seismic data. These data offer constant imaging of the subsurface in a way not probable with other forms of data because they allow the explanation of the total geologic and tectonic setting of the basin [6]. The 2-D seismic data afforded a cross sectional sight of the seismic data.

The second step is to understand the depositional systems and facies by means of all accessible data. Diverse para sequence piling outlines (roughening upward, fining upward, blocky, symmetrical and jagged outlines) observed were examined in association with those below and above separate para sequences to determine depositional systems. This variety of outlines associates with those designated by [20,21,22,23].

The third step is to split the stratigraphic sequence through the documentation of maximum flooding surfaces and sequence boundaries [19,24]. Gamma ray logs were scrutinized for uppermost peaks that might indicate the flooding surfaces, maximum flooding surfaces and sequence boundaries were recognized afterwards.

Check shot data was used for well log to seismic tie, this was essential in order to be able to discover and mark evidence from the well data in

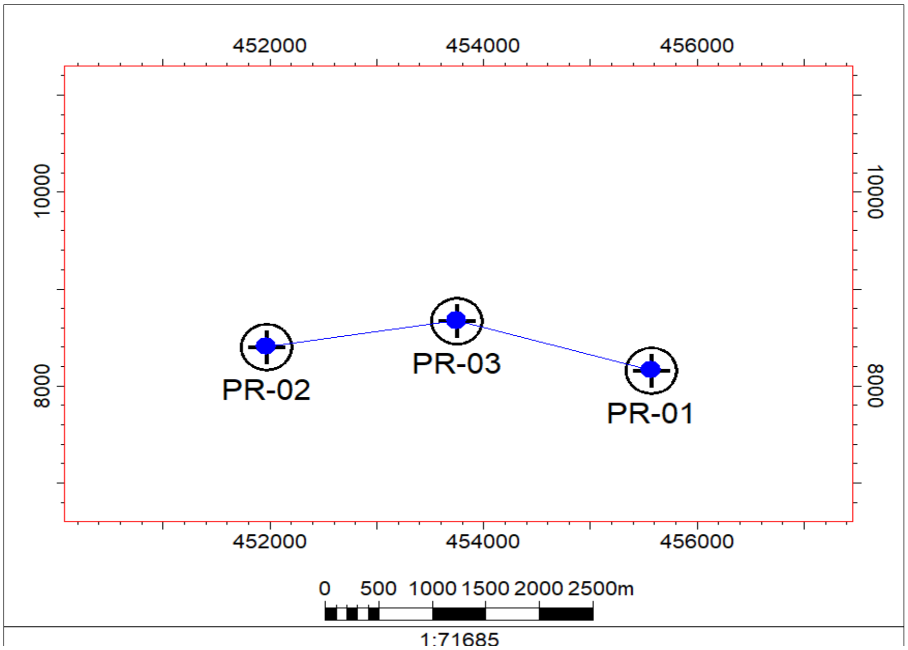


Fig. 3. Base map of the study area

the form of geologic tops on the time (seismic) section. Well logs were used to identify diverse lithofacies existing within the study area. Gamma ray (GR) logs were used as the prime paraphernalia for lithology identification and descriptions.

Lithology construal was done for all the wells and through cautious study of log outlines, para sequences and structures tracts were recognized. Well association for the Rho field was done after lithology interpretation based on well logs.

4. RESULTS AND DISCUSSION

Well correlation for the Rho Field was done after the lithological explanation based on gamma ray log patterns. Authors were focused on recording sequence boundaries and maximum flooding surfaces, recognized by the sudden alteration in well log assets, such as gamma-ray, resistivity and density. The subsequent steps were taken in order to associate the maximum flooding surfaces across the field on well logs:

Points of the maximum gamma ray value and the minimum shale resistivity values were picked as maximum flooding surface

Association of the maximum flooding surfaces in all wells within a contextual of para sequence and para sequence sets heaping outline [18,19,25].

The important bounding surfaces recognized in the study area are the maximum flooding surfaces (MFS) and sequence boundaries (S B) with their conforming depths. Two sequence boundaries and three maximum flooding surfaces were recognized across the wells in the Rho Field.

The Niger Delta Chronostratigraphic chart assisted in this identification and is also used in seeing the crucial bounding surfaces, the maximum flooding surfaces branded in the study area agree to the transgressive marker shale of the chronostratigraphic chart and they are marked by Dodo shale and Cassidulina 7. Both marker shales were identified in the Rho fields.

Transgressive systems tract (TST) and high stand systems tracts were predictable by stacking outlines and bounding surfaces (maximum flooding surfaces and sequence boundaries). Low stand systems tract (LST) is inattentive in the field. This is perhaps due to the erosion of an older deltaic composite assembled across the shelf during the preceding LST. System tract parades fluctuating degree of illustration across the three known depositional sequences in the Rho Field.

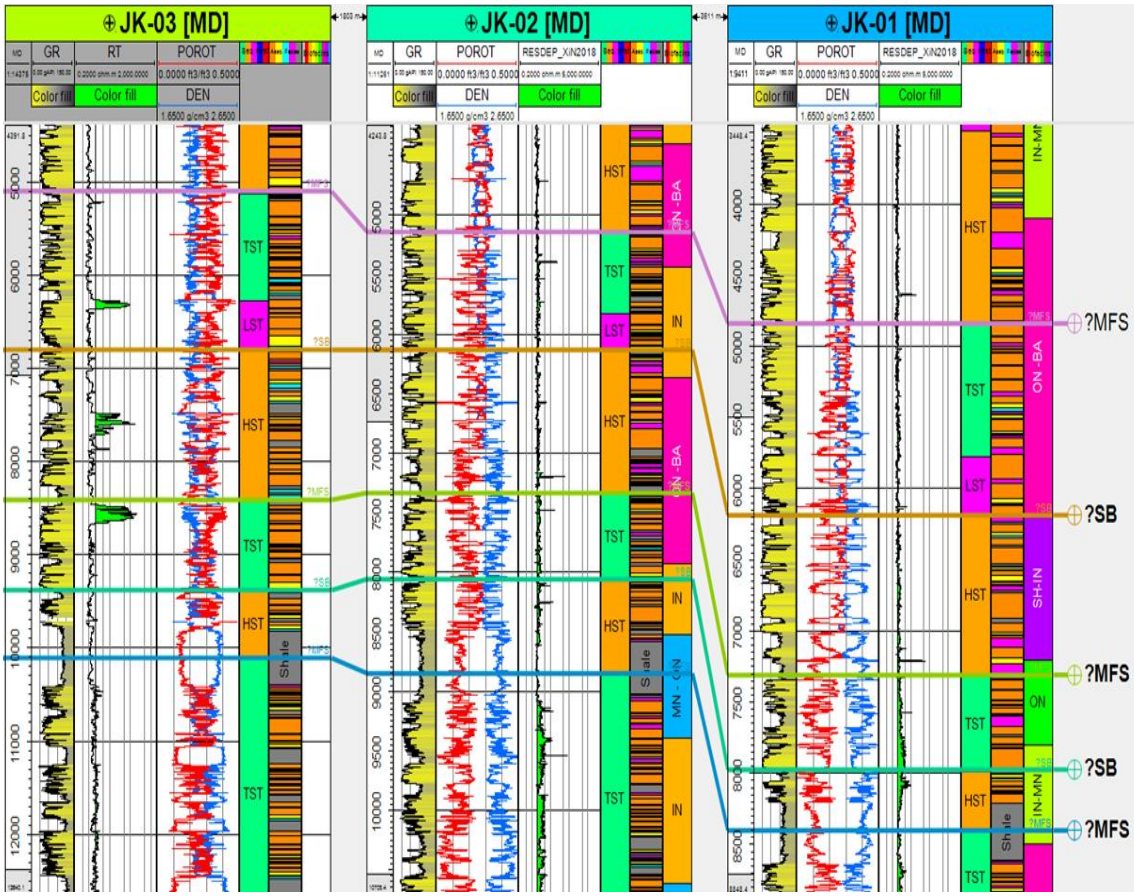


Fig. 4. Correlation of the genetically related strata across the wells in the Rho field

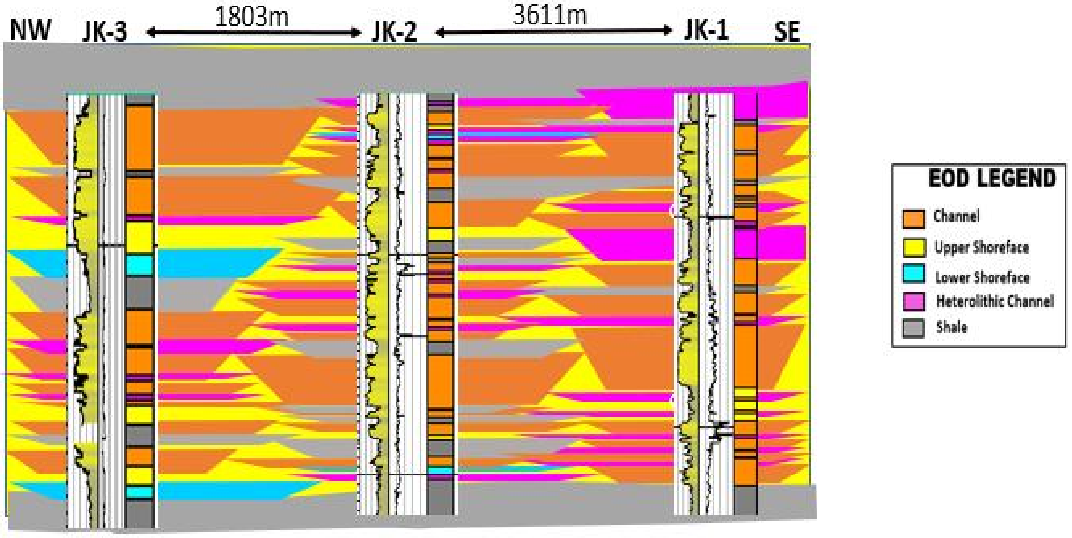
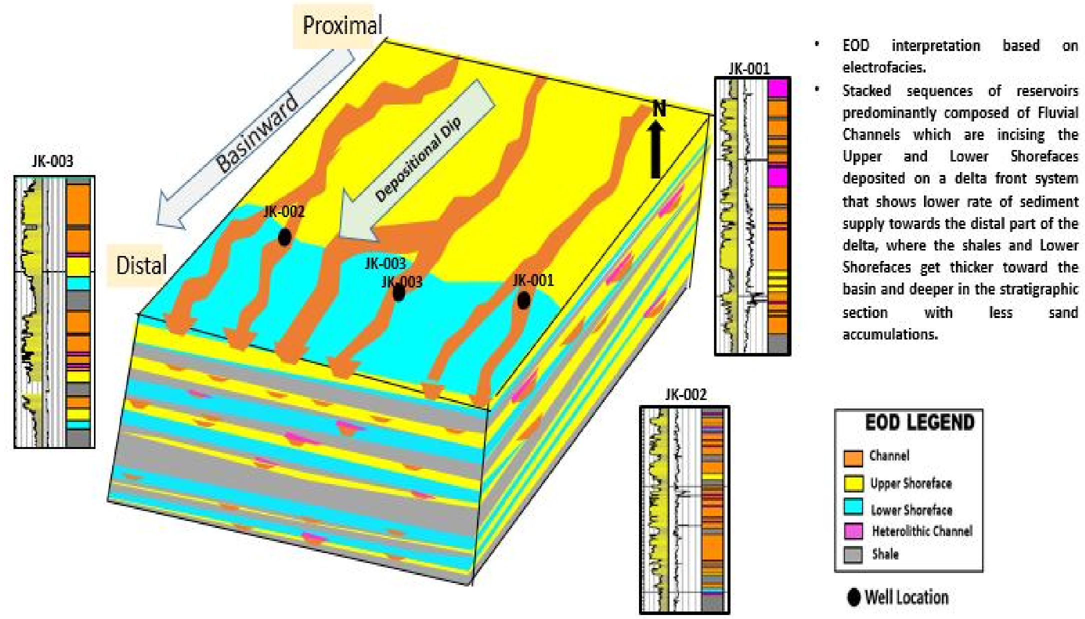


Fig. 5. Conceptual depositional environment model
(Strike direction, E5000_Base - E7000_Base)



- EOD interpretation based on electrofacies.
- Stacked sequences of reservoirs predominantly composed of Fluvial Channels which are incising the Upper and Lower Shorefaces deposited on a delta front system that shows lower rate of sediment supply towards the distal part of the delta, where the shales and Lower Shorefaces get thicker toward the basin and deeper in the stratigraphic section with less sand accumulations.

Fig. 6. Conceptual depositional environment model
(E5000_Base - E7000_Base)

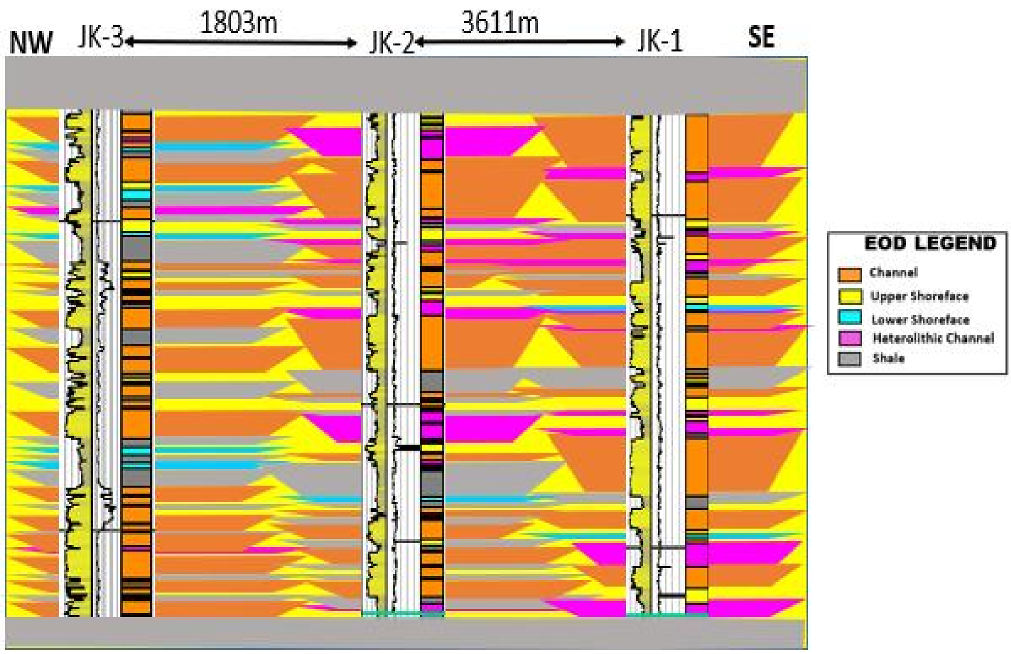
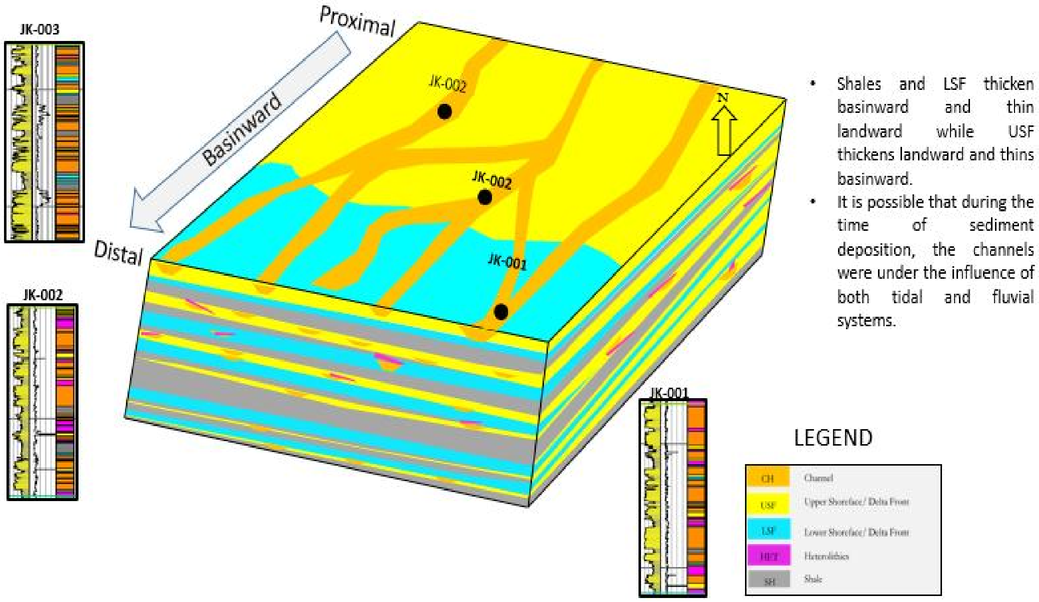


Fig. 7. Conceptual depositional environment model
(Strike direction, E5000_Base - E7000_Base)

Studies of strata termination outlines extant on the seismic contour of the Rho Field aided in the identification of seismic sequences bounded above and below by seismic sequence boundaries. These sequence boundaries were recognized by stacking patterns in well logs and then moved onto the seismic. Mostly, sequence boundaries are branded by physiognomies onlap and erosional truncation outlines. These structures are not present on the seismic.

Uniqueness surface categorized by a down lap at the top and an seeming truncation at the bottom, signify the abbreviated sections of the depositional sequence. The maximum flooding surface is categorized by plunging strata geometries on a seismic section. The high stand system (HST) was acknowledged on the seismic profile by clinoforms down lapping onto the maximum flooding surface (MFS).



- Shales and LSF thicken basinward and thin landward while USF thickens landward and thins basinward.
- It is possible that during the time of sediment deposition, the channels were under the influence of both tidal and fluvial systems.

Fig. 8. Conceptual depositional environment model
(E8000_Base – D8000_Base)

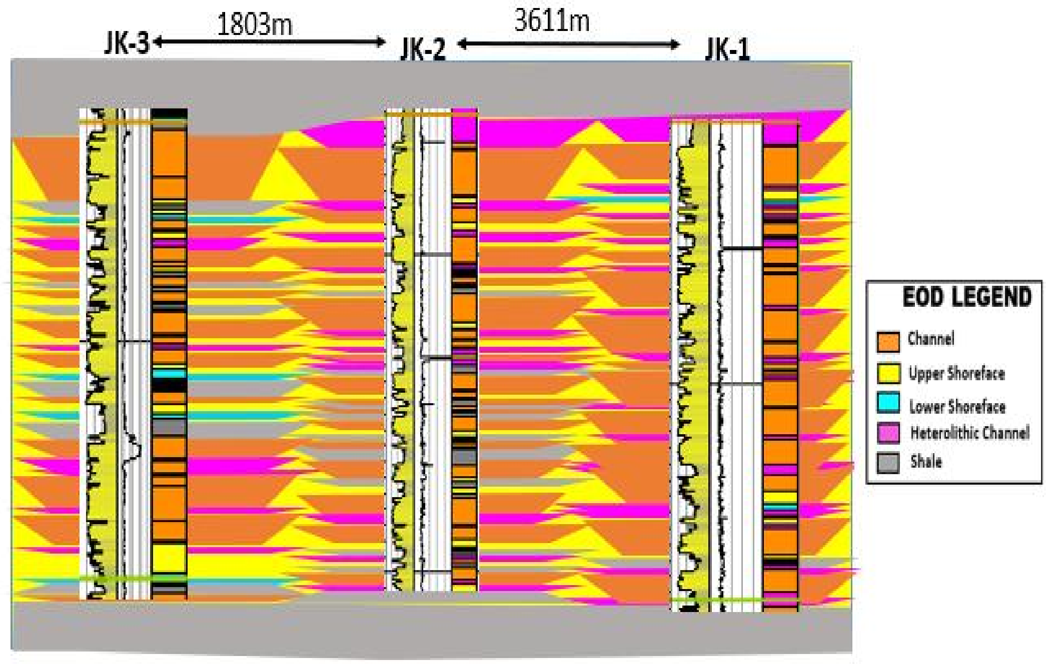
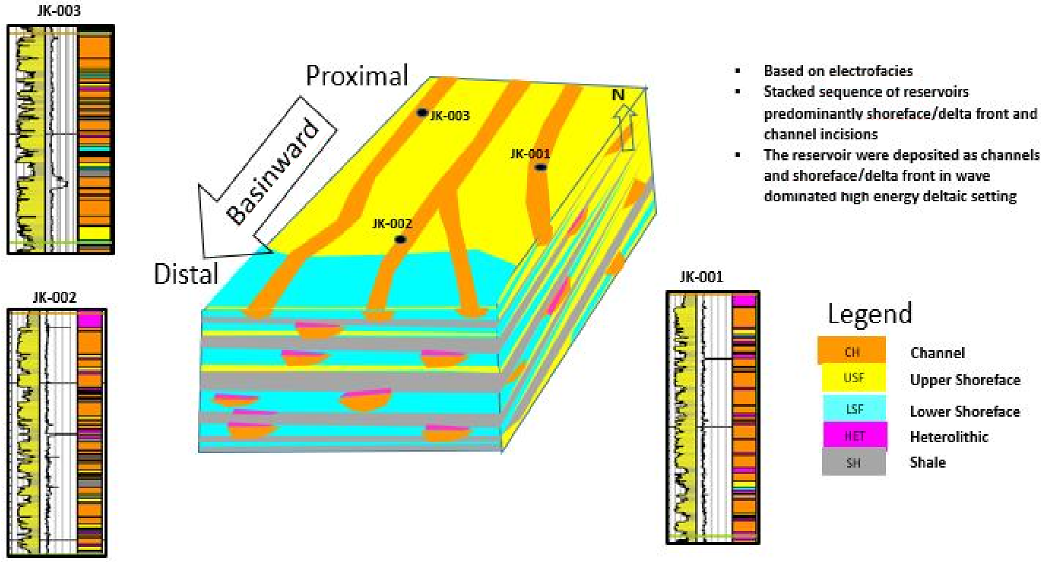


Fig. 9. Conceptual depositional environment model
(Strike direction, D8000_Base – E3100_Base)



- Based on electrofacies
- Stacked sequence of reservoirs predominantly shoreface/delta front and channel incisions
- The reservoir were deposited as channels and shoreface/delta front in wave dominated high energy deltaic setting

Fig. 10. Conceptual depositional environment model
(D8000_Base – E3100_Base)

The Rho Field stratigraphic intermissions fall inside the paralic sequence of blinking sand and shale bodies of flexible thicknesses. The sand/shale proportions normally reduce with depth signifying of a fining downward pattern. Log trends normally variation from thicker, more sand, blocky and fining upward successions to thinner upward- coarsening successions, telling an evolution from the channel deposits to the dominantly offshore prograding lobes. This imitates a development from the fluvial depositional sceneries to pro delta and deltaic shorelines. The Agbada Formation is mostly understood to encompass fluvial deltaic deposits [26].

The maximum flooding surfaces (MFS) outlined in the study area are understood to have settled during the maximum sea level rise and landward invasion of the shoreline. They parade pelagic deposition and sediment starvation on the shelf and slope, and splits the phases of shoreward retrogradation (contravention) from those of basin ward progradation (reversion). Three maximum flooding surfaces were defined across the field and these agree to the transgressive indicator shales of the Niger Delta chrono-stratographic chart. Two sequence boundaries (main attrition surface) split the strata sequence in the Rho Field into three classifications, each fashioned through the relative stages of eustacy. Two system tracts were described. These are the high stand system tract and transgressive system tract. Low stand systems tract are inattentive in the study area and the likely source is that during contravention, older deltaic multiplexes, built up and out across the shelf during the preceding low stand system tract stages, which eroded or overstepped the low stand system tract, a course which expansively reallocates sands as sheet across the shelf [27].

The high stand systems tract (HST) superimposes the transgressive system tract (TST) stage in the study area across the six wells considered. Such outline transpires when the sediment supply amount surpasses the accommodation interplanetary, instigating the para sequence deposition to either aggrade upwards or prograde basin-wards. The high stand systems tracts (HST) in the studied wells are thick with mainly sandy units happening within its lithological sequence. The sands within the high stand systems tracts HST might oblige as good reservoir rocks, while growth faults, vigorous in this area, can aid as channels for the upward movement of hydrocarbon. Pelagic shales of the transgressive systems tract can procedure good cap rocks for the underlying and overlying HST assuming the precise circumstances. Stratigraphic association across the wells in the Rho Field has revealed sequence 3 to be the thickest sequence within the field.

5. CONCLUSION

The Rho fields were analyzed by means of sequence stratigraphic principles, i.e of para-sequence stacking patterns to understand the systems tracts, sequences and depositional environment. Geological structures were interpreted based on a seismic reflection profile; these structures contain growth faults and antithetic faults.

Flooding surfaces stood distinct mostly by the highest gamma ray and lowest resistivity values. Maximum flooding surfaces were noticeable after the cautious reflection of the attractiveness of flooding surfaces and deliberation of neutron porosity and bulk density values of the individual flooding surfaces. Three (3) maximum flooding surfaces were definite within the study area, mapped autonomously on well logs and seismic volume.

Hydrocarbon bearing sands interpreted from well logs were found to be laterally continuous in the Rho field. With the presence of such structures as growth faults and rollover anticlines throughout the field, it is highly plausible that these sands comprehend hydrocarbon also in the yet to be evaluated parts of the Rho field. Seismic reflections with routinely high amplitude across the study area also support this position.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
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