Petroleum and Coal

Article **Open Access**

Sequence Stratigraphy and Reservoir Quality Assessment of "SOKA" Field, Coastal Swamp, Niger Delta Basin, Southern Nigeria

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Received September 5, 2023; Accepted January 16, 2024

Abstract

This study presents an integration of various approaches to delimit potential play elements and prospects in the 'Soka' Field Coastal swamp, Niger Delta. This study is a multiple cross-disciplinary work that combined sequence stratigraphy and petrophysical principles to delineate potential reservoirs, seals, and the source rock in the study area. One genetic sequence was identified using seismic sequence stratigraphy and well logs data; the depositional key surfaces, system tracts and their various parasequences were mapped out with the aid of biostratigraphic makers. The result for this study showed that there are two major reservoirs sand that contained hydrocarbon from the well log readings, named top- 3 and top-10 reservoirs, regardless of other reservoirs that were encountered. Three major system tracts were encountered, the progradational stacking sediment package of both HST and LST and transgressive sand Package of TST. The depositional environments are of fluvial and deltaic or shallow marine interaction. The following environments were predicted from their various log signatures; they include pro-delta, trangressive marine shelf, slope fan, and tidal channel deposits with this corresponding lithology: shale, sand, heterolith and shaley sand respectively. From the seismic interpretation, it was discovered that this field is highly faulted. The petrophysical analysis revealed that Soka-002 and Soka-004 amongst other wells have much and better reservoir than the rest wells. The average effective porosity is between 20-25%, the average net-to-gross ratio is about 75-75% and hydrocarbon saturation ranges from 65-95%. From the petrophysical crossplot it was discovered that the area of study has good reservoirs capable of habouring hydrocarbon, also the volumetrics estimation showed that Soka-002 and Soka-004 has more and better reservoir zones than the other wells in the field. Generally, the results from sequence stratigraphy, petrophysical analysis and volumetric estimation showed that the study area is highly petroliferous and viable for any economical investments since most of the reservoirs are saturated with either oil or gas.

Keywords: *Sequence stratigraphy; Petrophysics; Volumetrics; Progradational and retrogradational reservoirs.*

1. Introduction

The Tertiary Niger Delta's stratigraphy is characterized by a complex syndepositional collapse of clastic wedges due to the mobilization of shales from the underlying Akata Formation under the loads of the prograding overlying deposits of the deltaic Agbada and fluvial Benin Formations. This intricate situation poses significant challenges towards correlating reservoirs of same genetic units. The application of a recently validated concept of sequence stratigraphy is expected to lead to a significant improvement in the understanding of the geology, structure, and reservoir architecture and continuity of the Tertiary Niger Delta basin fills. Sequence stratigraphy, as a field of study, delves into the relationships between rocks within a chronostratigraphic framework, in which the sequence of rocks is cyclic and generally constituted of genetically linked stratal units [1-2]. This concept elucidates the vertical and lateral variations in sedimentary successions with regard to fluctuations in relative sea level and basin tectonics.

Many scholars and researchers have integrated methodologies for subsurface hydrocarbon exploration in the Niger-Delta. Works of [1-7] attest to that. For instance, Onyekuru *et al.* [1] conducted an integrative study of well logs and biostratigraphic data from six wells situated in the "XB Field" of the central Swamp Depobelt in the Niger Delta. The aim of the study was to conduct a sequence stratigraphic analysis of the depositional systems in this region. The results of the analysis revealed the presence of four 3rd order depositional sequences, denoted SEQ1 through SEQ4. These sequences were found to be bounded by three erosional unconformities, which were identified as Sequence Boundaries (SB1 to SB3). In their paper, Onyekuru *et al.* [8] expound upon the integration of core and log data, which serves to validate petrophysical evaluation results and enhance reliable facies prediction in the offshore depobelt of Niger Delta, Nigeria. The calibration of log-derived properties with core-derived properties demonstrated a strong correlation. It was determined that intervals of observed poor matches between log and core permeability were the result of a sparsely laminated porosity-permeability environment, as the logs average a 3-foot interval and the core data is measured at a much finer increment, thereby rendering a perfect match unattainable. Onyekuru *et al.* [6] conducted an analysis of the irreducible water saturation thresholds in the 'OKX' field reservoirs using well log data from five wells, along with core and analogue well data. The authors utilized well log data from five wells, in addition to core and analogue well data, to arrive at their findings. The primary objective of the investigation was to curtail unanticipated water production and enhance productivity. A Flow Zone Indicator (FZI) was predicted using a regression model founded on reservoir delineation and well log correlation. Onyekuru *et al.* [9] undertook an assessment on the depositional environments and reservoir quality of sediments found in the "OLI" field, offshore Niger Delta, Nigeria, utilizing a suite of wireline logs from five (5) distinct boreholes, one analogue well, and core data. The main aim of this inquiry was to scrutinize the depositional environments and reservoir quality of the said sediments. The findings demonstrated that the characteristics of the rock were heterogeneous and were regulated by sequential depositional environments that transpired during the Oligocene-Late Miocene. Evidently, the hydrocarbon potentials of various fields and depobelts in the Niger-Delta Basin especially the Coastal Swamp depobelt are yet to be fully captured, in that vein the detailed and proper integration of petrophysical and sequence stratigraphic tool will go a long way to give us a wider view of any reservoir characteristics.

Integration of sequence stratigraphy and petrophysics has not been widely employed to the study of Coastal Swamp, Niger-Delta Basin regardless of large data base of 2D/3D seismic lines, well logs and bio facies data obtained from oil exploration activities within the basin. The breakthrough most indigenous company are encountering in the marginal fields abandoned by most multinational companies due to their focus on giant fields offshore Niger Delta has shown that there are much to expect and smile about in the onshore part of the basin. That is to say with proper application of sequence stratigraphy and proper petrophysical studies in these marginal fields, more and even bigger oil fields or traps could be discovered; that has been bypassed (missed) by previous explorer caused by either complex distinctive structural characteristics or the complexity of the stratigraphic nature of the delta which may have mislead them and hinder the discovering of some trap. The goal of this study is to integrate 3D- seismic, sequence stratigraphy, biostratigraphic data, well data and petrophysical parameters in order to carry out an improved reservoir quality assessment and an accurate estimation of the in-place hydrocarbon volumes.

2. Description of study area

The Niger Delta, situated in the Gulf of Guinea, spans an expanse exceeding 70,000 square kilometres. Geologically speaking, the Niger Delta originated during the early Tertiary period, with deposition originating in rift zones in relation to the separation of the African and South American continents during the Mesozoic era [10-12].

Notably, the Niger Delta consists of five offlapping siliciclastic sedimentation cycles, or depobelts, which grade 250 kilometers southwestward over oceanic crust underpinning the Gulf of Guinea [13]. The depobelts are defined by syn-sedimentary fault trends that formed in response to differing rates of subsidence and sediment supply [12]. Moreover, Allen [14] and Oomkens [15] have described the depositional environments, sedimentation, and physiography of the modern Niger Delta.

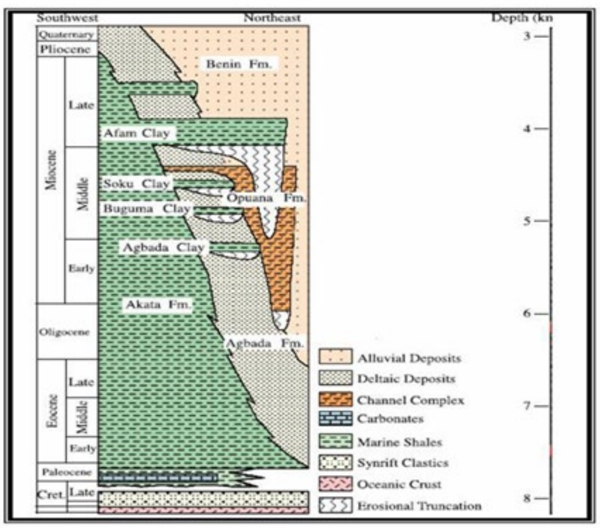

Fig. 1. Stratigraphic column showing formations of the Niger Delta (*modified from Doust and Omatsola* [12]).

These deposits have subsequently been classified into three large-scale lithostratigraphic units, encompassing the basal Paleocene to Recent Pro-Delta facies of the Akata Formation; Eocene to Recent, paralic facies of the Agbada Formation; and Oligocene to Recent, fluvial facies of the Benin Formation [11,16-17] (Fig. 1). It is noteworthy that the petroleum reserves in the Niger Delta predominantly exist in paralic sands, with hydrocarbons typically trapped in rollover anticlines or against growth faults, particularly along footwalls. Minor stratigraphic traps may also occur [18]. Petroleum in the Niger Delta is largely produced from sandstones and unconsolidated sands, primarily in the Agbada Formation.

The Coastal Swamp Depobelts in the Niger-Delta basin (Fig. 2) is home to the "Soka" Field, covering an area between longitudes 4ºE – 9ºE and latitudes 4ºN - 9ºN. Shell Petroleum Development Company (SPDC) operates the field.

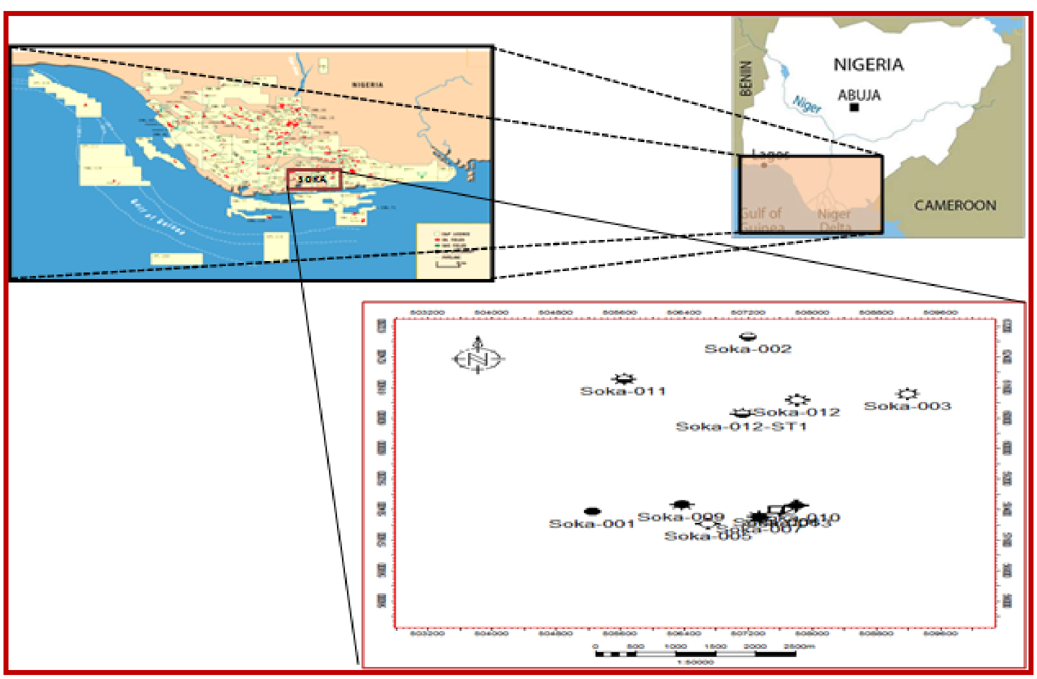

Fig. 2. Base map of the study area showing different well positions.

3. Methodology

The workflow of this study is described in Fig. 3.

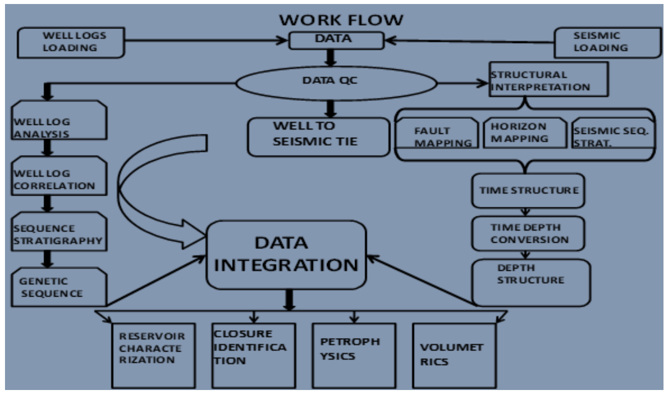

Fig. 3. Work flow for this work.

3.1. Data set

The data set used for this study includes well head, well deviation data, composite log suits from twelve wells in "Soka" Field Coastal Swamp Onshore Niger Delta; which were Gamma Ray, Sonic, Neutron, Density, and Resistivity log. Also, Biostratigraphic data, 3D-seismic volume that covers the study area with a Checkshot data were used. The wells used are, Soka-001, Soka-002, Soka-004, Soka-005, Soka-006, and Soka-007 (Fig 3). The data used for this work was compiled by Shell Petroleum Development Company of Nigeria (SPDC).

3.2. 3D-Seismic interpretations

The faults in this field were picked from the seismic, this helped in ascertaining the kind of structures prevalent in the field and which is capable of hosting fluid.

3.3. Well log analysis

Well logs which represent the geophysical recording of various rock properties in borehole were employed in this study for facies analysis i.e. lithostratigraphy identification through well log correlation and sequence stratigraphy.

3.3.1. Well log correlation

Lithilogical correlations between wells were established with the biomarker information provided. Correlation was carried out across the wells in the study area and appropriate sand makers were chosen in order to delineate the various reservoirs and sands of interest. The parasequences and system tracts were delineated from the logs as well, to help identify the part of the basin where the sediments were laid and also identify probable reservoirs; also, the size of the parasequences were shown using different colours for easy interpretation. The hydrocarbon bearing sands were noted for evaluation of reservoir potential of the field. The reservoir sands units were delineated in The Vertical Depth Sub Sea (TVDSS), while the marker shales were correlated using the biostratigraphic report which aided the interpretation of Maximum Flooding Surfaces (MFSs) and Sequence Boundaries. The checkshot data was used to match the seismic and well data both in depth and time. This was also used for the depth correlation of the interpreted faults and horizons.

3.3.2. Sequence stratigraphy

Biostratigraphy provides the ground truth for any sequence stratigraphic interpretation incorporating biostratigraphic information. Soka 006 well in the study area was used to correlate across other wells; sequence stratigraphy allowed us to identify with ease, the candidate strata surfaces, for accurate correlation across the wells in the field. These interpreted MFSs and SBs were carried across other wells in the fields in order to establish a chronostratigraphic framework for the delineation of genetic sequences and interpretation of their depositional environment. For this work the sequence was delineated using Genetic Sequence Model by Galloway [19], i.e., were Maximum Flooding Surfaces (MFSs) were used as top and base of the sequence.

3.4. Petrophysical analysis

Through petrophysical log analysis, both qualitative and quantitative determination of reservoir properties can be achieved using gamma ray and resistivity logs. The gamma ray (GR) log, employed to procure lithologic information, gauges the natural radioactivity of formations, reflecting the shale content of a given lithology. Meanwhile, the SP log manifests excursion from the shale baseline, with both logs serving to identify the sand/shale lithology in the study area. The resistivity log, used in combination with the GR log, enables differentiation between hydrocarbon and non-hydrocarbon bearing zones. Lithologic correlation of equivalent strata across the six wells was performed using the gamma ray log, matching similar intervals of log motiff from different wells. The gamma ray and resistivity logs were employed to correlate potential hydrocarbon reservoirs in the various wells, thereby determining their lateral extent. These findings were presented in chapter four as correlation panels. From the well logs, diverse crossplots were analyzed, particularly Poro-Perm and PHIE Vs NTG, with the aim of ascertaining the various relationships among some reservoir petrophysical parameters and their impact on the capacity of the reservoir to hold or transmit fluids.

4. Results and discussion

The sequence stratigraphic interpretation for this study was based on the 'Genetic Sequence' model proposed by Galloway [19] in which the stratigraphic packages are constrained chronostratigraphically within the Maximum Flooding Surfaces (MFSs). The general textural gradients of the sediments were defined as the system tracts within the genetic sequences while the parasequences were also defined within the sequences. Well log data were used to delineate the relative textural grading pattern which is anchored on relative shoreline movement, either towards the land or basin wards. The environments of deposition within the genetic units were interpreted and were used to compliment the reservoir quality assessments. Also, the well logs were used to do some petrophysical analysis to add the veracity of the reservoir predicted using sequence stratigraphy. The structural controls to these sediments supplied rate and accommodation space created is as shown below using seismic section, inline 6955 in (Fig. 4.).

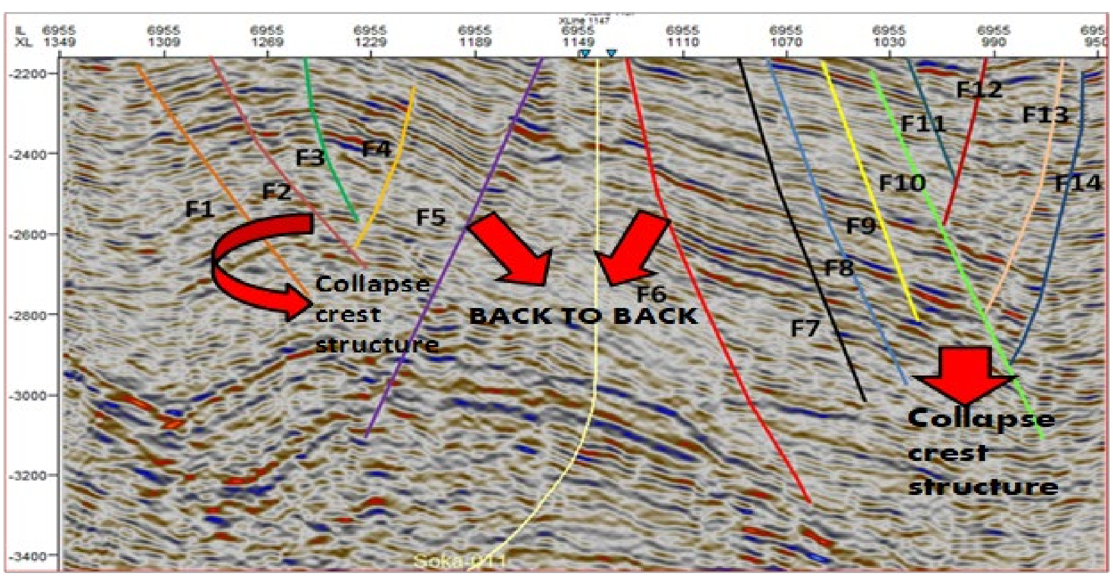

Fig. 4. Showing different faults in the field at time slice (inline) of 6955.

Within the faults are some rollovers indicated by strong reflection (which can be termed Direct Hydrocarbon Indicators) of the seismic which could connote presence of fluid. The fault types are mostly ‘back-to-back’ and ‘collapse crest’ faults which is typical of Niger Delta basin. Also, there are some regional faults and other antithetic faults.

4.1. Genetic sequence stratigraphic correlation

For the interpretation of the key surfaces, only two candidate Maximum Flooding Surfaces (MFS) were excerpted from biostratigraphic data given, associated with sub-aerial unconformities (SU) and their correlative conformities; conversely most of the interpreted logs did not penetrate down to the depth of the deepest MFS so what is available was used. The MFS's penetrated by the wells are 9.5 Ma and 10.4 Ma of age and these candidates MFSs were deposited between Late Tortonian and Early Seravllian and the maker shale zonation is between Uvigerina 8 and Nonion 4 according to the Niger Delta chronostraigraphic chart by Haq *et al.* [20] In the other hand the Sub-aerial unconformities are SU 8.5 Ma, and 10.6 Ma of age.

The genetic sequence initiated by [21] used for this interpretation was bounded by two Maximum Flooding Surfaces as MFS’s 9.5 Ma and MFS 10.4 Ma, shown in (Fig. 5, and 6). Ten (10) reservoirs were interpreted within the genetic unit with the top and base of those respective reservoirs shown in a correlation panel as can be seen in (Fig 4). The parasequences that generate the system tracts were delineated as shown in (Fig. 5); this helped to understand how the stacking pattern of the system tracts were generated and subsequently built.

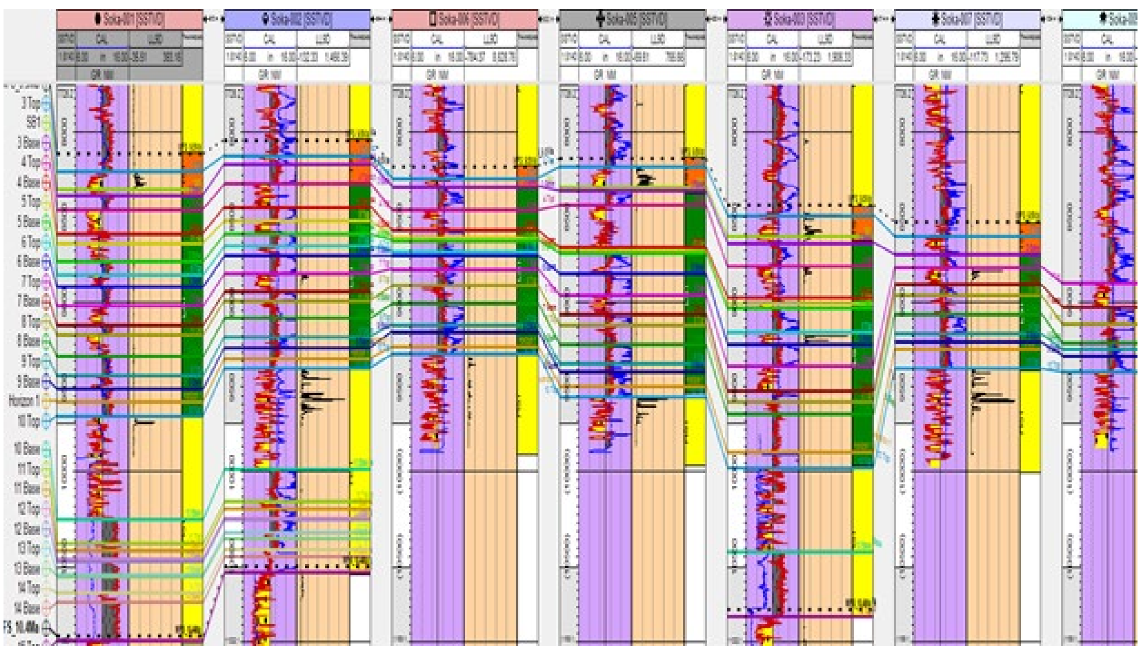

Fig. 5. Genetic stratigraphic correlations showing the system tracts.

The parasequence were delineated with different colours with their sizes shown; also shown in (Fig. 5) are three different system tracts (HST, TST and LST), the environment of deposition in which some of the system tracts were formed and reservoir fluid content of some of the reservoirs. Most of the parasequences seen in this field are mostly progradational. As seen from (Fig. 4 -5) some sand packages could be observe which entail the presence of reservoirs and also some thick packages of shale at some point which gives the assurance that the petroleum system elements (source, reservoir seal and overburden rock) according to Magoon and Dow [22] are fully represented. From the correlation as well, it can be seen that the resistvity log reading were high at two major reservoirs, 3-top and 10-top within the genetic sequence; showing the presence of hydrocarbon. These hydrocarbon occurrences are well established in Soka-002, 005 and 007, unlike in Soka-001, 003, and 006. Among the wells with best chances of success for hydrocarbon exploration, Soka-002 takes the prize, reason being that, at 10-top reservoir which fell in between HST and LST, as can be seen clearly in (Fig. 4), have thick package of sand bounded at top and base by two regressive shales. And those two can serve as both source rock and seal rock respectively that is if all the petroleum system processes (Generation, Migration and Accumulation) are in place.

Also, another important thing to note about the reservoir in Soka-002 is that, it is progradational channel sand, and channel sands' makes one of the best reservoirs especially in deltaic depositional setting like the Niger Delta.

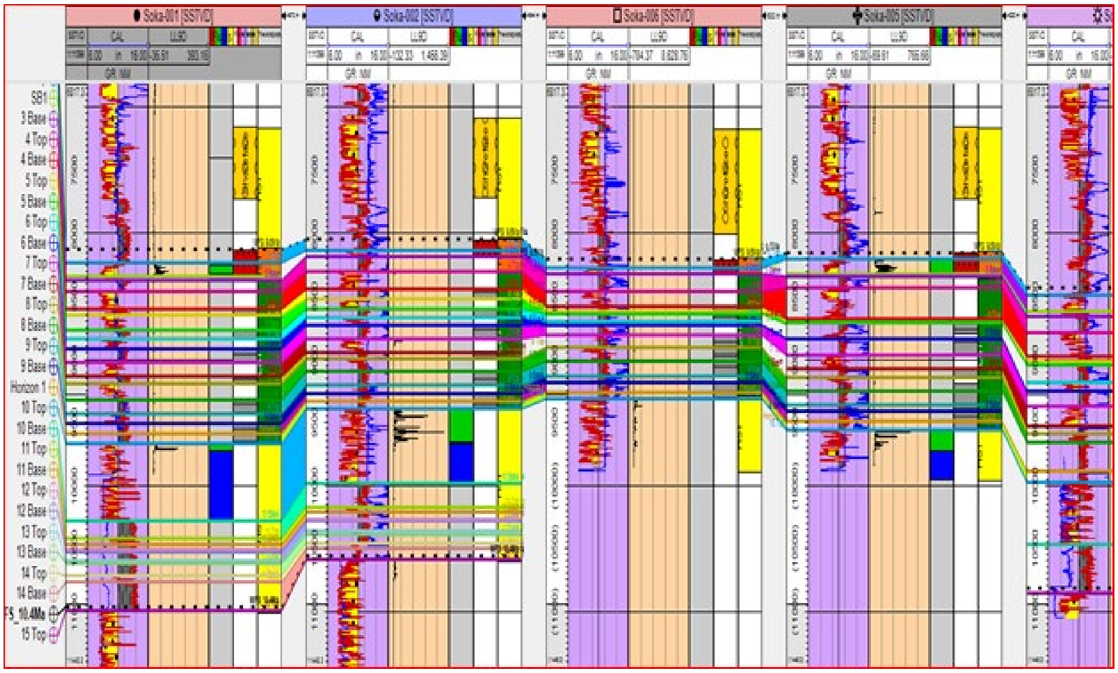

Fig. 6. Genetic stratigraphic correlation showing system tracts, sizes of the parasequences and environment of deposition of some reservoirs and reservoir fluid content.

4.2. Depositional system tracts

Three major system tracts were identified in this field, they include: HST, TST and LST, which are shown in (Fig. 7, 8 and 9).

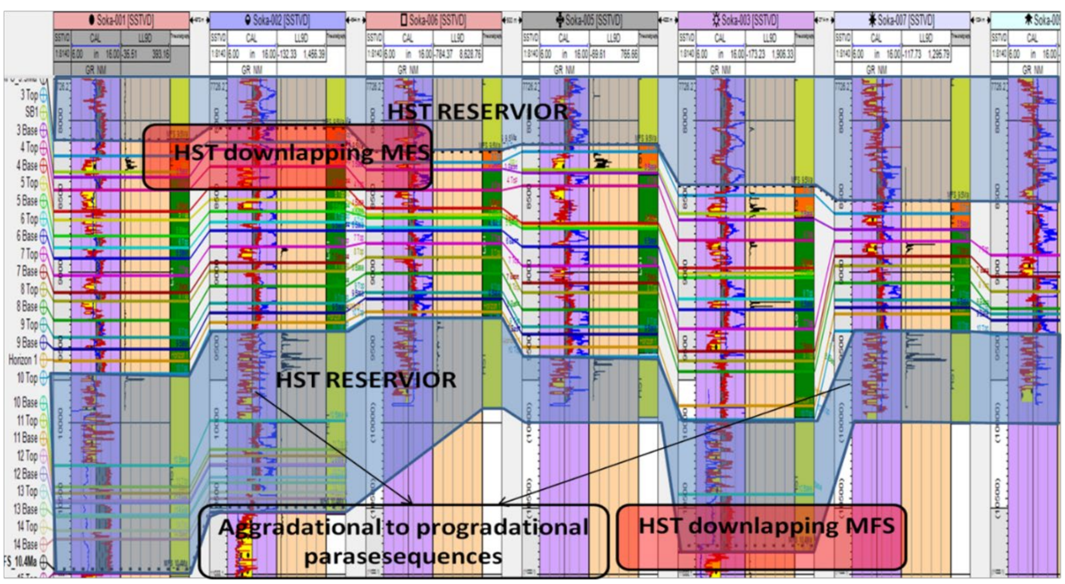

Fig. 7. Showing high stand system tracts (HST) of six wells.

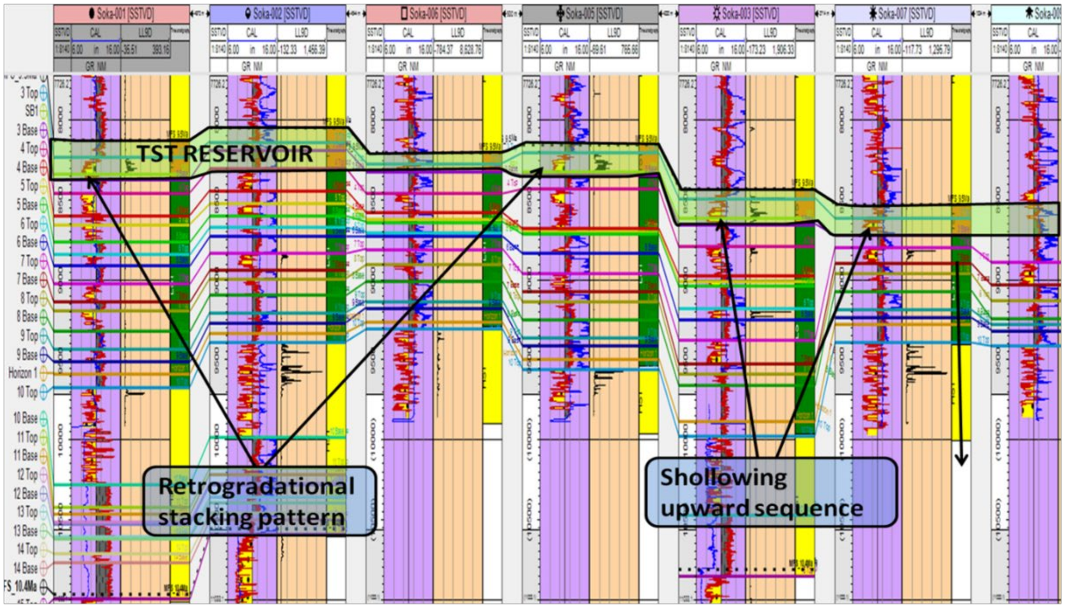

Fig. 8. Showing transgressive stand system tracts (TST) of six wells and their upward fining stacking pattern.

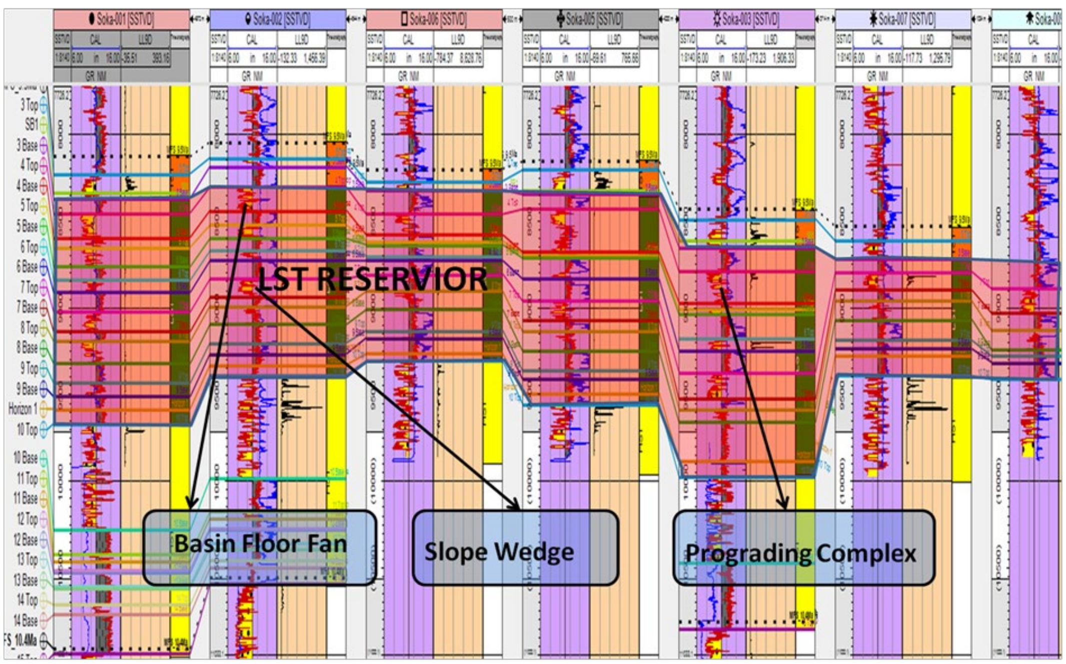

Fig. 9. Showing low stand system tracts (LST) of six wells and their various reservoirs.

4.2.1. Highstand system tract

Reservoir 2, 10, 11, 12, 13 and 14 make up the Highstand System Tracts (HST) in this study area. These reservoirs generally down-lapped the Maximum Flooding Surface (MFS), as seen in (Fig. 7). Reservoir 2 down lapped MFS 9.5Ma while reservoirs 10, 11, 12, 13 and 14 down lapped MFS 10.4Ma. These interpreted HST reservoirs varies mainly from the base to top i.e. (aggradational to progradational) and are possibly charged by the underlying organofacies rich shales which is the Maximum Flooding Surfaces. The HST reservoirs encountered in this study area are coarser towards the top and as such will have better porosities and permeabilities as interpretative from the porosity logs such as neutron, density and sonic. These reservoirs were influenced by shoreline movement from terrestrial or littoral settings towards the marine environments forming a coarsening upwards textural gradient sequence as depicted by the well logs in (Fig. 7), which is typical of progradational stacking pattern because the sea has reached its maximum height (at MFS) and has begun to regress due to high sediment influx (Normal Regression) or due to general sea level or base level fall (Forced Regression) but for this field as seen on well and seismic, the regression type is of normal regression due to high sediment influx. The hydrocarbon bearing capacities in these HST reservoirs varies from one reservoir to another for the following factors such as charged depth, migration trends, sealing capacities and structural profiles amongst others.

For all the HST reservoirs encountered in this study, only reservoir 10-top is hydrocarbon bearing with more accumulation towards the crest due to fluids density differentials (Fig. 8). Also, the shale accumulation at the top of the 10-top HST reservoir due the earliest phase of the LST in 9-top can act as a seal rock which depend on the pressure implications and other factors which are related to the oil accumulation.

4.2.2. Trangressive system tract

The sand 3-top reservoir is typical of Transgressive System Tracts (TST) with fining upward stacking pattern; this is best developed in Soka-001 well and diminishes towards Soka-002 and Soka-003 well. This is a typical transgressive channel reservoir which came into place because the shoreline at that time was moving landward as a result of sea level rise, the sea level rise made sediment from the marine area to lie on top of the continental sediment, therefore giving rise to fining or shallowing upward sequence as we have it in (Fig. 9). The general stacking pattern is of retrogradational type. Before the TST is a trangressive surface known as Trangressive Surface (TS) of erosion caused by wave or tidal action on LST sediment initially lay; also capping the TST is a thick shale sequence of the 9.5 Ma MFS. The sand 3-top reservoir in Soka-001 has hydrocarbon occurrence in its retrogradational channel reservoir but diminishes towards Soka-002 and Soka-006 and afterwards in Soka-003, Soka-005, and Soka-007 the reservoir emerged again. This could be attributed to an unconformity (i.e., period of non-deposition or erosion which might have been intense in Soka-002 and Soka-003 area at the same time others were laid or may be as a result of local variation in deposition).

4.2.3. Lowstand system tract

The Lowtand System Tracts (LST) interpreted in this study is shown in (Fig. 9). This system tract is formed at earliest sea level rise and normal regression relative to the accommodation space created and sediments rate deposited. The LST in (Fig. 9) is underlain by a Sequence Boundary (SB) and overlain by the Transgressive Surface of Erosion (TSE). The reservoirs found within the LST are generally of progradational stacking pattern which came in place as a result of shoreline movement from the continental area to the marine realm. Within the interpreted LST reservoirs, are found some shale units which depict progradding complexes, slope wedges and basin floor deposits which is typical of low energy environments and tidally influenced deposits. The reservoir quality assessment indicates that no hydrocarbon accumulations were found within the LST reservoirs as shown in the (Fig. 9) below. The absence of hydrocarbon in these reservoirs might be as a result of poor petrophysical quality of these reservoir sands. Nevertheless, minor oil show is observed in Soka-003 at the 6th reservoir.

4.3. Environment of deposition interpretation

The general lithology within the 'Soka' field are mostly sand, shale and their intercalations as seen in (Fig. 10). The major environment of deposition delineated using Soka-001 are Pro-delta, trangressive marine shelf, slope fan and tidal channel deposits. Pro-delta which are shaley sediment laid in the marine realm, form as a result of fine suspended sediment which settled after coagulating in a gentler environment.

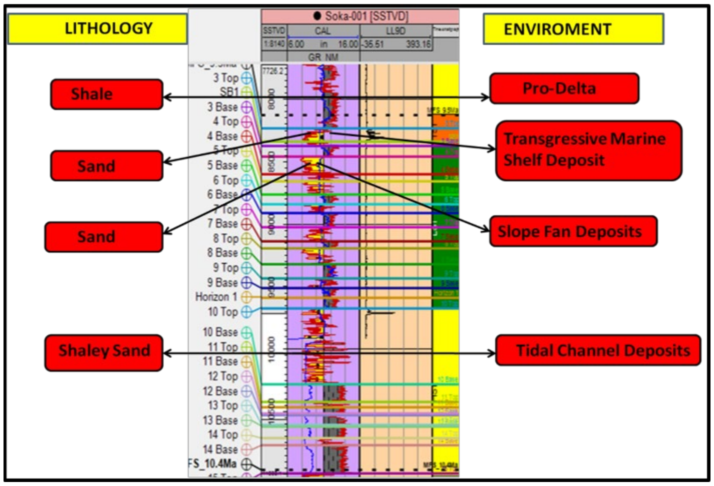

Fig. 10. Depositional environments interpretation from Well, Soka-001.

The MFS (which is as a result seal level increase at its peak) with its condensed section are typical of these types of deposits. Most of the flora, fauna and some authigenic minerals are found in this place. Most of the source and seal rocks are mostly made up of shale and marine in origin. Also, within Soka-001 is a Trangressive Marine Shelf deposits which is typical of a retrogradational stacking pattern. The fining upward sequence is because, coarser continental sediments brought down during HST and, due to sea level fall are now being overlain by finer marine sediment during sea level rise. Another depositional environment delineated is Slope Fan Deposit; this came about as a result of fall in sea level which enhanced the movement of coarser clastic sediment beyond the shelf margin thereby deposited on marine finer sediment giving a coarsening upward sequence. This is typical of LST deposits sometimes termed the Prograding Complex. Most slope fan deposits are usually within channels, created by river incision known as incisive valley.

Tidal Channel is another environment encountered by Soka-001. Their deposits are as a result of different stages of tidal cycles. When a strong ebb tide and the river act together, the combined current may transport sand, but a strong flood tide may completely counter the river flow, resulting in standing water, which allows deposition from suspension [12]. These kinds of deposits are usually an alternating layer of sand and mud known as heterolith. There may be other environment for other wells, but with sequence stratigraphy predictive power and correlative capacity, what is obtainable in one well can be successfully correlated with other well(s) within a particular field. So let us assume that the same depositional environment cut across the whole field.

4.4. Petroleum system elements of study area (source, reservoir and seal)

The major source rock identified from the well logs is the 11-top thick shale found underlying the HST 10-top sand shown in (Fig. 11). There are other thick shale packages seen in the study area, but it is believed that the 11-top shale is a major source rock charging the 10-top reservoir due its thickness and position. The shale is a major trangressive parasequence deposited when sea level rose. At its base is the Maximum Flooding Surfaces (MFS) which ascertain to the fact that the sea (base) level has risen.

Additionally, a seal rock was also identified at 8-top and 9-top capping the 10-top reservoir. If all things are in place (i.e., without faults passing through it) it is believed that this seal rock has the capacity and integrity to hold hydrocarbon from migrating to another reservoir or gushing out to the surface. The shale which is of marine sediment is covered by prograding sand from the continent belonging to the HST (i.e., sediment moving below the shelf break) it is clearly shown in (Fig. 11). Between the source rock and seal is a grabben and horst block sandwiched between Soka-004 and Soka-006 as seen in (Fig. 11). It is a major normal fault block found in the study area.

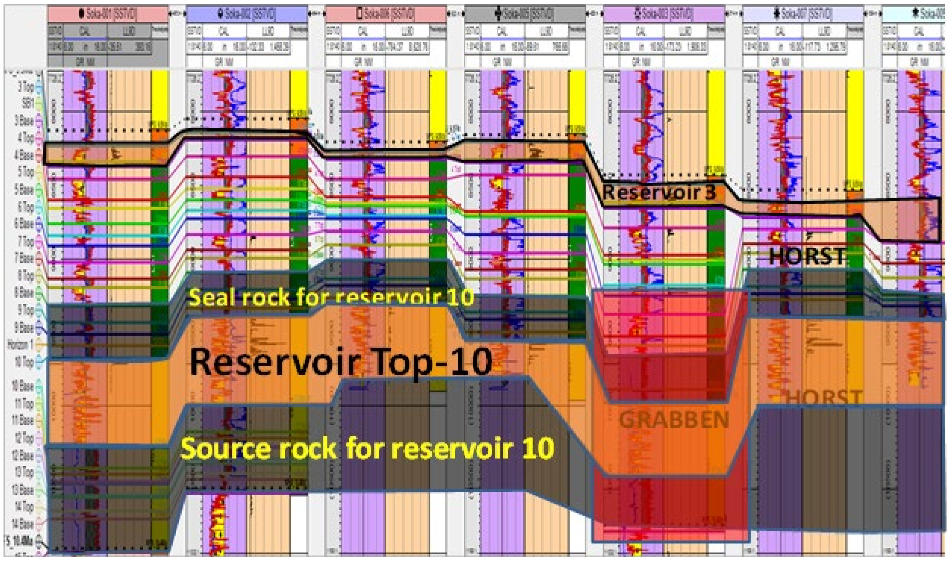

Fig. 11. Source, reservoir and seal rocks, as well as Horst and Grabben Structure (A major normal fault throw in the field).

The top-3and top-10 Reservoir are shown in (Fig. 11); the top-10 reservoir remains the best reservoir for hydrocarbon exploration in the study area due to thickness and its position in between two shales which serve as seal and source rock respectively. 3-Top reservoir is also viable for hydrocarbon, since the resistivity log showed minor spike.

4.5. Petrophysical evaluation of the study area

For some of the petrophysical interpretation done in this work, four wells log data out of seven wells in the 'Soka' field, Soka-002, Soka-004, Soka-006 and Soka-007 were used. These wells were chosen due to their high hydrocarbon presence, Soka-001, 003, 005 does not have very appreciable hydrocarbon occurrence.

4.5.1. Cross plot analysis result comparison between Soka-002 and 004

4.5.1.1. Poro-Perm crossplot comparison between Soka-002 and Soka-004

The poro-perm or porosity-permeability crossplot was colour coded with NTG. The net to gross, effective porosity and permeability in Soka-002 is greater than that of the Soka-004 as can be seen in (Fig. 12 and 13). Permeability increases with increase in effective porosity and this two makes very good net to gross.

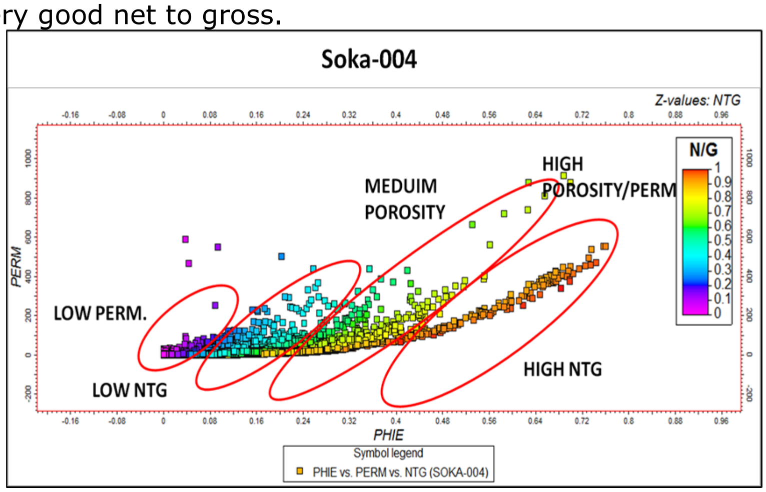

Fig. 12. A Poroperm crossplot color-coded by NTG for Soka-002 well. Permeability increases with increasing effective porosity.

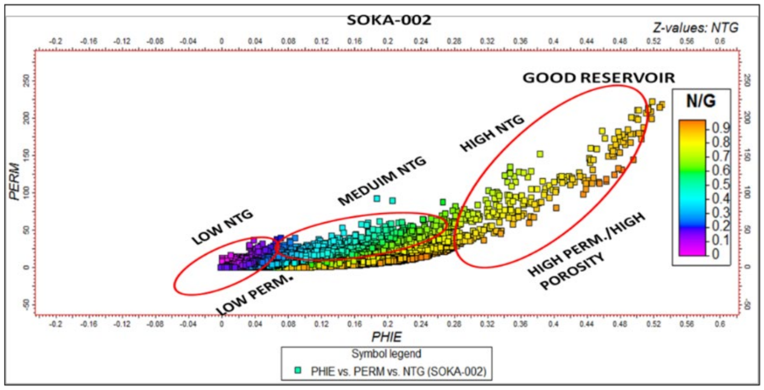

Fig. 13. A Poro-perm crossplot color-coded by NTG for Soka-004 well. Permeability increases with increasing effective porosity.

4.5.1.2. Effective porosity vs NTG

Here the effective porosity was plotted against NTG colour coded with Vsh. For this crossplots Soka-002 has almost the same result as Soka-004 and the reservoir sand has high NTG with increasing effective porosity, as shown in (Fig. 14 and 15).

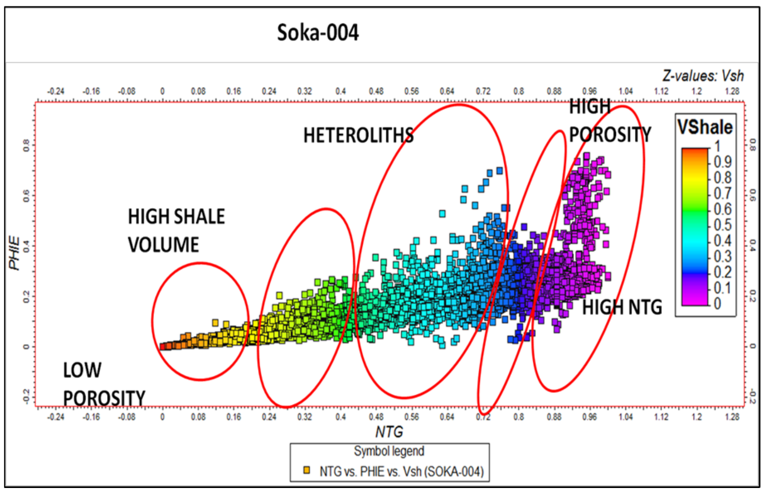

Fig. 14. PHIE vs NTG colored in Vsh for Soka-002. Sand reservoirs in the field have higher NTG with increasing effective porosity.

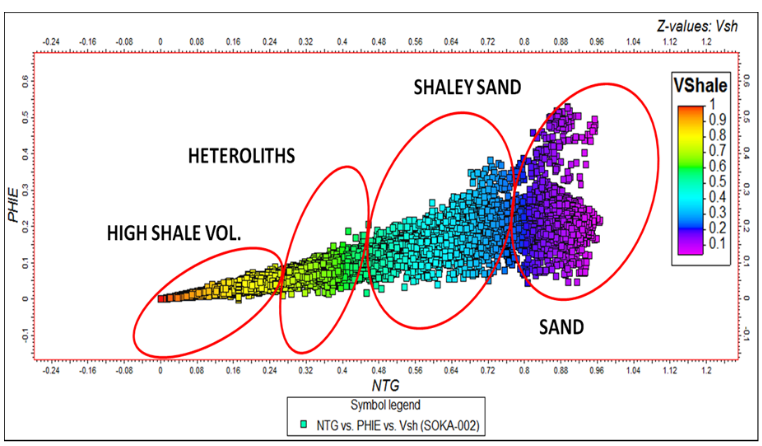

Fig. 15. PHIE vs NTG colored in Vsh for Soka-002. Sand reservoirs in the field have higher NTG with increasing effective porosity.

4.6. Average petrophysical results for some reservoirs in four different wells

From the general petrophysical analysis and sequence stratigraphic estimation it was observed that Soka-002 and Soka-004 has better reservoir quality than the rest. The well has about five very good reservoirs zones with seven reservoir compartments; but zone 5 has the highest NTG value of 0.82 while zone 4 has lowest NTG value with 0.53. Zone 1 and zone 3B has the highest effective porosity value of 0.30 while zone 4 has the lowest with 0.18. Zone 5 has the highest Hydrocarbon Saturation (Sh) with a very high value of 0.95 while zone 2B has the lowest hydrocarbon saturation with 0.54; all are shown in (Table 4).

Table 1. Porosity and permeability values for reservoirs qualitative description (after Rider, [23])

Qualitative evaluation of porosity	
0-5	Negligible
5.10	Poor
15-20	Good
20-30	Very Good
> 30	Excellent
Qualitative evaluation of permeability	
< 10.5	Poor to Fair
15 - 50	Moderate
50 - 250	Good
250 - 1000	Very Good
> 1000	Excellent

Soka-004 is another well with very good reservoir properties with three major zones and five reservoir compartments saturated with hydrocarbon. Zone 3A has the highest NTG value of 0.86 while zone 1 has the lowest NTG value of 0.54. Zone 2A has the highest effective porosity with a value 0.31 while zone one has the least effective porosity with value of 0.20. The hydrocarbon saturation is highest at zone 3A with a high value of 0.91 and lowest in zone 3C with a value of 0.77; all are shown in (Table 2)

Table 2. The Range of porosity values for rocks. (after Glover, [24])

Lithology	Porosity range (%)
Unconsolidated sands	35 – 45
‘Reservoir’ sandstones	15 – 35
Compact sandstones	5 – 15
Shales	0 – 45
Clays	0 – 45
Massive limestone	5 – 10
Vuggy limestone	10 – 40
Dolomite	10 - 30
Chalk	5 - 40
Granite	< 1
Basalt	< 0.5
Gneiss	< 2
Conglomerate	1 - 15

Soka-006 has two major reservoir zones with three reservoir compartments filled with hydrocarbon. Zone 2B has the highest NTG with a value of 0.74 while zone 1 and zone 2A has the least with the same value of 0.52. The effective porosity is highest at zone 2B with a value of 0.28 while the lowest value for effective porosity in this well is 2A with a value of 0.17. It has high hydrocarbon saturation at zone 2B with a value of 0.87 while the lowest occurred at zone 1 with a value 0.74; these also are well elucidated in (Table 3).

Table 3. Petrophysical results for five wells in "Soka" Field

Reservoir	Top (Ft)	Bottom (Ft)	Net (Ft)	Highest Φe %	Highest K %	Highest NTG %	Highest Vsh %	Highest SW %	Highest Sh %	Reservoir Quality
Zone 1	9205	9229	19	30	53	78	22	32	68	Very Good
Zone 2A	9674	9683	6	21	31	64	36	32	68	Good
Zone 2B	9690	9699	6	24	52	62	38	46	54	Very Good
Zone 3A	9877	9889	7	20	38	58	42	19	80	Good
Zone 3B	9898	9931	10	30	71	72	28	13	87	Very Good
Zone 3C	9931	9963	25	25	30	79	21	32	68	Good
Zone 4	10585	10617	17	18	35	53	47	20	80	Good
Zone 5	10801	10822	17	24	23	82	18	5	95	Good
Average	-	-	13.375	24	41.625	68.5	31.5	24.875	75	Good
	SOKA-004									
Zone 1	9575	9604	16	20	52	54	46	14	86	Good
Zone 2A	9665	9741	62	31	54	81	19	9	91	Good
Zone 2B	9741	9805	49	24	28	77	23	32	68	Good
Zone 3A	1000	10083	71	25	23	86	24	10	14	Good
Zone 3B	10090	10145	19	24	23	80	20	14	86	Good
Zone 3C	10145	10195	35	25	36	74	26	23	77	Good
Average			42	24.8	36	75.3	26.3	17	83	Good
	SOKA-005									
Zone 1	-	-	-	21	51	-	-	-	-	Very Good
Zone 2	-	-	-	29	47	-	-	-	-	Good
Average	-	-	-	25	49	-	-	-	-	Good
	SOKA-006									
Zone 1	8963	8993	16	18	39	52	48	26	74	Good
Zone 2A	9362	9399	16	17	31	52	48	21	79	Good
Zone 2B	9412	9442	22	28	49	74	26	13	87	Good
Average			18	21	39.6	59.3	40.6	20	80	Good
	SOKA-007									
Zone 1	8859	8908	35	26	42	72	28	15	85	Good
Zone 2B	9449	9460	8	22	31	69	31	24	76	Good
Zone 2B	9466	9478	7	21	39	61	39	15	85	Good
Average			16.7	23	37.3	67.3	32.7	18	82	good

Soka-007 has two zones with three reservoir compartments saturated with hydrocarbon. The highest NTG occurred at zone 1 with a value of 0.72 while the lowest is at zone 2B with a value of 0.61. The effective porosity occurred highest at zone 1 with a value of 0.26 while the lowest value is at zone 2B with a value of 0.21. Hydrocarbon saturation for this well occurred most at zone 1 and zone 2 B with a value of 0.85, these are well shown (Table 4).

Table 4. Average petrophysical values for four different wells

Wells	φ (%)	K (%)	NTG (%)	Vsh (%)	Sw (%)	Sh (%)
SOKA-002	24	41.6	68.5	31.5	24.9	75
SOKA-004	24.8	36	75.3	26.3	17	83
SOKA-006	21	39.7	59.3	40.6	20	80
SOKA-007	23	37.3	67.3	32.7	19	82

Generally, from the petrophysical studies, the 'Soka' Field has 'very good' to 'good' reservoir qualities, although some are fairly good. Also, the effective porosities across the delineated four wells were very good as well. The hydrocarbon saturations for all the wells are high, which make this field economical viable for hydrocarbon exploitation.

4.6.1. Hydrocarbon volumetric calculation

The volumetric calculations for this study are presented in (Table 5) for Soka-002, Soka-004 and Soka-007 respectively. With respect to Soka-002, oil zones are five (2A, 2B, 3C, 4 and 5) while the gas zones are three (1, 3A, and 3B). The highest occurrence of oil is at zone

3C with Stock Tank Oil Initial In Place (STOIIP) value of 288.3 Million Barrel (MBBL) while the lowest occurrence is at zone 5 with a value of 21.6 MBBL; there Recovering Factor (RF) are 45.7 and 4.32 MBBL respectively. The gas in this well has highest occurrence at zone 3B with a value of 1.72 Trillion Cubic Feet (TCF) while the lowest occurrence is at zone 1 with a value of 0.28 TCF; there RFs are 1.38 TCF and 0.22 TCF respectively; they are all shown in (Table 5).

For Soka-004 four reservoir zones were saturated with oil (2B, 3A, 3B and 3C) while two zones were saturated with gas (1 and 2A). The highest occurrence of oil is at zone 2B with a value of 418.7 MBBL, (the highest in this field) while the lowest value occurs at zone 3A with a value of 9.34 MBBL; there RFs are 83.7 and 1.87 MBBL respectively. For the gases the highest occurrence is at zone 2A with a value of 13.0 TCF while the lowest is at Zone 1 with a value of 1.36 TCF; their various RFs are 10.3 and 1.09 TCF respectively. It should be noted that the reservoir with the highest Oil and Gas occurrence in this field are found in this well; they are all shown in (Table 5).

Table 5. Volume calculation summary report sheet for wells in "Soka" Field

Highest Oil Occurrence				Highest Gas Occurrence	
Reservoir name	Fuid type	STO IIP (MBBL)	G IIP (TCF)	Recoverable oil @ 20% (MBBL)	Recoverable gas 80% TCF
SOKA-002					
Zone 1	Gas	-	0.28	-	0.22
Zone 2A	Oil	33.8	-	6.77	-
Zone 2B	Oil	32.8	-	6.56	-
Zone 3A	Gas	-	0.59	-	0.47
Zone 3B	Gas	-	5.72	-	1.38
Zone 3C	Oil	228.3	-	45.7	-
Zone 4	Oil	88.2	-	17.6	-
Zone 5	Oil	21.6	-	4.32	-
Soka-004					
Zone 1	Gas	-	1.36	-	1.09
Zone 2A	Gas	-	13.01	-	10.3
Zone 2B	Oil	418.7	-	83.7	-
Zone 3A	Oil	9.34	-	1.87	-
Zone 3B	Oil	21.3	-	4.27	-
Zone 3C	Oil	339	-	67.8	-
SOKA-007					
Zone 1	Gas	-	5.11	-	4.08
Zone 2A	Gas	-	0.08	-	0.06
Zone 2B	Gas	-	0.06	-	0.05

For Soka-007, three major zones were delineated with all of them saturated with gas, the zones are (1, 2A and 2B). The highest occurrence of gas in this well is at zone 1 with a value of 5.11 TCF while the lowest is at zone 2B with a value of 0.06 TCF. Their RFs are 4.08 and 0.05 TCF respectively, shown in (Table 5).

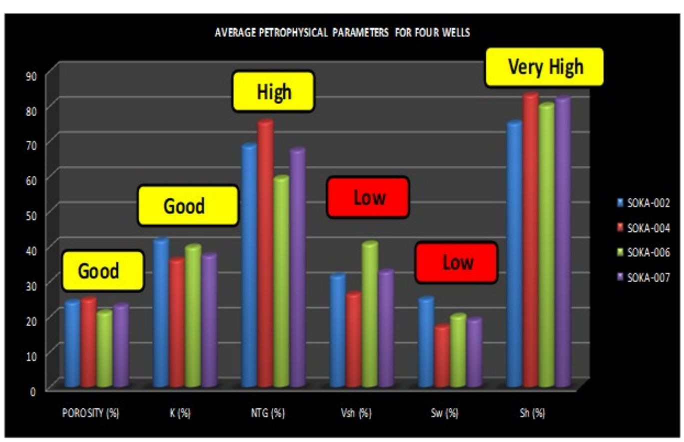

Fig. 16. Average Petrophysical Parameters and reservoir quality for four wells.

From all the petrophysical studies, especially the volumetric, the "Soka" Field is petroliferous and the hydrocarbon within are viable economically in case any investor wants to invest in this field.

5. Conclusion

Predictions of potential petroleum plays and prospects of the 'Soka' Field, Coastal Swamp Depobelt, Niger Delta using Sequence Stratigraphy and Petrophysical technique was carried out in this study. Two major reservoir sand bodies were envisaged to be potential viable for hydrocarbon prospects owing to their unique petrophysical and sequence stratigraphic properties. These reservoirs were named 3-top and 10-top reservoirs.

Two candidate MFSs were identified, and were used to generate a genetic sequence using the Genetic Sequence Model of Galloway [19]. The geologic ages of the two bounding shales are 9.5 MA and 10.4 Ma respectively. From the petrophysical fluid types, it was observed that some reservoir tested oil while some had gas while others were saturated with water. Volumetric estimations of the in–place hydrocarbon revealed that these reservoirs contain considerable economic quantities of oil and gas viable for any economical purpose.

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