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RESERVOIR CHARACTERISTICS AND PALAEO-DEPOSITIONAL ENVIRONMENT OF DUSKI FIELD, ONSHORE, NIGER- DELTA, NIGERIA

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ABSTRACT

The Niger Delta is a prolific hydrocarbon producing belt in the southern Nigeria sedimentary basin on the continental margin of the Gulf of Guinea. This study used well log suites to delineate the hydrocarbon reservoirs, depositional environments and lithostratigraphy of the Duski Field, Onshore Niger Delta, Nigeria. A comprehensive interpretation of the three wells revealed five (5) reservoir units with low volume of shale and thickness variations between 24m and 60.20m. The average porosity values ranged from 12% to 34%, with high hydrocarbon saturation in all the reservoir sands. Generally, porosity and permeability values decrease with depth in all the wells. Cross-plots of water saturation (Sw) and porosity (ϕ) (Buckles plot) revealed that some reservoirs were at irreducible water saturation; hence producing water-free hydrocarbons. Therefore the hydrocarbon accumulation of this field is commercially viable and promising. This study revealed that the reservoir sand units were deposited within marginal marine depositional environment which include fluvial channel, transgressive marine, progradational and deltaic settings.

KEYWORDS: Reservoir characteristics, depositional environment, Niger Delta.

INTRODUCTION

The Niger Delta Basin occupies the Gulf of Guinea continental margin in equatorial West Africa between Latitudes 3^0 and 6^0 N and Longitudes 5^0 and 8^0 E. It ranks among the world's most prolific petroleum producing Tertiary Deltas (Kulke, 1995). The stratigraphy, sedimentology, structural configuration and palaeo-environment of the Niger Delta have been discussed by various workers (Short and Stauble, 1967; Weber, 1971; Weber and Daukoru, 1975; Evamy et al, 1978; Nton and Adesina, 2009) among others. Doust and Omatsola (1990) noted that from the Eocene to the present, the delta has prograded southwestwards, forming depobelts, which represents the most active portion of each stage of the development of the delta. According to Kulke (1995), the Niger Delta contains only one identified petroleum system referred to as the Tertiary Niger Delta (Akata-Agbada) petroleum system. The Niger Delta province is ranked the twelfth richest petroleum province with 2.2% of the world's discovered oil and 1.4% of world's discovered gas by the US Geological Survey's World Energy Assessment (Klett et al., 1977).

In the Niger Delta, petroleum is produced in sandstone and unconsolidated sands of the Agbada Formation. This formation is characterized by alternating sandstones and shales with rock units varying in thickness from 30m to 4600m (Short and Stauble, 1967). The sandstones in this Formation are the main hydrocarbon reservoirs with shale providing lateral and vertical seals. Petrophysical interpretation of logs plays an important role in the discovery and development of petroleum and natural gas reserves. It also helps to correlate zones, assist in structural mapping, identification of productive zones, determination of depth and thickness of zones to distinguish between oil and gas or water in a reservoir and to estimate hydrocarbon reserves (Darwin and Singer, 2008).

This study provides a better understanding of the reservoir properties (porosity, permeability) and related sedimentological features likely to impact on fluid flow. The fluid types and their contacts were determined as well as the palaeodepositional environment. Such findings will assist in future exploration and exploitation activities within the Field and can help locate new targets.

Location of Study Area and Geology

The study area is located within the Duski field, onshore Niger Delta and belongs to Addax Petroleum Development Company, Nigeria Concession (Figure 1). The three wells within the field are all located around the centre of the field as shown in the base map (Figure 2).

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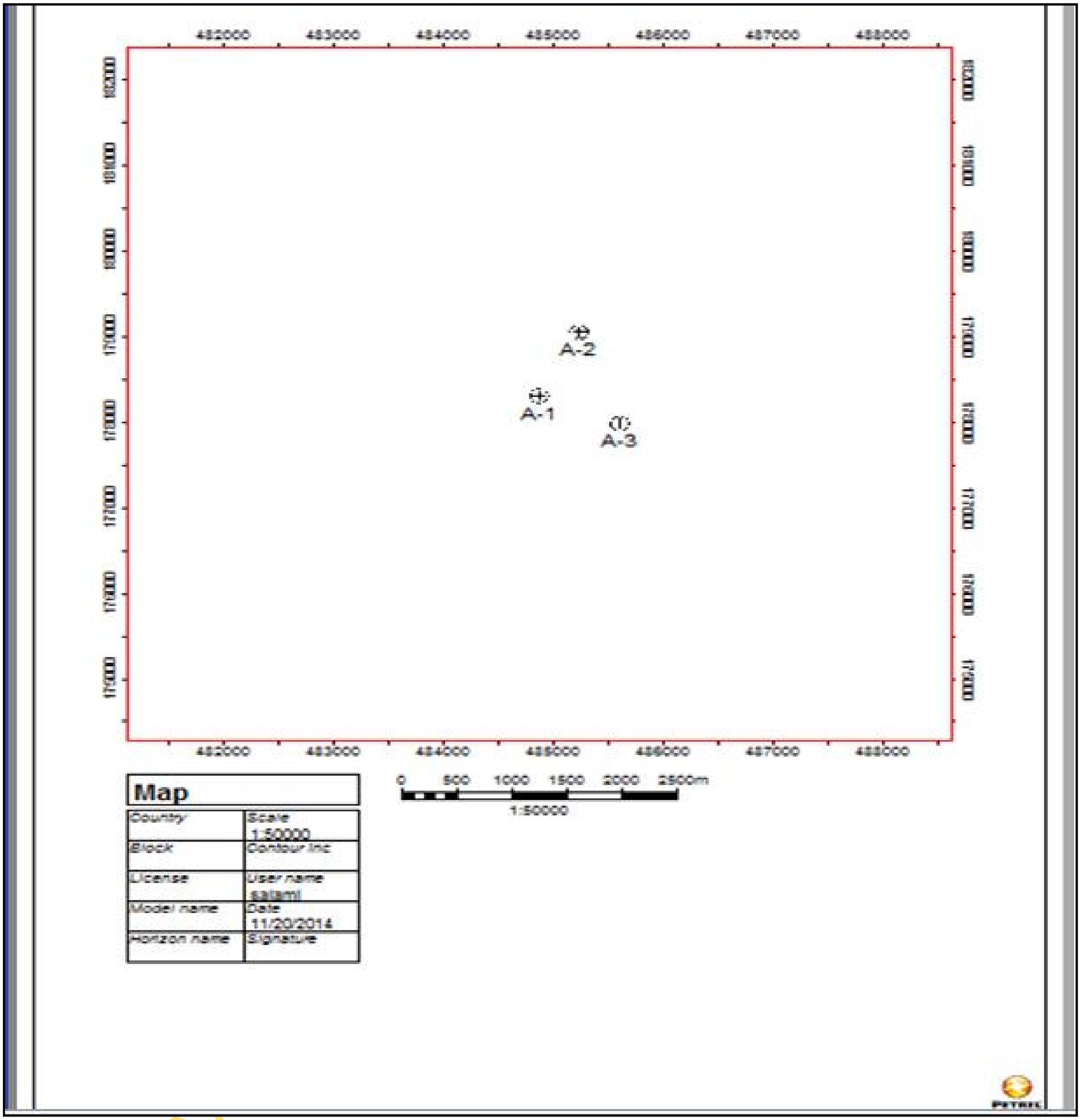
NIGERIA
Gulf of Guinea
Duski field
E&P LICENCE
OIL FIELDS
GAS FIELDS
OIL DISCOVERIES
PIPELINE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A-2
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A-3
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Country
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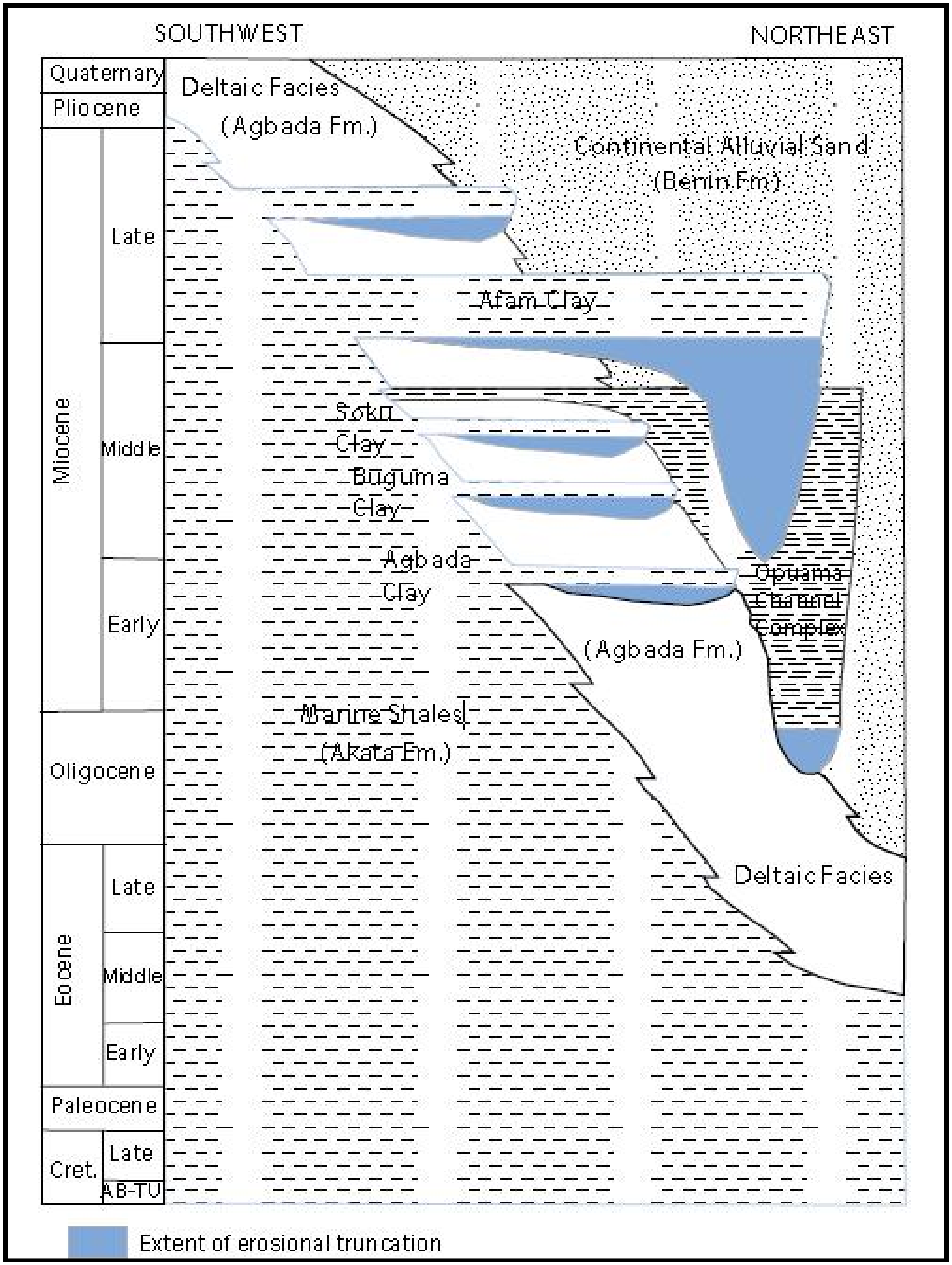

SOUTHWEST
NORTHEAST
Quaternary
Pliocene
Miocene
Late
Middle
Early
Oligocene
Eocene
Late
Middle
Early
Paleocene
Cret.
Late
AB-TU
Deltaic Facies
(Agbada Fm.)
Continental Alluvial Sand
(Benin Fm)
Afam Clay
Soku Clay
Buguma Clay
Agbada Clay
Opuama Channel Complex
(Agbada Fm.)
Marine Shales
(Akata Fm.)
Deltaic Facies
Extent of erosional truncation

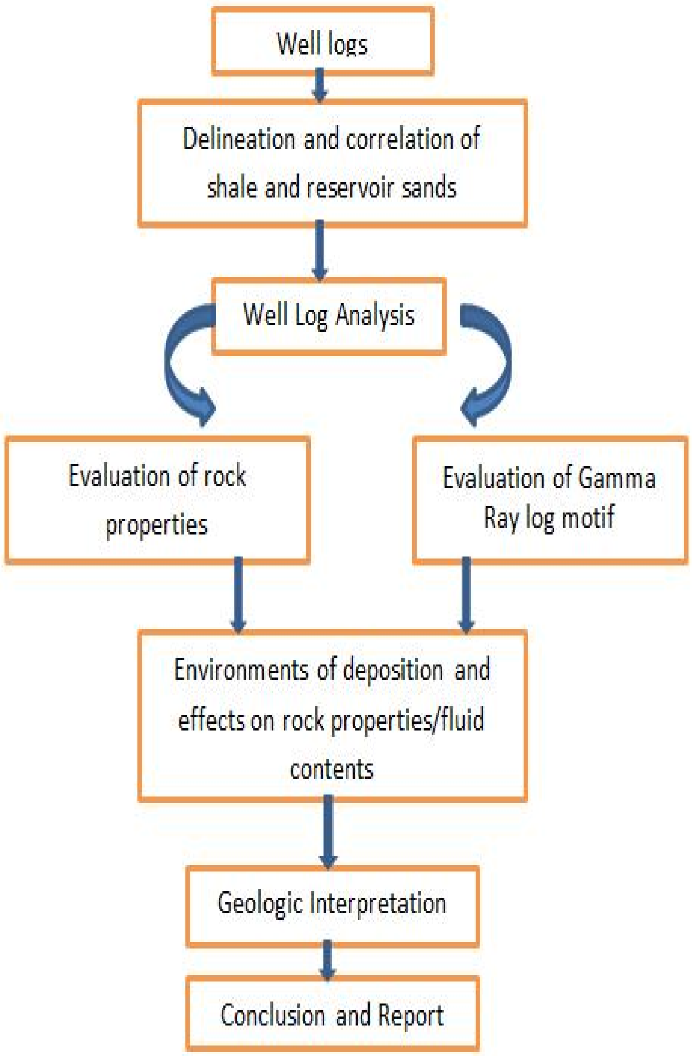


Figure 4: Work flow chart showing different stages and methodology

deflection to the left of the GR log due to the low concentration of radioactive minerals in sands while deflection to the right signifies shale unit, with high concentration of radioactive minerals (Schlumberger, 1989). Conventionally, GR log is set to a scale of 0-150 API unit and a central cut off point of 65 API was inferred based on the sand-shale discrimination. This implies that API value greater than 65, is interpreted as shale unit while lesser indicates sandstone (Schlumberger,1989).

Correlation

The three wells A1, A2, and A3, located within the Duski Field, were correlated using gamma ray and resistivity logs responses. According to Schlumberger, (1989), the gamma ray and resistivity logs are good correlation tools in both open and cased holes. The wells were correlated from bottom to top using lithological log responses that may be product of similar depositional processes and environment. Sand units of interest were carefully picked and correlated across the wells to give an idea of the continuity of the reservoirs at different depths across the whole Field. This is based on the concept of electric log correlation procedures and guidelines (Daniel and Richard, 2003)

Evaluation of Petrophysical Parameters

The petrophysical parameters such as permeability, porosity, effective porosity, hydrocarbon saturation, water saturation, bulk volume of water, volume of shale, net-gross, formation factor, irreducible water saturation and hydrocarbon pore volume were estimated from the logs responses using Schlumberger Petrel (2009) software.

Volume of shale (Vsh)

The magnitude of the gamma ray count in a formation of interest (relative to that of nearby clean and shale zones) is related to the shale content of the formation. This relationship may be linear or non-linear. The gamma ray log was used to calculate the volume of shale by first determining the gamma ray index using the formula proposed by Asquith and Gibson, (1982):

$$Igr = \frac{GRlog - GRmin}{GRmax - GRmin} \quad \ldots\ldots (1)$$

Igr = Gamma ray index which describes a linear response to shaliness or clay content.
GRlog = log reading at the depth of interest
GRmin = Gamma Ray value in a nearby clean sand zone
GRmax= Gamma Ray value in a nearby shale

Using Larionov non-linear relationship for Tertiary rocks, volume of shale can therefore be calculated as:

$$Vsh = 0.083\,(2^{2Igr} - 1) \quad \ldots\ldots (2)$$

Vsh = is the volume of shale
Igr = Gamma ray index

Bulk volume of water

This is the product of water saturation and porosity corrected for shale:

$$BVW = Sw * \Phi e \quad \ldots\ldots \text{(Asquith and Krygowski, 2004)} \ldots\ldots (3)$$

Where:
BVW = bulk volume water;
Sw = water saturation;
Φe =effective porosity

If values for bulk volume of water (BVW), calculated at several depths within a formation are consistent, then the zone is considered to be homogeneous and at irreducible water saturation. Therefore, hydrocarbon production from such zone should be water - free (Morris and Biggs, 1967).

Identification of fluid type

A general indication of fluid type was inferred from the resistivity readings. High deep resistivity readings corresponding to sand units indicated hydrocarbon bearing or freshwater zones while low deep resistivity readings, showed water bearing zones (Schlumberger, 1989).Usually, a definite identification of fluid type contained within the pore spaces of a formation is achieved by the observed relationship between the Neutron and Density logs. The presence of hydrocarbon is indicated by increased density log reading which allows for a cross-over. Gas is present if the magnitude of cross-over, that is, the separation between the two curves is pronounced while oil is inferred where the magnitude of cross-over is low (Asquith and Krygowski, 2004). Hence, log responses of Density and Neutron compensated logs made the identification of fluid type in the studied wells practicable.

Irreducible water saturation

Irreducible water saturation (sometimes called critical water saturation) defines the maximum water saturation that a formation with a given permeability and porosity can retain without producing water. The irreducible water saturation was calculated using the following relationship:

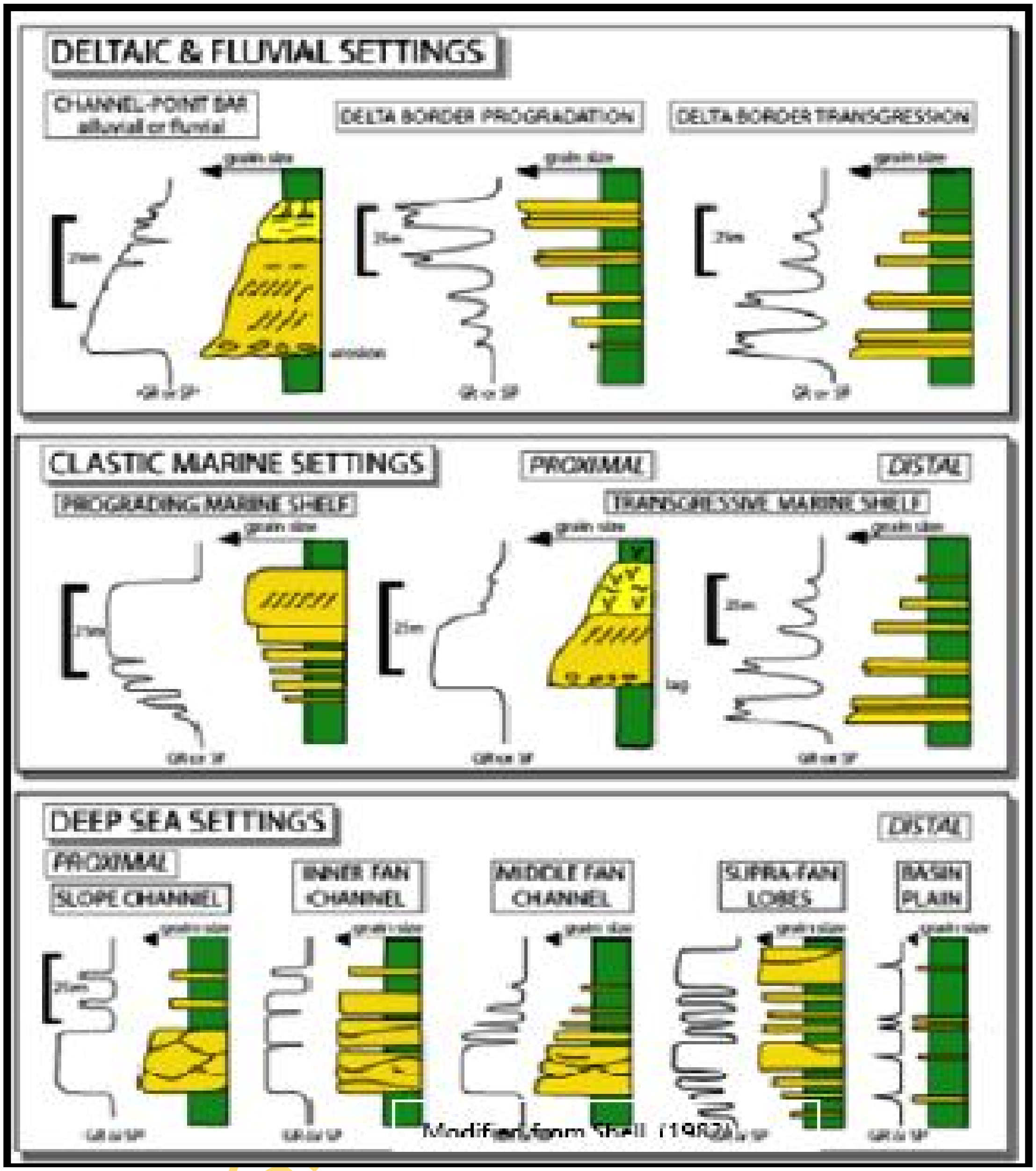
$$Swirr = \sqrt[2]{F/2000} \quad \ldots\ldots (4)$$

Where:
Sw_{irr} = irreducible water saturation
F = formation factor.

However, this theoretical estimate of irreducible water is useful in the estimation of relative permeability.

Identification of facies and depositional environments

A basic scheme of classifying sand bodies in the Gulf Coast area of the USA, apparently developed by Shell (Serra and Sulpice, 1975) is based on the shapes of the SP along with the resistivity logs. The principal shapes are the bell, the funnel and the cylinder (Fig.5). Since the gamma ray log measures the shaliness of a formation, it can indicate the lithofacies and depositional environment of a rock and was used as such in this study.



Modified from Shell (1982)

sizes or thickness of interbeds and abrupt upper and lower contacts. It also shows even block with sharp top and base. It is indicative of aggrading condition which may be interpreted as eolian, braided stream, distributary channel-fill, submarine canyon-fill, carbonate shelf margin and evaporite fill basin.

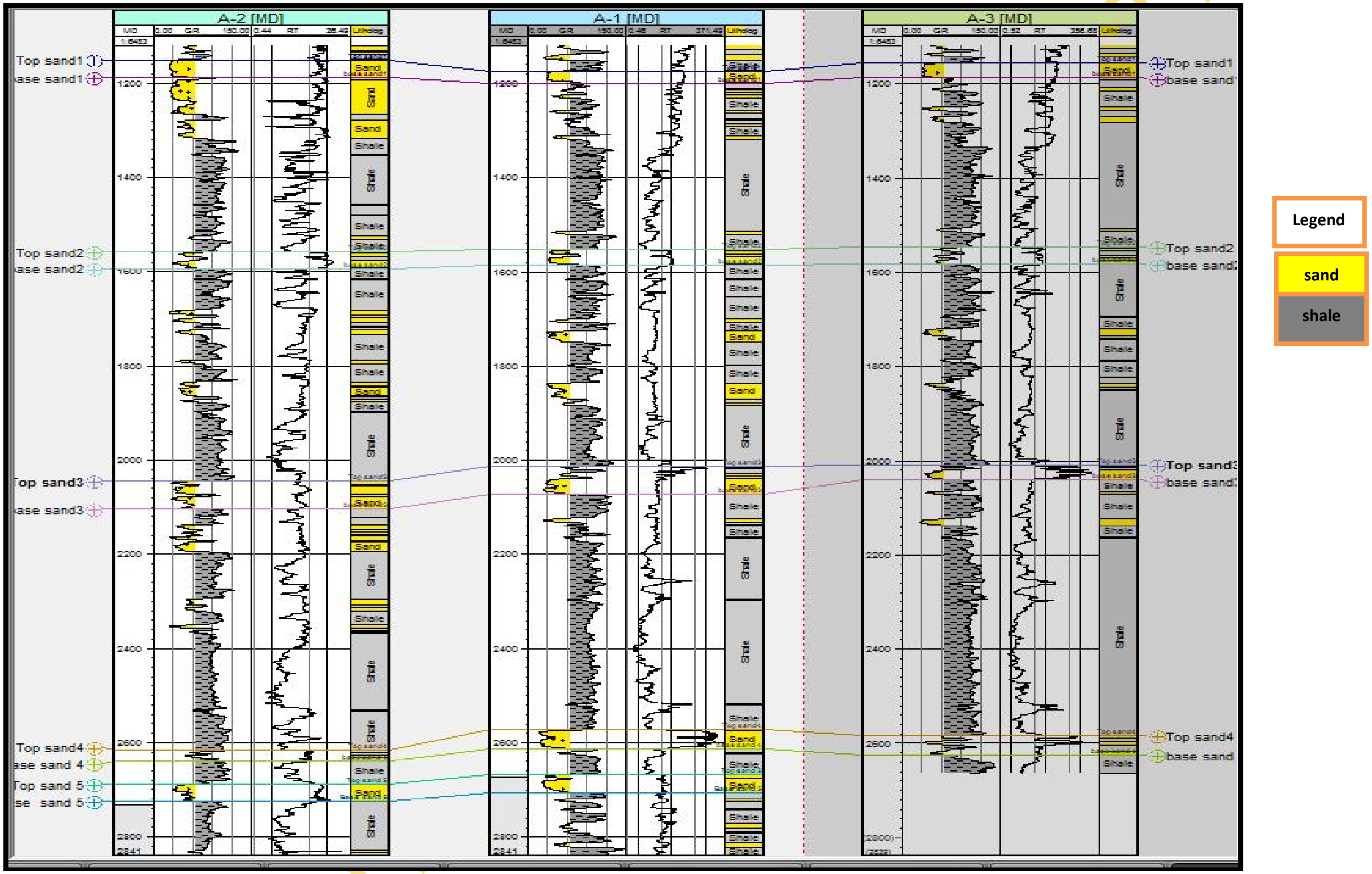
Irregular shapes

The irregular or serrated-shaped GR log pattern is indicative of environments such as fluvial flood plain, storm dominated shelf and distal deep marine slope. According to Emery and Myers (1996), the trend has no character, representing aggradation of shales or silts. The irregular shape of gamma ray log patterns may also indicate basin plain environment (Coleman and Prior, 1980)

RESULTS AND DISCUSSION

Lithology

The lithology of the wells comprised mainly of parallic sequence of sandstone with interbedded shale, characteristic of the Agbada Formation (Fig.6). The lower portion of this section contains thick shale unit while the upper portion is made up of more sands than shale. This corroborates the findings of Weber, (1971); Avbovbo, (1978); Doust and Omatsola, (1990) and Kulke, (1995) for the description of the Agbada Formation.


A-2 [MD]
A-1 [MD]
A-3 [MD]
Top sand1
base sand1
Top sand2
base sand2
Top sand3
base sand3
Top sand4
base sand 4
Top sand 5
base sand 5
Legend
sand
shale

ϕe)
6 in

WELL A1															
Sand Units	Depth(md) (top-bottom)	Thickness (m)	Vsh (%)	NTG (%)	(ϕD) (%)	Sw (%)	Sh (%)	BVW (%)	HCPV (%)	F	Swirr	K (md)	ϕN-D	(ϕe)	Fluid Type
Sand 1	1175-1199	24.38	12.77	87.23	28.94	18.8	81.20	6.39	27.61	11.05	0.07	34349	0.34	0.29	Oil and Water
Sand 2	1551-1585	34.44	20.84	79.16	26.41	34.17	65.83	9.57	18.43	12.01	0.08	6017	0.28	0.19	Gas, Oil, and Water
Sand 3	2012-2072	60.05	16.80	83.20	24.46	37.40	62.60	8.98	15.02	15.34	0.09	2371	0.24	0.17	Gas, Oil, and Water
Sand 4	2572-2613	40.99	8.92	91.08	23.12	12.20	87.80	2.32	16.68	23.64	0.10	531.4	0.19	0.17	Gas
Sand 5	2668-2705	37.03	10.59	89.41	19.05	36.94	63.06	6.65	11.35	24.82	0.11	262.2	0.18	0.16	Gas, Oil, and Water

Swir
ϕD:
ϕe: E
ϕN-

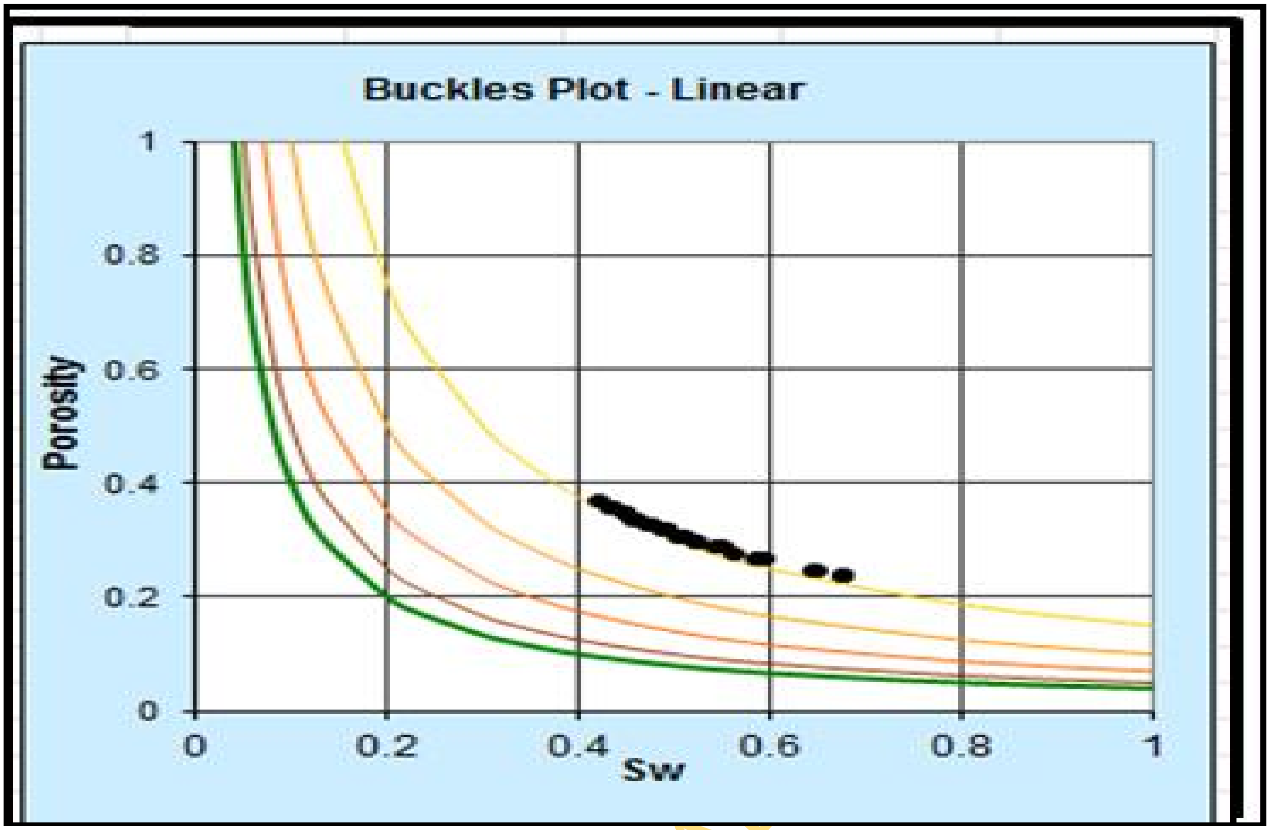
WELL A2															
Sand Units	Depth(md) (top-bottom)	Thickness (m)	Vsh (%)	NTG (%)	(ϕD) (%)	Sw (%)	Sh (%)	BVW (%)	HCPV (%)	F	Swirr	K (md)	ϕN-D	(ϕe)	Fluid Type
Sand 1	1150-1187	37.34	4.85	95.15	47.01	29.00	71.00	13.05	31.95	4.55	0.05	102595	0.45	0.43	Gas, Oil, and Water
Sand 2	1557-1593	35.97	10.87	89.13	28.77	26.25	73.75	7.61	21.39	10.84	0.07	10602	0.29	0.20	Gas, Oil, and Water
Sand 3	2044-2104	60.20	19.97	80.03	24.40	41.26	58.74	9.90	14.09	14.67	0.08	2545	0.24	0.18	Gas, Oil, and Water
Sand 4	2614-2640	25.60	39.55	60.45	16.53	36.83	63.17	7.50	12.63	39.14	0.13	407.3	0.20	0.08	Oil and Water
Sand 5	2689-2724	35.81	12.75	87.25	17.21	28.22	71.78	4.52	11.48	30.47	0.12	110.5	0.16	0.13	Gas, Oil, and Water

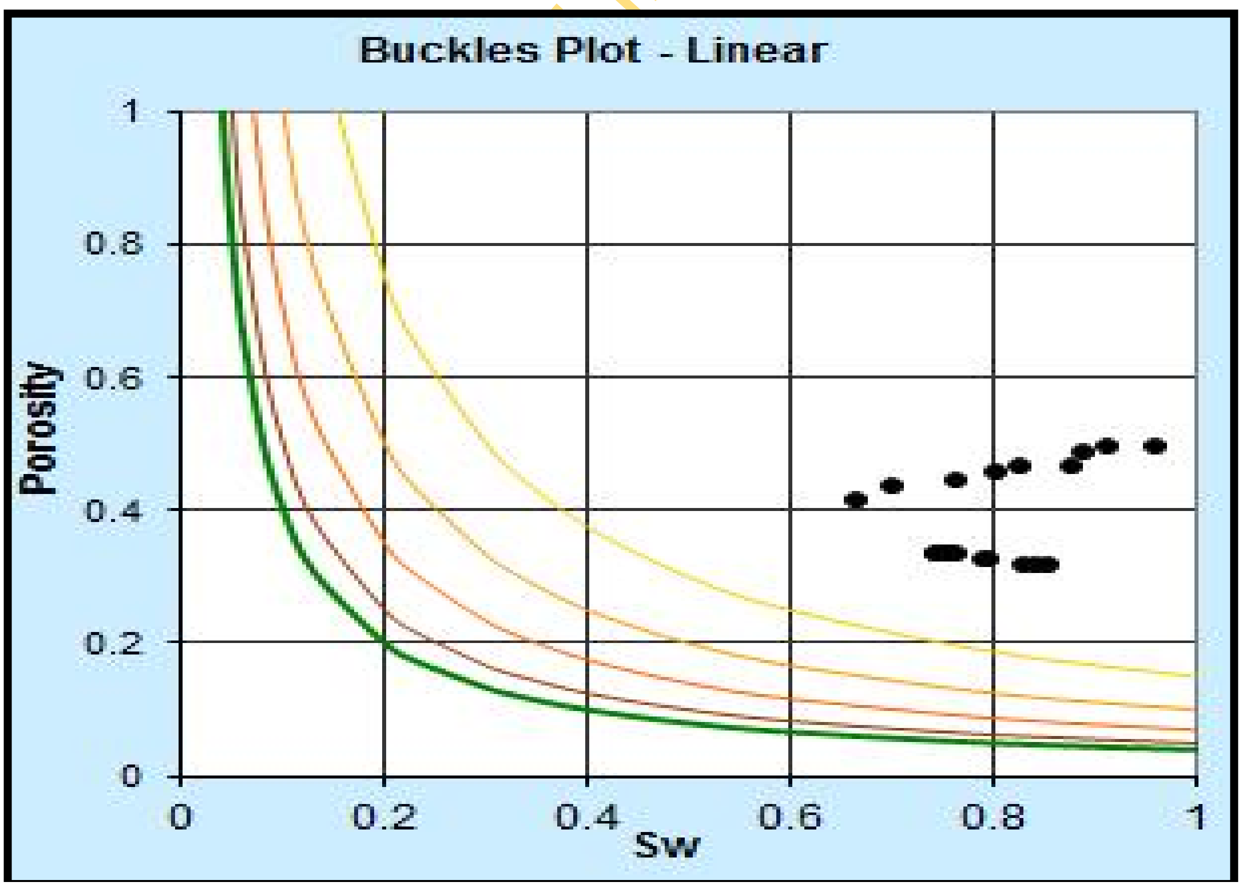
Swi
ϕD:
ϕe: E
ϕN-D

WELL A3															
Sand Units	Depth(md) (top-bottom)	Thickness (m)	Vsh (%)	NTG (%)	(ϕD) (%)	Sw (%)	Sh (%)	BVW (%)	HCPV (%)	F	Swirr	K (md)	ϕN-D	(ϕe)	Fluid Type
Sand 1	1156-1187	30.70	7.13	92.87	29.72	20.84	79.16	7.29	27.71	9.33	0.07	27850	0.35	0.31	Oil and Water
Sand 2	1546-1583	37.10	19.75	80.25	28.44	38.15	61.85	14.49	23.50	11.54	0.07	42911	0.38	0.21	Oil and Water
Sand 3	2009-2041	31.40	22.69	77.31	26.65	20.10	79.90	5.23	20.77	12.27	0.08	3627.4	0.26	0.16	Gas, Oil, and Water
Sand 4	2584-2624	40.80	15.86	84.14	18.16	27.77	72.23	6.66	17.33	29.36	0.12	1095.6	0.24	0.12	Gas, Oil, and Water

Swi
ϕD:
ϕe: E
ϕN-I

Litho Units	Well A1		Well A2		Well A3	
	Fluid type	*Fluid contact*	*Fluid type*	*Fluid contact*	*Fluid type*	*Fluid contact*
Sand 1	Oil and Water	ODT: 1195	Gas, Oil and Water	GOC: 1155 OWC: 1169 ODT: 1184	Oil and Water	ODT: 1185
Sand 2	Gas, Oil and Water	GOC: 1553 GUT: 1563 GOC: 1568	Gas, Oil and Water	OWC: 1578 ODT: 1592	Oil and Water	OWC: 1553 OUT: 1565
Sand 3	Gas, Oil and Water	OWC: 2072 GOC: 2029 GUT: 2013	Gas, Oil and Water	GOC: 2072 OWC: 2078	Gas, Oil and Water	GUT: 2011 GOC: 2024 OWC: 2030
Sand 4	Gas	GUT: 2573	Oil and Water	OWC: 2625	Gas, Oil and Water	GDT: 2588 GOC: 2594 OWC: 2602 WDT: 2619
Sand 5	Gas, Oil and Water	GOC: 2673 ODT: 2703	Gas, Oil and Water	GDT: 2704 GOC: 2714 ODT: 2724		


Buckles Plot - Linear
Porosity
Sw
0
0.2
0.4
0.6
0.8
1

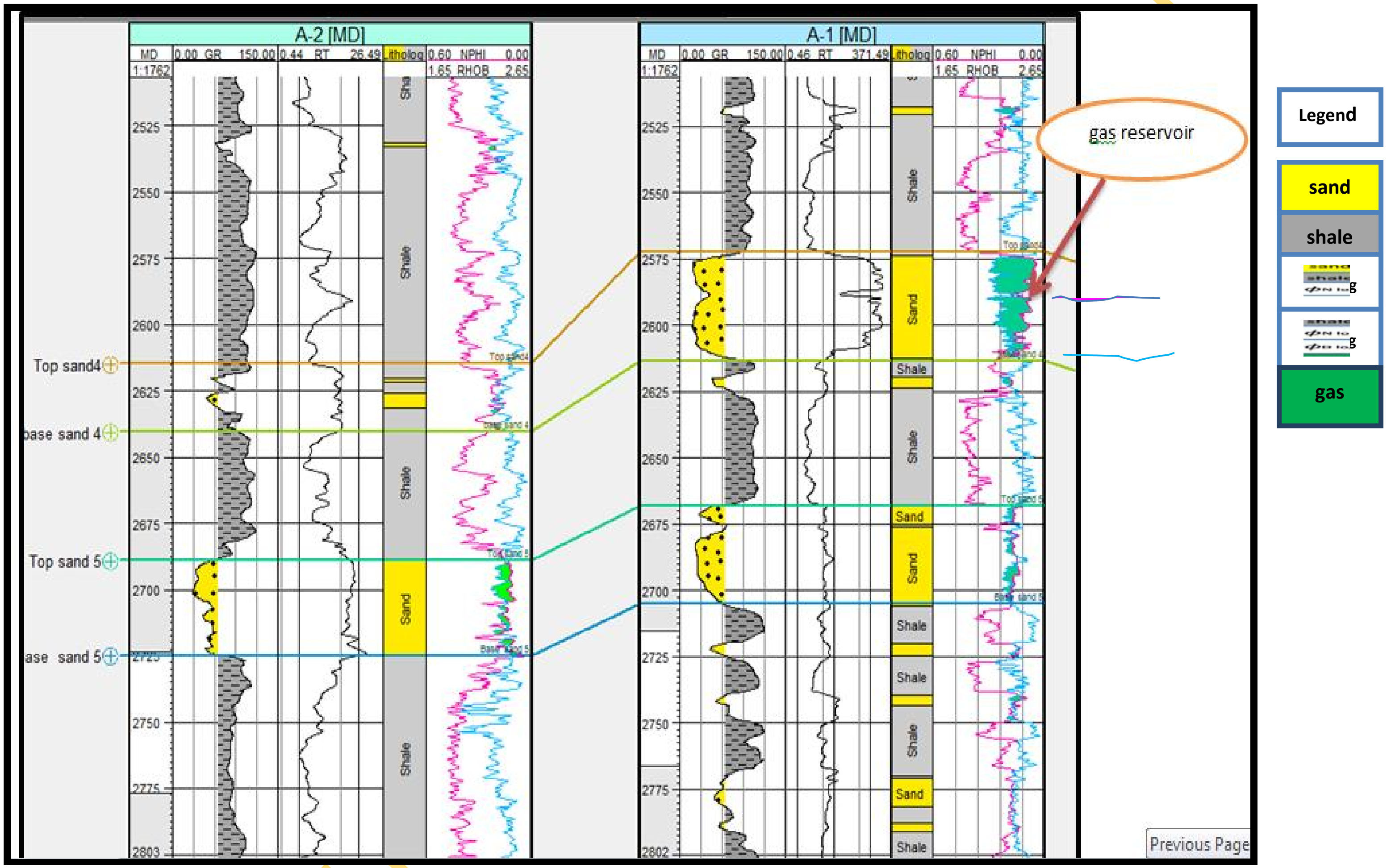

Buckles Plot - Linear
Porosity
Sw
0
0.2
0.4
0.6
0.8
1

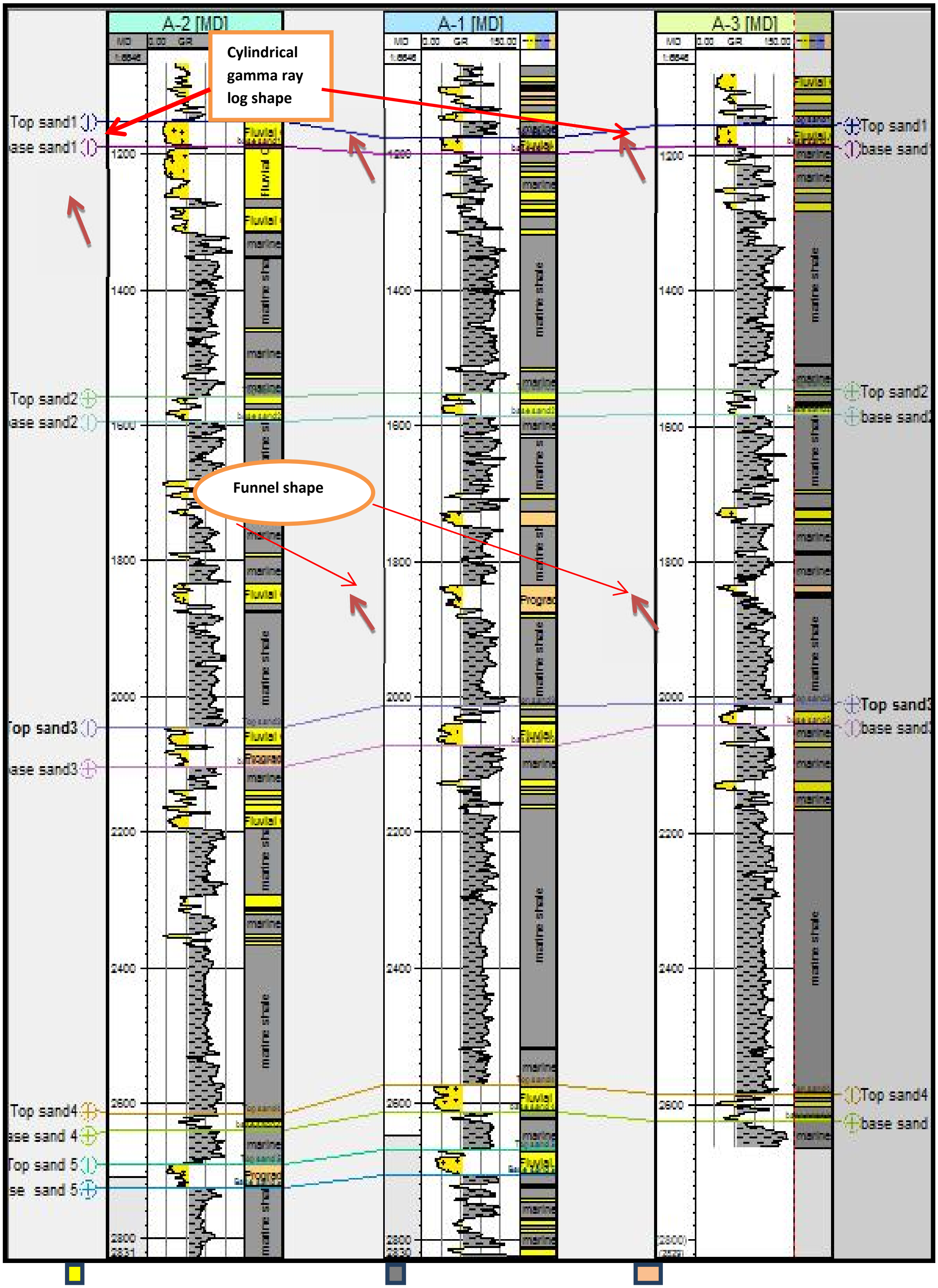
Reservoir fluid and contacts

The reservoirs were interpreted for their fluid contents using appropriate logs. In estimating the fluid content and contacts in clastic reservoirs such as obtained in the Niger Delta, shaliness, water saturation, neutron-density porosity and resistivity logs responses are parameters to be considered. These parameters are essential in the identification of the fluid types and their various contacts within the reservoirs (Table 4).

The combination of neutron-density porosity log overlay, water saturation, volume of shale and resistivity logs were used to delineate hydrocarbon and water bearing zones. The large cross-over of Neutron-Density log overlap (Fig.9) indicates the occurrence of gas reservoir (Asquith and Krygowski, 2004 and Adepelumi et al. 2011).

The utilization of petrophysics to study the lateral changes in fluid content in reservoirs can be very useful in the sense that it helps presume the lateral continuity or extent of the reservoir when seismic data is not available and thus reduces failure in oil/gas exploration (Adeoye and Enikanoselu, 2009).


A-2 [MD]
A-1 [MD]
MD
1:1762
GR
RT
litholog
NPHI
RHOB
Top sand4
base sand 4
Top sand 5
ase sand 5
Shale
Sand
gas reservoir
Previous Page
Legend
sand
shale
gas



A-2 [MD]
A-1 [MD]
A-3 [MD]
Cylindrical gamma ray log shape
Funnel shape
Top sand1
base sand1
Top sand2
base sand2
Top sand3
base sand3
Top sand4
base sand 4
Top sand 5
base sand 5
Fluvial
marine
marine shale
Prograd
1200
1400
1600
1800
2000
2200
2400
2600
2800

Depositional Environments and Facies

Gradual changes in shaliness are associated with changes in grain size and sorting that are controlled by facies and depositional environment as well as lithology (Shell, 1982; Nton and Odundun, 2012; Emery and Myers, 1996; and Selley, 1998). Analysis of the gamma ray logs indicated that the log trends fall mostly into four categories namely; irregular, funnel, cylindrical and bell shaped successions.

The reservoir sands were deposited within the transitional environments which comprise fluvial channel, deltaic and basin floor sand bodies. The bell-shaped gamma ray log motif in the wells varies between 5m and 10m thick in places where it occurred. This was observed in the upper part of reservoir sand 3 at depth interval 2044-2104m of well A2, with a sharp break from the overlying shale (Fig.10).This was also found in the reservoir sand 4 of well A3, at depth interval 2584-2624m (Fig.10). The bell-shaped successions are usually indicative of a transgressive sand, tidal channel or deep tidal channel and fluvial or deltaic channel. As reported by Nelson and James (2000), tidal channels commonly contain glauconite and shell debris.

Bell shaped successions with carbonaceous detritus are associated with fluvial or deltaic channels (Selly, 1998); however, in this study, core samples and biostratigraphic data were not available to establish this. According to Weber (1971), most cycles of sedimentation begin with the erosion of underlying sand unit and the deposition of thin fossiliferous transgressive marine sand. The analysis revealed that the bell-shaped successions are thin, which may suggest that the sands were deposited in a transgressive marine setting.

The irregular log motifs occur in several sections of the three wells. These trends show no systematic change in gamma ray values and represent aggradation of shale or silt (Emery and Myers (1996). The trend is extensive, particularly at deeper depths of all the wells; in well A1 for instance, it occurred between the depths interval 2100-2550m (Fig.10). These log facies are interpreted as basin plain environment, which is characterized by clays and fine silts, deposited from suspension, with high lateral continuity and low lithologic variation.

The funnel shaped log motifs occurred in the lower part of sand 2 and sand 3 reservoirs of well A2 with thicknesses of 18m and 30m respectively (Fig.10). Also, this trend appeared as serrated and dominant in sand 5 unit of well A2 with thickness of 35m. The trend is usually interpreted to indicate deposition of cleaning upward sediment with an increase in the sand content of the sand bodies, as applied to a marine setting. The environment of shallowing-upward and coarsening successions is divided into three categories Selley (1998). They include: regressive barrier bars, prograding marine shelf and prograding delta or crevasse splays. The regressive barrier bars and prograding marine shelf fans environments are commonly deposited with glauconite, shell debris, carbonaceous detritus and mica (Selley, 1998). This cannot be established due to absence of core samples and biostratigraphic data. These log shapes cannot be associated with crevasse splay on the account of thicknesses (Nton and Odundun, 2012).

One of the main differences between a crevasse splay and a prograding delta is the depositional scale. According to Chow et al., (2005), the prograding delta is comparatively large. The funnel-shaped successions in well A2 which are 18 m, 30 m and 35 m, are likely to be a prograding marine shelf or a prograding delta (Rider, 1999). In non-reservoir portions of the wells, prograding sand units were also observed above sand unit 1 across the wells. It was also observed between the depths interval 1700- 1750m below sand 2 and depth interval 1825-1870m in each of the three wells.

The cylindrical log shape patterns are observed in most of the sand units across the wells. This trend is very obvious in the reservoir sand 1 unit across the three wells of the field (Fig.10). This pattern is also observed in the lower part of reservoir sand 2 of well A1. This shape characterized the gamma ray logs of the upper portion of the reservoir sand 3 in well A2 and lower part of reservoir sand 3 in both well A1 and A3. It is a dominant pattern in both reservoir sand 4 and 5 of well A1.The upper and lower boundaries of reservoir sand 1 across the three wells are sharp and bounded by marine shale. The thickness of the cylindrical gamma ray log shapes of reservoir sand 1 in the wells range from 24 m to 37 m. The thickness is about 34m in reservoir sand 2 of well A1. The thicknesses of 31m and 22m were observed in reservoir sand 3 of well A1 and A2 respectively. Also in sand 4 of well A1, 41m thickness was observed.

The cylindrical-shaped gamma ray logs could indicate a slope channel and inner fan channel environments according to Shell (1982) log shape classification scheme. Reservoir sand 1 across the three wells together with sands 2, 3 and 4 of well A1, were deposited in a slope channel environment due to the irregular trends and their thicknesses. The cylindrical log shapes trends with greater range of thickness indicate turbidite sands (Emery and Myers; 1996).

CONCLUSION

This study involved analyses of composite well logs for reservoir evaluations and palaeo-depositional environment interpretation in Duski Field, Onshore Niger Delta. It was observed that the five oil-bearing reservoir sand units across the field were very prolific. These units were characterized by porosity, permeability, hydrocarbon saturation, water saturation, irreducible water saturation, hydrocarbon pore volume and bulk volume of water values which compared closely with that obtained for sands of other Niger Delta producing fields.

The rock properties of the Duski Field are variable due to environmental influence and depth of burial. Sand units have good quality properties as reservoir rocks while the shale units function both as source rock and seal. The variability in the rock properties was controlled by the different environments of deposition. It was deduced that the study area is within the marginal marine depositional environment and comprised fluvial channel, transgressive marine, progradational and deltaic settings.

All the reservoirs in well A1, except sands 5, reservoir sand 2 in well A2; reservoirs sands 1, 3, and 4, are at irreducible water saturation and would produce water-free hydrocarbons. Some other sand units, namely: sands 1, 3, 4, and 5 of well A2; sand 5 in well A1 and reservoir sand 2 in well A3; are not at irreducible saturation. Much water and wet hydrocarbons would be produced by wells bored through these units.

It is envisaged that with the availability of seismic, check shot and biostratigraphic data, more information could be gathered on the volumetric, depositional environments and the structural configuration of the reservoirs.

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