EVALUATION OF WIRELINE LOG DATA FOR RESERVOIR CHARACTERIZATION OF THE ADONI FIELD, NIGER DELTA.

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Abstract: Reservoir Characterization of four wells (Adoni-5, Adoni-6, Adoni-7 and Adoni-11) and biostratigraphic data of one well (Adoni-5) in the Adoni field, onshore Niger Delta was undertaken. The study was carried out to evaluate wireline log data for reservoir characterization of the Adoni field. The well log was qualitatively and quantitatively analyzed using Schlumberger Petrel 2017 software. The research has shown that the hydrocarbon bearing sand thickens in the South-Western direction and pinches out in the North-Eastern section of the field. The effective porosity values range between 24 to 30 % and the permeability values range between 2326.2 to 4123.2 mD and indicates very good to excellent reservoirs. The petrophysical parameters indicate a gassy reservoir which was validated by the bubble effect of neutron-density (log) crossplot. The biostratigraphic data suggest the reservoir is of possible Oligocene in age on the basis of microfossils identified and the log motif suggest channelized fluvio-detaic transitional environment of deposition. on this further field development plan should give recourse to South western section, due to high degree of certainty with respect to high pay zones. The study has assisted in the direction of potential producible prospect and has also help in characterization of the reservoir which may aid in technical decision of developing the field.

Keywords: Adoni Field, Heterogeneity, Niger Delta Basin, Reservoir Characterization, Reservoir properties.

Introduction

Evaluation of well log for Reservoir characterization involves the study of reservoir attribute employing geologic, geophysical, petrophysical, and engineering discipline, as well as uncertainty analysis. (Ma, 2011). The major purpose of formation evaluation and reservoir estimation in the petroleum industry is to understand and precisely measure important reservoir parameters such as lithology, porosity, fluid saturation, permeability and shale volume. Multiple types of heterogeneity in reservoir properties exist on different scale (Mavko et al., 2020). This heterogeneity also encompasses differences in property, permeability, particle size, mineralogy, mechanical properties and diagenetic features (Odedede, 2019a). Natural heterogeneity and uncertainty of reservoir parameters make problems related to hydrocarbon characterization difficult (Koneshloo *et al.* 2018). Reservoir Characterization of Hydrocarbon wells have been fundamental aspect in exploration and exploitation. Similarly, uncertainty such as heterogeneity associated with reservoir is a major problem in the recovery of hydrocarbon from such reservoir. This makes it inevitable to properly and adequately characterized a reservoir and evaluate a formation. In order to ascertain the hydrocarbon potentials of the reservoir, updates on petrophysical parameters such as porosity, permeability, fluid saturation among others would in turn reduce the risk associated with drilling for the search of hydrocarbon. In light of the above, the research is undertaken to add knowledge and information to the geology of the greater Ughelli Depobelt, Niger Delta.

Several studies have been carried out on reservoir characterization primarily to address development and production challenges, such studies include the work of Mujakperuo et al., (2020) Who applied well log data to characterized the X-field reservoir, the study reveals the petroleum potential of the wells and also help to enhance the proper characterization of the reservoirs. Sarhan, (2021) applied well log for petrophysical characterization of the Thebes and Mutulla reservoirs in Rabeh East Field, Gulf of Suez Basin. Adiela & Ayodele (2018), also applied well log to study the petroleum explorative potentials of the Chuna well and the study area was said to be prolific in terms of hydrocarbon production.

The Adoni Field is located in the Greater Ughelli Depobelt of the Niger Delta Basin, Nigeria (Fig. 1). The Greater Ughelli depobelt ranges from Oligocene to Early Miocene in Age. The structural province of deposition is the central delta where large and simple structure can be grouped into well distinguished megastructures. This present work involves the use of well log suites and biostratigraphic data to evaluate the petrophysical properties of Adoni Field for reservoir characterization, which will aid the interpretation of the data sets acquired, correlation of the reservoir sands, determine the age of the hydrocarbon bearing sand as well as the environment of deposition.

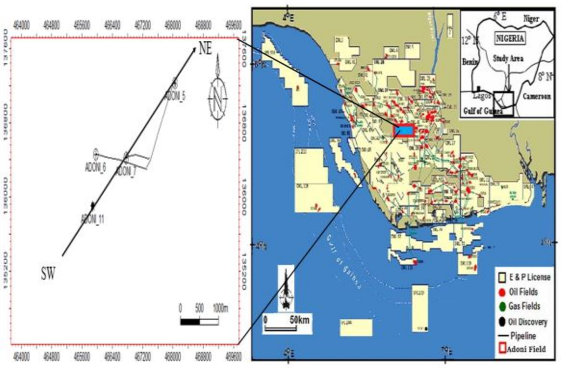

Fig. 1: Map of Niger Delta showing the location of the studied field (Modified after Doust and Omatsola, 1990)

Geologic Setting

The Niger Delta Basin which encompasses 75,000km^2 and consists of 9000–12,000 m of clastic sediments is located on the western frontier of Africa and in the southern section of Nigeria (Ojo *et al*., 2012; Aminu & Oloruniwo, 2012). The development of the Niger Delta Basin (Fig.2) began during the Cretaceous period when the African continent separated from South America (Doust & Omatsola, 1990; Odedede 2019a). The interplay between rates of sedimentation, subsidence, and eustatic cycles has shaped the evolution of the Niger Delta throughout its geologic history (Fig. 2). Three main lithostratigraphy have been recognized in the subsurface of the Niger Delta Basin (Fig. 2), from the oldest to the youngest; Akata Formation, Agbada Formation and Benin Formation (Short & Stauble, 1967; Weber & Daukoru, 1975). The Akata Formation is a marine prodelta megafacies, undercompacted and overpressured. It is mainly made up of marine shale with occasional siltstone and sandstone (Short & Stauble, 1967; Adiela & Ayodele, 2018). It ranges in thickness from 600m – 6000m. Agbada Formation lies beneath the Benin Formation, it is made up of interbedded fluvio-marine sands, sandstones and siltstones of varying proportions (Weber 1971). Shaliness in the Agbada Formation increases downward into the Akata Formation (Reijers 2011). The sand constitutes the main hydrocarbon reservoir while the shale acts as cap rocks (Weber & Daukoru, 1975, Chukwuma et al., 2017, Odedede, 2019b). The Benin Formation is the topmost unit which is made up of fluviatile gravel and sands. The deposit is composed of primarily highly porous, fresh water bearing sandstone (Okoh & Nwachukwu, 1997, Mujakperuo et al; 2020). It ranges from 0 – 2100m (Short & Stauble, 1967).

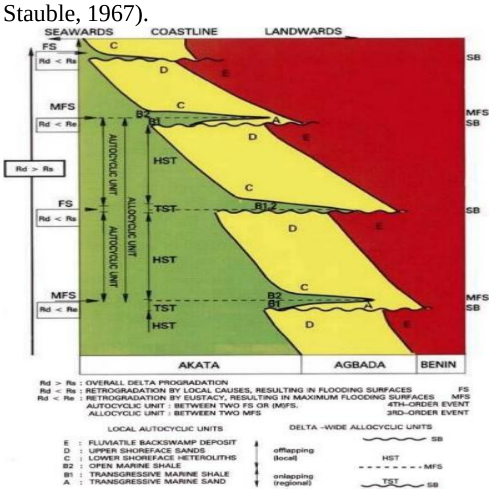

Fig. 2: Mechanisms and units of delta evolution (After Reijers, 2011)

Materials and methods

The data set used for this research was acquired from an international oil Company via Department of Petroleum Resources (DPR). The data comprise well logs from four (4) wells (AD-5, AD-6, AD-7 and AD-11) and biostratigraphic data. The well logs consist of gamma ray, resistivity, neutron and density logs. These logs were used to evaluate and characterize the petrophysical properties such as hydrocarbon saturation (Sh), porosity (Φ), permeability (K), water saturation (Sw), water resistivity (RW).

The following data was used to analyze the field using Petrel 2017 Software; Well header, Deviation data, Four (4) composites Well logs, Biostratigraphic data for one (1) well and Base map.

Delineation of Shale Beds and Vsh Determination

The fraction of shale in the zone of interest was done using the formula below according to (Asquith & Krygowski 2004):

$$Vsh = \mathbf{I_{GR}} = \frac{\mathbf{GR_{LOG} - GR_{MIN}}}{\mathbf{GR_{MAX} - GR_{MIN}}}$$

Where,

I_{GR} = gamma ray index

GR_{LOG} = gamma ray reading of formation from log

GR_{MIN} = minimum gamma ray (clean sand),

GR_{MAX} = maximum gamma ray (shale)

Porosity Estimation

The porosity values were computed using the below equation

$$\mathbf{\Phi_D} = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$$

Where,

ϕ_D = density derived porosity (PhiT)

ρ_{ma} = density of rock matrix

ρ_b = bulk density (obtained from the log)

ρ_{fl} = density of fluid occupying rock pore spaces.

Estimation of Effective Porosity

This was generated using the relation (Krygowsky, 2003) to reflect the degree of interconnectivity of pore spaces within Sand A

$$\boldsymbol{\phi_E = \phi_D - (\phi_{shale} - V_{sh})}$$

Where: ϕ_E= Effective Porosity (PhiE)

ϕ_D= Derived Porosity

ϕ_{shale}= Value of porosity measured in a nearby shale of targeted reservoir

Vsh= Volume of shale

Permeability Estimation (K)

Permeability log was computed using correlation from Rider (1986) Equation, given below:

$$K = \frac{\mathbf{7*10^8}}{\boldsymbol{F^{4.5}}}$$

Where:

K= Permeability and

F= Formation factor

Estimation of Water/Hydrocarbon Saturation

Water Saturation computation was estimated by giving recourse to porosity log through which degree of hydrocarbon saturation was established. This was based on Archie's Equation (the relation below):

Water Saturation, (S_W)

$$S_W = \sqrt[n]{FR_W / R_t}$$

Where,

R_t = True formation resistivity

R_w = Water resistivity

n = Saturation exponent

S_W = Water saturation

F = Formation factor

Hydrocarbon Saturation (S_h)

S_h = (100 - S_W) %

Where,

S_h = Hydrocarbon Saturation

S_W = Water saturation

Net to Gross Reservoir Thickness

The net reservoir thickness was obtained for all the reservoirs in the well thus:

$h = H - h_{shale}$

Net / Gross = $\frac{h}{H}$

Where,

H = Gross reservoir thickness

h = Net reservoir thickness

h_{shale} = Shale thickness

Results and Discussion

Lithostratigraphic Correlation and petrophysical Analysis within Adoni Field

The Gamma Ray (GR) log was used along with other logs like resistivity and porosity logs for better prolific reservoir delineation (where they assisted in delineating hydrocarbon bearing zone). Detailed results are presented as well and discussed below.

Normalization of Gamma ray log (Adoni 5) was done to assure log consistency having observed anomalous effect possibly resulting from data acquisition e.g., sampling with irregular frequency, cycle skipping, environmental effect/hole eccentricity etc.

A careful well log inventory was carried out and are presented in Table 1, below.

Table 1: Adoni well log inventory performed to sort out desired well logs for analysis

Well log ID	Gamma Ray (GR)	Spontaneous Potential (SP)	Deep Resistivity Log (LLD)	Shallow Resistivity (LLS)	Density Log (RHOB)	Neutron Log (NPHI)
Adoni 5	Yes	No	Yes	Yes	Yes	Yes
Adoni 6	Yes	No	Yes	Yes	No	No
Adoni 7	Yes	No	Yes	Yes	Yes	No
Adoni 11	Yes	No	Yes	Yes	Yes	Yes

Lithological Correlation Assessment

Prior to lithostratigraphic correlation (Fig. 5) abnormality within logs were observed and correction through normalization process was carried out (Fig. 3). The results of the interpreted well log shows that the lithology type is basically sand and shale which were seen to occur in alternating sequence (Fig. 4). One area of interest was identified (reservoir zone) across the four wells (AD-5, AD-6, AD-7 & AD-11 and lies between 2876 to 2890 m top and 2948 to 2978 m base. Lithostratigraphic correlation of the identified hydrocarbon bearing reservoir (Sand A) showed that the reservoir thickens in SW direction and pinches out in NE Direction (Fig. 4). Details of these are seen, where it showed a maximum gross thickness of 75m with top and bottom values depths (SSTVD) of 2876m and 2951m respectively at AD-11 positioned in the Southwestern section of the study area; and 60m gross thickness with top and base values (SSTVD) of 2888m and bottom of 2910m respectively at AD-5 in the Northeastern section of the study area (Fig. 4).

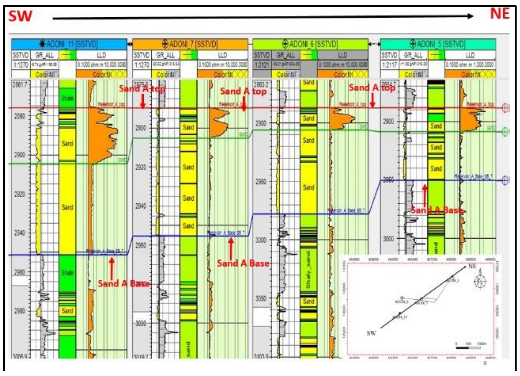

Fig. 4: Lithology type identified across the Adoni Field

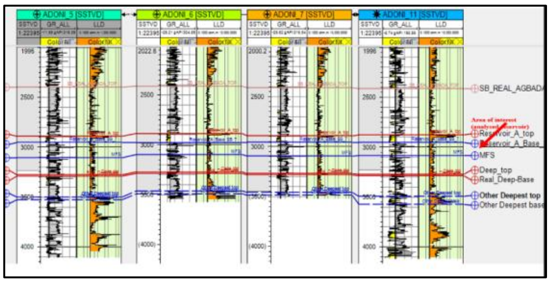

Fig. 5: Lithostratigraphic correlation across the Adoni Field

Analysis of Gross Depositional Environment (GDE) of Sand A Reservoir

The depositional environment was analyzed from the log motif using Emery & Myers (1996) models. Analysis of log motif in the Adoni field showed that the reservoir is a channel sand facies unit (Fig. 6). This is evident at the NE section of the field (Adoni-5), where a block sandy unit is capped by a preserved bell shaped, fining upward (arrow), unit sand deposits

Volume of Shale (V_{sh}) Estimation

The gamma ray log was used to calculate the volume of shale by first determining the gamma ray index using the formula according to (Asquith & Krygowski 2004) as seen in the methodology part. The resulting average computation of Vshale was used to generate a Vshale log; and this Vshale log was compared with the original Gamma ray log (normalized) of which the comparative appraisal assured log consistency hence improved confidence in the computation exercise (Fig. 7).

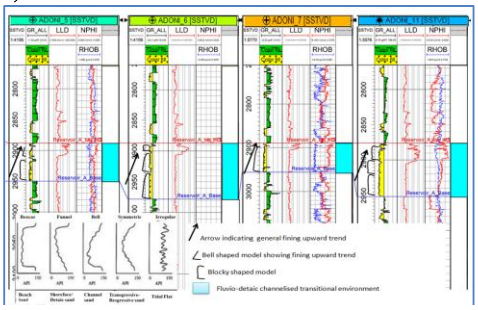

Fig. 6: Gross Depositional Environment (GDE) Analysis of sand A, Adoni Field

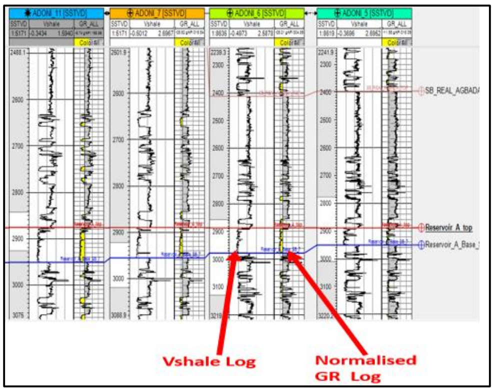

Fig. 7: Evidence of log consistency in the Vshale computation in Sand A reservoir.

Scale-up of well log was further carried out to improve on confidence level of the modelled Vshale (Fig. 8). The upscaled result further validated high degree of shaliness in the NE section of the reservoir.

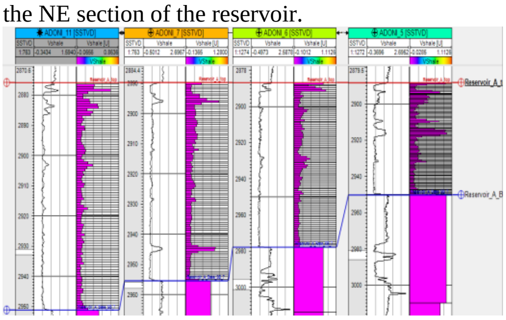

Fig. 8: Upscaled Vshale log showed high degree of shaliness in the NE section of the reservoir (Adoni Field)

Quantitative Petrophysical Analysis of Sand A

This employed the use of empirical formulae to estimate the reservoir properties of the formations intersected by the wells. The reservoirs identified through the use of gamma ray and resistivity tools were further characterized quantitatively to arrive at the desired parameters, which include: volume of shale, porosity, water saturation, permeability among others.

The computed result of petrophysical parameters (Table 2) has it that the effective porosity (Φ) and permeability (K) delineated range from 24 to 30 % and 2326.2 to 4123.2 mD respectively with AD-5 having the least effective porosity (24 %) and permeability (2326.2 mD), and AD-11 having the highest effective porosity (30 %) and permeability (4123.2 mD) values. This values therefore range from very good from the NE direction of the field (AD-5) to excellent (AD-11) in the SW section of the field (Rider, 1986). The water saturation and hydrocarbon saturation ranges from 0.11 for AD-11 which has the lowest water saturation (Sw) and (0.27) for AD-7 which has the highest water saturation (Sw). The low result of the water saturation implicates high hydrocarbon saturation; 0.81, 0.82, 0.25 & 0.89 for AD-5, AD-6, AD-7 & AD-11 respectively. The parameters calculated across the wells shows the reservoir are single phase reservoir (non associated gas reservoir). The shale volume ranges from 0.062 and 0.186 from SW to NE of the Adoni field. The net pay thickness values range from 15 m at AD-7 to 28 m at AD-11 with the SW seen to be characterized by high hydrocarbon saturation, having a very good porosity and excellent permeability with a very low shale volume which may result in high hydrocarbon production in that section.

Table 2: Summary of petrophysical parameters computed from selected Reservoir in the Adoni Field, Niger Delta.

WELLS	LITHOLOGY	TOP (m)	BASE (m)	BASE (GWC)(m)	GROSS (m)	NET PAY (m)	NET/GROSS (N/G)	VOLUME OF SHALE (Vsh)	EFFECTIVE POROSITY (PhiE)	PERMEABILITY (mD)	WATER SATURATION (Sw)	HYDROCARBON SATURATION (Sh)	FLUID TYPE
ADONI 5	SAND	2888	2948	2910	60	22	0.36	0.186	24	2326.2	0.19	0.81	GAS
ADONI 6	SAND	2887	2978	2906	91	19	0.21	0.167	-	-	0.18	0.82	GAS
ADONI 7	SAND	2890	2957	2905	67	15	0.22	0.092	27	2894.6	0.25	0.75	GAS
ADONI 11	SAND	2876	2951	2904	75	28	0.37	0.062	30	4123.2	0.11	0.89	GAS

Estimation of Porosity and Effective Porosity

Porosity log was generated using the derived bulk density log equation and the log showed high consistency with the resistivity log where hydrocarbon saturation showed significant increase in porosity. The equation used for density derived porosity is as in the methodology. Hence the computed porosity PhiT, was further used to compute effective porosity.

The effective porosity (PhiE) discounts amount of shale (Vsh) from a reservoir as seen in the comparative appraisal between PhiT and PhiE logs below (Fig. 9)

Fig. 9: Qualitative appraisal of PhiT and PhiE assured consistency in analysis

Hydrocarbon (Fluid Type Delineation)

From resistivity log, fluid type was delineated and hydrocarbon was separated from water to decipher hydrocarbon water contact. The type of hydrocarbon was confirmed using Neutron-Density cross plot to validate the hydrocarbon type. The analysis confirmed the reservoir is a "gassy" reservoir, as seen from the established gas-water contact, validated by the bubble effect of the Neutron-Density (log) cross plot (Fig. 10).

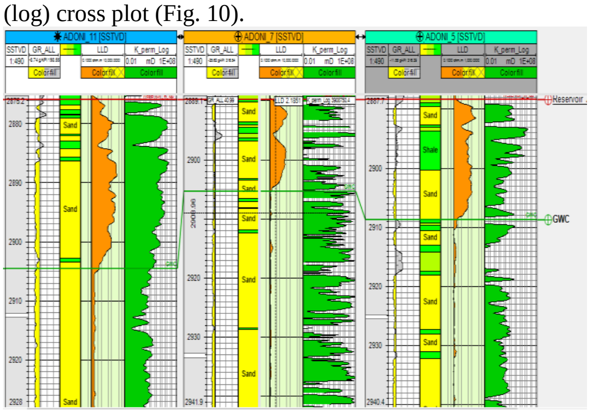

Fig. 10: Permeability log computed across wells

Estimation of Water/Hydrocarbon Saturation

Water Saturation computation was estimated by giving recourse to porosity log through which degree of hydrocarbon saturation was established. This was based on Archie's Equation as in the methodology.

The averaging system was established by leveraging on the net (pay) zone, in agreement with fluid type delineated from resistivity log; as well as hydrocarbon distribution plot through Neutron-Density cross-plot (Fig. 11)

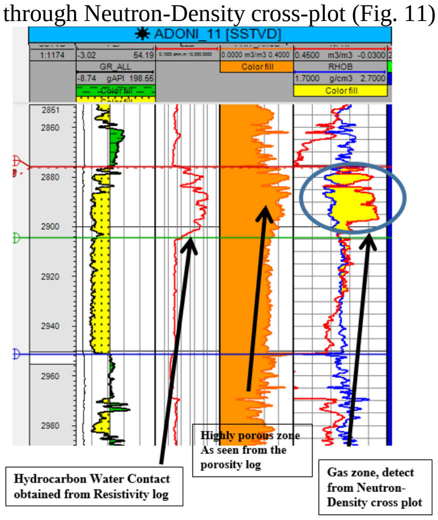

Fig 11: Hydrocarbon fluid type delineation for AD-11, Adoni Field.

Biostratigraphic analysis of Adoni 5 (Adoni Field)

On the basis of certain diagnostic Foraminifera and Ostracoda the following units have been identified.

Planktonic Foraminifera:

They are poorly represented in the whole interval. Only three units have been identified.

2070-2510 m: *Globigerina cf. acostaensis* and *Globigerinoides sacculifer* zone.

Age: probably Lower Miocene

2510-2670 m: *Globigerinoides primordius, Catapsydrax unicavus* zone

Age: basal Miocene (N4)

Some of the species are associated with the two guide ones: *Globigerinoides gr. trilobus, Globotoralia obesa,* but planktonic association is still very poor. Some species like *Chiloguembelina martini* are reworked from Eocene.

2670-2790 m: *Globigerina ciperoensis* zone

Age: Oligocene

G. ciperoensis is very scarce, but its occurrence agrees with the associated benthonic population.

2790-4122 m: Uncharacterized zone

Planktonic Foraminfera are very scarce and not characteristic enough to identify this zone.

Benthonic Foraminifera:

Five units based on benthonic Foraminifera are determined

2070-2355 m: *Miogypsinoides sp*. and *Uvigerina peregrina* zone

Age: lower Miocene

Some *Quinqueloculina sp*., *Nonion gr. boueanum, Eponides praecinctus, Haplophragmoides/Ammobaculites, Textularia mexicana. Baggina mexicana. Cibicidoides perlucidus* are associated with the two guide-species.

2355-2510 m: *Eponidopsis eschira* zone

Age: lower Miocene

E. eschira is associated with some other species. such *as Robulus americanus*. *R. sumatrensis*, *Cibicidoides lobatulus* and *Stilostomella sp*.

2510-2670 m: *Gavelinella beninensis* - *Brizalina* imperatrix zone

Age: basal Miocene

This interval can almost be identified by the abundance of *G. beninensis* and *Uvigerina sparsicostata*. They are associated with some other species *Pseudoglandulina laevigata, Reophax sp., Bathysiphon sp., Gyroidina sp., Eponides umbonatus, Sphaeroidina bulloides, Lenticulina sp*.

2670-3060 m: *Eponides umbonatus multiseptus - Nonion centrosulcatum* zone

Age: Oligocene

In this interval, as in the upper one, *G. beninensis, U. sparsicostata and B.* imperatrix are still abundant associated with few *Uvigerinella subfusiformis*.

3060-4122 m: *Wheelerella osazae - Hopkinsina sp*. Zone

Age: Oligocene

Gavelinella beninensis is still abundant, some species occur: *Haplophragmoides carina tum, Cassidulina sp*. Ni 45 *C, Virgulina grandis, Baggina robusta* and *Bolivina striatellata.*

Ostracoda:

Three units have been identified

2070-2905 m: Ni T4 zone

Age: lower Miocene

The most important species encountered in this interval are *Thalmannia* Ni A1-A2, *Basslerites* Ni A 31, *togoina* Ni A 12 *Chryzocythere* Ni A 23 and *Paracypris* Ni A 28.

2905-3455 m: Ni T3? Zone

Age: Oligocene?

The occurrence of isolated species *Cytherelloidea* Ni B 33 and *Chryzocythere* Ni B 52 allow us to place the T3 zone at this interval

3455-4296 m: Ni T3

Age: Oligocene

The occurrence of *Togoina* Ni B 45 at 3455 m confirms the assignment of the Ni T3 zone**.**

Biostratigraphic analysis Sand A (Adoni Field) Assessment

Leveraging on biostratigraphic data made available in the South Eastern section of the field (Adoni-5), having been depth matched (Fig. 13) with corresponding wireline logs in order to calibrate them for quality assurance for the purpose of paleo-bathymetry and relative age interpretation, two (2) zones of interest were delineated with respect to depth interval of 2670 m to 4122 m for planktonic foraminifera which encompassed Reservoir A sand (whose gross reservoir top and base are respectively 2888 m and 2948 m at Adoni-5 point). Findings showed the First Downhole Occurrence (FDO) of planktonic (calcareous) Foraminifera named Globigerina ciperoensis, which corresponds to Last Appearance Depth (LAD), 2670m while its corresponding Last Downhole Occurrence (LDO) i.e. First Appearance Depth (FAD) corresponds to 2790m. This first unit/zone, was tagged Globigerina ciperoensis zone and was adjudged to be Oligocene in age. The second zone was characterised by scarce foraminifera, not adequate to identify as a zone and was tagged uncharacterised zone. This uncharacterised zone bed the Sand A reservoir. Two zone of interest for the benthonic foraminifera was also determined within the depth 2670 to 4122 m, The first unit was tagged Eponides umbonatus multiseptus - Nonion centrosulcatum zone (2670-3060 m) while the second unit was tagged Wheelerella osazae - Hopkinsina sp. Zone (3060-4122 m) and an Oligocene age was adjudged for both units. Three zone of interest for the ostracoda was identified from 2070 to 4296. The first unit which was from the depth of 2070-2905 m and was termed Ni T4 Zone with lower Miocene adjudged, the second unit which was from 2905-3455 m was tagged Ni T3? Zone, the third unit was from 3455-4296 m termed Ni T3 zone and an Oligocene age was adjudged. Adoni 5 has penetrated a series which can be assigned to lower Miocene at the top (2015/2070) to the Oligocene at 4122 m. Age of Sand A reservoir, (Adoni-5) is thus adjudged to be Oligocene in Age based on the microfossils identified. This claim is subject to further study, due to paucity of data (biostratigraphic data only limited to Adoni-5).

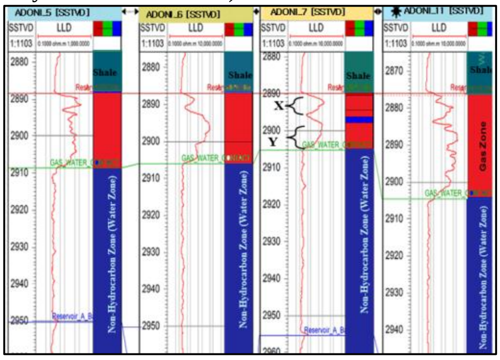

Fig. 12: Hydrocarbon fluid distribution plot across Sand A (Adoni field).

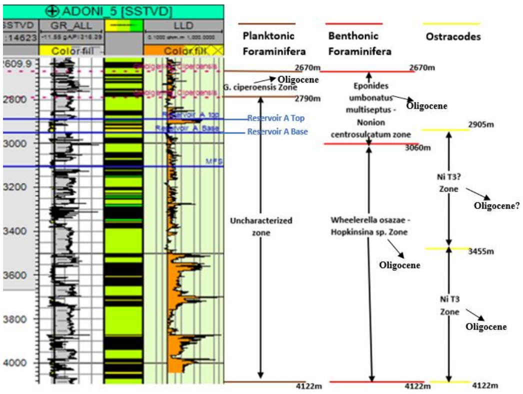

Fig. 13: Biostratigraphic analysis of Sand A at Adoni-5 (Adoni field).

Conclusion

Reservoir characterization of four wells (AD-5, AD-6, AD-7 & AD-11) in the Adoni field shows that the reservoir is mainly sand and shale characterized by alternating sequence. The hydrocarbon reservoir thickens to the South-Western direction and pinches out in the North-Eastern Direction.

The effective porosity and permeability values of the reservoir zone of interest range from 24 to 30 % and 2326.2 to 4123 mD respectively. These indicates very good to excellent reservoir with net pay thickness of about 28 m in the south-Western section of the field. Analysis of depositional environment on the basis of gamma ray log motif infers a channelized fluvio-detaic transitional environment. The microfossils such as Eponides Umbonatus multiseptus, Nonion centrosulcatum, Thalmania, Basslerites, Paracypris and Togoina sp. suggest the reservoir is of Oligocene in age and confirmed the penetrated sections in the Adoni field belongs to the Agbada Formation.

Based on the aforementioned findings, field development plan should give recourse to south western section, due to high degree of certainty with respect to high pay zones.

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