Sudan University of Sciences & Technology

College of Petroleum Engineering and Mining

Petroleum Exploration Department

Comparative study of Petrophysical Properties in Bentiu & Aradeiba Formations & Their implication to Reservoir Quality

دراسة للمقارنة الخصائص البتروفيزيائية في تكوين بانتو و عرديبة وتأثيرها علي جودة المكمن

A THESIS SUBNITTED IN PARTIAL FULFILMENT FOR DEGREE OF B.Sc. IN B-TECH EXPLORATION ENGINEERING

Prepared By:

1. Abuobaida Musa Ahmed
2. Ahmed Mohammed Abdalgader
3. Akram Mojahed Fadl Elseed

Supervised By:

T. Amro Yousof

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الإستهلال

أَعُوذُ بِٱللَّهِ مِنَ ٱلشَّيۡطَٰنِ ٱلرَّجِيمِ

بِسۡمِ ٱللَّهِ ٱلرَّحۡمَٰنِ ٱلرَّحِيمِ

﴿ ۞ ٱللَّهُ نُورُ ٱلسَّمَٰوَٰتِ وَٱلۡأَرۡضِۚ مَثَلُ نُورِهِۦ كَمِشۡكَوٰةٖ فِيهَا مِصۡبَاحٌۖ ٱلۡمِصۡبَاحُ فِي زُجَاجَةٍۖ
ٱلزُّجَاجَةُ كَأَنَّهَا كَوۡكَبٞ دُرِّيّٞ يُوقَدُ مِن شَجَرَةٖ مُّبَٰرَكَةٖ زَيۡتُونَةٖ لَّا شَرۡقِيَّةٖ وَلَا غَرۡبِيَّةٖ يَكَادُ زَيۡتُهَا
يُضِيٓءُ وَلَوۡ لَمۡ تَمۡسَسۡهُ نَارٞۚ نُّورٌ عَلَىٰ نُورٖۚ يَهۡدِي ٱللَّهُ لِنُورِهِۦ مَن يَشَآءُۚ وَيَضۡرِبُ ٱللَّهُ ٱلۡأَمۡثَٰلَ لِلنَّاسِۗ
وَٱللَّهُ بِكُلِّ شَيۡءٍ عَلِيمٞ ٣٥ ﴾

سورة النور الآية [35]

الإهداء

إلى من ساندتنى فى صلاتها و دعائها *** إلى ممن سهرت الليالى تنير دربى ***إلى من شاركتنى أفراحى و أحزانى ***إلى نبع العاطفه و الأمان***إلى أجمل إبتسامه فى حياتى (الجنه).

الى من كان لهم الفضل العظيم فى حياتى (عماتى).

الى من علمنى ان الدنيا كفاح***وسلاحها العلم والمعرفة***الى الذى لم يبخل على باى شئ ***إلى من سعى لأجل راحتى ونجاحى ***إلى اعظم وأعز رجل فى الكون (أبى)

إلى كل صديق وعزيز

اهدى هذا البحث المتواضع

الشكر والعرفان

قال رسول الله صلى الله عليه وسلم : (لا يشكرالله من لا يشكر الناس)

الحمدلله والشكر لله الذى يسر وسهل لنا طريقنا و أعاننا فى إكمال هذا البحث .

و الشكر و الفضل من بعد الله للأساتذه الأجلأ على وقوفهم بجانبنا فى إكمال مسيرتنا التعليميه و جزيل الشكر موجه للأستاذ الفاضل عمرو يوسف جزاه الله عنا كل خير على مساندته لنا وتقديم يد العون لنا بتفان و بلا هوادة .

ABSTRACT

In this study wire line logging data of exploration well Laloba AG-1 in Muglad basin were analyzed in order to discriminates between the petro-physical properties in Aradeiba & Bentiu formations and accordingly to identify the formation of better reservoir quality. The petro-physical properties used were: shale volume (V_{sh}), total & effective porosities (PhiT & PhiE) as well as water saturation (S_w). Aradeiba formation was found to be more enriched in shale as compared to Bentiu which is cleaner. The Vsh in Aradeiba range between (0.17) to (0.9) with average value of (0.65), while Bentiu has V_{sh} range between (0) to (1) with average value of (0.44). The net to gross ratio was found to be (0.63) to (0.74) in Aradeiba, while in Bentiu (0.67) to (0.46) net to gross range was observed. The average effective porosity in Aradeiba formation was (0.23), while in Bentiu it was found to be (0. 22).

The average water saturation in Aradeiba was found to be (0.8), while for Bentiu it averages about (0.89). The pay reservoir thickness in Aradeiba at zone one (1.83) and zone two (4.42) and in Bentiu at zone three (13.11), zone four (5.05) and zone five (4.42).

Accordingly, Bentiu formation was found to be of better reservoir quality and more prolific compared to Aradeiba.

التجريد

في هذه الدراسة تم تحليل بيانات التسجيل السلكي لبئر الاستكشـــاف Laloba AG-1 في حوض المجلد من أجل التمييز بين الخصائص البتروفيزيائية في تكــويني Aradeiba& Bentiu وبالتالي تحديد جودة أفضل تكوين. الخصائص البتروفيزيائية المستخدمة هي: حجم الطين (Vsh)، المسامية الكلية والفعالة (PhiT & PhiE) وكذلك تشــبع المـــاء (Sw). تـــم التوصل إلى أن تكوين Aradeiba أكثر وفره في حجم الطين بالمقارنة مع Bentiu الأكثـــر نظافة. يتراوح Vsh في Aradeiba بين (0.17−0.9) بمتوسط قيمة (0.65) ، بينما لـــدى Bentiu نطاق Vsh بين (0-1) بمتوسط قيمه (0.44) تم التوصل إلى أن النسبة الصافية إلى الإجمالية لتكون(0.63−0.74) في Aradeiba، بينمـــا فـــي Bentiu (0.4- 0.67) لـــوحظ صافي إلى النطاق الإجمالي. كان متوسط المسامية الفعالة في تكـــوين Aradeiba (0.23)، بينما وجد في Bentiu أنه (0.22)، تم التوصل إلى أن متوسط تشبع الماء فـــي Aradeiba ليكون (0.8)، بينما بالنسبة لبنتيو وجد أن متوسطه حوالي (0.89) تتراوح ســـماكة (pay reservoir) في Aradeiba فـــي zone one (1.83) وفـــي zone two (4.42) وفـــي Bentiu في zone three (13.11) و في zone four (5.03) وفي zone five (4.42).
وفقًا لذلك، وجد أن تكوين بانتيو يتمتع بجودة مكمن أفضل وأكثر وفرة مقارنةً بعرديبه.

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ABBREVIATIONS

G_R =Gamma ray, API.

I_{GR}=Gamma ray index.

K = permeability(mD).

Φ = Formation porosity, (v/v).

S_W = Water saturation.

SP = spontaneous potential.

SSP = static spontaneous potential.

PSP = psedu-static spontaneous potential.

R_w = Formation water resistivity, ohms-meter.

R_t = Formation resistivity, ohms-meter.

G_{NT} = The Gamma Ray/Neutron Tool.

SNP = The Sidewall Neutron Porosity Tool.

CNL = The Compensated Neutron Log.

Δt = Interval transit time.

R_{mf} = mud filtrate resistivity.

R_{xo} = flushed zone resistivity.

DLL = dual laterolog tool.

V_{sh} = shale volume.

Φ_D = Density porossity.

Φ_{Dsh} = Density porosity in shale formations.

Φ_e = Effective porosity.

Φ_n = Neutron porosity.

Φ_{Nsh} = Neutron porosity in shale formations.

CHAPTER ONE

INTRODUCTION

1.1 Overview:

Well logging is the technique of making petrophysical measurement in the sub-surface earth formation through the drilled borehole in the order to determine both the physical and chemical properties of rocks and the fluids they contain.

Logging, electro logging or well logging means continues recording of a physical parameter of the formation with depth.

Well logging measurement are carried out through the drilled borehole and measurement are recorded either in an open hole(and uses logs are Density, SP, Resistivity, neutron, acoustic, GR, Caliper, etc) or a cased hole (VDL, CBL, etc).

Formation Evaluation is the process of using borehole measurements to evaluate the characteristics of the subsurface formations. It is ultimate objective is the identification and evaluation of commercial hydrocarbon-bearing formations.

1.1.1 Why we use Well Logs?

1. Simple and economic method of acquiring reservoir information.
2. Continuous and accurate measurements.
3. Recognize depositional environments or other geologic features.
4. Detection and estimation of the potential of hydrocarbon zones.

1.2 Problem statement

We have two formations Aradeiba and Bentiu and we went to know both hydrocarbon potentiality and quality of the reservoir (porosity, permeability, water saturation and volume of shale) and we are use well logs information to evaluate the formation and hydrocarbon.

1.3 Objectives

1. Lithology identification of subsurface formations.
2. Quantification of the shale volume (V_{sh}).
3. Evaluation of the formation porosity (Total & Effective).
4. Evaluative of the hydrocarbon reservoir saturation for the target layers.
5. To evaluate the reservoir quality (phi/permeability).
6. Establish a comparison between the petrophysical properties in Aradeiba & Bentiu formation.

1.4 Geological setting of study area: (Muglad Basin)

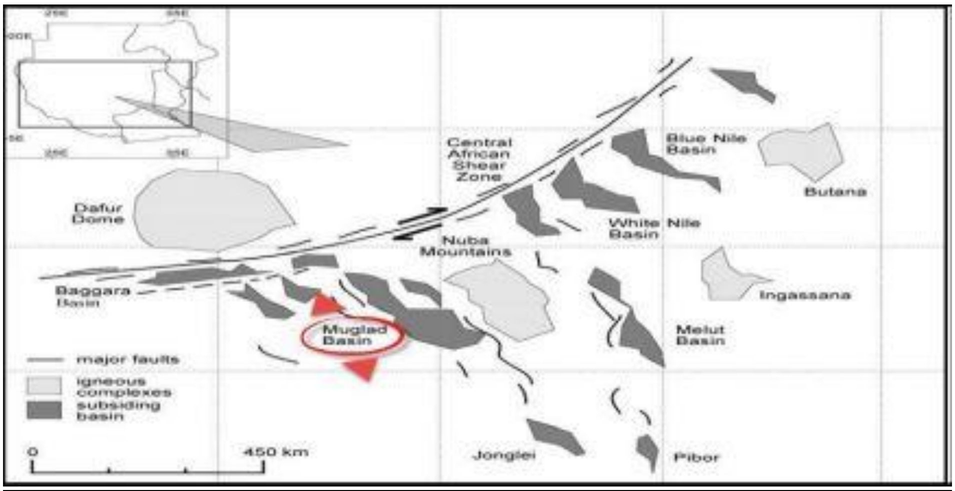

Fig. (1. 1) Shows the area of study in the Muglad Basin, Sudan and the main oil fields discovered

1.4.1 General

The published work in the Muglad Basin is mostly regional, relating to general aspects of the petroleum geology of the interior Sudan basins. However an Atlas of the Unity field was published by Giedt (1990) following work by Schull (1988).

McHargue et al. (1992) focussed on the tectonostratigraphy and development of the basin. They showed that the sedimentary sequence formed as a result of three rifting phases, each followed by a period of thermal subsidence.

Mann (1989) reported on the structural styles of the graben system, the type of faults and their detachment.

In general, two fault trends are noticed. The southern part is bounded by major northwest-southeast faults and includes the Sharaf-Abu Gabra Ridge.

1.4.2 Stratigraphy

Three continental sedimentary depositional cycles are defined by three rifting episodes which occurred in the Early Cretaceous (140-90 Ma), Late Cretaceous and Lower Tertiary (90-60), and the Tertiary to recent respectively. Of the 28 oil exploratory wells drilled, only three penetrated the top basement. Thermal history and hydrocarbon generation studies in the southern part of the Muglad Basin (Mohamed et al., 1999, 2000), showed relatively high heat flow during the three rifting.

1.4.3 Sharaf-Abu Gabra formations

During the Late Jurassic?-Early Cretaceous period, rifting occurred and resulted in deposition of continental fluvial-lacustrine deposits. These sediments are known as the Neocomian-Barremian Sharaf for- mation and the Aptian-Albian Abu Gabra formation and contain the main known potential hydrocarbon source rocks (Fig. 1.2). The Abu Gabra formation is mainly consists of lacustrine shales (e.g. Abanus-1). However in some localities (e.g. Hiba Sub-basin) the sediments are sandy, reflecting lake margin deposition.

1.4.4 Bentiu formation

Which the Bentiu sands were deposited, being derived from the upliftedThe end of the Albian is marked by a break in basin development, during basin flanks. The Bentiu formation consists mainly of massive sands with some claystone interbeds deposited in an alluvial environment. The top of the Bentiu formation is marked by an unconformity. The duration of deposition was short (7 Ma) but the section is thick in most of the deep areas and reflects a high sedimentation rate (Fig. 1.2). The Bentiu formation consists mainly of massive sands with some clay stone interbeds deposited in an alluvial environment. The top of the Bentiu formation is marked by an unconformity

1.4.5 Darfur group

During the second rifting phase (Late Cretaceous- Early Tertiary), uplift occurred. This resulted in the deposition sediments. The sediments of the Darfur group consist mainly of shales and siltstones in the Aradeiba and Zarga formations and sandstones with thin beds of claystones in the Ghazal and Baraka formations.

1.4.6 Kordofan group

The Kordofan group was deposited during the Tertiary rift phase (60 Ma-recent), and consists of the Nayil, Tendi, Adok and Zaraf formations. The Nayil, Tendi and Adok formations form the syn-rift sedimentary section of Cycle 3 and consist mainly of shales with sandstone interbeds.

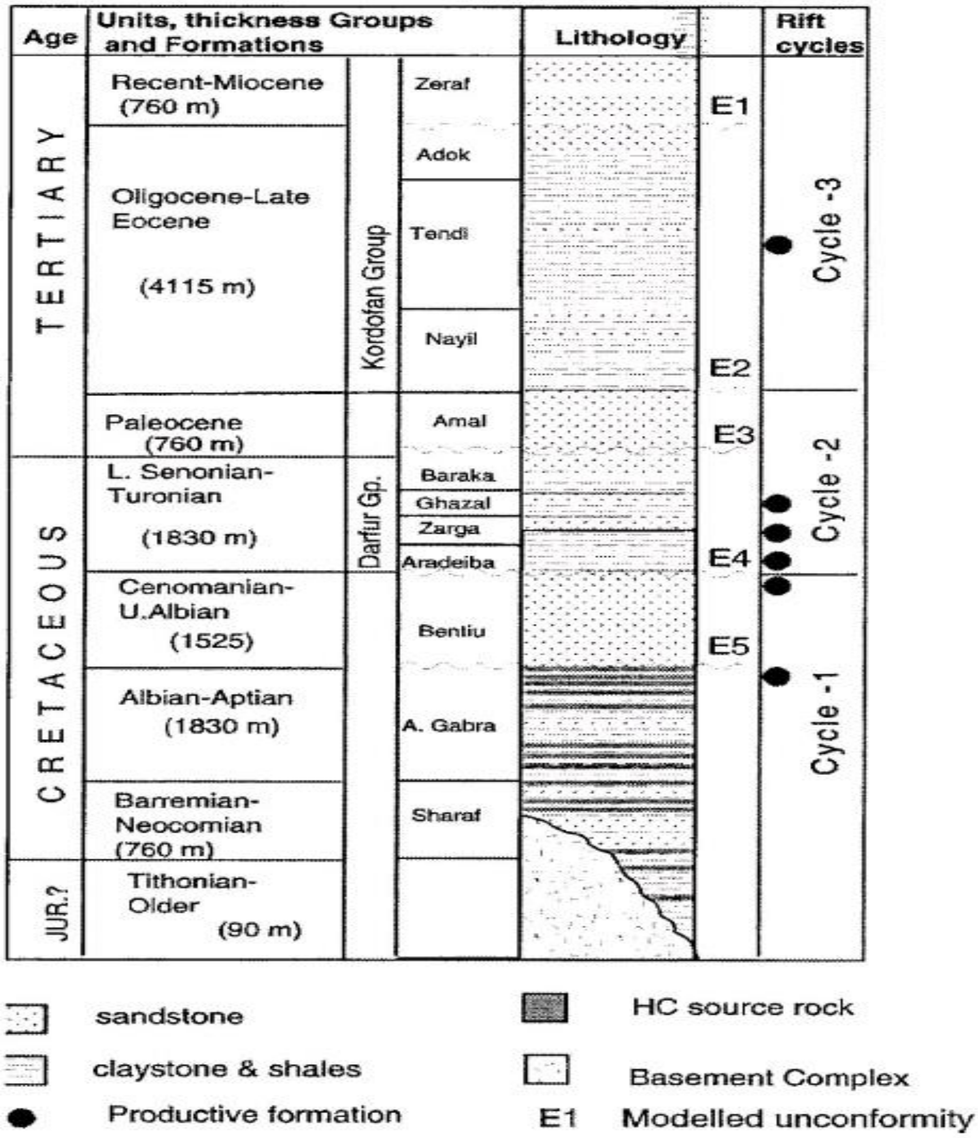

Fig. (1. 2) The main stratigraphic column of the Muglad Basin with the depositional cycles (adapted from Schull (1988), Kaska (1989) and Giedt (1990))

1.4.7 Laloba AG-1

Laloba AG-1well is located within the Laloba field and is approximately 0.5km away from Laloba-2 well. The well is located 3km to the northeast of Heglig field and is producing oil from Pantu reservoir and to date 2 wells have been drilled. The primary objectives of this well are Abu Gabra sands.

The GNPOC Laloba AG-1 well was spudded in at 23:45 on August 20, 2007 by Great Wall Drilling Company Rig 73.

1.5 Literature Review:

In June 2005 Maura Patricia Segunda Gimbe conducted a study about ormenlange field and the aim of the study was to do the formation evaluation using petrophysical parameters from wireline logs in order to determine lithology, porosity, permeability and fluid saturation and to understand the importance of the uncertainty analysis on reservoir permeability and predict gas recovery. In this work, Techlog software was used to computation of petrophysical properties and computed average of shale volume, porosity and water saturation are used to determine the reservoir interval pay zone. The permeability computation uncertainty analysis presented in this paper was done by using Monte-Carlo simulation that allowed understanding the relative weight and the gas recovery was predicted based on porosity, saturation and net productive thickness average of all the given wells. The determination of lithology based on cross-plot neutron versus density log the quality of the reservoir as determined by permeability is good with permeability value around 45, 135 mD and by porosity was very good values between 24 to 30 percent. In general by plotting porosity values against permeability values showed strong linear relationship between the two variables of the reservoir indicating that Ormen Lange field reservoir are permeable and it should be noted that the presence of shale in the entire reservoir influenced negatively in the permeability values. The petrophysical properties of the reservoir in Ormen Lange field are enough to permit hydrocarbon production.

In 2013, Studied by sanaz Javid 39 thin sections and petrophysical log data from the Skalle well in the Hammerfest Basin, in the southwestern part of the Barents Sea , have been studied to interpret lithology , and dingenesis and their effect on the reservoir quality , and to compare reservoir properties of the different reservoir units . Petrophysical log data have been calibrated for reservoir description in cases where core material is not available.The studied formations are comprised by the Stø, Fuglen, Hekkingen, Knurr, Kolje and the Lower Kolmule Formations. All the formations are water filled which is reflected by the low resistivity logs.

Fadiya, Alao and Adetuwo also condected study about an effect in reservoir rocks is one of the most controversial problems in formation evaluation. The presence of highly-radioactive material in shaly sand reservoirs, overestimates the shale volume producing an overall pessimistic scenario of the reservoir quality. An accurate determination of shale volume impacts in the calculation of formation porosity and water saturation and therefore affects the original oil in place and reserves. This paper presents a comprehensive approach for handling this problem of radioactive shaly sand reservoirs. A combination method is provided to calculate the accurate value of shale volume for different scenarios from different shale volume computation methods. The study concluded that the combination method was the most reliable for estimating shale volume which fall within the acceptable range. It also concluded that the Clavier method was most reliable in oil bearing radioactive reservoirs while the resistivity method was most reliable in estimating shale volume in gas bearing radioactive reservoirs.

In 2018 Fozao, Ndeh and Zebaze also conduted study about Shales in the reservoir, shales in the reservoir causes complications for the petrophysicist because they generally are conductive and mask the high resistance characteristic of hydrocarbons. Data from a suite of well logs were used to estimate the effect of reservoir shaliness on petrophysical parameters of some reservoir rocks of the eastern Niger Delta Basin. The log section was digitized using Neuralog software. Delineation of the productive clean and dirty formations, as well as mapping of the fluid contents of the possible reservoir zones was carried out using Interactive Petrophysics software. Fifteen shaly sand bodies were identified. It was observed that, shale correction leads to a significant change in petrophysical parameters. The results obtained indicate that, the Simandoux and Indonesian models used for the study are both suitable for water saturation, and hydrocarbon saturation analysis in shaly sands of this part of the Basin. The porosity results for the Indonesian and Simandoux models gave, respectively 0.14-0.23.

CHAPTER TWO

THEORY & METHODOLOGY

Theory

2.1 Permeability logs:

2.1.1 Caliperlog

The Caliper Log is a tool for measuring the diameter and shape of a borehole. It uses a tool which has 2, 4, or more extendable arms. The arms can move in and out as the tool is withdrawn from the borehole, and them movement is converted into an electrical signal by arm potentiometer.

Fig. (2. 1) Caliper tools

2.1.2 GR LOG

The Gamma ray (GR) is a measurement of the natural radioactivity of the formation, that originate from three main elements in nature: Uranium 235, uranium 238, and thorium 232, and potassium (K-40).

The simple GR log gives the radioactivity of the three elements combined, while the Spectral GR log shows the amount of each individual element contributing to this radioactivity.

Clays and shales are usually more rich in radioactive material than other sedimentary rocks and are, therefore more radioactive. However, all that is radioactive is not necessarily shale.

Fig. (2. 2) GR Tool

2.1.3 SP log

SP log records the naturally occurring potential differences or self-potential between a movable electrode in the borehole and a fixed reference electrode at the surface.

The SP log is measured in millivolts (mv) and the scale is negative deflection to the left and positive to the right of the baseline.

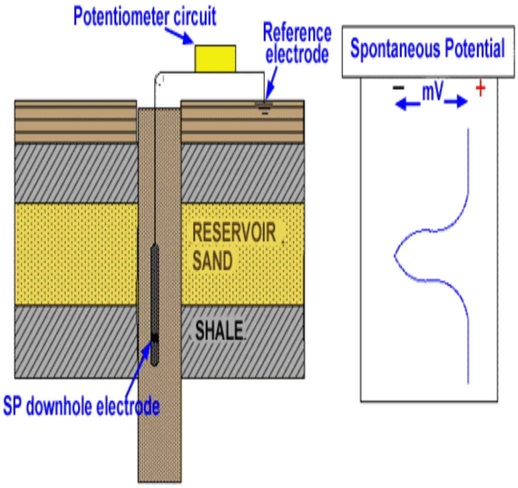

Fig. (2. 3) SP tool

2.2 Porosity log

2.2.1 DENSITY LOG

The density log is a continuous record of a formation's bulk density. This is the overall density of a rock including solid matrix and the fluids enclosed in the pores. It is being used widely as a primary indicator of porosity and in combination with other logs as a lithology indicator.

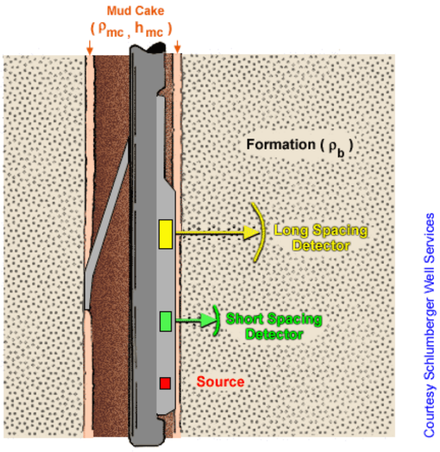

Fig. (2. 4) Density tool

2.2.2 NEUTRON LOG

The neutron log provide a continuous record of a formation's reaction to a fast neutron bombardment.

This reaction depends mainly on the amount of the hydrogen in the pore spaces (Hydrogen Index) and therefore is used as porosity measurement tool.

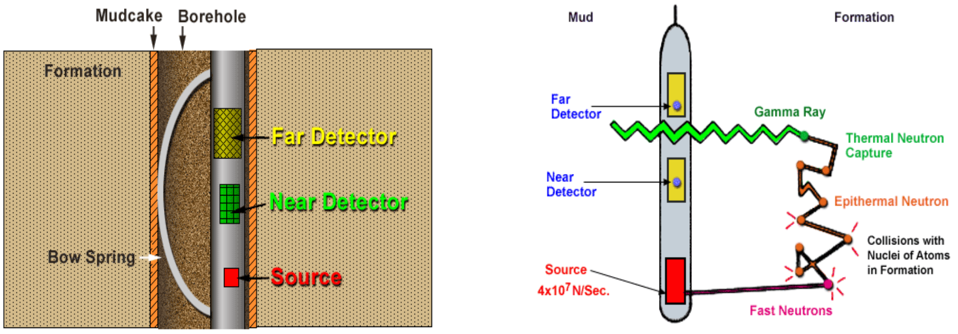

Fig. (2. 5) neutron logging tool

2.2.4 Sonic log

The sonic log is a porosity log that measures interval transit time (Δt) of a compressional sound wave traveling through a unit length of the formation. The interval transit time is a measure of the formation’s capacity to transmit sound waves which is controlled by the lithology and porosity of the formation.

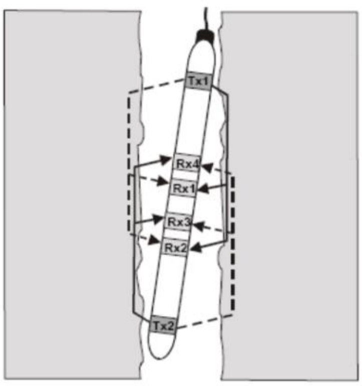

Fig. (2. 6) Borehole-Compensated sonic tool (BHC).

2.3 Resistivity log

The whole of resistivity logging is based upon a few very important equations. The equations, which are known as the Archie Equations, relate the resistivity of a formation to the resistivity of the fluids saturating a formation, the porosity of the formation and the fractional degree of saturation of each fluid present. As always, the story begins with Ohm's Law.

Ohm's Law states that the current flowing from point A to point B in a conductor I is proportional to the difference in electrical potential DE between point A and point B. The constant of proportionality is called the electrical conductance c. Current is measured in amperes (A), potential difference in volts (V), and conductance in siemens (S).

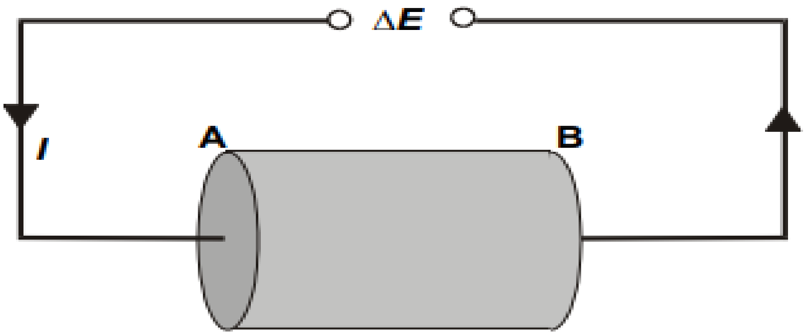

Fig. (2. 7) Ohm's Law for a rock sample

2.3.1 Focusing Electrode devices

These resistivity tools use focusing currents to control the path taken by the measure current.

These currents are emitted from special electrodes on the sondes.

The focused family of tools is designed for accurate Rt determination where:

1. R_t/R_m ratios are large.
2. Beds are resistive or thin.
3. Drilling muds are salty and conductive (where the ratio Rmf/Rw< 4).
4. Large adjacent-bed resistivity contrasts.

The focusing electrode tools include:

1- The laterolog.

2- SFL* spherically focused devices.

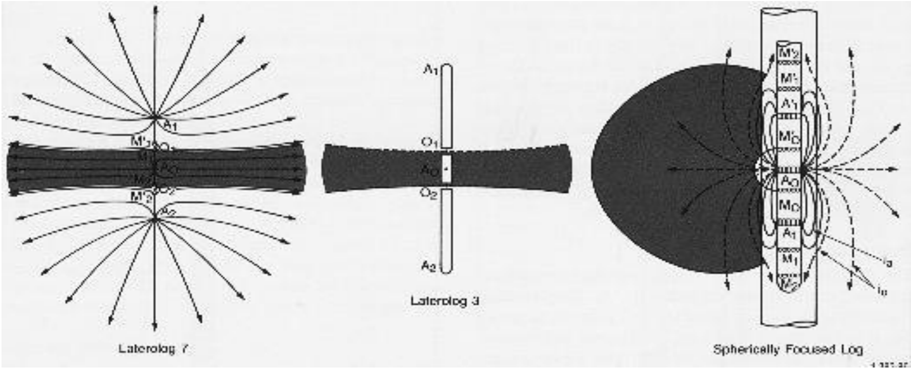

Fig. (2. 8) Focusing Electrode devices

Focusing electrode systems are available with deep, medium, and shallow depths of investigation.

Devices using this principle have a quantitative applications in determination of R_t, R_{xo} and diameter of invasion.

The deep-reading devices include the Laterolog 7, the Laterolog 3, and the deep laterolog of the DLL* dual laterolog tool.

The medium- to shallow-reading devices, all integral with combination tools, are the Laterolog 8 of the DIL* dual induction-laterolog tool, the shallow laterolog& MSFL of the DLL tool, and the SFL of the ISF and DIL-SFL combinations.

2.4 Methodology:

2.4.1 Data Availability:

The data used to accomplish this work comprises master log & slam log run of an exploration well taken from Laloba oil field. The master log was used and we took the LAS file, it include GR log, caliper, bit size, SP, N-D, sonic, resistivity (shallow, deep and medium).

2.4.2 Workflow:

In this study fig (2.9) show workflow

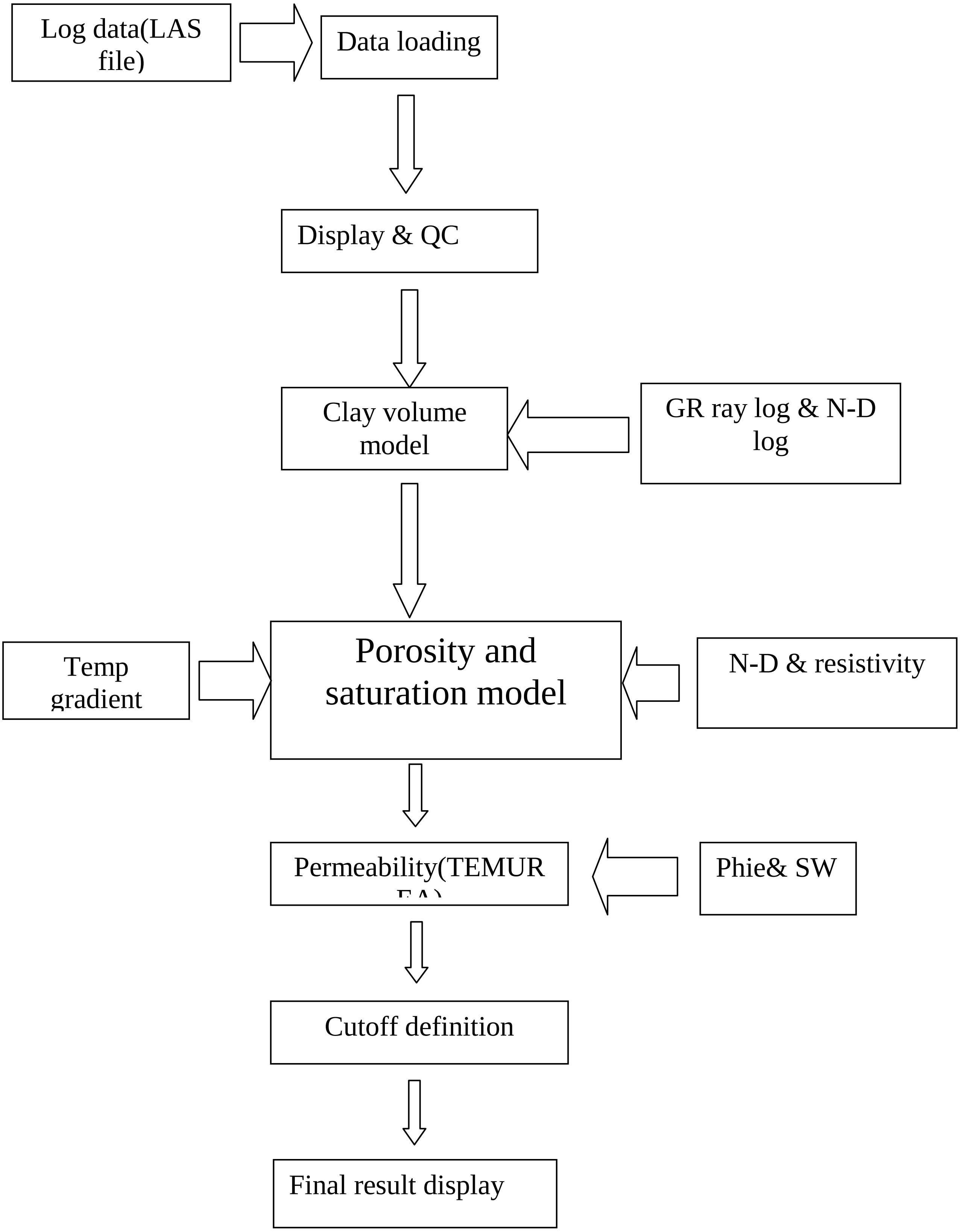

Fig. (2. 9) orkflow

2.4.3 Lithology Identification& Clay Quantification

One of the main application of the density log is to determinate the porosity. In addition, when used in combination with neutron porosity, it is used to determine the lithology.

Knowing how much clay is in the system is important because it tends to have a disproportionate influence on the petrophysical properties.

In the summaries computation module the average of the shale volume, porosity and water saturation was computed in order to define the reservoir interval zone.

GR log along with Neutron-Density (cross plot/overlay) were the primary source of data for lithology recognition & clay volume calculation.

2.4.3.1 Master log

The master log was used to identify the distribution of clay and sand in the formation. Although less accurate and representative for the actual lithology, master log was used for verification and cross check for the lithology interpretation result.

2.4.3.2 GR log:

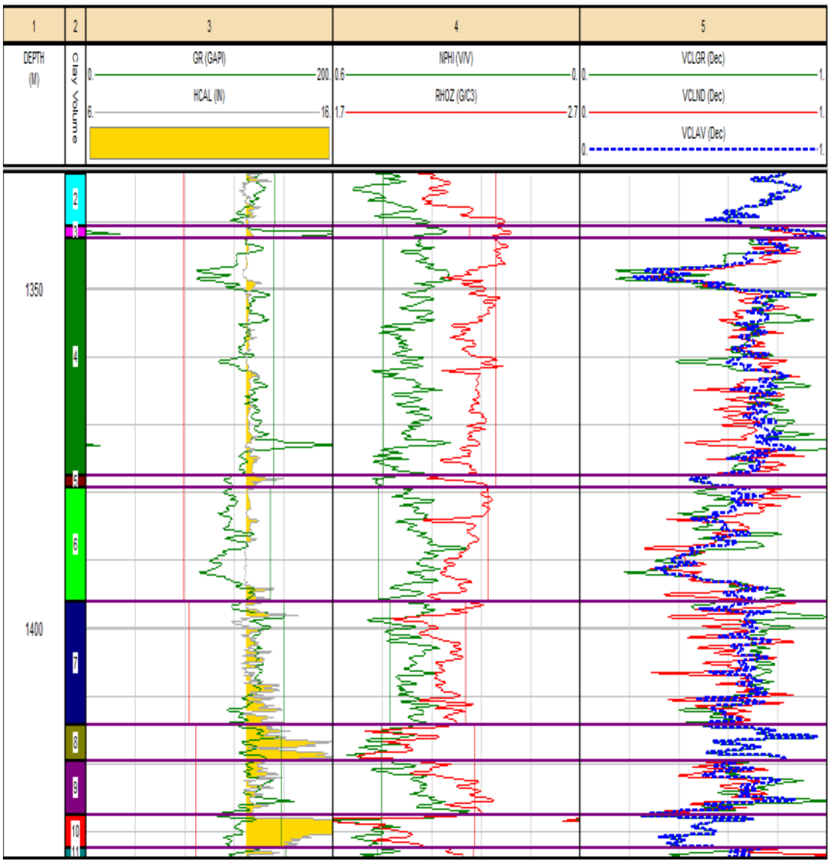

Fig. (2. 10) GR log response

G_R log was used as main shale volume indicator, since G_R can differentiate shale from sand. Based on G_R log, V_{sh} was calculated the following equation:

$$I_{GR} = \left[\frac{GR_{\log} - GR_{min}}{GR_{max} - GR_{min}}\right] \qquad Eq.(2-1)$$

Where,

I_{GR} = gamma ray index

GR_{log} = gamma ray log reading of formation

GR_{min} = minimum gamma ray(clean sand)

GR_{max} = maximumgamma ray(shale)

Linear approach was utilized for shale volume quantification:

$V_{sh} = I_{GR}$

V_{sh} is calculated in IP software using Clay volume module by identifying GR_{min} & GR_{max} Fig. (1.11). Histograms were also used to better locate GR_{min} & GR_{max}. Fig. (2.12) GR log response

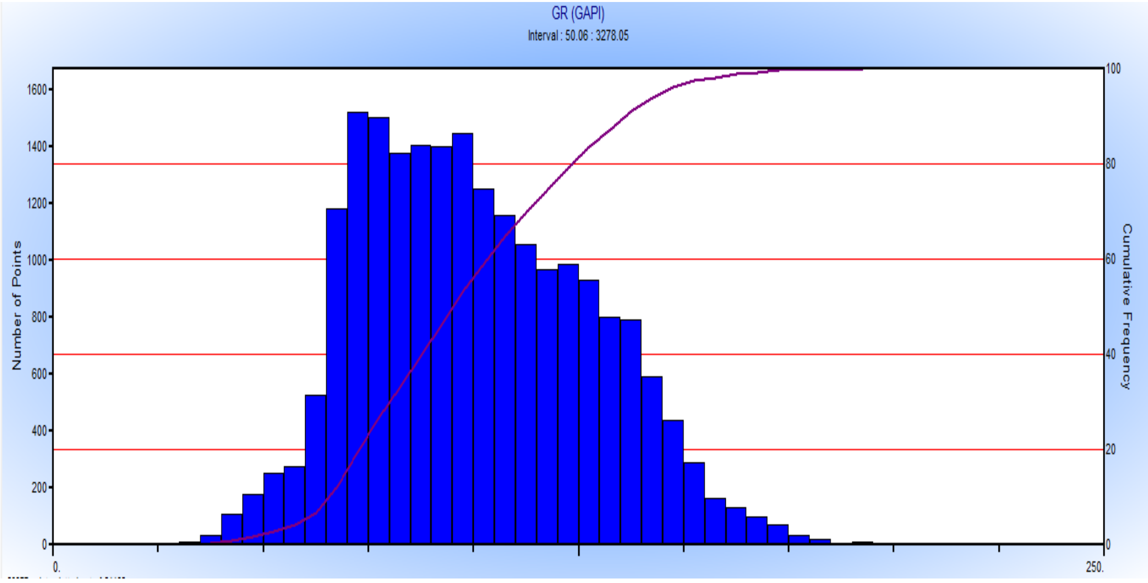

Fig. (2. 11) GR histogram

2.4.3.3 Neutron - density combination

The Neutron & Density porosities responses can be combined together to obtain a reliable estimate of the effective porosity and shale volume.

$$\varphi_D = \varphi_e + V_{sh}(\varphi_D)_{sh} \qquad Eq.(2-2)$$

$$\varphi_N = \varphi_e + V_{sh}(\varphi_N)_{sh} \qquad Eq.(2-3)$$

$$\varphi_e = \left(\frac{\varphi_D + \varphi_N}{2}\right) - V_{sh}\left[\frac{(\varphi_D)_{sh} + (\varphi_N)_{sh}}{2}\right] \qquad Eq.(2-4)$$

$$V_{sh} = \left(\frac{\varphi_D - \varphi_N}{(\varphi_D)_{sh} + (\varphi_N)_{sh}}\right) \qquad Eq.(2-5)$$

•The two equations can be solved for φe and Vsh provided that the pure shale zone can be identified (e.g using GR) for obtaining density and neutron shale porosities [(φD)sh& (φN)sh]. Shaly formation is chosen to be thick enough to be resolved and is not suffering frombad-hole.It also should be genetically related to the reservoir rock.

A correlation can be established between Vsh obtained this method and IGR obtained from GR.

Where,

φ_D = Density porosity in sand

φ_N = Neutron porosity in

V_{sh}= volume of shale

$(\varphi_D)_{sh}$ = Density porosity in adjacent shale

$(\varphi_N)_{sh}$ = Neutron porosity in adjacent shale

Φ_e = Effective porosity

For determining porosity & shale from volume Neutron – density porosity cross-plot is established using linear graph paper. Clean water-bearing sandstones will fall on the straight line of equal density and neutron porosity estimates. Gas-bearing sandstones would plot to the left of this line.

Neutron porosity of shaly zones always show higher neutron porosity and plot to the right of clean sand line. From the cross plot in a very shaly zone (determined using GR), one can establish a 100% shale point [(φD)sh& (φN)sh].

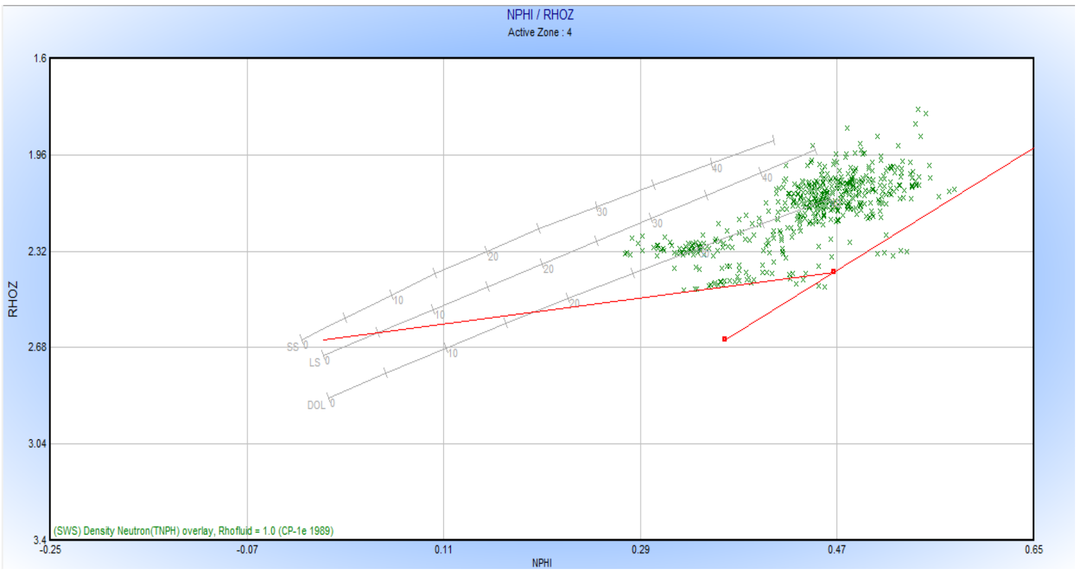

Fig. (2. 12) Neutron – density cross-plot

2.4.3.4 Temperature Gradient

The temperature gradient is calculated by input the surface temperature and the bottom hole temperature. A reference depth and temperature is also needed to be entered to give starting point for the temperature curve. The output curves are important and used in the interpretation models to make the correct temperature gradient.

$$Temprature\ Gradient = \frac{BHT - T_o}{DT} \qquad Eq.(2-6)$$

Where:

BHT = Bore hole temperature

T_o = Surface Temperature

DT = Total Depth

2.4.4 Porosity computation

Porosity is the fraction of the pore space that is not occupied by the rock matrix. Porosity is one of the key parameters used to estimate the initial hydrocarbon in place. Any wrong calculation in porosity can translate directly to an error in volume estimation (Anyaehie and Olanrewaju 2010). There are various types of porosity being recognized within the petroleum industry. Only two types are mainly considered in use, which are Effictive porosity and Total porosity.

Total porosity is defined as the fraction of the bulk volume of reservoir rock that is not occupied by fluid and Effictive porosity is defined as the total porosity subtracting clay bond water (Gimbe, 2015).

Neutron – density cross-plot was used to calculated effective and total porosity Fig (14).

2.4.5 Water saturation Evaluation

Indonesian modelwas first introduced by Poupon &Levaux (1971) to work with low salinity & high shaliness sandstone reservoirs in Indonesia where dispersed clay type is common. Oil was produced from low resistivity reservoirs.

In such models, the shale term appear to be clearly affected by hydrocarbon saturation.

In case of water saturated formations:

$$\frac{1}{R_o} = \frac{1}{FR_w} + 2 * \sqrt{\frac{V_{sh}^{(2-V_{sh})}}{FR_w\ R_{sh}}} + \frac{V_{sh}^{((2-V_{sh}))}}{R_{sh}} \qquad Eq.(2-7)$$

For hydrocarbon saturated formations:

$$\frac{1}{R_t} = \frac{1}{FR_w} * S_w^2 + 2 * \sqrt{\frac{V_{sh}^{(2-V_{sh})}}{FR_w\ R_{sh}}} * S_w^2 + \frac{V_{sh}^{(2-V_{sh})}}{R_{sh}} * S_w^2 \qquad Eq.(2-8)$$

2.4.5.1 Rw Determination

The pickettcrossplotis one of the simplest and most effective cross-plot methods in use.

This technique gives estimates of water saturation and can help in determine: Formation water resistivity, cementation factor and matrix parameters for porosity logs. Apickettcrossplot is developed by plotting porosity values with deep resistivity.

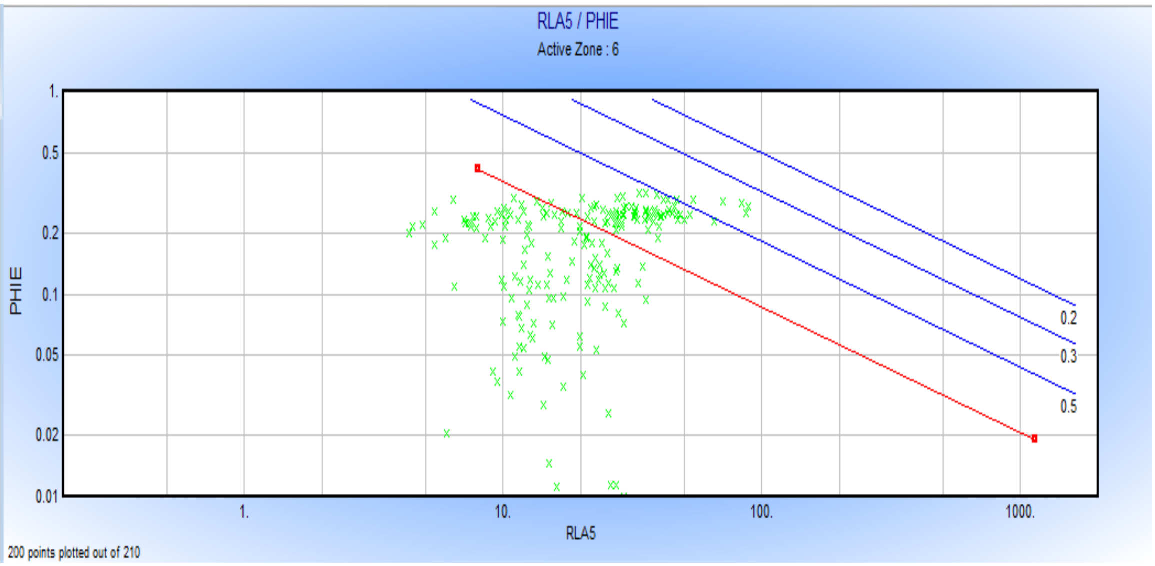

Fig. (2. 13) Pickett crossplot

The Rwa curve is presented in salinity track is another means for formation water resistivity dtermination employed in this study. In water saturation bearings zones,the archie equation for the uninvaded zone can be written as follows:

$$S_W = \sqrt{F * \left(R_W / R_t \right)} \qquad Eq. (2-9)$$

Or:

$$1.0 = F * \sqrt{\left(R_W / R_t \right)} \qquad Eq. (2-10)$$

Where

$S_w = 100\% \; or \; 1.0$

Next square both sides:

$$1.0 = F * \left(R_W / R_t \right) \qquad Eq. (2-11)$$

Now solve for R_W

$$R_{wa} = R_o / F \qquad Eq. (2-12)$$

Remember:

$$R_t = R_o \qquad when \qquad S_W = 100\%$$

Where:

S_W = water saturation of the un-invaded zone

R_W = resistivity of formation water at formation temperature

R_t = true formation resistivity ($R_t = R_o \;\; when \;\; S_W = 100\%$)

F = formation factor ($a/\emptyset^m$)

F= $1/\emptyset^2$ Carbonates

F = $0.18/\emptyset^2$ Consolidated sands

F = $0.62/\emptyset^{2.15}$ un-consolidated sands

R_{wa} = apparent water resistivity ($R_{wa} = R_w in \; water - bearing \; zones$)

In water-bearing zones, the calculated Rwa value is equal to Rw, if hydrocarbons are present, Rt will be greater than Ro and Rwa will be greater than Rw, low Rwa values are recorded on the left hand side of the log, the Rwa curve will deflect to the left in wet zones and to the right in hydrocarbon-bearing zones.

2.4.5.2 Clay Resistivity:

Clay resistivity is one of the most important parameters affecting the calculated saturation using Indonesian model. Clay resistivity of the zone was chosen through the shaly interval and displayed on the resistivity track, Figure (2.14).

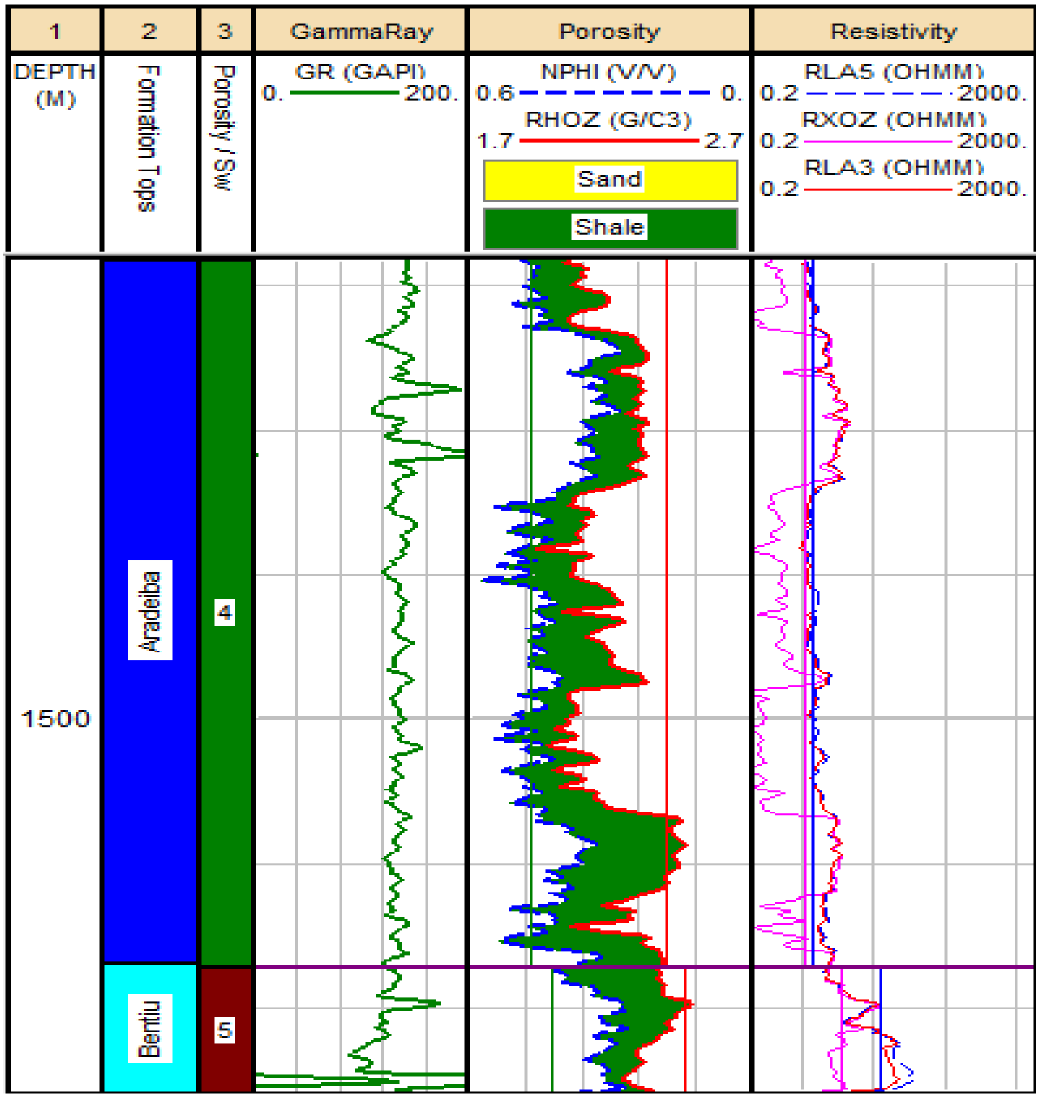

Fig. (2. 14) clay resistivity from log

2.4.5.3 Master log shows

Hydrocarbon shows as indicated by master log were used to calibrated the calculated water saturation since good to fair shows were expected to give very low water saturation, while poor to none shows were expected to give high water saturation, Fig. (2.15).

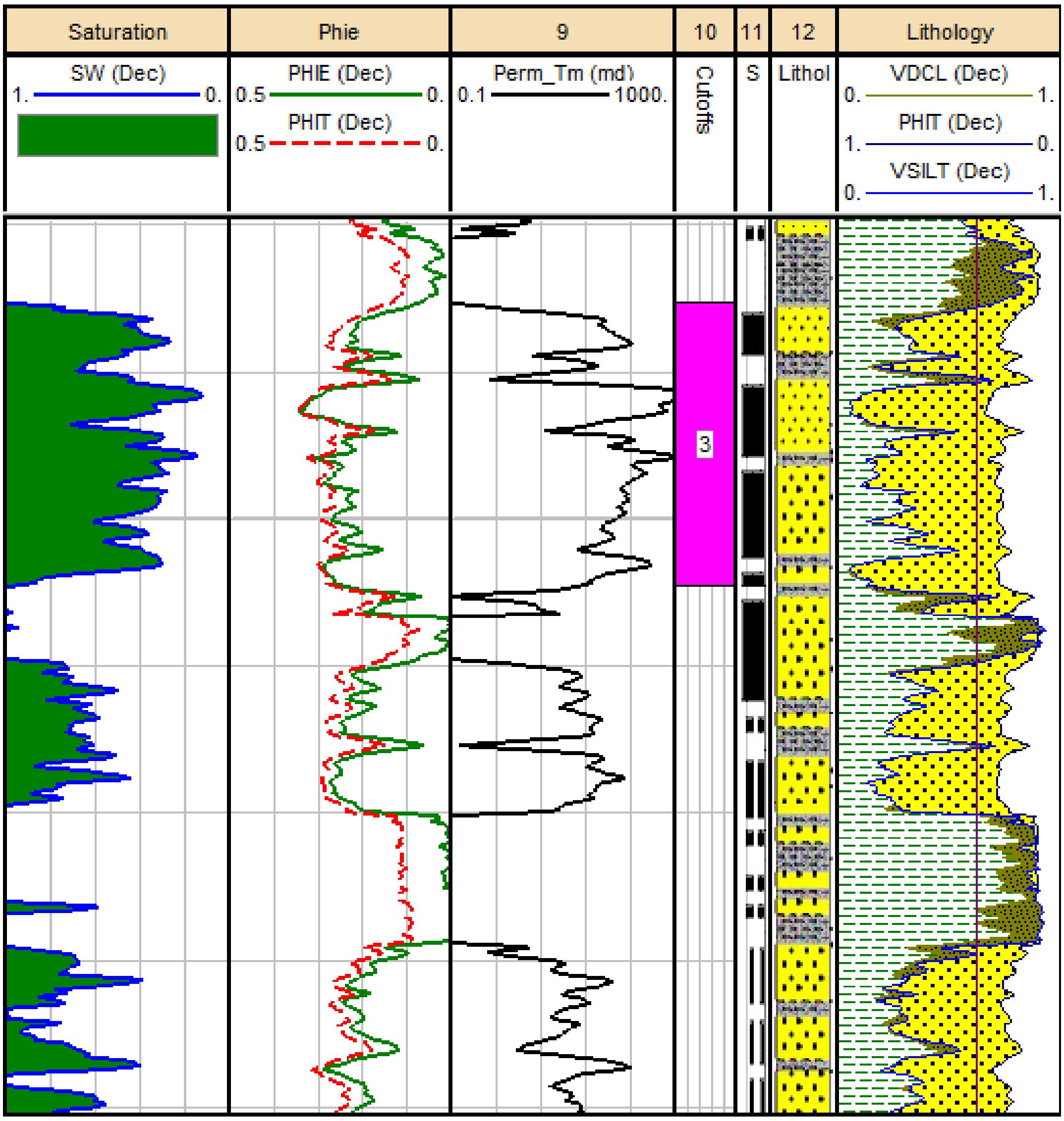

Fig. (2. 15) comparative between master log and log.

2.4.6 Cutoff Determination:

The cut-off module allows the user to interactively define (Net reservoir and Net pay) cut-off criteria and zones, and to calculate the average petrophysical properties of porosity, clay volume and water saturation for each zone within a petrophysical interpretation.

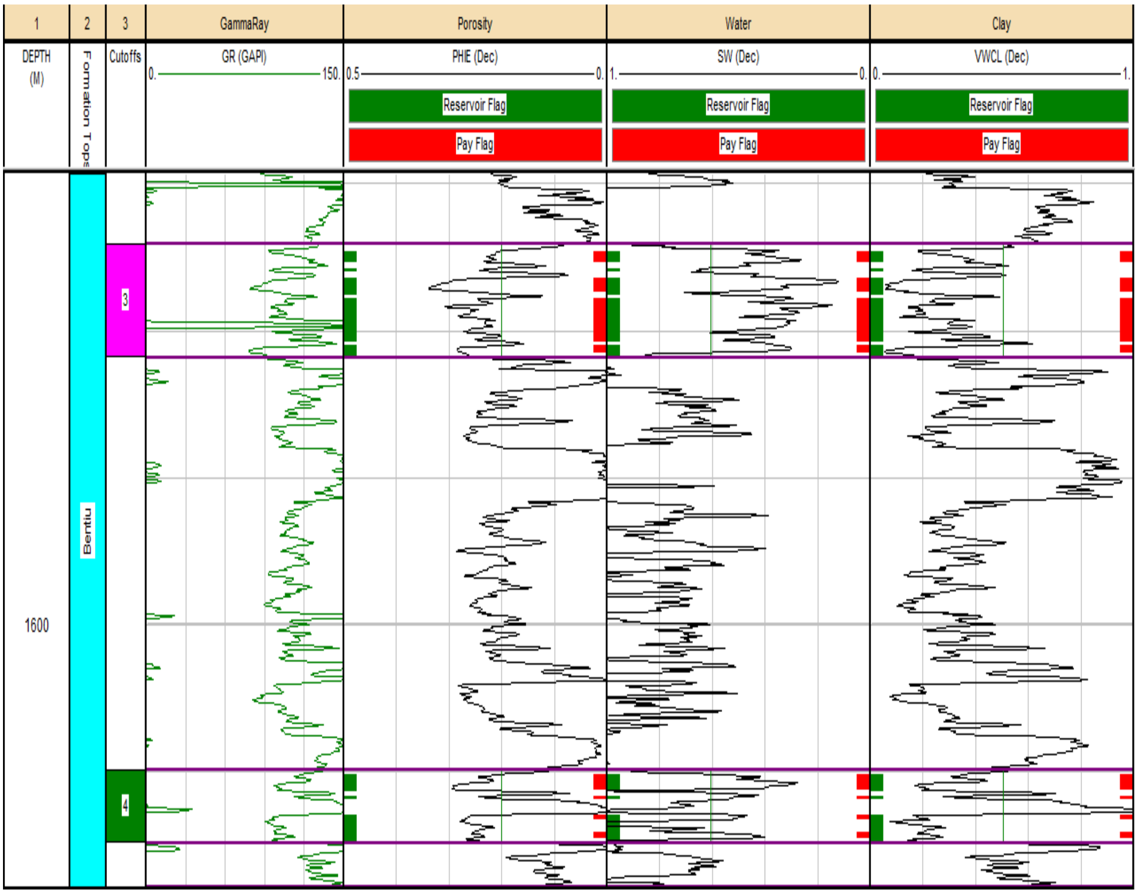

Fig. (2. 16) cutoff from log

2.4.7 Permeability determination

Permeability is also one of important parameters of a reservoir, which describes the ability of fluid flowing through the rock and is the main control factor on the reservoir production. However, none of the current well logging techniques can be used to measure it directly up to now.

In this work Timur equation was used for determination the permeability

As follow:

$$k = a.\frac{Phi^b}{Swi^c} \qquad Eq.(2-13)$$

a = 8581

b = 4.4

c = 2

Phi = effective porosity

Swi = irreducible water saturation

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 Lithology& Clay volume Interpretation

The shale volume was determined using GR log and the neutron versus density cross-plots. It represents the variation in shale or clay volume along the well track. The shale volume is simply used as a cut-off to define reservoir quality rock.

Neutron versus density cross-plot appear to be more reliable than GR log (if not severely affected by washout), because GR log sometimes reading high clean sandstones due. Presence of radioactive minerals unrelated to clay such as uranium& K-feldspar.

3.1.1 Aradeiba formation

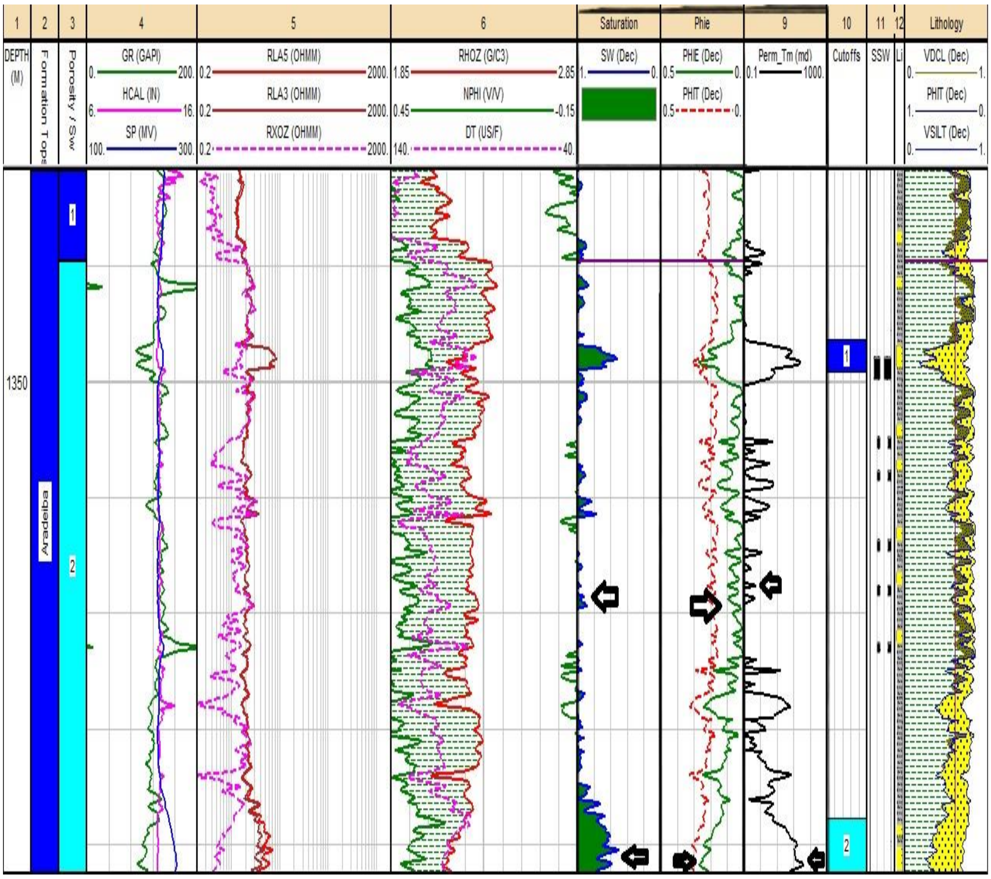

Fig. (3. 1) laloba Ag -1 Aradeiba result log

Fig (3.1) shows section from Aradeiba formation. The Aradeiba (depth: 1318-1518.m) Formation has high clay contents than sandstones. Clay average in Aradeiba (0.65). This fact is further verified with master log lithology which indicates dominant clay lithology.

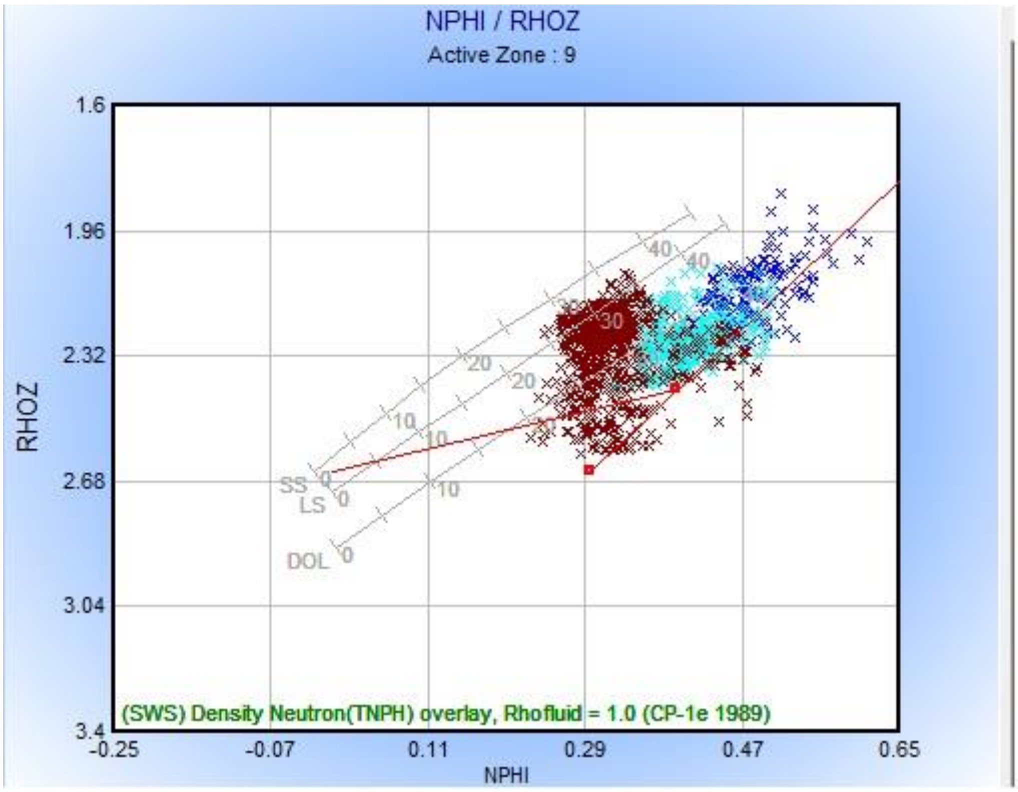

Fig. (3. 2) Neutron density cross-plot

3.1.2 Bentiu formation

Fig (3.3) shows section of Bentiu formation. The Bentiu Formation (depth: 1518-2440.m)

This is a relatively clean sandstone formation. This formation consists mainly of sandstones and clay interbeds. Clay average in Bentiu (0.44). again this is clearly reflected in the master log as shown in figure (21).

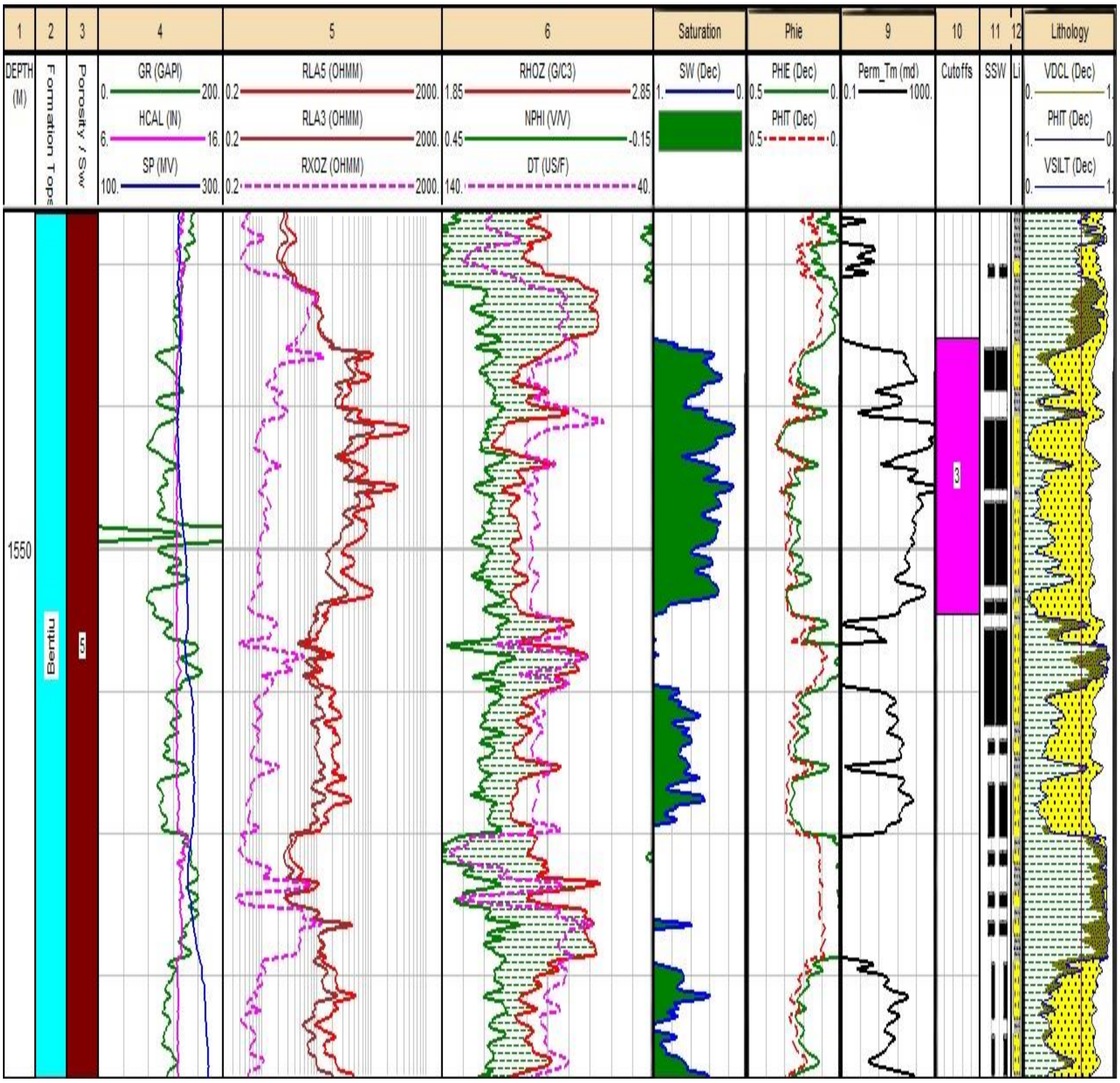

Fig. (3. 3) laloba AG -1 Bentiu result log

3.2 Porosity Estimation

Density curve and Neutron curve are used in this study. The clay mineral have an influence on neutron tools response by increasing the apparent neutron porosity, but their effect depends on clay mineral type available in the formation. In general, Aradeiba formation is characterized by less porosity as compared to Bentiu.

3.2.1 Aradeiba

The porosity histogram better resolve the porosity distribution across the zone shows the porosity distribution at value range of (0.2-0.27) as it shown in (Fig (3.4) after applying clay volume cutoff of 0.3.

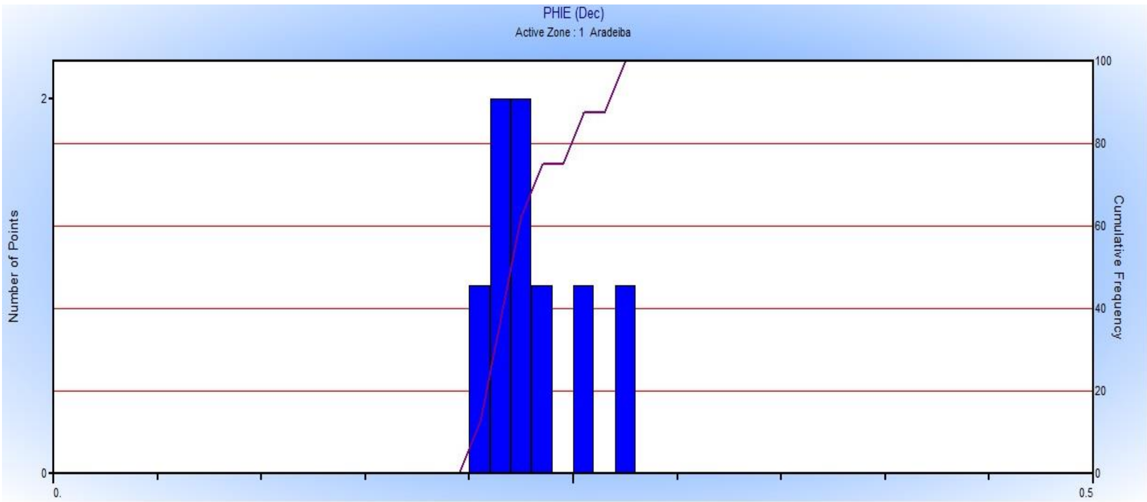

Fig. (3. 4) Effective porosity histogram for Bentiu formation

3.2.2 Bentiu formation

The porosity histogram across Bentiu shows thej porosity distribution at value range of (0.06 – 0.33) as it shows in (Fig (3.5) after applying clay volume cutoff of 0.2.

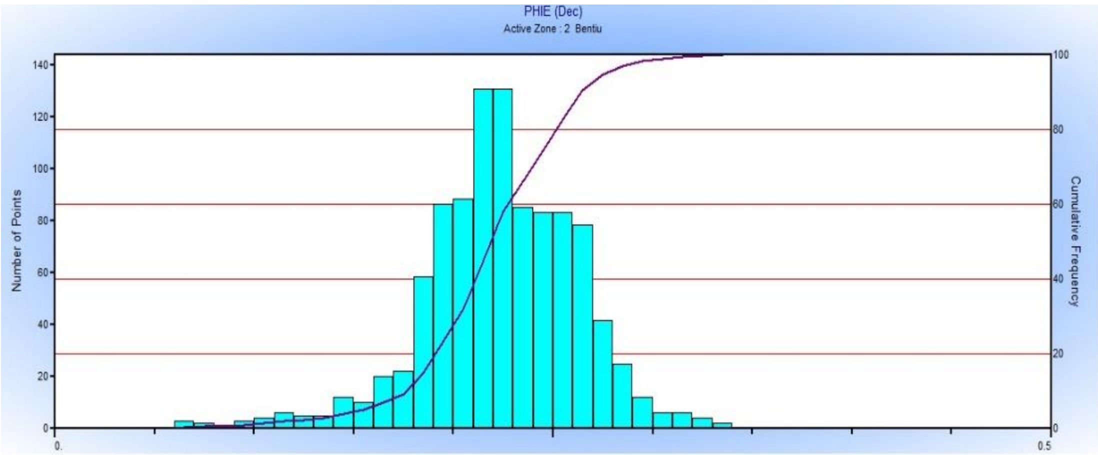

Fig. (3. 5) Effective porosity histogram for Bentiu formation

3.3 Permeability estimation

Presence clay minerals in the formation considerably reduce the permeability. Therefore, Aradeiba formation indicate again less permeability range compared to Bentiu which is cleaner more porous.

3.3.1 Aradeiba

Track 9 in Fig. (3.6) permeability values ranged 10 to 40 mD due presence clay minerals after applying clay cutoff of 0.3.

3.3.2 Bentiu

Track 9 in Fig. (3.6) permeability values ranged 0.04 to 380 mD indicating a very good reservoir quality after applying clay cutoff of 0.2.

3.4 Water saturation

In this study area, the sand units are considered as the reservoir units because shale is not porous and permeable enough to host, retain and release fluid. In the formation units described, the resistivity of hydrocarbon is higher than that of the formation water and hydrocarbon sand units were inferred from high resistivity values observed so the reservoir fluids (hydrocarbon and water) were distinguished by using the resistivity logs

3.4.1 Aradeiba formation

After applying cutoff Aradeiba have two zones and at zone one the value of s_w range of (0.4- 1) and zone two (0.5- 0.7). Fig (3.6)

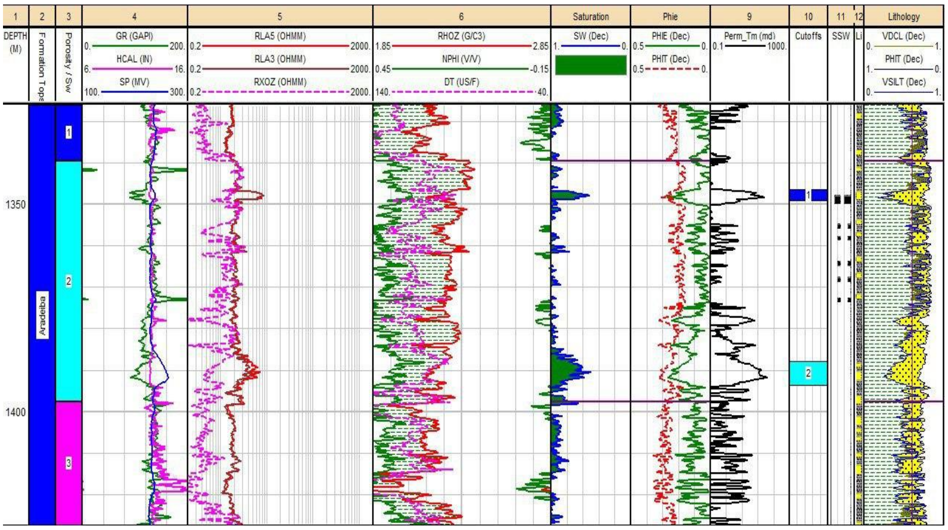

Fig. (3. 6) saturation water log for Aradeiba formation

3.4.2 Bentiu formation

After applying cutoff Bentiu have three zones and at zone three the value of s_w range of (0.12- 1) and zone four (0.28- 0.1) and zone five (0.4- 1). (Fig (3.7))

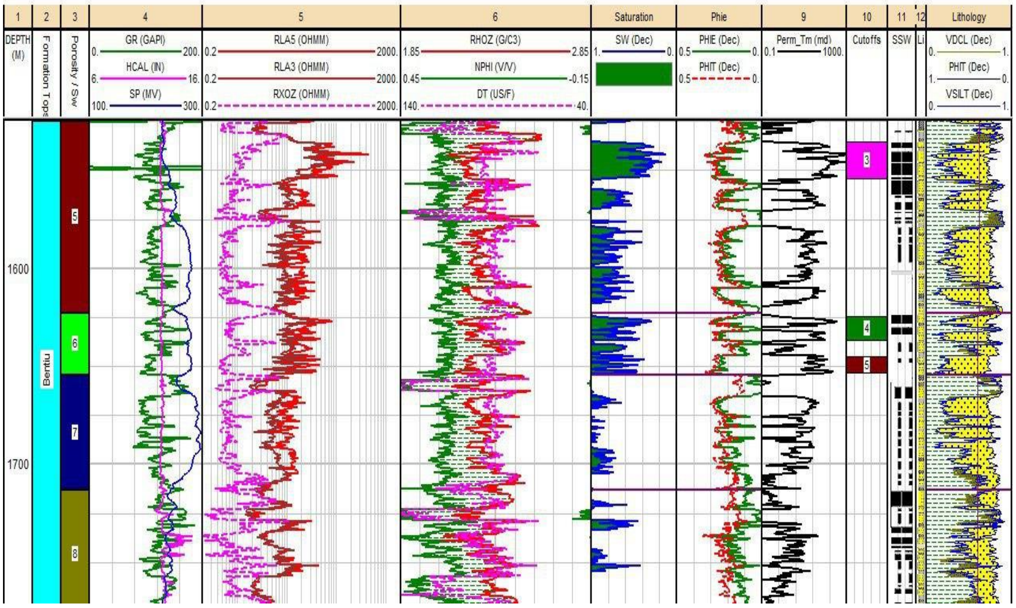

Fig. (3. 7) saturation water log for Bentiu formation

3.5 Cutoff Values:

Cutoff values are set to help restrict attention to rock that passes certain simplecriteria.

The outputs of such criteria are:

1. A ratio that describe how much of the interval is judged to be reservoir quality (or equivalently the thickness represented by the reservoir quality material).
2. The average value of each property of interest for the reservoir quality rock.

Typical cut-offs that are used are a lower limit on porosity and/or an upper limit on shale volume for Net and these together with an upper limit on water saturation for Pay.

The cutoff values for Aradeiba formation are: Vsh (<=0.51), Phie (>=0.138) &Sw (<=0.791), while those selected for Bentiu formation are: V_{sh} (<=0.5), Phie (>=0.2) &Sw (<=0.6)), Table (3.2).

Two zones were found to fulfill the cutoff criteria in Aradeiba formation (zones 1 & 2 in Table (3.1)), while in Bentiu formation three zones were valid (zone 3, 4 & 5 in Table (3.1)).

Pay SUMMARY

Table (3. 1) pay summary from the cutoff

Zone Name	**Top**	**Bottom**	**Gross**	**Net**	**N/G**	**Av Phi**	**Av Sw**	**Av Vcl**	**Phi*H**	**Phi*H**
1	1346.38	1349.27	2.90	1.83	0.632	0.203	0.656	0.324	0.37	0.13
2	1387.83	1393.77	5.94	4.42	0.744	0.214	0.659	0.408	0.95	0.32
3	1535.20	1554.71	19.51	13.11	0.672	0.253	0.349	0.237	3.32	2.16
4	1624.66	1637.31	12.65	5.03	0.398	0.251	0.444	0.266	1.26	0.70
5	1644.78	1654.23	9.45	4.42	0.468	0.258	0.499	0.226	1.14	0.57
All Zones	1346.38	1654.23	50.44	28.80	0.571	0.244	0.448	0.272	7.04	3.88

CUTOFFS USED

Table (3. 2) Reservoir summary from the cutoff

Zn Zone Name	Top	Bottom	Min. Height	Phi PHIE	Sw Sw	Vcl Vwcl
Reservoir						
1	1346.38	1349.27	0.	>= 0.138		<= 0.511
2	1387.83	1393.77	0.	>= 0.138		<= 0.511
3	1535.20	1554.71	0.	>= 0.2		<= 0.505
4	1624.66	1637.31	0.	>= 0.2		<= 0.505
5	1644.78	1654.23	0.	>= 0.2		<= 0.505
Pay						
1	1346.38	1349.27	0.	>= 0.138	<= 0.791	<= 0.511
2	1387.83	1393.77	0.	>= 0.138	<= 0.791	<= 0.511
3	1535.20	1554.71	0.	>= 0.2	<= 0.606	<= 0.505
4	1624.66	1637.31	0.	>= 0.2	<= 0.606	<= 0.505
5	1644.78	1654.23	0.	>= 0.2	<= 0.606	<= 0.505

Depth Units : m

Net reservoir should fulfill the Vsh & Phie cutoff, while pay reservoir should further fulfill the saturation cutoff.

CHAPTER FOUR

CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion:

Aradiba found to be dominated by shale and Bentiu found to be dominated by sand.

Porosity and permeability values are higher in Bentiu than Aradeiba, and this indicatebetter reservoir quality in Bentiu as compared toAradeiba.

Potential intervals saturated with hydrocarbon were verified using both wireline logs and master log shows. Bentiu is considered to be more prolific than Aradeiba.

4.2 Recommendations:

1. Analysis of the pressure data to verify the oil and water intervals.
2. Perform drill stem testing (DST) through zones as shown in table (2). Zones 1 & 2 in Aradeiba formation & zones 3, 4, & 5 in Bentiu formation to confirm interpretation result and fully evaluate the zones.
3. Analysis of conventional core data to calibrate the interpreted porosity and further refine the permeability model.
4. Using dual water model to calculate the water saturation.
5. Verify the formation water resistivity for both Aradeiba & Bentiu formations using water sample from FMT data or DST.

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