Evaluation of Log-Derived Cation Exchange Capacity for Water Saturation Estimation

By

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I.D.17759

Dissertation submitted in partial fulfilment of requirements for the

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Petroleum Engineering

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CERTIFICATION OF APPROVAL

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Approved by,

____

(Dr. Shiferaw Regassa Jufar)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources of persons.

Hamedelgzali Abdullah Hamed Ahmed

ABSTRACT

A common method to investigate the hydrocarbon content of a reservoir rock is through the evaluation of wireline logs. Lithology and Porosity logs combined with resistivity log are used to estimate the water saturation of a reservoir. However, several factors affect evaluation of wireline logs. One of such factors is presence of clay in the formation. Since clay mineral introduces additional conductivity, its presence is an extremely perturbing factor in formation evaluation. Many models are developed to account for the extra conductivity of clay minerals during log evaluation. Some of these models attempt to account for the extra conductivity due to clay presence through the introduction of cation exchange capacity (CEC). Usually, CEC is determined through a laboratory study and the process is complicated and tedious.

In this study, CEC values are determined from log and the normalized Waxman-Smits (nWS) shaly sand evaluation model is used to estimate water saturation in clean and shaly sand zones. The results are compared with the Archie equation. In the clean sand zone, the average CEC value is 0.018 meq/cm3. The average CEC value in the shaly sand zone is 0.11 meq/cm^3 (0.8 meq/g). This suggests that the major clay composition in this zone is Montmorillonite.

In the clean sand zone where V_{sh} is about 10 %, the deviation in water saturation between the Archie and the nWS models is about 12 %. In the shaly sand zone where V_{sh} = 66 %, the deviation in water saturation between the Archie and the nWS models is about 67 %. Although, the water saturation needs to be compared with the true value, the results found indicate that with the application of CEC values determined from logs, the nWS shaly sand model can be used to estimate water saturation with reasonable accuracy. As such, it can eliminate the challenges in CEC value determination in the laboratory. The other main advantage of determining the CEC from logs is that it is the average value from many intervals unlike the laboratory determined CEC. The laboratory determined CEC value is from a core sample taken from some particular section and it may not represent the whole formation. As such, the water saturation estimation may not be correct. However, the value determined from the logs represents the whole section through the zone of interest. As a result, given the CEC determination from log is well calibrated using core data, the water saturation estimation should be better.

ACKNOWLEDGMENT

All praise and thanks to Allah, the creator, the maker, the fashioner, for his boundless blessings and guidance throughout my life and the success, he granted me in completing this project in easiness and success Alhamdulillah.

The Author would like to express his great thanks to his supervisor Dr. Shiferaw Jufar for the valuable support, knowledge and the assistance during the development of the project.

Special thanks also extend to all people who direct or indirectly were involved in making this project a reality.

Finally, I wish to offer my special heart thanks to my parents for their faith, love, support and encouragement throughout my life and study.

Contents

List of Figures

ABBREVIATION AND NOMENCLATURES

CEC	Cation exchange capacity of a rock sample (meq/g rock)
V_{sh}	Volume of Shale (percentage)
F	Formation resistivity factor
R_o	resistivity of saturated rock
R_w	Resistivity of electrolyte fluid (water)
(a)	Cementation coefficient
(m)	Cementation exponent
S_w	Formation water saturation
R_t	True formation resistivity
C_o	Formation conductivity
C_w	Water conductivity
X	term of Shale conductivity
N	Saturation exponent
Qv	Cation exchange capacity per unit total pore volume (meq/cm^3)
Qvn	normalized Qv.
Q_{tsh}	total porosity of shale (percentage)
Q_t	total porosity (percentage)
R_{we}	equivalent bulk water resistivity of shaly formation.
S_{wt}	total water saturation

Chapter 1

Introduction

1.1 Introduction and Background

Well logging plays an important role in identifying and evaluating the zones of hydrocarbon in the reservoir. The types and quantities of hydrocarbon and fluids present on the formation reservoir will be expected by estimating its water saturation (S_w) from well logs. The determination of water saturation (S_w) is one of the important calculation in the field development.

In the clean zones, which are zones with low volume fraction of shale, water saturation is regularly estimated through Archie's equation. However, Archie's equation is established on the assumption that the saline is the only conductive element in the formation. While, in the case of shaly sand formation the clay appears to provide an additional conductivity to the formation, the structure of clay minerals produce a negative surface charge that results in decrease of the SP deflection, and rise in the rock conductivity, C_t. Therefore, Cation Exchange Capacity of the formation is a main factor for the modification and improvement of resistivity measurements, which is required to complete the calculation of water and Hydrocarbon saturation. However, the use of clean sand model (Archie's Equation) to estimate the water saturation in shaly sand formation will results in inaccurate estimation; higher level of water saturation than the actual present in the formation will be predicted. Designing of the field facilities and development are depend on the estimated amount of hydrocarbon subsequently the water saturation estimated. There for incorrect estimation of water saturation will lead to improper designing. Which will appear in increasing the capital development expenditure by redesigning the facilities after production.

Usually, the ways to determine Cation exchange capacity (CEC) is in the laboratory, but this method is rather expensive to produce and does not allow the distribution of the results to different laboratories, as there is commonly a varied effectivity in Cation replacement and possible environmental interference, thus reducing the effectivity.

Calculating Cation exchange capacity from well logs has showed promising results that agree with continuous Cation exchange capacity log derived values.

The detection and estimation of water saturation in a hydrocarbon zone that has areas of shale formation can be estimated using CES models and V shale (V_{sh}) models. However, V_{sh} assume that the shale effect is only relative to the shale volume.

The main limitation of V_{sh} models that they have no universal V_{sh} indicator and those models do not reflect to the type of clay in the formation. Subsequently V_{sh} shale sand models fail to predict values that represent values of hydrocarbon saturation in the formation from wire line data. Modern Cation exchange capacity models produce better results than the V_{sh} models as Cation exchange capacity reflects and takes into consideration different clay types.

1.2 Problem Statement

The Estimation of the amount of hydrocarbon present in the reservoir is one of the most important factors for the investors in the oil and gas industry, as it is relied upon in making the decision to proceed with projects and to develop facilities toward start operation. Determining the water saturation is the key to estimate the amount of hydrocarbon present in the formation. However, in the clean sand formations determination of water saturation usually uses the Archie's equation, which in shale sand formation will result in incorrect estimation. Therefore, evaluation of water saturation in a shaly sand needs to include the effect of shale. There are a number of models to estimate water saturation in shaly sand. some of which is based on Cation Exchange Capacity (CEC) which is excess conductivity associated with the presence of shale. Although there are models to estimate water saturation of shaly sands using CEC values, determination of CEC from core sample is a complicated and time-consuming process. If the CEC values are not accurately determined, it leads to erroneous water saturation estimation. Apparently, erroneous water saturation estimation affects reserve estimation, development strategies, and facilities design to handle the produced hydrocarbon.

1.3 Scope of study

The main goal of this study is to predict the water saturation using the log derived cation exchange capacity (CEC). In addition comparing the results with the water saturation values from the production data and Archie's equation. Therefore, the author could come with evaluation for the CEC models.

1.4 Objectives

The following are the main objectives of the study:

- To review shaly sand evaluation techniques.
- To Calculate CEC or Qv values from logs and estimate, water saturation based on the log derived CEC.
- To compare the water saturation obtained from the log derived CEC with the water saturation from Archie's Equation for validation.

Chapter 2

Literature Review

2.1 Concept of Clean Sand formation Model

Ipek and Bassiouni (2002) state and review the different petrophysical models for shaly sands.

Archie equation is playing the main role in estimating the water saturation from clean sand

$$F = \frac{R_o}{R_w} = \frac{C_w}{C_o}$$

Where F is the formation resistivity factor, R_o is the resistivity of the rock when it fully saturated with an electrolyte fluid with a resistivity of R_w.

The formation factor is empirically related to the porosity of the rock as:

$$F = \frac{a}{\phi^m}$$

Where (a) is coefficient and (m) is the cementation exponent

$$S_w^n = \frac{a}{\phi^m} \frac{R_w}{R_t} \qquad C_t = \frac{C_w}{F} S_w^n$$

Generally:

Where Sw is the water saturation expressed as a fraction of pore space, n is the exponent of saturation.

2.2 Concept of shaly Sand formation Models

Regardless the assumption of that the water (brine) is the only conductive element. At this model even with low concentration of salt in the brine, the conductivity of shale rapidly increases with greater rate than increase in C_w.

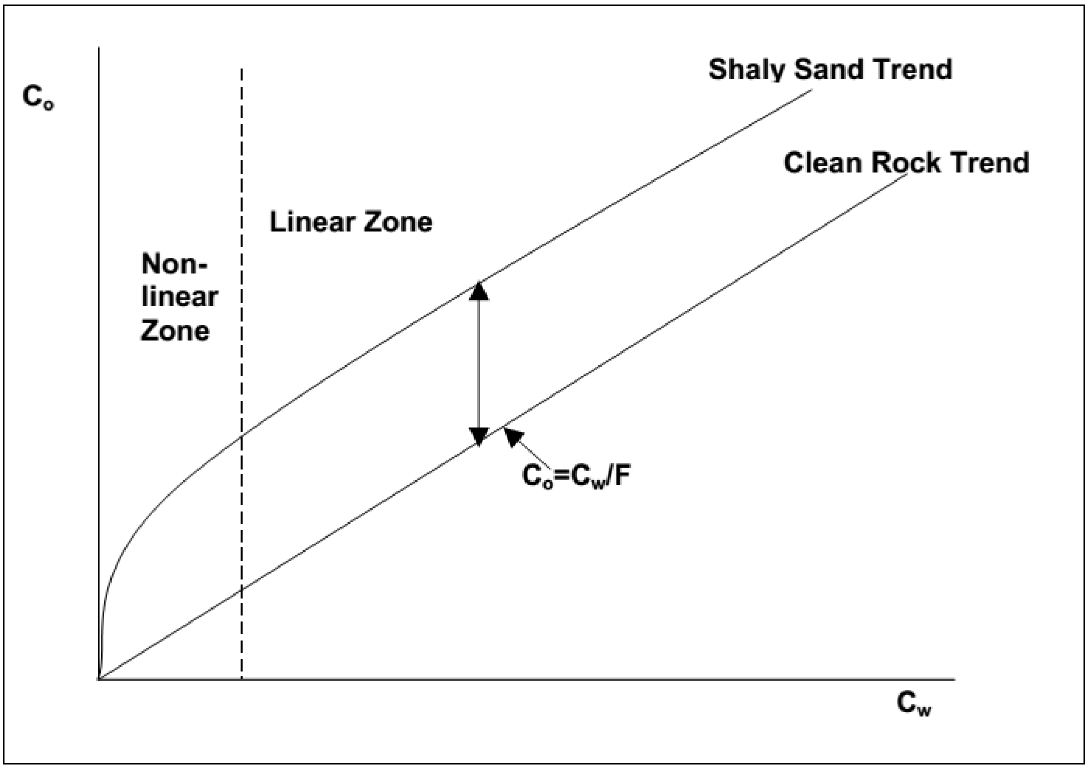
The following equation can describe the general relation between the conductivity of the formation C_o, and the water conductivity C_w, for shale sand formation (Worthington & Johnson, 1991).

$$C_o = \frac{C_w}{F} + X$$

Where:

C_o = formation conductivity when 100% saturated with water

C_w = water conductivity



Where:

The Figure above shows the typical C_o – C_w plot for shaly sands

F = Formation Factor

X = term of shale conductivity

2.3 V_{sh} Shaly Sand Models

V_{sh} is defined as the volume of the wetted shale per unit volume of reservoir rock.

Hossin (1960) generated the coming equation for the shale conductivity term, X:

$$X = V_{sh}^2 C_{sh}$$

This relationship involving V_{sh} in water bearing formation and in hydrocarbon formation respectively

$$C_o = \frac{C_w}{F} + V_{sh}^2 C_{sh}$$

$$C_t = \frac{C_w}{F} S_w^n + V_{sh}^2 C_{sh}$$

Where:

S_w = water saturation above the irreducible water saturation

N = saturation exponent

2.4 Types and Distribution of shale:

Ramirez (1990) has define and classified the types of shale as:

The term clay indicates natural earthy fine-grained materials that create plasticity when mixed with a small amount of water.

The most common types of clay minerals found in sedimentary rocks are kaolinite, illite, smectite (montmorillonite) and chlorite.

Kaolinite and Chlorite are considered as ineffective shale's. Kaolinite is the simplest clay mineral in structure and the purest in composition has low CEC ranged from (1-10 meq/100gm). While chlorite is a hydrous green silicate consisting of ordered layers of alumina octahedrons and silica tetrahedrons with basal cleavage between the layers, has zero cation exchange capacity.

On the other hand, illite and smectite are considered as effective shale's. Illite crystal is composed of two unit layers each of which consists of one alumina octahedron sandwiched between two silica tetrahedrons, has CEC ranged between (10-40 meq/100gm). However, smectite is similar in structure to illite, different is that Magnesium, Sodium and Calcium ions tend too be substituting cations rather than potassium, smectite has CEC from (80-100 meq/ 100gm).

Crain (2001) has explain the types of shale distribution in sand as shown below

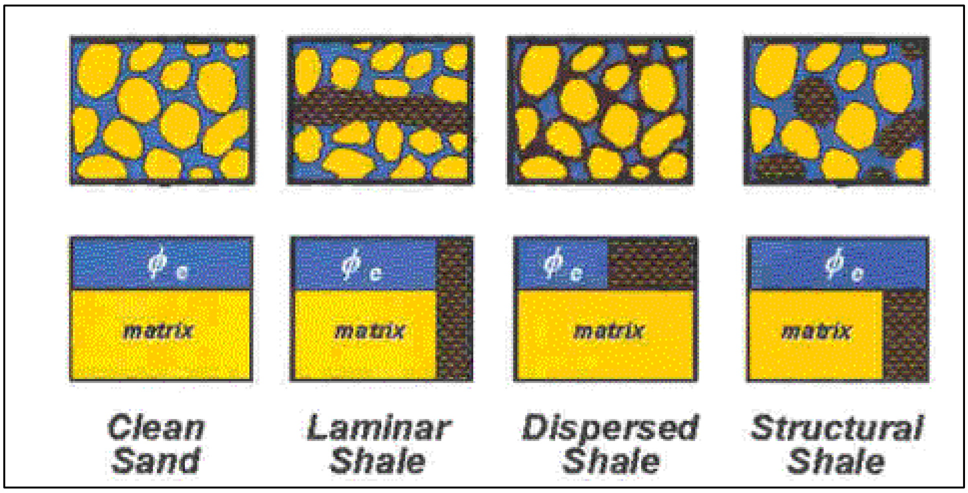


Figure 1: Types of Shale distribution

As seen by the figure, the laminar shale case is special case where petrophysical analysis done under standard models do not work when using standard porosity and saturation.

Due to the chemical reactions between the chemicals in the water and the minerals of the rock, Clay minerals will form in place after deposition. This usually composes what is called Dispersed Shale.

For the initial phase of deposition, normally the structural shale is set down as particles, grains, or clasts.

Chapter 3

Research Methodology

The objective of this study is to compute CEC values from logs, which are normally readily available in comparison to CEC values determined from laboratory measurements. The log derived CEC values will be used to estimate water saturation using shaly sand evaluation models based on CEC. Once the water saturation is determined, it will be compared with the water saturation from Archie's equation for evaluation.

3.1 Methodology steps

The research Methodology was conduct through the following steps:

1. Gathering of preliminary information and review about types of shale, structure and distribution of shale in sand. Which are important to understand the effectiveness of clay on sand.
2. The brainstorming session, the main idea of this session is to take into consideration all the features, qualities, effectiveness, efficiency and other constraints, of the shale on Sand.
3. Research is the essential part of the project since it provides general information for the project and constructs the overall fundament. Hereby, I can obtain a more detailed understanding and technical explanations for CEC Models.
4. Convey the well logs data for several wells for the analysis.
5. Data then compiled as a form of ideas and research data thought several discussions with the supervisor, this involved comparison and analysis of the well logs data in each well. A conceptual analysis is being accomplished, so that important and useful ideas are putted on mind.
6. Interpreting and determine CEC values from the logs, then calculate the water saturation based on the CEC values obtained. All the aspects and

effects of clay are put under continuous investigation and observations, so that the final estimation corresponds to all the desired requirements.

7. Comparing the results of water saturation obtained from CEC logs with Archie equation and evaluate the difference between them.

8. During the development of this project there might occur some problems. Any problem that occurs due to the incorrect reading from logs or any other reasons were put into critical considerations at this stage. All works had to be reviewed all over again in order to identify possible reasons of problem extraction in order to overcome the problem pertaining to it.

9. At this stage, all the results and comparison obtained from this analysis were put into to the final checking and concluding.

3.2 Software used

This project is focus on evaluating the water saturation estimated from the log-derived cation exchange capacity. To accomplish the project objectives the use of Interactive Petrophysics Software was very important which facilitate the log interpretation part. The important of log interpretation is to identifying the interest zones (sand zones and shaly sand zone).Microsoft office excel has also been used for all the calculation required for the CEC and water saturation.

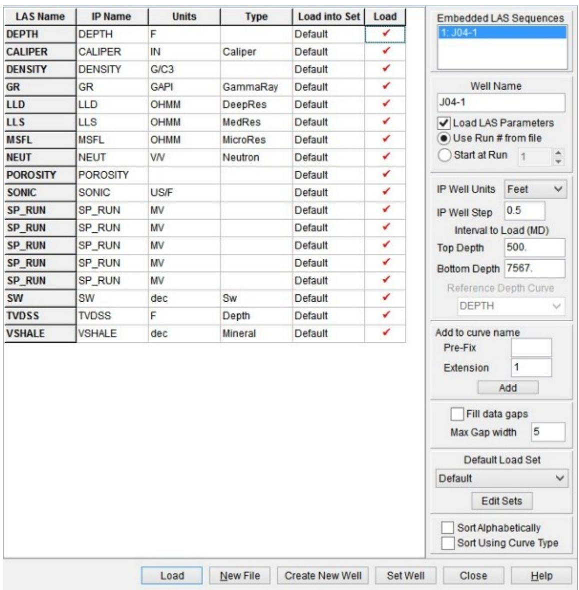


Figure 2: Import the logs to the interactive petro physics software

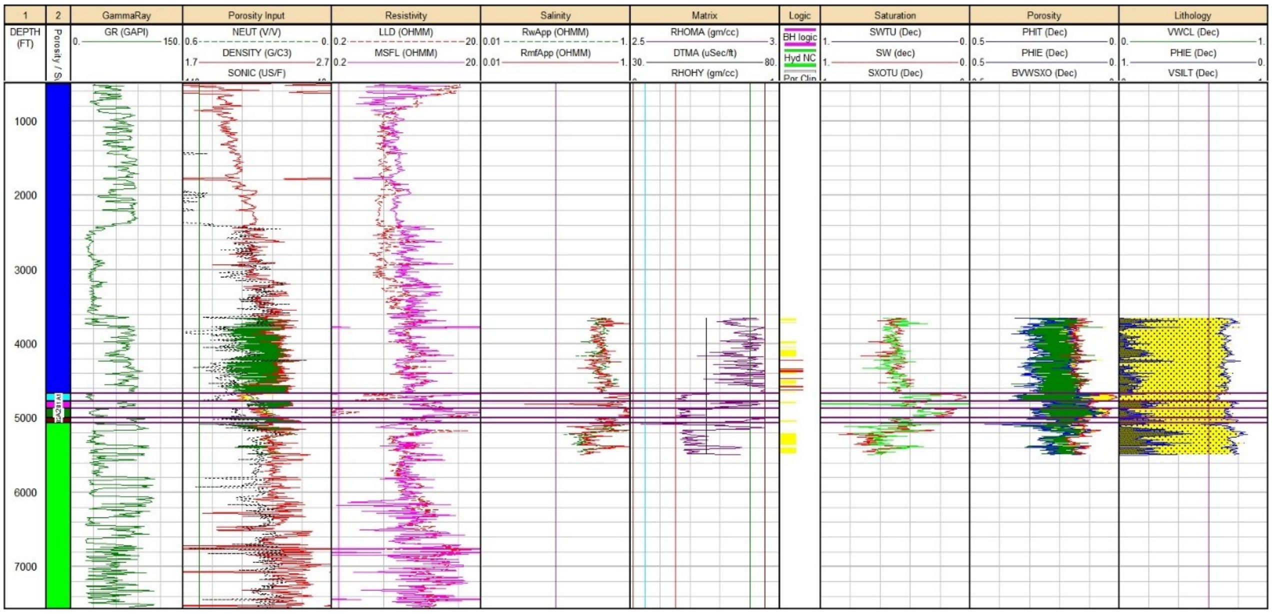


Figure 3: full view of logs at interactive Petrophysics software

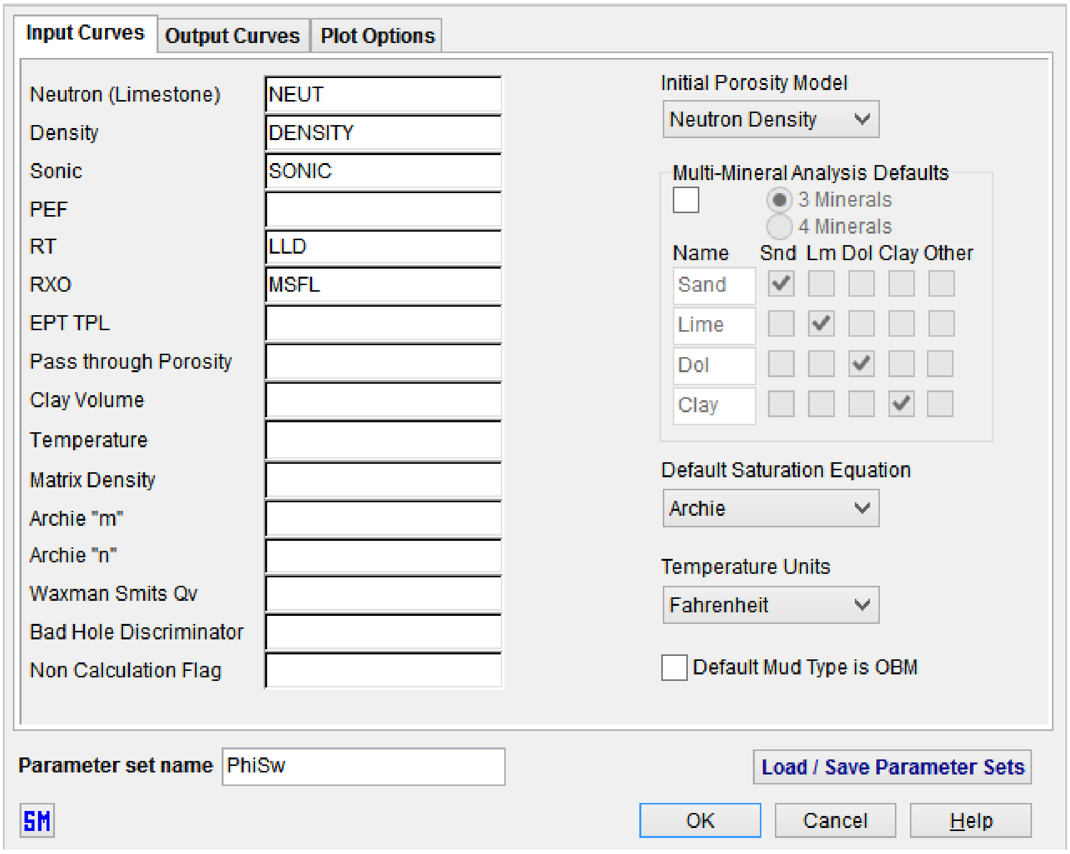


Figure 4: set up porosity and water saturation calculation

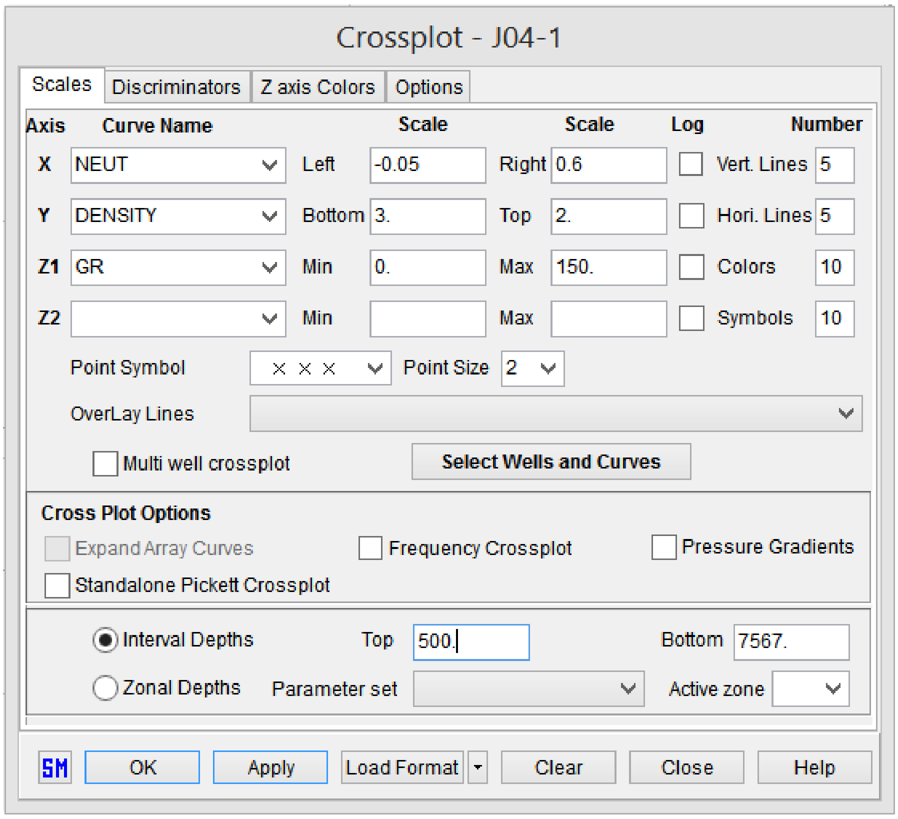
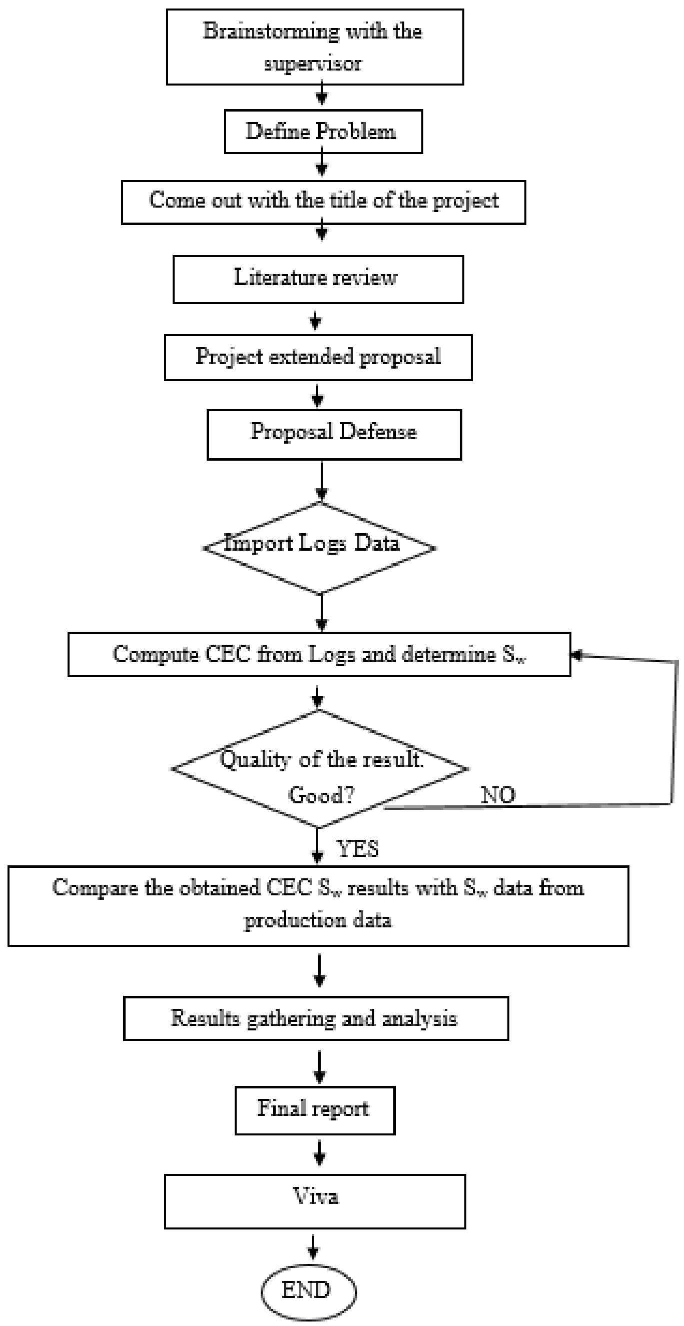
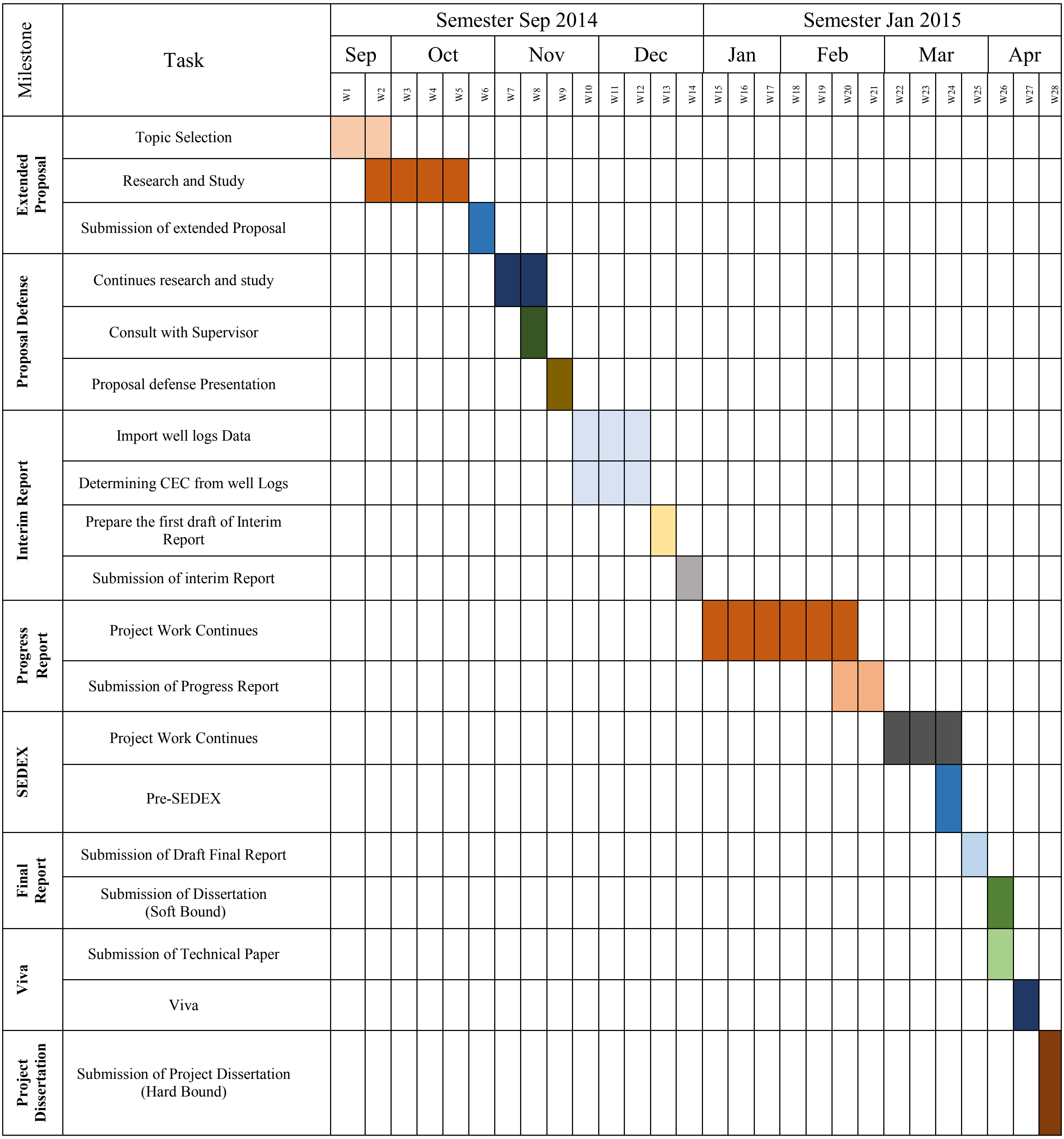


Figure 5: creating the crossplot at interactive Petrophysics software

3.3 Plan and Schematic Flow Process of the Project



3.4 Gantt chart



3.5 Project Milestones

- Import the sets of well logs data for the project (Dec 2014).
- Interpret the logs, identifying the zones and compute CEC (Feb 2015).
- Calculate water Saturation based on Computed CEC (Mar 2015).
- Compare the result obtained (Mar 2015).

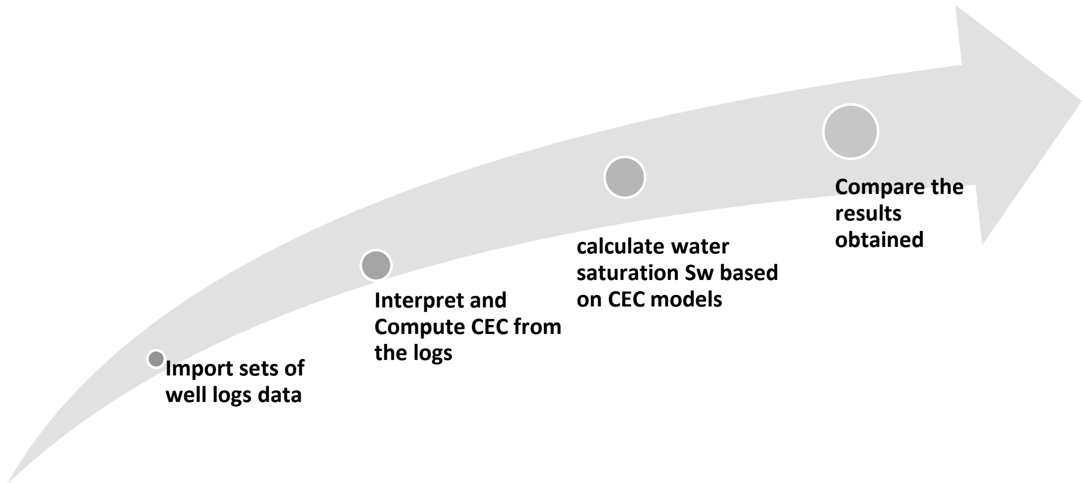


Figure 6: Key milestones

Chapter 4

Results and discussion

4.1 Data Gathering

Required data for the project are sets of Well logs data, which have been imported from the field, X in Malaysia. Author gather well logs data for five wells from the field (X). The set of well logs consist of the following logs:

- Gama Ray log
- SP log
- Caliper log
- Density log
- Neutron log
- Sonic Log
- Resistivity log

The Author has used gamma ray logs and SP logs to identify the lithology. The use of Resistivity log in order to differentiate between the fluids inside the reservoir. Neutron and density logs are used to identify the porosity of the rock, Lithology and the types of shale distribution.

4.2 Log Interpretation

The aim of log interpretation is to locate and identify the zones that possible to contain hydrocarbon. The first step was scanning the gamma ray and SP logs and determine the permeable zones base on the shale base line. The permeable zones to the left of the gamma ray log track. The following step was scanning the resistivity logs and highlights the zones with high resistivity. High resistivity reflects either hydrocarbon in the pore space or low porosity. After that was scanning the porosity logs track (density and neutron logs) and determine which zones, have good porosity against the high resistivity zones.

The figure (7) shows the identification of the zones A1, B1, A2 & B2. The zones A1 and A2 are clean sand zones, both of them contain hydrocarbon. While the zones B1 and B2 are shaly sand zones. The zone B1 is containing amount of hydrocarbon with large amount of water. However, zone B1 is containing hydrocarbon.

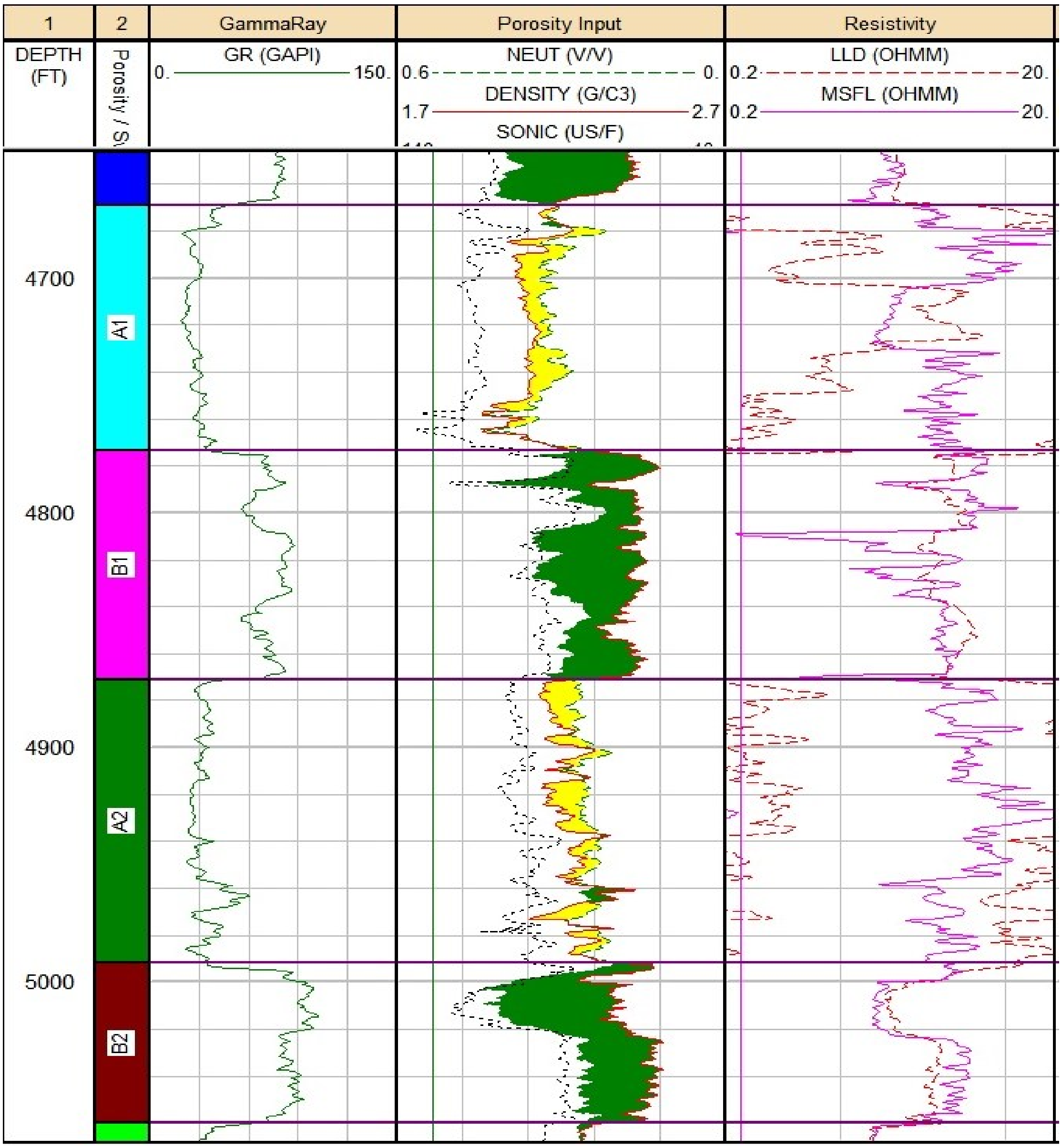


Figure 7: logs interpretation

The figures (8&9) shows the zones of interest that has been evaluated in this project. Figure (8) shows the zone A1, which is the clean sand zone with less volume of shale in the zone. The good porosity and high resistivity in the zone indicate hydrocarbon present in the formation. The figure (9) shows the zone B2 that is shaly sand zone with high percentage of shale.

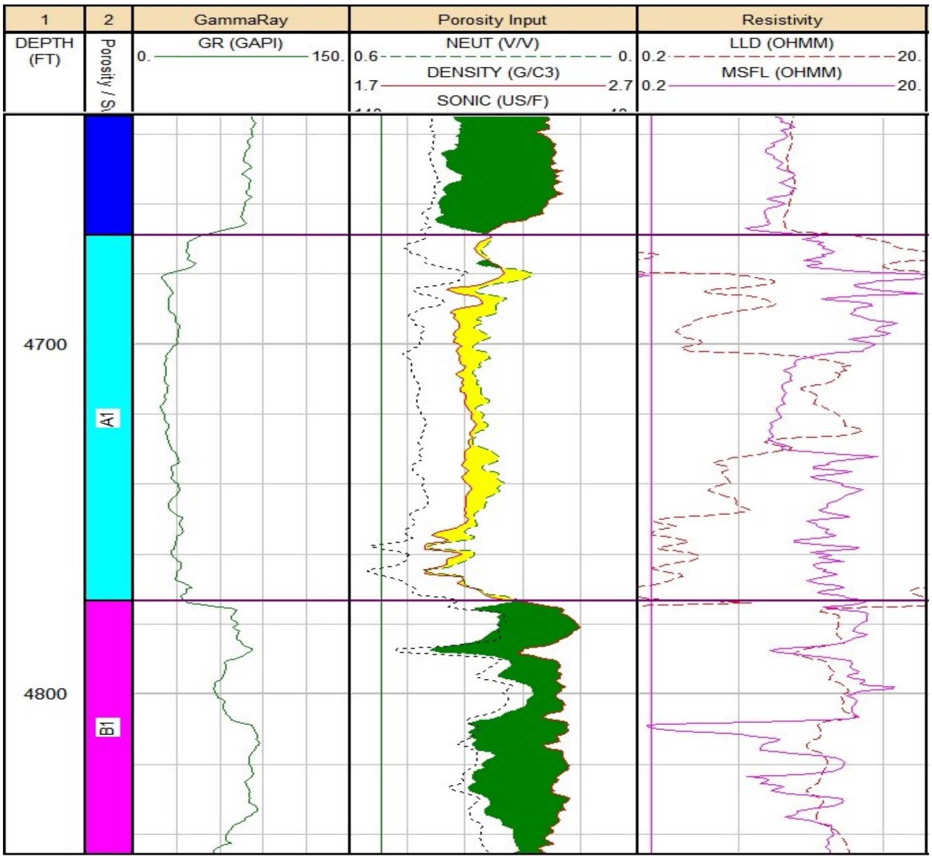


Figure 8: Zone A1 (Clean sand)

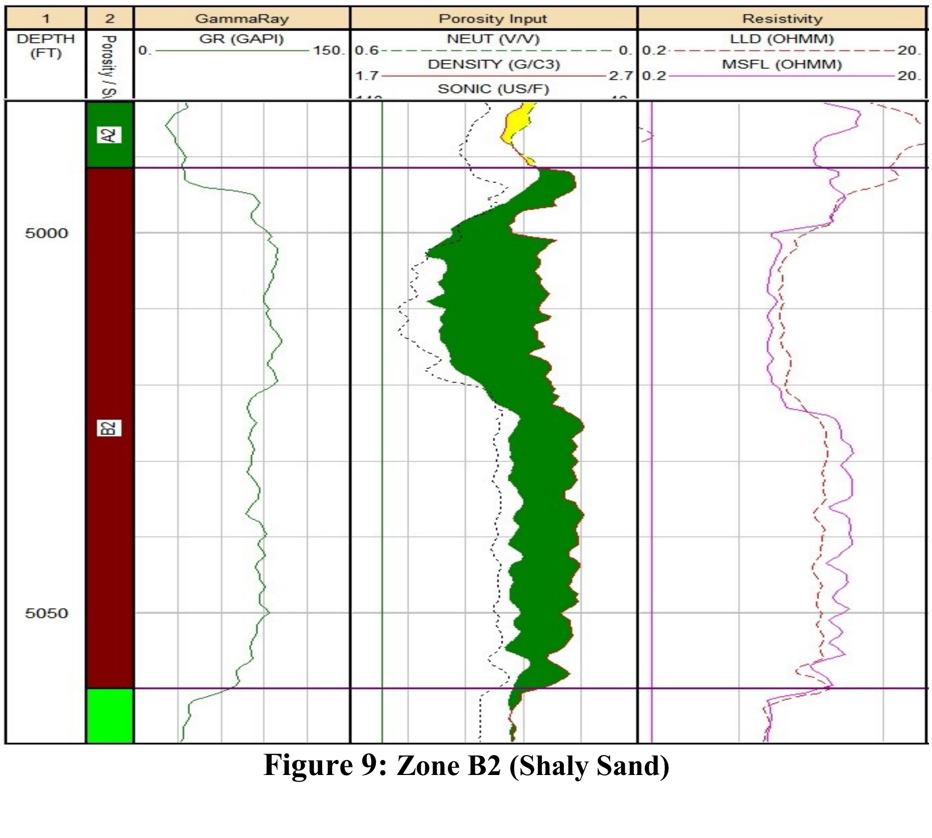


Figure 9: Zone B2 (Shaly Sand)

The figures (10&11) shows the use of neutron density crossplot for matrix identification and the distribution of shale in the formation. The figure (10) shows the points of zone A1 neutron density crossplot are with in the sandstone and limestone lines. The figure (11) illustrate the lithology difference in zone B2 ranged from lime stone, dolomite and shale, and identify the type of shale distribution based on the position of shale points at the crossplot which are laminated shale at the zone B2.

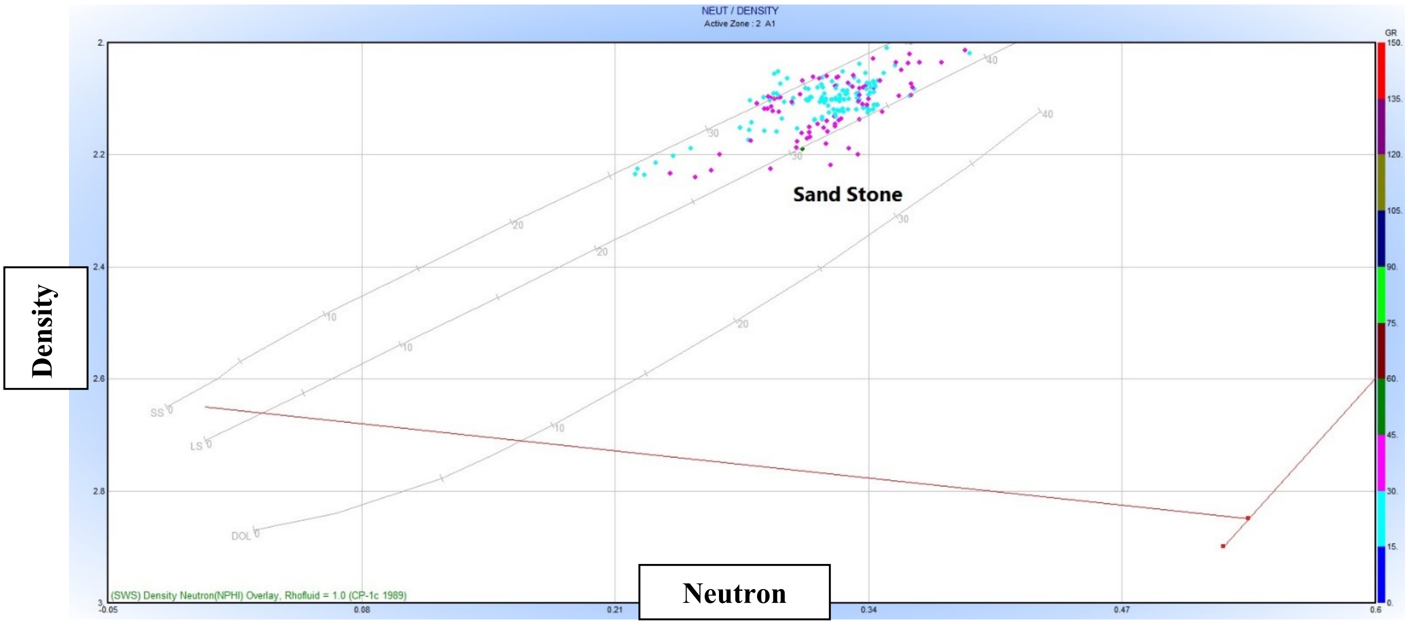


Figure 10: Neutron Density crossplot for zone A1

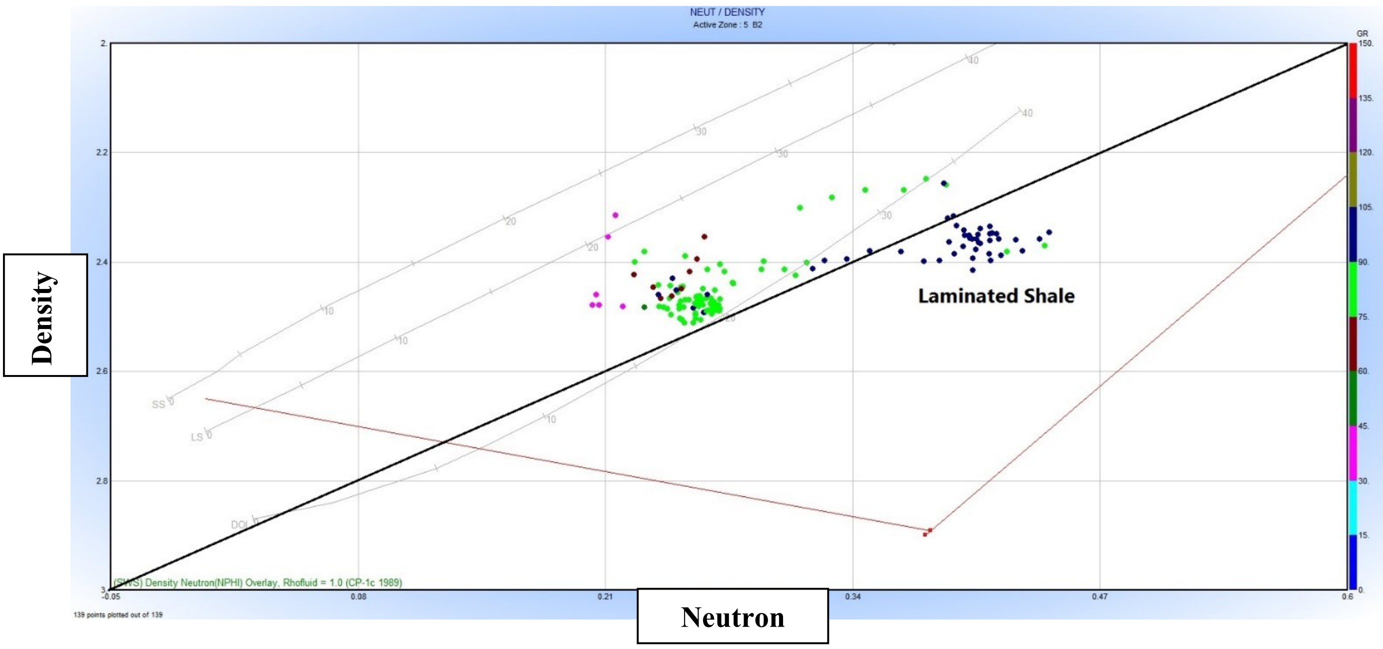


Figure 11: Neutron Density crossplot for zone B2

4.3 Volume of Shale (V_{sh})

Shale volume is on the method used to correct the porosity and water saturation from the effects of clay. Generally the geologist describe the clay as any mineral in the rock with grain size less than 4 microns, however the mineral may not be a clay mineral. Cation exchange capacity (CEC) is the capacity of a material, such as clay or soil, for ion exchange of positively charged ions between the clay and the nearby water. A positively charged ion, which has less electrons than protons, is known as a cation. The quantity of positively charged ions (cations) that a clay mineral can accommodate on its negatively charged surface is expressed in milli-equivalent per 100 g.

The equation below shows the use of gamma ray log to estimate the volume of shale:

$$Vshg = \frac{GR - GR0}{GR100 - GR0}$$

Where:

GR = gamma ray log reading in zone of interest (API unit).

GR0 = gamma ray reading in 100% clean zone (API unit).

GR100 = gamma ray reading in 100% shale zone (API unit).

V_{shg} = shale volume from gamma ray log (Percentage).

The average gamma ray reading at the clean sand on this study was 18.6 API, while the reading for the average shale zone was 117 API.

The figure (12) shows the distribution of shale volume against the depth in the clean sand zone A1 where the average Vshale at that clean zone is 10%. While the figure (13) shows the distribution of shale volume against the depth in the shaly sand zone B2, the average Vshale at that zone was determined to be 66%.

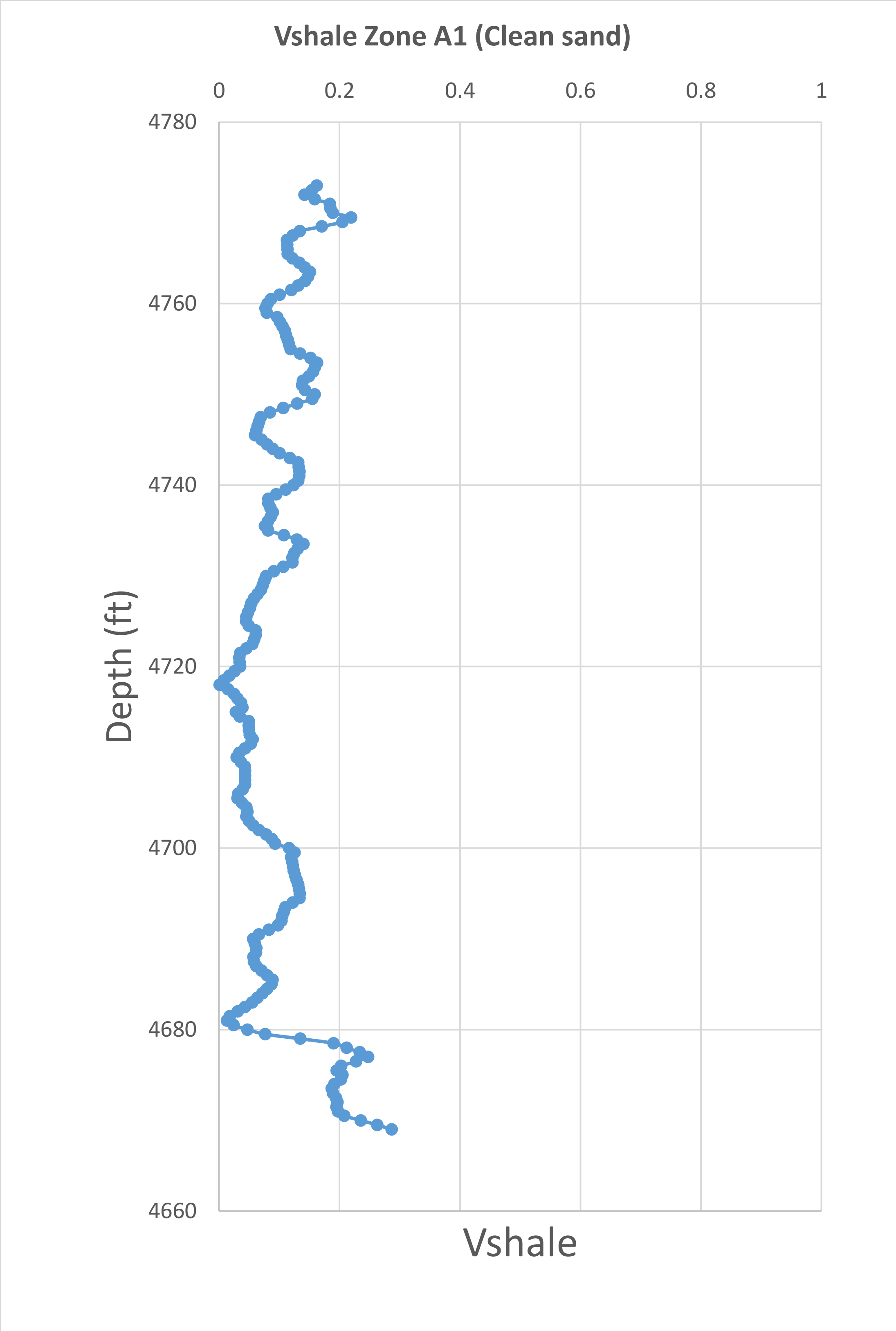


Figure 12: Vshale vs depth in clean sand zone A1

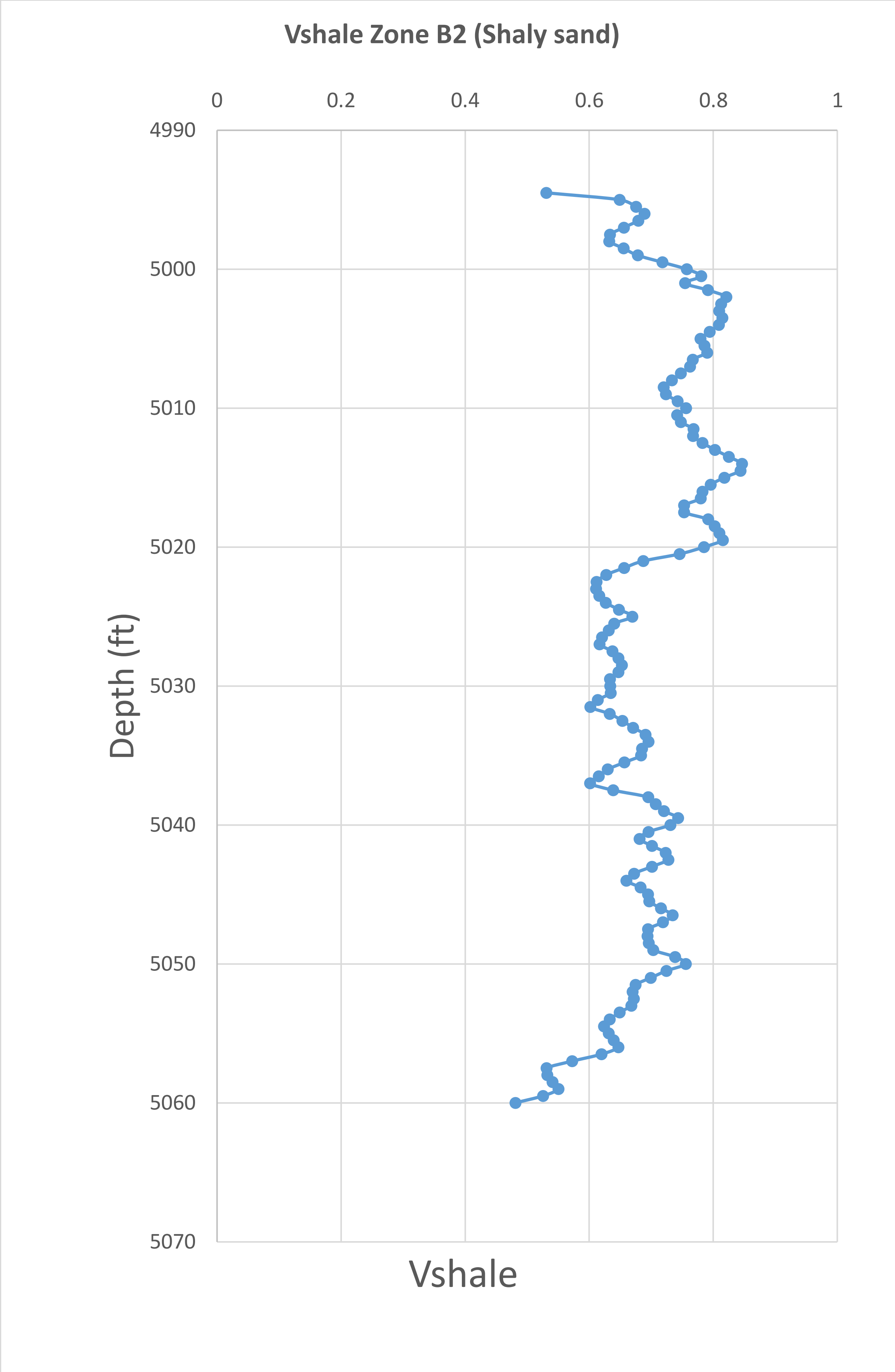


Figure 13: Vshale vs depth in the shaly sand zone B2

4.4 Normalized Waxman-Smits (nWS) equation

The author has used the normalized Waxman-Smits equation which has been proposed by Juhasz (1981) in order to estimate the cation exchange capacity and calculate the water saturation, the method depend on the parameter Qv (Cation exchange capacity per unit total pore volume). Usually Qv will be obtained from the core data. By the use of normalized Qv concept all, the parameter except the saturation can be obtained from logs.

The Equations below have used to determined Cation exchange capacity from logs and determine the water Saturation:

$$Qvn = \frac{Vsh\,.\,\emptyset tsh}{\emptyset t}$$

$$Qv = [\frac{CEC\,.\,(1-\emptyset)\,.\,\rho ma}{\emptyset\,.\,100}]$$

$$Rwe = \frac{Swt.\,R_{wsh}.\,Rw}{Qvn.\,Rw + (Swt - Qvn)Rwsh}$$

$$Rwsh = \emptyset_{Tsh}^{m}.\,R_{sh}$$

$$Swt = [\frac{\emptyset_T^{-m}.R_{we}}{R_t}]$$

Where:

Qv = Cation exchange capacity per unit total pore volume (meq/cm^3)

Q_{tsh} = total porosity of shale (percentage)

Q_{vn} = normalized Qv.

Q_t = total porosity (percentage)

V_{sh} = volume of shale (percentage)

The figures (14 & 15) show the calculated cation exchange capacity plotted against the volume of shale. It is very clear to notice that the value of the V_{sh} and CEC at the shaly sand zone (figure 15) are much higher than the values at the clean sand zone in (figure 14). As can be seen from the figure (14) which is in the clean sand zone as the volume of shale increase the CEC values increase by following one trend line. While the figure (15) represent the shaly sand zone, as can be notice from the figure as the shale volume increase the CEC increase following two trend line that my represent occurs of two types of shale or two different shale distribution.

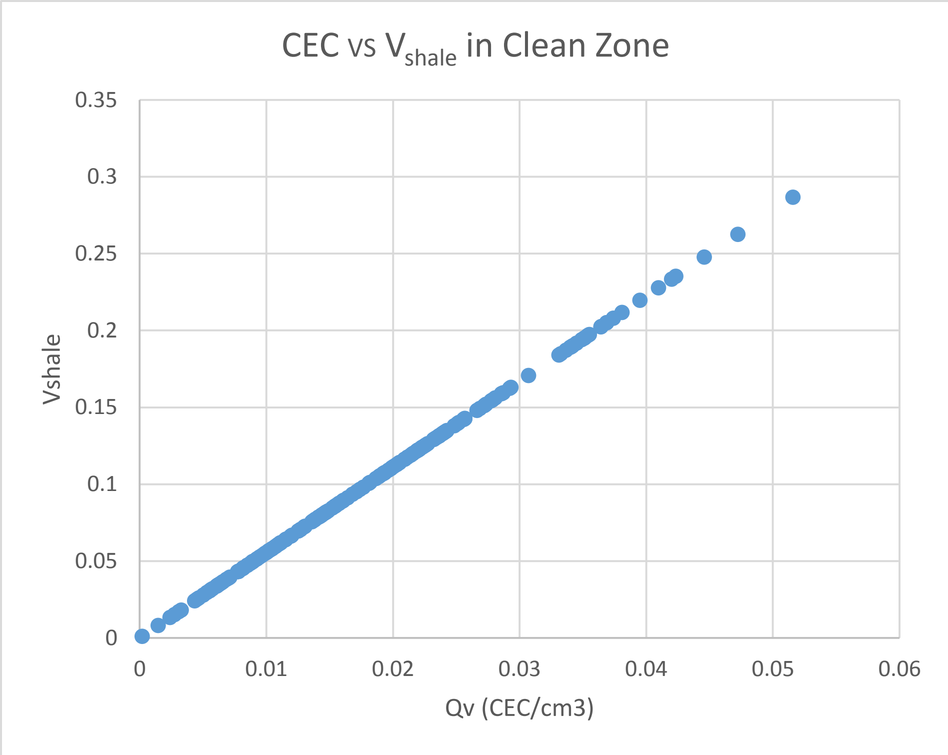


Figure 14: CEC vs Vshale vs Depth in Clean sand zone A1

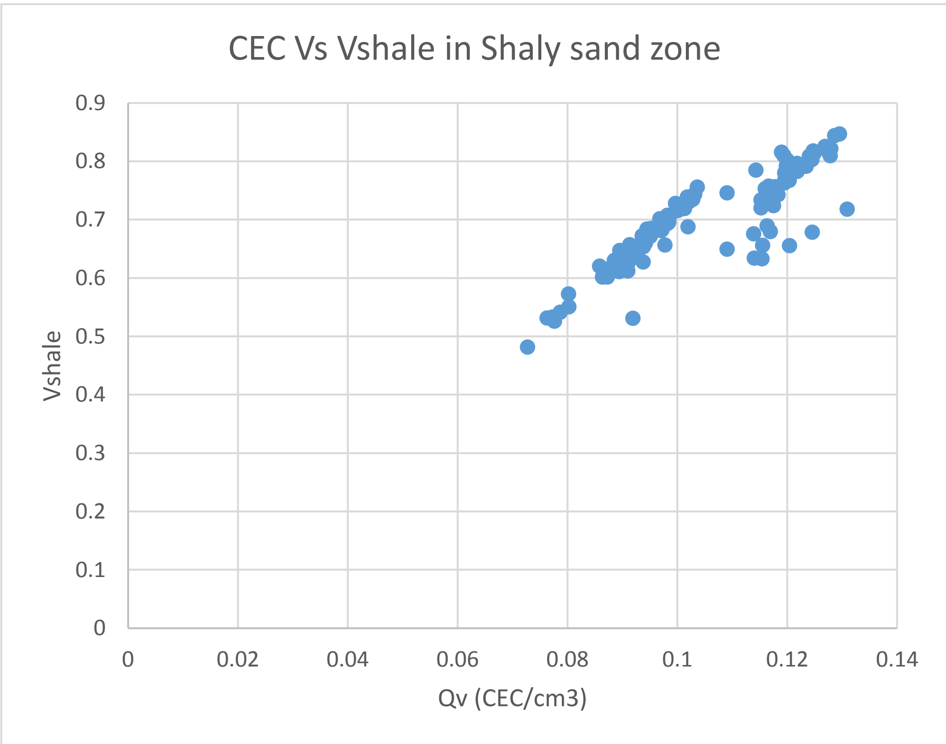


Figure 15: CEC vs Vshale vs Depth in shaly sand zone B2

4.5 Water Saturation

The water saturation has been calculated the normalized Waxman and Smith equation and Archie equation for both zones clean sand zone A1 and shaly sand zone B2. The figure (16) shows the calculated water saturation plotted against depth at zone A1 the clean sand zone. Using Archie equation and Normalized Waxman and Smith equation, as it can be seen that the values form the both methods are almost match each other. The average value of water saturation using Archie equation is 6.5%, while it slightly do up to 7% when using Normalized Waxman equation.

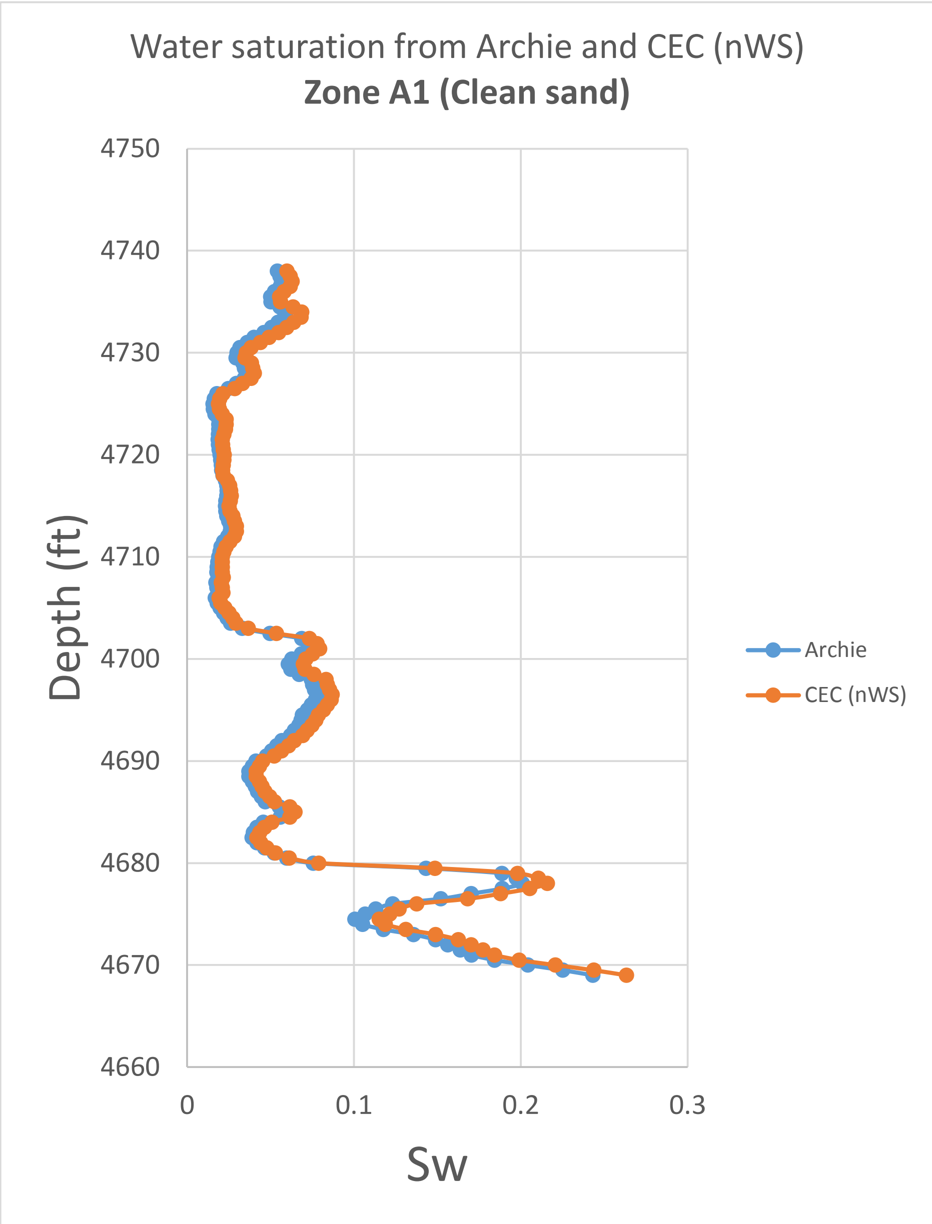


Figure 16: Water saturation from Archie and CEC (nWS) Zone A1 (Clean sand)

The figure (17) shows the calculated water saturation plotted against depth at zone B2 the shaly sand zone. Using Archie equation and Normalized Waxman and Smith equation, I can be noticed that the value of water saturation from Archie equation is much higher than the Normalized Waxman and smith equation and this is due to the shale (clay) effect on the formation. The average value of water saturation using Archie equation is 75%, while it drop to 24% when using Normalized Waxman equation.

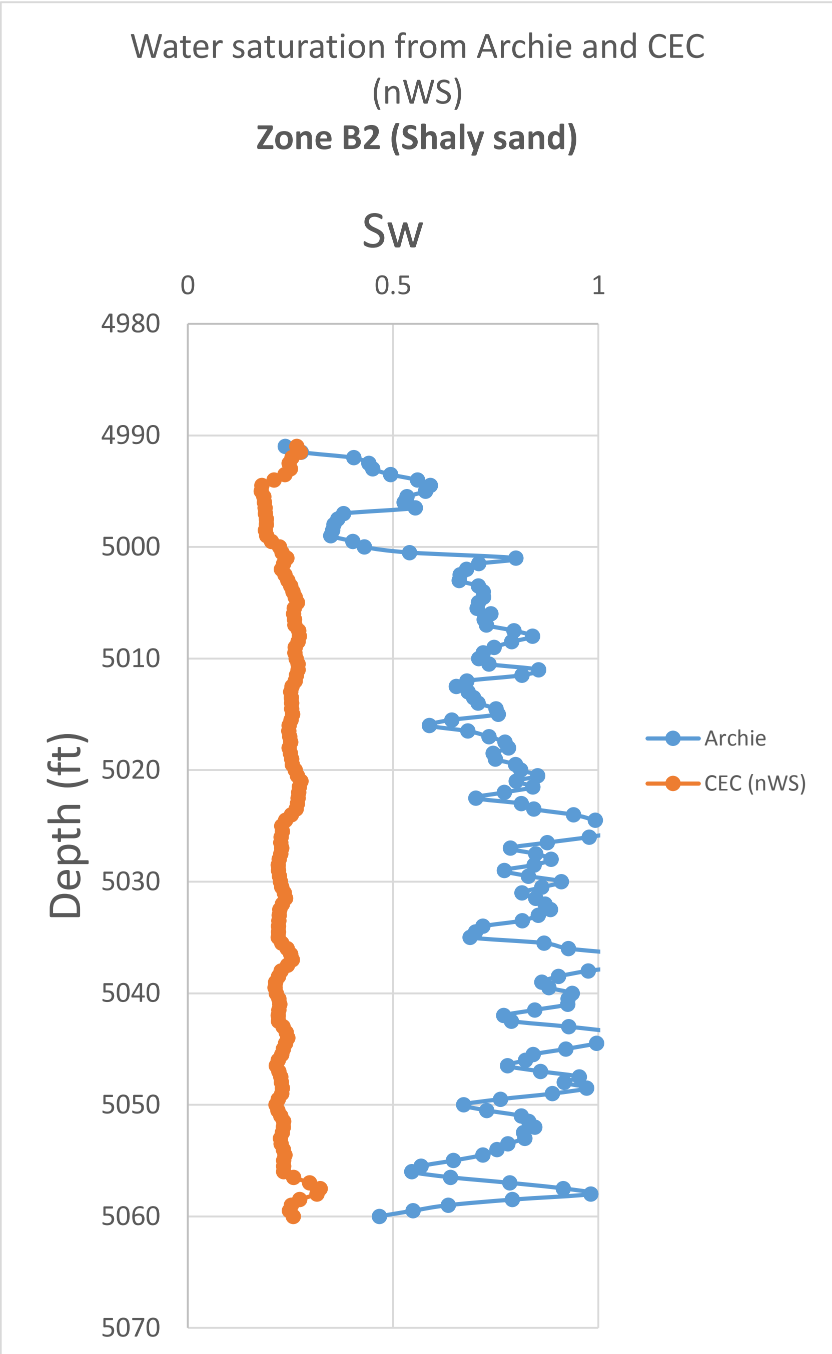


Figure 17: Water saturation from Archie and CEC (nWS) Zone B2 (Shaly sand)

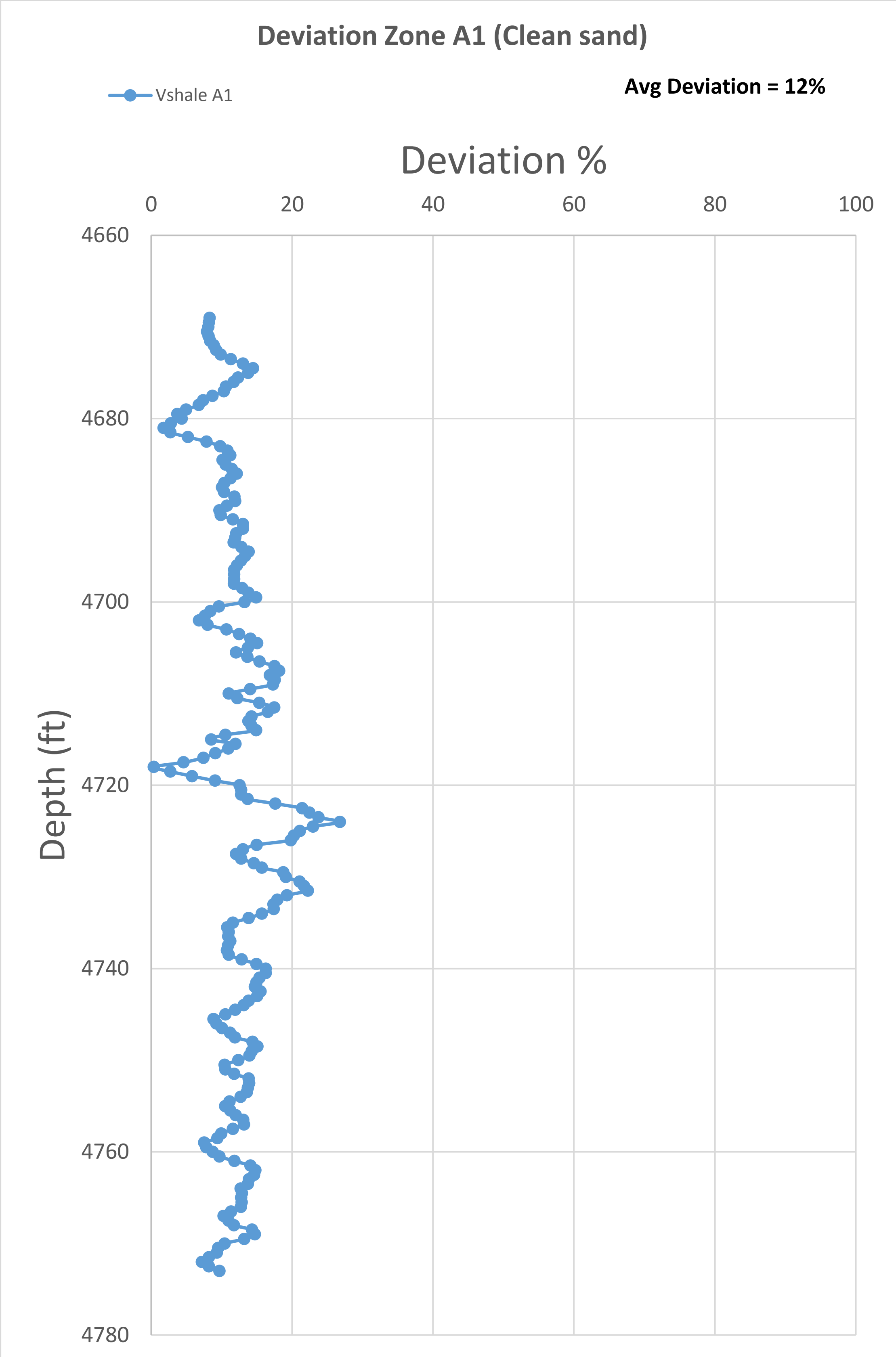


Figure 18: water saturation between Archie and nWS deviation in clean sand zone A1

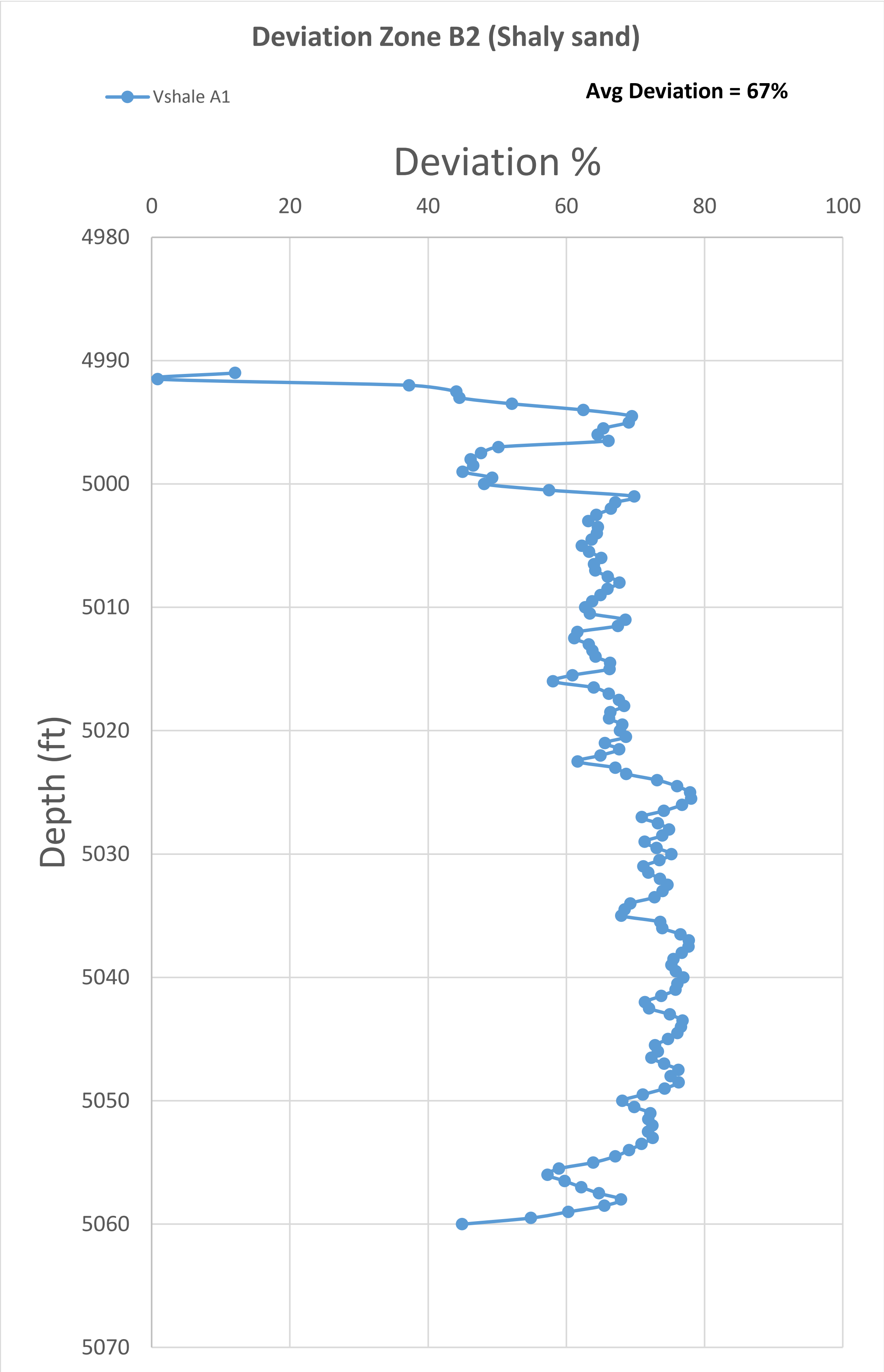


Figure 19: water saturation between Archie and nWS deviation in shaly sand zone B2

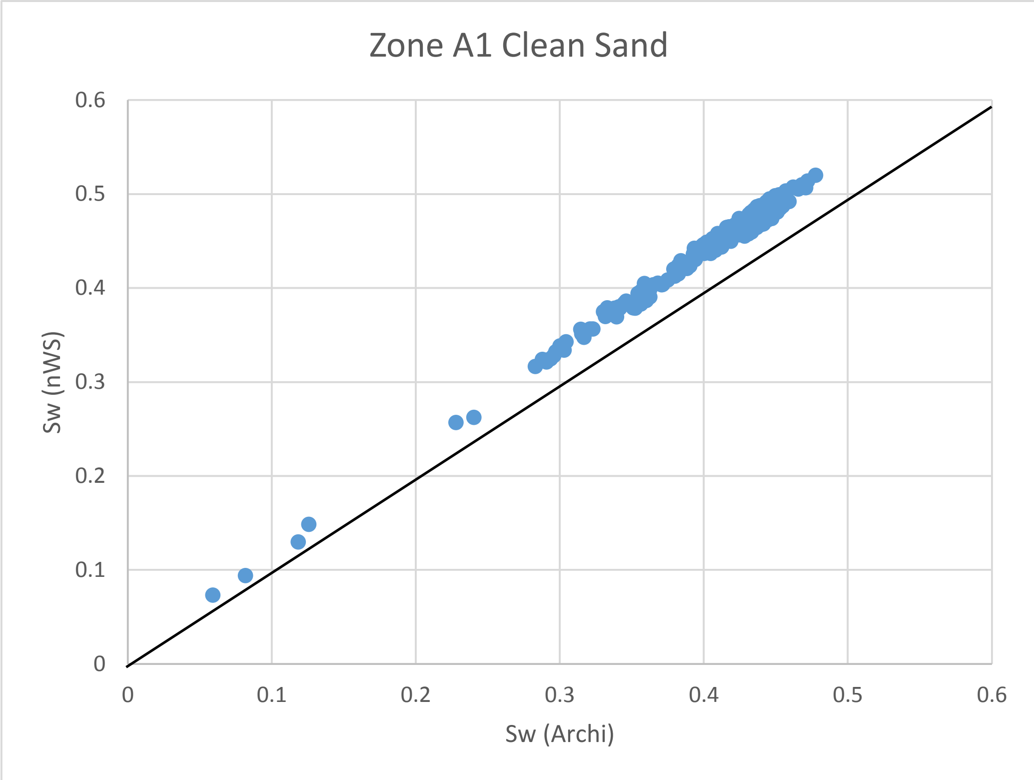


Figure 20: water saturation nWS vs Archie in clean sand zone A1

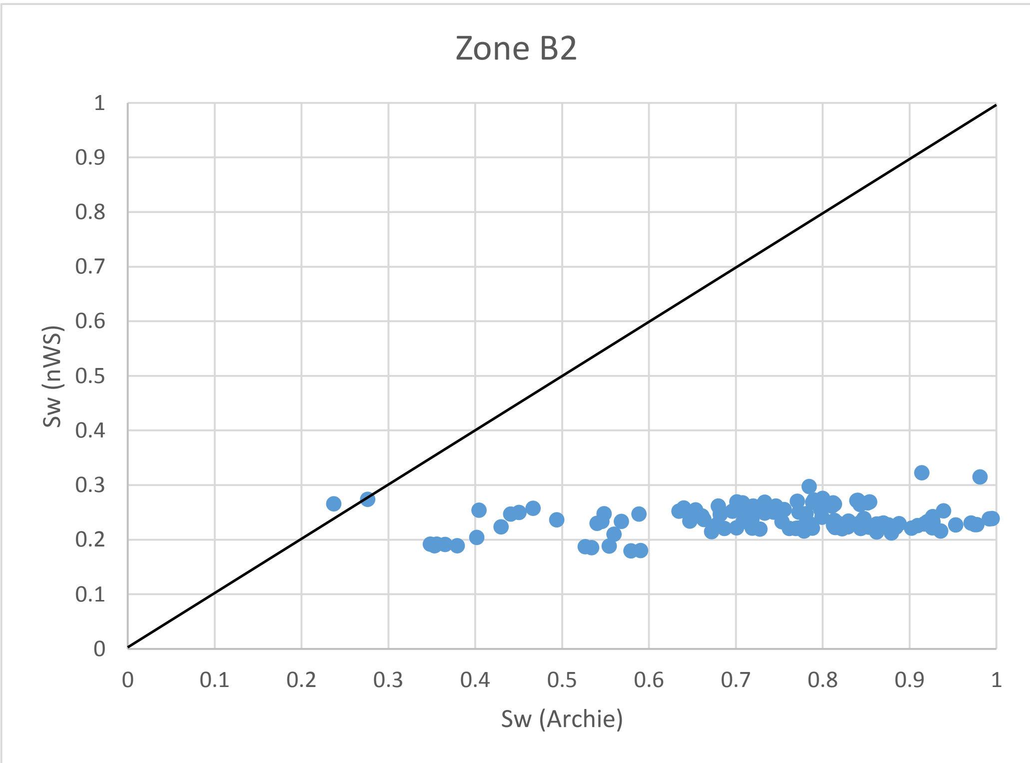


Figure 21: water saturation nWS vs Archie in shaly sand zone B2

The figures (18 & 19) show the deviation between calculated water saturation using Archie equation and Normalized Waxman and Smith equation. The average deviation in the sand zone is 12% showed in figure (18). While the deviation is 66% in the shaly sand zone presented in figure (19).

The figures (20 & 21) presented the water saturation from Archie Equation versus the water saturation from Normalized Waxman and Smith equation. It can be notice that the values are almost match between the two methods at the clean sand zone in figure (20). While there is a huge difference between the two methods at the shaly sand zone; that is due to the effect clay on the formation and the limitation of Archie equation shows in figure (21).

Chapter 5

Conclusion and Recommendation

5.1 Conclusion

Determination of Cation exchange capacity (CEC) from logs is easy to apply and more reflect to the real behavior of the formation since the log has been recorded each half feet. While the cores samples are to be taken from specific points and apply the average to the whole reservoir. CEC values are determined from logs and the normalized Waxman-Smits (nWS) shaly sand evaluation model is used to estimate water saturation in clean and shaly sand zones. The results are compared with the Archie equation. In the clean sand zone, the average CEC value is 0.018 meq/cm3. The average CEC value in the shaly sand zone is 0.11 meq/cm^3 (0.8 meq/g). This suggests that the major clay composition in this zone is Montmorillonite.

Cation Exchange Capacity (CEC) values derived from logs are successfully used to estimate water saturation (Sw). In the clean sand zone where V_{sh} is about 10 %, the average water saturation estimated through Archie is about 6.5% and through nWS is about 7%, The average deviation in water saturation between the Archie and the nWS models is about 12 %. In the shaly sand zone where V_{sh} = 66 %, the average water saturation estimated through Archie is about 75% and through nWS is about 24%, The average the deviation in water saturation between the Archie and the nWS models is about 67 %.

In clean sand, Archie's formula and Normalized Waxman and Smits (nWS) models estimation agrees with each other, since there is no clay in the formation all the assumptions of Archie will be valid.

In the shaly sand zones, Archie's formula will estimate higher values of water saturation due to the effect of shale (clay) on the formation, where the clay appear to add an extra conductivity to the formation. Archie equation assume all of the conductivity in the formation is from the water based on its assumption; therefor it will give us an incorrect estimation. Normalized Waxman and Smits (nWS) model, which is one of the Cation

Exchange Capacity (CEC) models, consider the additional conductivity from the shale and give us estimation that is more accurate.

The right estimation and determination of water saturation and hydrocarbon is very important since it will lead to save the expenses of facilities redesigning and related problems. If the effect of shale was not considered during evaluation of shaly sands, it may lead to erroneous reserve estimation, which in turn affects development strategies, and facilities design to handle the produced hydrocarbon.

The water saturation from estimated from Normalized Waxman and Smits (nWS) model has only been compare with Archie equation due to the lack of the real production data which it has requested. However, the results obtained matched with the principals of each model.

5.2 Recommendation

This evaluation and study can be improve by comparing the results with real production data from the field (X), which will help to estimate the accuracy of the Normalized Waxman and Smits (nWS) model and Archie equation in each case.

Moreover, better results and accuracy can be achieved by applying more than one model of CEC models to estimate the water saturation and compare the results between all the models, which could give a chance to evaluate the difference between the CEC models, the advantages and limitations of each model.

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Appendixes

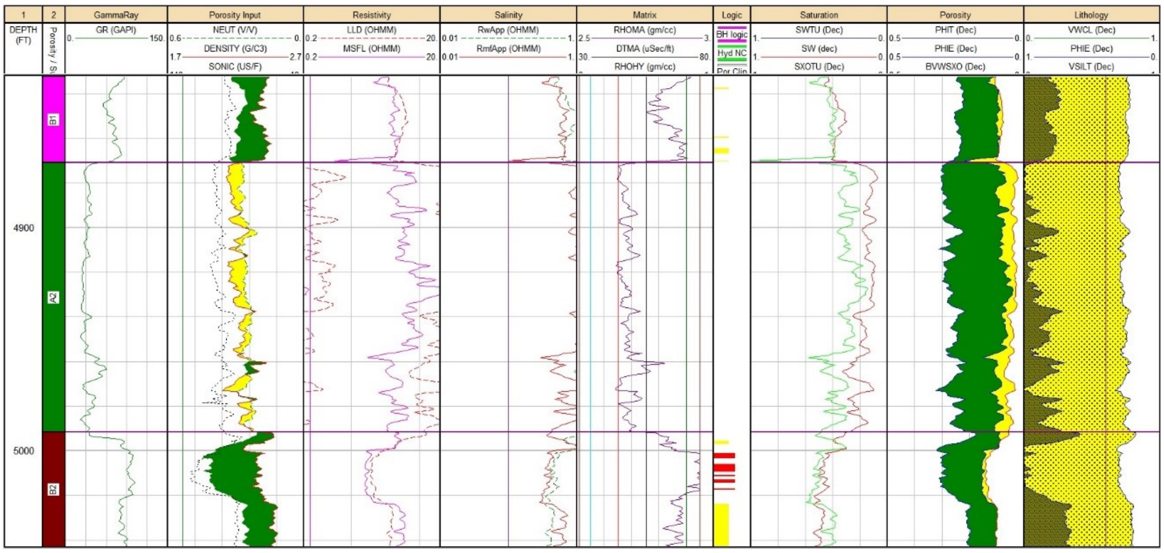

Figure 22: Zone A2 (Clean sand)

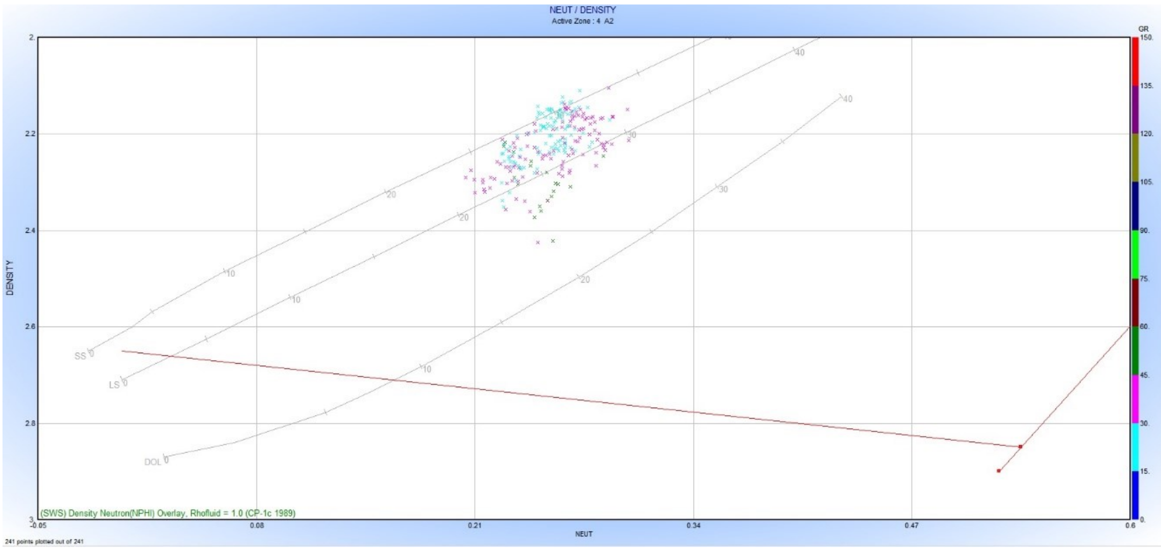

Figure 23: Neutron Density crossplot for Zone A2 (Clean sand)

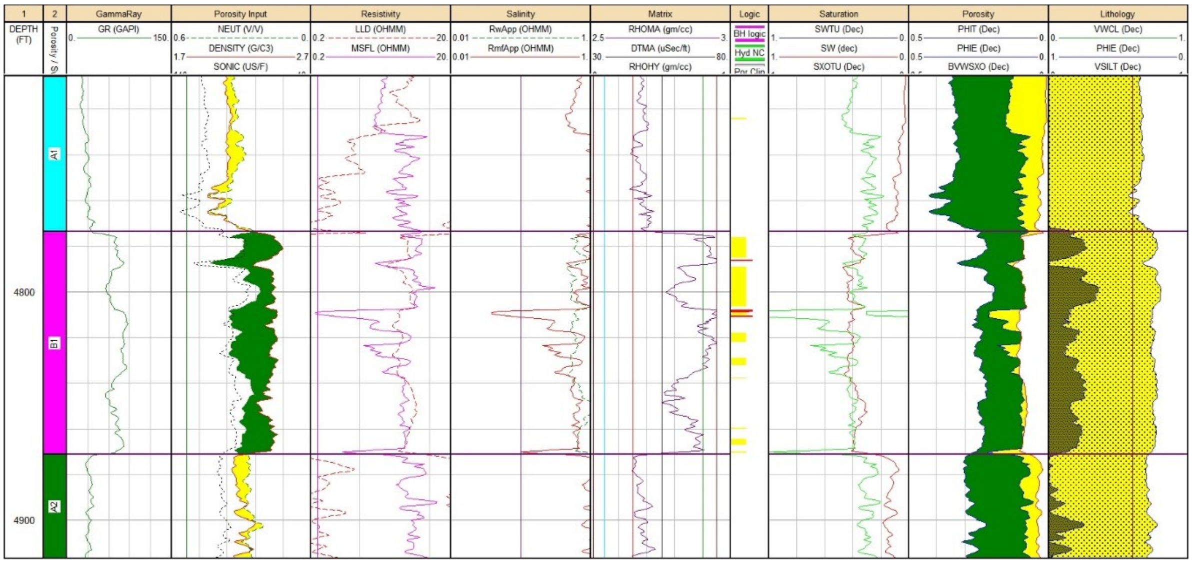

Figure 24: Zone B1 (Shaly sand)

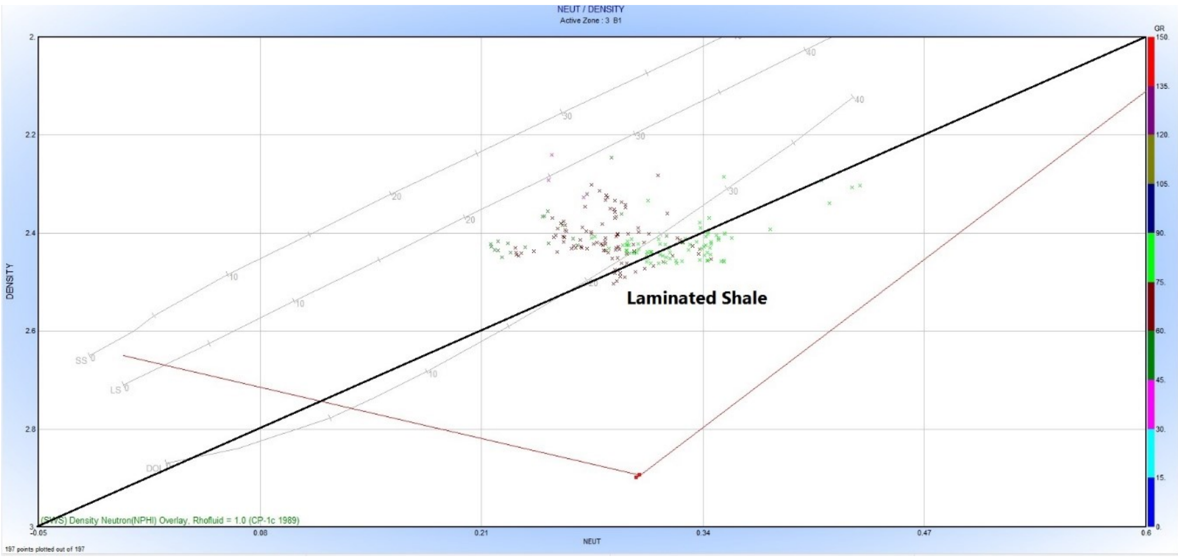

Figure 25: Neutron Density crossplot for Zone B1 (shaly sand)