CERTIFICATE OF APPROVAL

Evaluating Petrophysical Parameters of A Well GG-21 In Malaysian Region Using Wireline Logging.

by

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project. Here, 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 or persons.

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SABENA BINTI SUHAIMI

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ABSTRACT

This project examines the petrophysical parameter of a Well GG-21 in Malaysian region using measurement while drilling (MWD) which is a type of wireline logging. It is an important stage to determine the petrophysical properties of a well because reservoir characterization and hydrocarbon reserves can be known. Therefore, evaluating the petrophysical parameters of a well in Malaysian region is crucial in order to determine whether or not the well is commercially productive. In this study, logging data studied comprises of gamma ray log, resistivity log, neutron log and bulk density log. In order to obtain the finalize results, certain steps need to be carried out. Firstly is the interpretation of Well GG-21, secondly data and information are gathered in order to calculate the petrophysical parameters using mathematical method and Geolog Software. Lastly, results from both methods are then compared and supposedly it will be quite same. For this study, the desired zone of interest is from K1 reservoir till L3 reservoir. This is because, as the well was drilled deeper, it soon began to water out. Average porosity and average water saturation (Sw) has been calculated using both Geolog software and mathematical method. Based on the results, it can be concluded that it shows quite the same results for both methods. In order to correctly estimate the porosity using mathematical method, the correction factor has to be taken into account. K1 reservoir has a moderate good average porosity of 21.2% and it has gas and oil bearing indication. As for K2 till L1 and L3 reservoir, the moderate average range from 17-23% and it has oil-bearing indication. L2 reservoir has clear water bearing sand as shown from logs and formation pressure data. As for the time being, the well has been suspended pending further development in the future.

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Final Year Project 1					Final Year Project 2				
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Project Development					Project Implementation				
Information Gathering									
Project Identification									
	Literature Review								
			Data Collection From Well GG-21						
				Mathematical Calculation					
					Geolog Software				
						Comparing Results From Both Method			
								Data Analysis & Result Evaluation	

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 BACKGROUND OF STUDY

In petroleum exploration and development process, the area of formation evaluation that includes porosity, permeability and water saturations (Sw) is very important in prospecting reservoir characterization and hydrocarbon reserves as oil and gas produced today comes from accumulations in the pore space of reservoir rocks.

Wireline logging has been used to identify petrophysical parameters and reduce completion uncertainty. Wireline logging procedure consists of lowering a logging tool on the end of wireline into a well to measure the petrophysical parameters of the formation. The reservoir or aquifer unit and hydrocarbon (HC) reservoir rocks is form from porous and permeable layers in which water, oil and gas could accumulate in commercial quantity. It is a challenging task in order to accurately estimate the reserves in potential reservoir formation and the impact of such estimation on project economics. Technologies introduced nowadays have meet such challenges and are already demonstrating economic value and the resultant petrophysical analysis of their measurement.

Logging data studied comprises of gamma ray, electrical (spontaneous potential, laterolog deep and shallow), formation density log (FDL) and compensated neutron log (CNL). Gamma ray log is used specifically to estimate the Net to Gross (N/G) and lithological identification efficiency. Porosity is obtained from formation density log (FDL) and Archie's equation is used to determine water saturation (Sw) in that area.

The basic objective in shaly-sand formation evaluation is the description of reservoir quality in terms of petrophysical parameters, type, volume of hydrocarbon resources in place and the expected production behavior. Digital well site 'quicklook' technique and Geolog software is used to evaluate Well GG-21 and the results from both methods are compared and analyzed.

1.2 PROBLEM STATEMENT

The oil industry has a mandate to provide an increasing supply of hydrocarbon while also enhancing ultimate recovery and increasing cost effectiveness of exploration and production. By determining porosity, permeability and water saturation measurements, the important stage in prospecting reservoir characterization and hydrocarbon reserves can be known. The reservoir or aquifer unit and hydrocarbon reservoir rocks in which water, oil and gas could accumulate in commercial quantity are from porous and permeable layers in the formation. Therefore, it is important to accurately estimate the potential reservoir formations because it has a great impact on project economics.

According to Business Times dated August 6th, 2010, Malaysia is expected to become the only net exporter of oil in Asia Pacific by 2014 although it's proven oil reserves in Malaysian Region is declining. A London- based independent information provider had projected Malaysia will account for 1.81 percent of Asia Pacific's oil demand by 2014, while providing 8.36 percent of supply.[6]

Regional oil imports are growing rapidly because demand growth is outstripping the pace of supply expansion. China, Japan, India and South Korea are the principal importers and by 2014, the only net exporter will be Malaysia. According to 2008 BP statistical energy survey Malaysia has proven oil reserves of 5.357 billion barrels at the end of 2007.[6]

Nowadays, with the increasing demand for hydrocarbon, accurate estimation of reserves in potential reservoir formation is challenging. New technologies have been introduced in order to meet such challenges and are already demonstrating economic value. Therefore, evaluating the petrophysical parameters of a well in Malaysian region is crucial in order to determine whether or not the well is commercially productive.

1.3 RESEARCH OBJECTIVES

The main objective is to evaluate the petrophysical properties of a well in Malaysian region using wireline logging. In order to achieve the above objective, the following actions are planned:

i. To examine the different wireline logging tools with their result (i.e: gamma ray log, resistivity log, neutron porosity log and density log) in Well GG-21.

ii. To determine the porosity of the formation and fluid identification using pressure plots.

iii. To determine the water and hydrocarbon saturation in Well GG-21.

iv. To analyze and compare the results obtain using quicklook interpretation and Geolog Software for Well GG-21.

1.4 SCOPE OF RESEARCH

The scope of this study would be on logging data from Well GG-21 using MWD (Measurement While Drilling). This comprises of gamma ray, resistivity, neutron porosity and density log. From the logging data, porosity, water and hydrocarbon saturation (Shc) can be calculated manually as well as software, which gives more authentic data.

As, porosity is define as the ratio of the volume of void or pore space (Vp) to the total of bulk volume (V) of the rock. In this research, only single density log is used which is the primary used as porosity log. Archie's equation will also be used to determine water saturation (Sw) content in that area.

The porous and permeable layers often form the reservoir unit and hydrocarbon reservoir rocks in which water, oil and gas could accumulate in commercial quantity. The petrophysical properties for Well GG-21 will be calculated using mathematical approach and then will be compared using Geolog software. The results should be approximately similar using Geolog software.

1.4.1 MEASUREMENT WHILE DRILLING (MWD)

In order to evaluate petrophysical properties of Well GG-21, Measurement While Drilling (MWD) logs will be used. MWD tools are tools that are conveyed down hole and contained inside a drill collar. This type of drilling method provide the oil and gas exploration operator on the surface with vital real time data such as tool face, borehole pressure, temperature, shock, torque and many more. There are certain MWD tools measure formation properties, such as resistivity, porosity, sonic, velocity and gamma ray. MWD is also capable in measuring accelerometers, which measure acceleration and magnetometers, which measure the strength of earth's magnetic field. The results obtained in MWD will be transmitted digitally to surface using mud pulser telemetry through mud. Telemetry technology is a communication process of data streaming between transmitting and receiving in inaccessible location. The data is transferred between a configured transmitter and a receiver using transmission mediums and carriers. It can be wired or wireless communication system.

MWD tools are powered by battery of a generator powered by circulating fluid. The advantage is that it can power the instrument for a very long period. On the other hand, the power unit can cause a large pressure drop in the circulation fluid. Meanwhile, for battery powered MWD tools, it tends to have limited operations life and must be replaced frequently. It is also very sensitive to the solids in drilling fluid. Sometimes, the battery powered MWD needs to be retrieved to the surface in order to replace the battery and repositioned again in the bottom of drill string.

The daily rate of MWD tools has dropped since the 1990s. MWD tools associated with bottom hole motors gave origin to the complex tool called steerable system. It was an essential ingredient in the advance to more complex trajectories. Improvement of the telemetry system and in the sensor technology increased the capabilities of MWD beyond the directional drilling purposes.

CHAPTER 2

LITERATURE REVIEW

2. LITERATURE REVIEW

2.1 FORMATION EVALUATION

According to Setyowiyoto J. (2008)[1], hydrocarbon saturation (S_{hc}) can be obtained from calculation of water saturation (Sw). The total summation of all saturations in a given rock must total to 100%. Therefore, the existence of water saturation should be less than 100%, where hydrocarbon saturation equal to 100% minus the water saturation (1-Sw). According to Heysse D. (1983)[2], fluids content of a rock formation include water, gas or oil can be predicted by integrated log, especially resistivity log.

According to Asquith G. (1982)[3], oil and gas will be replaced immediately by mud filtrate around the borehole when there is hydrocarbon in the rock formation. Resistivity profile will show a flush zone with resistivity ranging from low to moderate since it is filled with mud filtrate and meanwhile in the virgin formation, resistivity shows an extremely high reading because of high saturation of hydrocarbon.

According to Dewan J.T (1983)[4], porosity is defined as the ratio of the volume of void space or pore space to the total of bulk volume of the rock. The common porosity measuring tools are density, neutron and sonic log. In this research, single porosity log named density log that is porosity log will be used.

Clay or shale volume (V_{sh}) will be calculated using gamma ray log since GR log reflects the proportion of the shale or clay content. By determining the GR max (shale line), GR min (sand line) and GR value of the log, the total volume of shale in the formation can be determined.

2.2 LOG DERIVED EVALUATION

According to Walter H. (1987)[5], hydrocarbon bearing clastic reservoirs is essentially free of clay minerals. The basic objective in shaly sand formation evaluation is a realistic logo derived description of reservoir quality in terms of petrophysical parameters, type and volume of hydrocarbon resources in place. In classic empirical equation, Archie's equation is used. From the equation, formation conductivity, formation water conductivity and formation water saturation (Sw) can be obtained. Archie's equation applies satisfactory to clean sand only . It is known that typical clastic reservoir rock formation may contain different clay minerals in various amounts, therefore no single clay parameter can be used universally to characterize a specific type of reservoir rock. Therefore, using Waxman-Smits model, reliable water saturation (Sw) calculations are provided for reservoirs with drastically different clay contents and over a wide range of formation water salinities. Two critical reservoir parameters, which are clay density and neutron response, can be determined using density, neutron and natural gamma ray data. From logs, the values of clay content, reservoir porosity and fluid saturation type can be determined.

2.3ARCHIE'S EQUATION PARAMETERS

Previously, according to Chen X. (2002)[7] Archie's equation parameters are determined in labs through experiments on the electric properties of rocks. Archie's parameters are influenced by petrophysical properties and wettability. G. E Archie (1942) has developed the first study of correlations between rock resistivity and reservoir characteristics. Based on the study, a model of water-wet rock having only intergranular pores using two basic relations now combined in Archie's equation has been proposed. Initially, Archie's equation has also been used for oil-wet rocks. It is a crucial step in determining the adjustable parameters m and n. The issue of using saturation regression analysis to determined Archie's parameters is the accuracy of the measured water saturation, reflecting the saturation distribution in the reservoir and guaranteeing the accuracy of the Archie parameters determined from the data. Errors can range from 5 to 35 percent. The fact that when different intervals in a well are cored at different pressure and temperature, oil and water in the cores with same lithology and physical properties will be loosed. Meanwhile, if the pores are filled with oil and water without free gas, the oil saturation and water saturation will be 100 percent. As for the rule of thumb, cementation factor m varies from 1.3 to 3.0 and as for the saturation exponent n it is usually very close to 2. For n, water-wet rocks could range from 2.5 to 2.0. Therefore, it can be concluded that wettability and saturation exponent have linear relations and apparently, saturation exponents obtained from saturation analysis reflect influence of wettability. Mathematically, Archie's equation can be expressed as:

$$Sw^n = \frac{a(R_w)}{\phi^m(R_t)} \qquad \text{(Equation 1)}$$

Where;

a = tortusity constant, 1

m = cementation exponent, 2

n = saturation exponent, 2

Φ = porosity

Rt = true resistivity

Rw = water resistivity

Sw = water saturation

2.4 COMPENSATED NEUTRON LOG (CNL)

According to Freitag H. C. (199)[8] , a new compensated neutron porosity instrument has been developed. The new instrument is hoped to be able to obtain high statistical precision while maintaining good porosity sensitivity and small environmental effects. This approach will somehow be more cost effective.This instrument is able to provide accurate porosity response over the entire porosity range, especially in shale's and shaly formations. Interpretation process will be much more easier and more accurate in high porosity, high salinity environments. It is known that, compensated neutron log tools respond primarily to the presence of hydrogen. Increasing hydrogen content will somehow decrease the count rates at the tool detectors. Furthermore, increasing in water salinity will eventually decrease the detector counts. This is because, high neutron capture cross section of chlorine. Therefore, in order to reduce the environmental effects on the porosity measurement and minimize measurement uncertainty, Mickael M. W (1994)[9] has designed a modified compensated neutron porosity tools. There are some tool response criteria that need to be considered such as to improve repeatability in order to increase measurement reliability, reducing borehole size and salinity effect on the porosity measurement in order to decrease measurement uncertainty in high salinity environments and to increase logging speed to acquire more effective and efficient data acquisition. Meanwhile, in order to meet the objectives, there are some steps that need to be carried out such as the need to do cross checks against measurements from existing tools, comparing actual to predicted response, incorporation of temperature, mud weight, formation salinity, bore hole size and mud salinity in computer aided tool design process and lastly, comparing and certificating with core data after environmental corrections.

2.5 RADIOACTIVITY LOGS

According to Fearon R. E. (1951)[10], radioactivity logging has been available over ten years and Well Surveys, Inc initiated this service in the United States. Over the past several years, gamma ray log and neutron curves were presented in the industry and till now these two curves remain the basic curves in radioactivity logging. Radioactivity logging main application is to determine stratigraphic correlation. Gamma ray curves is use to obtained the relative gamma ray intensities emitted by the strata and the result is excellent because it is affected by bore hole condition such as casing and hole size. Concentration of radioactive contaminants in sands, limestones, dolomites and shale's was found consistent over wide range of areas. Then, the neutron curve was introduced in order to assist in solving correlation problems because it is more strongly affected by lithological conditions and hydrogen content. The combined use of gamma ray curve and neutron curve resulted in a well log, which has very helpful in distinguishing and locating shale, fluid field porosity, anhydrite and granite. In order to obtain the gamma ray curve, an instrument consisting of a detector of gamma ray and electronic equipment for transmitting the indications of the detector to surface equipment is lowered into the well. The purpose of lowering the tool is to collect data so that the intensities of the gamma rays emitted naturally by the rock strata can be recorded. As for neutron curve, the measurements used are similar but it is equipped with a shorter detecting chamber. The detecting chamber is affected by gamma radiation, which has resulted from the bombardment of the formation by neutrons. Some rocks radiate more gamma rays than others and there is a strong correlation between a rock classification type and the intensity of the gamma ray radiation emitted by the rock type. As for the neutron curve, there are three kinds of gamma radiation differing in both energy and origin. The three main sources of origin are I_1, which is the intensity of gamma ray, produced by the action of neutrons upon the formation, I_2 is the intensity of the scattered radiation and lastly I_3 is the intensity of gamma ray radiation emit by the formation rock themselves.

2.6 FORMATION DENSITIES AND NEUTRON POROSITY

According to Evans. M. (1989)[12], it is critically important to know the formation bulk density and neutron porosity in order to know the quantitative evaluation of potential oil and gas deposits. By knowing the two measurements, accurate formation porosity can be determined together with lithology identification and gas detection. The purpose of running them in one drill collar is because to minimize the tool length and to safely retrieve both nuclear sources independently in the drillstring. Measurements while drilling will provide an excellent borehole conditions and therefore the invasion of mud filtrate is minimized, borehole washouts can be decrease and lastly the effective logging speed is often 20 to 100 times slower than conventional wireline log. Therefore, nowadays Compensated Density Neutron (CDN) is run in combination with Compensated Dual Resistivity (CDR) to provide a real time log while drilling. Neutron porosity measurements have been modified in order to enhance the epithermal nature of neutron porosity response and to reduce the adverse environmental effects on the gamma ray that has been captured. The main reason the energy of the detected neutrons is predominately is because high percentage of the incoming thermal neutron flux is absorbed as it passes through the drill collar wall. Underneath the detector banks, there is a wrap of cadmium that shields the neutron flux from thermal neutrons arriving from the inner mud column. This will eventually eliminates the adverse effect caused by thermal absorber in the borehole or formation. The most common thermal absorber found in drilling environment is chlorine. In order to determine the sensitivity of Compensated Density Neutron (CDN) response towards salinity, measurements from a large water tank where the salinity was changed from fresh to fully saturate were taken and analyzed. The result shows that Compensated Neutron Density (CDN) is principally epithermal with the count rate only drops at a very minimum rate. As for the bulk density measurement, a 1.7 Curie cesium-137 gamma ray source is used in conjunction with two gain stabilized in order to provide a high quality borehole compensated and density measurements. Principally Compton scattering attenuates gamma rays that are emitted by the source and the received gamma ray flux is inversely proportional to the electron density of the formation.

2.7 CURRENT CALIBRATION AND QUALITY CONTROL

According to Brami J. B. (1991)[13], measurement While Drilling (MWD) logs are usually run in high operating cost and hostile environments. They are used in the case when wireline logs cannot be obtained. Therefore, when MWD exhibits desired or expected results, it is believed. On the other hand, if the MWD records unexpected results, the data is suspected to be inaccurate or uncalibrated. As a conclusion, regardless of the type of measuring device, wireline or MWD, calibrations must be understood before a log is trusted. As for Gamma Ray (GR), the primary calibration is done at the University of Houston. Unfortunately, the gamma ray pit was too small for most MWD tools therefore, a reference tool is placed in the test pit and transforms are created to relate larger tools to the reference tool's measurements. Gamma ray can also be calibrated using a radioactive device clamped around the sensor. This device contains a precise volume of radioactive material such as potassium, uranium and thorium mixture and is similar to the test pit. As for resistivity, primary calibration is not done and therefore there are no pits or single points of reference taken to calibrate resistivity tools. Meanwhile, for density and photoelectric absorption factor (PEF), the primary calibrations for MWD density tools are identical with those performed on wireline tools. Calibration pits containing slabs of quarried rock or simulated formations, such as tanks of rock chips are used for the calibration purpose. Then, the MWD density sensor measurements are compared with known values for the calibration pits. Similar techniques are used in order to perform secondary calibration. Measurements of blocks of pure materials are taken using MWD tools. As standards, aluminum and magnesium blocks are used. In real field situation, clamp on jigs containing radioactive source are used for reference. Similar to density tools, the primary calibration for MWD neutron tools is also achieved in a test pit. As for the secondary calibrations, it uses water tanks to calibrate.

2.8 EFFECT OF WIRELINE CONDITION ON WIRELINE LOG

According to David L. B. (1993)[14], there are difference characterizations between measurement while drilling (MWD) and wireline density logs. One of the differences is the effect of wellbore condition on Compensated Density Neutron (CDN) measurement which is generally greater than on a wireline Compensated Neutron Log (CNL) porosity measurement. This is because CDN tool is centered nominally in the borehole while wireline is eccentered. This will eventually results in environmental corrections for CDN neutron porosity measurements compared with the wireline CNL tool. Based on some experiments that have been done, by centralizing the CDN neutron measurement it will eventually have a strong effect on the borehole correction. This is because the tool is centered in the borehole and therefore the correction is quite large. Meanwhile, using the eccentered CNL tool, the effect is small because by increasing the borehole size, it only removes formation to the other side of the tool whereas it removes formation from every side of the CDN tool. In fact, the borehole size effect for the CDN neutron tool is comparable in magnitude to the standoff effect for the CNL tool in a large borehole. Furthermore, by centralizing the CDN tool it eventually has a profound effect on the mud weight corrections. As it is known, the centralized CDN tool will have greater sensitivity to mud weight compare to CNL tool. This is because, neutrons that interact mainly with formation and enter the tool after passing through little mud dominate CNL tool. On the other hand, CDN tool will detect neutrons that pass through a substantial volume of mud because the tool is centered in the borehole. By centralizing the CDN tool, it will not have a large effect on salinity response compared with the eccentered CNL.

2.9 GAMMA RAY LOGS

According to Keith W. K (1995)[15], gamma ray (GR) log is usually run in conjunction with resistivity log. The main objective of gamma ray log is to determine the amount of shale in the formation. Although gamma ray response is attenuated by the cement and pipe thickness, the logs can still be run in air or mud filled open holes and also in cased holes. Gamma rays that the tool is measuring are known to be the naturally occurring gamma ray and not the induced gamma ray caused by radioactive logging source, which is density tool. However, these natural gamma rays tend to emanate from radioactive potassium, thorium and uranium. As for potassium and thorium, they are closely associated with shale, while uranium may be found in sands, shale's and some carbonates. Over the years, gamma ray (GR) tools are used to measure total natural radiation present in the wellbore. Today, technology has improved tool designs by dividing the natural gamma rays into parts contributed by each element. This is based on assumption that all the radiation comes from uranium, potassium and thorium. By doing this, accurate estimation of shale content can be determined. Most uranium is found in sandstone, therefore, by removing the uranium from the total gamma ray (GR) curve, percent of shale present can be estimated accurately. By using gamma ray (GR) log, volume of shale (V_{sh}) in the formation can be calculated.

$$Vsh = \frac{GR\log - GR\min}{GR\max - GR\min} \times 100 \qquad \text{(Equation 2)}$$

Where;

V_{sh}	=	volume of shale
GR_{max}	=	gamma ray value at the shale point
GR_{log}	=	gamma ray value in the zone of interest
GR_{min}	=	the lowest gamma ray value in a nearby zone.

2.10 DENSITY LOG

Darwin E. (2003)[11] concluded that, Compton scattering method is used in order to assist in measuring the electron density. Density (ρ) determined by the density tool is called RHOB (ρ_b) where b is the bulk volume of a rock. Meanwhile, rock structure of minerals such as sandstone or limestone is called matrix. Where the density of this structure is called matrix density, ρ_{ma}. This is the density that the tool would read if the formation had zero porosity. Density in the pore space, which is usually filled with mud filtrate, is called fluid density, ρ_f. In order to apply porosity equation, density of the matrix and the density of the fluid in the pore space should be determine. Based from experience and laboratory measurements, the matrix density for limestone is 2.71 g/cc, 2.87 g/cc for dolomite and 2.65 g/cc for sandstone. Since the density tool has a shallow depth of investigation, the formation will be most likely filled with mud filtrate. Therefore, the fluid density is generally assumed to be 1.0 g/cc but correction can be applied to the value if necessary. Mathematically, porosity equation can be expressed as:

$$\phi = \frac{\rho_{ma} - \rho_{\log}}{\rho_{ma} - \rho_f} \qquad \text{(Equation 3)}$$

Where:

ρ_{ma}	=	matrix density
ρ_f	=	fluid density
ρ_{log}	=	log density

2.11SAMPLE CALCULATIONS

Log samples from a field have been taken in order to do 'quicklook' interpretation and to determine cutoff value, volume of shale, porosity and water saturation using Archie's equation.

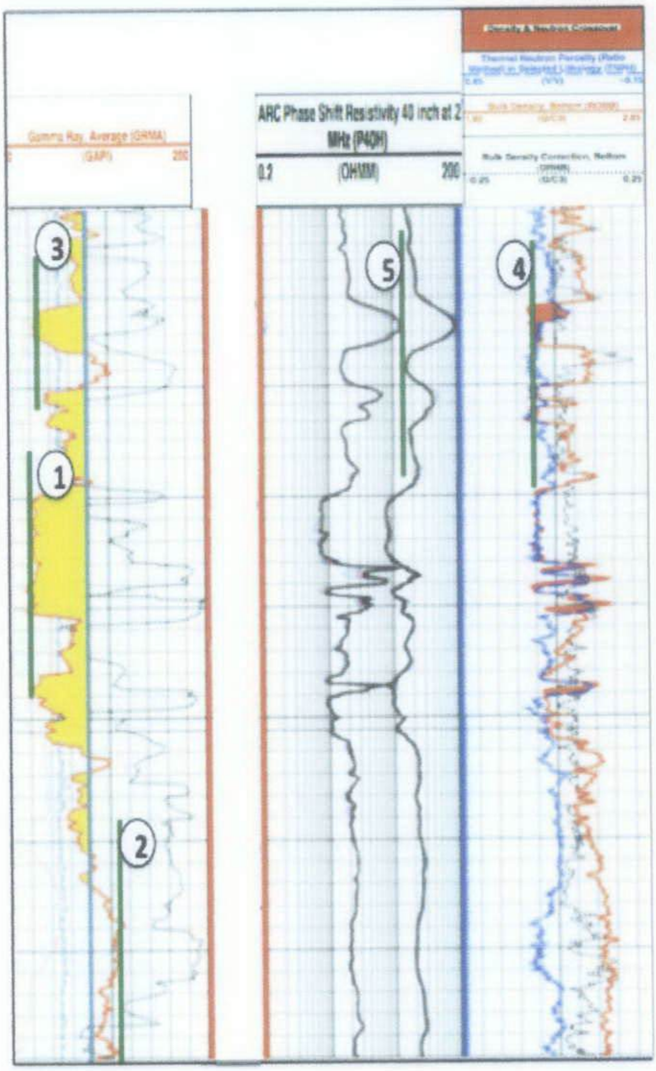

Figure 1: Log Sample

Where:

Point 1	=	gamma ray value at the lowest point
Point 2	=	gamma ray value at the highest point
Point 3	=	gamma ray value at the zone of interest
Point 4	=	density log value at the zone of interest
Point 5	=	resistivity log value at the zone of interest

2.11.1 CUTOFF VALUE

According to Worthington P. F. (1995)[16], the purpose of calculating cutoff value is to determine the reservoir and non-reservoir area. Therefore, Point 1 is taken to be the lowest gamma ray value reading at that area which comes to be 18. Meanwhile, for the maximum gamma ray reading, Point 2 is taken to be 118. The calculation on determining the cutoff value was done as shown in Appendix 1. The cutoff value was found to be 68.

2.11.2 VOLUME OF SHALE

According to Keith W. K (1995)[15], the main objective of gamma ray log is to determine the amount of shale in the formation. Therefore, in order to calculate the volume of shale based on Figure 1, Point 3 is taken from the above log, which appears to be 24 based on the Gamma Ray log reading. The calculation on determining the volume of shale was also done in Appendix 1. The Volume of Shale (Vsh) was found to be 6%. This indicates that at that area, the volume of shale is only 6% and 94% is sandstone. Thus, this shows that the area is a reservoir area and there is hydrocarbon potential.

2.11.3 POROSITY

According to Freitag H. C. (1996)[8], porosity is defined as the percentage of pore volume or void space, or that volume within rock that can contain fluid. Therefore, determining the porosity of a given formation is crucial in order to estimate how much hydrocarbon can be stored in the formation. Thus, Point 4 is taken to be 2.2, which is the Density Log (ρ_{log}) of that formation. For 'quicklook' purpose, Density Fluid (ρ_f) is taken to be 1, which is freshwater, and meanwhile, Density Matrix (ρ_{ma}) is taken to be 2.65, which is for sandstone. The calculation on determining the porosity of the formation was done as shown in Appendix 1. The porosity value was found to be 0.2727.

2.11.4 WATER SATURATION

According to Saleh B. A (2005)[17], by using Archie's equation, water saturation (Sw) value can be obtained. In order to do 'quicklook' interpretation, petrophysical properties such as saturation exponent (n) and cementation exponent (m) will be taken as 2. Meanwhile, tortusity factor (a) is taken to be 1. True resistivity value (Rt) is 25 based on Point 5 on the log and the value of water resistivity (Rw) is obtained using a Pickett Plot. The calculation on determining the water resistivity (Rw) value and water saturation (Sw) value was done as shown in Appendix 1. The water resistivity (Rw) value was found to be 0.2 and water saturation (Sw) value is 0.328.

2.11.5 HYDROCARBON SATURATION

Saleh B. A (2005)[17], states that hydrocarbon amount in the formation cannot be directly measure. Therefore, resistivity log is used to infer the volume of hydrocarbon in that area. The calculation on determining the hydrocarbon saturation (S_{hc}) was done as shown in Appendix 1. The hydrocarbon saturation (S_{hc}) was found to be 0.672, which equals to 67%.

CHAPTER 3

METHODOLOGY

3. METHODOLOGY

3.1 RESEARCH METHODOLOGY

This section consists of project analysis where it involves interpretation of Well GG-21, data and information gathering, calculating the petrophysical parameters using mathematical method and Geolog Software, comparing the results and lastly analyzing the data.

The first step is to do some research, collecting and summarizing data from Well GG-21. Literature sources such as experimental studies, journals and reference books related to wireline logging method also contribute information to this project.

After analyzing all the data from the log, the petrophysical parameters of the well will be calculated using mathematical method and also by generating Geolog software. Next, the results will then be compared to and supposedly the results will be quite the same.

Finally, after prior research and analytical calculation, the petrophysical parameters for Well GG-21 can be obtained.

CHAPTER 4

RESULTS AND DISCUSSIONS

4. RESULTS AND DISCUSSIONS

In this section, all results from Well GG-21 log interpretation are presented. The results are as follows:

4.1 FORMATION EVALUATION

The formation evaluation of Well GG-21 was divided by reservoir sections. Results of each zone were discussed and rock types were also identified in the subsection. Methods that were used for evaluation are gamma ray log, resistivity log, neutron log and bulk density log.

4.1.1 WELL GG-21

Well GG-21 log is presented at Figure 4 (Appendix 2). As for these particular studies, the author will be doing interpretation till L3 reservoir because the rest of the log has been confirmed water.

i) K1 reservoir

Gamma Ray reading gives low reading; indicate low radioactive formation, which is free shale formation, (sandstone). Resistivity log give high reading indicates formation contains hydrocarbon. This zone has a gas oil contact. Therefore it gives high resistivity values, which indicate a hydrocarbon bearing formation. Neutron porosity log give low reading while density log gives high reading. This indicates that it is fills with gas; neutron porosity is low due the lower concentration of H+ ion in gas than in oil/ water. Beside, gas has lower density than oil/water.

In this zone, we can clearly see the Neutron and Density log curve crossover each other, indicate gas effect/ butterfly effect. It can also be seen that, at the lower part of the K1 reservoir, oil section can be seen.

ii) K2 reservoir

Gamma Ray reading gives low reading; indicate low radioactive formation, which is free shale formation indicating probable reservoir formation. Resistivity log give relatively high reading indicates formation contains hydrocarbon. This zone give high resistivity values may indicate a hydrocarbon bearing formation. While the density and neutron log difference is relatively small, mirror image, indicating that this is a probably oil bearing zone.

iii) K3 reservoir

Gamma Ray reading gives low reading; indicate low radioactive formation, which is free shale formation, (sandstone). Resistivity log give relatively high reading at the upper section, which indicates formation contains hydrocarbon. In other hand, at the lower section, the resistivity reading is very low indicates formation contains water formation due to high conductivity. The density and neutron log difference is relatively small, mirror image, indicating that this is a probably oil bearing zone at the upper K3 reservoir. As for the lower part, the neutron and density log are shown intersecting /stacking effect indicating that this is an aquifer zone from quick look method. It can be concluded that this zone is an oil water contact (OWC) zone.

iv) K4 reservoir

Gamma Ray reading gives low reading; indicate low radioactive formation, which is Sandstone. Resistivity log give high reading and formation may contain hydrocarbon. At the lower K4 reservoir section, neutron give low concentration reading of H^+, so probability of oil-bearing formation is high in this zone. Density porosity reading is high, that indicate the probability of oil is high in this zone. We can also see at the lower K4 reservoir, both lines neutron density are shown stacking effect, which indicate oil zone in a sandstone formation.

v) L1 reservoir

Gamma Ray gives low reading; indicate low radioactive formation, which is free shale formation, (sandstone). Resistivity log give high reading at the upper section that indicates formation may contains hydrocarbon bearing. Meanwhile, at the lower section, the resistivity log reading is quite low indicates water-bearing zone. The density and neutron log difference is relatively small, mirror image, indicating that this is a probably oil bearing zone at the upper L1 reservoir. As for the lower part, the neutron and density log are shown intersecting /stacking effect indicating that this is an aquifer zone from quick look method. It can be concluded that this zone is an oil water contact (OWC) zone.

vi) L2 reservoir

Gamma Ray reading gives low reading; indicate low radioactive formation, which is free shale formation, (sandstone). Resistivity log give very low reading indicates formation contains water formation due to high conductivity. Most probably this zone is at the water zone. The neutron and density log are shown intersecting /stacking effect indicating that this is an aquifer zone from quick look method.

vii) L3 reservoir

Gamma Ray gives low reading; indicate low radioactive formation, which is free shale formation, (Sandstone). Resistivity log give high reading that indicates formation may contain hydrocarbon bearing at the upper zone. The density and neutron log difference is relatively small, mirror image, indicating that this is a probably oil bearing zone at the upper L3 reservoir. As for the lower part, the neutron and density log are shown intersecting /stacking effect indicating that this is an aquifer zone from quick look method. It can be concluded that this zone is an oil water contact (OWC) zone. We can conclude that both water and oil exist in this zone, but water is more than oil.

4.2 PETROPHYSICAL INTERPRETATION

4.2.1 FLUID TYPE

In order to identify fluid type and contact, based on the well report, MDT (Modular Formation Dynamics Tester) was run in Well GG-21 and 34 pretests were taken. 22 valid, 7 tight and 1 supercharged. Pressure plot was done in order to proved the type of fluid in that particular sand. There are three (3) main fluids encountered in Well GG-21, which are gas, oil and water.

Depth versus pressure was plotted on a graph paper in order to determine the gradients and contacts. Pressure plot for K1 reservoir (Figure 5-1) is presented in Appendix 2-1. It can be seen clearly that there is a GOC (gas oil contact) at depth 7391.7 ft in that particular reservoir area.

Based on the pressure plot for K2 reservoir in Figure 5-2 (Appendix 2-1), the gradient shows oil gradient, which is 0.29 psi/ft.

There is an OWC (oil water contact) at depth 7493ft in K3 reservoir as shown in Figure 5-3 (Appendix 2-1). This is based on the fact that both pressure gradients, 0.330 psi/ft and 0.420 psi/ft lies in the oil and water gradient.

In K4 reservoir, as shown in Figure 5-4 (Appendix 2-1), the gradient shows there is oil.

As for in L1 reservoir, there is an OWC (oil water contact) at depth 7686 ft. This is shown in Figure 5-5(Appendix 2-1). Pressure gradient for both oil and water is 0.326 psi/ft and 0.447 psi/ft respectively.

Last MDT (Modular Formation Dynamics Tester) point was taken at L2 reservoir. 3 points were taken in order to do pressure plot. Based on Figure 5-6 (Appendix 2-1), it is proved to be water gradient.

Figure 5-7 in Appendix 2-1 shows the overall formation pressure that was done in Well GG-21. MDT (Modular Dynamics Tester) was run till L2 reservoir, this is because as the well was drilled deeper it soon began to water out. Based on the report, wireline logs has been run in order to further confirmed this.

4.2.2 POROSITY AND WATER SATURATION

In order to assist in calculating porosity and water saturation (Sw), the author had used mathematical method and also by generating Geolog software. The results from both methods supposedly will be quite the same. For this purpose, the author will determine porosity and water saturation (Sw) till L3 reservoir. This is because; as the well was drilled deeper it soon began to water out. Therefore, it is not the zone of interest for this specific case of studies.

In K1 reservoir, based on the Geolog at Figure 6-1 (Appendix 2-1), the average porosity, water saturation and hydrocarbon saturation comes to be ~21.2%, 36% and 64% respectively. Meanwhile, in K1 reservoir, there are two (2) types of fluid, which are gas and oil. Therefore, by using mathematical method, average porosity is also 21.2%, average water saturation (Sw) 37.4% and average hydrocarbon saturation (S_{hc}) in K1 reservoir is 62.6%. The calculation on determining average porosity, water saturation (Sw) and hydrocarbon saturation (S_{hc}) value was done as shown in Appendix 2-1.

In K2 reservoir, the value that had been obtained using Geolog at Figure 6-2 (Appendix 2-1) is 22% for average porosity, 51% average water saturation (Sw) and 49% average hydrocarbon saturation (S_{hc}) The values obtained using mathematical method is slightly different compared to value obtained using Geolog. As for porosity, the average value is 21.8%, average water saturation (Sw) 49% and lastly the average hydrocarbon content in that specific reservoir is 51%. Calculation on determining the average porosity, water saturation (Sw) and hydrocarbon saturation (S_{hc}) value was done as shown in Appendix 2-1.

As for K3 reservoir, based on the Geolog at Figure 6-3 (Appendix 2-1), average porosity is estimated to be 19.5%, 52% for average water saturation, and 48% hydrocarbon saturation (S_{hc}). In order to determine the petrophysical properties, the author had also done mathematical calculation. Results obtained for average porosity is 20%, average water saturation (Sw) is 49% and average hydrocarbon saturation (S_{hc}) is 51%. Calculation was done in Appendix 2-1.

Figure 6-4 (Appendix 2-1) shows the value for average porosity for K4 reservoir which is 17%, average water saturation (Sw) value in 60% and average hydrocarbon saturation (S_{hc}) is 40%. Compared to the values obtained using mathematical calculation, average porosity comes to be 18%, average water saturation (Sw) 60% meanwhile average hydrocarbon saturation (S_{hc}) is 40%. Calculation was done in Appendix 2-1.

Reservoir L1 has an average porosity value of 21.5%, average water saturation (Sw) value of 50% and average hydrocarbon saturation (S_{hc}) is 50%. All results are obtained using Geolog as shown in Figure 6-5 (Appendix 2-1). In order to compare the results obtained using mathematical calculation, the final results showed an average of 48% water saturation (Sw) in that desired reservoir, 21% average porosity and lastly 52% average hydrocarbon saturation (S_{hc}). Calculation to obtain the results was done in Appendix 2-1.

After generating the Geolog, L2 reservoir is found to be water interval. This is because, based on Figure 6-6 (Appendix 2-1) is clearly shows that the water saturation (Sw) value is very high which is almost reaching 100%. Meanwhile, as for the average porosity it comes to be 23%. Values obtained using mathematical calculation are quite identical from the Geolog results. As for porosity, the average is 24%, average water saturation (Sw) is 97% and lastly average hydrocarbon saturation (S_{hc}) is 3%. Calculation to obtain the results was done in Appendix 2-1.

Lastly, for L3 reservoir, by generating Geolog as shown at Figure 6-7 (Appendix 2-1), the value for average porosity comes to be 20%, average water saturation (Sw) value is 67% and average hydrocarbon saturation (S_{hc}) in 33%. By using mathematical calculation, it gives the similar result as obtained by Geolog, which are 20% for an average porosity, 67% average water saturation (Sw) and 33% average hydrocarbon saturation (S_{hc}) content. This shows that, by using mathematical calculation and Geolog, the results obtained should supposedly will be quite the same.

4.3 PETROPHYSICAL PROPERTIES

4.3.1 TORTUOSITY CONSTANT (a), CEMENTATION EXPONENT (m) AND SATURATION EXPONENT (n)

In order to calculate water saturation (Sw) adopting Archie's Model to get a quicklook evaluation of the water saturation, electrical properties such as a, m, & n are known from core sample reports which are (1, 1.86, & 1.75 respectively).

4.3.2 FORMATION WATER RESISTIVITY, R_W

Formation water resistivity, or Rw, is calculated in order to determine Sw. In this study, Rw is obtain by using a Picket Plot. This approach is to use log where clean sand and water-bearing zone is identified manually before calculating Sw using Archie calculation. The interval for the clean sand is located at L2 reservoir and initially at depth 11525m TVD till 11550m TVD. This is shown at Figure 7 Appendix 2-2.

The basis for this plot is to assume cementation exponent, m, is unknown and that we can use an Archie Equation relationship which transform to the base ten logarithm equation which is the equation of a straight line in log-log coordinates.

By plotting true resistivity, Rt versus porosity, Φ on a log-log plot, we should get a straight line as long as cementation exponent, m, is constant. The intersection between Rt and Φ is Rw. The results for the Picket plot for Well GG-21 is as shown in Figure 8 (Appendix 2-2). Based on the plot, the value of Rw for Well GG-21 is 0.1.

4.4 RESULT SUMMARY

Below are the result summaries of all petrophysical properties obtained for Well GG-21 (K1 reservoir till L3 reservoir). The results obtained using Geolog software and mathematical calculation are put side by side to allow better comparison between all values.

Table 2: GOC and OWC for Well GG-21 at specific unit sand and depth

Unit Sand	Contact
	Well GG-21
K1	GOC at 7392 ft TVDSS
K2	-
K3	OWC at 7492.5 ft TVDSS
K4	-
L1	OWC at 7686 ft TVDSS
L2	-
L3	-

Table 3: Summary of petrophysical parameter for Well GG-21

Unit Sand	Φ_{avg} (%)		Sw_{avg} (%)		Shc_{avg} (%)	
	Geolog	Mathematical	Geolog	Mathematical	Geolog	Mathematical
K1	21.2	21.2	36	37.4	64	62.6
K2	22	21.8	51	49	49	51
K3	19.5	20	52	49	48	51
K4	17	18	60	60	40	40
L1	21.5	21	50	48	50	52
L2	23	24	100	97	-	3
L3	20	20	67	67	33	33

As shown above, the results obtained using Geolog software and mathematical method are quite the same. Therefore, it is an important part of the learning experience to get close to hardware and software workings of Geolog and to understand the physics behind it.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Results from the studies showed that Well GG-21 initially had shown signs of hydrocarbon potential. However, as the well was drilled deeper it soon began to water out and wireline logs have confirmed this. Therefore, the author had selected several zone of interest in order to assist in these studies.

From the formation evaluation, 'butterfly effect' can be seen clearly at upper K1 reservoir. This is because, the resistivity log shows high reading, which indicates hydrocarbon bearing. By doing further evaluation on neutron porosity log and density log, it confirms that it is a gas-bearing zone. As for K3 and L1 reservoir, looking at the high resistivity log reading and stacking of neutron porosity log and density log, it shows that it is an oil-bearing zone. L2 reservoir has clear water bearing, which indicates low resistivity log reading.

In order to further prove the results obtained by quicklook interpretation, MDT (Modular Formation Dynamics Tester) data results have been used to construct a pressure data. Based on the pressure data constructed, K1 reservoir was proved to have gas oil contact (GOC) at depth 7392 ft TVDSS. Meanwhile, for K3 reservoir and L1 reservoir, oil water contact (OWC) can be seen at depth 7492.5 ft TVDSS and 7686 ft TVDSS respectively.

Average porosity has also been determined in this study. In oil and gas reservoir, it is important to estimate the pore volume available for storage of hydrocarbons and water. Therefore, it can be concluded that K1 reservoir has moderate good porosity 21.2% and it has gas and oil bearing indication. Meanwhile, K2 till L1 and L3 reservoir has moderate good porosity range from 17-23% and it has oil-bearing indication. As for the rest of the reservoir, it has been confirmed water bearing zone.

There are many techniques available to determine the water saturation of a formation and therefore the hydrocarbon saturation. However, for simplicity Archie

Equation has been selected. Saturation is a percentage or fraction of total capacity that hold particular fluid. As for K1 reservoir, it has good average hydrocarbon saturation (Shc), which is 62.6%. Meanwhile, K2 till L1 and L3 reservoir has moderate average water saturation (Sw) range from 50-67%. As for L2 reservoir, it has clear water bearing zone.

As for the time being, the best recommendation is to suspend the well pending to further development in the future. This is because, as mentioned before, the well began to water out as the well was drilled deeper.

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APPENDICES

APPENDIX 1 (CALCULATIONS)

Calculation of Cutoff Value

Cutoff Value = $\frac{(GR\max - GR\min)}{2} + GR\min$ (Values taken from Figure 1)

= $\frac{(118-18)}{2} + 18$

= **68**

Calculation of Volume of Shale (Vsh)

Vsh = $\frac{GR\log - GR\min}{GR\max - GR\min} x100$ (Values taken from Figure 1)

= $\frac{24-18}{118-18} x100$

= **6%**

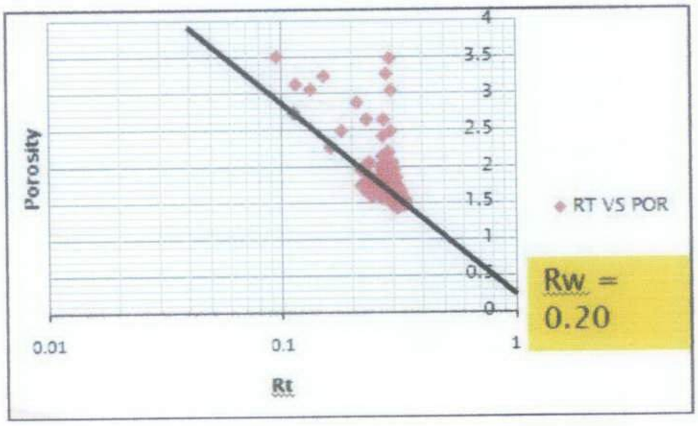
Calculation of Porosity

Φ = $\frac{\rho ma - \rho\log}{\rho ma - \rho f}$ (Values taken from Figure 1)

= $\frac{2.65-2.2}{2.65-1}$

= **0.2727**

Calculation of Water Resistivity (Rw)



(Values taken from Figure 1)

Figure 3 : Pickett Plot

In order to obtain the water resistivity for the Pickett Plot, there are certain rules that needs to follow. Firstly, the cleanest sand zone is selected where there is no shale content. Secondly, the section is confirmed water bearing zone. Water Resistivity (Rw) value is the intersection between porosity and resistivity which is **0.2**.

Calculation of Water Saturation (Sw)

(Values taken from Figure 1)

$$Sw^n = \frac{a(Rw)}{\Phi^m(Rt)}$$

$$Sw^2 = \frac{1(0.2)}{0.2727^2(25)}$$

$$= \sqrt{\frac{1(0.2)}{0.2727^2(25)}}$$

$$= \mathbf{0.328}$$

Calculation for Hydrocarbon Saturation

$S_w + S_{hc} = \quad 1$ (Values taken from Figure 1)

$S_{hc} \quad = \quad 1 - S_w$

$S_{hc} \quad = \quad 1 - 0.328$

$\quad = \quad$ **0.672**

APPENDIX 2
(FORMATIONEVALUATION)

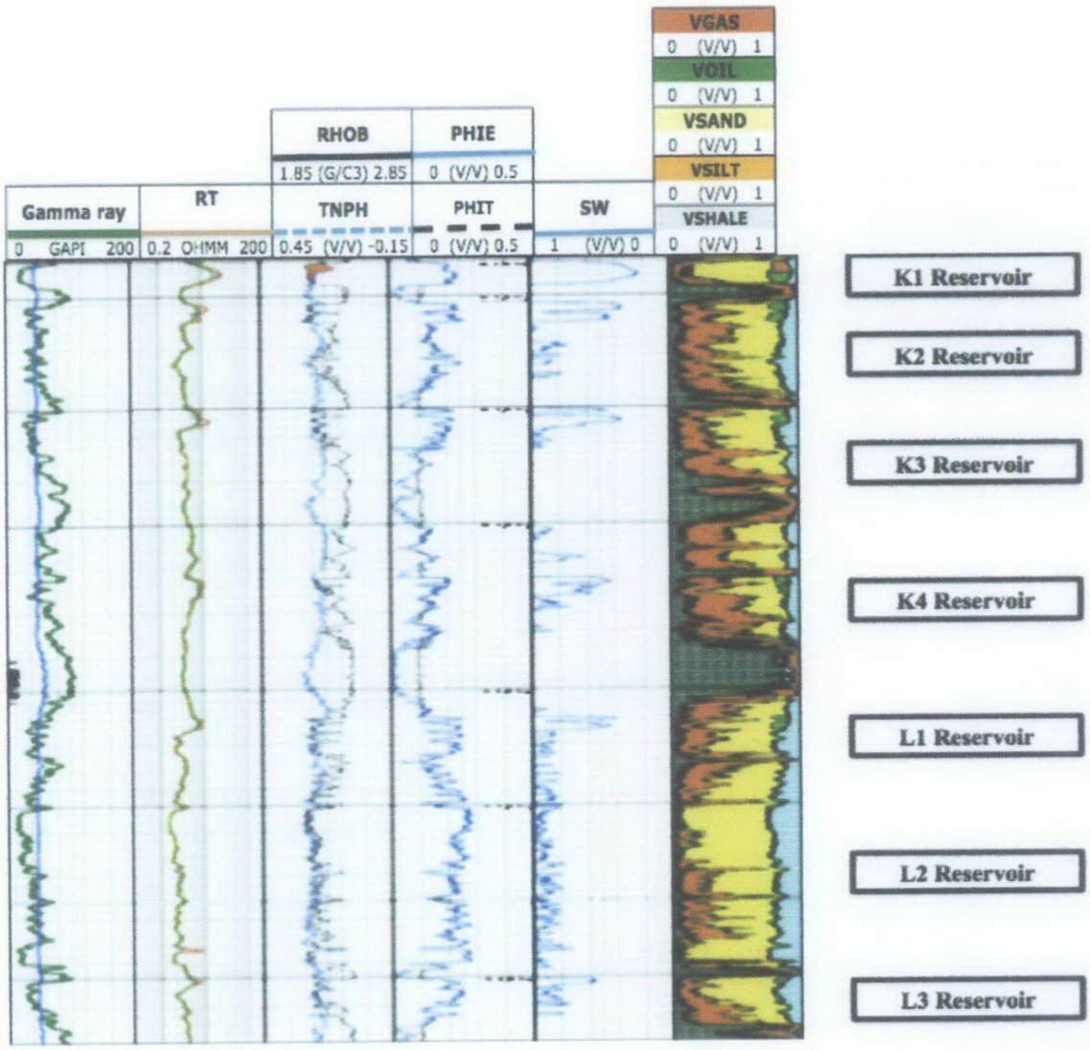


Figure 4: Well GG-21 overall log

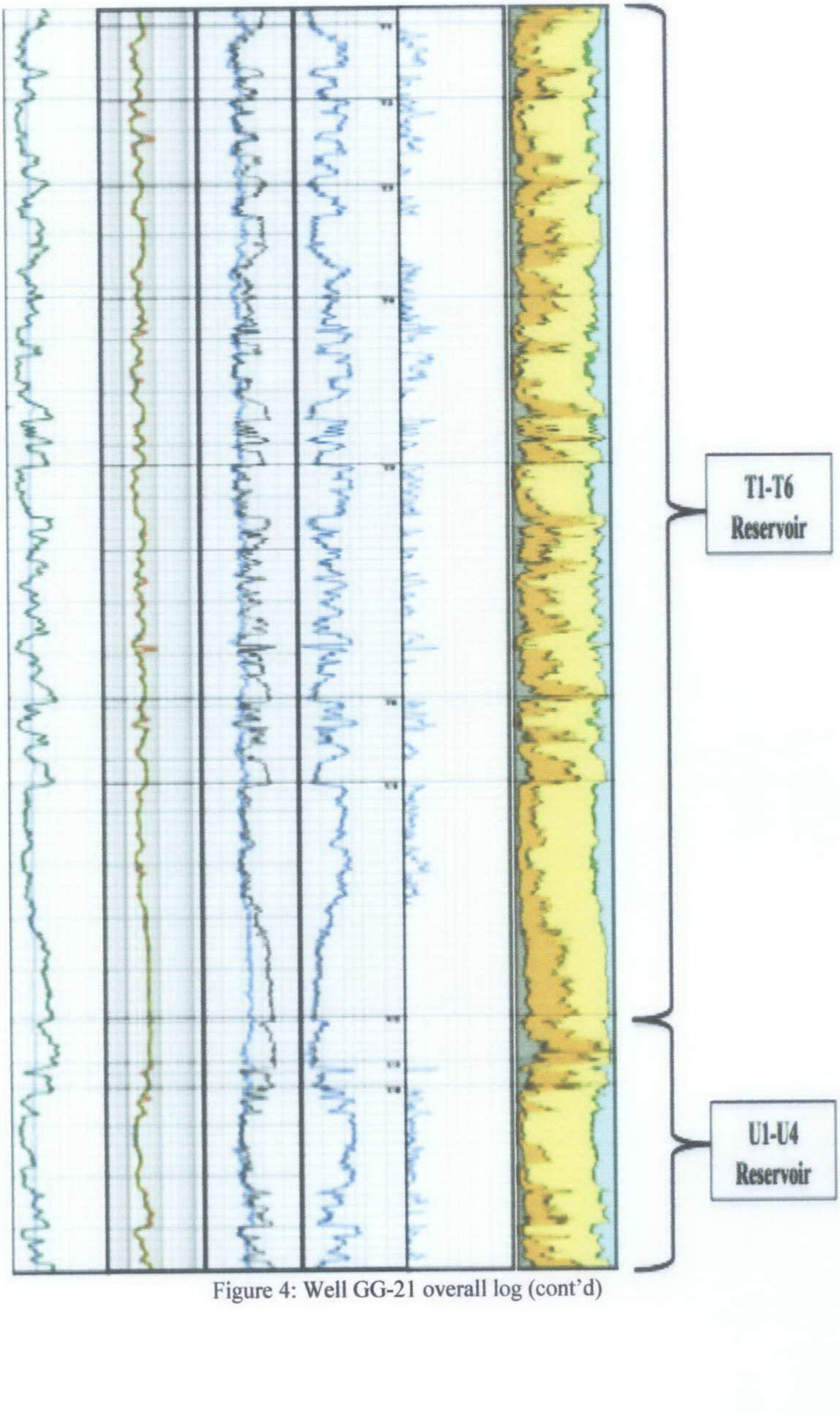


Figure 4: Well GG-21 overall log (cont'd)

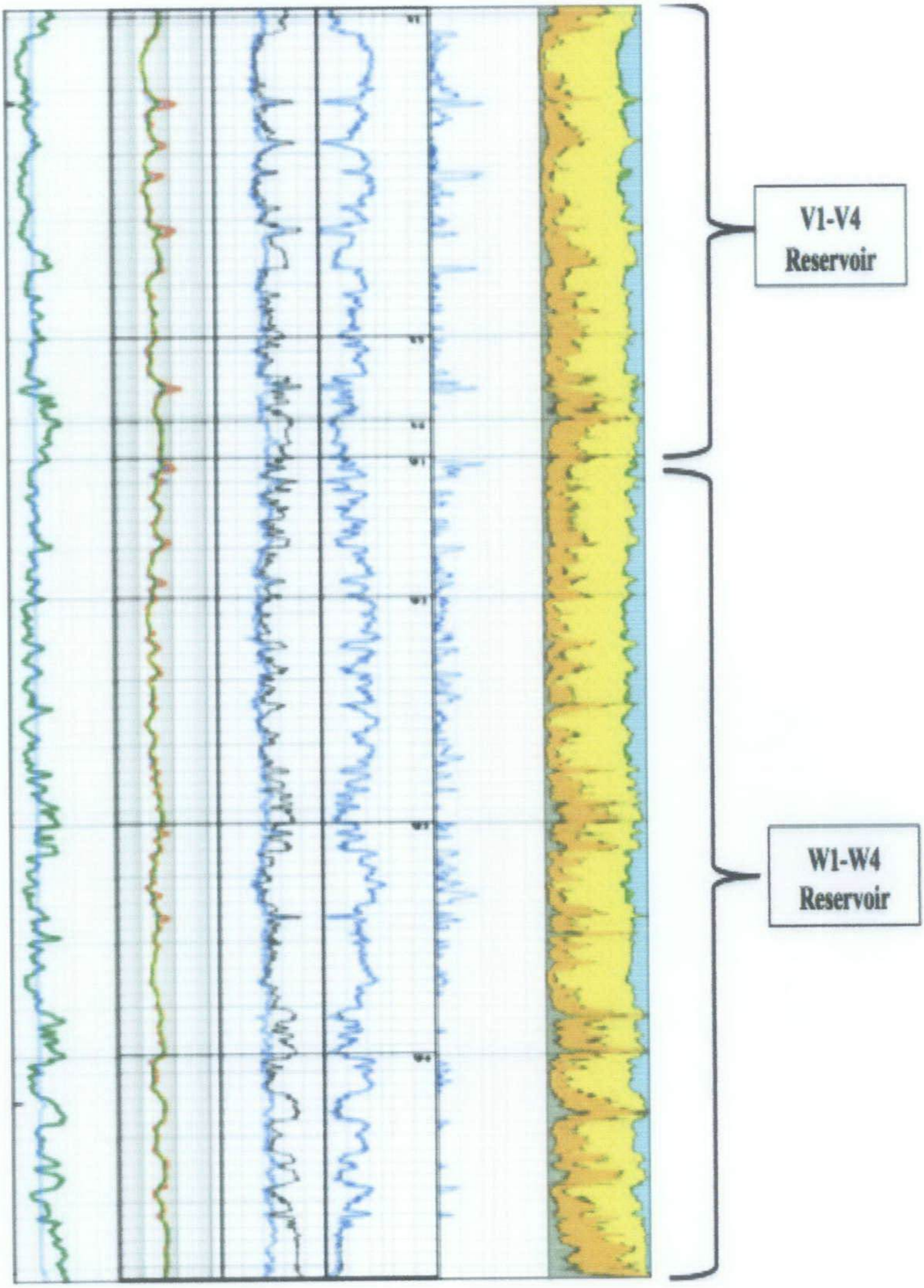


Figure 4: Well GG-21 overall log (cont'd)

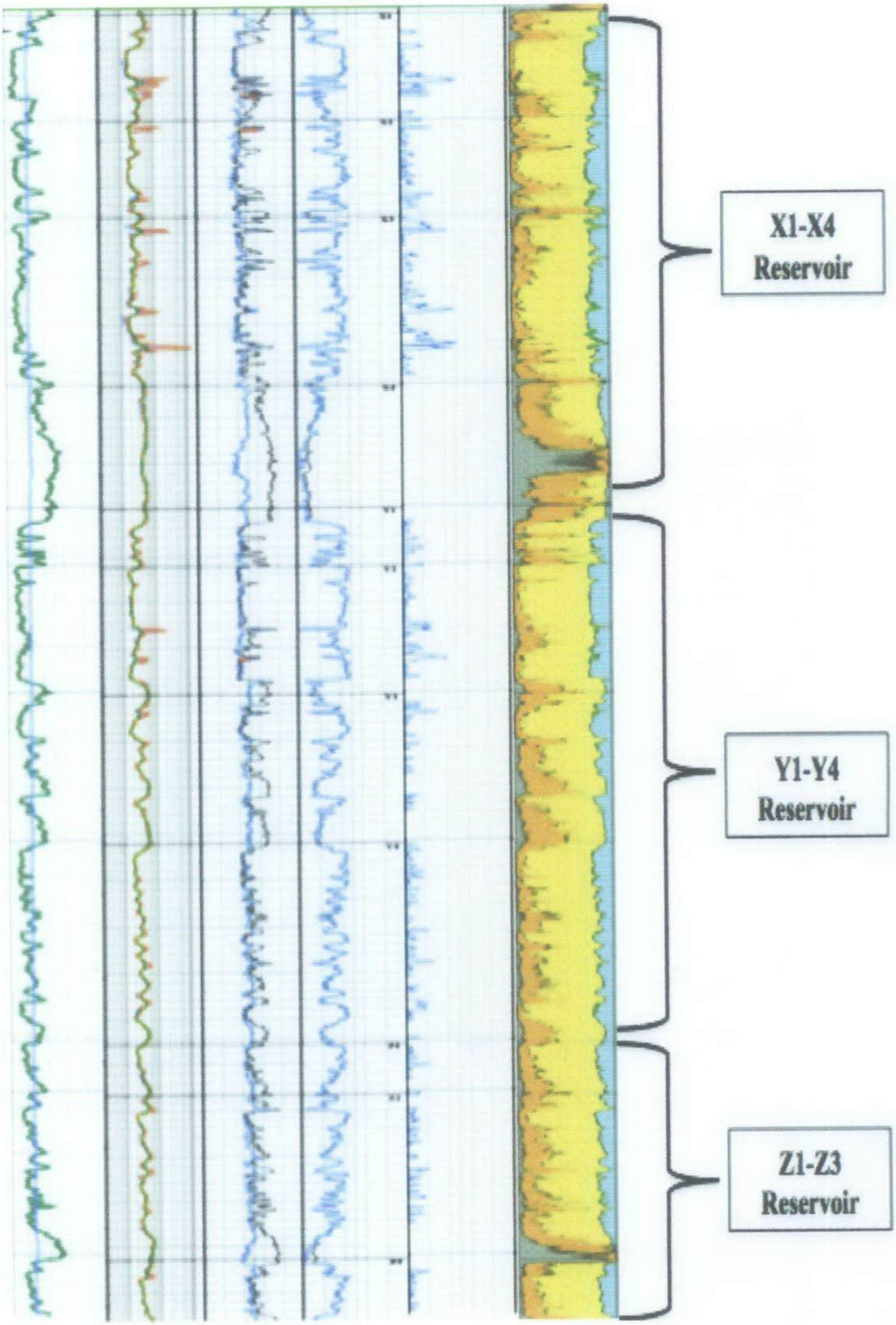
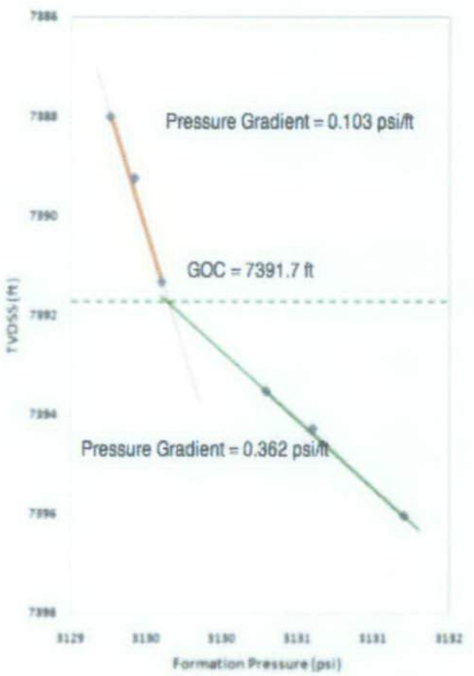


Figure 4: Well GG-21 overall log (cont'd)

APPENDIX 2-1 (PETROPHYSICAL INTERPRETATION)



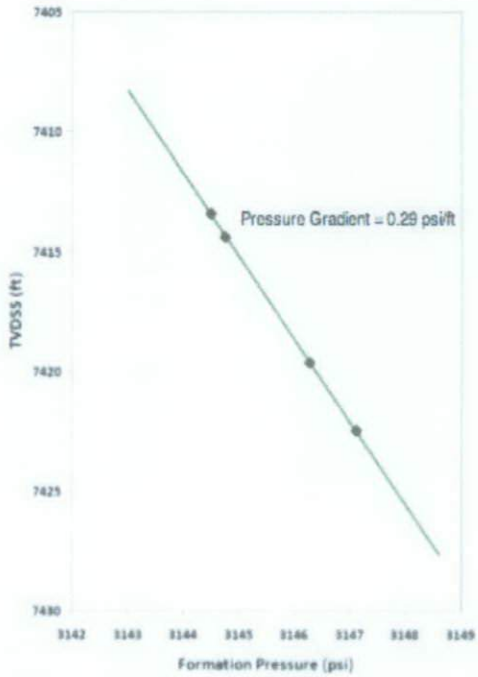
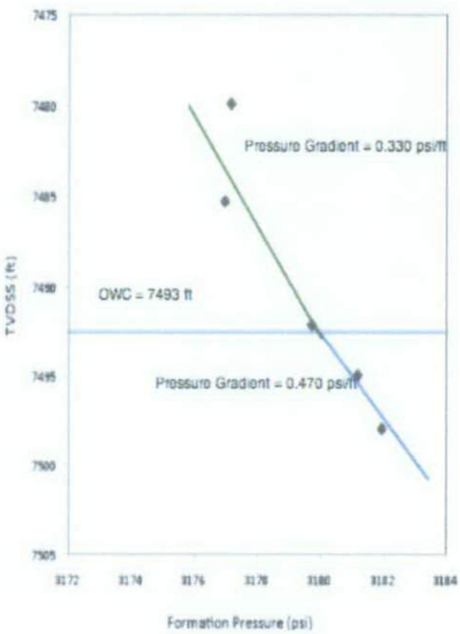


Figure 5-1: Formation Pressure–K1 reservoir Figure 5-2: Formation pressure–K2 reservoir



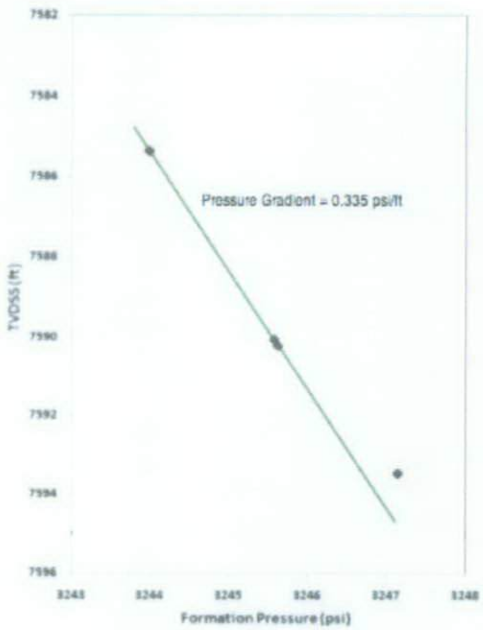
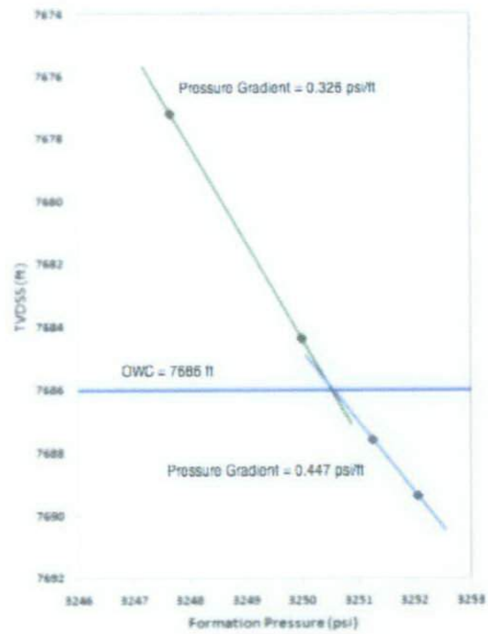


Figure 5-3: Formation Pressure–K3 reservoir Figure 5-4: Formation pressure–K4 reservoir



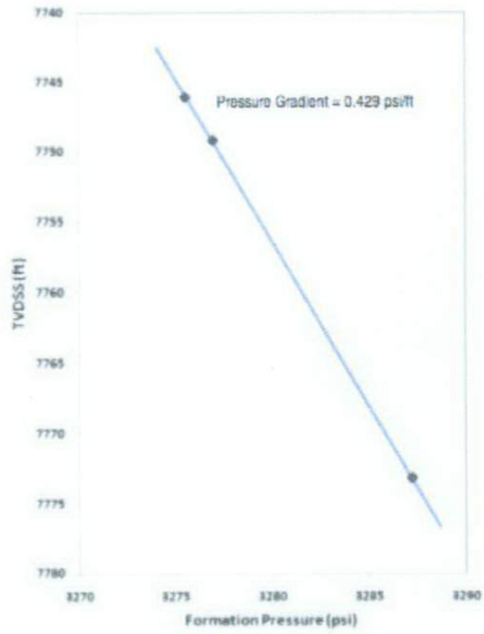


Figure 5-5: Formation Pressure–L1 reservoir Figure 5-6: Formation pressure–L2 reservoir

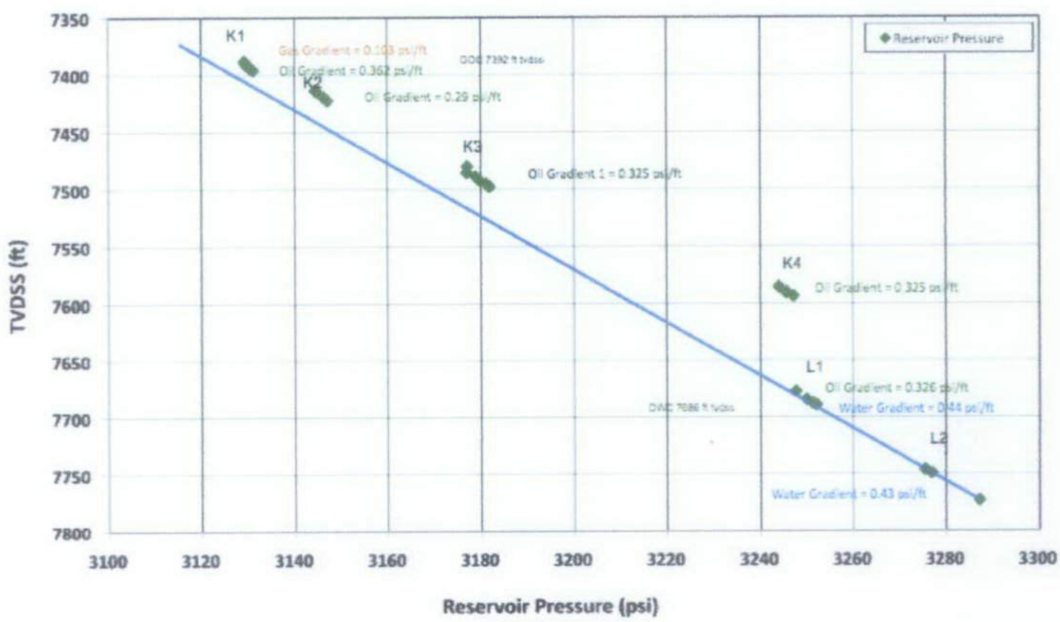


Figure 5-7: MDT Results-Reservoir Pressure

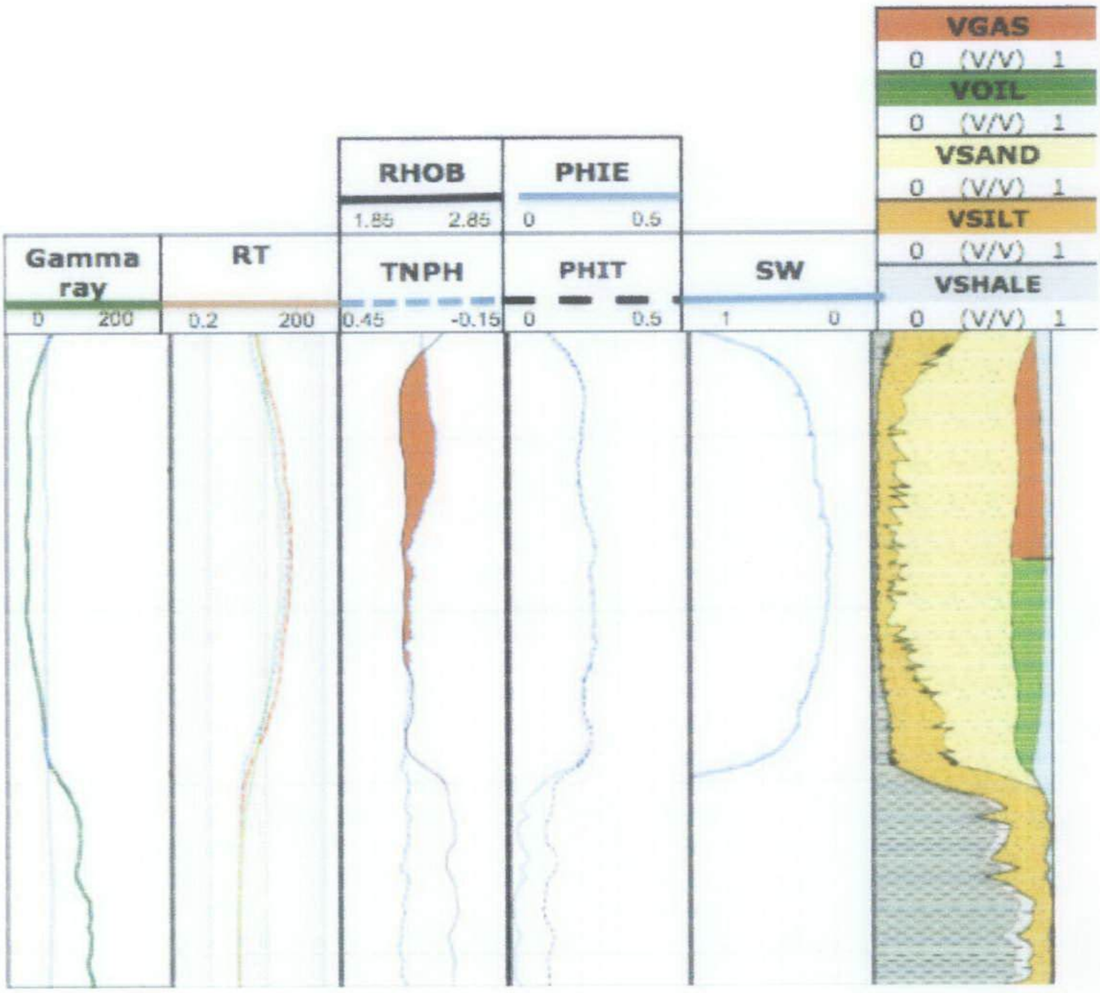


Figure 6-1: Petrophysical Result GG-21 in K1 reservoir

Porosity, Φ_{avg}	Water Saturation, Sw_{avg}	Hydrocarbon Saturation, S_{hcavg}
$\Phi_{oil} = \frac{2.65-2.3}{2.65-1.0}$ $= 0.212$ $= 21.2\%$	$Sw^n = \frac{a(Rw)}{\Phi^m (Rt)}$ $= \sqrt[1.75]{\frac{1(0.1)}{0.212^{1.86}\ (10)}}$ $= 0.374$ $=37.4\%$	$S_{hc} = 1 - S_w$ $=1-0.374$ $=0.626$ $=62.6\%$

(Values taken from Figure 6-1)

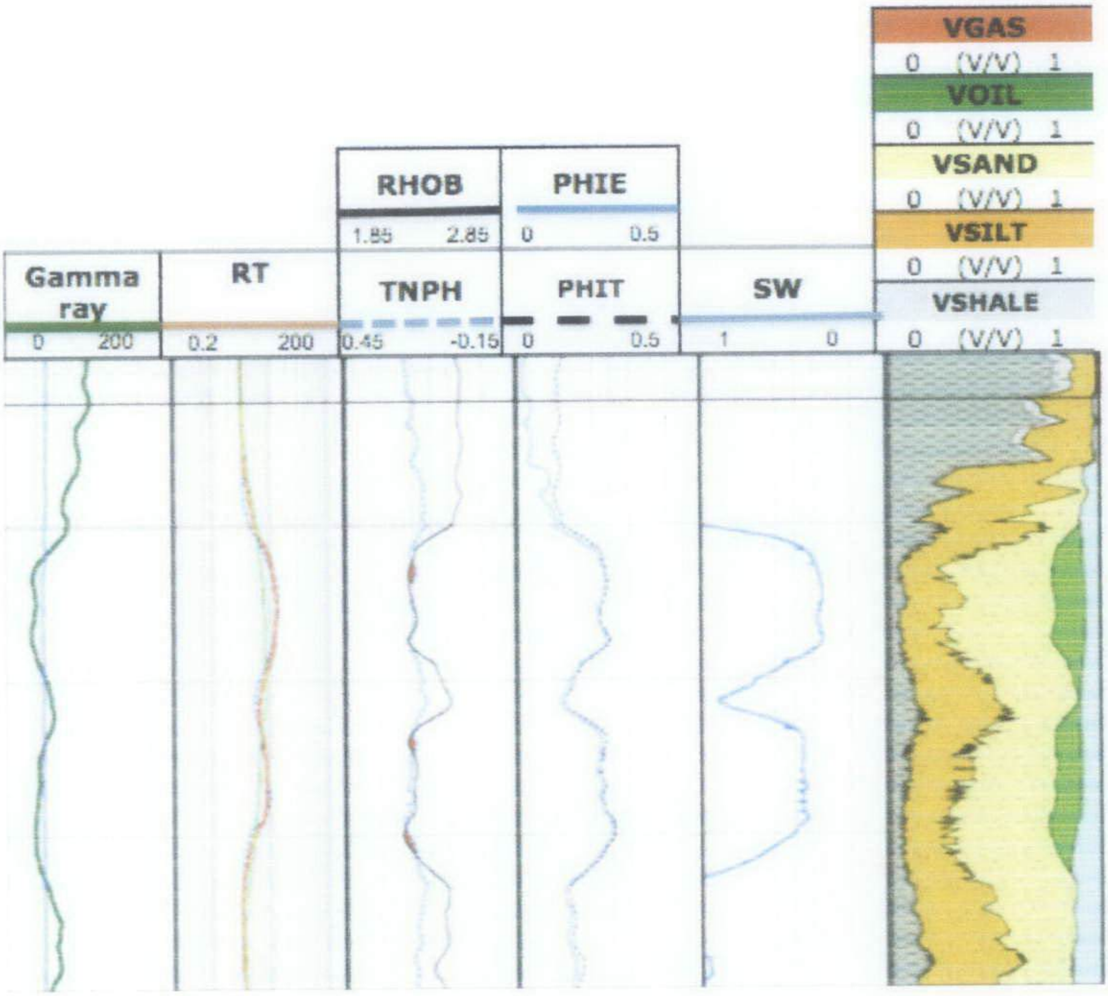


Figure 6-2: Petrophysical Result GG-21 in K2 reservoir

Porosity, Φ_{avg}	Water Saturation, Sw Sw_{avg}	Hydrocarbon Saturation, S_{hcavg}
$\Phi = \dfrac{\rho ma - \rho \log}{\rho ma - \rho f}$ $= \dfrac{2.65 - 2.29}{2.65 - 1.0}$ $= 0.218$ $= 21.8\%$	$Sw^n = \dfrac{a(Rw)}{\Phi^m (Rt)}$ $= \sqrt[1.75]{\dfrac{1(0.1)}{0.218^{1.86}\ (6)}}$ $= 0.49$ $=49\%$	$S_{hc} = 1 - S_w$ $= 1 - 0.49$ $= 0.51$ $= 51\%$

(Values taken from Figure 6-2)

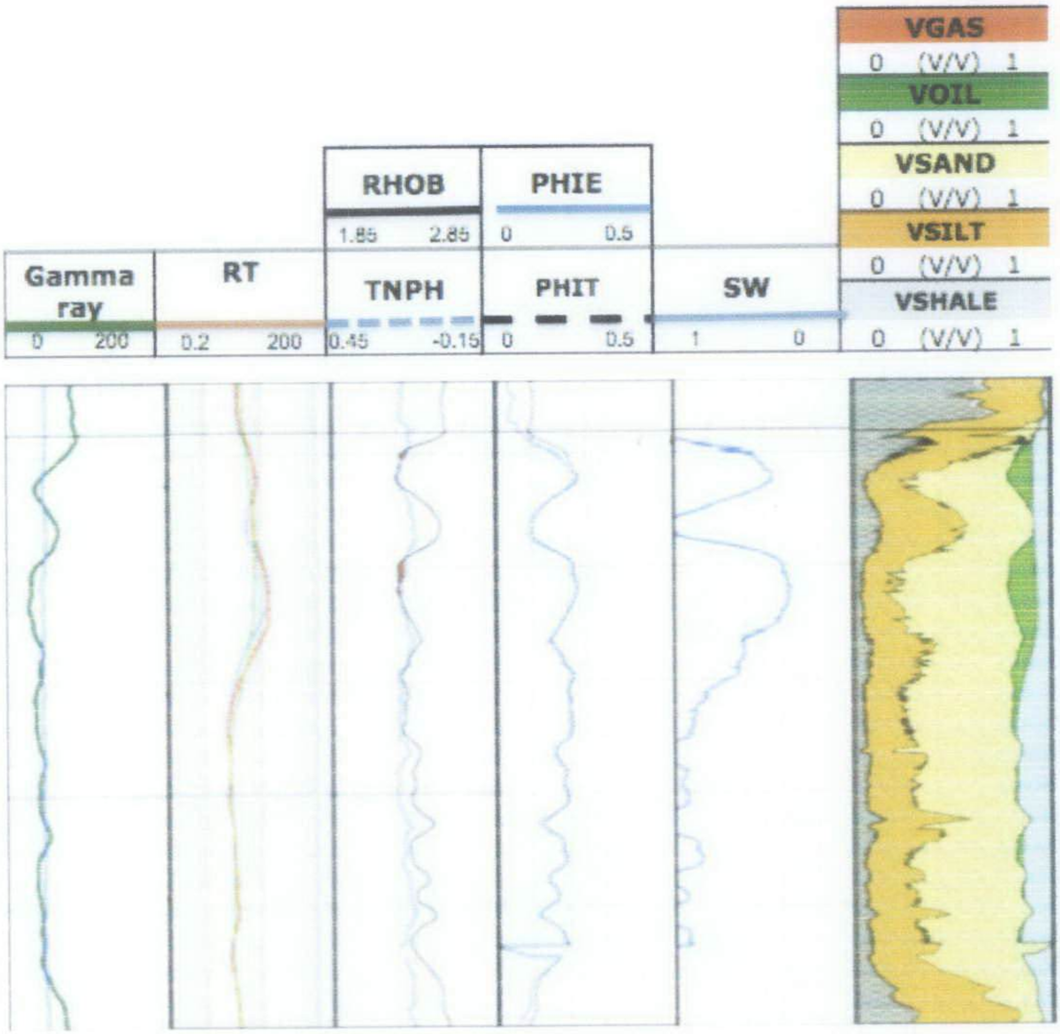


Figure 6-3: Petrophysical Result GG-21 in K3 reservoir

Porosity, Φ_{avg}	Water Saturation, Sw_{avg}	Hydrocarbon Saturation, S_{hcavg}
$\Phi = \dfrac{\rho ma - \rho \log}{\rho ma - \rho f}$ $= \dfrac{2.65 - 2.32}{2.65 - 1.0}$ $= 0.2$ $= 20\%$	$Sw^n = \dfrac{a(Rw)}{\Phi^m (Rt)}$ $= \sqrt[1.75]{\dfrac{1(0.1)}{0.2^{1.86}\ (7)}}$ $= 0.49$ $=49\%$	$S_{hc} = 1 - S_w$ $= 1 - 0.49$ $= 0.51$ $= 51\%$

(Values taken from Figure 6-3)

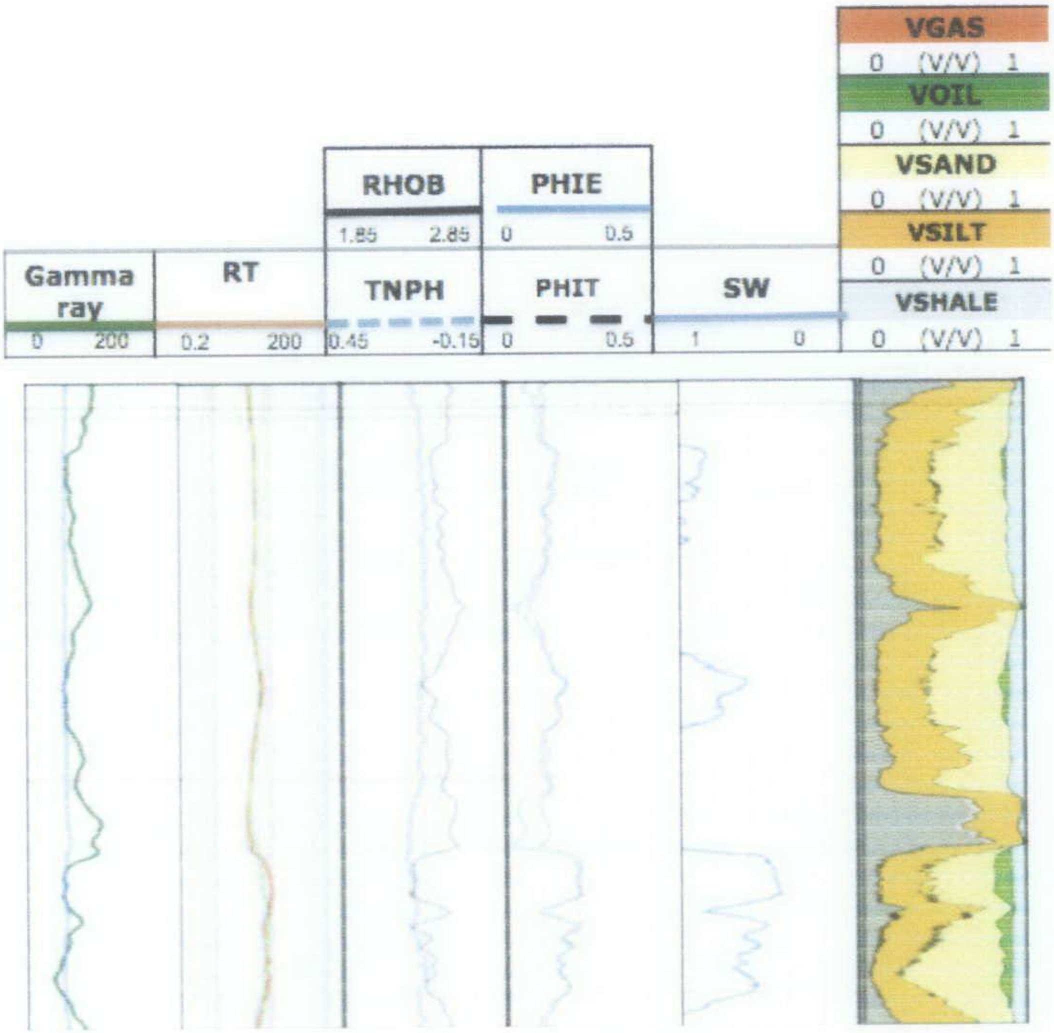


Figure 6-4: Petrophysical Result GG-21 in K4 reservoir

Porosity, Φ_{avg}	Water Saturation, Sw_{avg}	Hydrocarbon Saturation, S_{hcavg}
$\Phi = \dfrac{\rho ma - \rho \log}{\rho ma - \rho f}$ $= \dfrac{2.65 - 2.35}{2.65 - 1.0}$ $= 0.18$ $= 18\%$	$Sw^n = \dfrac{a(Rw)}{\Phi^m (Rt)}$ $= \sqrt[1.75]{\dfrac{1(0.1)}{0.18^{1.86}\ (6)}}$ $= 0.60$ $=60\%$	$S_{hc} = 1 - S_w$ $= 1 - 0.6$ $= 0.4$ $= 40\%$

(Values taken from Figure 6-4)

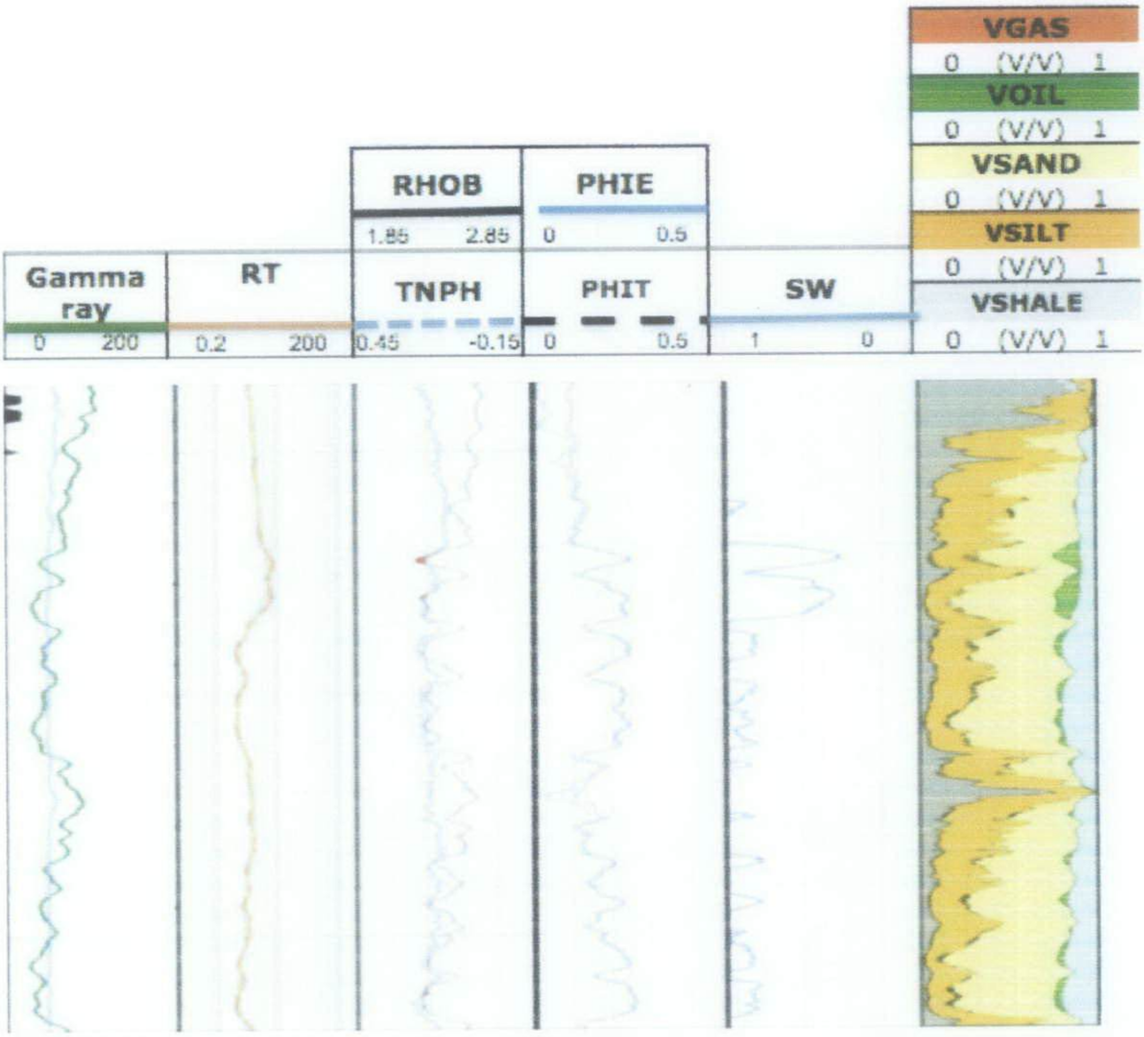


Figure 6-5: Petrophysical Result GG-21 in L1 reservoir

Porosity, Φ_{avg}	Water Saturation, Sw_{avg}	Hydrocarbon Saturation, S_{hcavg}
$\Phi = \frac{\rho ma - \rho \log}{\rho ma - \rho f}$ $= \frac{2.65 - 2.31}{2.65 - 1.0}$ $= 0.21$ $= 21\%$	$Sw^n = \frac{a(Rw)}{\Phi^m (Rt)}$ $= \sqrt[1.75]{\frac{1(0.1)}{0.21^{1.86}\ (6.5)}}$ $= 0.48$ $=48\%$	$S_{hc} = 1 - S_w$ $= 1 - 0.48$ $= 0.52$ $= 52\%$

(Values taken from Figure 6-5)

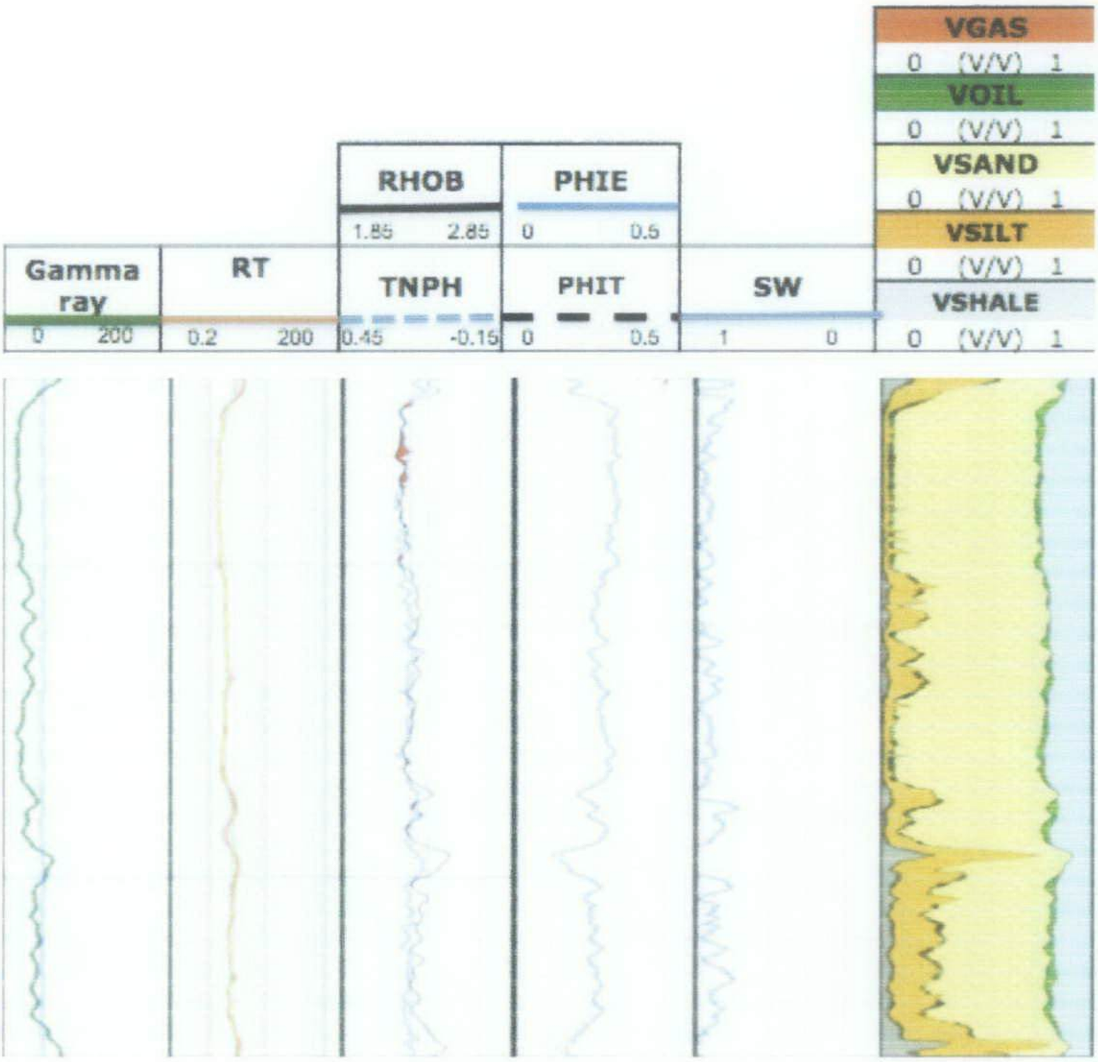


Figure 6-6: Petrophysical Result GG-21 in L2 reservoir

Porosity, Φ_{avg}	Water Saturation, Sw_{avg}	Hydrocarbon Saturation, S_{hcavg}
$\Phi = \dfrac{\rho ma - \rho \log}{\rho ma - \rho f}$ $= \dfrac{2.65 - 2.25}{2.65 - 1.0}$ $= 0.24$ $= 24\%$	$Sw^n = \dfrac{a(Rw)}{\Phi^m (Rt)}$ $= \sqrt[1.75]{\dfrac{1(0.1)}{0.24^{1.86}\ (1.5)}}$ $= 0.97$ $=97\%$	$S_{hc} = 1 - S_w$ $= 1 - 0.97$ $= 0.03$ $= 3\%$

(Values taken from Figure 6-6)

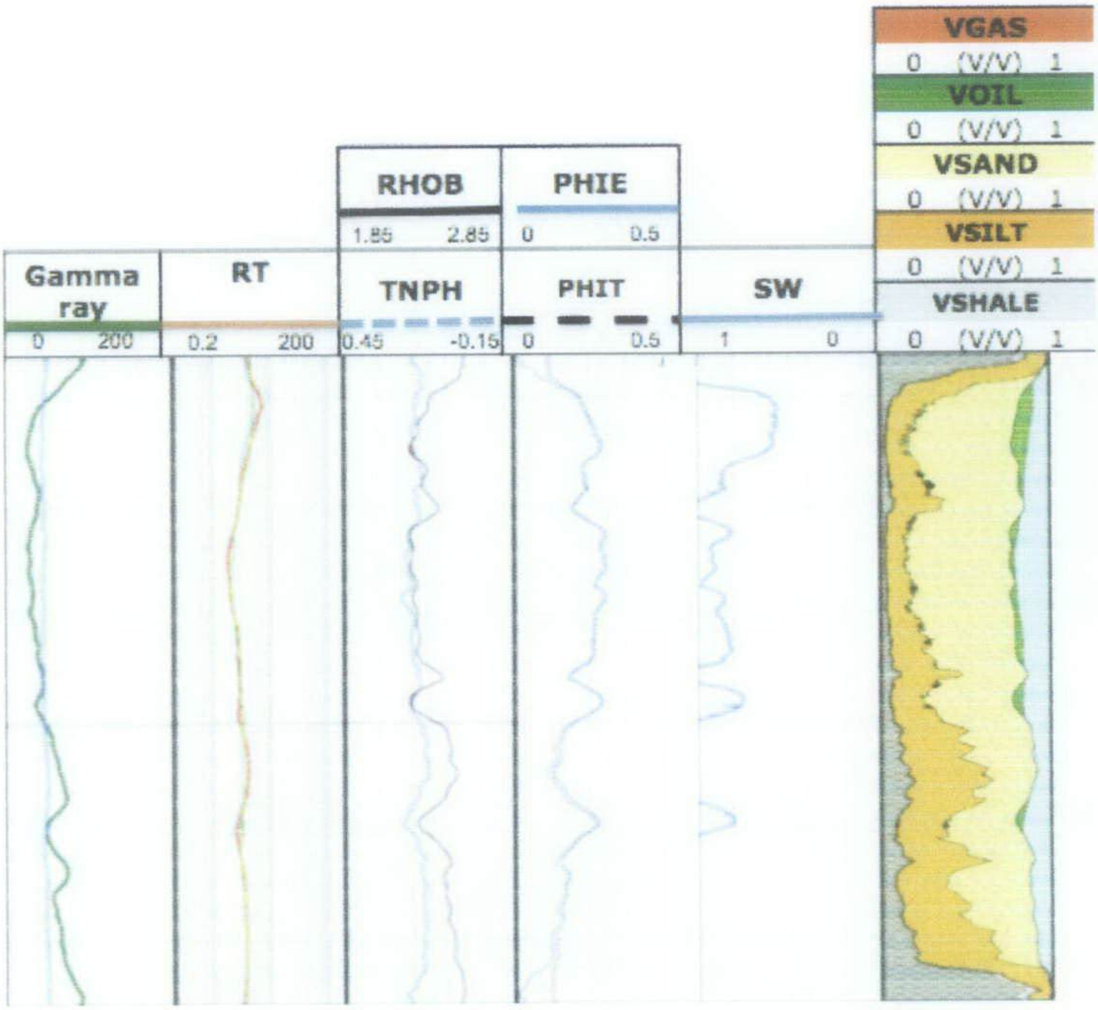


Figure 6-7: Petrophysical Result GG-21 in L3 reservoir

Porosity, Φ_{avg}	Water Saturation, Sw_{avg}	Hydrocarbon Saturation, S_{hcavg}
$\Phi = \dfrac{\rho ma - \rho \log}{\rho ma - \rho f}$ $= \dfrac{2.65 - 2.32}{2.65 - 1.0}$ $= 0.2$ $= 20\%$	$Sw^n = \dfrac{a(Rw)}{\Phi^m (Rt)}$ $= \sqrt[1.75]{\dfrac{1(0.1)}{0.2^{1.86}\,(4)}}$ $= 0.67$ $=67\%$	$S_{hc} = 1 - S_w$ $= 1 - 0.67$ $= 0.33$ $= 33\%$

(Values taken from Figure 6-7)

APPENDIX 2-2 (PETROPHYSICAL PROPERTIES)

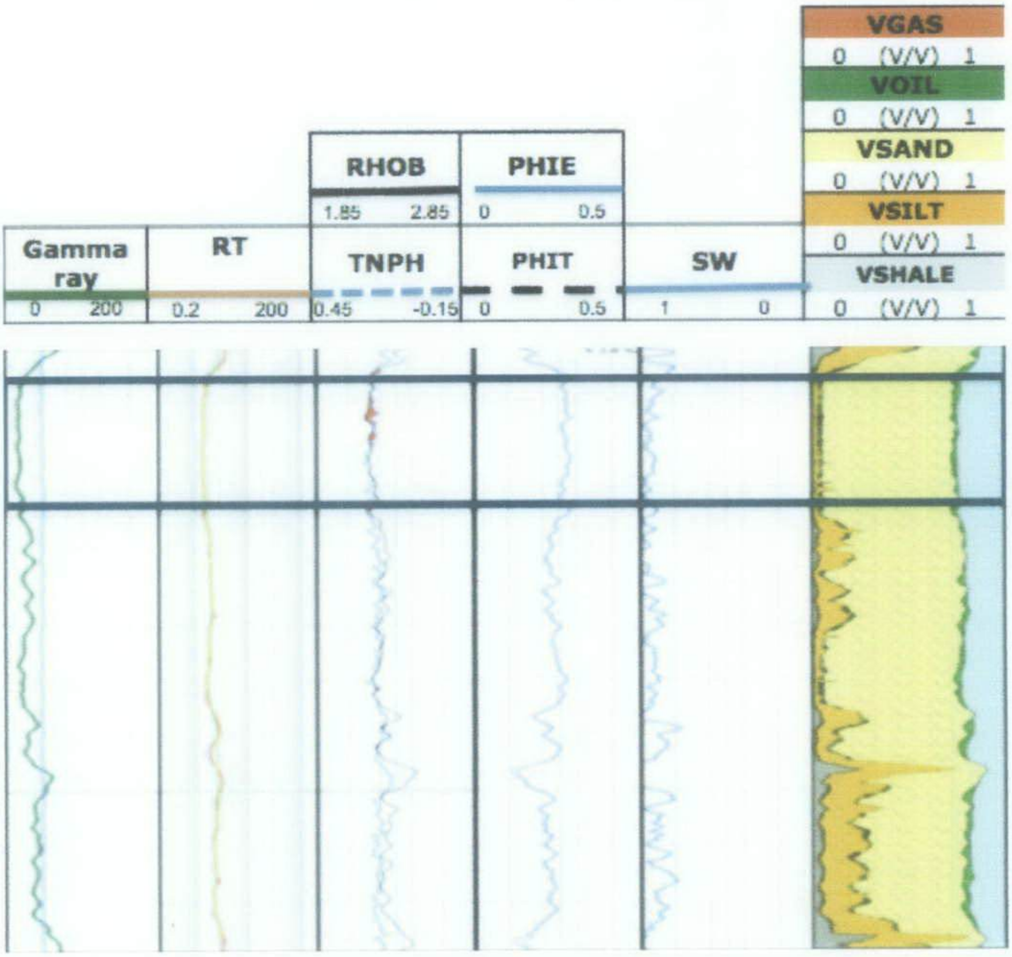


Figure 7: Determination of Rw at L2 reservoir at depth 11525m till 11550m

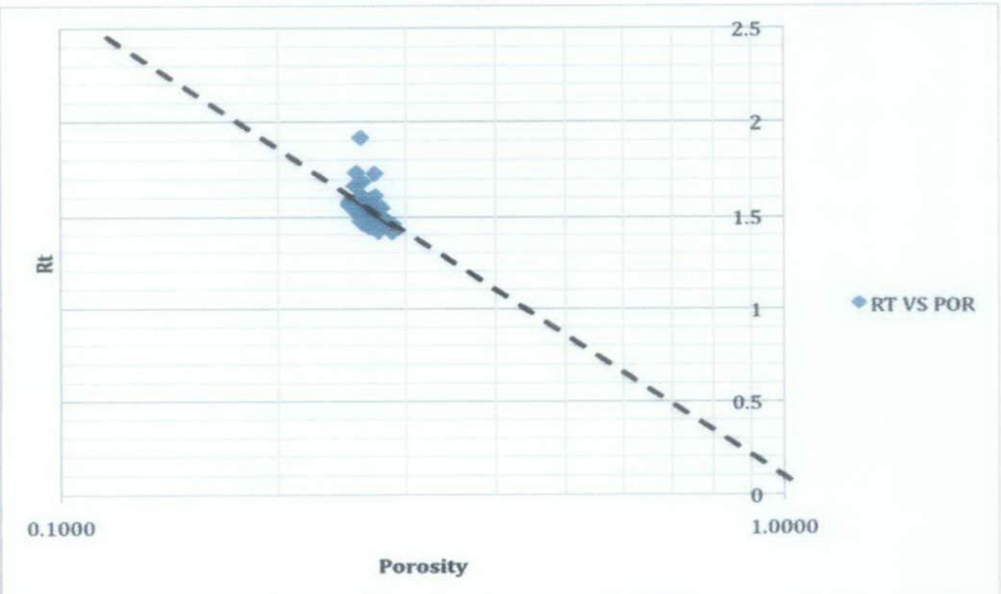


Figure 8: Picket Plot for Well GG-21