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Petrophysical Study of Improve Oil Recovery (IOR) Potential in Iraqi Fields

Graduation research submitted to the Council of the College of Engineering - Petroleum Department as an implementation of the requirements for obtaining a Bachelor's degree

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1446 AH **2025 AD**

بسم الله الرحمن الرحيم

﴿يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنكُمْ وَالَّذِينَ أُوتُوا
الْعِلْمَ دَرَجَاتٍ ۚ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ﴾

[سورة المجادلة، الآية11]

Supervisor Certification

I certify that the preparation of this project entitled **"Petrophysical Study of Improve Oil Recovery (IOR) Potential in Iraqi Fields"**

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Was made under my supervision at Petroleum Department in College of Engineering - Misan University in partial fulfillment of the Requirements for the Degree of Bachelor of Science in Sciences Petroleum Engineering.

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Date: / / 2025

الاهداء

بسم الله الرحمن الرحيم

{قُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ}

الحمد لله الذي بنعمته تتم الصالحات، وبفضله تتحقق الغايات، والصلاة والسلام على أشرف الخلق، سيدنا محمد وعلى آله وصحبه. أجمعين إن إعداد هذا العمل هو ثمرة رحلة علمية دامت سنوات سعينا خلالها إلى اكتساب المعرفة، وفهم الظواهر العلمية بمنهج أكاديمي رصين. نرجو أن يكون هذا الجهد المتواضع لبنة في بناء البحث العلمي في مجال هندسة النفط ومساهمة نافعة للمهتمين بهذا التخصص .

اهدي عملي

الى مدمر عروش الظالمين، المنتقم من أعداء أئمة الأمة، ومنقذ الإنسان من الحيرة والضلالة، الإمام المهدي (عج)، راجين أن يكون هذا الجهد خطوةً في طريق العلم الذي يُمهّد لظهوره المبارك وإلى من وهبني الله نعمة وجودهم في حياتي، إلى العقد المتين، من كانوا سندًا وعونًا في رحلتي العلمية والحياتية، عائلتي العزيزة، الذين لولا دعمهم لما وصلت إلى ما أنا عليه اليوم وإلى كل من ساندني، وكان له دور - من قريب أو بعيد - في إنجاز هذا العمل، من أصدقائي وزملائي، الذين شاركوني الطريق بكلمة، أو دعم، أو دعاء

الشكر والتقدير

بسم الله والحمد لله والصلاة والسلام على اشرف الخلق محمد وآله وصحبه. ومن والأه

اما بعد ، فقد وجب علينا في نهاية بحثنا هذا ان نتقدم بخالص شكرنا وتقديرنا إلى استاذنا و مشرفنا الاستاذ رسول حسين راضي لما ابداه من توجيهات قيمة ولما بذله من جهد طيلة فترة اعداد هذا البحث ، كما نتقدم بالشكر الجزيل إلى عمادة كلية الهندسة في جامعة ميسان ورئاسة قسم هندسة النفط.

ولايفوتنا إن نتقدم بالشكر والامتنان للاستاذ علي ظاهر ولجميع الاساتذة والتدريسيين لما قدموه من دعم علمي ومعنوي.

ويدعونا واجب العرفان والجميل ان نتقدم بالشكر والتقدير الى افراد عائلتنا الذي كان لهم الاثر في دعمنا ومساندتنا لتخطي الصعوبات التي واجهتنا لاكمال مسيرتينا الدراسية.

ومن (مهدي جاسم محمد) كما يفرض علي الواجب ان اتقدم بشكري وتقديري الى كل من مد لي يد العون والمساعدة واخص بالذكر الاستاذ حسن كاظم يازع الإخوة العباس اباذر محمد وحسن فاخر حلو وحسن محمد الكعبي

وفي الختام نقدم شكرنا واعتزازنا بمن ساندنا وازرنا طيلة هذه المسيرة العلمية وجميع زملائنا في الدراسة ولا سيما المقربون من دفعتنا في الدراسة الصباحية والمسائية ونعتذر لمن فاتنا ذكرهم سهوا ... لهم منا كل

الشكر والامتنان.

Abstract

This study addresses the critical issue of uneven water front advancement during water injection operations in heterogeneous reservoirs, where differences in permeability between layers lead to early water breakthrough and reduced oil recovery. Water tends to move quickly through high-permeability zones, bypassing significant amounts of oil trapped in low-permeability areas. To solve this, the study proposes a zonal injection technique, where high- and low-permeability zones are identified through well logging tools, and water injection is controlled accordingly using isolation packers and adjustable valves.

The method was applied in the Halfaya oil field, specifically in the Mishrif formation, where petrophysical analysis using Techlog software revealed significant variations in porosity and permeability. Gamma ray, density, neutron, and sonic logs were utilized to determine reservoir quality parameters such as effective porosity and water saturation.

The findings demonstrate that integrating petrophysical data with zonal injection strategies can significantly improve sweep efficiency, reduce early water breakthrough, decrease water production costs, and enhance the overall hydrocarbon recovery factor, particularly in challenging reservoir conditions.

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Chapter One

Introduction

1.1 Introduction

Oil represents one of the most vital energy sources in the global economy, serving as the backbone of major industries and a key driver of economic growth. However, the oil industry faces significant challenges, including declining production from conventional fields and the persistence of large quantities of unrecovered oil even after applying primary and secondary recovery methods (such as water flooding). In certain heterogeneous reservoirs, up to 70% of the original oil in place may remain trapped.

This situation underscores the urgent need to develop improved or enhanced oil recovery (IOR/EOR) techniques to efficiently exploit these remaining resources. These techniques range from "improved" methods like polymer and gas injection to "enhanced" or "tertiary" approaches, including chemical methods (such as surfactants and foams), miscible gas techniques (like CO_2 injection), and thermal methods (such as steam injection or in-situ combustion).

The significance of these techniques lies in their ability to enhance the sweep efficiency and recover trapped oil from reservoir capillaries. However, such processes require a deep understanding of the chemistry, physics, and fluid mechanics of flow within porous media issues that are rarely comprehensively reviewed in existing studies.

In the Iraqi context, the country's oil fields rank among the largest globally but face numerous challenges, including geological variability, aging reservoirs, and environmental and economic pressures. Consequently, studying the petrophysical properties of these fields is a critical step in identifying the best techniques to improve productivity and minimize resource loss.

Petrophysical studies are fundamental in reservoir evaluation within oil fields, providing a detailed understanding of rock properties such as porosity, permeability, and fluid saturation. This knowledge is crucial for optimizing production and enhancing reservoir development strategies. Additionally, petrophysical analysis plays a key role in water injection planning and monitoring by identifying suitable injection zones and evaluating reservoir response, ultimately contributing to improved field performance and recovery.

The importance of water injection

Maintaining reservoir pressure. When producing oil and gas, the natural pressure of the reservoir gradually decreases. Water injection restores the pressure to levels that help continue the natural flow of oil to the surface.

Improving oil recovery. Water injection contributes to pushing the remaining oil inside the reservoir towards the producing wells, which increases the recovery rate.

Reducing production deterioration.

Maintaining pressure helps reduce the rates of production decline over time.Balancing production and injection.

Water injection replaces the produced fluids (oil and gas), which maintains the stability of the reservoir and its physical properties.

Mechanism of operation

Water is injected through dedicated wells called injection wells.

Water flows into the reservoir, creating a water drive that helps move the oil toward the production wells.

Injection processes are carefully designed to avoid problems such as premature water breakthrough or corrosion in the pipes.

Challenges associated with water injection.

Water-reservoir compatibility:

Using water that is chemically incompatible with the reservoir can lead to mineral deposition and clogging of pores. Corrosion problems

Injected water may contain materials that cause corrosion of the pipes.Produced water management

Water associated with oil needs to be treated to ensure that it does not contaminate the environment.

Petrophysical properties

Are fundamental in evaluating and characterizing subsurface formations, especially in the context of hydrocarbon exploration and production. These properties describe how rocks interact with fluids, and they play a critical role in determining the storage capacity and flow behavior of fluids within a reservoir. The most important petrophysical properties include porosity, which measures the void spaces in a rock; permeability, which describes the rock's ability to transmit fluids; water saturation, which indicates the fraction of pore space occupied by water; and fluid saturation, which helps in estimating hydrocarbon volumes.

In addition, other properties such as bulk density, capillary pressure, and electrical resistivity are also essential for accurate reservoir characterization. These parameters are usually derived from well logs, core samples, and laboratory measurements. By analyzing petrophysical properties, engineers can identify productive zones, estimate reserves, and optimize recovery strategies. Therefore, a thorough understanding of petrophysical properties is vital for making effective decisions throughout the life cycle of an oil or gas reservoir.

1.2 Importance of the Research

Water injection is a critical secondary recovery technique employed to enhance oil production from reservoirs. However, these operations face a significant challenge: the uneven advancement of the water front (water breakthrough) during injection, particularly in formations with heterogeneous permeability. When water is injected at equal rates into a heterogeneous layer containing zones of high and low permeability, most of the water flows rapidly through the high permeability zones, bypassing the oil trapped in the low permeability areas. This behavior leads to an increased water cut in production, causing a significant decrease in recovery efficiency and leavina hehind substantial amounts of oil behind the water front.

To address this issue, this research aims to employ advanced techniques to diagnose high-permeability zones using logging tools and sensors, followed by adjusting the injection rates to match the layer properties.

This is achieved through the application of zonal injection technology, which involves dividing the reservoir into separate zones using isolation packers and installing special valves in completion equipment.

These valves are opened at specific rates according to the permeability characteristics of each zone, ensuring a more balanced distribution of injected wate..

The research aims to enhance the efficiency of water injection operations by reducing water breakthrough in high-permeability zones and increasing recovery efficiency in low-permeability zones. This approach can lead to higher oil recovery rates and reduced water production, thereby improving operational efficiency and lowering the costs associated with water production and treatment.

Improved Oil Recovery (IOR) and Enhanced Oil Recovery (EOR) are methods used to increase oil extraction beyond conventional techniques.

IOR: Refers to any method that improves oil recovery above natural flow, including additional drilling and well stimulation

EOR: Involves specific processes like thermal recovery and chemical flooding to extract more hydrocarbons after primary production

IOR encompasses broader techniques, while EOR focuses on advanced methods targeting residual oil saturation

Both aim to maximize production efficiency and extend the life of oil fields

The main differences between Improved Oil Recovery (IOR) and Enhanced Oil Recovery (EOR) are:

Scope: IOR includes a broad range of methods to improve oil recovery, such as infill drilling, well stimulation, artificial lift, and secondary recovery (e.g., waterflooding). EOR is a subset of IOR, focusing on advanced techniques like thermal recovery, chemical flooding, and gas injection to reduce residual oil saturation

Objective: IOR improves overall reservoir performance, while EOR specifically targets immobile oil left after primary and secondary recover

Techniques: EOR alters physical or chemical properties of the reservoir fluids or rocks, unlike the broader operational improvements in IOR

1.3 Area of Study

Halfaya oil Field is one of the Iraq's seven major oilfields and was discovered more than 30 years ago. The field is located in Missan province in Iraq southeast, 35 Km southeast of Amara city, as shown in Fig.1. It is a gentle elongated anticlinal structure with its long axis extending in a NW – SE direction about the structure is approximately 32 km long by 8.8 km wide. The structure was defined by 2D seismic data shot during years 1976 and 1980. Up to June 2010, eight wells were drilled by Missan Oil Company. The deepest well (HF-2) reached a depth of 4,788 m, down to the Lower Cretaceous Sulaiy formation. Significant oil accumulations have been discovered in multiple reservoirs of Tertiary and Cretaceous formations. In addition, 3D seismic acquisition was executed through 2010 and 2011, covering a total area of 496 km2. Up to June 2017, a total of 197 new wells have been completed drilling.

Figure (1.1) Field location

Mishrif Formation was deposited in the secondary (Cenomanian-early Turonian) sedimentary phase, which was widespread throughout the Arabian Gulf during the Cretaceous period. Mishrif Formation is a carbonate series represented by oxidized shallow open marine carbonates. Various diagenic processes involving porosity and permeability have been affected (Burchett, 1993). The Late Cenomanian to Early Turonian was a period of generally favorable conditions for high organic productivity worldwide and the eustasy was the main element controlling the growth, development and location of the buildings (Van Buchem et al., 2002). The Mishrif is composed of two major sedimentary cycles abruptly terminated by the unconformity which separates the Mishrif from the overlying Khasib Formation (Aqrawi et al., 2010). The equivalent formations of the Mishrif Formation are Gir-bir Formation in the North and the Balambo Formation of the deeper eastern and intrabasinal part of the same basin of the Dokan Formation

The lower boundary of Mishrif Formation represents the change from basinal Rumaila Formation to shallow open marine facies. It is a conformable surface. The upper boundary with the Khassib Formation is truncated by an unconformity surface separating the Middle from Late Cretaceous.

Chapter Two

Theoretical Review

2.1 Theoretical Review

The material of which a petroleum reservoir rock may be composed can range from very loose and unconsolidated sand to a very hard and dense sandstone, limestone, or dolomite. The grains may be bonded together with a number of materials, the most common of which are silica, calcite, or clay. Knowledge of the physical properties of the rock and the existing interaction between the hydrocarbon system and the formation is essential in understanding and evaluating the performance of a given reservoir. Rock properties are determined by performing laboratory analyses on cores from the reservoir to be evaluated. The cores are removed from the reservoir environment, with subsequent changes in the core bulk volume, pore volume, reservoir fluid saturations, and, sometimes, formation wettability. The effect of these changes on rock properties may range from negligible to substantial, depending on characteristics of the formation and property of interest, and should be evaluated in the testing program. There are basically two main categories of core analysis tests that are performed on core samples regarding physical properties of reservoir rocks.

These are: Routine core analysis tests

- Porosity
- Permeability
- Saturation

2.1.1 Importance of Porosity in Geology

Porosity is a fundamental property in geology, playing a crucial role in fluid storage in aquifers, oil and gas fields, and geothermal systems. The structure and connectivity of pores directly influence the flow and transport of fluids through geological formations. Furthermore, the relationship between individual mineral properties and rock properties is significantly affected by porosity. To understand the links between porosity, storage, transport, and rock properties, it is essential to measure and quantitatively describe pore structures, as highlighted by T. S. Hunt in his early studies on rocks and their applications (Hunt, 1875; Espinal, 2002). This important rock property is determined mathematically by the following generalized relationship:

$$\varphi = \frac{pore\ volume}{bulk\ volume}$$

Where φ = porosity

2.1.2 Measurement of Porosity

Various methods have been developed to measure porosity, each tailored to specific sample types and study objectives. Common techniques include:

1. Gas Sorption: Measures pore volume based on gas adsorption within the pores.

2. Liquid Intrusion: Utilizes liquid penetration, such as mercury intrusion, to assess pore characteristics.

3. Microscopy: Uses microscopic imaging to study pore structures.

4. X-ray and Neutron Scattering: Provides detailed data on pore distribution and size in solid materials (Espinal, 2002).

2.1.3 Types of Porosity

Porosity can be classified into several types based on its nature and function

1. Total Porosity: Represents the overall ratio of void volume to the total volume of the rock.

2. Effective Porosity: Refers to interconnected voids that contribute to fluid flow.

3. Secondary Porosity: Develops due to later processes such as dissolution or erosion.

4. Geochemical Porosity: Describes the volume of fluid involved in chemical reactions (Hook, 2003; Pearson, 1999).

2.1.4 Impact of Porosity on Physical Properties of Rocks

Porosity significantly affects the physical properties of rocks and materials, including:

1. Mechanical Properties: Rock strength and durability decrease with increasing porosity.

2. Thermal and Electrical Conductivity: Both conductivity types diminish as porosity increases, as void spaces act as insulators.

3. Thermal and Diffusive Transport: These processes depend on pore size and distribution, especially in clay rocks, where diffusive porosity plays a key role in determining the rates of fluid and solute transport (Rice, 1995; Pearson, 1999).

2.1.5 Porosity in Clay Rocks

Clay rocks exhibit unique porosity characteristics, including:

1. Physical Porosity: Reflects the voids between mineral grains.

2. Diffusive Porosity: Governs the movement of solutes through the rock.

3. Geochemical Porosity: Represents the chemical reactions between fluids and rocks, essential for modeling geochemical processes (Pearson, 1999).

2.1.6 Conclusion Porosity

Porosity is a vital property for understanding rock behavior in geological and hydrocarbon applications. The capacity for storage, transport, and chemical reactions within geological formations heavily depends on pore type, size, and connectivity. Modern techniques, such as X-ray diffraction and gas adsorption, provide precise measurements of this essential property, enhancing the ability to analyze and utilize natural resources effectively.

2.1.7 Absolute Porosity

Absolute porosity refers to the total volume of voids within a material or rock compared to its total bulk volume, including both connected and isolated pores. It is a fundamental property in reservoir characterization as it affects the rock's ability to store and transmit fluids, making it essential for understanding the physical properties of rocks and fluid flow dynamics within reservoirs. The relationship between porosity and permeability is critical for evaluating absolute permeability and flow capacity (Fengbing et al., 2020). The absolute porosity is generally expressed mathematically by the following relationships:

$$\varphi a = \frac{bulk\ volume - grain\, volume}{bulk\ volume}$$

Where φa = absolute porosity

The structural characteristics of pores play a significant role in determining absolute porosity and permeability. These include pore size distribution, pore-to-throat ratio, and pore geometry and connectivity, which directly influence fluid flow through rocks. Experiments involving mercury injection on samples from the Chang-7 Formation revealed that the pore radius ranged from 115.79 to 129.07 µm, while the throat radius ranged from 0.15 to 0.41 μm. The results showed a strong correlation between the pore-to-throat ratio and permeability (Fengbing et al., 2020).

Various techniques are used to measure absolute porosity, including gas injection, mercury intrusion, microscopy, and X-ray/neutron scattering methods. The pressure/mass method is particularly effective for determining open porosity, relying on mass measurements at fixed pressures and calculations based on the ideal gas law (Salisu & Paneton, 2007).

The impact of porosity on the physical properties of rocks is evident in their thermal and electrical conductivity as well as mechanical properties. For example, increased porosity reduces rock strength and diminishes its ability to conduct heat and electricity. Additionally, the presence of water within pores can create significant structural changes upon freezing, affecting the integrity of the rock (Madgwick, 1931).

Absolute porosity also plays a vital role in evaluating the fluid storage capacity of reservoirs and the dynamics of fluid flow, making it crucial for practical applications such as hydrocarbon exploration and assessing the weathering resistance of building stones. Models that incorporate pore structure and pore-to-throat ratios demonstrate high accuracy in predicting absolute permeability, enhancing the characterization and optimization of geological reservoirs (Fengbing et al., 2020).

Absolute porosity is a key factor in understanding and characterizing geological reservoirs as it significantly impacts fluid storage and transport. Advances in measurement techniques, such as mercury injection and the pressure/mass method, have provided precise insights into this property, aiding in the effective utilization of natural resources and the analysis of rock physical properties.

2.1.8 Effective Porosity

Definition and Importance

Effective porosity refers to the interconnected void spaces within a rock that contribute to fluid flow. It is critical for reservoir characterization as it determines the permeability and capacity for fluid storage and transmission. Understanding the relationship between effective porosity and stress is essential for predicting reservoir behavior under varying conditions (Goulty, 1998).

$$\varphi = \frac{interconnected\ proe\ volume}{bulk\ volume}$$

φ = effective porosity

In shale gas reservoirs, effective porosity plays a vital role in gas absorption, storage, and production. Studies have shown that both gas adsorption and stress significantly influence effective porosity, making their combined effects crucial in accurately modeling and predicting reservoir performance (Memon et al., 2020). The total bulk volume of the reservoir can be determined from the following expressions:

Bulk volume = 43,560 Ah, ft3

Or

Bulk volume = 7,758 Ah, bbl

where A = areal extent, acres

h = average thickness

Arithmetic average $\phi \sum \phi$ i/n

Thickness-weighted average $\phi = \sum \phi$ ihi / $\sum$ hi

Areal-weighted average $\phi = \sum \phi_i A_i / \sum A_i$

Volumetric-weighted average $\phi = \sum \phi_i A_i h_i / \sum A_i h_i$

where

n = total number of core samples

h_i= thickness of core sample i or reservoir area i

φ_i = porosity of core sample i or reservoir area i

A_i= reservoir area i

2.2 Permeability

Permeability which is the capacity of a porous material to allow fluids to pass through it, depends on the number, geometry and size of intercon- nected pores, capillaries and fractures (right). Permeability is an intrinsic property of porous materials and governs the ease with which fluids move through hydrocarbon reservoirs, aquifers, gravel packs and filters Permeability is defined in units of area, which relates to the area of open pore space in the cross section that faces, or is perpendicular to, the direc- tion of flowing fluid. In the International System of Units (SI), the unit for permeability is m2. The common unit is the darcy (D) [about 10–12 m2]; this unit is named for the French engineer Henry Darcy, who conducted experi- ments with water flowing through sand. These experiments led to the for- mulation of Darcy's law, which describes the steady-state flow of fluid through porous media. In most oilfield applications, the common unit is the millidarcy (mD) [about 10–15 m2]. Permeability is not to be confused with mobility or with hydraulic con- ductivity. Mobility is the medium's permeability divided by the dynamic viscosity of the fluid flowing through the medium. Hydraulic conductivity, or transmissivity, is the discharge, or effective, velocity of fluid flow through the medium and is equal to the fluid flux—volume of fluid passing through a cross section during a time interval—divided by the cross-sec- tional area.

$$v = -\frac{k}{\mu}\frac{dp}{dl}$$

Where

V= apparent fluid flowing velocity, cm/sec

k = proportionality constant, or permeability, Darcy's

μ = viscosity of the flowing fluid, cp

dp/dL = pressure drop per unit length, atm/cm

The geometric average is defined mathematically by the following relationship:

$$k_{avg} = exp\left[\frac{\sum_{i=1}^{n}(h_i \ln(k_i))}{\sum_{i=1}^{n} h_i}\right]$$

Where

ki = permeability of core sample i

hi = thickness of core sample i

n = total number of samples

2.2.1 Saturation

Saturation is defined as that fraction, or percent, of the pore volume occupied by a particular

fluid (oil, gas, or water).

This property is expressed mathematically by the following relationship:

Applying the above mathematical concept of saturation to each reservoir fluid gives:

$$So = \frac{volume\ of\ oil}{pore\ volume}$$

$$Sg = \frac{volume\ of\ gas}{pore\ volume}$$

$$Sw = \frac{volume\ of\ water}{pore\ volume}$$

Where

So= oil saturation

Sg= gas saturation

Sw= water saturation

2.2.2 Water Saturation

is a critical property influencing reservoir behavior and sedimentary rocks. It plays a significant role in determining the efficiency of oil recovery techniques, particularly secondary recovery methods like water flooding. Water saturation directly affects the physical properties of rocks, such as porosity and permeability, making it essential for understanding reservoir dynamics and evaluating the economic performance of recovery processes (Rathmell et al., 1973).

2.2.3 Effect of Water Saturation on Rock Mechanical Behavior

Water saturation significantly impacts the mechanical properties of rocks, particularly low-permeability rocks like siltstone and shale. Studies have shown that increasing water saturation reduces rock strength and elastic modulus.

2.3 Well log

2.3.1 Introduction Types of Well Logs:

Here are many different types of well logs. Some of the logs that are used to interpret the rocks in a well are discussed below. Other types of logs measure temperatures, the flow rate of oil and gas that is being produced in the well, and the quality of cement used to bond production pipe (which is actually called casing) to the surrounding rock (Evenick, 2008). There are many types of geophysical well logs used today. The information derived from a geophysical log can be exact (e.g., using particular values to calculate water saturations) or interpreted (e.g., correlating stratigraphy using basic pattern recognition or identifying a section repeated by faulting). There are three main categories of logs: electric, radioactive, and structural Electric and structural logs are typically run in uncased holes because the sensors need to be in contact with the borehole; whereas, radioactive logs can be run in either cased or uncased holes. With sub-meter drilling and sub-centimeter logging accuracies, identifying and drilling potential targets is becoming easier. (Evenick, 2008) The increased drilling accuracies have increased the demand for proper subsurface correlations by well log analysts and seismic interpreters. A fundamental understanding of each log is vitally important in understanding the subsurface geology. This chapter will cover basic well logs, what they measure, and common responses. (Evenick, 2008).

2.3.2 Types of Well Logs:

The most basic types of Well Logging:

1. Lithology logs:

- SP (Spontaneous Potential).
- Natural Gamma Ray Tool (NGT)

2. Porosity logs:

- Density
- Neutron
- Sonic

3. Resistivity logs

4. Caliper log

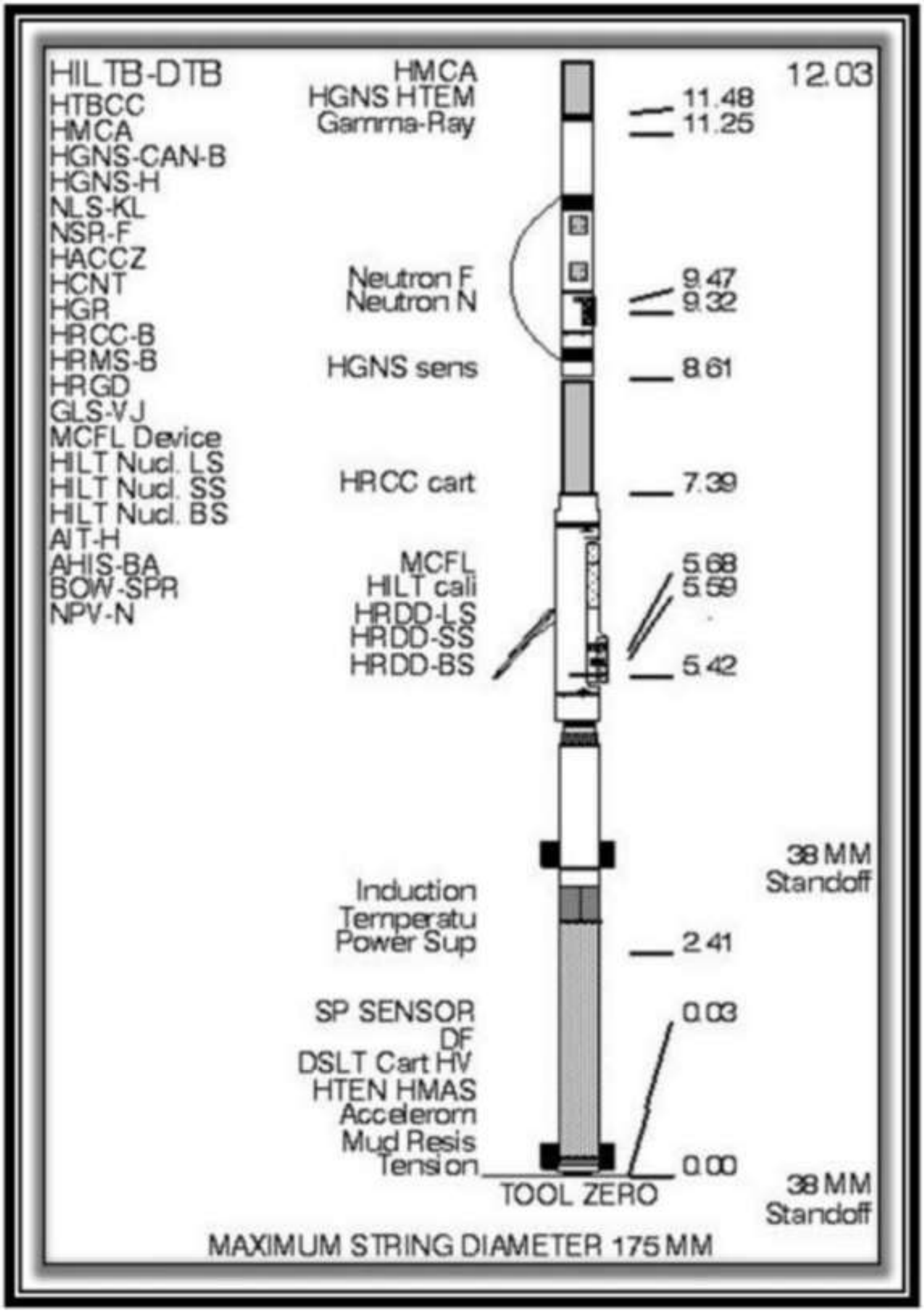

Figure (2.1) Show type of well logging (Schlumberger, 2008)

2.3.2.1 Porosity logs:

Rock porosity can be obtained from the sonic log, the density log, or the neutron log. For all these devices, the tool response is affected by the formation porosity, fluid, and matrix. If the fluid and matrix effects are known or can be determined, the tool response can be related to porosity. Therefore, these devices are often referred to as porosity logs. All three logging techniques respond to the characteristics of the rock immediately adjacent to the borehole. Porosity may be defined as the measure of void space in the reservoir material which is available for the accumulation and storage of fluids. In general, naturally occurring rocks are permeated with water, oil, gas or combination of these fluids. Absolute or total porosity is defined as the ratio of pore space to the total volume of reservoir rock and is commonly expressed as a percentage. Two measurements, pore volume and bulk volume are required to obtain the percentage porosity in accordance with the equation.

Table (2.1) Porosity quality based on porosity range (Miah, 2014).

Porosity (%)	Porosity quality
0-5	Negligible
5-10	Poor
10-15	Fair
15-20	Good
20-25	Very good

Porosity varies greatly both laterally and vertically within most reservoirs. The porosity measurements ordinarily used in reservoir studies is the ratio of the interconnected pore space to the total bulk volume of the rock and is termed effective porosity. The effective porosity is commonly 5 to 10 percent less than the total porosity. It may also be termed as the available pore space, since oil and gas to be recovered must pass through interconnected voids. Porosity in sandstone varies primarily with grain size distribution and grain shapes, packing arrangement, cementation and clay content. A reservoir having a porosity of less than 5 percent is generally considered noncommercial. A rough field appraisal of porosities is included in below Table. (Miah, 2014).

2.3.2.2 Density log:

The density logs are porosity log measure the electron density of a formation (bulk density), by using Compton scattering of gamma rays. This bulk density can be related to porosity when lithology is known. The log consists of a medium-energy gamma ray source, which emits gamma rays into the formation. These gamma rays collide with electrons in the formation and at each collision; a gamma ray particle loses some of its energy. This interaction is referred to as Compton scattering. The scattered gamma rays, which reach the detector, located at a fixed distance, are counted as an indicator of formation density. The following figure shows the density (pekiner, 2015).

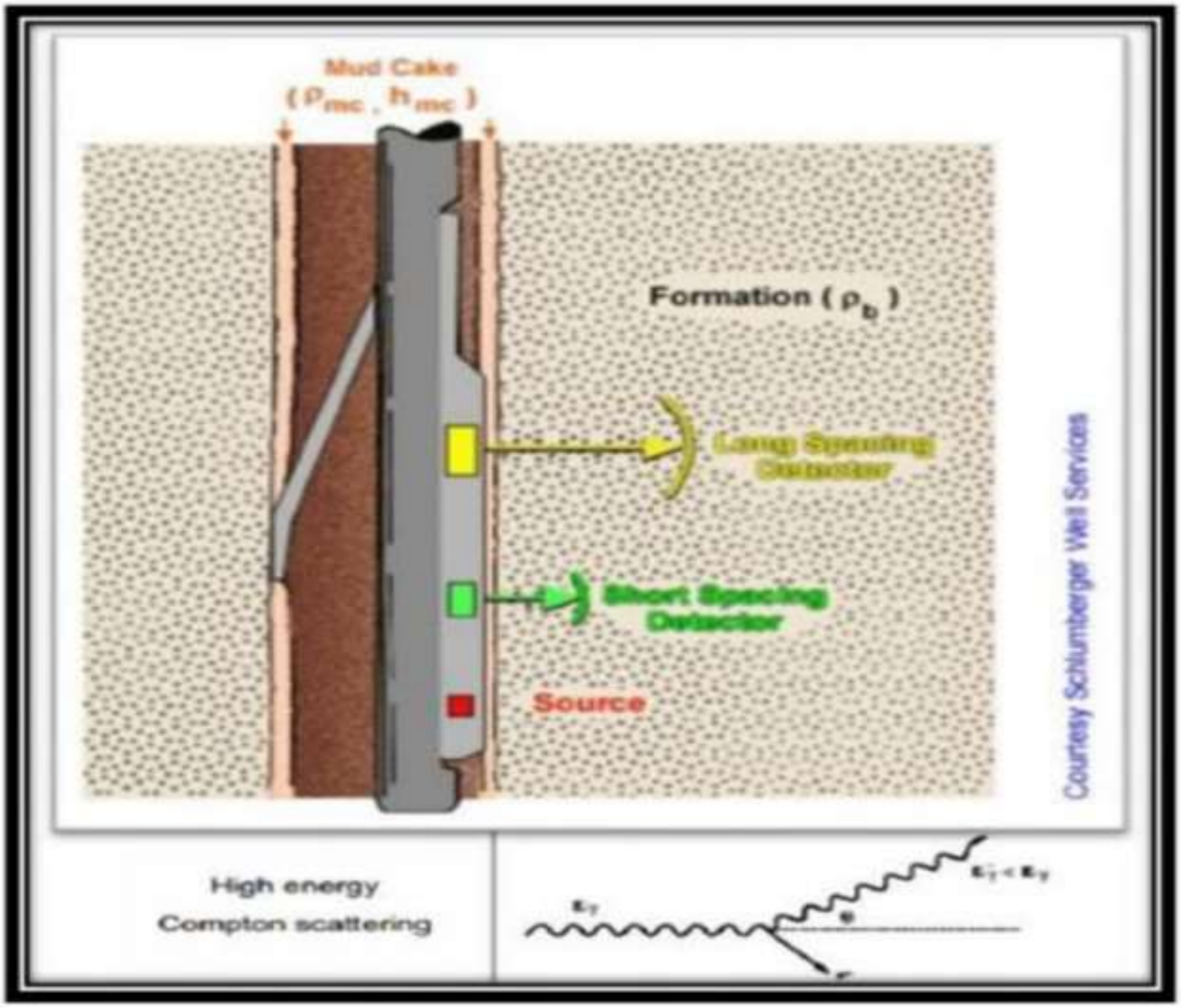

Figure (2.2) Density log reading (pekiner, 2015).

Theory and Principle:

A radioactive source, applied to the borehole wall in a shielded sidewall skid, emits mediumenergy gamma rays into the formations. These gamma rays may be thought of as high-velocity particles that collide with the electrons in the formation. At each collision a gamma ray loses some, but not all, of its energy to the electron, and then continues with diminished energy. This type of interact- ton is known as Compton scattering. The scattered gam- ma rays reaching the detector, at a fixed distance from the source, are counted as an indication of formation density. The number of Compton-scattering collisions is related directly to the number of electrons in the formation. Con- sequent, the response of the density tool is determined essentially by the electron density (number of electrons per cubic centimeter) of the formation. Electron density is related to the true bulk density, ebb, which, in turn , depends on the density of the rock matrix material, the formation porosity, and the density of the fluids filling the pores (Schlumberger, 1989).

Log presentation:

Log information is presented. The bulk density curve, Q, is recorded in Tracks 2 and 3 with a linear density scale in grams per cubic centimeter. An optional porosity curve may also be recorded in Tracks 2 and 3., using preset values of em0 and unselected according to Condi- tions. The Ae (which shows how much density compen- sation has been applied to correct for mud cake and hole rugosity) is usually recorded in Track3 (Schlumberger, 1989).

2.3.2.3 Neutron logs:

The neutron log is a porosity log that measures the hydrogen-ions concentration of a formation. In clean formations where the porosity is filled with water or oil, the neutron log measures liquid filled porosity. Neutrons are neutral atomic particles; its mass is almost as the mass of hydrogen atom. The logging tool continuously emits high energy (high velocity) neutrons from a radioactive source; these neutrons collide with the nuclei of the formation material. Each collision causes the neutron to loss some of its energy, and the amount of energy loss per collision depends upon the relative mass of the nuclei of the neutrons hit. Maximum energy loss occurs when the neutron hits a nucleus of almost equal mass (i.e. hydrogen nucleus). The greatest amount of energy loss of the neutron is therefore due to the hydrogen concentration in the formation. A few microseconds after the neutrons have been slowed by Collision to thermal velocity, they diffuse rapidly until they are captured by the nuclei of other atoms. The nuclei, which capture the neutrons, become excited and emit high-energy gamma rays. The detectors on the neutron logging tool will receive this rays or the neutrons themselves, and made up the reading of neutron-density log the following figure shows the neutron log tool (Douglas, 1982).

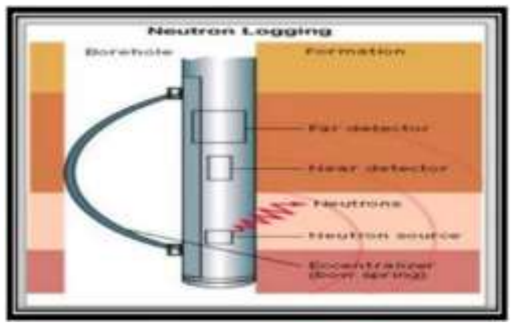

Figure (2.3) The Neutron tool (Douglas, 1990).

The neutron is affected by the amount of hydrogen in the formation, since gas is much less dense than either water or oil it has fewer hydrogen atoms in a given volume. Therefore the neutron tools tend to read too low of a porosity in gas zone. When the neutron porosity and either density or sonic are compared, any large difference in which the neutron porosity reads low and the density or sonic porosities reads high is an indication of gas, this separation is known as the effect. As shown in the following figure.

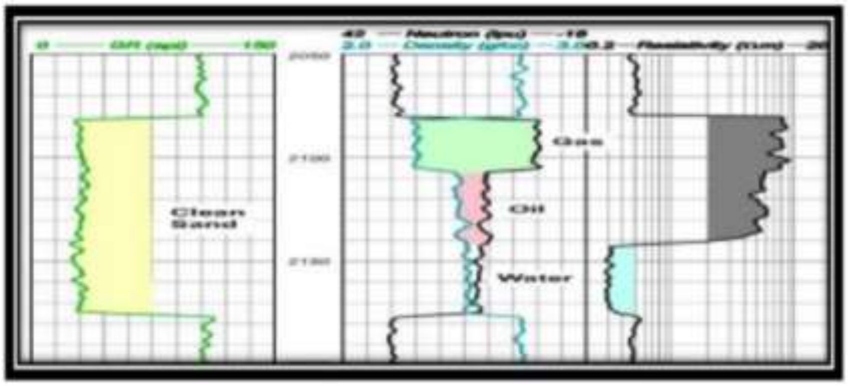

Figure (2.4) The effect phenomena (Douglas, 1990)

2.3.2.4 Sonic log:

The sonic log is a porosity log that measures interval transit time (Δt, delta t, or DT) of a compressional sound wave traveling through the formation along the axis of the borehole. The sonic log device consists of one or more ultrasonic transmitters and two or more receivers. Modern sonic logs are borehole-compensated (BHC) devices. These devices are designed to greatly reduce the spurious effects of borehole size variations (as well as errors due to tilt of the tool with respect to the borehole axis (by averaging signals from different transmitter-receiver combinations over the same length of borehole (Hilchie, 1990).

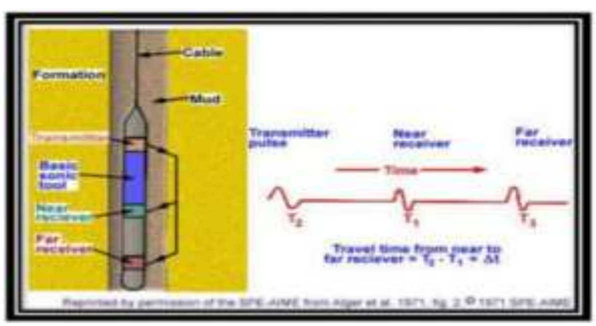

Figure (2.5) Sonic log tool (hilchie. 1990)

Chapter Three

An Overview of Petrophysical

3.1 Basic Information

Well 1HFY was drilled as a deviated development well in Halfaya field, located Southwestern part of the crest of the anticline. The target is to systemically collect data from all the penetrated oil-bearing and reservoirs and to produce oil from Mishrif.

3.2 Geologic Information

This well is a development well in Halfaya oil field. The main interested formations are Tertiary and Cretaceous (K). Based on the Master-logs and the characteristics of logging response, the formation can be divided as described in.

Table (3.1) Distribution Top and Bottom of the Mishrif Formation.

Well Name	Top	Bottom	Zone Name
HF-Y1	2835	2851	MA_1
HF-Y1	2851	2866	MA_2
HF-Y1	2866	2937	MB1_1
HF-Y1	2937	2980	MB1_2
HF-Y1	2980	3029	MB_2
HF-Y1	3029	3110	MC_1
HF-Y1	3110	3170	MC_2
HF-Y1	3170	3230	MC_3

3.3 Log Service and Quality Control

The log service includes GR/SP/CALS/LLD/LLS/MSFL/NPHI/RHOB/DT, and service was run by CNLC using ASEP2920 Well Logging System. Before petrophysical analysis the data was properly checked. All logging curves are in accord with ASEP2920 Log Quality Control standards, and conform to the rule of local area.

1. Data Preprocessing

Before processing, all data had to be preprocessed very well. The main procedure of preprocessing includes depth matching and environmental correction.

2. Depth Matching

As all logs used for petrophysical analysis were logged in one combination run: LLD – LLS – MSFL – NPHI – DT – RHOB – SP – GR – CAL – PEF – HDRA, the depth of each curve is matched very well at each measuring point.

Normally, the depth of curve GR is used for reference of depth matching to all curves, and the final depth is checked and corrected by the depth of casing shoe.

3. Environmental Corrections

All data were corrected for environmental effects. Density logs were corrected for hole size and mud weight. Neutron logs were corrected for hole size, temperature, pressure, mud weight, and borehole salinity. Resistivity logs were corrected for borehole effects and mud filtrate invasion to derive the true formation resistivity and flushed zone resistivity.

The caliper log indicated hole rugosity and wash out across a few hole sections. This resulted in an uncontrollable standoff of the density pad thereby affecting the bulk density measurement across such hole sections. Porosity computation relied more on the sonic and neutron logs across the affected hole sections.

Table (3.2) Parameters of mud property

Mud Type	Density	Viscosity	Resistivity / Temperature	Maximum
BH-WEI	3g/cm 1.26	S48.0	C° 25 $\Omega \bullet m/0.13$ RM: C° 25 $\Omega \bullet m/0.08$ RMF: C° 25 $\Omega \bullet m/0.25$ RMC:	C° 89.5

Porosity (POR) Calculation

Normally lithology density, compensated neutron and sonic logging data are used in cross-plot method to calculate the total porosity and effective porosity. During the calculation, iterative method was used to correct the hydrocarbon effect, and compute a final effective porosity. When the clay content is larger than the shale cutoff, the shale effect correction on porosity will be done. For example, when using lithology density curves, the calculation equation is as following:

$$POR = \frac{DEN - P_{ma}}{P_f - P_{ma}} - Vsh \times \frac{P_{sh} - P_{ma}}{P_f - P_{ma}}$$

Where:

POR= effective porosity;

DEN= measured density value

P_{sh}= measured shale density value;

Vsh= shale volume

P_f= fluid density value;

P_{ma}= density of rock matrix

The main parameters of rock matrix are listed in table (3.3)

Table (3.3) Parameters list of rock matrix and fluid

Rock Matrix	$\Delta^{t_{ma}}(us/\ m)$	$P_{ma}(g/\ cm_3)$	Φ_{Nma} (%)
Sand	186~186	2.65~2.68	-1-~5
Shale	270~400	2.35~2.6	30~45
Calcite	153	2.71	0
Dolimate	143	2.87	2.0
Fresh water	620	1	100
Brine	590	1.05	100

Water Saturation (Sw) Calculation

The Archie formula is used to calculate the water saturation after comparing different water saturation models.

$$sw = \left(\frac{a \times Rw}{Rt \times POR^m}\right)^{(1/n\ )}$$

Where:

POR= effective porosity

Rt= formation resistivity

Rw = formation water resistivity;

a = formation resistivity factor;

m= cementation factor;

n= saturation exponent

The parameters a, m, n and Rw are provided by our client (Table 3.4)

Table (3.4) Processing parameters

Strata	A	M	n	Rw(ohm)
Mishrif	1	1.8	2	0.02

Interpretation

The procedures of final interpretation mainly include effective reservoir discrimination, fluid type determination and oil and gas bearing zone identification

1. Criterion of Effective Reservoir Discrimination

According to the local experience, the cutoffs for discriminating the effective zones are:

Effective porosity >8%

Thickness > 0.4m

2. Criterion of Fluid Type Determination

Due to the effects of shale content and bound water, the resistivity in most pay zones is lower than that of usual clean carbonate rocks oil/gas zone, and even there is no difference from the shale zone. The criteria for fluid type discrimination are:

Oil zone —— Oil saturation ≥50% (Sw≤50 %)

Water zone —— Oil saturation <50% (Sw>50%)

Hydrocarbon Zones Analysis Bearing

Based on the data processed result, 19 potential oil and gas zones had been fond

NO. 6, which with better physical characteristics, 18.5% of average computed porosity, 29. 5ohm.m of average formation resistivity, 18.2% of water saturation, good oil and gas shows on Master-logs, is integrated interpreted as oil bearing zone.

NO. 7-9, which with better physical characteristics, 15.1% 18.6% of average computed porosity, 21.5% 47.4% of oil saturation, good oil and gas shows on Master-logs, is integrated interpreted as oil bearing zone. The detailed information is showed in Table 5 and 6.

NO. 10-12, which with better physical characteristics, 10.8-18.9% of average computed porosity, high formation resistivity, 6.6-13.3% of water saturation, good oil and gas shows on Master-logs, is integrated interpreted as oil bearing zone.

NO. 13, which with better physical characteristics, 11.3% of average computed porosity, 41ohm.m of average formation resistivity, 18.2% of water saturation, fair oil and gas shows on Master-logs, is integrated interpreted as poor oil-bearing zone.

NO. 14, which with better physical characteristics, 19.4% of average computed porosity,110. 3ohm.m of average formation resistivity, 6.0% of water saturation, fair oil and gas shows on Master-logs, is integrated interpreted as oil bearing zone.

NO. 15-17, which with better physical characteristics, 11.9-19.8% of average computed porosity, high formation resistivity, 10.7-15.7% of water saturation, good -fair oil shows on Master-logs, is integrated interpreted as oil –poor oil-bearing zone.

NO. 18, which with better physical characteristics, 26.5% of average computed porosity, 14. 6ohm.m of average formation resistivity, 15.0% of water saturation, good oil and gas shows on Master-logs, is integrated interpreted as oil bearing zone.

NO. 19, which with better physical characteristics, 23.9% of average computed porosity, 1. 4ohm.m of average formation resistivity, 51% of water saturation, good gas shows on Master-logs, is integrated interpreted as transition zone.

Table (3.5) Statistics of Effective Oil Reservoir Properties

Formation	NO.	Zone	Interval (m)		Thick (m)	POR (%)	SW (%)	VSH (%)	RESULT
Mishirif-A	10	28	2868.7	2871.6	2.9	11.7	13.3	1.4	Oil
	11	29	2873.2	2877.5	4.3	10.8	10.4	1.3	Oil
	12	30	2879.7	2897.1	17.4	18.9	6.6	1.1	Oil
Mishirif-B2	13	31	2904.9	2943.0	38.1	11.3	18.2	2.4	Poor Oil
	14	32	2943.0	2973.5	30.5	19.4	6.0	0.7	Oil
	15	33	2973.5	2976.9	3.3	11.9	15.7	0.6	Poor Oil
	16	34	2976.9	3025.7	48.8	19.8	10.7	1.8	Oil
	17	35	3025.7	3036.8	11.1	12.6	11.0	2.1	Poor Oil
Mishirif-C1	18	36	3037.0	3112.2	75.2	26.5	15.0	0.9	Oil
	19	37	3129.2	3148.0	18.9	23.9	51.0	2.5	Transition

Borehole Trajectory Computation

Based on deviation survey, the TVD, horizontal drift, east-west drift, north-south drift and closure direction are calculated by Horizontal Well Process software. Following plots are offered.

1. Borehole trajectory (plan view)

2. Borehole trajectory (side view from azimuth) 0

3. Borehole trajectory (side view from azimuth) 90

4. Borehole trajectory (depth vs. drift)

Spectrometry Log Analysis

Natural gamma-ray spectrometry log can not only provide the total gamma-ray of formation, but also the contents of KTh, U, Th and K. The contents obtained may be used for studying formation characteristics and sedimentary environment.

The Clay Minerals Analysis

The clay minerals were inferred from the SGR using standard POTA-THOR cross plots, Figure 9-16 are POTA-THOR cross plots across Upper Kirkuk, Jaddala, Sadi, Tanuma, Khasib, Mishrif fomations. The main clay minerals are montmorillonite and illite-montmorillonite mixed layer clay, a little glauconie and chlorite.

The KirKuk and Jaddalas formations mainly contain illite-montmorillonite mixed layer clay, montmorillonite and illite. The main clay minerals are illite and glauconie in the Aaliji and Shiranish formations. The Hartha formation mainly comprises of montmorillonite, illite and glauconie. The Montmorillonite and illite are the main clay minerals in the Sadi formation. The Tanuma formation contains montmorillonite and illite-montmorillonite mixed layer clay. The clay minerals of the khasib formation is montmorillonite, illite-montmorillonite mixed layer clay and illite. The Mishrif formation mainly comprises montmorillonite, illite-montmorillonite mixed layer clay and glauconie.

3.4 The Sedimentary Environment Analysis

The ratio of thorium to uranium (Th/U) from the SGR can be used to analyze the sedimentary environment. The $Th/U>7$, if the environment is continental sedimentation, oxidation environment and weathering zone. If the formation is marine deposit or gray shale, the $Th/U<7$. When the formation is carbonate or marine black shale, The Th/U is less 2.

The Th/U is between 2 and 7 in the Kirkuk formation the formation is marine environment. The Th/U is less 2 from the Jaddala to Mishrif formation it shows that the Sedimentary environment is marine.

Chapter Four

Results

4.1 Method of study

- Get the data in text form
- Open the Techlog software and load the data
- Do the calculations in the software
- Extract the result

4.2 Techlog software

Techlog is a software platform developed by Schlumberger for wellbore data analysis and petrophysics in the oil and gas industry. It integrates various workflows for processing, visualizing, and interpreting data related to subsurface formations, helping engineers make informed decisions in exploration and production.

4.3 Data Processing

Petrophysical characteristics must be determined and assessed in order to infer reservoir properties of the Mishrif formation to the Halfaya field for HF-Y1 well by as following using Techlog software:

1. We does the following steps through Techlog program (Project New) by input las file HF-Y1 well data then by Log View windo for prsentation (caliper, bit size, GR, Rt, Rxo, DT, N, D) logs.

2. From Petr ophysics window calculate Formation temperature from Precomputations windo for HF-Y1 well.

3. Calculation Shale volume (Vsh) from gamma ray log: Techlog works instead of the previously mentioned mathematical equations as shown in the

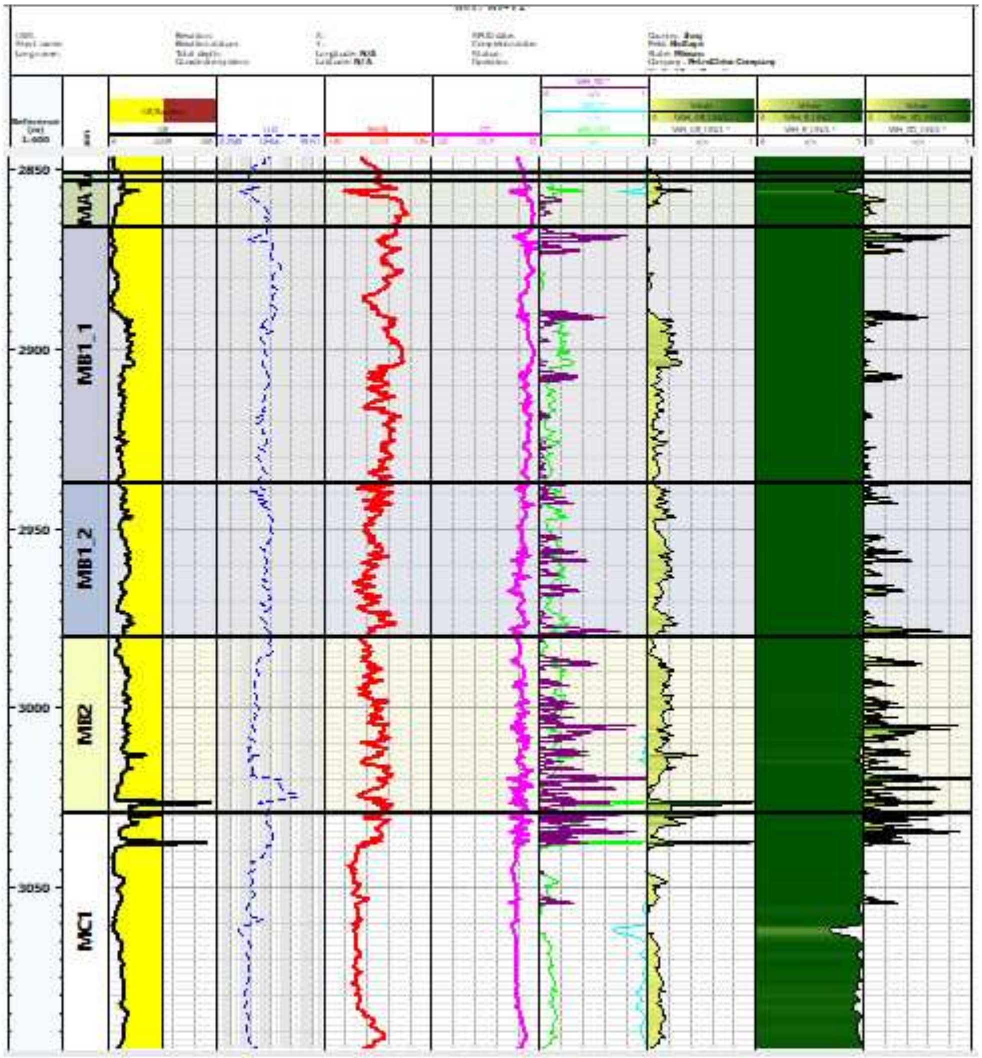

Figure (4.1) Calculation Shale volume (Vsh) from gamma ray log

Calculation Porosity (∅): "As shown in the Figure

- The total porosity of the Mishrif formation was calculated by using of the Neutron-Density logs._
- The total porosity of the Mishrif formation was calculated by using of the Sonic log.
- The total porosity of the Mishrif formation was calculated by using of the Density log.

- The effective porosity of the Mishrif formation was calculated by using of the Neutron-Density logs.

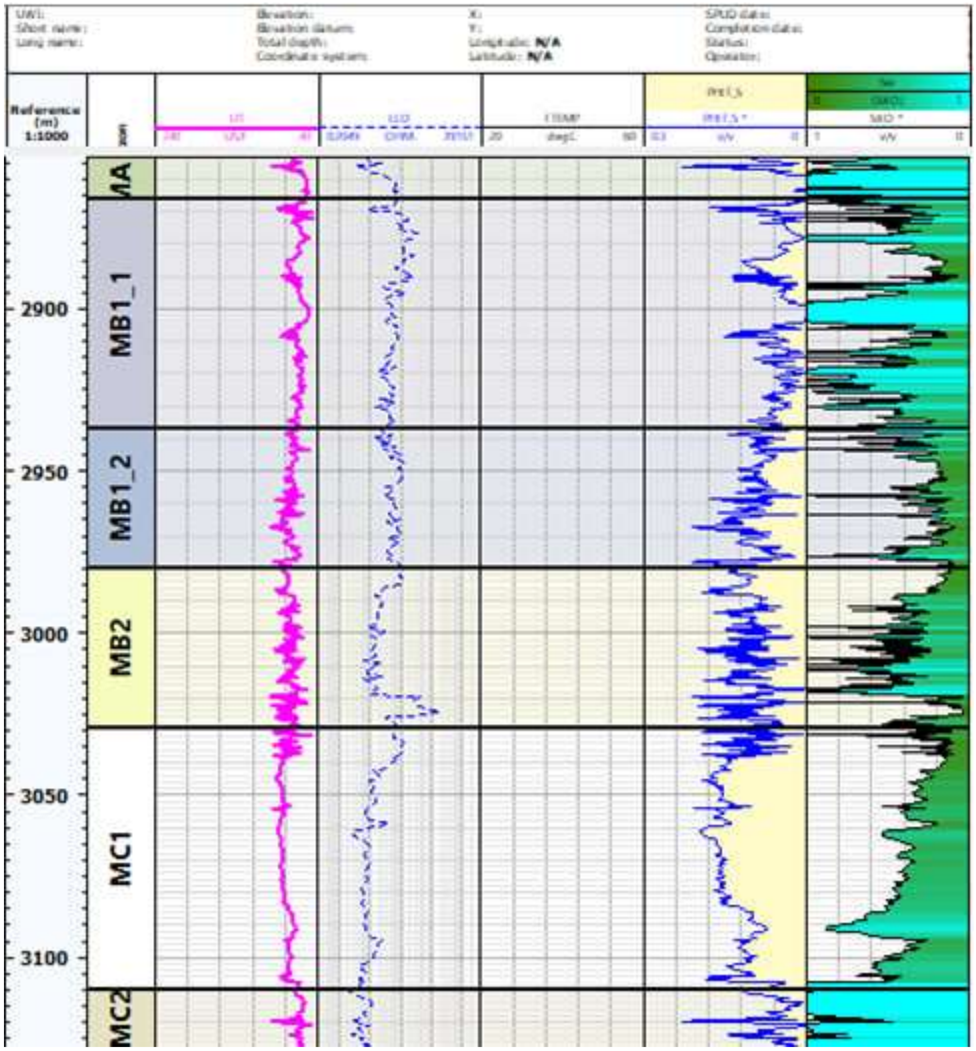

Figure (4.2) Calculation Porosity (∅)

In the Figurethe total porosity of the Mishrif formation was calculated by using of the Sonic log and this log only measures primary porosity is developed during deposition of the sediment. While also was calculated total porosity of the Mishrif formation by using of the Density log and Neutron-Density logs idicator to measures primary porosity and secondary porosity is caused by some geologic process subsequent to formation of the deposit and this is the reason for the differences in porosity readings. The effective porosity of the Mishrif formation was calculated by using of the Neutron-Density because Neutron and density logs are used as reliable tools for measuring effective porosity because they provide vital information about the water condition and stress handling in soils and rocks

Calculation of water Saturation:

After level by level porosity determination, water saturations are calculated. The Archie equation is adopted to achieve this task. Water saturation of both limestone and dolomite determined through using Archie equation inserting number of real data including n, m and a which are all constant as shown in the Figure

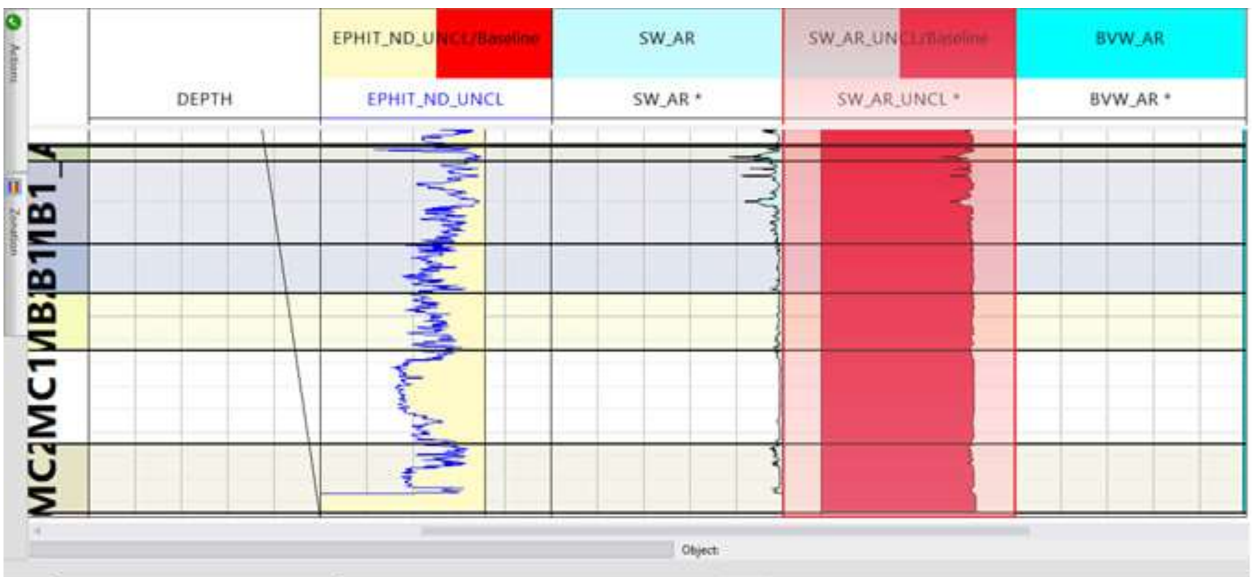

Figure (4.3) Calculation of water Saturation

Calculation of permeability:

The permeability of the Mishrif formation will be calculated using Coates model and Wyllie-Rose model by using Techlog software; But the Coates model is better for calculating permeability because it takes effective porosity into account as shown in the

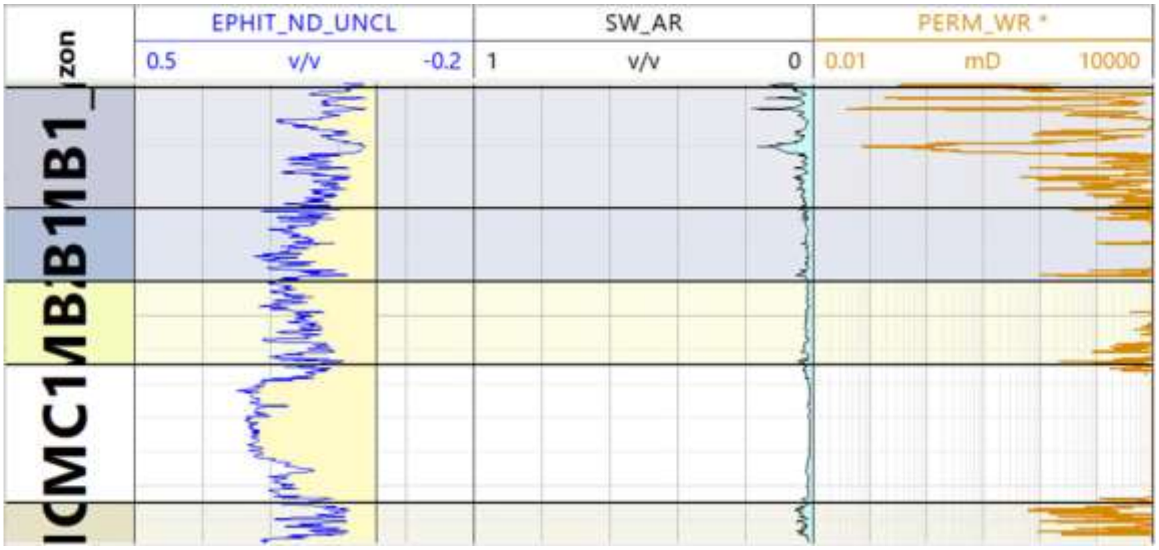

Figure (4.4) Calculation of permeability

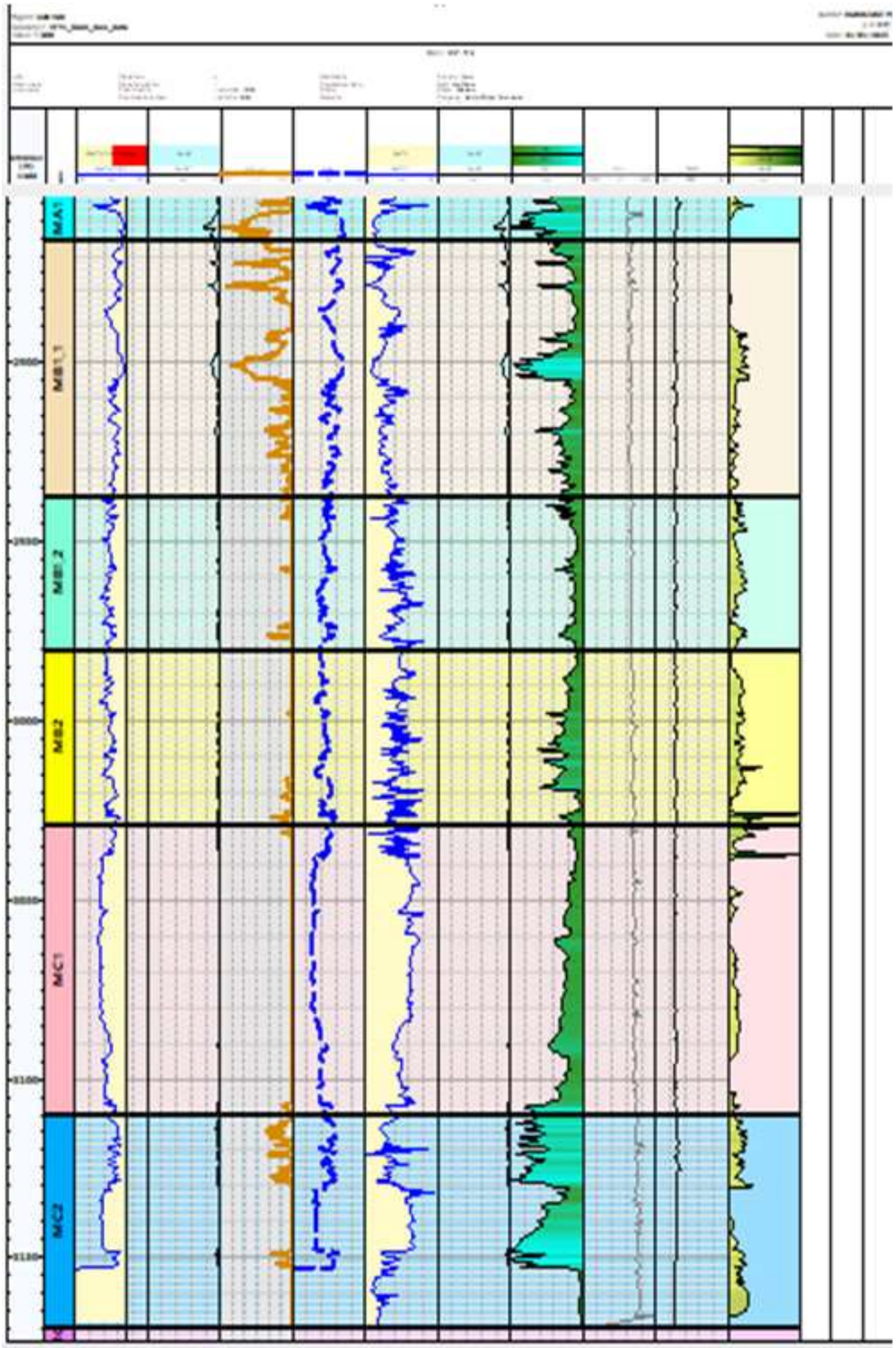

Figure (4.5) All logs Calculate

Chapter Five

Discussion and Recommendations

5.1 Discussion

1. Understanding the distribution of High Permeability Streaks (HPS) in the Mishrif reservoir requires comprehensive data, including:

- Core data analysis, PLT measurements, and well logging for geological characterization and petrophysical properties.
- Pressure measurements using MDT to study the impact of these zones on fluid movement during water flooding.

2. After examining the key petrophysical properties such as porosity, permeability, and water saturation, it becomes clear how these parameters influence reservoir performance and hydrocarbon recovery.

3. Special attention is given to how variations in porosity and permeability affect fluid flow and the overall performance of the reservoir zones.

4. how variations in porosity, permeability, and water saturation affect reservoir performance and fluid behavior.

5. The aim is to interpret the significance of the petrophysical data in the context of reservoir quality, potential productivity, and fluid distribution.

6. Moreover, the analysis explores the implications of water saturation levels and their impact on hydrocarbon mobility and production strategies.

7. Log analysis shows that the reservoir layer is heterogeneous, especially in permeability. This suggests that future water injection should be zonal to avoid early water breakthrough and ensure better sweep efficiency.

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