PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
Ministry of Higher Education and Scientific Research

N° Series … … …/2025

University of Kasdi Merbah -Ouargla-

Faculty of Hydrocarbons, Renewable Energies And Science Of Earth And Universe
Drilling and Oilfield Mechanics department

DESSERTATION

To obtain the Professional

Master degree Sector:

Petroleum Engineering

Option: Drilling

Presented by:

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- TITTLE–

Petrophysics Parameters Determination & Interpretation by Using Techlog 15.3 Software in Hassi Messeoud field

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Publicly defended on: 12/06/2025

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Academic year: 2024/2025

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General Introduction

General Introduction

Algeria's complex geological framework plays a pivotal role in the exploration and production of hydrocarbons, particularly within the Saharan Platform, home to some of the country's most significant oil and gas reserves. This thesis focuses on the Hassi Messaoud field, located in the Eastern Province of the Saharan Platform, which has emerged as a cornerstone of Algeria's petroleum industry since its discovery in 1956. Characterized by a vast Cambrian sandstone reservoir with variable petrophysical properties, Hassi Messaoud exemplifies the intricate interplay between geological history, structural formation, and reservoir behavior.

The present work aims to investigate the geological, structural, and petrophysical characteristics of the Hassi Messaoud field using advanced interpretation techniques and well log analysis. Particular emphasis is placed on evaluating porosity, permeability, saturation, and shale volume—parameters that are critical to understanding reservoir performance. By leveraging both qualitative and quantitative approaches in Schlumberger's Techlog software, this study provides a comprehensive evaluation of the field's productivity potential, contributing to more effective reservoir management and development strategies.

This dissertation focuses on the characterization of the reservoir in the Hassi Messaoud field, It is subdivided into 3 chapters:

- Chapter I: Geographic and geological overview of the Hassi Messaoud field.
- Chapter II: Overview of logging and petrophysical analysis.
- Chapter III: Interpretation of logs using Techlog software.

CHAPTER I

Geographic and Geological Overview of the Hassi Messaoud Field.

CHAPTER I: Geographic and Geological Overview of the Hassi Messaoud Field.

1. Introduction:

In Algeria, the geological landscape is characterized by two major structural units: the Atlas (or Alpine domain) in the north, shaped by Alpine tectonics, and the Saharan Platform in the south, which is relatively stable and was primarily formed during the Paleozoic era. The relief of Algeria consists of three large groups: Tell in the North, the highlands and the Saharan Atlas in the center, and the Sahara in the South. The Saharan Platform is subdivided into two provinces by the Amguid Ridge: the Western Province, rich in gas, and the Eastern Province, where both oil and gas deposits are found. The provinces differ due to their distinct Mesozoic and Cenozoic histories. In the Eastern Province, sediments from these periods are well-developed and tectonically active, while in the Western Province, they are more stratiform and less developed. Additionally, hydrocarbon formation and trapping in Paleozoic basins vary between the provinces, with Mesozoic-Cenozoic influences in the East and Paleozoic influences in the West. Notably, the Hassi Messaoud Field, a multi-billion barrel oil field discovered in 1956 within the Triassic Basin of Algeria, contains a 2000 km2 Cambrian sandstone reservoir at an average depth of 3400 m, characterized by variable and unpredictable petrophysical properties (porosity, shaliness, and permeability) that impact productivity, despite extensive drilling and coring over decades. The Hassi Messaoud oil field, situated in the Eastern Province of the Saharan Platform, exemplifies these geological processes. It is a major oil-producing area, with oil extracted from Cambrian sandstone reservoirs within a large dome structure. The field's significance underscores the importance of understanding Algeria's geological structure for effective resource management and exploitation.

2. Geographical situation:

Hassi Messaoud can be located 800 km southeast of Algiers (between meridians 5°30'–6°00 and parallels 31°00'–32°00'N) and 350 km from the Algerian-Tunisian borders, 80 km east of Ouargla . The city spans 71,237 square kilometers and houses approximately 88,000 people [1]. For decades, Hassi Messaoud has been a vital economic and geostrategic piece of the inner perimeter of a sprawling oil field. Its oil reserve is a sizable one located in its industrious zone.

Figure I.1: Location map of Hassi Messaoud-Algeria. [1]

Climate & Vegetation:

Hassi Messaoud experiences a hyperarid climate, marked by scorching, dry, and clear summers, as well as cool, dry, and mostly clear winters. Temperatures generally range between 4.6°C and 35.5°C. Rainfall is scarce, with an average annual precipitation of just 34.65 mm. [2]

Vegetation is sparse due to the desert environment, although some studies focus on monitoring vegetation and surface water dynamics in the broader Oued M'ya region near Hassi Messaoud.

3. Geological Situation

The Hassi Messaoud field is located in the central part of the Triassic region, to the east of the Oued Mia depression within the fourth region. This area is recognized as the largest oil and gas region in Algeria in terms of both surface area and reserves. Spanning approximately 53 by 44 kilometers, it is the country's most extensive petroleum reservoir. [3]

- From a geological perspective, the Hassi Messaoud field is bounded by:
- West: The Oued Mya depression.
- North: The Djemmâa-Touggourt structure.
- South: The Amguid El Biod high.
- East: The Dahar highlands, Rhourde El Baguel, and the Ghadamès depression.
- From a reservoir perspective, the field is bordered by:

- Northwest: The Ouargla oil fields, including Gellala, Ben Kahla, and Haoud Berkaoui.
- Southwest: The El Gassi, Zotti, and Al Agreb fields.
- Southeast: The Rhourde El Baguel and Mesdar.

4. History of the Hassi Messaoud Field

The deposit was discovered by two separate companies: CFPA (Compagnie Française des Pétroles (Algeria), Total Group) in the northern part of the field, and SN Répal (Société Nationale de Recherche et d'Exploitation de Pétrole en Algérie, ELF Group) in the southern part of the field. In 1946, SN Répal began its exploration across the Algerian Sahara, and three years later, geophysical prospecting started with a gravity survey.

In 1951, the first seismic survey was conducted in the Ouargla region. This exploration of the perimeter of the Saharan basins allowed SN Répal and its partner, CFPA, to submit their first exploration permit applications. The Hassi Messaoud field was discovered on January 16, 1956, by SNREPAL, which initiated the first MD1 well. This well was installed following a seismic survey conducted on June 15 of the same year. This well, discovered at a depth of 3,338 meters, confirmed the existence of oil in the Cambrian sandstone. In May 1957, 7 km northwest of MD1, the CFPA confirmed the existence of another deposit with the OM1 well.

The number of wells drilled, which was then 10 per year, has continued to increase since 1967, particularly since the nationalization of hydrocarbons on February 24, 1971.

Currently, the field is divided into 25 production zones. These zones are relatively independent and correspond to a group of wells that communicate with each other and behave similarly in terms of reservoir pressure.

5. Structural Framework:

The Hassi Messaoud field is a vast, highly eroded anticline, cut by a series of faults or structural features oriented North-Northwest to South-Southeast, resulting in a Horst and Graben geometry. These faults are detected either by structural displacement of formations or by the repetition of sedimentary series.

The Paleozoic, represented only by the Cambro-Ordovician, is unconformably overlain by a thick Mesozoic-Cenozoic cover, with a basal Triassic salt sedimentation that is very thick, ensuring the sealing and trapping of hydrocarbons within the formation.

The absence of the upper Paleozoic series is likely due to a period of non-deposition linked to a long period of emersion rather than intense erosion.

The Hassi Messaoud field occupies the central part of the Triassic province. In terms of area and reserves, it is the largest oil field in Algeria, covering nearly 2200 km².

6. Stratigraphy of the Hassi Messaoud Field:

The Hassi Messaoud field appears as a vast mole on which a significant part of the Paleozoic stratigraphic series is absent, thus removing any trace of geological history for 230 million years (Figure 4).

These are Paleozoic deposits, resting on a granitic basement, which have been eroded. As a result, Mesozoic deposits rest unconformably on the Cambro-Ordovician. Moving towards the periphery of the field, the series becomes more complete. From the base to the top of this series, we distinguish (Figure 5):

6.1. The Crystalline Basement:

It was observed in wells Md2 at 3658 meters and Om81 at 3533 meters, described as porphyritic granite of pink color, altered at the top.

6.2. Infracambrian:

This is the oldest lithological unit encountered in well Omg47 at a depth of 4092 meters, consisting of red clayey sandstones.

6.3. Paleozoic:

On the basement, the Paleozoic formations rest unconformably; this is the Pan-African unconformity. From the base to the top, we distinguish:

a. Cambrian:

Mainly composed of heterogeneous sandstones, fine to very coarse, interspersed with clayey siltstone layers. The average thickness is 590 meters. It constitutes the main reservoir of Hassi Messaoud and has been subdivided into four distinct units . This division is based on petrographic, petrophysical, and diagraphic criteria. From bottom to top, we distinguish:

- **Lithozone R3:** Its average thickness is 370 meters.

The R3 lithozone rests on the Infracambrian or directly on the basement. It consists of feldspathic and micaceous sandstones, medium to very coarse-grained, conglomeratic at the base, with abundant clay cement, admitting ferruginous sandstone layers and clayey siltstone layers. It has no petroleum interest due to its low matrix properties and its deep position above the water table.

- **Lithozone R2:** Its average thickness is 100 meters.

The R2 lithozone consists of medium to coarse-grained, poorly sorted, micaceous sandstones, with abundant clay cement and siltstone intercalations. The stratifications are often oblique. It is exploitable when in a high position.

- **Lithozone Ra:** Its average thickness is 125 meters.

It consists of medium to coarse-grained, anisometric quartzitic sandstones, with clay and siliceous cement, admitting numerous centimeter to decimeter-thick siltstone layers. The stratifications are often oblique to cross-bedded, sometimes horizontal. Tigillites are present in the upper part of the series. The entire "Ra" has been eroded in the center of the field.

According to LHOMER 1966, the "Ra" is subdivided into three granulometric classes:

- The lower coarse zone or lower Ra: subdivided into drains 1: "D1, ID, D2," which are coarse, poorly sorted sandstones with oblique stratifications.
- The middle fine zone: corresponds to drain "D3," consisting of fine to very fine-grained, well-sorted materials with abundant Tigillites and clayey and silty intercalations.
- The upper coarse zone: corresponds to lithozone "D4," consisting of almost the same sandstones as those of the lower Ra.

- **Lithozone Ri (Cambro-Ordovician):** Its average thickness is 42 meters.

The transition between the Cambrian and Ordovician is not well marked, which is why a transition zone called "Cambro-Ordovician" can be distinguished.

It consists of isometric, fine, well-sorted, glauconitic quartzitic sandstones, with clay and siliceous cement, and abundant Tigillites. In terms of petroleum, this zone represents a secondary reservoir.

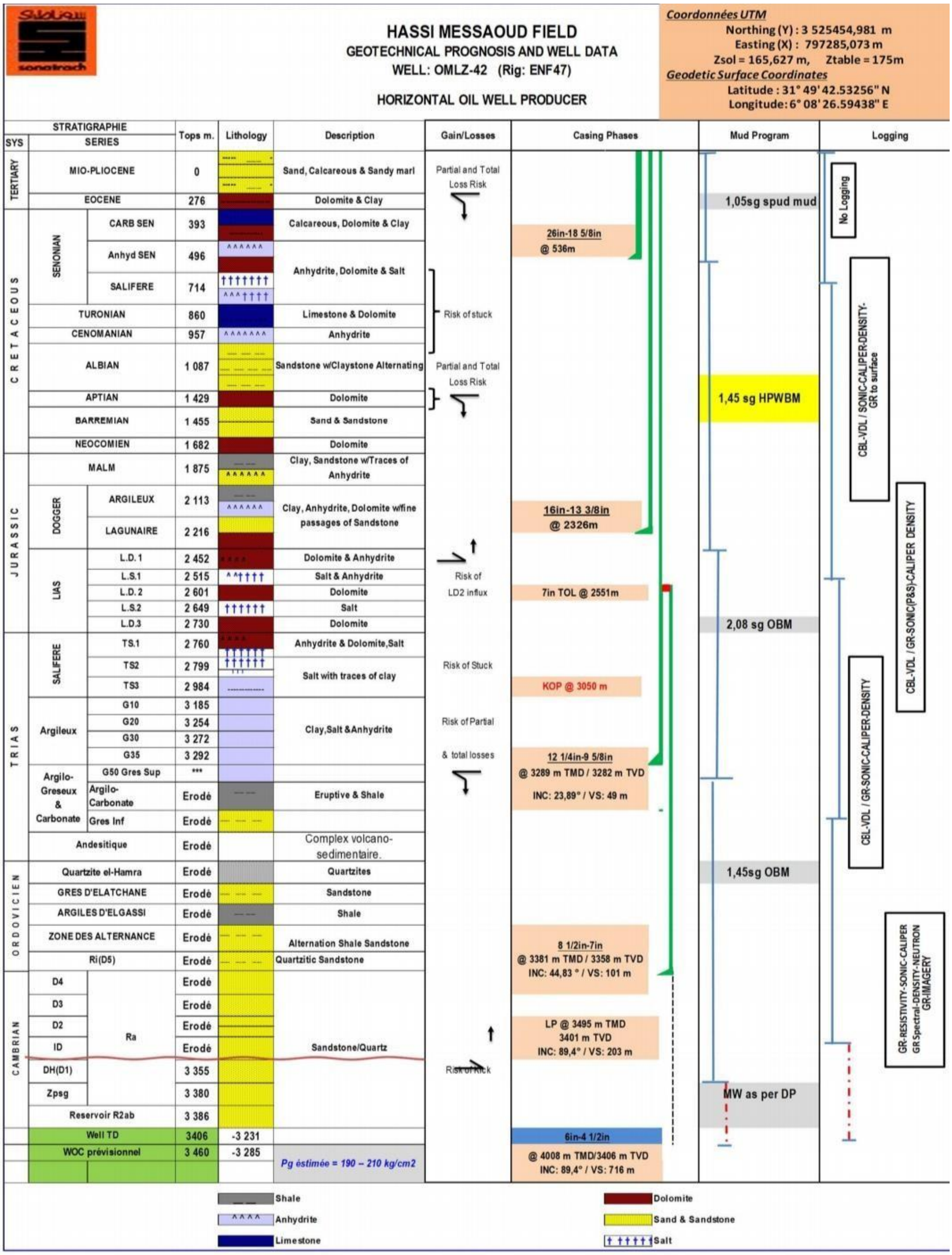

Figure I.2: Lithological Column and Wellbore Architecture. [4]

b. Ordovician:

At the regional scale, the Ordovician is composed of several lithological units; however, it should be noted that the series is incomplete.

For the Hassi Messaoud field, only four (4) lithological units are distinguished from the base to the top:

- **Zone of Alternations:** Its average thickness is 20 meters.

As its name suggests, this term alternates irregularly between black silty clays and fine isometric quartzitic sandstones with abundant Tigillites and some Lingulidae (Ordovician-Present), its mineral fraction includes glauconite and siderite.

- **El Gassi Clay:** Their average thickness is about 50 meters.

This formation consists of indurated, schistose clay, presenting a green to black color, rarely red. This clay can be glauconitic or carbonated, presenting a fauna (Graptolites) indicating a marine depositional environment. This formation is mainly encountered in the peripheral zones of the field.

- **El Atchane Sandstones:** Their average thickness varies from 12 to 25 meters.

This formation consists of fine to very fine sandstones, gray-beige to dark gray in color. This sandstone can be clayey, admitting numerous clayey and silty layers.

- **Hamra Quartzites:** Their average thickness varies from 12 to 75 meters.

These are fine, siliceous quartzitic sandstones, light gray to beige, with rare clayey, silty, micaceous, and indurated intercalations of glauconite, anhydrite, and numerous Tigillites.

6.4. Mesozoic:

a. Triassic:

It rests unconformably on the Cambrian in the center and on the Ordovician on the flanks of the structure.

It is a very varied ensemble resulting from a transgression that was of a lagoonal-marine character accompanied by eruptive flows. It is subdivided into four (4) units:

- **Eruptive Triassic:** Its thickness varies between 0 and 92 meters.

Locally, eruptive flows interstratified with Triassic sandstones are encountered, indicating the presence of several volcanic outpourings intercalated within the detrital facies. These flows often occurred in Hercynian valleys.

- **Argillaceous-Gritty Triassic:** Its average thickness is 35 meters.

It constitutes the first filling of the Paleozoic relief and is subdivided into several units that differ in their lithologies and diagraphic responses. It rests, locally, on an eruptive flow filling deep Hercynian erosion valleys:

- Upper Sandstones: these are fine sandstones with clay cement.
- Lower Sandstones: consisting of fine to medium sandstones with abundant clay cement.

- **Argillaceous Triassic:** Its average thickness is 113 meters.

It consists of dolomitic or silty clays intercalated with layers of brown-red salt.

- **Saliferous Triassic:** Its average thickness is 340 meters.

It plays the role of a cap rock, consisting of massive salt layers with anhydrite intercalations and slightly silty and dolomitic clay layers at the top. It consists of three (3) units:

- Saliferous Triassic "3" or "TS3": its thickness is 202 meters.

At the base of the saliferous Triassic, it consists of massive salt layers with anhydrite intercalations and slightly silty and dolomitic clay layers at the top.

- Saliferous Triassic "2" or "TS2": its thickness is 189 meters.

It consists of massive salt layers with anhydrite and gypsiferous clay intercalations.

- Saliferous Triassic "1" or "TS1": its thickness is 46 meters.

It consists of salts with a predominance of anhydrites and dolomitic clays.

b. Jurassic: Its average thickness is 844 meters.

The Jurassic is an argillaceous-gritty ensemble with limestone intercalations at the top (Malm) and alternations of lagoonal and marine facies at the base (Dogger and Lias).

- **Lias:** Its average thickness is 300 meters.

The transition from the Triassic to the Lias is characterized by a zone of dolomitic marls known as "Horizon B," which is a seismic marker. The Lias is subdivided into five (5) distinct levels intercalated throughout the thickness:

- Dolomitic Lias "LD3":

With a thickness of 31 meters, it consists of gray marls with gray dolomite layers.

- Saliferous Lias "LS2":

With a thickness of 58 meters, it consists of translucent salts and brown-red clay layers.

- Dolomitic Lias "LD2":

With a thickness of 55 meters, it is formed by an alternation of massive, fine-grained, grayish dolomite layers with gray, slightly dolomitic marl layers.

- Saliferous Lias "LS1":

With an average thickness of 90 meters, it consists of brown clays with salt and white anhydrite layers.

- Dolomitic Lias "LD1":

With a thickness of 66 meters, it consists of dolomite and anhydrite layers with clay and limestone intercalations.

- **Dogger:** Its average thickness is 320 meters.

The Dogger is subdivided into two (2) formations, the lagoonal Dogger at the base and the argillaceous Dogger at the top.

- Lagoonal Dogger:

It is represented by a lagoonal series at the base, essentially of anhydrite and dolomite over 210 meters in thickness.

- Argillaceous Dogger:

With a thickness of 107 meters, it consists of soft, silty clays with fine, clay-carbonate cemented sandstone layers.

- Malm: Its average thickness is 226 meters.

It is characterized by the deposition of clays and marls with intercalations of limestone and dolomite layers accompanied by some traces of anhydrite.

c. Cretaceous: Its average thickness is 1620 meters.

It consists of seven stages, from the base to the top, we distinguish:

- **Neocomian:** Its thickness is 182 meters.

It includes two levels, at the base a gritty term consisting of sandstones and some clay layers, at the top an argillaceous term represented by clays with numerous limestone and dolomite intercalations.

- **Barremian:** Its average thickness is 280 meters.

It is formed of fine to medium carbonated sandstones with anhydrite layers, alternating with gritty and dolomitic clay layers.

- **Aptian:** Its thickness is 25 meters.

It is represented by two dolomitic layers framing a clay level. The Aptian-Barremian boundary coincides with the calcareous-dolomitic bar, which represents a good seismic marker.

- **Albian:** Its average thickness is 350 meters.

Consisting of sandstones and fine sand, with silty clay intercalations, it includes a vast aquifer.

- **Cenomanian:** Its average thickness is 145 meters.

Alternation of anhydrite and brown-red clay, gray marls, and dolomites. The Cenomanian-Albian boundary coincides with the transition from evaporitic series to more gritty series of the Albian.

- **Turonian:** Its average thickness varies from 70 to 120 meters.

Alternation of clayey limestone, dolomitic limestone, and chalky limestone; at the top appear the limestone layers. The Turonian represents the saline water table.

- **Senonian:** Its average thickness is 230 meters.
- Lagoonal Senonian:

With a thickness of 350 meters, it presents in its lower part massive salt layers with clay intercalations and an alternation of anhydrites, clays, and dolomites at its top.

- Carbonated Senonian:

With a thickness of 110 meters, it is characterized by a succession of dolomitic, clayey limestone layers and anhydrite layers with gypsiferous dolomite intercalations.[5]

7. Petroleum System of the Hassi Messaoud Field

The Hassi Messaoud petroleum system is primarily controlled by the Oued Mya depocenter, which serves as the main source kitchen for hydrocarbon generation. The field's vast oil reserves are attributed to a combination of efficient source rocks, long-distance migration pathways, structural trapping mechanisms, and an effective regional seal.

7.1. Soure Rock

The primary source rock for hydrocarbons in Hassi Messaoud is the Lower Silurian graptolitic shale, which is approximately 30 meters thick. This organic-rich formation is widely recognized as the most significant contributor to petroleum generation in the region. The Devonian source rock, which could have been an additional contributor, has been largely eroded due to the Hercynian unconformity, leaving the Silurian shale as the dominant hydrocarbon source. The high total organic carbon (TOC) content and sufficient burial depth of these shales enabled them to generate large volumes of oil.

7.2. Migration Pathways

Hydrocarbons in the Hassi Messaoud system migrated primarily from the west, originating in the Oued Mya depocenter. The Oued Mya basin lacks large structural traps capable of holding the massive amounts of oil generated, resulting in excess hydrocarbons migrating eastward onto the Hassi Messaoud Ridge. This west-to-east migration model is supported by geochemical similarities between the hydrocarbons in Hassi Messaoud and those found in Triassic fields further west.

The presence of late oil-to-gas window kitchens in the southeast suggests that if hydrocarbons had migrated from this direction, the field would have a higher gas content. However, the field is undersaturated with gas, confirming that the primary migration occurred from the west and northwest, rather than from the southeast. The migration process occurred after the late Jurassic to early Cretaceous, likely during the deposition of thick Late Cretaceous sediments over the Oued Mya depocenter.

7.3. Reservoir Rocks

The Hassi Messaoud field contains two main reservoir types. The primary and most significant reservoirs are the Cambro-Ordovician quartzite sandstones, which have excellent porosity and permeability, allowing for effective hydrocarbon storage. Secondary reservoirs exist within the Lower Devonian and Lower Triassic sandstones, but these accumulations are relatively small and associated with stratigraphic traps such as sand pinchouts.

7.4. Trap and Seal Mechanisms

Hydrocarbon entrapment in Hassi Messaoud is controlled by structural traps, primarily broad, low-relief anticlines within the Cambro-Ordovician formations. These traps were formed before hydrocarbon migration, ensuring that the reservoirs were already in place to capture migrating oil.

A key factor in preserving hydrocarbons is the Liassic evaporite seal, which extends continuously across the region. This thick evaporitic layer plays a crucial role in preventing vertical migration and hydrocarbon leakage, ensuring that petroleum remains trapped in the Cambro-Ordovician reservoirs. No hydrocarbons have been discovered in post-salt formations, and there are no recorded surface seeps, further confirming the effectiveness of this regional seal.

7.5. Hydrocarbon Composition and Maturity

The oil in Hassi Messaoud is highly mature, with biomarker studies confirming its Silurian origin. Due to the long-distance migration from the Oued Mya kitchen, some geochemical fractionation has occurred, affecting hydrocarbon composition. The field remains undersaturated with gas, further supporting the conclusion that migration occurred primarily from oil-mature source rocks in the west rather than from gas-prone source rocks in the southeast. [6]

CHAPTER II

Overview of Logging and Petrophysical Analysis.

CHAPTER II: Overview of Logging and Petrophysical Analysis.

1. Introduction:

Geophysics is the scientific discipline focused on studying the Earth's internal layers at depth, using a range of quantitative physical methods to investigate regions hidden beneath the surface. The detection of hydrocarbons in deep geological formations can only be confirmed through drilling, which reveals certain characteristics of the reservoir.

To better evaluate these properties, well logging is introduced. This technique provides immediate and valuable data, enabling the qualitative identification of different rock types, the analysis of fluids within the formation, and the estimation of porosity. Logging also enables the correlation between wells, helping to trace lithological horizons across drill sites and construct a three-dimensional model of the subsurface.

Because of the depth and precision of the insights they offer, logs have become essential tools in modern geological studies—making it nearly impossible to conduct a comprehensive geological synthesis without them.

2. Petro physical Rock Proprieties:

2.1. Porosity:

2.1.1. Definition:

Porosity (ϕ) is the measure of the void space within a rock. It is defined as the ratio of the volume of void space (pore volume, PV) to the bulk volume (BV) of the rock. It can be expressed as fraction or percentage.

$$\Phi = \frac{PV}{BV} \dots\dots\dots (1)$$

The porosity of earth materials originates during two phases: 1) during the deposition of sediments, lithification, or cooling of crystalline rock ; and 2) after deposition as the earth material is exposed to other conditions such as compaction, weathering, fracturing and/or metamorphism. As a result, earth materials can have porosities dominated by primary conditions during initial formations, secondary events after formation, or both.

Porosity is a scalar dimensionless variable that tends to change in a linear manner.

2.1.2. Porosity types:

a. Primary porosity:

It is the porosity that was formed during rock deposition. This includes inter-granular porosity in sandstones and inter-crystalline porosity in carbonates.

b. Secondary porosity:

It’s an additional porosity that was formed due to later geological events. It includes fractures in different rocks and solution cavities in carbonates. It is more popular in carbonates and basements reservoirs.

For basement reservoirs the secondary porosity (fractures) is probably the only rock voids available. It is to be mentioned that a rock with dominant primary porosity is more homogeneous than the one with dominant secondary porosity.

c. Absolute or total porosity:

Is the one given by the previous basic definition.

d. Effective or interconnected porosity:

Is the one calculated by replacing the volume of void space (Pore Volume, PV) by the volume of interconnected void space in the porosity basic definition.

$$\Phi = \frac{\text{Interconnected PV}}{\text{BV}} \ldots\ldots\ldots (2)$$

According this definition, the effective porosity is either equal to or less than the absolute porosity. To avoid misuse, the reservoir engineer should be aware about the definitions of total porosity and effective porosity used by some open-hole log analysts. In their analysis, the open-hole log analysts consider the total porosity as the average of the two porosity values obtained from formation density and neutron logs [t = (D + N)/2]. This value is actually an apparent porosity value which affected by different factors especially by the water bound in shale. After doing necessary corrections to that apparent porosity value, they define the resulted value as the effective porosity (Φ_E). This is the supposed to be the correct total or active porosity and has nothing to do with interconnection. [7]

2.2. Fluid Saturation:

2.2.1. Definition:

Fluid saturation is the measure of the void space within a rock filled with a specific fluid. It is defined as the ratio of the pore volume filled with a specific reservoir fluid to the total pore volume (PV). Accordingly, water saturation (S_w) is defined as,

$$Sw = \frac{\text{Water Filled PV}}{\text{Total PV}} \ldots\ldots\ldots. (3)$$

Similar formulae can be written for other fluids' saturation in the reservoir system; oil saturation (So) and gas saturation (Sg).

It is obvious that the saturations of all fluids in the system are summed up to unity;

$$S_w + S_o + S_g = 1.0 \ldots\ldots\ldots\ldots\ldots (4)$$

Like porosity, saturation is a dimensionless scalar variable. It can be expressed as fraction or percentage. Fluid saturation is one of the essential parameters for estimating the hydrocarbon in place. It is also needed for studying fluid flow in reservoir and reservoir development planning. [8]

2.2.2. Fluid Saturation Types:

a. Connate Water Saturation (S_{wc})

Is defined as the water saturation at time of reservoir discovery. It can have any value from the irreducible water saturation to the maximum of 100 value 3.0–5.0%)% in the aquifer. Connate water (also called fossil water) was trapped in the pores of the rock during its formation. The chemistry of the connate water could change along the rock history.

b. Irreducible water saturation (S_{wirr})

Is the minimum possible value of water saturation in the reservoir system. However, it is generally determined in laboratory and not always detected in reservoir. Its value depends upon the rock quality.

c. Critical Water Saturation (S_{wcr})

Is the minimum water saturation at which the water phase starts to be mobile. In most applications, it is considered equals to the irreducible water saturation.

At any point in an oil reservoir, the initial oil saturation is calculated by,

$$S_o = 1.0 - S_w \ldots\ldots (5)$$

Similar equation can be written for gas reservoir,

$$S_g = 1.0 - S_w \ldots\ldots\ldots (6)$$

Where:

S_o: Oil saturation.

S_w: Water saturation.

S_g: Gas saturation.

d. Residual Oil Saturation (S_{or})

Is the oil saturation at which the oil phase become immobile and it is the minimum possible oil saturation in the oil reservoir. This saturation is reached as result of complete displacement of oil from the pores. There are two different residual oil saturation, the water–oil residual oil saturation (S_{orw}) which reached by water displacing oil and the gas-oil residual saturation (S_{org}) caused by gas displacing oil. These residual oil saturations are the ones that can be achieved by primary drive forces and secondary recovery methods. Successful tertiary recovery methods would reduce the residual oil saturation and consequently increase ultimate oil recovery. We should be clear about the difference between residual oil saturation and remaining oil saturation.

e. Remaining Oil Saturation (ROS)

Is the average oil saturation in a reservoir at the end of its production life. When an oil reservoir comes to its economic limit, there will be pores that still have mobile oil.

f. Critical Gas Saturation (S_{gcr})

Is the minimum free gas saturation at which the gas phase starts to be mobile. The value of critical gas saturation is generally small (typically 3.0 to 5.0%). [7]

2.3. Permeability:

2.3.1. Definition:

Permeability of rock indicates how easily the reservoir fluids can move within the porous network. Relatively high values of rock permeability lead to good well productivity and better recovery efficiency from the reservoir as a general rule. In most unconventional reservoirs, however, rock matrix permeability is found to be extremely low rendering traditional methods of production ineffective. Technological innovations enable oil and gas recovery from unconventional resources on a commercial scale where natural or artificial conduits for flow of fluids play a crucial role.

2.3.2. Darcy's Law :

Permeability was introduced for the first time through the experimental work by Darcy (1856).

His study of the water movement through sand in water purification system led to establishing the famous formula (Darcy's Law). This law relates the fluid flow through the porous medium with the applied differential pressure. Figure 5.1 is a schematic representation of Darcy's experiment.

Considering a horizontal cylindrical sample of a porous medium Darcy's Law, in c.g.s. units, will be written as, [9]

$$Q = \left(\frac{K.A}{\mu}\right) . \left(\frac{P}{L}\right) \ldots\ldots\ldots..(7)$$

Where:

Q = Flow rate, cc/s

A = Cross sectional area of the sample, cm^2

μ = Fluid Viscosity, poises

P = Pressure Difference (P1−P2), dyne/ cm^2

L = Length of the sample, cm

K = Constant (Later defined as the porous medium permeability).

2.3.3. Types of permeability:

a. Absolute permeability

The permeability of the porous medium when it is 100% saturated with a single fluid is defined as the absolute permeability. This absolute permeability (Kabs) is the same regardless of which fluid saturates the rock.

b. Effective permeability:

When saturated with more than one fluid, the same porous medium has different permeability values to each specific fluid. The permeability of a porous medium to one specific fluid in the existence of other fluid/s is defined as the effective permeability to that fluid. A porous medium that contains oil, water and gas has effective permeability to each one of the three phases (Ko, Kw and Kg). It is important to note that (Ko + Kw + Kg < Kabs). It is also important to insist that the permeability is a rock property. It is quite misleading to say air permeability or oil permeability. This should be replaced by permeability to air or permeability to oil.

c. Relative permeability:

Relative permeability to one specific fluid is the ratio of the effective permeability to that fluid to the absolute permeability of the rock. It was found that the relative permeability to a specific fluid changes with its relative saturation.

Permeability is a vector variable which has different values in different directions (Fig. 5.5). It tends to change in logarithmic or power manner. It is a common practice to consider two different permeability values in ; horizontal permeability (Kh = Kx = Ky) and vertical permeability (Kv = Kz). However, such simplification should be avoided for reservoirs with high level of anisotropy. [8]

2.4. Wettability:

2.4.1. Definition

Wetting refers to the phenomenon of how a liquid deposited on a solid substrate spreads out under the force of surface tension. Understanding wetting enables us to explain why water spreads readily on clean glass, where a droplet of mercury cannot spread at all. Figure 8.17 shows the phenomenon.

When the term “wetting” is mentioned, three phases, solid, liquid, and gas, must be involved in the studied system. And, moreover, whether a liquid can wet up a solid or not is always suggesting that it is a comparison relative to the third phase (gas or another liquid). That is to say, if one of the non-solid phases can wet up the solid, the other cannot.

2.4.2. Parameters Describing the Degree of Wetting

The degree of wetting can be described by the contact angle or the adhesion work.

a. Contact Angle (Also Called Wetting Angle)

At any point located on the liquid–liquid–solid (or gas–liquid–solid) triple line, as shown in Fig. 8.18, where each sketch illustrates a small liquid droplet is resting on a flat horizontal solid surface, the tangent line drawn tangential to the liquid–liquid (or gas–solid) interface forms an angle with the solid–liquid interface. This angle, symbolized as θ, is rightly called the contact angle. It is stipulated that θ should be reckoned from the side presented by the liquid phase with higher polarity.

For a system composed of oil, water, and rock, wetting can be characterized into the following types

- Water-wet, where the rock surface prefers to be coated with water and thus the rock has a high affinity towards water, allowing water to spread on the surface (Figure 7.5a). This means that the contact angle will be less than 90° as the water spreads on the surface.
- Intermediate-wet or neutral-wet, where the surface has an almost equal tendency to be coated by one of the fluids (either oil or water). This means that the contact angle is around 90° as the surface has equal affinity towards both oil and water.
- Oil-wet, where the rock prefers to be in contact with oil, opposite to the water-wet case. In this case, the contact angle will be greater than 90° as the surface prefers to be in contact with oil over water. The cohesive forces between the water molecules are stronger than the adhesive forces between the water molecules and the surface, and thus water droplets will stick together to form a sphere. Every system undergoes an energy minimization phenomenon, in which the system tends to go towards the lowest energy state and hence the droplet takes the shape of a sphere as spheres have the smallest surface area.
- Mixed-wet, where parts of the rock prefer to be in contact with oil and the other parts prefer to be in contact with water. Mixed wettability can also be referred to as fractional wettability and the contact angle will vary depending on the region of the rock. [7]

3. Reminder On Well Logging:

3.1. Definition

There are two categories of logging: instantaneous logging and delayed logging (O. SERRA, 1997). This work focuses on delayed logging. Delayed logging is a geophysical technique implemented inside a borehole. It involves recording the physical parameters of rocks as a function of depth. The investigation radius is not much greater than that of the borehole. The result of a logging is presented in the form of a curve in a coordinate system where depth is indicated on a vertical axis pointing downward and the measurement result (resistivity, density, advance rate, etc.) is indicated on a horizontal axis. (O. SERRA, 1997). There are close relationships between the recorded physical parameters and the geological parameters. A "geophysical facies" can be defined as the sum of the characteristics observed by the logs for a given level. As a result, a change in a geological parameter must have an impact on one or more physical parameters. Similarly, a variation in a physical parameter will have geological significance. (O. SERRA, 1997).

3.2. Borehole Environment

Where a hole is drilled into a formation, the rock plus the fluids in it (the rock-fluid system) are altered in the vicinity of the borehole. The borehole and the rock surrounding it are contaminated by the drilling mud, which affects logging measurements. Figure 1.1 is a schematic illustration of a porous and permeable formation that is penetrated by a borehole filled with drilling mud.

Some of the more important symbols shown in Figure 1.1 are:

3.2.1. Hole Diameter (d_h)

The borehole size is determined by the outside diameter of the drill bit. But, the diameter of the borehole may be

- Larger than the bit size because of washout and/or collapse of shale and poorly cemented porous rocks.
- Smaller than the bit size because of a build-up of mud cake on porous and permeable formations (Figure II.1). [10]

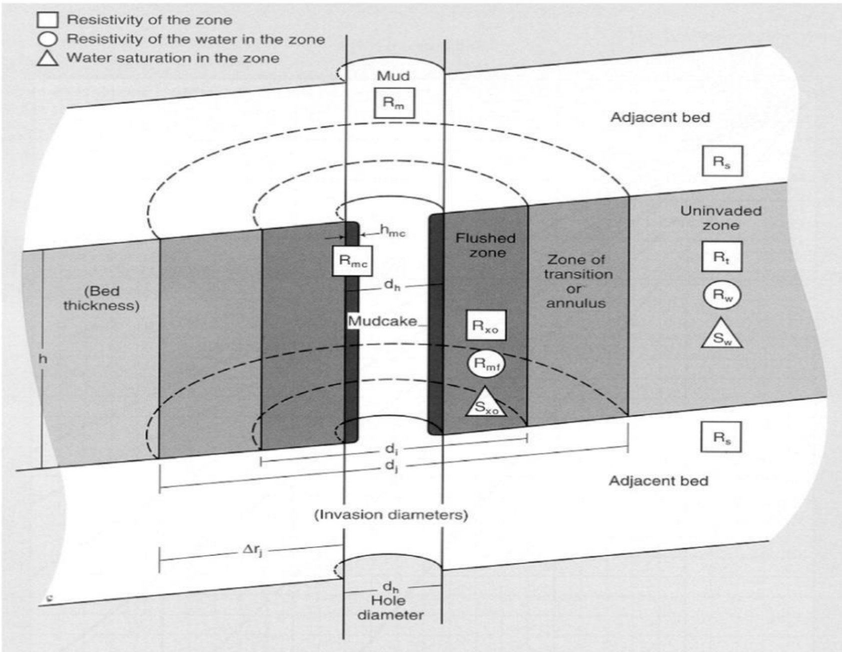

Figure II.1: The borehole environment and symbols used in log interpretation. [10]

Common borehole sizes normally vary from 7-7/8 in. to 12 in., and modern logging tools are designed to operate within these size ranges. The size of the borehole is measured by a caliper log.

3.2.2. Drilling mud Resistivity (Rm)

The density of the mud is usually kept high enough so that hydrostatic pressure in the mud column is greater than formation pressure. This pressure difference forces some of the drilling fluid to invade porous and permeable formations. As invasion occurs, many of the solid particles (i.e., clay minerals from the drilling mud) are trapped on the side of the borehole and form mud cake (having a resistivity of Rmc; Figure II.1). Fluid that filters into the formation during invasion is called mud filtrate (with a resistivity of Rmf; Figure II.1). The resistivity values for drilling mud, mud cake, and mud filtrate are recorded on a log's header, and are used in interpretation.

3.2.3. Invaded Zone

The zone in which much of the original fluid is replaced by mud filtrate is called the invaded zone. It consists of a flushed zone (of resistivity Rxo) and a transition or annulus zone (of resistivity Ri). The flushed zone occurs close to the borehole (Figure II.1) where the mud filtrate has almost completely flushed out a formation's hydrocarbons and/or water (Rw). The transition or annulus zone, where a formation's fluids and mud filtrate are mixed, occurs between the flushed zone and the uninvaded zone (of resistivity Rt). The uninvaded zone is defined as the area beyond the invaded zone where a formation's fluids are uncontaminated by mud filtrate. [11]

3.2.4. Flushed zone Resistivity (R_{xo})

The flushed zone extends only a few inches from the wellbore and is part of the invaded zone. If invasion is deep or moderate, most often the flushed zone is completely cleared of its formation water by mud filtrate (of resistivity R_{mf}). When oil is present in the flushed zone, the degree of flushing by mud filtrate can be determined from the difference between water saturations in the flushed (S_{xo}) zone and the uninvaded (S_w) zone (Figure II.1).

Usually, about 70% to 95% of the oil is flushed out; the remaining oil is called residual oil [$S_{ro} = (1.0 - S_{xo})$, where Sro is the residual oil saturation, (ROS)].

3.2.5. Uninvaded zone Resistivity (R_t)

The uninvaded zone is located beyond the invaded zone (Figure II.1). Pores in the uninvaded zone are uncontaminated by mud filtrate; instead, they are saturated with formation water (R_w), oil, and/or gas.

Even in hydrocarbon-bearing reservoirs, there is always a layer of formation water on grain surfaces.

Water saturation (S_w; Figure II.1) of the uninvaded zone is an important factor in reservoir evaluation because, by using water saturation data, a geologist can determine a reservoir's hydrocarbon saturation.

The ratio of the uninvaded zone's water saturation (S_w) to the flushed zone's water saturation (S_{xo}) is an index of hydrocarbon moveability. [10]

3.3. Invasion And Resistivity Profiles

Invasion and resistivity profiles are diagrammatic, theoretical, cross-sectional views of subsurface conditions moving away from the borehole and into a formation. They illustrate the horizontal distributions of the invaded and uninvaded zones and their corresponding relative resistivities. There are three commonly recognized invasion profiles :

- step
- transition
- annulus

These three invasion profiles are illustrated in Figure II.2.

The step profile has a cylindrical geometry with an invasion diameter equal to dj. Shallow-reading resistivity logging tools read the resistivity of the invaded zone (R_i), while deeper reading resistivity logging tools read true resistivity of the uninvaded zone (R_t).

The transition profile also has a cylindrical geometry with two invasion diameters: di (flushed zone) and dj (transition zone). It is probably a more realistic model for true borehole conditions than is the step profile. At least three resistivity measurements, each sensitive to a different distance away from the borehole, are needed to measure a transitional profile. These three measure resistivities of the flushed (R_{xo}), transition (R_i), and uninvaded zones (Rt) (see Figure II.2). [11]

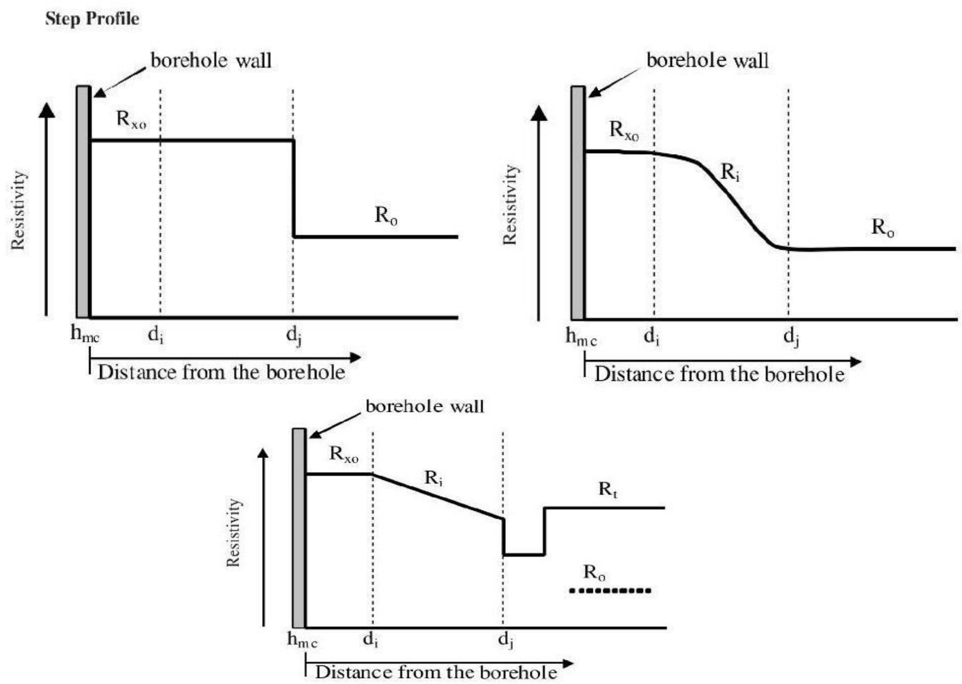

Figure II.2: Resistivity profiles for three idealized versions of fluid distributions in the vicinity of the borehole. [11]

An annulus profile is only sometimes recorded on a log, because it rapidly dissipates in a well. The annulus profile is detected only by an induction log run soon after a well is drilled. However, it is very important to a geologist, because the profile can only occur in zones that bear hydrocarbons. As the mud filtrate invades the hydrocarbon-bearing zone, the hydrocarbons are moved out first. Next, formation water is pushed out in front of the mud filtrate, forming an annular (circular) ring at the edge of the invaded zone (Figure II.2). The annulus effect is detected by a higher resistivity reading on a deep induction log than by one on a medium induction log.

3.4. Types Of Well Logging:

3.4.1. Nuclear logs

Nuclear logs are an important group of log measurements using nuclear radiation. Measurements are possible in open hole and cased hole. Basic types of nuclear methods are

- Measurement of the natural gamma radiation of the formation (Gammalog)
- Measurement of the radiation as result of an interaction of the source-emitted radiation with the formation
- Gamma-Gamma-logs (uses a gamma source),
- Neutronlogs (uses a chemical neutron source or neutron generator)

a. Gamma Ray Log

The Gamma Ray (GR) logging tool measures the natural radioactivity from potassium, thorium, and uranium isotopes in the earth surrounding the wellbore. The GR detector is a scintillation counter that is 10-30 cm long; the resolution of a GR log is thus about 30-50 cm. The counter calibration can be traced back to one of the American Petroleum Institute (API) test facilities in Houston, and the radioactivity is expressed in API units, which range from almost zero in anyhydrites to more than 200 in some shales and sylvite.

The measured GR response is a function of the natural radioactivity of the formation, the density of the formation, the type of mud, the hole size, and the position of the tool in the wellbore. In modern logs, the effects of the mud type, hole size, and tool location are generally small, except when there is potassium (increased GR readings) or barite (attenuated GR readings) in the mud. If the log is not compensated, adjustments can be made using the appropriate borehole correction charts produced by logging companies. The GR reading is less reliable in washed out zones, because the hole dimensions and tool location are not well defined.

After adjustment, the GR reading responds primarily to the natural radioactivity of the surrounding formation. Heavy radioactive elements tend to concentrate in shales and clays. Also, K40 is an element in some clay minerals. Therefore, the radioactivity of shales and shaly sands are higher than clean sands and carbonates (Figure II.3). [12]

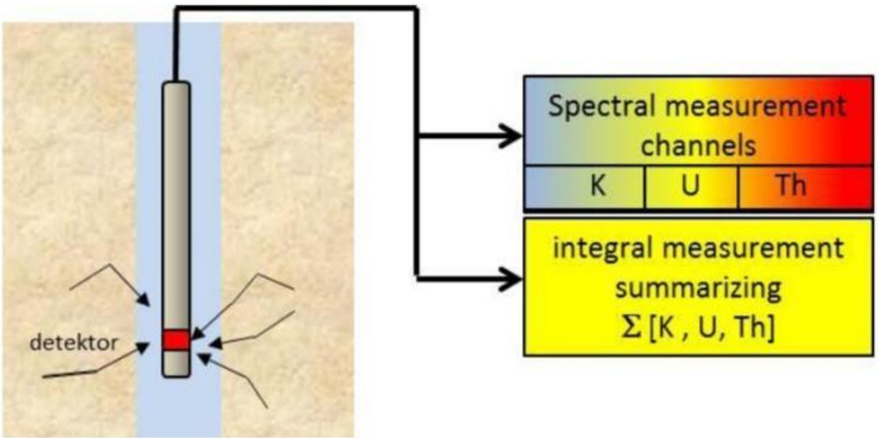

Figure II.3: Gamma measurements-Principles. [12]

Factors Affecting Gamma Ray Log Response:

A number of factors influence the response of the gamma ray log. A partial list of these factors would include:

- Type of detector,
- Logging speed and time constant,
- Bore hole size,
- Borehole fluid,
- Type of casing in borehole,
- Amount and type of cement,
- Formation thickness and radioactivity,
- Adjacent bed thick ness and radioactivity,
- Statistical variations.

Application of the Gamma Ray Log:

The gamma ray log has number of uses:

- Design of a lithological profile, particularly sand-shale separation, localization of “clean zones”,
- Estimate of shale content,
- Depth adjustment: This processing step removes depth discrepancies between the different logging runs. Discrepancies are caused for example by cable stretch. One Gamma log is chosen as reference log for data quality. The other gamma logs are matched to the reference using an automatic routine. Resulting depth shifts are applied to the other logs on the tool strings.
- Lithological correlation from well to well if a number of wells is logged in a field.[11]

b. Neutron Log

Neutron logs are primarily used to delineate porous formations and provide an estimate of their porosity.

This log responds to the hydrogen content of the formation and, therefore, in clean formations the neutron log will reflect the liquid filled porosity. By cornparmg the neutron log with another porosity log or core data, gas zones can often be identified. Combinations of the neutron log with one or two other porosity logs will yield even more accurate porosity values and allow lithology identification (Figure II.4)

There are three types of hydrogen logging tools commonly used:

- Neutron-gamma tool,
- Neutron-slow neutron tool,
- Neutron-fast neutron tool.

The fundamental principle involved in each of these tools is the same, the slowing down of neutrons by nuclei.

The basic principle involved in the hydrogen-neutron logging can be described as follows. In this tool, a neutron source bombards the formation with energetic neutrons. These neutrons are emitted at high speed and energy, and in their travel through the borehole and formation will experience numerous collisions .with the nuclei present. If these nuclei arc hydrogen, the neutrons are slowed down rapidly and can be captured (nearly all elements in nature can capture these slow neutrons or thermal neutrons). Once captured, a gamma ray of capture is emitted from the capturing clement. As the hydrogen content of the material surrounding the source increases, the neutrons will be captured sooner. [13]

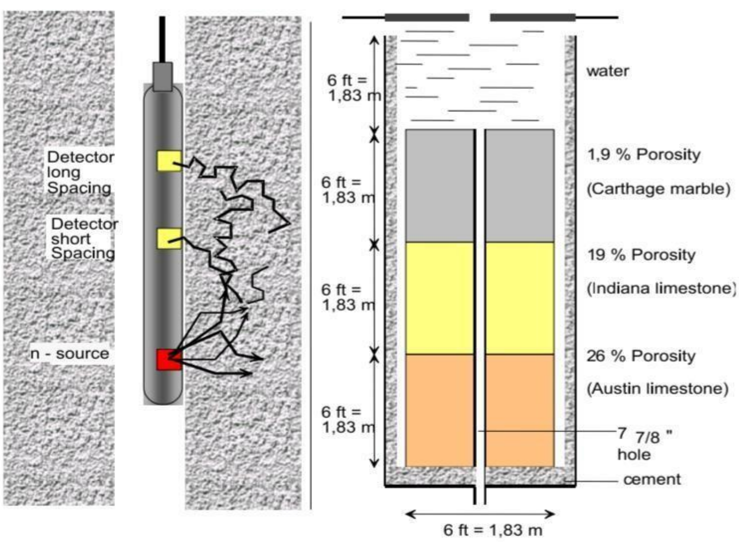

Figure II.4: Neutron log-Principle of tool and calibration facility. [13]

Factors Affecting Standard Neutron Tool Response:

A number of factors affect the standard neutron tool response including the following:

- Borehole environment,
- Source strength,
- Source-detector separation,
- Logging speed and time constant,
- Statistical variations,
- Formation factors.

Application of The Neutron Log:

- Distinguishes between gas, oil , and saltwater bearing formations, particularly in cased holes.
- Determines water saturation.
- Finds and follows gas-oil-water contacts behind casing.
- Indicates abnormal pressure.[10]

c. Density log

The density logging tool measures the amount of GRs scattered by the formation.The GRs are emitted from a radioactive source that is held against the borehole wall, as shown in Figure II.5. In the basic tool, there are two detectors, a short-spaced and a long-spaced detector. To minimize wellbore effects, the source and the detectors are located on a skid, pressed against the borehole wall. GRs are scattered when they collide with electrons (Compton scattering). The amount of scattering is proportional to the electron density of the medium. The electron density is proportion to the bulk density of the medium. Hence, the GR count at the detector is proportional to the bulk density of the formation. Density logging tools are calibrated in the laboratory using fresh water filled limestones to determine the proportionality constant. The calibration is used to convert the GR counts to density, which is plotted versus depth, as shown in Figure II.6.

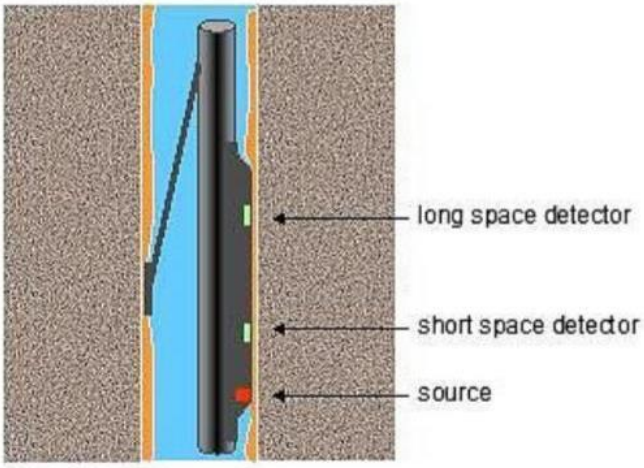

Figure II.5: Density log-Principles. [13]

The scattering of the GRs may be affected by mudcake. However, the difference in readings between the short- and long-spaced detectors correlates to the effect of the mudcake and is used to calculate a compensated log reading. After compensation, the log resolution is comparable to that of an acoustic log (approximately 2 ft). The density tool is shallow reading and usually only detects the flushed zone. While the log is compensated for mudcake, the readings can be unreliable in rough hole. [13]

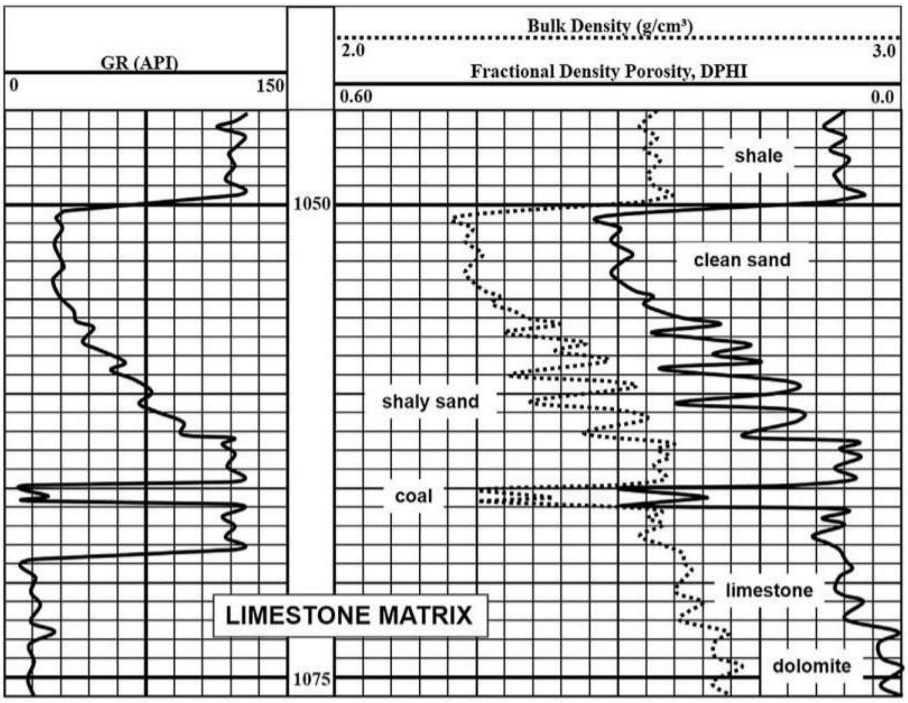

Figure II.6: Hypothetical density and density porosity log (on right) including GR trace (on left) and with depth intervals of 1m. [10]

Application of The Density Log:

The density log is used to determine porosity. The bulk density is related to the density of the formation rock, the density of the fluid in the formation, and the porosity of the formation.

Factors Affecting Density Log Response

The density log response depends On the following factors:

- Mud cake,
- Borehole size,
- Time constant and logging speed,
- Rock matrix density,
- Pore fluid density,
- Porosity.

3.4.2. Electrical Logs

a. Resistivity logs

There are main two types of resistivity logs: electrode logs and induction logs. Each are discussed below.

- **Electrode Logs:**

The electrode logging tool measures the voltage drop between electrodes held adjacent to the formation as a current is passed through the formation, as shown schematically in Figure II.7. In a "normal" tool configuration, the measuring electrode is connected to a galvanometer at the surface. Typically, the spacing between the current electrode and the measuring electrode is 16 in (short-normal) or 64 in (long-normal). In a "lateral" tool, the voltage drop is measured between a pair of electrodes. The spacing between the current electrode and the midpoint of the pair of measuring electrodes is 18 ft 8 in. Note that the greater the spacing, the greater the depth of investigation.

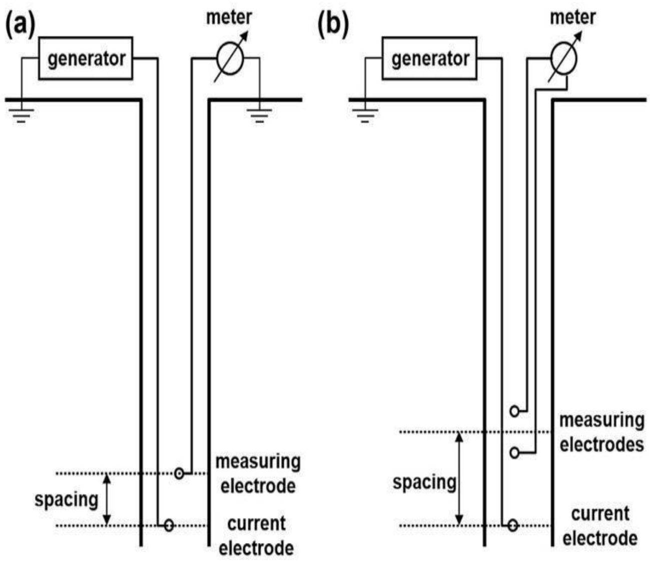

Figure II.7: Simplified schematic of electrode arrangement in old-style electrode logs: (a) normal configuration, (b) lateral configuration. [12]

The electrode logs of the 1940s and 1950s all suffered from significant borehole and shoulder bed effects. These logs have been replaced by focused-current devices called guard logs or laterologs. Vertical resolution of modern tools is typically 1 - 2 ft. Modern electrode logs usually have a deep resistivity measurement, corresponding to readings which represent the resistivity of the uninvaded zone. So-called shallow measurements are usually not shallow enough to measure only the flushed zone; they read some combination of the flushed, transition, and uninvaded zones.

In order to measure the flushed zone resistivity, a very shallow (1 or 2 in) reading device is needed but one that is not affected by the borehole mud. To achieve this, the electrodes for the “microresistivity” logs are placed on a rubber pad, which is pressed against the borehole wall. The term “micro” in the name of the log, e.g., microlaterolog and micro spherically focused log, denotes this is a very shallow measurement. The vertical resolution of such logs is about 2 - 6 in. [11]

- **Induction logs:**

The induction logging tool measures a voltage induced by an alternating magnetic field so there is no need for electrodes. The field is generated by an alternating current inside an insulated transmitter coil. The magnetic field induces alternating current loops in the formation around the wellbore.

The nominal spacing of induction tool transmitter-receiver placements ranges from 16 to 40 in.

Electrode logs are recommended for wells drilled with highly conductive drilling muds, such as salt muds. Induction logs are recommended for wells drilled with moderately conductive or nonconductive muds, such as air, fresh water, or oil-based muds.

Older induction logs suffered from poor vertical resolution (5 - 10 ft). The resolution of a modern induction tool is 2 - 4 ft. Modern induction logs include several sets of coils with focused currents used to minimize the effects of the borehole and surrounding formations. Most modern resistivity log suites include some combination of measurements having different depths of investigation:

- Shallow (Rmsfl): approximately 1 - 2 in into the formation;
- Medium (RILm, Rsfl, RLLs): approximately 6 - 12 in into formation;
- Deep (RILd, RLLd): more than 12 in into formation.

b. Spontaneous Potential Log (SP)

The spontaneous potential (SP) is the electrical potential between an electrode placed at the borehole wall and a fixed electrode at surface. The SP log records the change in the potential as the mobile electrode is moved up or down the wellbore. The electrical potential is the sum of the potentials arising from contacts between different formations (membrane potential), contact between different fluids (fluid junction potential), and the motion of fluid through the formation (electrokinetic potential).

- **Membrane potential:**

The SP response is primarily determined by shales. Shales consist of layers of clays that are permeable to Na^+, but impermeable to Cl^-. The positive ions move from the more concentrated fluid (usually a more saline formation water) to the less concentrated fluid (usually a less saline mud). The movement of the positive ions creates a positive current across the shale, as shown in Figure II.8.a. The potential created across the shale is termed the membrane potential, Em.

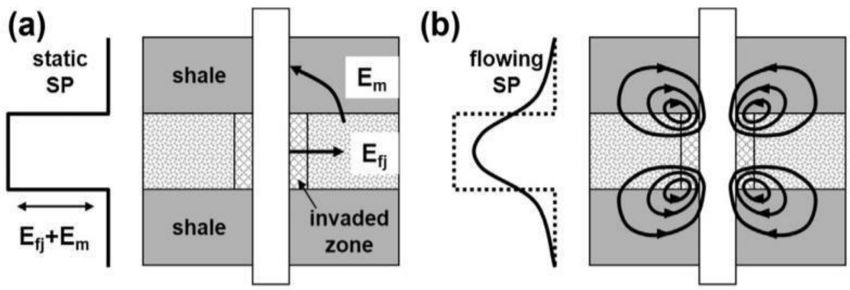

Figure II.8: Static potential (a) and measured flowing potential (b) for a fresh mud and saline formation. The arrows indicate shape and direction of potential. [11]

- **Fluid junction potential:**

A second potential is created between the mud filtrate in the invaded zone that is in direct contact with the formation water. The Cl^- ions are more mobile than Na^+ ions, and therefore a negative current is generated from the more concentrated solution to the less concentrated solution, as shown in Figure II.8.a. The potential associated with this current is termed the fluid junction potential, E_{fj}. It is approximately 20% of the magnitude of the membrane potential and acts in the same direction.

- **Electrokinetic potential:**

The flow of an electrolyte through a permeable medium can also generate a current and a potential termed the electrokinetic potential or streaming potential.

Electrokinetic potentials can occur in the mud cake and in the formation. The net potential is usually negligible, but can be significant if there is a large pressure drop and flow through the mudcake or in very low permeability formations (less than a few millidarcies).

Application Of SP Log:

The SP log is used in the same manner as the GR log to detect shales and potentially permeable formations, Figure II.9. The SP log can also be used to determine the resistivity of the formation water if the SSP can be determined from the log response. In practice, this is usually only possible for thick, clean (non-shaly) formations in which the SP response is close to the SSP. [11]

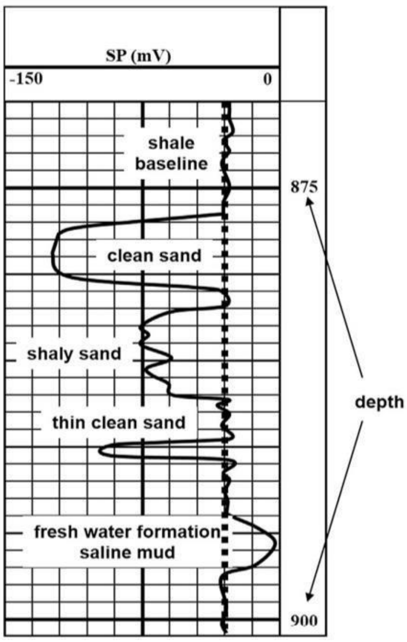

Figure II.9: Hypothetical SP log with depth intervals of 1 m. All responses are for fresh mud and saline formation water unless otherwise indicated. [11]

3.4.3. Acoustic Log:

Figure II.10, shows the simplest configuration of an Acoustic log probe. The ultrasonic transmitter generates a compressional wave, which is transmitted through the mud and hits the formation at the borehole wall. From this boundary incident wave propagates as reflected and refracted waves. The Acoustic log uses the refracted wave. If the wave velocity of formation > wave velocity of mud, the refraction wave moves in the direction of the boundary. At the so called critical angle a refracted wave propagates with the velocity of the formation along the borehole. The wave generates secondary waves passing the mud and arriving at the two receivers. Difference of the arrival time divided by receiver distance gives the slowness of the formation (if the tool is centered).

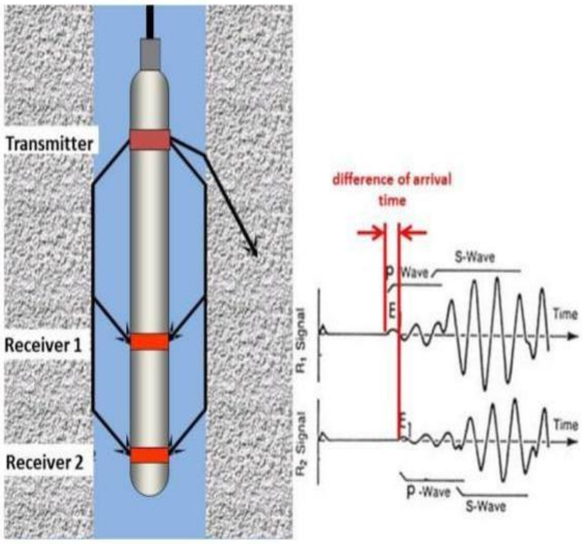

Figure II.10: Sonic log/Acoustic log-Principle. [10]

The right part of the figure shows the wave traces with first arrival for compressional wave, second arrival for shear wave. A third arrival (not marked) is the Stoneley wave.

For Quality Control you may check DT values in anhydrite (50 µs/ft = 164 µs/m) or casing (57 µs/ft = 187 µs/m).

"Compensated" tools use multiple transmitter-receiver pairs in order to minimize the borehole effect.

"Array" tools have many receivers. Data from all receivers are processed for a precise and robust determination of wave arrivals (compressional, shear, Stoneley). A powerful part of these sophisticated systems is the application of correlation techniques (Semblance technique).

An important part of the tool is the transmitter. Particularly in so-called “slow formations” where the shear wave velocity of the formation is lower than the compressional wave velocity in the mud no refracted shear wave can be observed. In such cases a special transmitter (dipole-shear) creates a shear wave in the formation. Sophisticated tools work with a simple monopole transducer, dipole and/or quadrupole transducers to initiate all wave types. [10]

Main applications of acoustic/sonic logs are:

- Support for seismic interpretation (velocity-depth function, synthetic seismograms),
- Porosity determination based on Wyllie’s equation or other empirical equations,
- Porosity and lithology determination (combination with neutron and gamma-gamma-density log (cross plots etc.),
- Derivation of elastic rock properties (Poisson’s ratio, Youngs modulus),
- Permeability estimate from Stoneley wave analysis (Tang and Patterson 2004),

CHAPTER III

Interpretation of Logs Using Techlog Software.

CHAPTER III: Interpretation of Logs Using Techlog Software.

1. Introduction:

1.1. Generalities and History of Techlog

Techlog, developed by Schlumberger (SLB), is a leading software platform designed for comprehensive wellbore data analysis in the oil and gas industry. Since its initial release in 2002, Techlog has become a flagship digital solution, enabling the integration, visualization, and interpretation of a wide range of wellbore data, including logs, core samples, drilling, and production information, within a single, user-friendly environment. The software was created by the French company Techsia, which was acquired by Schlumberger in 2009, ensuring continued development and expansion of its capabilities to meet evolving industry needs.

Techlog's primary purpose is to streamline multidisciplinary workflows by providing robust tools for petrophysical, geological, geomechanical, and reservoir engineering analyses. Its integrated platform allows users to conduct advanced data processing, quality control, and reporting, reducing reliance on multiple specialized tools and enhancing collaboration among geoscientists, engineers, and data managers. The software's intuitive interface supports both domain experts and generalists, facilitating efficient data interpretation and decision-making throughout the well lifecycle.

1.2. Applications and Benefits of Techlog

Techlog software is a specialized tool for integrating and analysing wellbore data in the oil and gas sector, offering advantages such as data consolidation, ease of use, and accurate reservoir property up scaling to support effective reservoir management:

a. Applications

- Analysis of all drilling related data from vertical, deviated, and horizontal wellbores
- Hole condition monitoring
- Drilling efficiency monitoring

b. Benefits

- Prevents drilling problems by recognizing potential hazards ahead of time
- Improves the efficiency of drilling operations
- Establishes drilling KPI benchmarks
- Increases operational performance
- Enhances integration and knowledge application. [15]

2. Getting Started with Techlog 2015

2.1. Home Page of the Software:

Techlog home page after opening it on the computer.

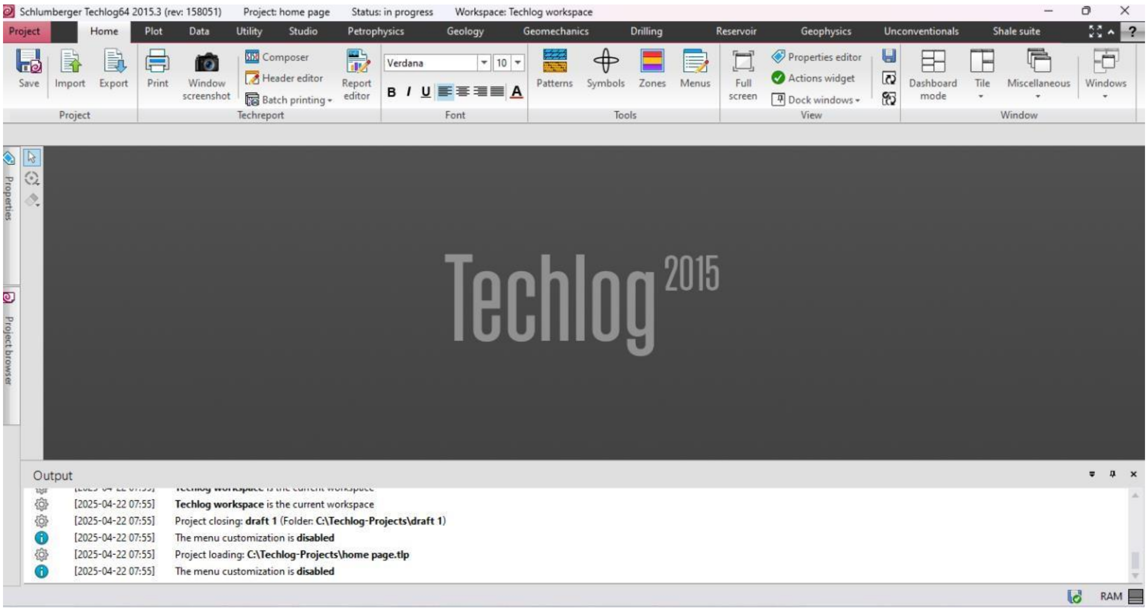

Figure III.1: Techlog main menu. [16]

2.2. Creating a new project in Techlog

To create a new project, follow these steps:

- Based on the study objective, enter information related to the study target (well, project name, country).
- The entered data will be stored in the new project.

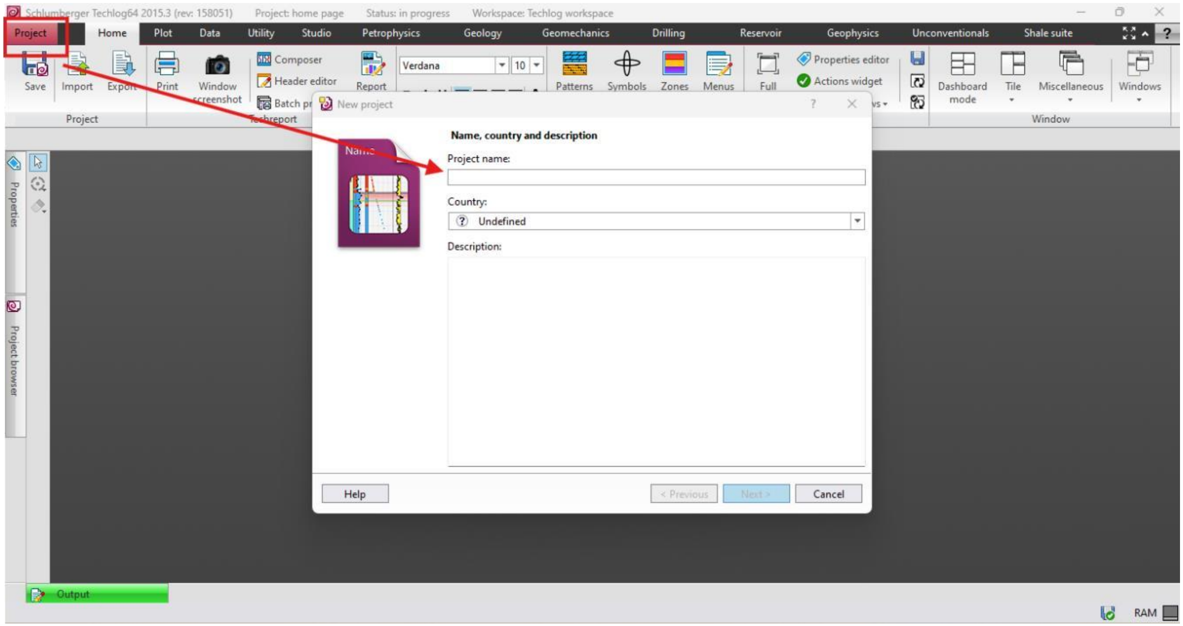

Figure III.2: Creating a new project. [16]

2.3. Importing Data (LAS Files):

To import the data, follow these steps:

- Click import.
- Chose the LAS file from the file icon showing in figure III.3.
- Finally, data display and interpretation can begin.

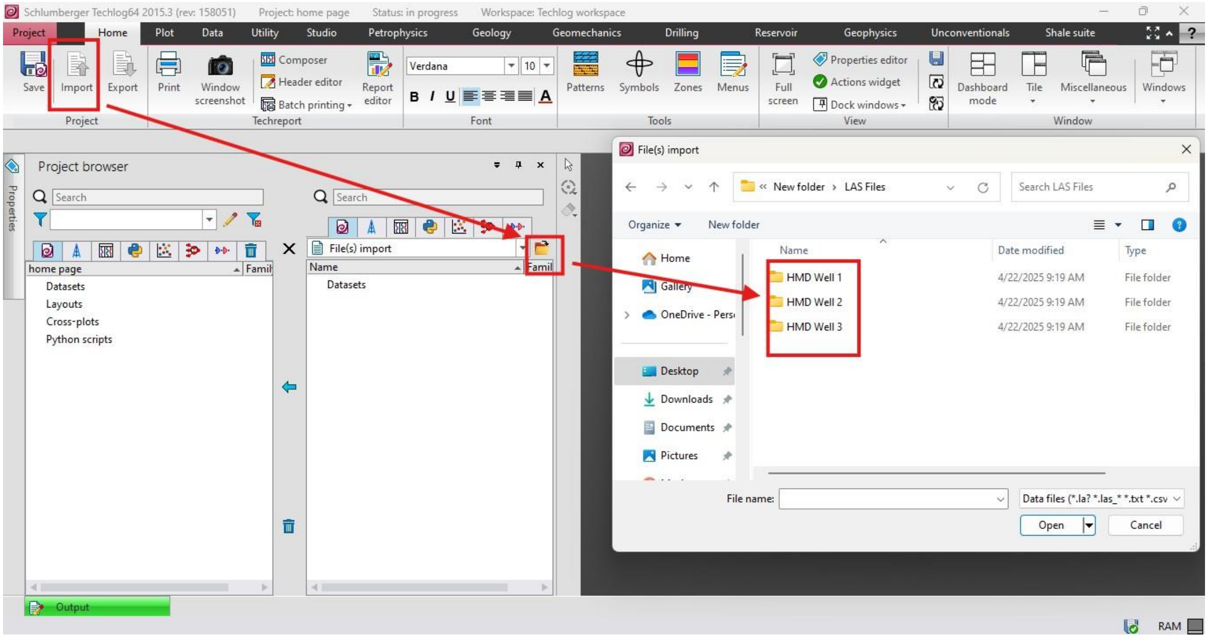

Figure III.3: Importing Data (LAS Files). [16]

2.4. Interpretation Methods in Techlog

There are two types of interpretation of diagraphic Interpretation: qualitative and quantitative:

2.4.1. Qualitative interpretation

Qualitative interpretation in Techlog involves visually analysing well log data to identify rock types, fluid contacts, and reservoir features.

- Creation of a project.
- Importation of data.
- Zonation and visualization of logs.
- Interpretation: Vshale calculation, Calculation of porosity (Φ) and saturation (Sw) and Estimation of permeability (k).
- Exportation of interpretation results.
- Representation of interpretation results.

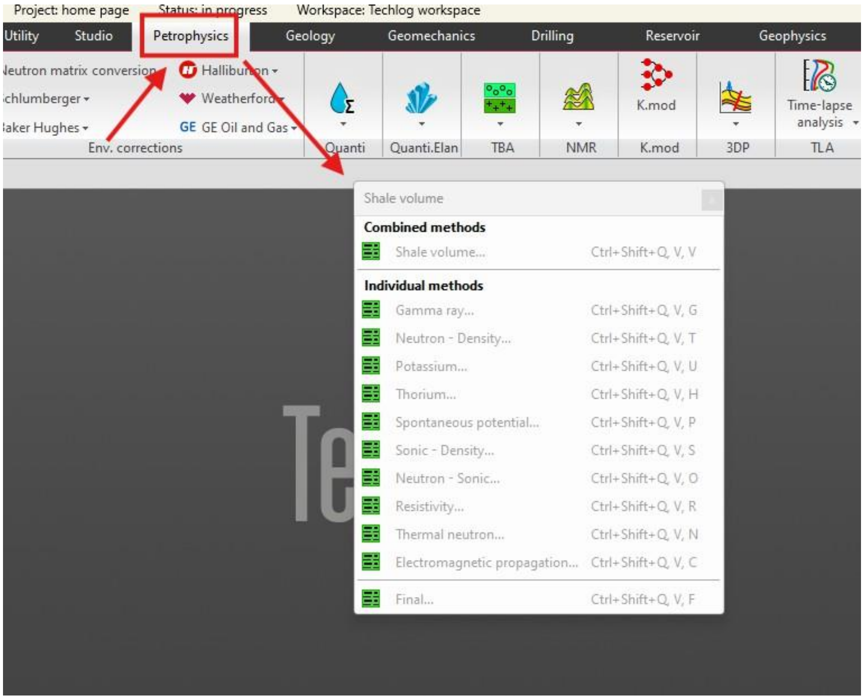

Figure III.4: Vshale on Techlog. [16]

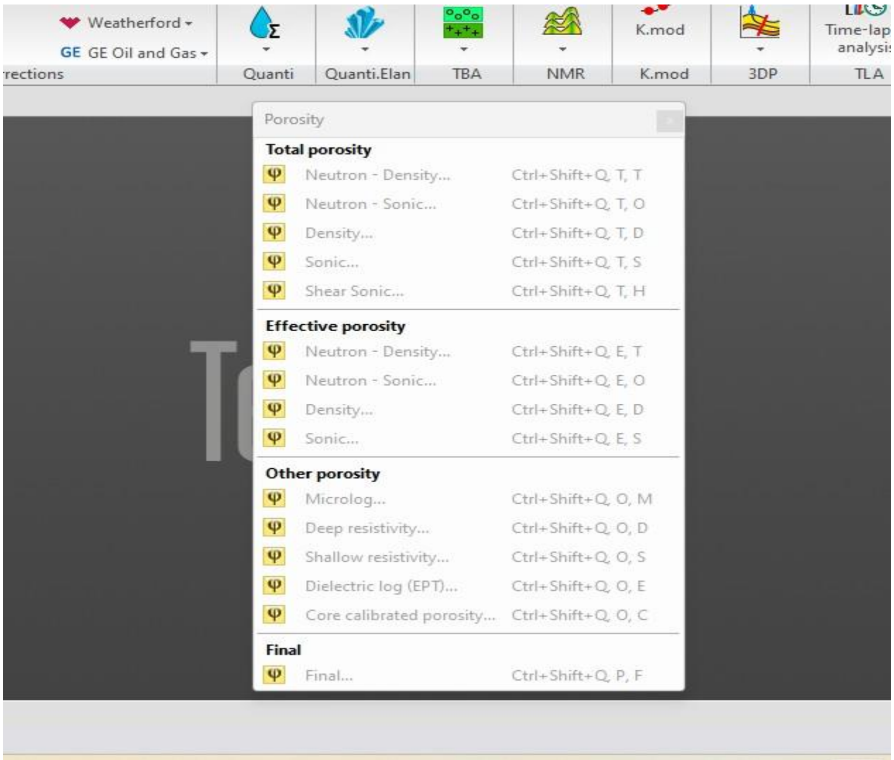

Figure III.5: Porosity on Techlog. [16]

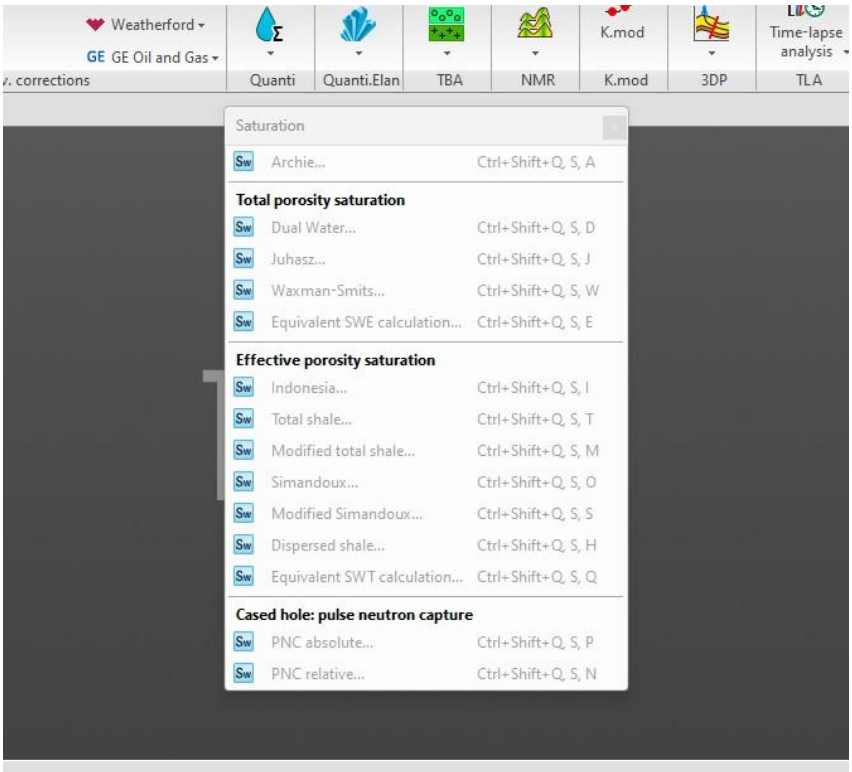

Figure III.6 : Saturation on Techlog. [16]

Figure III.7 : Permeability on Techlog. [16]

2.4.2. Quantitative Interpretation

The Quanti Elan method (TechLog SLB) is a mineralogical inversion application that can provide a quantitative assessment of the formation, from the cased portion to the open hole. This evolution is achieved through the simultaneous optimization of the equations described by one or more interpretation models.

- Creating a Project.
- Importing Data.
- Displaying Data from the Following Logs :GR-KTH-CAL From M2R1 to M2R9 U-TH-K ZDEN-PE-CNC.
- Filling Between TH and K Inserting Fill Between GR and KTH.
- Measuring Formation Temperature.
- Initializing Salinity and Temperature Data.
- Mineralogical Evaluation of the Well with Quanti. Élan.
- Spread sheets and Editing Zones.
- Creating a Productivity Summary.

2.5. Well Data Processing (LAS files) in Techlog

2.5.1. Calculation of Shale Volume (Vsh)

a. From Gamma Ray Log

This method estimates the shale volume using only the GR curve as input. When applied to one or more zones, the Vsh-GR is automatically computed and presented in a designated format.

Equations:

Calculation of shale index (I_{sh}):

$$I_{sh} = \frac{GR_{log} - GR_s}{GR_{sh} - GR_s} \quad (8)^{[11]}$$

Where:

GR_{log}: gamma ray response in the zone of interest.

GR_s: the average gamma ray response in the cleanest sand formation.

GR_{sh}: the average gamma ray response in the cleanest shale formation.

Linear Method:

$$V_{sh} = I_{sh} \quad (9)^{[11]}$$

The non-linear response in increasing optimism (lower calculated shale volume), are:

For tertiary rock, the Larionov equation is:

$$V_{sh} = 0.083 \times (2^{(3.7 \times I_{sh})} - 1) \ldots\ldots\ldots\ldots (10)^{[11]}$$

The Stieber equation is:

$$V_{sh} = \frac{I_{sh}}{3 - 2 \times I_{sh}} \ldots\ldots\ldots\ldots (11)^{[11]}$$

The Clavier equation is:

$$V_{sh} = 1.7 - (3.38 - (I_{sh} + 0.7)^2)^{\frac{1}{2}} \ldots\ldots\ldots\ldots (12)^{[11]}$$

For older rocks, the larionov equation is:

$$V_{sh} = 0.33 \times (2^{(2 \times I_{sh})} - 1) \ldots\ldots\ldots\ldots (13)^{[11]}$$

b. Vsh From the Thechlog

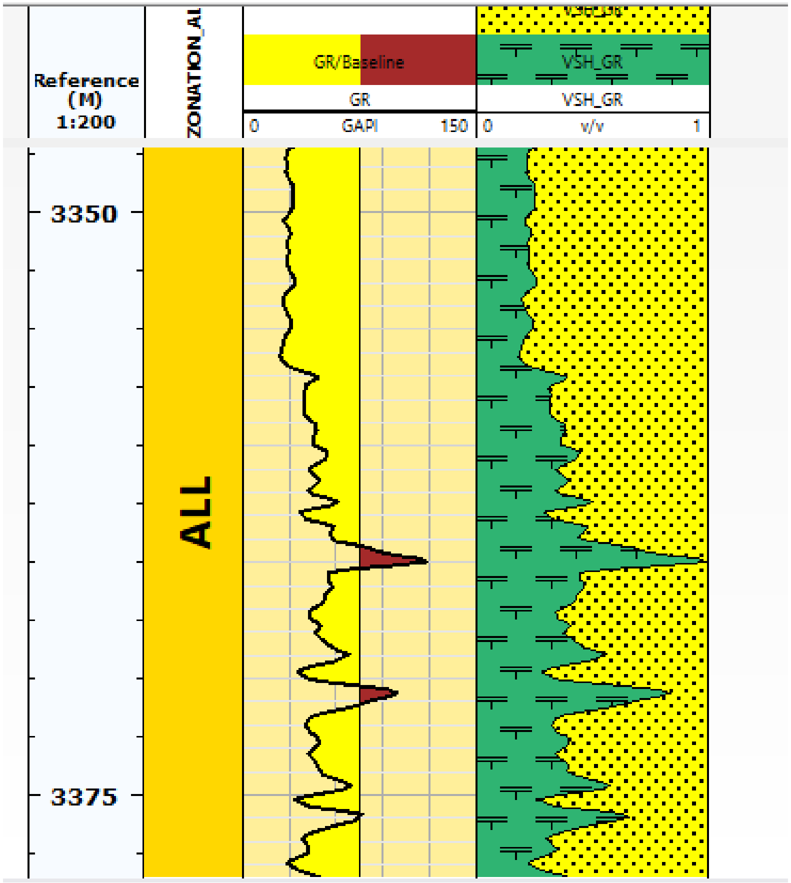

Figure III.8: Vsh of Well HMD-1. [16]

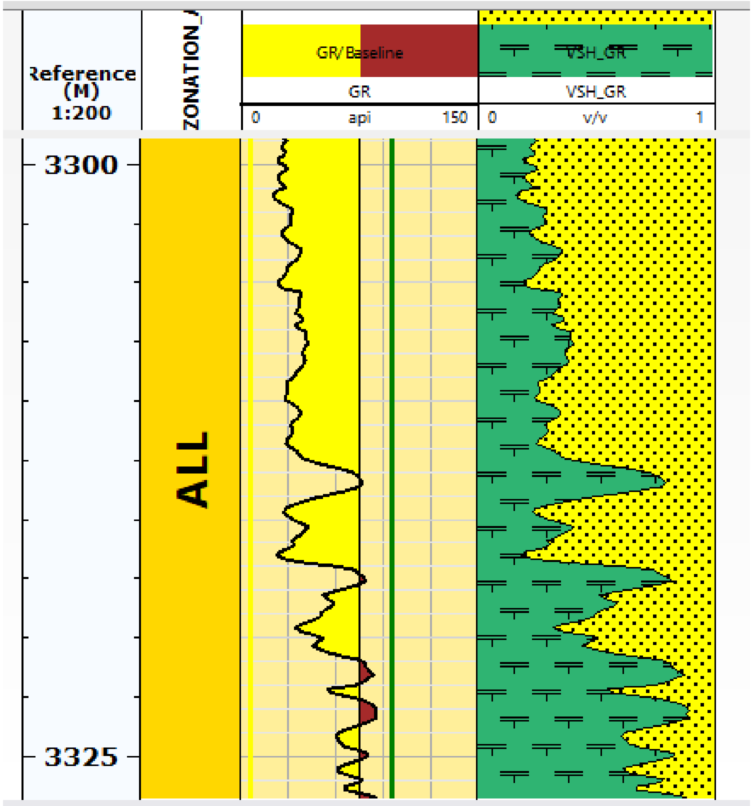

Figure III.9: Vsh of Well HMD-2. [16]

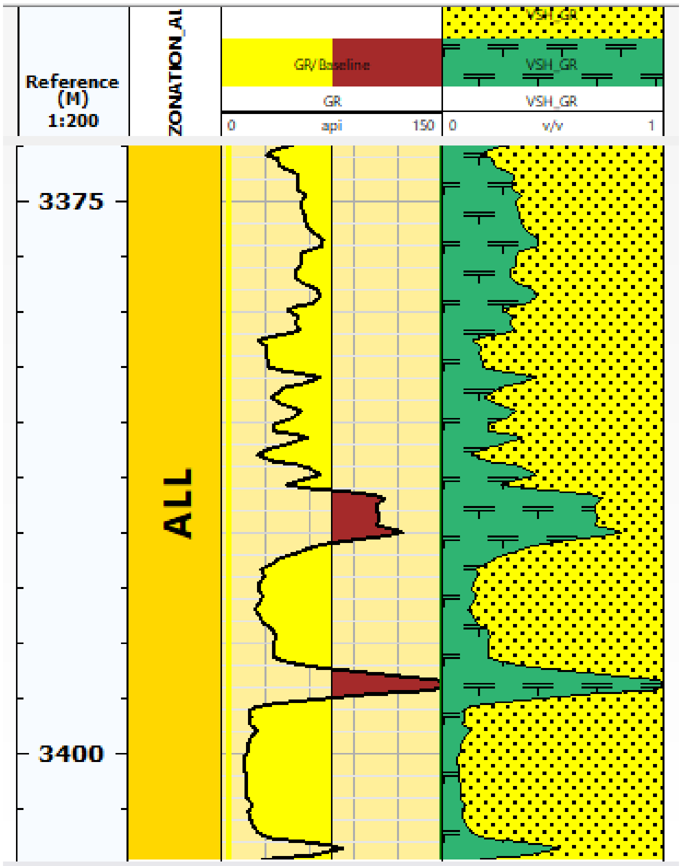

Figure III.10: Vsh of Well HMD-3. [16]

- **Results:**

Table III.1: Results of the calculation of Vsh by using Techlog. [16]

well	zone	Top (m)	Bottom (m)	GR_{min}	GR_{max}	$Vshale_{moy}$ (%)
HMD-1	Reservoir	3216.707	3416.046	4.42362	122.306	32.1264
HMD-2	Reservoir	2536.088	3391.205	4.1783	94.1783	32.9191
HMD-3	Reservoir	3127.248	3433.115	3.6185	122.791	32.9737

c. Interpretation of results:

We note through the results acquired from the Gamaray recording (fig.III-8 to fig.III-10) and the results of the calculations (tab.III-1) that:

- The shale volume (V_{sh}) has an average of: 32.6730%
- All the three (HMD-1, HMD-2 and HMD-3) wells have high volumes of clay which is likely to have negative impacts on permeability.

2.5.2. Calculating Porosity (Φ)

a. Porosity from Techlog:

- **From density log**

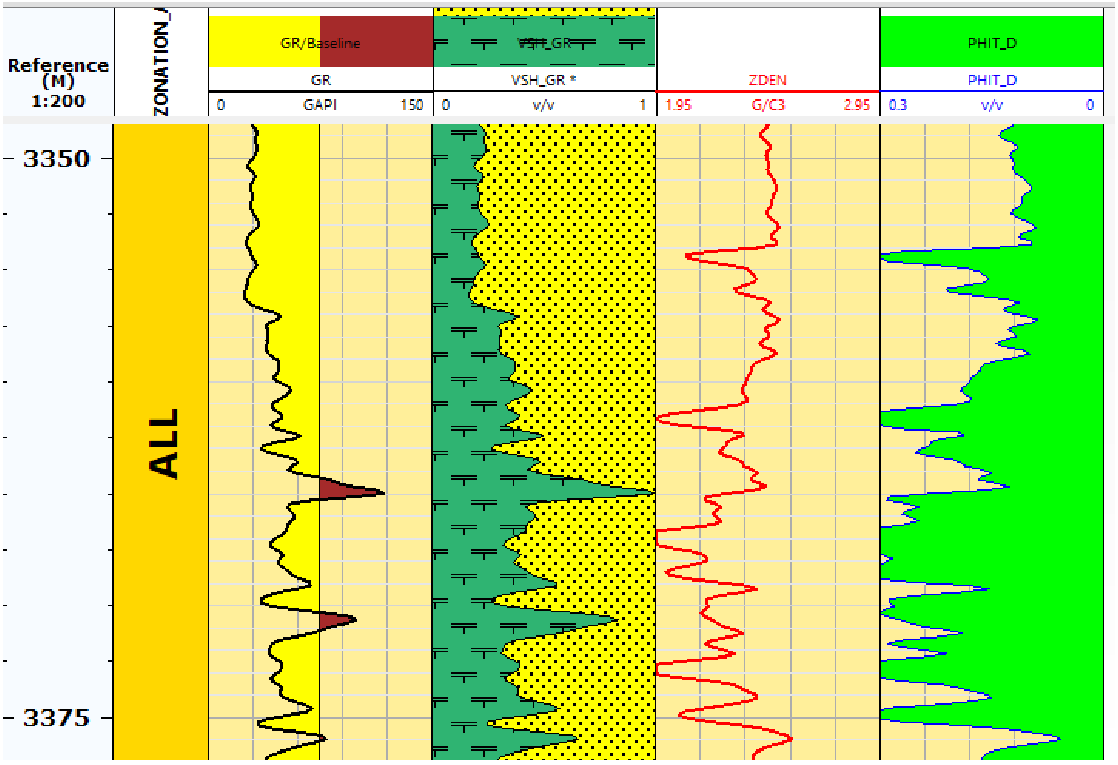

Figure III.11: Porosity of well HMD-1 by using Density log. [16]

- **From neutron porosity and density logs:**

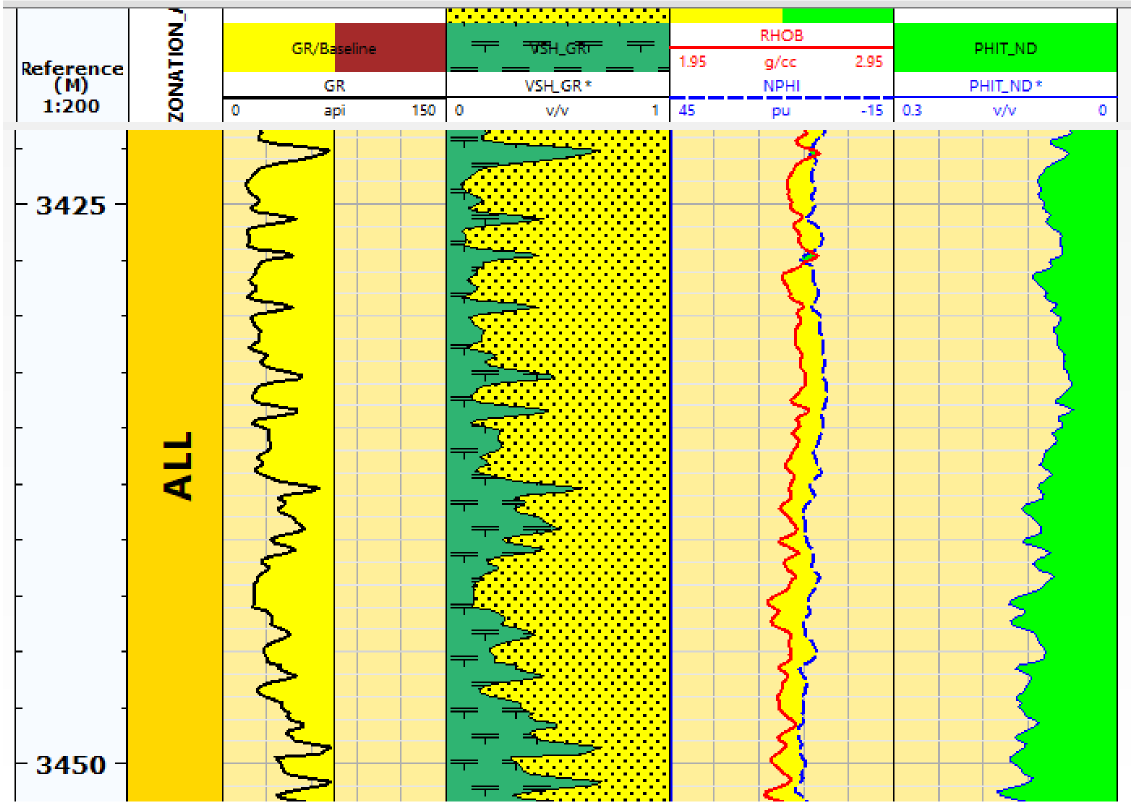

Figure III.12: Porosity of well HMD-2 by using Neutron porosity log and Density log.[16]

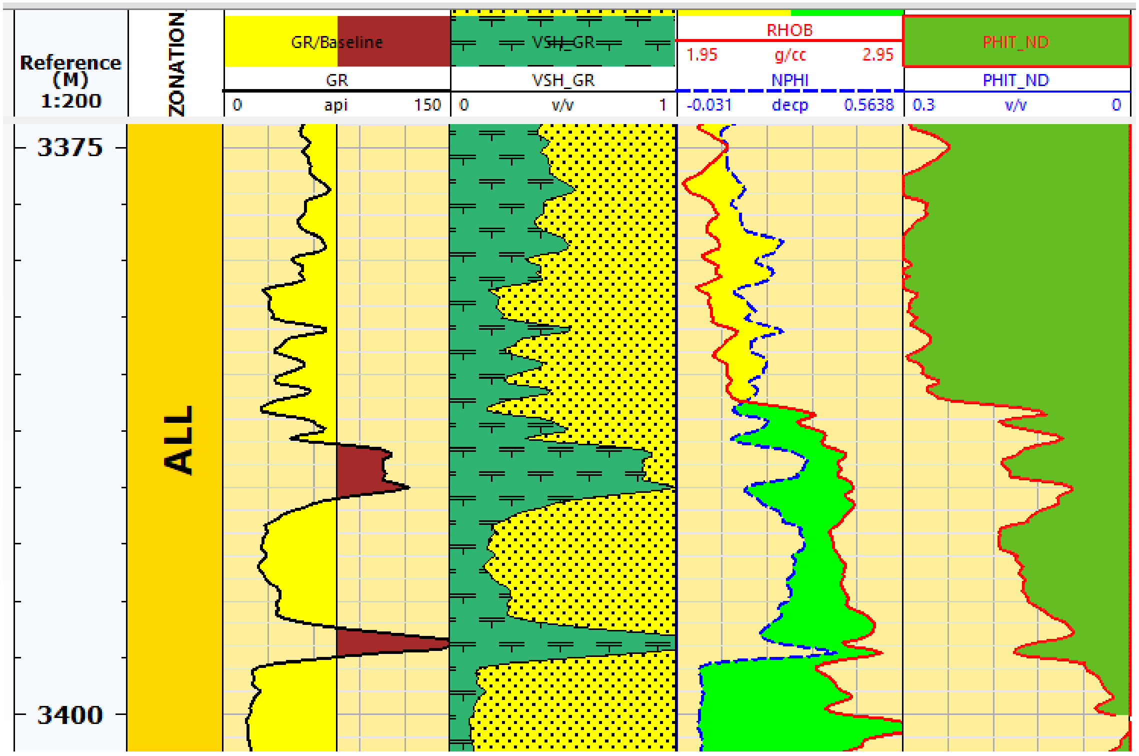

Figure III.13: Porosity of well HMD-3 by using Neutron porosity log and Density log.[16]

- **Results:**

Table III.2: Results of the calculation of porosity by using Techlog. [16]

Well	Zone	Top (m)	Bottom (m)	PHIT (v/v)	Porosity (%)
HMD-1	Reservoir	3216.707	3416.046	0.1572	15.72
HMD-2	Reservoir	2536.088	3391.205	0.1242	12.42
HMD-3	Reservoir	3127.248	3433.115	0.1687	16.87

b. Interpretation of results:

From the Neutron Log and Density Log records (Fig. III-11 to Fig. III-13) and the calculation results presented in Table III-2, we can see that:

- Porosity has an average value of 15%.
- Also, the highest recorded value is that of well HMD-3 with 16.87%, which is a fairly average value (10% ≤ φ ≤ 20%, in these cases the porosity is said to be average).
- Next comes well HMD-1 with a porosity very close to that of well HMD-3 with a value of 15.72%.

It should also be noted that good porosity is generally an indication of the reservoir's potential capacity for fluids such as water or hydrocarbons (oil, gas).

- Arrival at the HMD-2 wells, still with an average porosity of 12.42%, nevertheless lower than that recorded at the HMD-3 and HMD-1 wells.

2.5.3. Calculating Saturation (From)

a. Saturation from Techlog from Archie:

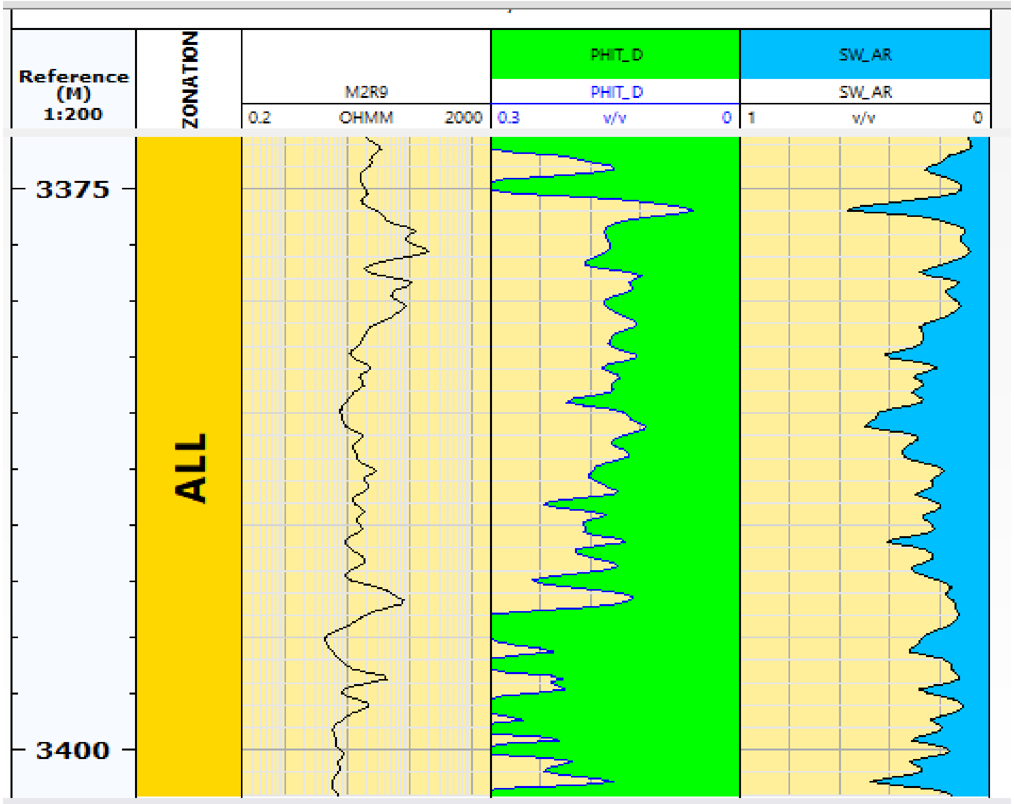

Figure III.14: Saturation of well HMD-1. [16]

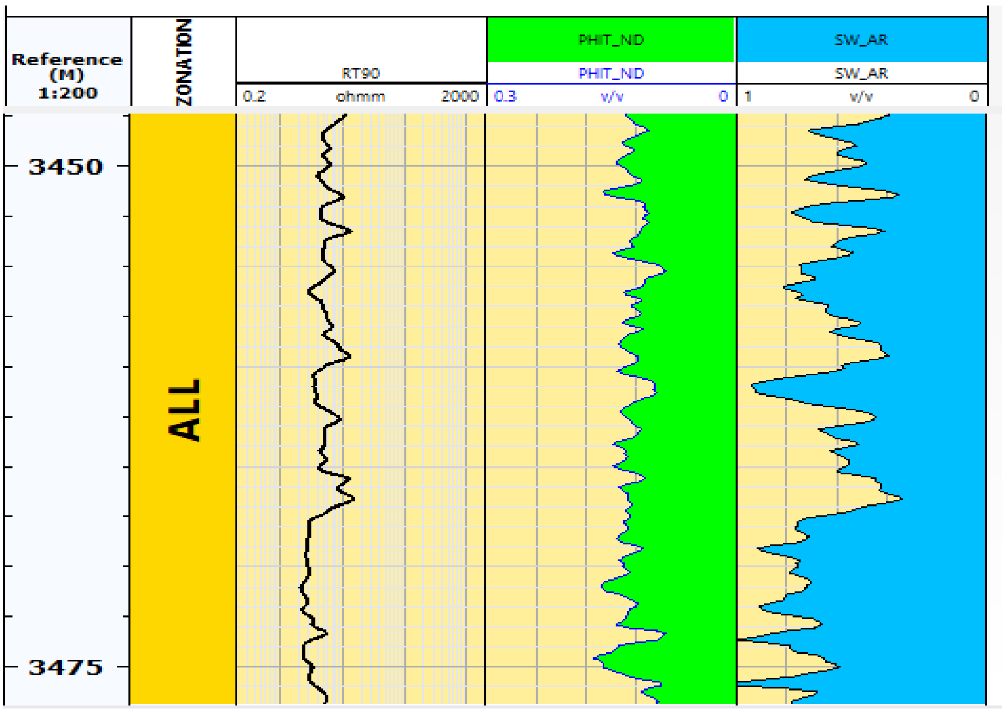

Figure III.15: Saturation of well HMD-2. [16]

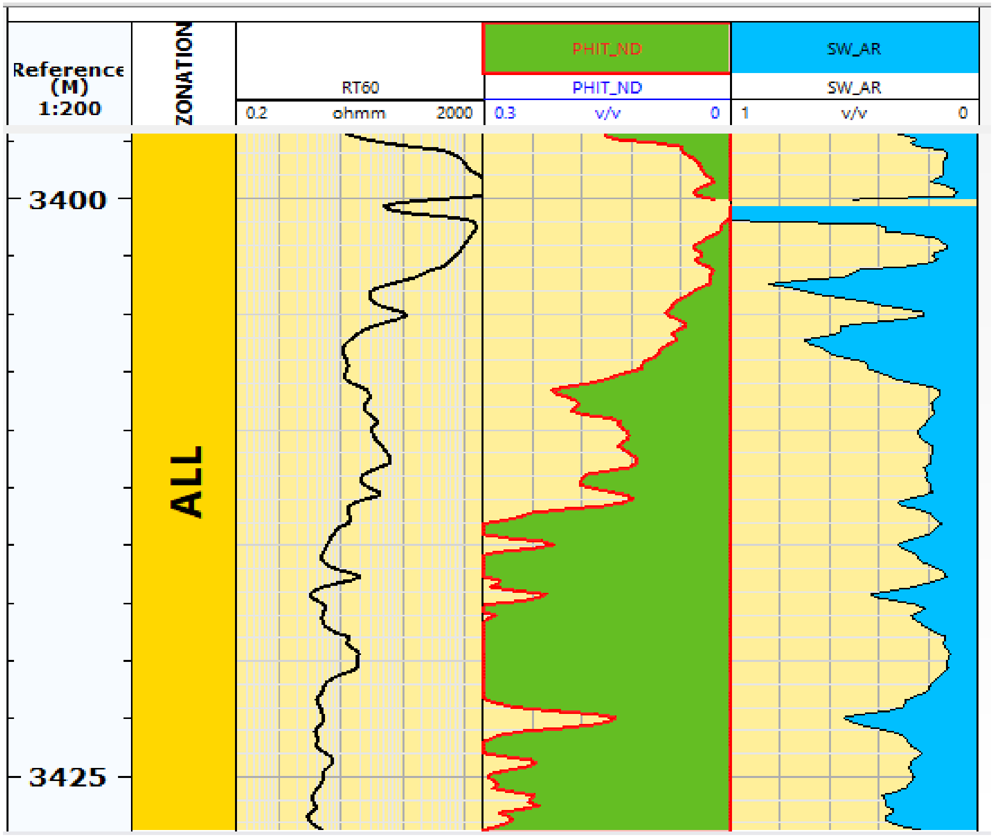

Figure III.16: Saturation of well HMD-3. [16]

- **Results:**

Table III.3: Results of the calculation of saturation by using Techlog. [16]

Well	Zone	Top (m)	Bottom (m)	SW_AR (v/v)	S_w (%)	S_{hc} (%)
HMD-1	Reservoir	3216.707	3416.046	0.313671	31.3671	68.6329
HMD-2	Reservoir	2536.088	3391.205	0.452188	45.2188	54.7812
HMD-3	Reservoir	3127.248	3433.115	0.306821	30.6821	69.3179

b. Interpretation of results:

From the Deep Resistivity Log and Porosity Log records (Fig. III-14to Fig. III-16) and the calculation results using Archie's law presented in Table III-2, we can see that:

The well with the highest hydrocarbon saturation is HMD-3 with a value of 69.3179% then the well HMD-1 with 68.6329% or these are the wells which have the most potential and are likely to be the most profitable, we also note the well HMD-2, with a fairly high value but which does not exceed 55% (54.7812%).

2.5.4. Permeability Estimation

a. Permeability from Techlog

Technically, there is no device (log) or technology that allows for direct calculation or measurement of permeability. However, using the Techlog software, it is possible to estimate permeability using the Wyllie-Rose method, which relies on the total porosity previously calculated using Techlog.

It is also worth noting that reservoir quality is determined by its permeability value.

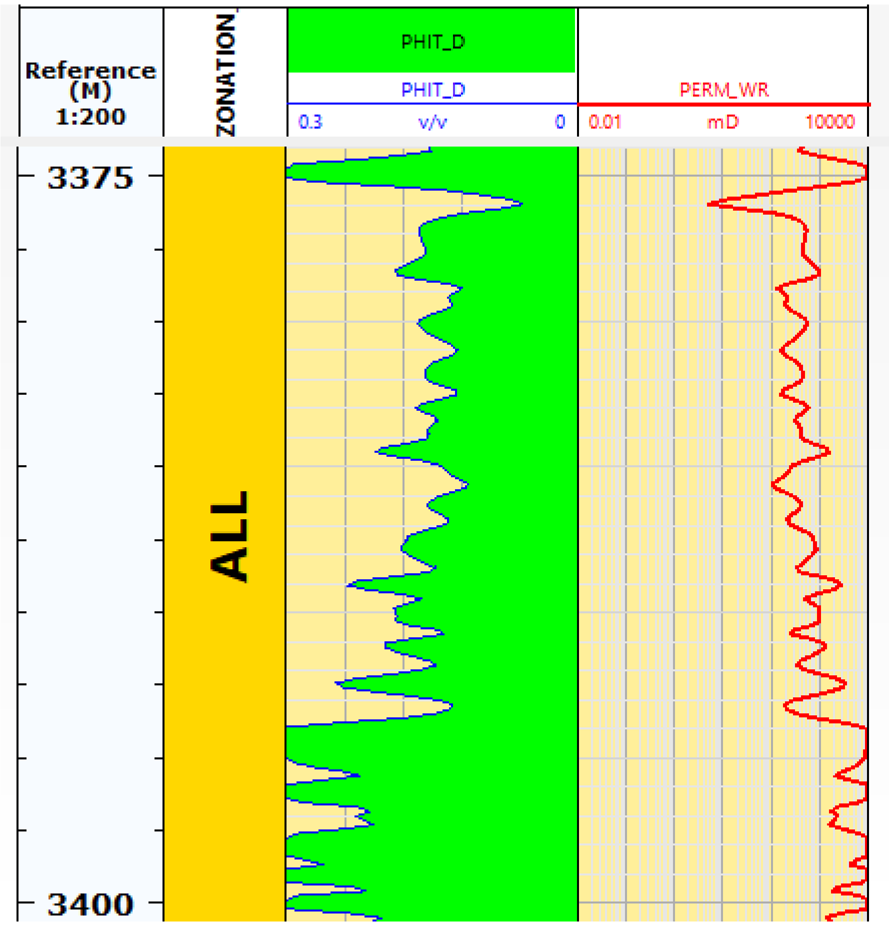

Figure III.17: Permeability of well HMD-1. [16]

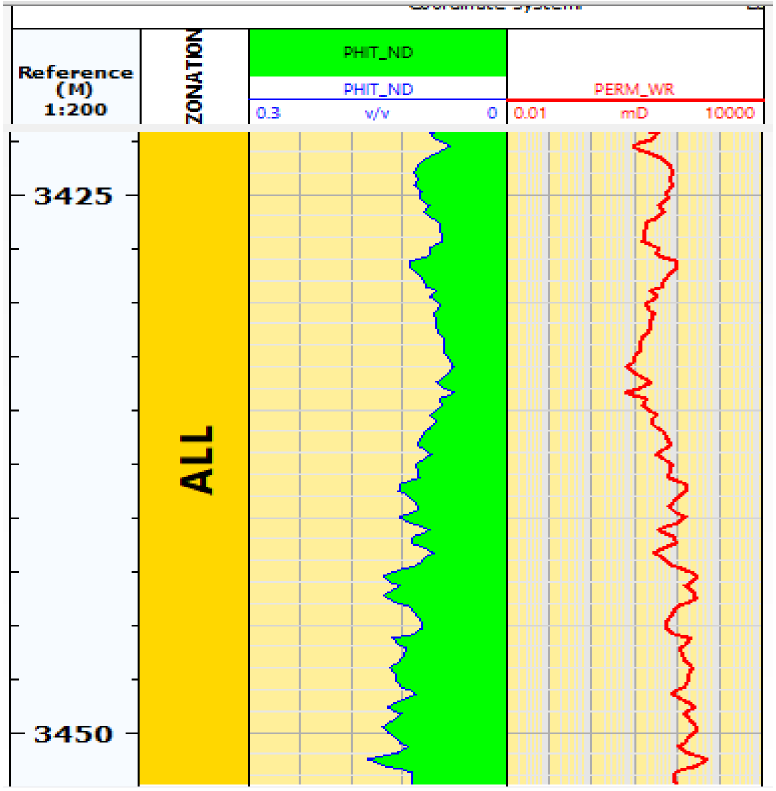

Figure III.18: Permeability of well HMD-2. [16]

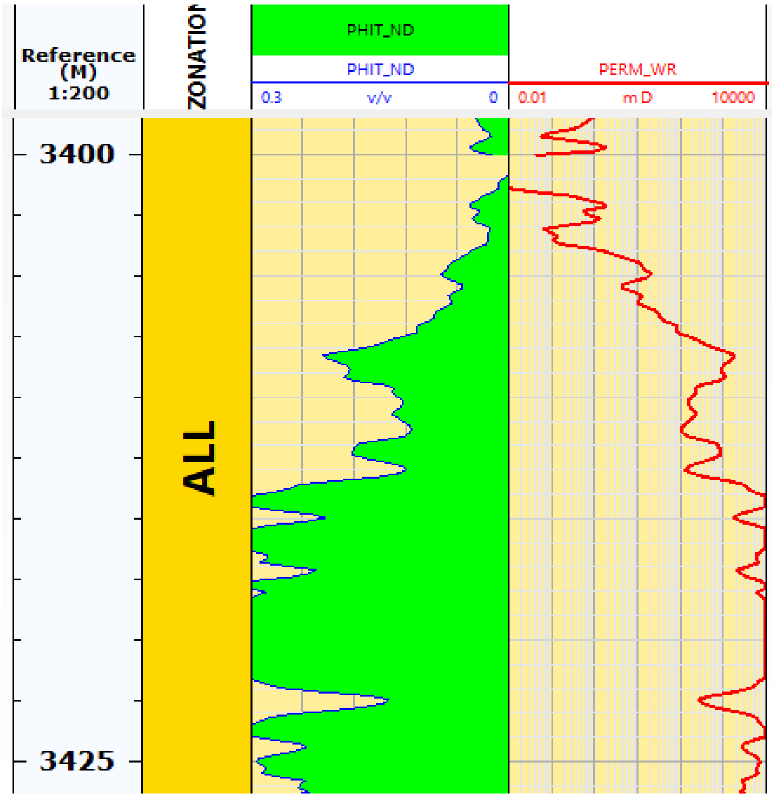

Figure III.19: Permeability of well HMD-2. [16]

- **Results:**

Table III.4: Results of the calculation of Permeability (K) by using Techlog

Well	Zone	Top (m)	Bottom (m)	Permeability (mD)
HMD-1	Reservoir	3216.707	3416.046	338.550
HMD-2	Reservoir	2536.088	3391.205	209.692
HMD-3	Reservoir	3127.248	3433.115	368.176

b. Interpretation of results:

It can be seen from the results obtained (Tab.III-4) that for all the wells treated, the permeability value is between 200 mD and 500 mD, therefore the seven (03) wells which were subject to the study all have good permeability.

3. Conclusion:

We conclude from the results obtained from the interpretation of LAS files and the calculation of petrophysical parameters (Vshale, Porosity, saturation, and Permeability) on the Techlog platform that the Hassi Messaoud field basin has fairly good petrophysical characteristics.

General Conclusion

General Conclusion

The petrophysical and geological analysis of the Hassi Messaoud oil field, as presented in this thesis, underscores the field's significance as a major hydrocarbon reservoir in Algeria. Through the integration of well-logging data and the use of the Techlog software platform, key reservoir parameters such as shale volume (Vsh), porosity (Φ), fluid saturation (Sw), and permeability (K) were systematically evaluated. The findings reveal that the Cambrian-Ordovician sandstone reservoirs exhibit favorable petrophysical characteristics, with average porosity values of approximately 15% and permeability ranging between 200 mD and 500 mD, indicating good reservoir quality. Hydrocarbon saturation levels further confirm the field's potential, with some wells showing values exceeding 68%.

The study also highlights the importance of advanced logging tools and software like Techlog in modern reservoir characterization. These technologies enable precise data interpretation, facilitating informed decision-making in hydrocarbon exploration and production. However, the presence of significant shale volumes in certain zones suggests potential challenges for permeability and fluid flow, necessitating further investigation and tailored extraction techniques.

In conclusion, this research provides valuable insights into the petrophysical properties of the Hassi Messaoud field, contributing to a deeper understanding of its reservoir dynamics. The results emphasize the need for continued technological innovation and multidisciplinary collaboration to optimize hydrocarbon recovery and ensure sustainable resource management in this geologically complex and economically vital field. Future studies could expand on these findings by incorporating additional wells, advanced modelling techniques, and real-time monitoring to further enhance reservoir performance.

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Abstract:

In order to evaluate and predict a reservoir's production capabilities, it is essential to determine the petro-physical properties of the reservoir rocks, such as porosity, permeability, saturation, and density.

This study focuses on the petrophysical characterization of the Hassi Messaoud field, using well log data analyzed through Techlog software. Reservoir productivity is largely influenced by porosity, hydrocarbon saturation, shale content, and permeability. The results obtained indicate that the studied area holds strong potential in terms of productivity.

The findings underscore the value of advanced petrophysics in optimizing recovery strategies for Hassi Messaoud structurally complex, heterogeneous reservoirs.

Keywords: Hassi Messaoud, reservoir, petrophysical properties, Techlog, saturation, shale, permeability, porosity, density.

Résumé :

Afin d'évaluer et de prédire la capacité de production d'un réservoir, il est essentiel de déterminer les propriétés pétrophysiques des roches réservoirs, telles que la porosité, la perméabilité, la saturation et la densité.

Cette étude porte sur la caractérisation pétrophysique du champ de Hassi Messaoud, à partir de données diagraphiques analysées par le logiciel Techlog. La productivité du réservoir est largement influencée par la porosité, la saturation en hydrocarbures, la teneur en schistes et la perméabilité. Les résultats obtenus indiquent que la zone étudiée présente un fort potentiel de productivité.

Ces résultats soulignent l'intérêt de la pétrophysique avancée pour optimiser les stratégies de récupération des réservoirs hétérogènes et structurellement complexes de Hassi Messaoud.

Mots-clés : Hassi Messaoud, réservoir, propriétés pétrophysiques, Techlog, saturation, schistes, perméabilité, porosité, densité.

ملخص:

لتقييم القدرات الإنتاجية للمكمن والتنبؤ بها، من الضروري تحديد الخصائص البتروفيزيائية لصخور المكمن، مثل المسامية والنفاذية والتشبع والكثافة.

تركز هذه الدراسة على التوصيف البتروفيزيائي لحقل حاسي مسعود، باستخدام بيانات سجلات الآبار المُحللة بواسطة برنامج Techlog. تتأثر إنتاجية المكمن بشكل كبير بالمسامية، وتشبع الهيدروكربونات، ومحتوى الصخر الزيتي، والنفاذية. تشير النتائج إلى أن المنطقة المدروسة تتمتع بإمكانيات إنتاجية قوية.

تؤكد هذه النتائج على أهمية فيزياء الصخور المتقدمة في تحسين استراتيجيات الاستخراج لمكامن حاسي مسعود المعقدة هيكليًا وغير المتجانسة.

الكلمات المفتاحية: حاسي مسعود، المكمن، الخصائص البتروفيزيائية، Techlog، التشبع، الصخر الزيتي، النفاذية، المسامية، الكثافة.