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**Departement of Hydrocarbons Production**

**MEMORY**

**To obtain the Master's degree**

**Option : Professional Production**

Submitted by :

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-TITEL-

# PETROPHYSICAL ANALYSIS IN CAMBRIAN RESERVOIR RA OF HASSI MESSAOUD (SOUTH EASTERN SECTOR)

Sustained on : 11 / 06 / 2023 before the examination board

**Jury :**

| | | | |
|---|---|---|---|
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**Academic Year 2022/2023**

# Dedicated.

I thank God Almighty first and foremost for the great grace that He has bestowed upon me, then

I thank those who favored them. My beloved parents do not cease to me for all their efforts from the moment of my birth to these blessed moments. For everyone who advised me, guided me, contributed, or directed me with me in preparing this research and connecting me to the required references and sources at any of the stages it went through, and I especially thank the distinguished : **Dr. Brahmia Nabil**", for helping me Supporting me and guiding me with advice, education, correction, and all that he did with me. I am also pleased to thank the esteemed college administration: University of Kasdi Merbah – OUARGLA Faculty of Hydrocarbons, Renewable Energy and Sciences of Earth and the Universe Department of Hydrocarbon Production.

**Abstract**

The current study presents the log analysis results from two vertical onshore wells in the Hassi Messaoud oil field. The geophysical logs comprising gamma ray (GR), spectral gamma ray log (TH, U, and K), caliper (CALI), density (RHOB), neutron (NPHI), and resistivity logs [AT10, AT20, AT30, AT60, and AT90] are used to obtain petrophysical properties of reservoirs such as shale volume, porosity, hydrocarbon saturation, net pay thickness, etc., for hydrocarbon exploration. The obtained results show that there are two hydrocarbon-bearing zones named (D5) and (D5 and D4) for Hassi Messaoud well 1 and Hassi Messaoud well 2, respectively; both had hydrocarbon reservoirs bearing oil. The generated cross-plots showed that the main reservoir lithology is composed of shale and sandstone. Below and above the oil-bearing reservoirs, there is a thick shale bed that acts as a potential source rock or as a seal rock. The overall results indicated that the sandy reservoir units of Hassi Messaoud Field have the potential to contain significant accumulations of hydrocarbons and essential oils.

**Key words:** reservoir, petrophysical parameters, log analysis, cross-plots, accumulations

**Résumé :**

L’étude actuelle présente les résultats de l’analyse des diagraphies enregistrées dans deux puits verticaux appartenant au champ pétrolier de Hassi Messaoud. Les enregistrements diagraphiques comprenant les logs : gamma ray (GR), gamma ray spectral (TH, U, et K), calliper (CALI), densité (RHOB), neutron (NPHI), et les logs de résistivité [AT10, AT20, AT30, AT60, et AT90] qui sont utilisés pour obtenir les propriétés pétrophysiques des bancs réservoirs tels que le volume d'argile, la porosité, la saturation en hydrocarbures, l'épaisseur nette, etc.,. Les résultats obtenus montrent qu'il y a deux horizons contenants des hydrocarbures nommées (D5) et (D5 et D4) pour le puits Hassi Messaoud 1 et le puits Hassi Messaoud 2, respectivement ; les deux avaient des réservoirs d'hydrocarbures contenant du pétrole oil. Les cross plots générées ont montré que la lithologie principale du réservoir est composée d’argile et de sable. Sous et au-dessus des réservoirs contenant de l'huile, il y a un lit de l’argile épais qui agit comme une roche mère potentielle ou comme un dôme de sel. Les résultats globaux indiquent que les unités de réservoir de sable du champ Hassi Messaoud ont le potentiel de contenir des accumulations importantes d’hydrocarbures et d’huiles essentielles.

**Mots clés** : Réservoir - Paramètres pétrophysiques - logs - Cross-plots - roche mère.

**الملخص.**

تعرض الدراسة الحالية نتائج تحليل القياسات البئرية الجيوفيزيائية لبئرين عموديين في حقل حاسي مسعود النفطي. تستخدم التسجيلات البئرية الجيوفيزيائية التي تضم أشعة جاما، وسجل أشعة جاما الطيفية، وسجلات المقاومة و النيوترون والكثافة للحصول على الخصائص البتروفيزيائية للخزانات مثل حجم الصخر الزيتي، والمسامية، ودرجة التشبع بالهيدروكربونات، والنفادية، وما إلى ذلك، لاستكشاف الهيدروكربونات أظهرت النتائج المتحصل عليها لمنطقتين D5,D4 تحتوي على الهيدروكربونات في الصخرة الخازنة بالنسبة لبئر حاسي مسعود 2 ومنطقةD5 في البئر 1 . أظهر مخطط توزع قيم قياسات النيترونية –الكثافية –اشعاعية البئر التي تم إنشاؤها أن صخور الخزان الرئيسية تتكون من الصخر الزيتي والحجر الرملي أسفل وفوق الخزانات الحاملة للنفط، يوجد قاع صخري سميك يعمل كصخرة مصدر محتملة أو كصخرة ختم. أشارت النتائج الإجمالية إلى أن وحدات الخزان الرملي في حقل حاسي مسعود لديها القدرة على احتواء تراكمات كبيرة من الهيدروكربونات والزيوت الأساسية.

**الكلمات المفتاحية:** الخزان - المعلمات البتروفيزيائية - تحليل السجل – التراكمات

# Summary.

# List of Figures.

# List of Tables.

# List of Obbreviations

**GR** : Gamma Ray

**HMD** : Hassi Messaoud

**K**: Permeability

**Rt**: Resistance of Training (Ω.m)

**Rw**: Water resistance (Ω m)

**Sw, So**: The saturation of fluids

**Vp**: Volume of pores (cm3) Vs: Solid volume (cm3), Vsh: Shale volume (%)

**Vt**: Total Volume (cm3)

**Ø**: The Porosity

**Øt**: Total Porosity (%)

**The units:**

**API**: American Petroleum Institue.

**C°** : Degrees of Celsius.

**D** : darcy.

**Ft** : feet (pied).

**gr:** Gram.

**M** = meters

**md**: mili darcy

**Psi**: Pound per square inch.

**Ω**: ohm.

## Author’s contributions

**1. Conceptualization** was developed by Dr. Brahmia Nabil_ Djilali Mohamed Amine_ Benouis Ahmed Chaker.

**2. Methodology** was proposed by Dr. Brahmia Nabil_ Eng .Abdellah El Hadj Brahim_Djilali Mohamed Amine_ Benouis Ahmed Chaker_Benmegdad Ahmed.

**3. Software and** validation was developed by Eng.Abdellah El Hadj Brahim _Djilali Mohamed Amine_ Benouis Ahmed Chaker and Dr. Brahmia Nabil.

**4. Formal analysis** was done by Djilali Mohamed Amine and Benouis Ahmed Chaker.

**5. Investigation** was done by Djilali Mohamed Amine Benouis Ahmed Chaker and Benmegdad Ahmed.

**6. Data curation** was performed by Benouis Ahmed Chaker_Djilali Mohamed Amine and

Benmegdad Ahmed.

**7. Original draft preparation** was done by Benouis Ahmed Chaker and Djilali Mohamed

Amine.

**8. Editing** were carried out by Benouis Ahmed Chaker _ Djilali Mohamed Amine. and Benmegdad Ahmed.

**9. visualization, supervision, and project** administration were performed by Dr. Brahmia

Nabil

## .Data Availability.

The dataset was collected from the SONATRACH company’s Engineering Production Division, and tests were conducted in a laboratory company based in Irara Hassi Messaoud, Algeria.

# The General Introduction

## The General Introduction

The study of the petrophysical parameters of rocks is an important step in the exploration and production of oil. To understand and anticipate the qualities of the production of a tank, it is necessary to know the petrophysical properties (porosity, permeability, saturation, and density) of reservoir rocks. In this context, the aim of this study is to give a petrophysical characterization of the region. Since their discovery, hydrocarbons have always remained the primary source of energy that meets the needs of a world that is rapidly developing on the socio-economic side. This progress challenges researchers to ensure an accelerated demand for this vital material. The adventure of oil exploration in Algeria dates back to the last quarter of the 19th century, with the first explorations in the north in 1877, in the region of Ain Zeft, near Relizane, in western Algeria. Since then, Algeria's hydrocarbon potential has continued to show its wealth through its development in the Sahara and today in the North, with the promises offered by exploration, which is finding new impetus in this region. After each discovery of a deposit with hydrocarbon potential, people turn to exploration and exploitation techniques; the latter depend on the characteristics at the same time of the formation and of the fluids that contain them, which determine the value and interest of this discovery from the point of view of profitability and economics. The optimization of the production of a hydrocarbon field is based on the study of the petrophysical parameters of the reservoir rocks, with the aim of increasing the oil production in Algeria. Sonatrach is oriented to the development of the peripheral fields of Hassi Messaoud, Hassi Khbiza (HKZ), Hassi Guettar (HGA), Rhourde Chegga fields (RDC), etc.; in this sense, it is interested in conducting in-depth petroleum studies on the latter to properly characterize their parameters and to facilitate their exploitation. The objective of this study is to evaluate the petrophysical parameters of the Hassi Messaoud reservoir from these wells. In this approach, the work presented as part of this memory comes as an attempt to characterize the tank in the HMD field using data from diagrams.

# Chapter I

# *Literature Review*

### I.1.1 Introduction:

Hassi Messaoud is located in the central part of the Algerian Sahara. It is known for its productive oil wells, mainly in the Cambrian reservoirs. The Hassi-Messaoud field is one of the most complex fields in the world. In geological history, this field has undergone intense tectonic evolution. It is characterized by distinctive compressive phases. On the other hand, the diagenetic transformation in the reservoir, when buried during geological times, continues until the field has taken on its current shape or configuration.

### I.1.2 The geographical situation:

Hassi Messaoud is the largest oil field in Algeria. about 850 km southeast of Algeria, 280 km south-east of the Hassi R'Mel gas field, and 350km west of the Tunisian border (**Figure I.1**). It extends over an area of 2500 km2. It has for coordinates Lambert (LSA) **[1]**:

X = [790,000 to 840,000]

Y=[110,000-150,000]North


**Figure I.1:**Geographical location of the Hassi-Messaoud field **[1]**:.

### I.1.3 Geological context

Hassi Messaoud Field occupies the central part of the Triasian province. by SA area and its reserves, which is known for its productive oil wells mainly in the Cambrian reservoir ( **Figure I.2**)

Geologically it is limited:

- This was due to the depression of Oued Mya.
- To the south by Amguid El Biod.
- It is located in the Djammâa-Touggourt structure.
- In the east by the high funds of Dahar, Rhourde El Baguel and the depression of and Ghadames.

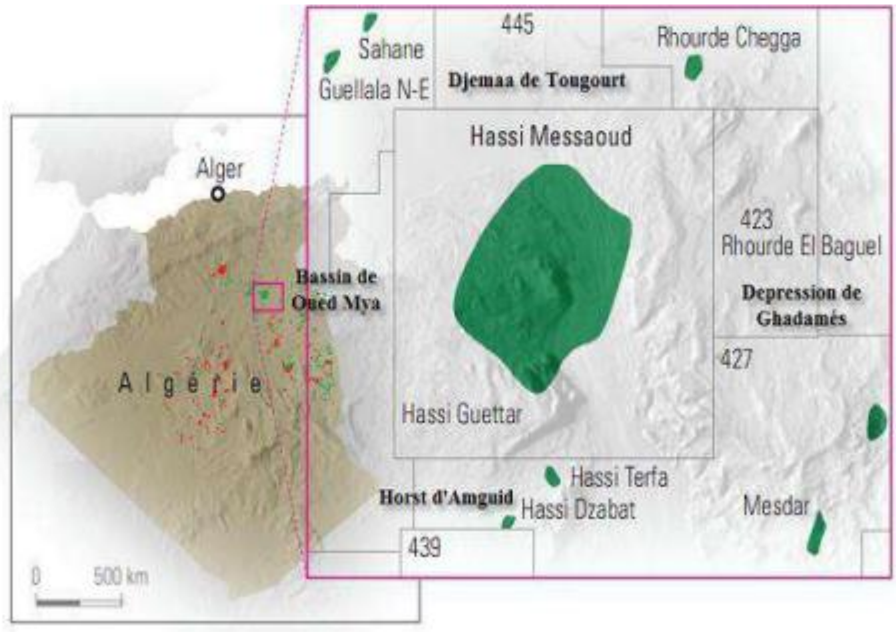


**Figure I.2:** Geological context of the Hassi Messaoud field **[1]**.

### I.1.4 Geology of the Sahara Platform

The geological history of the Sahara platform is very ancient. Its evolution is influenced by the presence of sometimes very old shields, such as the Reguibat Shield, which stabilized between 1800 and 2000 MA, and younger shields, such as the shield touareg, resulting from the Pan-African phase, which dates back to approximately 500 MD.

The main structural feature is the presence of large vertical sub-meridian gaps, highlighted by powerful bands of mylonites. These sub-meridian accidents are delayed. It is a network of combined faults. The accidents of the orientation bases N-S, NE-SO, and NOSE are at least of late pan-African age. This fracturing network will later play an important role in the structure and sedimentation of the Sahara platform (**Figure I.3**).

Several tectonic phases have shaped the Sahara platform, namely:

- The Cambro-Ordovician Distance
- The tectonic compression
- The Caledonian Compression
- The various tectono-sedimentary events of the Devonian
- The Hercynian Movements
- The Meso-Cenozoic Events (phases Autrichienne et Alpine).

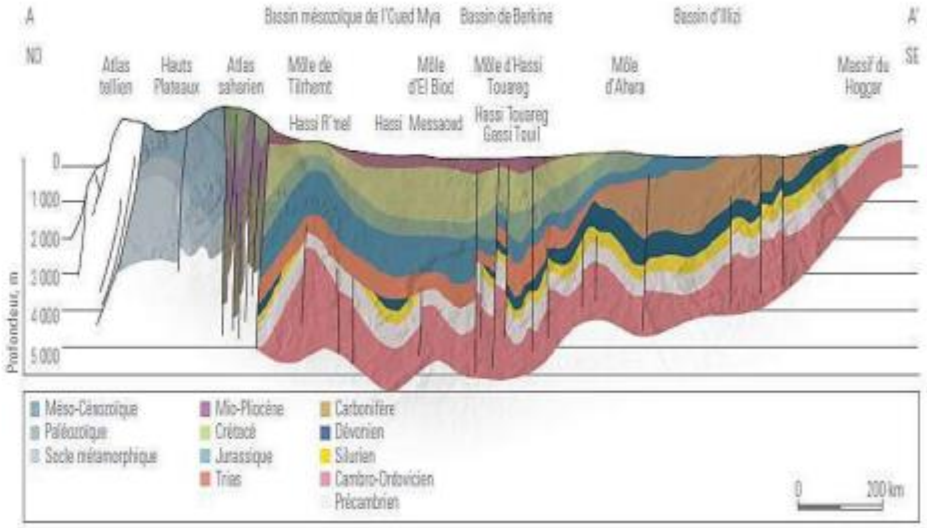


**Figure I.3:** Regional Geological Coup Figure **[1]**..

The pan-African orogenic phase, which ends during the Cambrian period, is followed by a period of significant erosion that levelled the previous structures and reliefs. The major hercenian movements, on the other hand, played a major role in the structure of the different basins of the Sahara platform and in the distribution of the rock reservoirs. The result is clearly visible on the pre-mesozoic cortex of the region, according to Hassi Messaoud. Several drilling sites in the Hassi Messaoud region and the Oued basin Mya crossed volcanic rocks interlaced in grasses attributed to the Cambrian (Ra and R2) and to the Ordinary. According to the BEICIP-Sonatrach (1972), we are in the presence of more or less basic spilites or fragments of spilites resedimented at the same time as the grasses are deposited.by Hassi Messaoud.

### I.1.5 Summary:

Hassi-Messaoud is defined in a perfect trilogy, heterogeneous on the plane. vertical and horizontal, anisotropic by the presence of silts, and discontinuous by the flow of fluid. This field is characterized by its Cambro-Ordovician age formation; its thickness is on the order of 200 m.

### I.2.1 Introduction:

Wireline logging provides various recordings of subsurface formation properties, and well logs are the main sources for petrophysical analysis. Logging records are first used for single-well evaluations and then extended to field-wide resource evaluation and reservoir modelling.

Logging technology has grown exponentially since the first electrical log was recorded in 1927. Modern log suites include gamma ray (GR), spontaneous potential (SP), density, neutron, and various resistivity logs. These data are used to evaluate rock properties, including porosity, fluid saturation, permeability.

### I.2.2 Porosity Characterization and Estimation:

Porosity describes fractional pore volume in the rock and is defined as the ratio of pore volume to bulk volume of rock. The pore volume is the difference between the bulk volume and grain volume of rock. Porosity is an important reservoir property because pore space in the subsurface provides storage for hydrocarbon accumulation and is often the main determinant for estimating permeability. There are several definitions of porosity, such as distinction of total porosity and effective porosity based on the connectivity or flow capacity of pores; distinction of matrix porosity and fracture porosity, or primary and secondary porosities, from the porosity generation mechanism; distinction of intergranular and intragranular porosities from the position of the pores relative to the lithological grains; and distinction of well-log porosity and core porosity from the source of measurement. In carbonate pore systems, seven to eight types of porosity are sometimes distinguished: interparticle, intraparticle, inter-crystal, moldic, fenestral, fractured, vuggy, and micro-porosities **[2].** The main factors that affect the porosity of rock are uniformity of grain size (sorting), compaction, cementation, consolidation, diagenesis (generation of secondary or solution porosity or destruction of primary porosity), and fracturing. In theory, grain size has a relatively small impact on porosity; however, grain size is often correlated to grain shape and sorting, and thus grain size can sometimes be significantly correlated to porosity.

### I.2.2.1 Total and Effective Porosities

Total porosity represents all the voids or pore spaces of the rock, including interconnected and isolated pores and pore spaces occupied by clay-bound water. Effective porosity represents interconnected pore space in the rocks, and it is part of the total porosity that contributes to fluid flow in the rock. Several definitions of effective porosity exist in the petroleum industry, and there are some subtle differences in definitions among core and log analysts and reservoir engineers, as shown in **Figure I.4**: **[3]** Even total porosity may be defined differently depending on the method of measurement. One of the common practices is to calculate effective porosity as the total porosity minus the porosities of the clay-bound water and isolated pore volumes. Obviously, the effective porosity is always smaller than or equal to the total porosity. In practice, when shale is not present, effective porosity is often equated to total porosity in conventional formation evaluations. Effective porosity is more useful for calibrating porosity to permeability because, by definition, permeability is determined by the interconnectedness of pores. Total porosity can be more useful for calibrating porosity to water saturation because water is present in both connected and unconnected pore spaces. Both total and effective porosities are derived from petrophysical analysis and can be used for reservoir modelling.

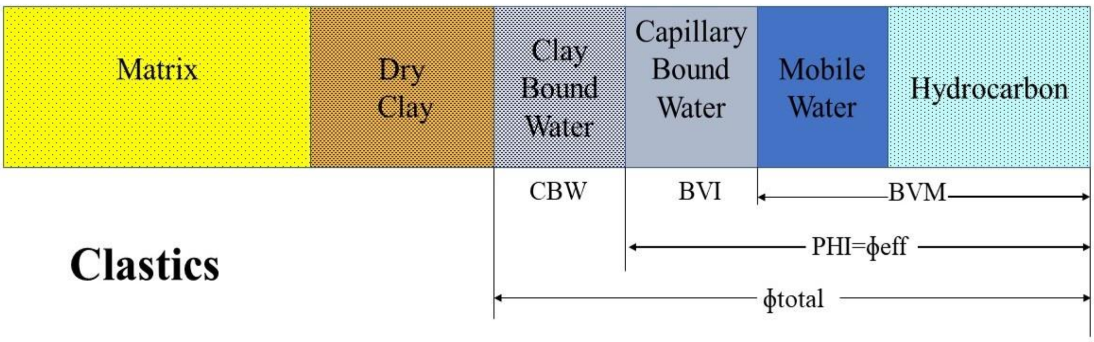


**Figure I.4:** Volumetric description of a hydrocarbon-bearing clastic reservoir. CBW –clay-bound water; BVI – bulk volume irreducible/non movable water; BVM – bulk volume movable fluids**[3].**

### I.2.3 Clay Volume and Its Impacts on Other Petrophysical Parameters

In conventional formation evaluations, lithological fractional volumes are usually calculated only for clay (or shale), sand, limestone and dolomite. Recently, mineral volumes are evaluated more commonly, especially for shale reservoir evaluations. Deriving all the mineral volumes Using well logs can be complex **[4]**; **[5]**. Here we discuss only the clay volume. This is related to shaly sand analysis **[6]**. Clay content reduces effective porosity and permeability and thus has an impact on volumetric estimations and hydrocarbon productivity. Moreover, many log-based petrophysical

Evaluation methods were initially developed using clean formations as a reference. With the presence of clay, readings of common logs are affected, and the estimation of effective porosity requires the estimation of Vclay. Common methods for shale volume estimation use GR, SP, neutron-density cross plots, and mineral compositional analysis **[7]**; **[8]**. **Figure I.5** shows three transforms from GR to Vshale. Two non-linear transforms were proposed to correct the observed deviations from the linear transform because a naive linear transform can overestimate the Vshale in those applications **[9]** .The linear transform for Vshale estimation often uses a low-end cutoff and a high-end cutoff. The cutoff values can be different for different applications, depending on the depositional environments and contents of heavy metals and radioactive minerals. Sometimes, heavy metals and radioactive minerals increase gradually in both shale and sand, so shale and GR can have a fuzzy relationship. For example, the Tertiary deposits in the Greater Green River basin often contain high contents of radioactive minerals, leading to higher GR, even for sandstones **[10]**; **[11]**. Shows a cross plot of Vshale and GR in a stratigraphic zone from these deposits. The correlation between Vshale and GR is only 0.58, in contrast to a much higher correlation in most conventional formations. Incidentally, the relationship between GR and Vclay in shale reservoirs is generally more complex, but with high-quality data, the complexity of the relationship can be used to identify formations with high organic matter.

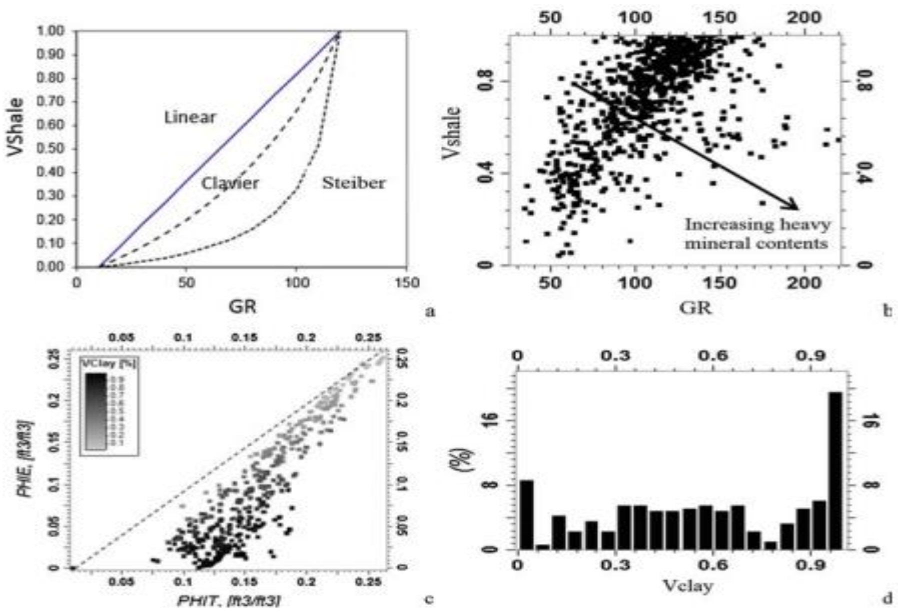


**Figure I.5:** Three different relationships between V shale and GR with cutoffs applied **[9]; [8].**

An example of a scattered relationship between V shale and GR in a heavy metal rich, tight shaly sand formation the arrow indicates the correction for Vshale estimation to account for the heavy mineral effect. (c) Example of effective porosity (PHIE) versus total porosity (PHIT) from a siliciclastic reservoir with sandstone, shaly sandstone, and shale. The dashed line is a one-to-one line for reference. (d) Histogram of Vclay in (c); it has a multi-modal distribution, and low total porosity values have little effective porosity because of the high Vclay.

### I.2.4 Permeability Characterization

Permeability is a measure of fluid flow in porous media, and it describes the capacity of a material for fluids to flow through it. While porosity describes the storage capability, permeability characterizes the dynamics of fluids in the rocks, and thus it is a critical petrophysical parameter for hydrocarbon production, reservoir simulations, and performance forecasts.

### I.2.5 Factors Affecting Permeability

The permeability of subsurface formations is affected by several geological factors, both depositional and post-depositional. The depositional variables that impact the permeability include **[12]; [13]** :

- Grain size of the rock: Larger grains lead to higher permeability.
- Grain sorting: better sorting leads to higher permeability.
- Lamination: laminations generally reduce the vertical permeability.

The post-depositional variables that impact permeability include:

- Cémentation reduces permeability.
- Fracturing tends to increase permeability.
- Diagenesis can increase or decrease permeability.

### I.2.6 Water Saturation (Sw) Characterization

The pores in subsurface formations are filled by water, oil, and/or gas. The fluid distributions in porous media are impacted by a variety of factors. Whereas buoyancy acts to segregate different fluids because of the density differences, capillary force acts to counter the buoyancy and tends to mix fluids together. In conventional reservoirs, a free-water level (FWL) is defined at the depth of the equilibrium of buoyancy and capillarity. Above it, a transitional zone, where water and hydrocarbons coexist, is created because of these two counteracting forces. A general profile of fluid distributions caused by the competition between gravity and capillarity. The distributions of fluids in a reservoir are typically described by their saturations. Oil saturation (So) is defined as the fractional oil volume of the pore volume, gas saturation (Sg) as the fractional gas volume of the pore volume, and water saturation (Sw) as the fractional water volume of the pore volume. These three quantities add up to 1, such as

$$\mathbf{Sw + So + Sg = 1}. \qquad \mathbf{(I.1)}$$

### I.2.7 Summary

Petrophysical data from log analysis provide basic inputs for resource evaluation and reservoir modeling. Porosity is the most basic petrophysical property for hydrocarbon resource evaluation. An accurate estimation of porosity from well logging tools provides an important basis for field wide evaluation of pore volume and its spatial distribution in a reservoir model. Permeability data typically is limited in core analysis, and permeability at wells is often generated from porosity-permeability relationships. Because a variety of variables may affect permeability, there are many possible relationships between these two variables. Subsurface fluids are distributed following basic physical laws; however, because of the heterogeneity, characterization of the fluid distributions in subsurface formations can be complex. The Archie equation and its variations provide methods for estimating water saturation using resistivities, porosity and other parameters.

### I.3.1.Introduction

After drilling, geophysical borehole measurements are carried out to obtain detailed information about, the subsurface stored in highly resolved logs. The subjects of investigation were the in-situ physical properties of the rocks in the direct vicinity of the borehole, e.g., petrophysical parameters like porosity, saturation, and permeability. The challenge of interpreting various geophysical logs is in the determination of those inferred physical parameters, describing the undisturbed formations, from directly measured ones like resistivity, interval transit times, and natural radioactivity.

### I.3.2 Parameters that influence measures:

These are parameters mainly related to the conditions of drilling. They have an influence

Positive or negative on the recordings of the diagrams; knowledge of these this allows us to have a better interpretation.

#### I.3.2.1 Diameters of survey:

The probe diameter is not constant along the drilling; it varies depending on the type and nature of the formations.

#### I.3.2.2 Drilling mud

It has a direct influence on the response of the tools due to the diameter of the hole (plus is

The larger the volume of fluid surrounding the tool, the greater the measurement.)

#### I.3.2.3 Tubing and Cementation:

This influence is felt in the case that the hole is made of tube and cement, which does not allow recording of some diagrams.

#### I.3.2.4 Speed of Recording:

The maximum recording speed depends on the recorded parameter. Varies depending on the type of tool used (each tool has a maximum speed that cannot be exceeded).

### I.3.2.5 Temperature and Pressure:

The temperature and pressure increase with the depth; therefore, the tools used must be able to withstand these variations during their descent into the hole. Why each tool has its own limitations and conditions of use.

### I.3.3 Different types of well logging and their application:

### I.3.3.1 Natural Radioactivity "GR":

These diagrams can be recorded in open holes and tubed holes since the gamma rays pass their energy through a more or less large particle. material according to its nature (density). This diagram measures using a scintillation meter lowered at the end of a cable.the natural gamma rays emitted by the formations through the drilling have a symbol, and their unit is the API. Gamma radiation is caused by the presence of three radioactive elements in the rocks: potassium 40 (40k), thorium 232 (232th), and uranium 238 (238u). This log provides the following lithological information:

- It highlights well the coal, the evaporation, and especially the levels of clay that

  These are often the limits of reservoirs.

- Permits estimating the percentage of clay in sand formations.
- In the presence of resistant mud and in drilling filled with air, the measurement of the Natural radioactivity is useful for studying lithology. And the arches, Evaporates, coal, etc. have characteristic responses that this allows them to be easily identified.

The factors that influence the measurement are recording speed, time constant, the counting rate, dead time, mud, piping, cement and the thickness of the banks. It is registered for all study wells.

#### I.3.3.1.1 Application:

- Evaluation of Vsh clay content.
- Determination of lithology by establishing a vertical lithological profile.
- Reference curve for depth .
- Estimate the percentage of clay in the tanks.

- Correlations between surveys and discrepancies.
- Evaluation of radioactive minerals.
- Approach to permeability.

### I.3.3.2 Resistivity:

Resistivity diagrams depend on the composition of the rock as a solid element and the nature of the fluids contained. The principle of measurement is to send a signal through an emitting energy source (electric current or magnetic field), which penetrates the formation and records the difference of potential (D.D.P.) by a measuring device (receiver), located at a certain distance from the source: spacing This is because, depending on the spacing and nature of the source of energy, several tool They are defined. Several combinations of resistance (macro-resistance and micro-resistance) are possible. For better estimation of Rt and Rxo resistance.

Array Induction Tool (AIT): The basic principle of the AIT is different from the others induction tools; it is recognized by the high precision of measurements of the conductivity; the AIT tool is used in oil-based mud; it is designed to different speeds of investigation; it allows us to record five curves of resistance to depths that vary between (10, 20, 30, and 90) inches, depending on the depth; 1ft, 2 ft, and 4 ft; and it is available according to 3 vertical solutions:

- A foot for the analysis of thin layers.
- 2 to 4 feet for easy correlation with the existing log.
- Determination of heterogeneity near the drilling well.

The electrical resistance of rocks depends on:

- The quality of the electrolyte (Rw water resistance quantity of dissolved salts)
- The amount of electrolyte contained in the unit volume of the rock
- Distribution of electrolytes
- In rocks, it is most often water that plays the conductor role.

The larger S (porosity and saturation), the more connections there are between the pores.

The direct plus (L) is small.

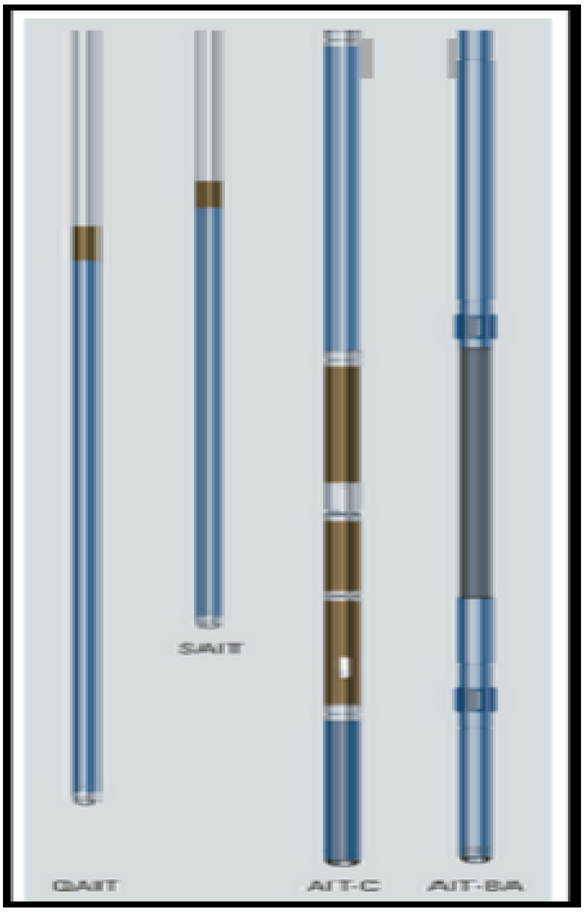


**Figure I.6:** Schlumberger's AIT tool **[12].**

**I.3.3.2.1 Application:**

- Identification of lateral heterogeneities
- Determination of the Rt and Rxo resistance.
- Quantitative Descriptions of Resistivity in Radial Invasion and Evaluation Volume of filters.
- Self-determination of mud resistance or hole diameter.
- Correction of the hole effect.

**I.3.4 Porosity:**

It includes three types of porosity:

- porosity Neutron and porosity density.

### I.3.4.1 Neutron diffraction (Hydrogen Index):

With the help of appropriate sources, the training is subjected to a bombardment. Due to the intense speed of neutrons, the initial energy ranges from 4 to 6 MeV. Due to their high initial speed (10,000 km/s), fast neutrons have great power. of penetration. They will collide with the nuclei of the atoms. They gradually go through it and lose their energy. The measurement of (IHn or n) depends somehow and especially on the number of atoms of hydrogen per unit of volume in the formation, these being either bound to water or to the hydrocarbon (thus to the porosity and saturation), or to the molecular composition of the rock, but also, to a lesser extent, to other atoms entering the composition of the rock, either due to its slowing power or its absorbing power. Unfortunately, many minerals also contain hydrogen. The analysis of the neutron log is not simple. The neutron curves recorded are on a scale that varies between 0.45 and 0.15 m3/m3.

- **CNL (Compensated Neutron Log):**

Using a radioactive source based on beryllium, the formation is subjected to a high-energy neutron bombardment. The thermal neutron number increases with the amount of hydrogen present in fluids; hence, the notion of indexing the hydrogen neutron (IH) is therefore related to the measurement of porosity.

The relationship between the thermal neutron, hydrogen index, and porosity is:

$$Lo(IH)n = A - B.Na \qquad \text{(I.2)}$$

**such as :**

Amplitude of the neutron curve.

A and B: Constants related to the tool and the parameters of the hole (bow, diameter, etc.),Neutron porosity is deducted from the previous equation and is given in units. Porosity (Porosity unit PU)

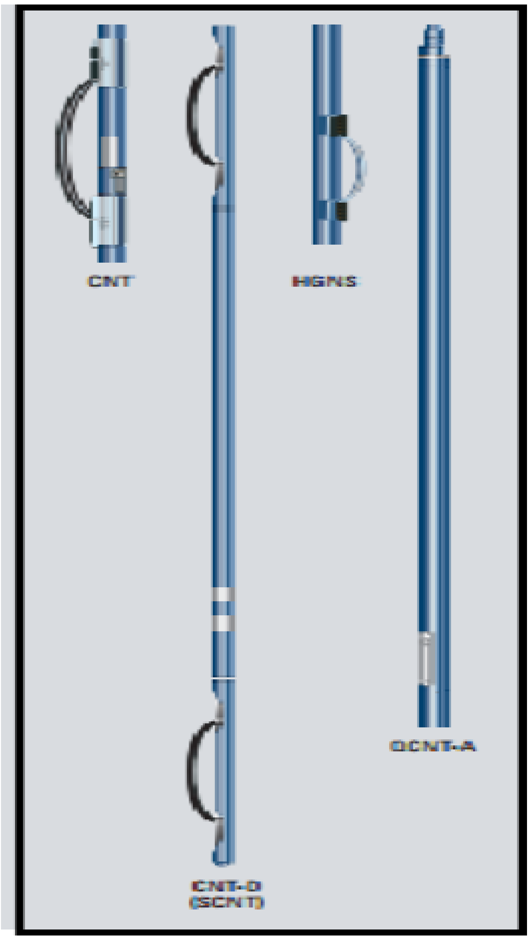


**Figure I.7:** Schlumberger's CNL tool **[13]**.

**III -3.3.1.1- Application :**

- Evaluation of the porosity of reservoir rocks.
- Combined with other tools, it helps to identify lithology.
- Combine with LDT for gas pockets.
- Evaluation of hydrocarbon density.
- Good criteria for correlation of wells to wells.

**I.3.4.2 Density:**

They are all based on the principle of intersection between radioactivity and components of the training subjected to radioactive bombardment. The radioactive source emits gamma radiation

that strikes the atoms of the formation. There are three types of interactions that occur according to the energy of the incident protons:

- The Compton effect occurs when the photon energy is between 0.1 and 1 MeV.

- The photoelectric effect occurs if the photon energy is less than 0.1 MeV.
- The pair production effect occurs if the photon energy is greater than 1, 01 MeV.
- The density curves recorded are on the sensitivity scale of 1.95 to 2.95 g/cm3.

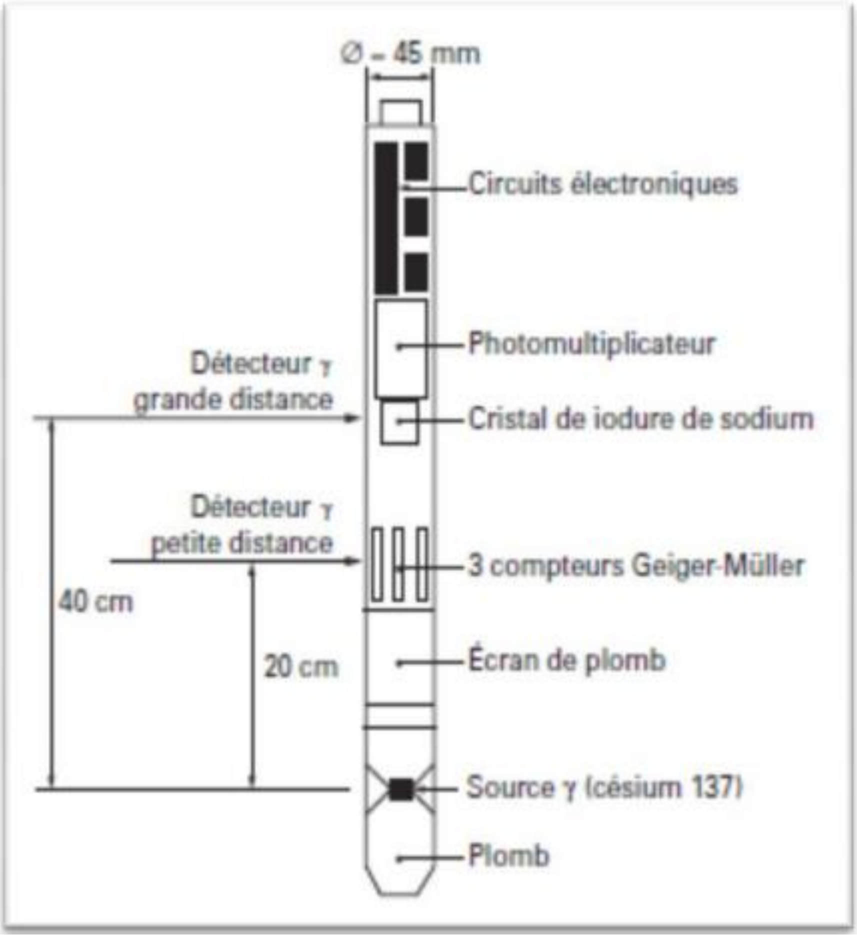


**Figure I.8:** tool and principle of measurement of the density **[13]**.

### I.3.4.2.1 Application:

- Determination a porosity density indispensable to modern interpretation.
- The comparison of neutron, density and resistance enables the identification of fluids in the tanks and the location of gas/oil and oil/water contacts
- Density is an abnormally high density

# Chapter II.

# Case study

# Well logging analysis in Cambrian reservoir Ra of Hassi Messaoud oil field

## II.1 View the data used

The well log data for this study was collected from the Sonatrach Company. The available drilled boreholes are named WELL1 and WELL-2; each well has main logs like gamma ray (GR), spectral gamma ray log (TH, U, and K), caliper (CALI), density (RHOB), neutron (NPHI), and resistivity logs [M2R1, M2R3, and M2R9 for Well 01 and AT10, AT20, AT30, AT60, and AT90 for Well 02]. These logs are used for calculating the petrophysical parameters as no core data is available; these logs are delivered as soft copies (Las files). The Interactive Petrophysical IP 3.5 software was used to integrate all the available data to interpret and compute the input of the different petrophysical properties to deliver a more realistic and accurate formation evaluation.

### Data analysis

For this investigation, two wells in the Hassi Messaoud oil field were chosen. The name and specific location of this well are not published in this paper for reasons of secrecy.

Generally, the well logs, like GR and caliper logs, were used for the correlation of depth and identification of permeable zones, in addition to identifying the same facies in the wells. Porosity logs (density logs, neutron logs, and sonic logs) were used to calculate porosity at each point. Resistivity logs were used to obtain water saturation. After obtaining water saturation, both oil and gas saturation can be calculated. The procedure for calculating petrophysical parameters is as follows:

### II.1.1 Lithology determination

The lithology identification is pivotal for reservoir characterization because all of the petrophysical parameters, such as porosity and permeability, depend on the facies type. Besides, fluid saturations directly depend on facies types **[14].** In this study, lithology across Hassi Messaoud wells was identified by using the gamma ray (GR) log. Cross-plots are used to define lithology and petrophysical parameters using different types of logs. Neutron-density-gamma ray and also Thorium-potassium-gamma ray Cross-plots indicate the lithology and porosity of the formation.

### II.1.2 Reservoir identification

The reservoir is the only zone with potential for economic interest because it contains storage space for fluid (hydrocarbon or water) to accumulate. A good reservoir rock must be porous, permeable, and contain hydrocarbons as well **[15].** In this study, reservoir rock was identified using the interpretation of the available log data. The gamma ray log was used in the identification of reservoir rock based on the fact that the sandstone reservoir exhibits very low radioactivity because of the low content of radioactive elements. Resistivity logs were also used in the sense that reservoir zones exhibit relatively higher resistivity values than non-reservoir zones. Based on neutron and density logs, reservoir rock was also marked by the presence of neutron-density crossover **[16].**

### II.1.3 Fluid identification.

It is very important to identify the interval zone and the type of fluid in the reservoir rock because reservoirs may contain hydrocarbons (oil and gas), non-hydrocarbon fluids (water), or both. For a reservoir to contain hydrocarbons, the zone should be porous with resistivity values higher than those of water-bearing zones **[17]**. In this study, the resistivity log and neutron density log were used to identify hydrocarbon- and non-hydrocarbon-bearing intervals. Hydrocarbons are poorer conductors than water and hence show higher resistivity than water-bearing intervals.

### II.1.4 Volume of shale (Vsh) calculation

The calculation of shale volume is crucial because it helps to calculate formation porosity, fluid content, and overall rock quality. In this study, the volume of shale was estimated using the gamma ray logs method using the following equation:

$$V_{Sh} = \frac{GR_{log} - GR_{m_{in}}}{GR_{max} - GR_{m_{i}n}} \quad \textbf{(II.1)}$$

where =shale volume, GRlog=gamma ray reading of the formation, GRmin=minimum gamma ray, maximum density log reading.

### II.1.5 Net to gross ratio (h/H).

It is very important to determine the net pay thickness to calculate the original hydrocarbon in place. NTG is the ratio of the thickness of sand bearing hydrocarbons to the total thickness of the sand formation **[17].** It shows the volume of shale present in the reservoir. Net reservoir thickness (h) can be calculated by using the following formula:

$$h = H - h_{shale} \quad \textbf{(II.2)}$$

where H=The gross reservoir thickness, $h_{shale}$=The thick-nesses of the shale, and Net/Gross=h/H.

### II.1.6 Porosity estimation

Porosity is a very important parameter for the characterization of the reservoir rock, as it is used to describe the amount of open space filled with fluid (hydrocarbon or water). In this study, total porosity and effective porosity were calculated as follows:

#### II.1.6.1 Total porosity.

By combining neutron-density logs, the total porosity within the reservoir interval was determined. The equation to compute the total porosity from neutron and density logs may be expressed as:

$$\phi_{Total} = (\phi_D + \phi_N)/2 \quad \textbf{(II.3)}$$

Where ΦN= Neutron porosity, ΦD= Density porosity, which is calculated from this equation **[18]:**

$$\phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \quad \textbf{(II.4)}$$

Where $\rho_f$: bulk density, which includes both fluid and rock (read directly from the log), $\rho_f$ : density of the saturating fluid, ma: density of the rock matrix, $\phi$ : porosity.

### II.1.6.2 Determination of effective porosity

The effective porosity is usually based on an adjustment of the total porosity by means of an estimated shale volume. The equation to compute effective porosity may be expressed as **Figure II.1 [19]**:

$$\phi_{eff} = \phi_T - [\phi SH * VSH] \qquad \textbf{(II.5)}$$

where Øeff = effective porosity, ØT = total porosity, Øsh=porosity reading in a shale zone, Vsh=Shale volume.

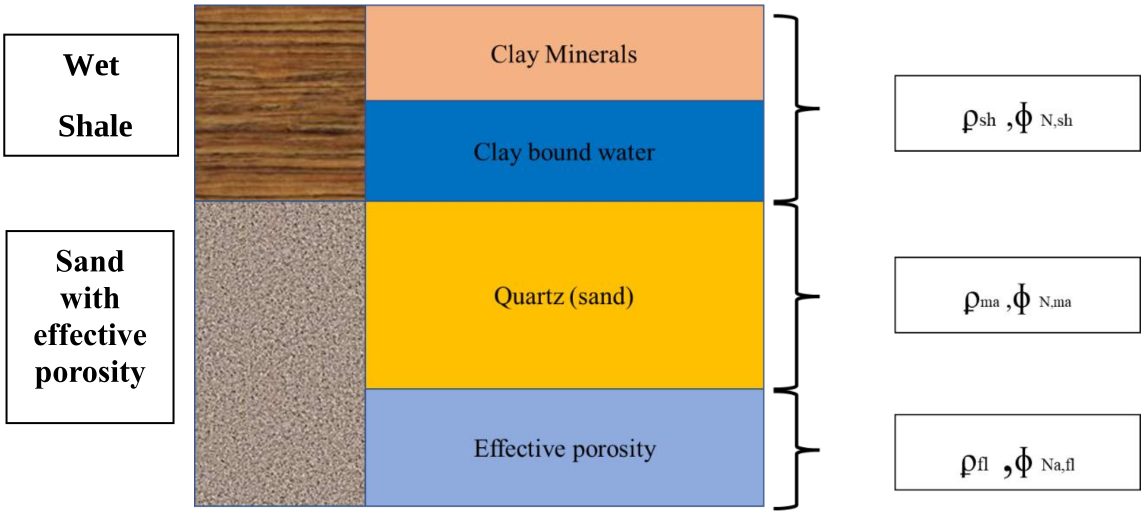


**Figure II.1:** The Porosity shaly sand model **[19].**

### II.1.7 Water saturation calculation

Water saturation can be defined as the ratio of water volume to pore volume. It is calculated by porosity and resistivity logs. Determining water saturation is crucial because hydrocarbon saturation can be calculated from water saturation. In this study, Archie's model is used to calculate the water saturation of the reservoir rocks. To calculate water saturation from Archie's model, the following equation was used **[20]**:

$$Sw=(a*Rw)/(Rt * \phi^{m})^{1/n} \qquad \textbf{(II.6)}$$

where Sw = water saturation of the uninvaded zone, a=tortuosity exponent, n=saturation exponent, Rw=formation temperature, φ=porosity, m =cementation exponent, Rt=true formation resistivity

### II.1.8 Hydrocarbon saturation

Hydrocarbon saturation ($S_h$) is the percentage of pore volume in a formation occupied by hydrocarbons. In this study, the hydrocarbon saturation was determined by subtracting the value of water saturation from 100%. Hydrocarbon saturation percentage $S_h$ is given as

$$S_h = (1 - S_w) \qquad \textbf{(II.7 )}$$

### II.1.9 Net pay

Net pay thickness is the most important factor in hydrocarbon in place calculations because it affects reservoir management and reservoir productivity. Table I shows the cutoffs applied in this study.

**Table I:**The applied cutoffs for net pay calculation

| Categories | Vsh and porosity (%) | Vsh ,porosity ,permeability and water saturation (%) |
|---|---|---|
| Cutoff equation | $0 \leq Vsh \leq 50$<br>$\phi \geq 5$ | $0 \leq Vsh \leq 50$<br>$\phi \geq 5$<br>$K \geq 1\ md$<br>$0 \leq Sw \leq 60$ |
| Zone name after the cutoff | Net reservoir | Pay zone |

### II.1.10 Presentation of the interpretation tool (Interactive Petrophysics, Version 3.5 IP)

Because of the large number of readings recorded by each of the sounders used in the well logging studies, it is difficult to draw curves that represent these values and interpret them manually because it takes a lot of time and effort. Therefore, it is necessary to use software that helps speed up the calculations and draw the curves after Introduce appropriate interpretation equations and factors to be determined by the interpreter. In this study, the IP program was used to interpret the readings of geophysical records measured well. The number of readings depends on the type of probe being measured, so probes generally take a reading.

every 15cm or 10cm, or it may be reduced to 5cm according to the required accuracy. The number of readings is determined by the body carrying out the measurement when the measurement is done with the same spacing between each reading and another but at different depths with each probe. The program returns all the readings taken from all the swabs to one depth; that is, it rearranges the readings so that we take all the readings at the same depth. The interpretation depends entirely on the interpreter, and the role of the program is limited to accelerating this process so that his experience and accurate knowledge of the region play the main role in the accuracy of the results. Reading the drilling fluid analysis reports helps by giving an initial idea about the lithological nature of the penetrated rocks, checking the values of the input factors to build assumed models of rock composition and available saturations, and identifying all factors related to the implemented study. Measurements are recorded on discs with certain internationally recognized suffixes (LBS, LAS, LAS, ASCII, LIST, DLIS). These suffixes are related to the way the program treats them, so that the suffix (ASCII) is considered the worst in terms of input and treatment because it needs to process the reading of each probe separately and leads to interruption of interpretation in the event of a lack or gap (gap) in certain probe readings. As for the other suffixes, they are better in that they avoid errors resulting from the presence of gaps in the readings by filling them with average values from the values adjacent to this gap. In this study, the suffix "LAS" was used for borehole measurement data.

**II 1.10.1 Steps to work on the program.**

1- Create a well and name it.

2- Download the well measurements data.

3- Create a temperature staircase curve in order to correct the values of resistors entered for interpretation.

5- Determine the depth to be interpreted.

6- Enter the value of the water resistance $R_{\omega}$ and the temperature corresponding to the depth at which the measurements are to be interpreted, as well as the value of the resistance of the mud filtrat $R_{m_f}$ in order to correct the true (deep) resistivity values measured on the surface and the temperature corresponding to the place at which the measurement was made. In certain cases, enter Rwb associated water resistivity values if available.

7- Determine the saturation equation to be applied (Archi) according to the nature of the studied area.

8-Determining the type of drilling fluid used (water based (WBM) - point based (OBM).

9-Enter the values of the saturation relationship constants (m n o).

10- Introducing models (models) that help in interpretation, which include measurements [density and Neutron, corrected gamma rays , UZ curve and other measurements, if any], as well as entering the types of penetrating lithology. In other models, saturations inferred from drilling indicators are added. All of them take standard fixed values from the measurements entered for each type of rock and saturation.

11- Setting conditions for interpretation, so that we apply a model to a specific depth because of its different lithology from other depths, or to set certain conditions that lead to canceling the calculation of saturations at certain ranges, due to an increase in the diameter of the well, taking wrong readings, or due to an increase in the size of the shell. .

After performing the previous steps, we start the interpretation process, which shows us paths for a group of curves, and the path resulting from the interpretation of these curves shows the expected lithology based on the entered models. In order to infer the validity of the interpretation, a special path is shown to us that shows the error percentage between the values entered in the model and the real values of the measured curves, that is, the difference between the assumed models of the studied lithology and the realistic values of the readings taken in front of the formations, and to correct these errors and reduce the difference to less. To the extent possible, we modify the values entered in the assumed model, not for all values but only for the values related to clay in terms of its density, its porosity, the travel times of sound waves through it, and the value of its radioactivity, as well as correcting the radioactivity for the rest of the types of lithology entered. To be consistent with other digital data, the analogue logs are filtered to get rid of false digitization errors. After the estimation of ($\phi_{avg}$, $S_{wavg}$, $V_{shavg}$, N/G) For all pay zones, the distribution of the possible errors associated with the interpretation parameters is calculated. Using error distributions, Monte Carlo simulation randomizes these parameters and executes multiple simulations through the analysis shown in subsequently, the results of each simulation are gathered and displayed in a distribution. For each parameter in a particular simulation, the shift in this parameter is calculated using a random number generated based on the CPU clock time Once a shift is randomly determined, several characteristics are determined, such as shift type, shift distribution, and shift value (high and low). Sensitivity analysis evaluates the relative importance of each input parameter on the overall results error. Graphically, the tornado plot displays the individual relative importance of each input parameter in the error analysis. To calculate an error for a parameter in Monte Carlo analysis, two runs are executed, one with the parameter set to its low value and the other for its high value, while all other parameters are kept at their default values. The same input parameters utilized in Monte Carlo simulation analysis are handled in sensitivity analysis, and the output can be displayed either graphically or in tables. All petrophysical analysis and calculations are completed using Interactive Petrophysics (IP) V3.5 software.This process continues until the best match between the real curves is obtained. Normalized and resulting curves from the entered models Due to its importance, the tool can determine the type of probe to be calculated from (Gamma Ray-Density-Resistivity), or it can be calculated from two tools together, each with a special resistivity equation. The clay volume was determined in our study from reading the radioactive tool (GR), so it is considered accurate and simpler than the rest of the tools, which need many corrections because they are greatly affected by the conditions of the well and need certain conditions for their applicability, unlike the radioactivity tool.

## II.2 Results

### II.2.1 Qualitative analysis

#### II .2.1.1 Lithology and potential reservoir identification

According to the petrophysical analysis of well logs and the low gamma ray response, neutron, and density crossover, we recognize the main lithology of Hassi Messaoud wells, which consist of two types of lithology: sandstone and shale. Generally, the neutron-density log combination and resistivity logs (ZDEN, CNC, M2R9, M2R3, and M2R1) were used for the identification and characterization of various fluids in the reservoir zone. After well-logged interpretation, eliminate uninterested zones (high gamma ray and low deep resistivity). There are two main permeable interesting zones identified: one situated in the D5 and D4 pay zones with a red colour for well 2 and the other situated in the D5 pay zones with a red colour for wells 1 and 2 (Figs. 2 and 3). These zones were characterized by a low gamma ray response, relatively high porosity, neutron-density crossover, and high resistivity values. The neutron density response shows the dominant reservoir lithology is sandstone. Also, the generated cross-plots indicate that the main lithology is sandstone. Figures II.4 and II.5; Figures II.6 and II.7; and the minerals contained are montmorillonite and chlorites. Figure II.2 and Figure II.3 The reason for categorizing the two sand units as two different potential reservoir zones was based on eliminating thick shale beds between reservoirs and low values of deep resistivity so as to reduce the effects of both increasing shale volume and high water saturation when computing other petrophysical parameters.

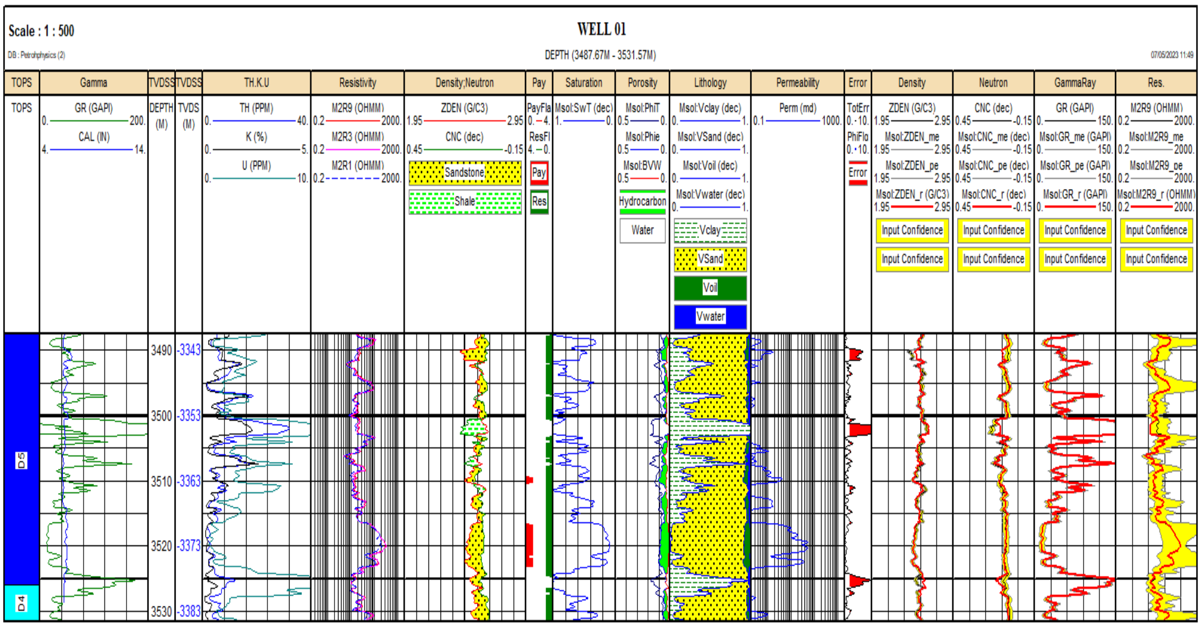


**Figure II.2:** The Composite log response and lithology interpretation of the hydrocarbon-bearing zone (pay zone) in Hassi messaoud well 1.

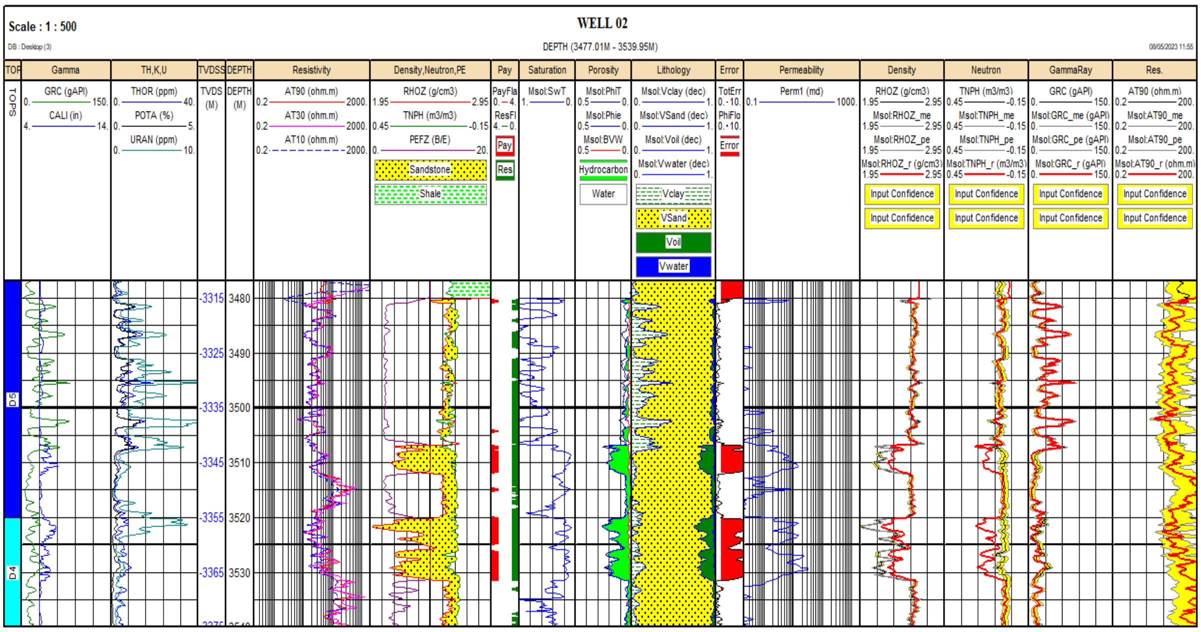


**Figure II.3:** The Composite log response and lithology interpretation of the hydrocarbon-bearing zone (pay zone) in Hassi messaoud well 2.

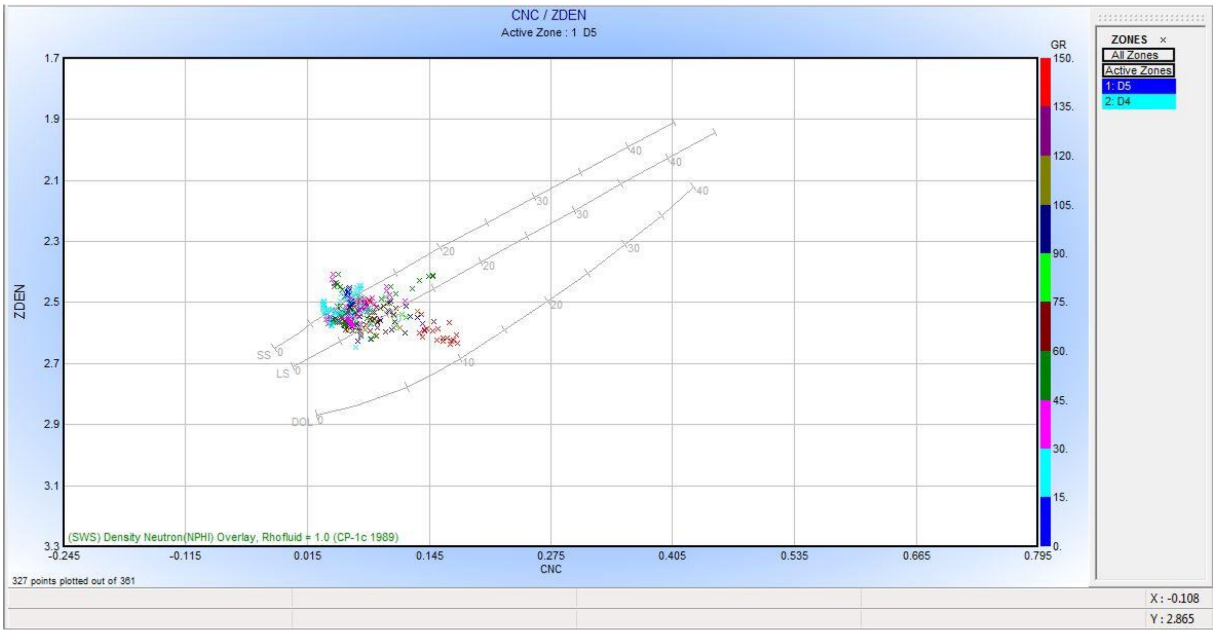


**Figure II.4:** Density-neutron-gamma ray cross-plot of the main reservoir (pay zone) in Hassi Messaoud well 01.

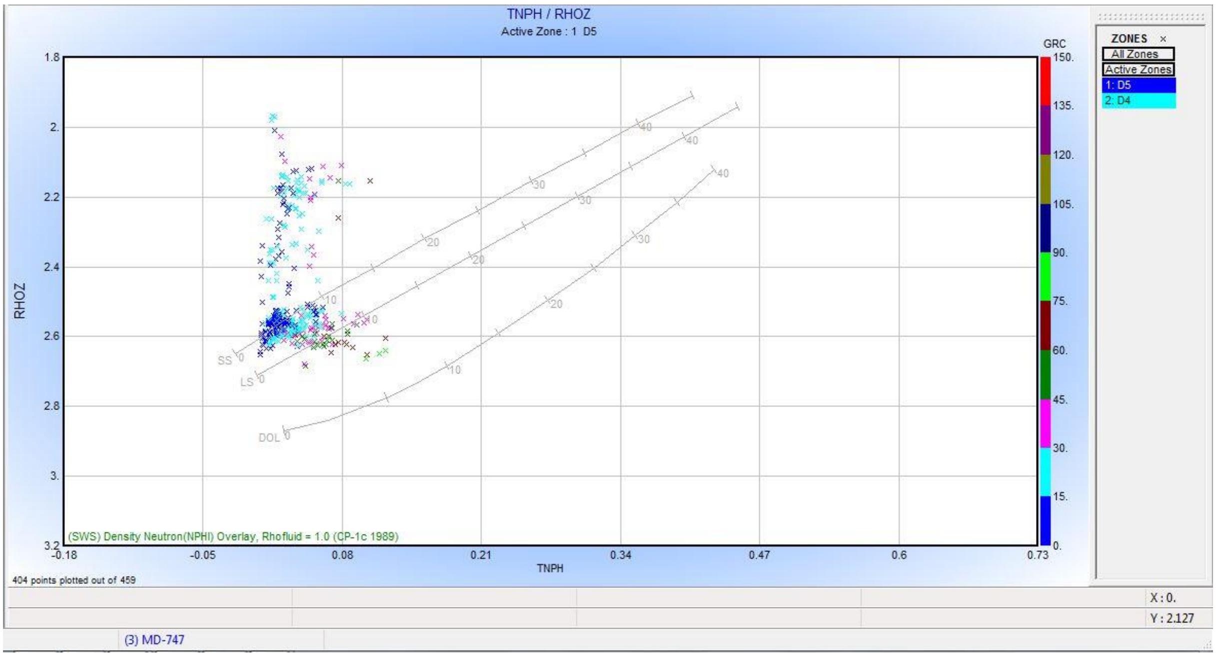


**Figure II.5 :** Density-neutron-gamma ray cross-plot of the main reservoir (pay zone) in Hassi Messaoud well 02.

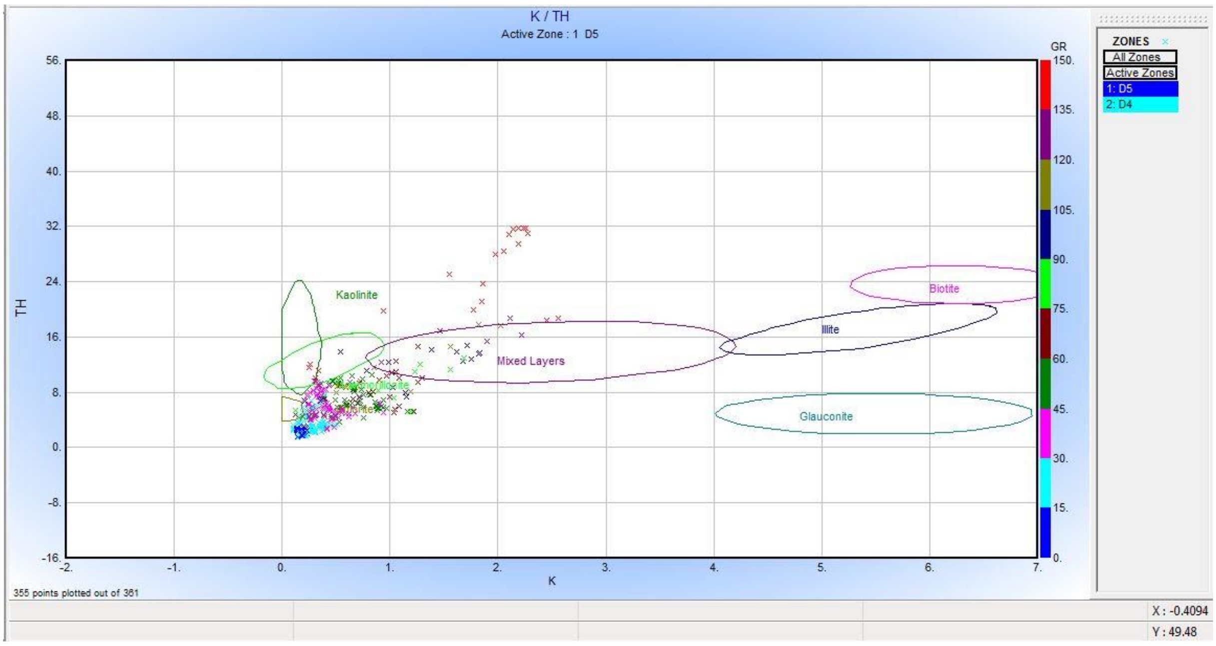


**Figure II.6:** Thorium- potassium -gamma ray cross-plot of the main reservoir (pay zone) in Hassi Messaoud well 01.

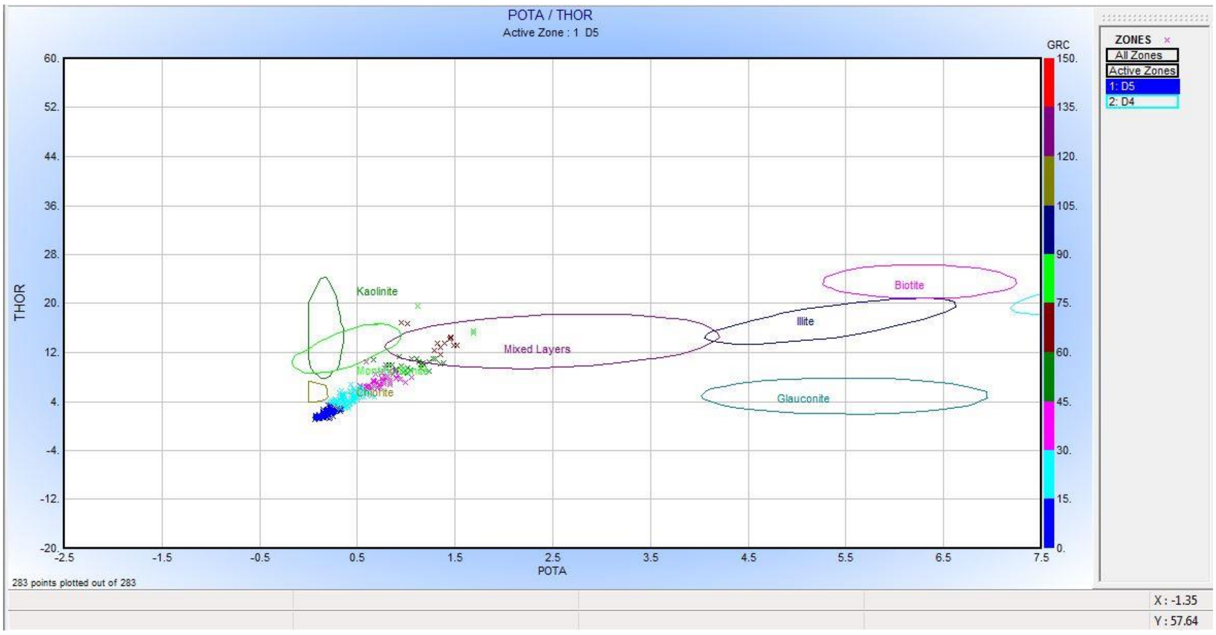


**Figure II.7 :** Thorium- potassium -gamma ray cross-plot of the main reservoir (pay zone) in Hassi Messaoud well 02.

### II.2.2 Quantitative analysis.

The two reservoir zones have been selected across Hassi Messaoud well interpretations and lie at depth intervals from 3369.70 to 3376 m for D5 pay zone well 1 and from 3504 to 3515 m for D5 pay zone well 2 and from 3520 to 3532 m for D4 pay zone well 2, with thicknesses ranging from 43.90 to 43 to 26 m, respectively, Figure I.2 and Figure I.3. The two selected zones were analyzed quantitatively to estimate the values of shale volume, porosity, water saturation, and net pay by using empirical formulas as described in the methodology part. The effective porosity results of the delineated D5 pay zone well 1 and D5 pay zone well 2 reservoir zones range from 9.6 to 16.1 to 17.8%, respectively. The average shale volume estimated from the gamma ray log was found to be 0.050 (v/v), 0.056 (v/v), and 0.069 (v/v) for D5 pay zone well 1 and D4 pay zone well 2, respectively. The calculated value of average water saturation from the arhi equation is 21.3% for D5 pay zone well 1 and 18.1% and 17% for D5 and D4 pay zone well 2, respectively. On the other hand, we used the average water saturation values to estimate the value of hydrocarbon saturation, which is ranged from 78.7% for D5 pay zone well 1 and 81.9% and 83 %for D5 ,D4 pay zone well 2 After applying cutoff in Table 1, the net pay thickness range from 7.1 m for D5 pay zone well1 to 6.04 m to 10.27 m for D5 ,D4 pay zone well 2. All petrophysical parameters estimated for the hydrocarbon-bearing zones and net pay are shown in Table II and Table III and Figure I.2 and FigureI.3.

**Table II:** Summary of sum and averages of computed petrophysical parameters for the identified hydrocarbon-bearing zones.

| Well name | Zone Name | interval (m) | Gross (m) | Net (m) | N/G (v/v ) | effective porosity (v/v) | Avg shale volume (v/v) | Avg $S_W$ (v/v) | Avg perm (md) | perm*h (md) |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **D5** | 3369.70 to 3376 | 43.90 | 37.19 | 0.847 | 0.089 | 0.176 | 0.560 | 1.975 | 73.45 |
| **2** | **D5** | 3504 to 3515 | 43 | 31.64 | 0.736 | 0.087 | 0.141 | 0.509 | 0.686 | 21.69 |
| | **D4** | 3520 to 3532 | 26 | 13.47 | 0.518 | 0.154 | 0.070 | 0.191 | 3.717 | 50.07 |

**Table III:** Summary of averages computed petrophysical parameters for the net pay of two identified hydrocarbon-bearing zones

| Well name | Zone Name | interval (m) | Gross (m) | Net (m) | N/G (v/v ) | effective porosity (v/v) | Avg shale volume (v/v) | Avg $S_W$ (v/v) | Avg perm (md) | perm*h (md) |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **D5** | 3369.70 to 3376 | 43.90 | 7.01 | 0.160 | 0.096 | 0.050 | 0.213 | 9.743 | 68.30 |
| **2** | **D5** | 3504 to 3515 | 43 | 6.04 | 0.140 | 0.161 | 0.056 | 0.181 | 3.040 | 18.35 |
| | **D4** | 3520 to 3532 | 26 | 10.27 | 0.395 | 0.178 | 0.069 | 0.170 | 4.767 | 48.96 |

## II.3 Discussions.

### II.3.1 Petrophysical parameter assessment from qualitative analysis

The well log analysis of Hassi Messaoud wells indicates that the subsurface lithostratigraphy consists of three types of lithology, which are sand and shale interbedding. Based on the interpretation of wireline logs, there are two permeable interesting zones considered as the main potential reservoirs identified and evaluated: one situated in the D5-D4 pay zone for well 02 and the other situated in the D5-D4 pay zone for well 01; neutron-density-gamma-ray and thaurium-potasium-gamma-ray cross-plots strongly show the dominant reservoir lithology is shale to sandstone, and the dominant minerals are montmorillonite and chlorites. The location of the shale formation related to the identified reservoirs could thus be a potential source rock or act as a seal rock.

### II.3.2 Petrophysical parameter assessment from quantitative analysis

The two reservoir zones have been selected across Hassi Messaoud well interpretations and lie at a depth interval of 3369.70 to 3532 m, with the high net to gross value ranging from 0.140 to 0.395. Table 3. The average effective porosity results of the delineated well 01 pay zone and well 02 pay zone of reservoir zones range from 9.6 to 17.8%, respectively, which indicates that the reservoir quality ranges from moderate to good porosity. The average shale volume is 0.050 (v/v) and 0.069 (v/v) for well 01 pay zone and well 02 pay zone, respectively, which reveal the low distribution of low permeable shale content in the reservoir zones. The estimated value of average water saturation is 17% for well 02 D4 pay zone and 21.3% for well 01 D5 pay zone, which indicates that the proportion of void space occupied by water is low in conjunction with high hydrocarbon saturation (83% for well 02 pay zone and 78.7% for well 01 pay zone). The net pay zone thickness ranges from 6.04 to 10.27 m and is characterized by high hydrocarbon saturation, good porosity, and very low shale volume, leading to high hydrocarbon production. Table II and Table I

### II.4 Summary.

Generally, by considering all parameters such as permeable zone identification, reservoir thickness, shale volume, porosity, water saturation, net pay thickness, and hydrocarbon saturation from the log analysis performed in this study, there are two hydrocarbon-bearing reservoirs, named D5 pay zone in well 1 and D5 and D4 pay zone in well 2, with varying thicknesses identified and evaluated. Different cross-plots are constructed (neutron-density-gamma ray cross-plots) to display the reservoir lithology. These cross-plots with well log analysis also reflect that the lithology in the D5 and D5-D4 zones varies in the available wells between shale and sandstone. The hydrocarbon zones were proven by petrophysical analyses that show high porosity, low water saturation, low shale volume, and a high net-to-gross ratio. Based on petrophysical parameters obtained, the two selected reservoir zones have moderate to good porosity due to the low effect of shale distribution, whereas average hydrocarbon saturation ranged from 78.7% for D5 pay zone well 1 to 81.9% and 83% for D5 and D4 pay zone well 2. The study reveals that the hydrocarbon-bearing reservoir has potential for commercial oil production and accumulation, including essential oil. Below and above the oil-bearing reservoirs, there is a thick shale bed, which acts as a potential source rock or as a seal rock.

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