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MASTER DISSERTATION

Submitted by:

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THEME

Determination of Reservoir Permeability Based on Irreducible Water Saturation and Porosity from Log Data and Flow Zone Indicator From Core Data (Hassi Messaoud Region, Hassi Terfa Field)

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بسم الله الرحمان الرحيم

أَلَمۡ نَشۡرَحۡ لَكَ صَدۡرَكَ (1) وَوَضَعۡنَا عَنكَ وِزۡرَكَ (2) ٱلَّذِيٓ
أَنقَضَ ظَهۡرَكَ (3) وَرَفَعۡنَا لَكَ ذِكۡرَكَ (4) فَإِنَّ مَعَ ٱلۡعُسۡرِ
يُسۡرًا (5) إِنَّ مَعَ ٱلۡعُسۡرِ يُسۡرًا (6) فَإِذَا فَرَغۡتَ فَٱنصَبۡ (7)
وَإِلَىٰ رَبِّكَ فَٱرۡغَب(8)

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First and foremost, praise be to God, who gave us the strength and patience to continue working and diligently and reach this blessed day.

We would like to express our deepest gratitude to our educator Dr.Sarra Robie for her help, seriousness and her valuable advice during all the project

Dedicate

It is a day full of joy, happiness and pride this is the day I dedicate my success to my dear parents for their patience and encouragement for us throughout our years of study.

To my family and friends

To my brothers and sisters, each in his name

To the friends with whom I shared my special and hard moments

To all the professor of the university of ouargla.

SOMMARY

Figure list:

Table list:

Acronym list:

φ,Φ= Porosity

Vp= Pore volume

Vt= Total volume

Vs= Solid volume

Sw= Saturation water

V_{pr}= filled pore volume

V_{tv}= Total void volume

K= Permeability (darcy)

Q= Fluid Volume flow (cm^3/s)

μ= Fluid Dynamic Viscosity (cp)

dx= length of porous medium

dp= Pressure gradient (atm)

Rt= Rock Resistivity

Rw= water Resistivity

F= Formation Fracteur

Rxo= Resistivity of the flushed zone close to bore gole

Rmf=Resistivity of the mud filtrate

Sxo=Water saturation in flushed zone

GR= Gamma-ray

Vsh= shale volume

Φ_D= Density Porosity

dma= matrix density

df=formation density

φ_N=Neutron porosity

φ_s=sonic porosity

Δt= Sonic transit time in micro-seconds per foot

Sh=hydrocarbon saturation

φ_e= effective porosity

Swirr= irreducible water saturation

A1= Kozeny constant

S= Surface area per unit bulk volume

d_h=hydrocarbon density

Rtcorr = Corrected Formation resistivity

Rtlog = Well log Formation resistivity

F_s= shape factor

S_{gv}= surface area per unit grain volum(μm^{-1})

FZI= Flow Zone Indicator

RQI= Reservoir Quality Index

φ_z= normalized porosity index

DRT= Discrete Rock Types

x_n = Constant

A=cross-sectional are

General Introduction

Hydrocarbons are widely recognized as the primary and leading worldwide energy source. However, they present substantial challenges during the exploration, exploitation and production procedures. One of the issues is the variation and insufficient accuracy in the techniques used to measure petrophysical parameters, especialy permeability.

Permeability prediction in uncored intervals or wells is an issue that all reservoir geologists tackle. An accurate method of estimating permeability in uncored wells using log data is necessary for generating a realistic reservoir description, since most wells are not cored.

Conventional methods for permeability estimation have been put forward by a number of researchers. Linear regression or empirical assumptions based on correlations among different well log answers were the methodologies used. Although there might be significant variations in depositional properties at different areas, the empirically inferred models are only used locally. Logarithmic permeability and porosity are assumed to have a linear relationship in the regression models. It was also suggested that log porosity is linearly related to core porosity. Both approaches treat data scatter as a result of measurement mistakes and disregard it around the fitted line. In geology and petroleum domain, a hydraulic flow unit (HFU) is a volume of reservoir rock that is both consistently and predictably distinct from other HFUs in terms of the geological and petrophysical characteristics that influence a fluid. When compared to more conventional methods, such as averaged regression, permeability calculations employing HFUs typically provide more accurate estimates.

This project explores one of the techniques of applying well logs and others data (FZI) to the problem of predicting permeability in non-borehole wells, because continuous log measurements such as NMR measure constant properties of formation that may or may not correlate with permeability. We applied this technique in two wells from the Hassi Terfa, which is affiliated with the Hassi Messaoud, the latter being pivotal in Algeria's economy in the oil sector.

The chapter arrangement is as follows:

Chapter 01: General Geology of Hassi Messaoud Field.

Chapter 02: Techniques to Establish Petrophysical characteristics.

Chapter 03: III. FZI FZI-based permeability estimation and nonlinear regression optimization.

Chapter 04: Case of study and findings analysis.

CHAPTER.I.GENERAL GEOLOGY OF HASSI MESSAOUD FIELD

I.1 Presentation of Hassi Messaoud Field:

I.1.1 Geographical location of the Hassi Messaoud:

The geographical location in eastern Algeria, specifically in the Ouargla province. It lies in Algerian Sahara, about 85 kilometers southeast of Ouargla city and about 650 kilometers southeast of Algeria. Figure (01).

The geographical coordinates of Hassi Messaoud are approximately 31.6944°N latitude and 7.9681°E longitude.

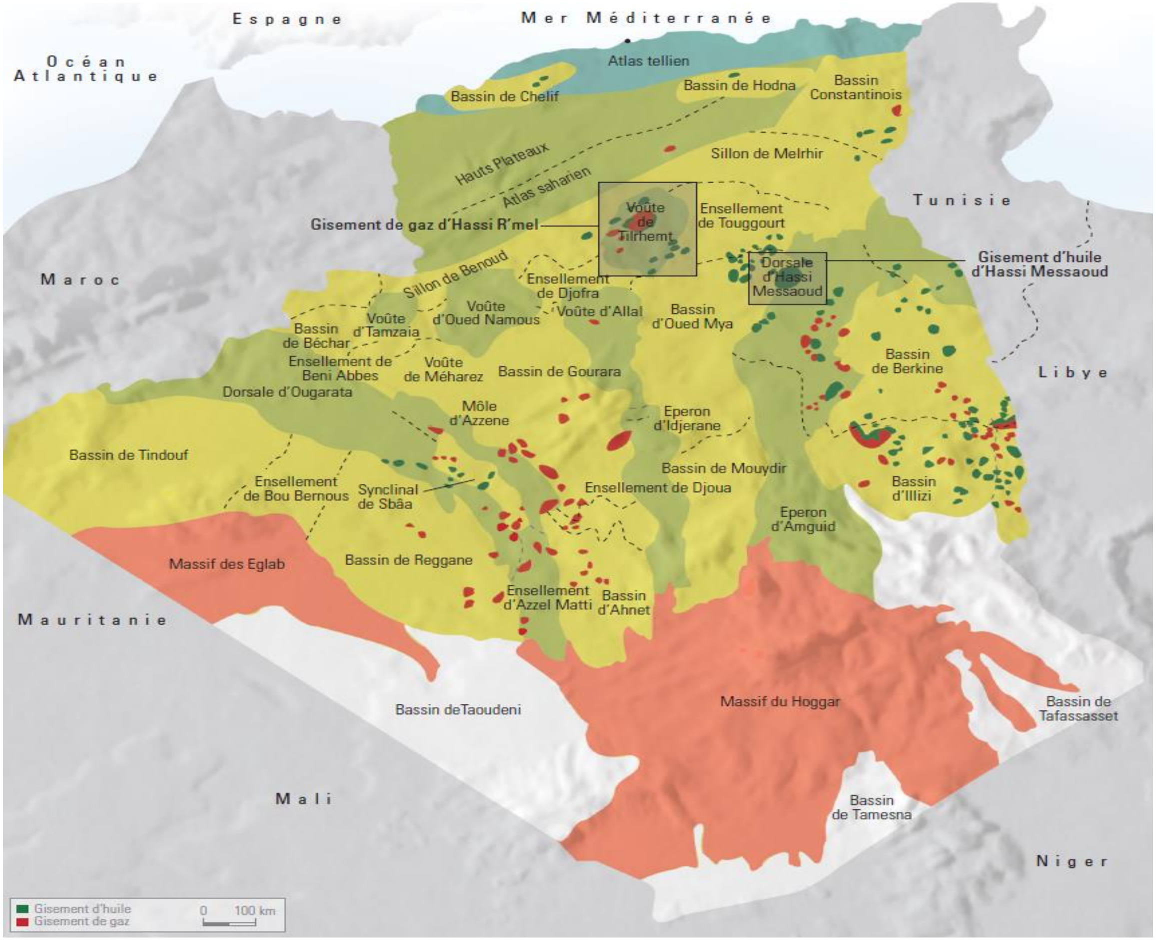


Figure 1. Situation of the Hassi Messaoud region

I.1.2 Geological situation of the Hassi Messaoud:

The limits of the Hassi Messaoud Trap:

To the North-West by the Ouargla traps (Gella, Ben Kahla and Houd Berkaoui).

To the South- West by the traps of El-Gassi, Zotti and El Agreb.

To the East by the Ghadames trap.

Geologically, it is limited:

To the West by the Oued M’ya depression.

To the South by Amguid El Biod mole.

To the North by the Djamaa-Touggourt structure.

To the east by the Dahar lshoals, Rhoude El Baguel and the Ghadames depression.

I.1.3 Tectonic evaluation:

The tectonic evaluation of the Hassi Messaoud basin includes assessing the geological processes that have shaped its formation and structural characteristics. This evaluation typically includes analyzing factors such as the basin’s sedimentary history, structural deformation, faulting, folding, and the influence of regional tectonic events. Additionally, understanding the basin’s tectonic evaluation helps in identifying potential hydrocarbon reservoirs and optimizing exploration and production strategies in the area, Figure (02).

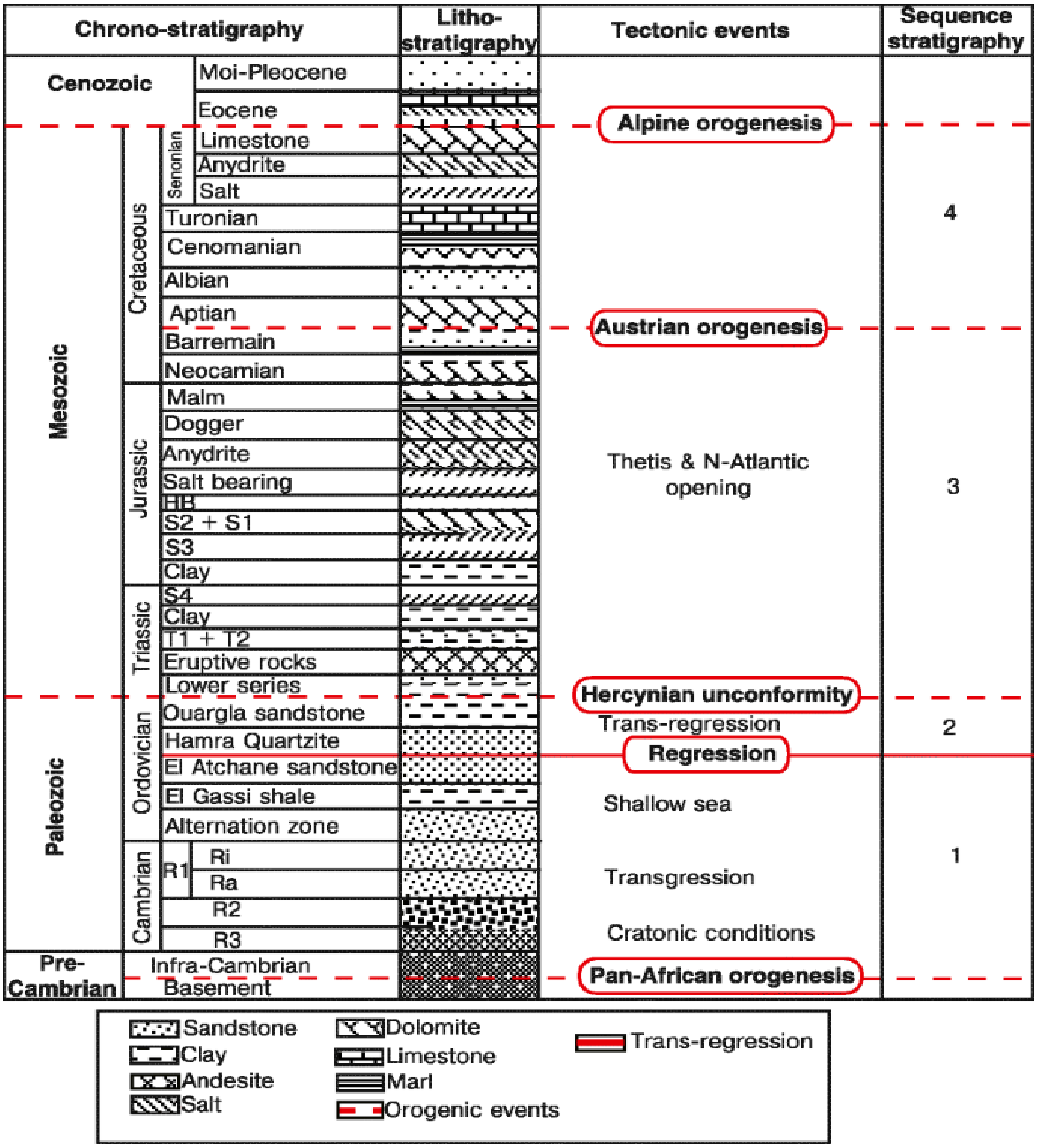


Figure 2.the tectonic phases in the Hassi Messaoud field

I.1.4 Structural Framework of Hassi Messaoud:

The Hassi Messaoud deposit is a very flattened anticline in the Cambro-Ordovician sandstones, placed on a high regional axis of NNE-SSW direction which was marked in the sedimentation until the beginning of the Upper Cretaceous. Figure (03).

The Hassi Messaoud structure corresponds to the northern extension of the Amguid-El Biod mole, it occupies the central part of the Triassic province. It is an elongated anticlinal structure, oriented NE-SW, with a closure to the West against a major fault. It is bordered by major and secondary faults in the same direction. The individualization of this structure was formed during the Paleozoic, with tectonic movements of Jurassic age also having a significant impact on the final structural pattern.

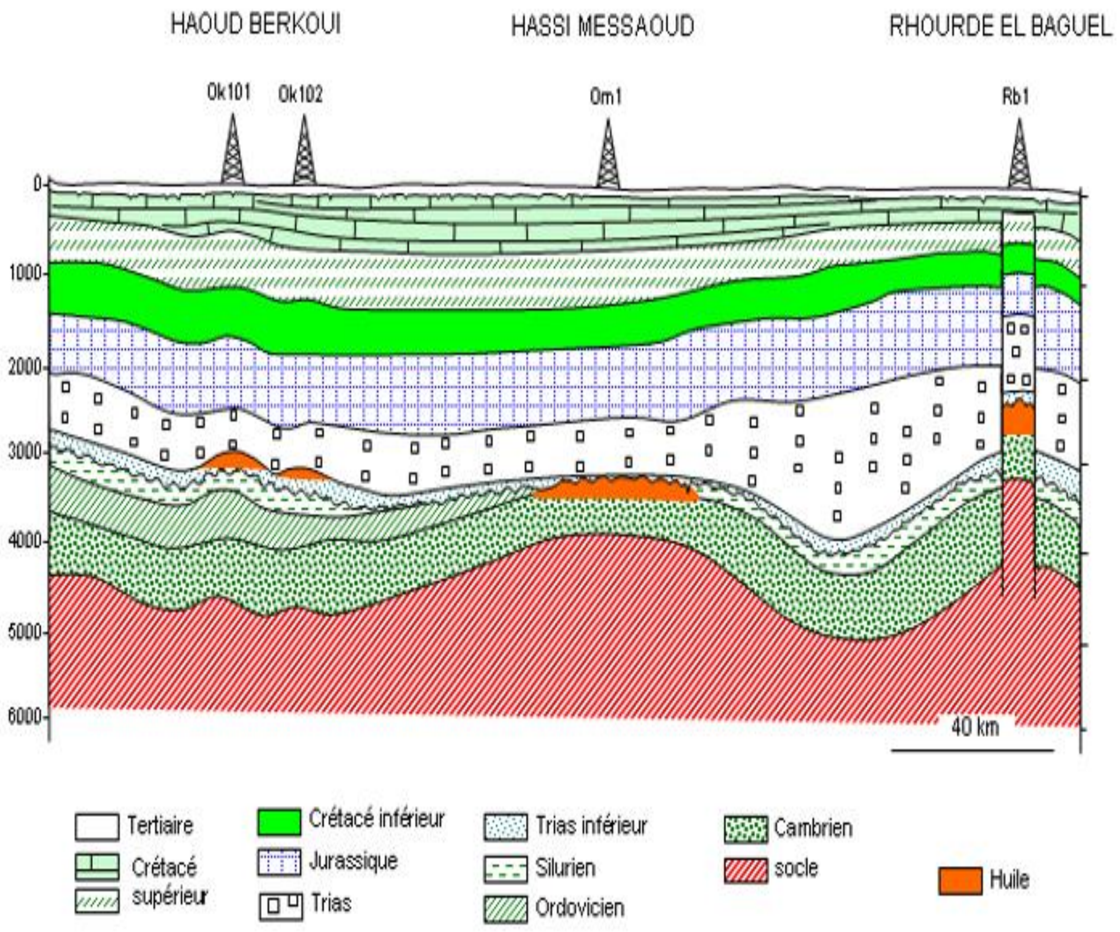


Figure.3. Hassi Messaoud Deposit

I. 2 Presentation of Hassi Terfa Field:

I.2.1 Geographical location of the Hassi Terfa:

The geographical location in eastern Algeria, specifically in the Ouargla province. Approximately 700km southeast of Algiers and 80km east of Ouargla. Is located south of Hassi Messaoud deposit, in the Algerian Triassic provice. Figure (04).

The geographical coordinates of Hassi Terfa: the parallel 31° and 32° North, the meridians 6° and 7°.

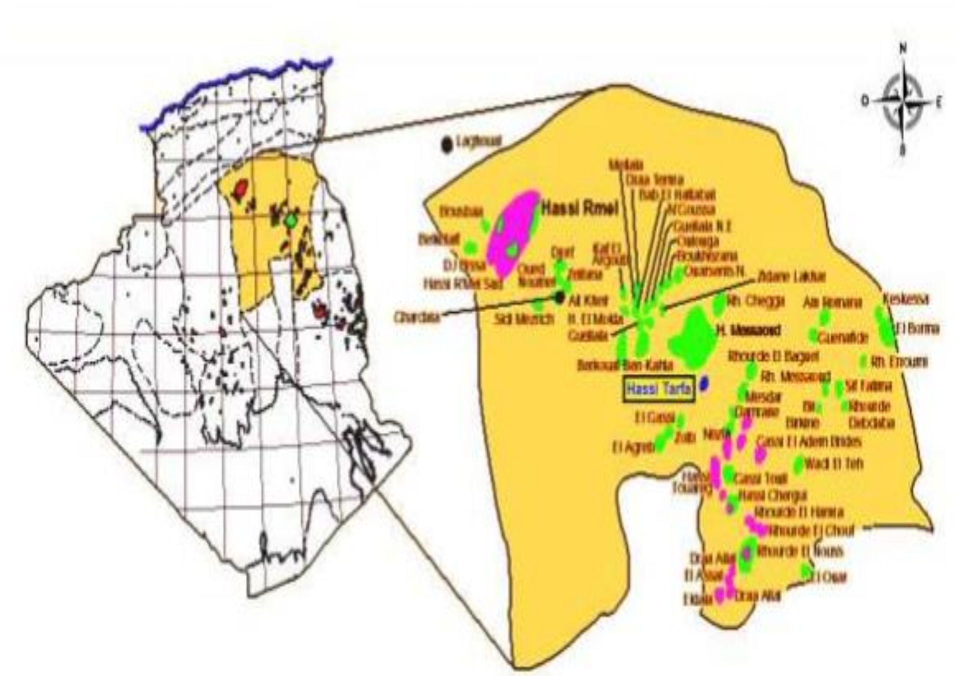


Figure 4 Geographical location of hassi terfa

I.2.2 Geological situation of the Hassi Terfa:

Is limited:

To the North and Northeast by the Hassi Messaoud field.

To the west by the anticlinal structure of Hassi D'zabat.

To the east by the Mesdar field.

To the south by the El Gassi field.

I.2.3 Geological Framework of Hassi Terfa:

The region of Hassi Terfa is located in the northern extension of the positive axis of Amguid El Biod, major tectonic element of submeridian direction, active throughout geological history with a Paleozoic series deeply eroded by the Hercynian unconformity. To the south, this axis extends continuously to the outcrops of the Tassili and the Massif du Hoggar by the Mole of Amguid-El Biod itself.(Sonatrach DP.2018)

I.2.4. The Stratigraphic of Hassi Terfa:

In the context of stratigraphic sequence stratigraphy, the formation of the Hamra Quartzites is associated with a transgressive procession (TST: Transgressive System Track) and locally low level (LST: Low stand Systems Track) for its lower part. (Sonatrach DP.2018).

I.2.5. The lithological of Hassi Terfa:

The lithological column of the region shows a succession of formations ranging from the Paleozoic to the Mesozoic:

-Paleozoic (407m):

Cambrian: sandstone and quartzite.

Ordovician: quartzite(AlHamra)

-Mesozoic (3118m):

Trias

Jurassic

Cretaceous

Cenozoic: low detrital spreading

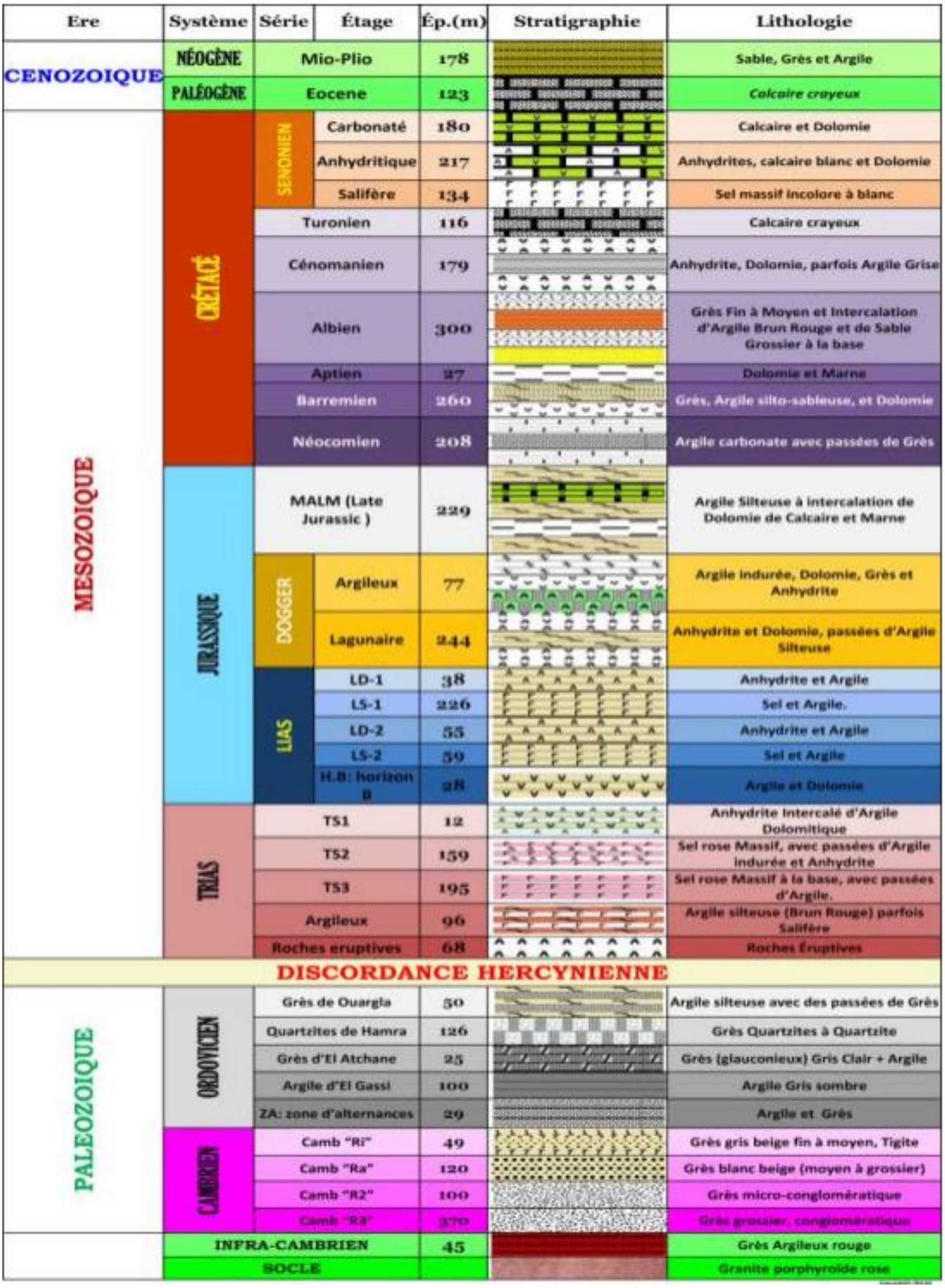


Figure 5 . The lithological column of Hassi Terfa

I.2.6 Petroleum System of Hassi Terfa:

The petroleum system of Hassi Terfa field involves several components including.(Sonatrach DP.2018):

Source Rock: Organic-rich sedimentary rocks in the region, possibly from the Mesozoic era, the Silurian formations, which represent the main source rock.

Reservoir Rock: Porour and permeable rock formation (Alhamra quartzite), likely from the Ordovician era, where hydrocarbons accumulate.

Seal: Impermeable rock layers that cap the reservoir, the shale of El Gassi provide cover for the Cambrian reservoirs and are distributed across the entire Saharan platform. Preventing the upward migration of hydrocarbons.

Trap: Geological structures or stratigraphic conditions that trap hydrocarbons, such as anticlines or faulted structures.

Migration Pathway: Pathways through which hydrocarbons migrate from the source rock to the reservoir rock, often facilitated by faults or permeable zones.

I.2.7.Reservoir Quality:

The average porosity varies between 6% and 9% and the average permeability is generally less than 0,5mD but it can reach higher values in the best drains with an average of 1,5mD. The useful thickness in this field is around 32m. .(Sonatrach DP.2018).

However, the reservoir qualities are variable due to diagenetic effects, the position of these Quartzites in relation to the Hercynian unconformity and also the presence or absence of fractures which significantly increase the permeability values.

I.2.8. The well we studied:

-well Z: The UTM coordinates: X=791 315.977(UTM) Y=3 468979.976(UTM)

Reservoir well (Z)

ALBIEN : depth: 1048m to 1393m ; thick= 345m

LD2 : depth: 2618m to 2675m ; thick= 57m

LD3 (HB) : depth: 2733m to 2761m ; thick= 28m

QH-6 : depth: 3343m to 3384m ; thick= 41m

QH-5 : depth: 3384m to 3404m ; thick= 20m

QH-4 : depth: 3404m to 3417m ; thick= 13m

QH-3 : depth: 3417m to 3425m ; thick= 08m

QH-2 : depth: 3425m to 3434m ; thick= 09m

QH-1 : depth: 3434m to 3450.5m ; thick= 17m

CHAPTER.II.:

Techniques to Establish Petrophysical characteristics

II. 1. Introduction:

Reservoir Petrophysical parameters are essential properties that characterize the rock and fluid properties of subsurface formations in the oil and gas industry. These parameters include porosity, permeability, saturation, and rock compressibility, among others. Understanding these parameters is crucial for reservoir engineers and geoscientists as they determine the feasibility and productivity of hydrocarbon reservoir.

How do we identify these petrophysical parameters, what are the methods of measuring or calculating them, and the drawbacks they encounter?

II. 2. Petrophysical parameters*:*

II. 2.1. Porosity:

In the petroleum domain is a measure of the voids or pores present in a reservoir rock that can contain fluids such as oil or gas. This porosity is crucial as it influences the rick's ability to store and allow the movement of these fluids.

II. 2.1.1. Types of Porosity:

Primary Porosity: Porosity present in a rock due its original formation processes, such as sedimentation or volcanic activity.

Secondary Porosity: Porosity formed after rock's initial formation due to processes like fracturing, dissolution, or mineral replacement.

Effective porosity: The portion of total porosity that contributes to fluid flow and storage.

Table01. Porosity classification

0 to 5%	**Mediocre**
5 to 10%	**Low**
10 to 15%	**average**
15 to 20%	**good**
>20%	**Very good**

II. 2.2. Saturation:

In petroleum refers to the relative quantity of different fluids present in the pores of a reservoir rock. Saturation directly affects the storage capacity and recovery of hydrocarbons from a reservoir.

II. 2.3. Permeability:

Permeability is a property of reservoir rock's that characterizes their ability to allow fluids, such as oil, gas, and water, to flow through their porosity. It is measured in Darcy's (D) and varies depending on the size and geometry of the rock's pores.

II. 2.3.1. Types of permeability:

Specific or absolute permeability: This is the permeability measured with only one fluid present, for example: air permeability, water permeability, oil permeability.

Effective permeability: When a fluid exists within the rock porosity (at a saturation different from the minimum irreducible saturation), the result of measuring permeability using a second fluid is called effective permeability for that fluid.

Relative permeability: It is the ratio of effective permeability to specific permeability. The relative permeability to a given fluid varies directly with the saturation of that fluid in the rock and is expressed as a percentage of displacement of one fluid relative to the other.

Table02. Permeability classification

<1 mD	**Very low**
1 to 10 mD	**Low**
10 to 50 mD	**Mediocre**
50 to 200 mD	**Average**
200 to 500 mD	**Good**
>500mD	**Excellent**

II. 3. Methods for Determining Petrophysical Parameters:

II. 3.1.Core drilling:

The oil drilling cores are cylindrical samples extracted from the subsurface during oil and natural gas exploration or production drilling. Enables the retrieval of these intact cores, which serve as a permanent record of the characteristics of the rock penetrated.

II. 3.1.1 Measurement of petrophysical parameters of core data:

II. 3.1.1.1 Porosity measurement:

- $\varphi = \frac{Vp}{Vt} \times 100 = \frac{(Vt - Vs)}{Vt} \times 100$……………….(01)

- porosimeter: This is an instrument that compresses gas (helium) into a sample and then calculates the pore volume Figure (06). The basic principal is as follows:
  1. Helium gas is introduced into the chamber under controlled pressure.
  2. The change in pressure of the Helium gas is monitored as it expands into the pore spaces of the sample.
  3. Using the know volume of the chamber and the pressure changes, the porosimeter can calculate the total pore volume of the sample.
  4. By dividing the pore volume by the bulk volume of the sample, the porosity (percentage of void space) can be determined.

Figure 6.Porosimeter

II. 3.1.1.2 Saturation measurement:

Sw= $\frac{Vpr}{VTv} \times 100$**…………… (02)**

II. 3.1.1.3 Permeability measurement:

- **Darcy Method K= Q*μ*** $\frac{dx}{dp*A}$**……………(03)**

- Permeameter: Measurement of pressure and volume and deduction of permeability using Darcy's law. Figure (07). . The basic principal is as follows:
  1. A cylindrical core sample is placed in a core holder and sealed.
  2. A confining pressure is applied to the exterior of the sample to simulate in-situ stress conditions.
  3. A fluid, typically gas like air or nitrogen, is injected into one end of the sample at a controlled flow rate.

4. The pressure drop across the length of the sample is measured using pressure taps.
5. Using Darcy's law, which relates flow rate, pressure gradient, fluid viscosity and sample dimensions.

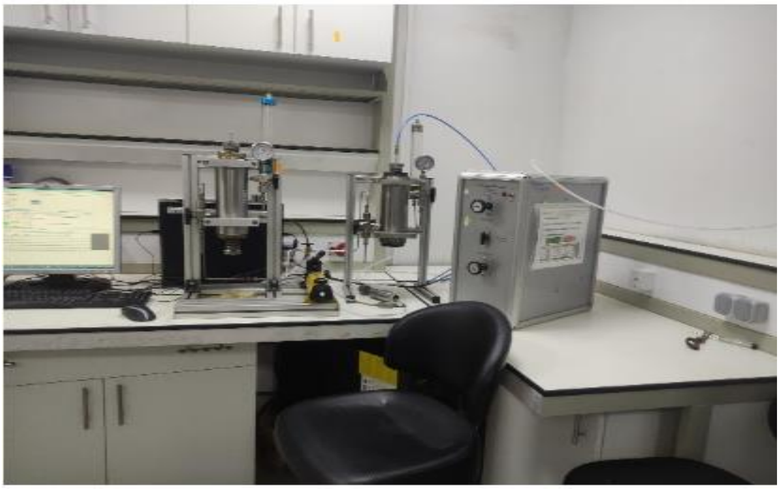


Figure 7. Permeameter

- CMS300: The CMS-300 uses helium as the measurement fluid in normal operating conditions, with automatic switching to nitrogen for low-permeability determination. Figure (08).

Figure 8. CMS300

II. 3.2 Logging:

Logging is a technique used in geology and petrology to measure and record various geophysical parameters in a wellbore, such as electrical resistivity, Gamma ray, density, porosity sonic,... This helps evaluate the properties of the rocks the well passes through.(Dobrin and C.H. Savit)

II. 3.2.1. Logging type:

II. 3.2.1.1 Instantaneous logging: are geological records made in real time during the process of drilling a well. They provide continuous data on geological characteristics, For Example: Mudlogging (MWD), logging while drilling (LWD).

II. 3.2.1.2 Delayed logging: refers to geological recordings conducted after the drilling of a well. Delayed logs can measure resistivity, radioactivity, density, porosity, permeability, formation minerals.

II. 3.2.1.2.1 Electrical logging: Is a technique used in boreholes to measure various electrical properties of subsurface formations, such as Resistivity, Spontaneous Potential**.**

Resistivity Log: that measures the resistivity of formation, which is the ability of a material to resist the flow of electrical current. Resistivity is typically recorded in ohm-meters and is displayed on track 4 of a well log. The resistivity of a formation is influenced by the presence of fluids, such as water or hydrocarbon, and can be used to infer information about porosity, water saturation, and the presence of hydrocarbons.

Archie's Formula:

- Uncontaminated zone : $Rt = F \times \frac{Rw}{Sw^2}$…………(04)
- Flushed zone: $Rxo = F \times \frac{Rmf}{Sxo^2}$………………(05)

F: formation fracture,It varies depending on the nature of the formation:

$F = a \times \varphi^{-m}$**…………….. (06)**

- **Carbonate formation:**
  a=1
  m=2
- **Sandstone formation:**
  a=0.81
  m=2
- **Sandy formation:**
  a=0.62
  m=2.15

II. 3.2.1.2.2 Nuclear Logging: Is a drilling technique that utilizes gamma rays and neutrons to measure the characteristics of the rocks being penetrated. Nuclear logs record the interactions between radiation and materials, allowing for the determination of porosity, density, permeability. From there, we can verify the presence, location, and quantity of hydrocarbons.

II. 3.2.1.2.3 Gamma-ray:

It is a technique that relies on measuring gamma radiation emitted from rocks, as it is affected by the presence of radioactive minerals, especially Uranium, Thorium and Potassium. These radioactive elements are abundant in clay, so we can say that this technique specifically determines for us the proportion of clay in the geological formation.

$$GR= \frac{dv}{db} - A \text{ .... } (07)$$

$$Vsh = \frac{GRx - GRmin}{GRmax - GRmin} \times 100 \text{ .... } (08)$$

II. 3.2.1.2.4. Porosity logs:

Density Logs: The logging tools measure the density of formations penetrated by a drilling well, enabling the estimation of porosity and lithology of reservoir rocks. Based on the bombardment of density (gamma-gamma)

$$\varphi_D = \frac{dma - db}{dma - df} \text{ .... } \mathbf{(09)}$$

- Neutron logs: They mainly measure the hydrogen concentration of formations penetrated by a drilling well, enabling the estimation of their porosity. based on the bombardment of Neutrons.

$$\varphi_N = \sum_{i=0}^{x} ai Ratio^{i} \text{ .... } (10)$$

- Sonic logs: They measure the velocity of acoustic waves propagating through the rocks penetrated by a drilling well.

$$\varphi_s = \frac{\Delta t - \Delta tma}{\Delta tf - \Delta tma} \text{ wyllie time-average................(11)}$$

$$\varphi_s = (1 - \frac{\Delta tma}{\Delta t})/(d_{ma} - d_f) \text{ Ramer-Hunt...........(12)}$$

II.3.2.3. **Measurement of petrophisical parameters of logging data:**

II.3.2.3.1. Water Saturation:

- Uncontaminated zone : $S_w = \sqrt{\frac{F \times Rw}{Rt}}$ **..........(13)**

- Flushed zone: $S_{xo}= \sqrt{\frac{F\times Rmf}{Rxo}}$…………….(14)
- $S_{xo} = S_w^{1/5}$……………..(14)
- $S_h = 1 - S_{xo}$……………(15)

II.3.2.3.2. Porosity measurement:

- Effective porosity (φ_E) estimates:
  $\varphi_E = \varphi_S$…………(16) $\varphi_E = \varphi_D - (\varphi_D - \varphi_N)/3$…………..(17)

II.3.2.3.3.Permeabilty measurement:

- **The law applicable to the Schlumberger Techlog software:**
  $\sqrt{K} = 70\times \varphi^2 \frac{(1-Swirr)}{Swirr}$…………….(18)

II.3.2.4. Disadvantages of both methods:

While methods for determining petrophysical propierties are widely used internationally, they have drawbacks, especially concerning permeability, which is a crucial property. Its absence undermines the significance of the reservoir, even with high porosity and saturation. Core data is note always available and is financially costly. Moreover, logs data drawback is that its results are other not always accurate. Hance, there are other effective methods that combine both to provide an equation through which we can predict permeability in new wells solely using logs data. This approach mitigates the issues with core and data, providing more accurate estimations of permeability.

***II*. 4. Methods for Predicting Permeability through Correlation between Logs Data and Core Data:**

***II*. 4.1. Wyllie-Rose:** This method makes it possible to estimate permeability from an empirical equation linking permeability, porosity and irreducible water saturation.

$$K = C\times \varphi^3/Swirr^2 \text{…………(19)}$$

C: Is a constant to be determined from measurement on core data

***II*.4.2. Kozeny-Carmen:** This first equation measuring permeability property of the rock was proposed by Kozeny and later modified by Varman (Shahab, Balan, & Ameri, 1995).

$$K=A1\times \varphi^{3} / (S^{2} \times(1- \varphi)^{2})\ldots\ldots\ldots\ldots(20)$$

***II*.4.3. Timur:** Based on the limitations to apply Konzen-Carmen (Kennedy, 2015) equation especially in finding specific surface area of the grain,Timur (Timur, 1968) proposed a generalized and simplified equation in the form of:

$$\sqrt{K}=100\times \varphi^{B} / Swirr^{C}\ldots\ldots\ldots\ldots\ldots(21)$$

Timur statistically evaluated the constants A, B and C on laboratory experiments conducted to more than 155samples from different field. He applied a Reduced Major Axis (RMA) method with high correlation coefficient and he obtained the constants as A= 0.136, B=4.4 and C=2. Timur assumed a cementation exponent of 1.95 applies in all field whereas porosity and water saturation are in percentage (Shahab, Balan, & Ameri, 1995).

***II*.4.4. Coates& Dumanoir:** Coates and Dumanoir established an improved permeability equation in an oil bearing formation with oil denity of 0.8 g/cc (Shahab, Balan, & Ameri, 1995). In a correction where hydrocarbon density is not equal to 0.8 g/cc, Coates and Dumanoir proposed a correction equation given as:

$$\frac{Rtcorr}{Rtlog} = 0.077+1.55d_h-0.627d_h^2 \ldots\ldots\ldots\ldots\ldots\ldots \quad (22)$$

With the support of core and log studies Coteates and Dumanoir established a common exponent for saturation and cementation factors as w, whereas m=n=w and therefor a generalized equation for permeability estimation is given as:

$$\sqrt{K}=C\times \varphi^{2w}\times Rti / W^{4}\, Rw\ldots\ldots\ldots\ldots\ldots(23)$$

Where $C=23+465d_h-188d_h^2$……………..(24)

$$\sqrt{K}=\frac{300}{W^4}\frac{\varphi^w}{Swirr^w} \text{ ………………..(25)}$$

II. 5.Conclusion:

Through these equations, the scientist Amaefule (1993) and some modifications were added by the scientist (Fazel Alavi 2014), has managed to achieve a more advanced and accurate technique in understanding the correlations between permeability and porosity when determining the Formation Zone Indicator (FZI) for reservoir rocks. This equation can be directly applied to wells.

C**HAPTER.III.:** FZI-based permeability estimation and nonlinear regression optimisation.

III.1. Introduction:

The FZI (flow zone indicator) method is more accurate than classical methods in predicting permeability, especially in un-cored wells. The permeability estimated by the FZI method shows more realistic values and provides the best correlation coefficient compared to classical methods.

III.2. FZI Method:

FZI techniques refer to methods used to determine the Flow Zone Indicator, a parameter used in reservoir characterization. These technique involve analyzing core into Hydraulic Units based on specific FZI values. The FZI is crucial for establishing accurate correlation between permeability and porosity in the reservoir rock. Typically, FZI is determined from core data in cored wells and then extrapolated to wells without cores through correlations with log attributes. However, it's important to note that existing correlation methods may not always provide precise permeability values for wells lacking core data.

The FZI method is based on the Kozeny-Carman (1927; 1937) general relation given in Eq.1, where permeability is in md:

$$K=1014\frac{\varphi e^3}{(1-\varphi e)^2}[1/F_s\tau^2S_{gv}^2]\ldots\ldots\ldots\ldots\ldots(26)$$

Determining permeability with this equation have not been successful (Amaefule et al. 1993) because the shape factor (**Fs**), tortuosity (**τ**) and surface area per grain volume (**S_{gv}**) are not typically known, as they are not constant within a reservoir and cannot be measured easily. However, Amaelfule et al. designated the square root of the term **$1/F_s\tau^2S_{gv}^2$** in the Kozeny-Carman equation as the "Flow Zone Indicator" FZI (**µm**) and showed that this indicator could be calculated from core permeability and porosity according to Eq. 2:

$$FZI = \frac{RQI}{\varphi z}\ldots\ldots\ldots\ldots\ldots(27)$$

Where RQI is Reservoir Quality Index and φz is the pore volume to grain volume ratio, obtained using Eq.3 and Eq.4 respectively. Note that permeability in Eq.3 is in md.

$$RQI= 0.0314\sqrt{\frac{K}{\varphi e}}\text{.................}(28)$$

$$\varphi_z=\left(\frac{\varphi e}{1-\varphi e}\right)\text{...................}(29)$$

Substituting the term $1/F_s\tau^2S_{gv}$ in the Kozeny-Carman formula with FZI^2 (Eq.5):

$$K=1014\ FZI^2\ \frac{\varphi e^3}{(1-\varphi e)^2}\text{................}(30)$$

This equation can calculate permeability in wells accurately when FZI of the formation versus depth is known. FZI in cored wells can be obtained through Eq.2, but FZI in wells without cores must be found by correlating or identifying the litho-facies in all of the wells and assigning a FZI for each facies (Shenawi et al.2007). To facilitate the determination of FZI in un-cored wells, core data are usually grouped into several Hydraulic Units (HU) or Discrete Rock Types (DRTs) using Eq.6 (Guo et al.2005):

$$DRT= Round(2\ln(FZI)+10.6)\text{..............}(31)$$

When RQI is plotted against φz on a log-log scale, the data from each DRT forms a straight line with a unit slope. The average FZI, or FZI constant of each DRT can be determined from the unit-slope straight line at φz=1. To find a correlation between permeability and porosity for each DRT, the log of permeability is plotted versus porosity, and a power trendline is fitted through the data points. A power relation of the general form shown in Eq.7 can be obtained from this trendline:

$$K=C_n\varphi^{x_n}\text{................}(32)$$

Eq.7 is a simplified form of Eq.5 where the constant C_n is almost proportional to the average FZI of the DRT to the second power and φ^{x_n} replaces the term $\left(\frac{\varphi e^3}{(1-\varphi e)^2}\right)$. The exponent x_n normally varies between 3.1 to 3.9 depending on the porosity range of DRT data and statistical error in the data. Eq.7 can be used to calculate permeability accurately at any depth of a well if the DRT at that depth is known. One of the main challenges for engineers, however, is the determination of DRT in wells without core data. (Fazel Alavi., 2014).

An oil reservoir is normally developed with tens or hundreds of wells. Only a few of these wells are cored, while log data is typically available in all wells for determination of porosity and water saturation. Several methods have been proposed to find FZI or DRT in wells without core data. Often, the DRT or FZI values from the core data of a cored well are related to well log attributes of other wells with regression models, neural networks and empirical correlation are obtained (kharrat et al.2009, Guo et al. 2005; Balan et al. 1995). Therefore, DRT or FZI can be predicted in other wells based on correlations between DRT and log attributes.

Experience has shown that main deficiency of the FZI method is the lack of a proper method for finding FZI in the wells without cores. The above methods do not always result in reliable permeability estimates from log attributes, and cannot typically calculate actual changes in permeability with depth. There are fundamental reasons for the inaccuracy of correlations between log attributes and FZI from core data. The lack of a proper relationship between FZI and log data been elaborated by other authors.(Svirsky et al.2004)

A new technique is proposed to calculate permeability (Fazel Alavi 2014) designated as the FZI-SWPHI (Flow Zone Indicator-irreducible Water Saturation porosity) method. It is based on a relationship between FZI and ($1/S_{wir}\varphi e$). FZI in Eq.5 is replaced by this relationship, which results in an equation relating permeability directly to effective porosity and irreducible water saturation. Since the effective porosity and irreducible water saturation are known in wells with log data, the determination of permeability is much more straightforward and provides for a more precise reservoir description. Additionally, the vertical resolution of calculated permeability provides another advantage. (Fazel Alavi., 2014).

Statement of problem: FZI is inversely proportional to the surface area per grain volume, tortuosity and square root of the shape factor. Normally FZI or DRT is correlated with neutron porosity, bulk density, sonic transient time, standard GR, computed GR, and resistivity logs. However, there is no theoretical relationship between the responses of most of these logs with the identified parameters. Additionally, FZI from a core sample represents the flow characteristics of the formation for a very small volume of reservoir rock (about 1 cubic inch), while log data at the same depth represents an average value of the physical properties of a larger volume of the rock. This volume can range from hundreds of cubic inches to several cubic meters, depending on the resolution and depth of investigation for the specific logging tool. Log attributes may or may not correspond to a core sample at the same depth depending on the vertical and lateral heterogeneity in the reservoir. FZI calculated from core data may fluctuate significantly at a certain depth. While porosity logs and resistivity logs often do not exhibit dramatic changes in properties with depth. Inaccurate depth matching of core and log data may also complicate correlations. (Fazel Alavi., 2014).

Log data from the saame intervals provides effective porosity and irreducible water saturation. FZI from core is correlated statistically to ($1/Sw_{irr}\varphi_e$). It is observed that an empirical correlation as given by Eq.9 exists between FZI and ($1/Sw_{irr}\varphi_e$). (Fazel Alavi., 2014).

$$\mathbf{FZI} = \frac{a}{\text{Swirr}\varphi\text{e}} + b \text{..................(33)}$$

$$\mathbf{K} = 1014\left[\frac{a}{\text{Swirr}\varphi\text{e}} + b\right]^2 \frac{\varphi e^3}{(1-\varphi e)^2} \text{............(34)}$$

III.3. Optimisation by non-linear regression:

Non-linear regression optimization is a mathematical method for finding the best non-linear function that fits a set of dataset.

III.3.1. Involves:

1. Selecting an appropriate non-linear model, such as an exponential or power finction, to represent the relationship between variables.
2. Adjusting the parameters of the no linear model to the data by minimizing the sum of the squares of the differnces between the model's predicted values and the observed values.
3. Using optimization algorithms like Levenberg-Marquardt, Gauss-Newton, or trust-region methods to find the optimal values of the model's parameters.
4. Evaluating the quality of the model fit to the data by calculating metrics such as the coefficient of determination R^2.

Non-linear regression optimization is widely used in engineering to model and optimize complex systems. It helps identify key system parameters to adjust to achieve desired performance.

Its main advantages include its ability to represent complex non-linear relationships with few parameters and provide accurate predictions about system behavior.

We used this method to optimize variables a1, a2, a3 and b

III.4. SPSS Software:

SPSS (Statistical Package for the Social Sciences) is statistical analysis software widely used in many fields such social sciences, health, economics and in some scientific fields, such as geology, in some of its specializations.

III.4.1. Features of SPSS Software:

Here are the main features of SPSS:

1. It allows you to manage and analyzed data efficiently, even on large data bases. SPSS provides many features for organizing, summarizing, and statistically analyzing data.
2. SPSS user-friendly graphical interface relies on drop-down menus and dialog boxes, making it easy to use even for beginners. However, it is also possible to program analyzes using a command language.
3. SPSS can read and write data in various formats like text files, spreadsheets, databases, etc. It allows basic descriptive and inferential analyzes to be carried out.

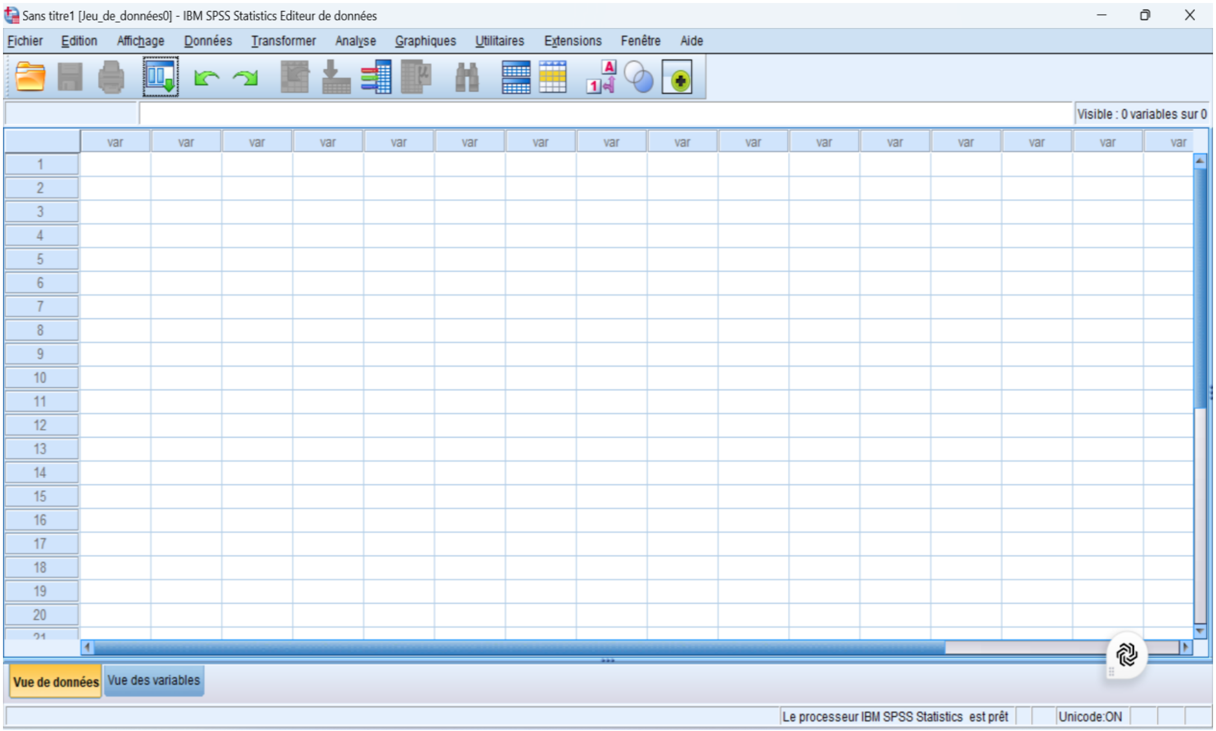


Figure 9. SPSS Interface

III.4.3.Use it in studies:

1. We found Percentile through it Figure 10:

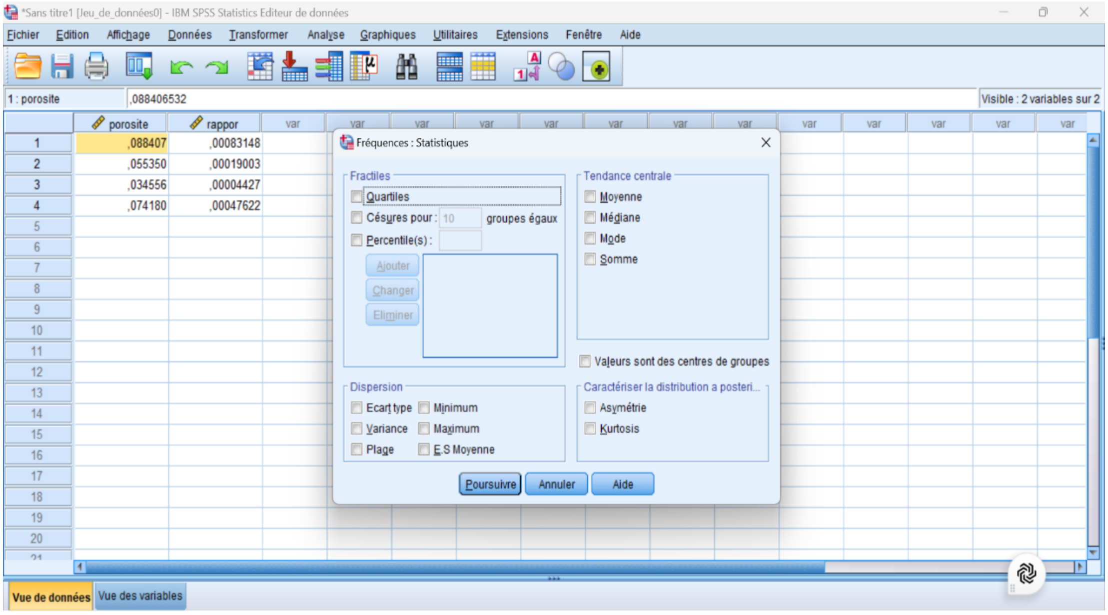


Figure 10. Statistical frequency percentile

2. We performed regression and correlation analysis, experimenting with all available models. Additionally, we utilized non-linear regression optimization within the same software (SPSS). Figure 11:

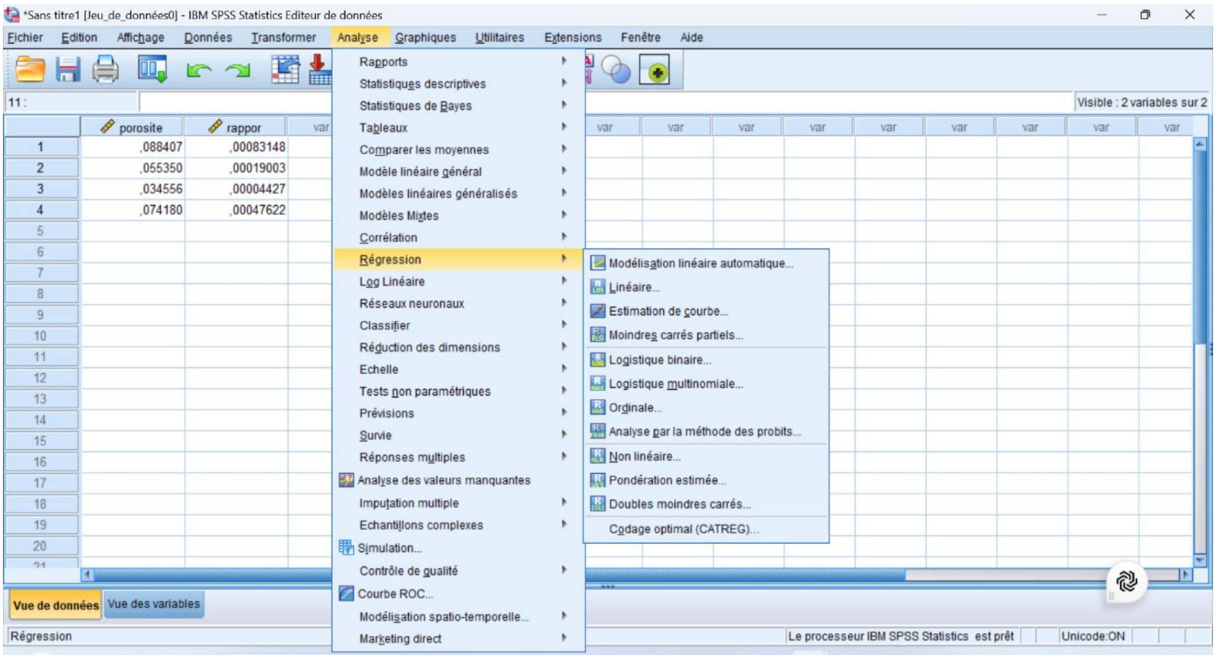


Figure 11 Regression analysis

III.5. Conclusion:

The application of the method is open to modifications and improvements according to the nature of the geological formation of the studied reservoir, as demonstrated by the scientist Fazel alavi in his work on the carbonate reservoir and his proposal of the proportionality concept.

CHAPTER.IV.: Case of study and findings analysis

IV.1. Introduction:

We applied this technique (FZI) in our project with modification to the law to align with the reservoir's nature, as this technique was only applied in a carbonate reservoir and was not implemented in a detritus reservoir.

IV.2. Procedure of FZI-SWPHI Method:

To find specific permeability function of the form of (Eq.34modified 36) for a reservoir or a geological zone, the following methodology is proposed (Fazel Alavi., 2014):

- Select a key well that has both good routine core and log data and log analysis results.
- Ensure that the well interval for analysis is above the transition zone of the reservoir to ensure that reservoir water saturation is close to irreducible water saturation.
- Match the depth of core data with depth of logs;
- Review the core permeability and core samples description, and remove samples with fractures and fissures from the analysis. As the FZI method evaluates matrix permeability, only matrix permeability data should be used.
- Calculate FZI of the core samples.
- Calculate ($1/S_{wirr}\varphi_e$) from the log derived effective porosity and irreducible water saturation values for the cored interval.
- Determine the 10^{th}, 20^{th},……90^{th} percentiles of the($1/S_{wirr}\varphi_e$) population.
- Determine the 10^{th}, 20^{th},……90^{th} percentiles of theFZI population.
- Plot the calculated percentiles of FZI population versus the calculated percentiles of the ($1/S_{wirr}\varphi_e$) population and fit a cubic trendline to find the constants a, a2, a3, b.

If there is good correlation and the R^2coefficient of determination for the trend line is close to unity, a single permeability equation can be used to describe the entire interval or reservoir. Otherwise, zones with similar geological setting should be detected and separately analyzed as follows:

- Calculate the average ($1/S_{wirr}\varphi_e$) from log in the cored interval.
- Find the ratio (R) of the average FZI to the average of ($1/S_{wirr}\varphi_e$).

- Plot FZI from the core and ($1/S_{wirr}\varphi_e$) multiplied by the ratio R versus depth on the same plot
- Determine geological zones with similar sedimentary and diagenesis environments from this plot. Other geological information such as rock description and log data like GR could also be used.
- Select the intervals where FZI data points are parallel and linear Interpolation with $R/S_{wirr}\varphi_e$ curve and the separation between the two is equal while also reling on Gamma ray. Each of these intervals where will have a separate correlation.
- Find the new correlation between FZI and ($1/S_{wirr}\varphi_e$) for each interval defined above.
- Calculate the permeability for all intervals in the key well from Eq.11 using the derived correlations.
- Taper calculated permeability at the interface of the two consecutive zones.
- Compare the core permeability with the predicted permeability in the key well. If a satisfactory match is not obtained, the geological intervals are likely not properly delineated.
- Find equivalent geological intervals in other wells by correlating the well logs of the key well with other wells.
- Calculated the permeability of other wells using equations derived from the key well.

IV.2.1. Analysis and Determination of lithology by round and the relationship between permeability and porosity in each facies:

Using equation number (31), we were able to infer the existence of seven (7) types of rocks, Each with specific porosity and permeability. We established the relationship between the porosity and permeability of each rock, as illustrated in figure (12).

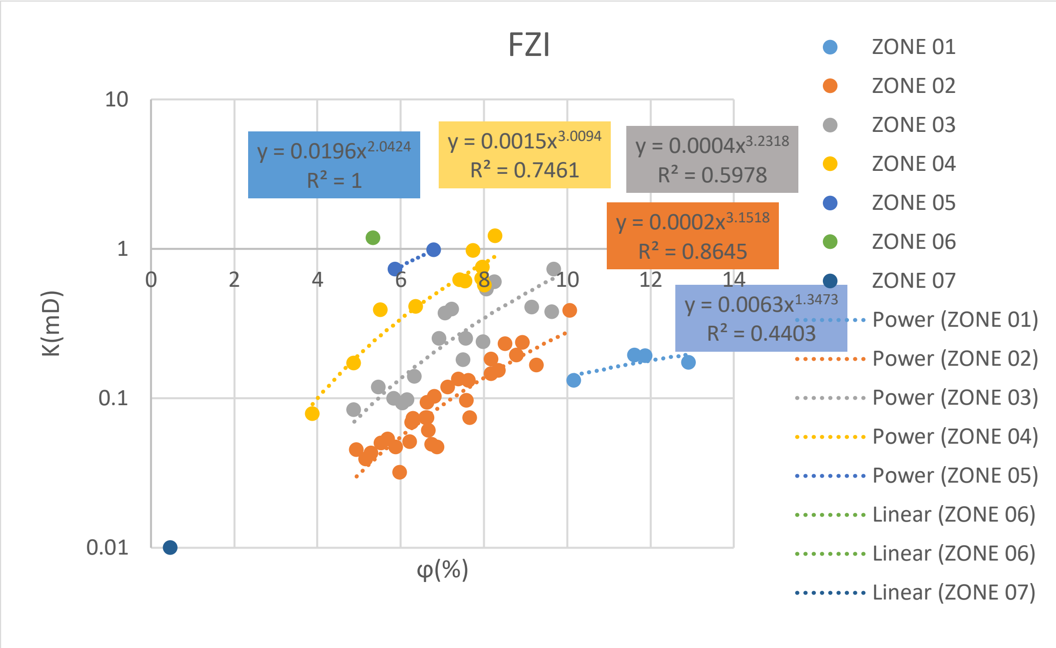


Figure12. Permeability versus porosity in well Z

By plotting the log-log RQI- graph, it was possible to obtain the constant for each DRT by intersecting the straight line with a unit gradient, as illustrated in figure (13).

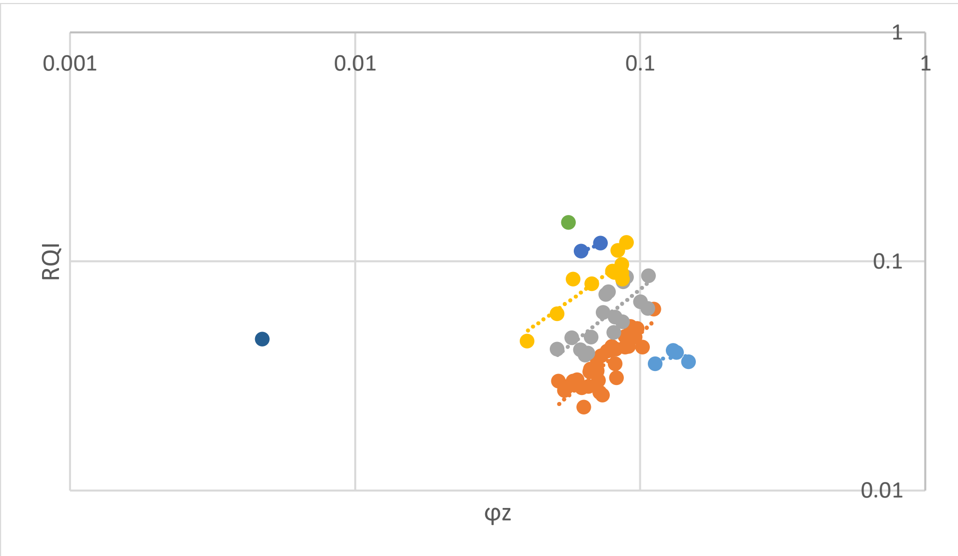


Figure13. RQI versus porosity index

IV.2.2. Modeling of FZI equations:

Upon conducting correlation and regression analysis using SPSS software, we determined that the cubic model exhibited the highest level of accuracy compared to other models. Consequently, it became necessary to modify the model presented by Fazel Lavi in Equation 33. This also implies an alteration in the permeability equation 34.

$$\mathbf{FZI}=\boldsymbol{a}\left[\frac{1}{\mathrm{Swirr\varphi e}}\right]^{1}+\boldsymbol{a}\left[\frac{1}{\mathrm{Swirr\varphi e}}\right]^{2}+\boldsymbol{a}\left[\frac{1}{\mathrm{Swirr\varphi e}}\right]^{3}+\boldsymbol{b}\ldots\ldots\ldots\ldots\ldots(35)$$

$$\mathbf{K}=1014\left[\boldsymbol{a}\left[\frac{1}{\mathrm{Swirr\varphi e}}\right]^{1}+\boldsymbol{a}\left[\frac{1}{\mathrm{Swirr\varphi e}}\right]^{2}+\boldsymbol{a}\left[\frac{1}{\mathrm{Swirr\varphi e}}\right]^{3}+\boldsymbol{b}\right]^{2}\frac{\varphi e^{3}}{(1-\varphi e)^{2}}\ldots\ldots\ldots(36)$$

Table03. Degree of correlation in each model in the cubic equation.

	R^2ZONE01	R^2ZONE02	R^2ZONE03	R^2ZONE04	R^2ZONE05	R^2ZONE06	R^2 percentile entier zone
Linear	67,9	78,2	75,5	42,6	100,0	38,2	97,5
Logarithm	61,8	81,8	76,1	37,3	100,0	29,1	83,6
Inveres	54,4	85,7	76,7	33,8	100,0	20,5	57,9
Quadratiq	79,6	99,7	75,5	98,0	100,0	100,0	98,2
Cubic	80,1	99,7	100,0	98,0	100,0	100,0	99,0
Compose	63,8	63,8	72,4	48,5	100,0	47,1	97,5
puissance	58,0	68,0	73,1	43,1	100,0	37,6	92,9
S	51,0	73,0	73,7	39,6	100,0	28,2	72,3
croissance	63,8	63,8	72,4	48,5	100,0	47,1	97,5
Expo	63,8	63,8	72,4	48,5	100,0	47,1	97,5
Logistic	63,8	63,8	72,4	48,5	100,0	47,1	97,5

Table.04.The coefficient values for the equation

	B	a 1	a 2	a 3
ZONE01	,548	,000	-7,961E-5	1,046E-6
ZONE02	-3,190	,107	,000	-9,586E-6
ZONE03	10,045	-,262	,000	2,836E-5
ZONE04	1,086	-,029	,000	4,770E-6
ZONE05	3,208	-,072	,000	,000
ZONE06	-1,645	,069	,000	-4,031E-6
percentile entier zone	,428	-,006	,000	-9,829E-7

Application example for zone01:

$$\mathbf{FZI}=0{,}000\left[\frac{\mathbf{1}}{\mathbf{Swirr\varphi e}}\right]^{\mathbf{1}}-7{,}961\mathrm{E}-5\left[\frac{\mathbf{1}}{\mathbf{Swirr\varphi e}}\right]^{\mathbf{2}}+1{,}046\mathrm{E}-6\left[\frac{\mathbf{1}}{\mathbf{Swirr\varphi e}}\right]^{\mathbf{3}}+\boldsymbol{b}$$

IV.2.3. 0ptemimisation of the results by regression non-linear and interpretation:

We applied the non-linear regression optimization technique using SPSS Software, as demonstrated in.

Table.05. Permeability results before and after optimization

	Depth(m)	AvKcalcu	AvKmesur	Error%	AvKcaop	AvKme	Error%
ZONE01	3354,65 TO 3360,53	0,05482	0,0686	-20,056	0,069238	0,0686	0,971589
ZONE02	3361,85 TO 3364,46	0,051	0,066	-23,16034	0,0634	0,066	-3,96637

ZONE03	3365,41 TO 3377,42	0,18102	0,09773	46,012242	0,082065	0,09773	-16,0266
ZONE04	3379,8 TO 3391,87	0,2982	0,316917	-5,9136	0,26839	0,316917	-15,31231
ZONE05	3395,82 TO 3403,09	0,250331	0,4176	-40,0549	0,27267	0,4176	-34,706
ZONE06	3406,21 TO 3423,66	0,32344	0,4895	-33,925	0,343708	0,4895	-29,784

Table.06.The coefficient values after optimization

	b	a 1	a 2	a 3
ZONE01	0,516	,000	-0,00006085	0,000001461
ZONE02	-1,109	0,048	,000	-0,00000406
ZONE03	0,635	-0,005	,000	0,0000003341
ZONE04	1,299	-0,003	,000	0,000000003382
ZONE05	0,951	-0,01	,000	,000
ZONE06	-1,574	0,076	,000	-0,000004301

We have noticed a substantial enhancement in the predicted mean permeability values, accompanied by significantly reduced error margins in comparison to the initial data.

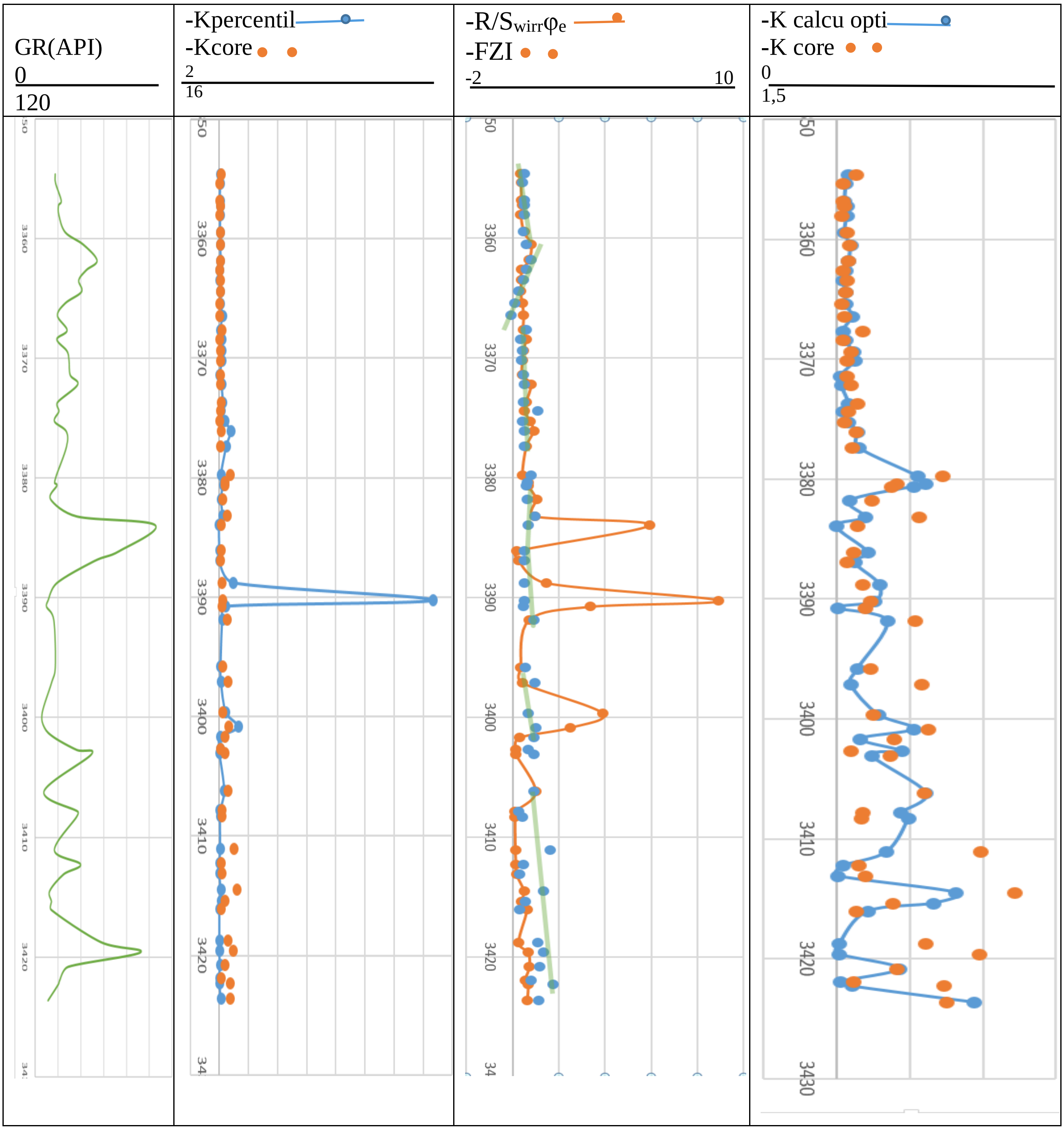
The lack of perfect parallelism or alignment between the R/Swirrφe and FZI, as shown in Plot final, and the presence of dispersed values that impacted the calculated permeability and the average permeability in each zone, including extremely anomalous values, led us to utilise the non-linear regression optimisation technique using SPSS software, as presented in table 06.

IV.2.4.Interpretation the results of comparison between the permeability estimated using the conventional method in permeability estimation from the logging performed Schlumberger and the results of our utilization of the FZI method:

Due the irrational disparity between the permeability values estimated in the logging and the actual permeability in the core, it is not at all reliable to depend on them in this reservoir.Table.07

Table.07.Comaprison results

	AvKcaopt	AvKmesu	Error%	Avklogging	AvKmesu	Error%
ZONE01	0,069238	0,0686	0,971589	0,1750691	0,0686	155,309105
ZONE02	0,0634	0,066	-3,96637	0,00714511	0,066	-89,174072
ZONE03	0,082065	0,09773	-16,0266	0,16481753	0,09773	68,6505005
ZONE04	0,26839	0,316917	-15,31231	0,23571741	0,316917	-25,621642
ZONE05	0,27267	0,4176	-34,706	0,29504162	0,4176	-29,34827
ZONE06	0,343708	0,4895	-29,784	0,22975166	0,4895	-53,064012



Fifure14. Final result plot

IV.3. Conclusion:

We find that the FZI method has proven its effectiveness even in heterogeneous reservoir like the one we studied (well Z), as it has provided better accuracy compared to other traditional methods.

General Conclusion

Based on the principle of the importance of petrophysical properties, with a focus on permeability as a key property, It is crucial for the measurement results to have the least possible margin of error, as inaccuracies can lead to biases in estimating and extracting hydrocarbons, By comparing the results of permeability measurement using logging with those using the core, we observed significant errors and inconsistencies in the logging results, prompting us to explore a more accurate method for permeability measurement, namely FZI. This method was applied in the Hassi Terfa field, where the results showed a significant improvement compared to the previous permeability (logging) after the optimization process. We concluded that, as mentioned earlier, logging records were illogical. Additionally, when encountering heterogeneous wells with illogical logging records, immediate optimization and subsequent permeability calculation are conducted.

Reference and Bibliographic:

.

Schlumberger r, 2018. Wellog interpretation.

Sonatrach DP, 2018. General information about the hammra Quartzite reservoir.

Dobrin & C.H.Savit, 1995. Introduction to Geophysical Prospecting.

Fazel Alavi, 2014. Determination of reservoir Permeability Based on Irreducible Water Saturation and porosity from Log Data and Flow Zone Indicator (FZI) from Core Data.

Amaefule, J.O., Altunbay, M., Tiab, D. et al. 1993. Enhanced Reservoir Description: Using Core and Log Data to Identify Hydraulic

(Flow) Units and Predict Permeability in Uncored Interval/Wells. paper SPE 26436 presented at the SPE Annual Technical Conference

and Exhibition in Houston, Texas, 3-6 October.

Balan, B., Mohaghegh, S., and Ameri, S. 1995. State-Of-The-Art in Permeability Determination From Well Log Data: Part 2-

Verifiable, Accurate Permeability Predictions, the Touch-Stone of All Models. paper SPE 30979 presented at the SPE Eastern Regional

Conference and Exhibition held in Morgantown, West Virginia, 17-21 September.

Carman, P.C. 1938. Fluid Flow Through Granular Beds. J Soc Chem Ind. 57, 225.

Coats, G.R. and Dumanoir, J.L. 1974. A New Approach to Improved Log-Derived Permeability. The Log Analyst, 15 (1).

Guo G., Diaz M.A., Paz F. et al. 2005. Rock Typing as an effective Tool for Permeability and Water Saturation Modeling: A Case

Study in a Clastic Reservoir in the Oriente Basin. paper SPE 97033 presented at the SPE Annual Technical Conference and Exhibition,

Dallas, Texas, 9-12 October.

Kharrat R., Mahdavi R., Bagherpour M.H. et al. 2009. Rock Type and Permeability Prediction of a Heterogeneous Carbonate Reservoir

Using Artificial Neural Networks Based on Flow Zone Index Approach. paper SPE 120166 presented at the SPE Middle East Oil and

Gas Show and Conference, Bahrain, 15-18 March.

Kozeny, J. 1927. Sitzber. Akad. Wiss. Wien. Math. Naturw. Klasse. 136, 271.

Shenawi S.H., White J.P., Elrafie E.A. et al. 2007. Permeability and Water Saturation Distribution by Lithologic Facies and Hydraulic

Units: A Reservoir Simulation Case Study. paper SPE 105273 presented at the 15th SPE Middle East Oil & Gas Show and Conference,

Bahrain, 11-14 March.

Svirsky, D., Ryazanov, A., Pankov, M. et al. 2004. Hydraulic Flow Units Resolve Reservoir Description Challenges in a Siberian Oil

Field. Paper SPE 87056 presented at the SPE Asia Pacific Conference on Integrated Modeling for Asset Management held in Kuala

Lumpur, Malaysia, 29-30 March.

Timur, A. 1968. An Investigation of Permeability, Porosity, and Residual Water Saturation Relationship for Sandstone Reservoirs. The

Log Analyst, 9 (4): 8

Tixier, M.P. 1949. Evaluation of Permeability from Electric-Log Resistivity Gradients. Oil & Gas J. pp.113

Wyllie, M.R.J. and Rose, W.D. 1950. Some Theoretical Considerations Related to the Quantitative Evaluation of the Physical

Characteristics of Reservoir Rock from Electric Log Data. J.Pet. Tech. 189, pp. 105.