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FACULTY OF ENGINEERING AND INFOMRATION TECHNOLOGY

OIL AND GAS ENGINEERING

# IMPACT OF UNCERTAINTY IN PETROPHYSICAL EVALUATION ON FLUIDS SATURATION CALCULATIONS OF SHALY SAND RESERVOIRS OF SHARYOOF FIELD IN BLOCK-53 ( SAY'UN MASILA BASIN)

A PROJECT SUBMITTED IN PARTIAL FULLFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR DEGREE OF OIL AND GAS ENGINEERING

DONE BY :

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SANA'A

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# DECLARATION

*We hereby declare that this project is the result of our own work, except for quotations and summaries which have been duly acknowledged*

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# APPROVAL

*This is to certify that the project entitled Impact of Uncertainty in Petrophysical Evaluation On Fluids Saturation Calculations of Shaly Sand Reservoirs of Sharyoof Field in Block-53 (Say'un Masila Basin) has been read and approved for meeting a part of the requirements and regulations governing the award of the Bachelor degree of Oil and Gas Engineering, Emirates International University, Sana'a, Yemen*.

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# ABSTRACT

Shale layers are generally characterized as conductive formation, unlike hydrocarbons which are resistant. So the petrophysical evaluation will usually encounter complications and errors in shaly sand reservoirs. This problem can lead to high water saturation value and as a result lose the opportunity and sometimes decisions are made to plug and abandon the well due to wrongly underestimated hydrocarbon saturation.

This project is focused on the impact of uncertainty in petrophysical evaluation on Sw calculations of shaly sand reservoirs of Sharyoof field in block-53 (Say'un Masila basin) by using TECHLOG software. The work was performed to define the petrophysical properties of upper Qishn clastic formations in Sharyoof ( S1a, S1b, S1c, S2, S3), calculate shale volume by using Larionov equation and compared it with Linear equation ( gamma ray), perform petrophysical evaluation of shaly-sand reservoir using methods and techniques such as Archie and Indonesian equations, to determine the effect of shale presence on fluids saturations calculations and calculate OIIP accordingly.

The petrophysical analysis in Sharyoof-02 concluded that, it has two hydrocarbon-bearing zones which are S1A and the upper part of S1C, and no hydrocarbon-bearing intrvals are revealed at S1B, S2, and S3. Similarly in Sharyoof-09 S1A and the upper part of S1C have hydrocarbon-bearing. In contrast, S1B, S2, and S3, no hydrocarbon-bearing zones are detected.

The results confirm that Archie equation results in higher Sw values in shaly sand comparing with Indoesian formula and it is more accurate in clean sand fomation. In addition it was noted that  the linear shale volume equation (response of gamma ray), produce a shale volume value higher  than that from the non-linear equations such as Larionov equation.

It is recommended, to redefine the process of the layers boundaries picking (S1A, S1B, S1C, S2, S3) to ensure that the reslts of petrophysical analysis is more accurate. Furthermore,it is recommended to  use models that take volume of shale into account when calculating water saturation to obtain more reliable results.

Finally, it is recomended to recalculate  STOIIP values based on the Sw results from equations that take into account the presnece of shale such as Indenosian or Simandoux equations to reduce the uncerinity of reserve volume calculations.

# ACKNOWLEDGMENT

*At the beginning, we definitely confess our most genuine gratitude to Allah, who is the most omnipotent and the powerful for granting us such, a strength, endurance, patience, immutability, capability to accomplish this research.*

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# LIST OF ABBREVIATIONS USED IN OUR GP

*μ: Viscosity*

***a** : Porosity Tortuosity Constant*

***API** : American Petroleum Institute*

***BBl** : Barrel*

***BHA :** Bottom-Hole Assembly*

***Bo** : Oil Formation Volume Factor*

***BS** : Bit Size*

***Bw**: Water Formation Volume Factor*

***CALI :** Caliper Log*

***CCL :** Casing Collar Locator*

***CGR** : Spectral Gamma Ray*

***CNC** : Compensated Neutron Log*

***DBDP** : Data Bank Development Project*

***DR** : Deep Resistivity*

***DST :** Drill-Stem Testing*

***F :** Formation Resistivity Factor*

***FR :** Formation Factor*

***FVF** : Formation Volume Factor*

***FWS :** Full Waveform Sonic*

***GL :** Ground Level*

***GOC** : Gas Oil Contact*

***GR** : Gamma Ray*

***GST** : Gamma Ray Spectroscopy Tool*

***HC** : Hydrocarbon*

$I_{GR}$ *: Gamma Ray Index*

***KB** : Kelly-bushing*

***LLD*** *: Deep Lateralog*

***LLS*** *: Shallow Lateralog*

***LWD :*** *Logging While Drilling*

***m :*** *Cementation Factor*

***ML :*** *Mud Logging*

***MSFL*** *: Micro-Spherical Focused Log*

***MW*** *: Mud Weight*

***MWD :*** *Measurement While Drilling*

***n :*** *Saturation Exponent*

***NMR :*** *Nuclear Magnetic Resonance*

***NPHI*** *: compensated Neutron Log*

***Ø eff*** *: Effective Porosity*

***Ø total*** *: Total Porosity*

***OIIP*** *: Oil Initially In Place*

***PE*** *: Photoelectric Effect*

***PEPA*** *: Petroleum Exploration & Production Authority*

***PHIE*** *: Effective Porosity*

***PHIT*** *: Total Porosity*

***POR-D*** *: Density ( porosity Log )*

***POR-N*** *: Neutron ( porosity Log )*

***PSA*** *: Production Sharing Agreement*

***PWD :*** *Pressure While Drilling*

***RHOB*** *: Corrected Bulk Density Log*

***Rmf*** *: Mud Filtrate Resistivity*

***ROP :*** *Rate Of Penetration*

***Rt :*** *True  Formation Resistivity*

***Rw*** *:  Formation Water Resistivity*

***So*** *: Oil Saturation*

***SP*** *: Spontaneous Potential*

***SR*** *: Shallow Resistivity*

***STOIIP*** *: Stock Tank Oil Initially In Place*

***Sw*** *: Water Saturation*

***SW-AR :*** *Total Water Saturation ( ARCHIE' S EQUATION )*

***SWCs :*** *Sidewall Cores*

***Sw-eff*** *: Effective Water Saturation*

***SWE-INDO*** *: Effective Water Saturation ( INDONESIAN MODEL )*

***Sw-total*** *: Total Water Saturation*

***TD :*** *Total Depth*

***TDT*** *: Thermal Decay Tool*

***Vsh :*** *Volume of Shale*

***WOC :*** *Water Oil Contact*

***ZDEN*** *: Corrected Bulk Density Log*

# CHAPTER ONE

# 1.INTRODUCTION

## 1.1INTRODUCTION

Say'un-Masila Basin is one of the onshore basins in Yemen, which is located in the east part of Yemen. Say'un-Masila Basin is classified as large hydrocarbon basin in Yemen and contains several hydrocarbon fields. It is considered as one of the most important basins in Yemen because of its significant contribution in oil and gas production.

Produced hydrocarbon from Masila region was discovered in 1991.

Block -53 is one of the most important blocks in Say'un Masila basin with an area about 474 square kilometers. The block contains three producing fields, Sharyoof, Bayoot, and Hekma fields. The production from Sharyoof field began in 2001[1]..The source rocks for block-53 are Madbi formation. The primary reservoirs in block-53 fields are Qishin clastic formation, carbonic Saar formation, and the basement [2].

The block was operated by Dove Energy Company [3] , and currently is operated by Petromasila National Company.

This project will discuss the impact of uncertainty in petrophysical evaluation of shaly sand reservoirs of Sharyoof field in block-53 and their effect on the estimation of hydrocarbon saturation.

## 1.2 Aims and Objectives

### 1.2.1 Aim

Investigate the impact of uncertainty in petrophysical evaluation of shaly sand of Sharyoof field.

### 1.2.2 Objectives

To achieve the aim of this study, the following objectives have been defined:

1. Define the petrophysical properties of upper Qishn clastic formations in Sharyoof (S1a , S1b ,S1c , S2 , and S3 )
2. Calculate shale volume by using Larionov equation and comparison with Linear equation.
3. Using spectral gamma ray to identify the reservoir quality including clay type.
4. Calculate the total and effective porosity.

5. Perform petrophysical evaluation of shaly sand reservoir using methods and techniques such as Indonesian, and Simandoux formulas.
6. Perform hydrocarbon saturation calculation.
7. Analyze the effect of shale presence on water saturation.
8. Calculate OIIP based on different scenario of Sw calculation.

## 1.3 Problem Statement

Shale layers are generally characterized as conductive formation, unlike hydrocarbons which are resistant. So, the petrophysical evaluation usually encounter complications and errors in shaly sand reservoirs because of the conductivity of shale that may mask high resistance characteristics of hydrocarbons. This problem can lead to high water saturation value and as a result lose the opportunity and sometimes decisions are made to plug and abandon the well due to wrongly underestimated hydrocarbon saturation.

In this graduation research project, we will try to investigate this problem and its effect on OIIP and look into the best way to determine fluids saturations, minimize the shale effect on porosity, and saturation calculation.

## 1.4 Research Questions

1- How shale presence will affect the porosity and saturations values?
2- What is the impact of uncertainty in petrophysical evaluation of shaly sand reservoir of Sharyoof field in block -53?

## 1.5 Significance of The Research

Study the impact of uncertainty in petrophysical evaluation of shaly sand reservoirs are critical as it will minimize the risk of taking wrong decision related to well status either to complete, suspend, or plug and abandon as a result of high-water saturation which in its turn is a result of non-considering of shale presence.

This analysis will be focusing on identifying the best approach and main solutions to minimize the above mentioned impact.

## 1.6 Scope of The Research

Qishn Clastic Reservoir in Sharyoof field block -53 is the scope of this research. Two wells were taken under consideration (Sharyoof -2 &Sharyoof-9). To conduct the analysis

## 1.7 Petroleum Basins of Yemen (Overview)

Yemen is situated in the southwestern part of the Arabian Peninsula and contains both onshore and offshore sedimentary basins, all of which are developed during discrete time intervals. Twelve onshore and offshore sedimentary basins have been identified in Yemen, categorized into three groups based on the geological era in which they originated: Paleozoic, Mesozoic and Cenozoic. Two sedimentary basins, Sab'atayn and Say'un-Masila, where oil was discovered in 1984 and 1991 respectively, are currently the only petroleum-producing basins in Yemen, while the other basins, including the onshore Paleozoic and offshore Cenozoic basins, remain little-explored. Sab'atayn and Say'un-Masila basins are parallel rift basins separated by the Jahi-Mukalla High developed in Late Jurassic to Early Cretaceous times during the fragmentation of Gondwana.They filled with syn- and post-rift sediments. They share many similarities including source and reservoir rocks of Late Jurassic-Early Cretaceous age[4].

## 1.8 Geological Setting:

Yemen Republic, situated at the southern part of the Arabian sub content, is both geographically and geologically transitional in nature between Arabia and Africa. It is situated close to the Tertiary triple junction between the Red Sea, Gulf of Aden, and east African rift systems. Structurally, Sayun-Masila basin has been affected by many normal faults trending NW-SE, NE-SW and E-W. Small number of folds (anticlines and synclines) is also present. The Jurassic and lower Cretaceous strata in Yemen regionally and at Say'un-Masila basin locally, reflect breakup of Gondwanaland and basin creation formed by rifting during Late Jurassic and Early Cretaceous and rifting of Gulf of Aden and Red Sea throughout Tertiary age. Rifting caused a series of NW-SE and E-W trending major faults basin bounding Say'un-Masila basin[5] .

## 1.9 Say’un Masila basin

Masila Basin is one of the onshore basins in Yemen, which is located in the east part of Yemen. It is classified as large hydrocarbon basins in Yemen and contains several hydrocarbon oil fields. Produced hydrocarbon from Masila region was discovered in 1991.

Masila fields are associated with the Upper Jurassic to Lower Cretaceous Say’un-Masila rift graben basin. Producible quantities of oil are found in a number of different reservoirs including Precambrian / Archean granitic basement, lower Cretaceous Qishn Formation Clastic deposits. Almost 90 % of the oil reserves discovered are in the Lower Cretaceous upper Qishn sandstones, Qishn Formation, Tawila Group.

The primary element, the reservoir, is the early cretaceous aged Qishn formation sandstones with excellent reservoir quality (average porosity of 20 % and permeability of up to 4 Darcy. Another hydrocarbon-bearing formation is Saar formation and encountered as a dolomitic limestone (primary porosity up to 19 %).

### 1.9.1 Stratigraphy of Say’un-Masila Basin

The general stratigraphy of the study area is ordered from oldest to youngest as the following (Fig 1-1):

**The basement** of the Say'un-Masila Basin consists mostly of metamorphosed Precambrian and crystaline igneous rocks.

**Kohlan formation:** Occupied with thick sedimentation within depositional lows of pre-Jurassic topography**.** It includes siltstone, sandstone, and conglomerate with thin limestones and green clay.

**Amran Group:** consists of three members:

- **Shuqra formation:** The Shuqra Formation of upper Jurassic Age, consists predominantly of a platform carbonate with reefal buildups. It is generally composed of limestones, including lime-mudstones, wackestones, and grainstones.

- **Madbi formation:** Deposited within an open marine environment. This unit is classified into two members:
  - **Lower Member**: commonly argillaceous limestones and sandstones and forms a good reservoir in some oil fields of the Masila Basin.
  - **Upper member:** composed of laminated organic rich shale, mudstone, and calcareous sandstone. This member is a prolific source rock in the Masila province.
- **Naifa formation:** was deposited as chalk and lime mudstones in shallow water to deep water marine conditions. It is formed mainly of silty and dolomitic limestone and lime mudstone with wackestone and chalk. The upper part of the formation is composed of very porous clastic carbonate overlain by the Saar dolomite facies.

**Tawila Group**: Consists mainly of six members:

- **Saar formation:** Overlies the Naifa Formation and is composed mainly of limestone with some mudstone and sandstone. It is classified into lower Saar carbonates and upper Saar clastics.
- **Qishn formation:** It is divided into two members which are clastic member (The Lowest) and carbonate member (The Upper).
- **Harshiyat Formation:** Deposited in shallow marine environment and consists mainly of sandstone.
- **Fartaq Formation:** Clastics with carbonate sequence.
- **Mukalla Formation:** Consist mainly of alluvial fan, Fluvial-deltaic and shallow marine sandstone and mudstone with shallow marine carbonate.
- **Sharwayn Formation:** Consists mainly of shallow and deeper Carbonate.

| Age | Rock Unit | Type of rocks | Description |
|---|---|---|---|
| Cretaceous | Qishn carbonate | Limestone | Cap Rocks |
| Lower Cretaceous and upper and lower Jurassic | Qishn clastic , carbonate clastic, Saar formation , Madbi limestone, kuhlan, and basement | Sandstone, siltstone ,limestone , and dolomite | Reservoir |
| Upper Jurassic | Madbi Formation | Shale | Source Rock |

*Table1- 1Petroleum System of Sharyoof Field*

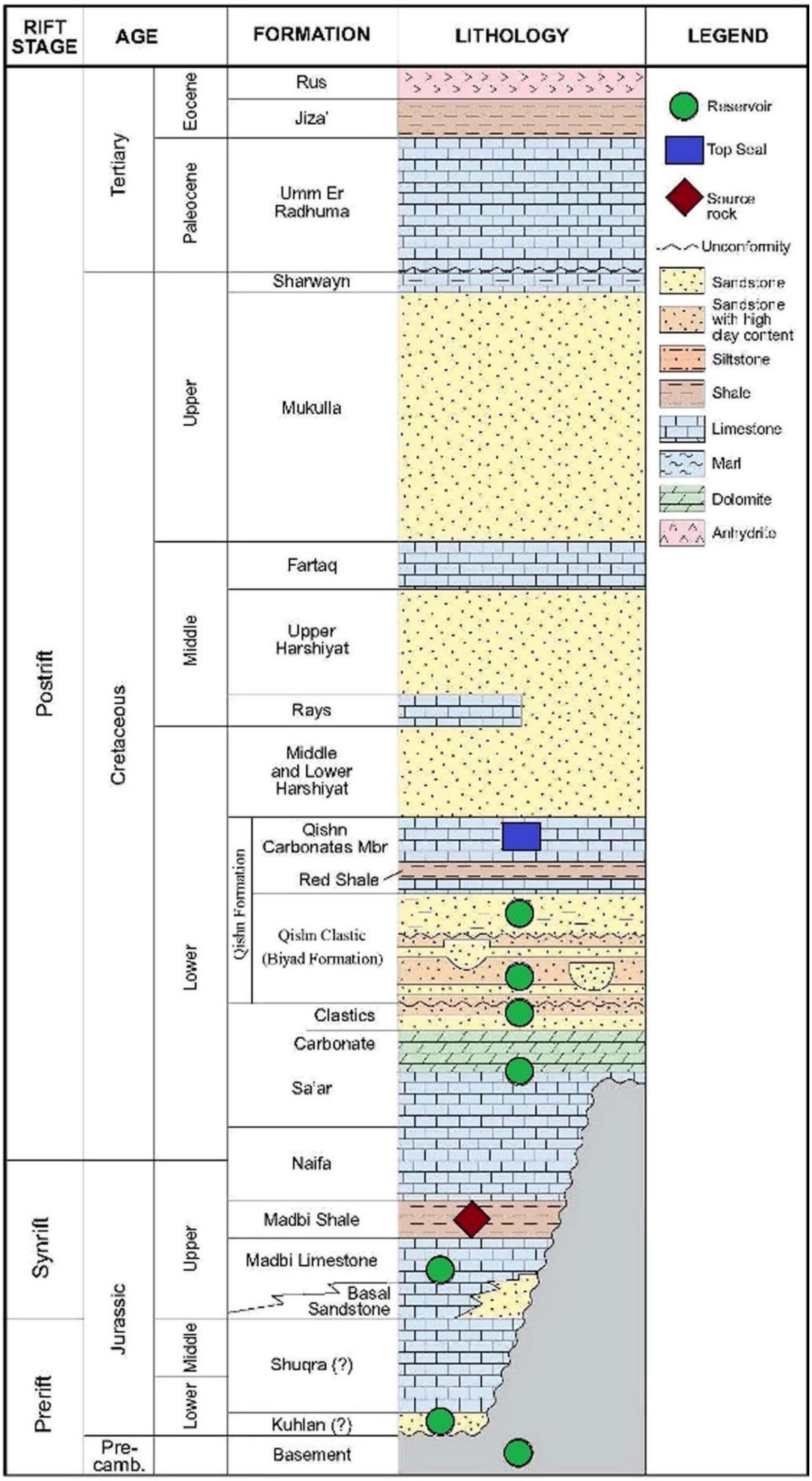


*Figure1- 1 Stratigraphy Column of the Masila Basin*

## 1.10 Block 53

Block-53 is located at northeastern portion of Masila Basin, towards the east of Hadhramaut province, adjacent to three prolific blocks which are, blocks-14 (contains 16 producing fields) that is operated by Nexen Petroleum Yemen Lid (Dove, 2000).

Block-32 (contains 2 producing fields) that is operated by DNO from east side and block-10 that is operated by Total (Now Petromasila) from west side. It was awarded to Dove in 1998 in relinquished acreage. Block-53 holds three discoveries Sharyoof, Bayoot, and Hekma [6].

The main reservoirs in the block are Qishn Clastic, Saar Sand, Saar Carbonate, and expected to be produced from fracture basement rocks in the future.

## 1.11 Sharyoof Field

Sharyoof oilfield is one of the most productive oilfields in the onshore of block-53 in Masila Basin, located in the N/W sector in Masila Basin with area of 474Km2. Sharyoof oilfield is also located north several successful producing oil fields (Fig 1-2):

- Sunah oilfield to the southeast,
- Kharir oilfield to the west, and
- Tasour field to the east.

Sharyoof field was discovered by DOVE Energy in June 2000 . Sharyoof-1 (TD 1765 m) and second well Sharyoof-2 (TD 1630 m) drilled which targeted the Cretaceous units.

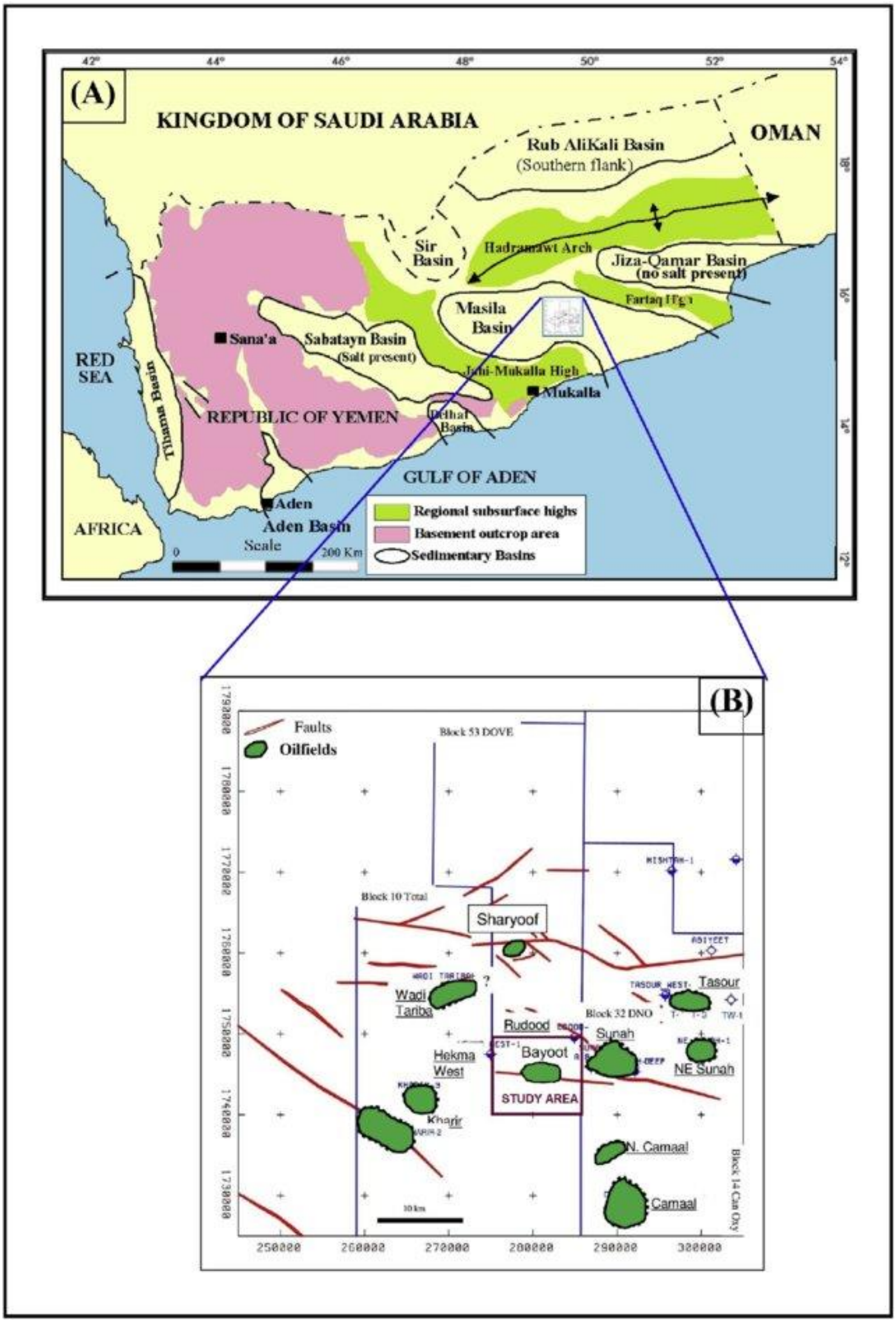


*Figure1- 2 Sharyoof field Location*

## 1.12 Formation Evaluation Overview:

Formation evaluation is the process of using borehole measurements to evaluate the characteristics of subsurface formations and its fluids when present. It applies to many areas of engineering where various rock properties are needed.

Formation evaluation represents the expenditure of a considerable sum of money each year. In each individual well, the evaluation cost may range up to 20 % of the total well cost. A wide variety of in-situ measurements are available for evaluating formations in an individual well. These measurements may be grouped into four categories:

- Drilling Operation Logs (Mud Logs): cuttings analysis, mud analysis, and drilling data collection and analysis
- Core Analysis: qualitative measurements (visual lithology, presence of shows. etc.) and quantitative measurements (porosity, permeability, formation factors...etc.)
- Wireline Well Logs: electrical (spontaneous potential, SP non-focused current resistivity, focused current resistivity, induction). Acoustic (transit time, Full-wave train, borehole tele-viewer), and radioactive (gamma ray, neutron, density, neutron lifetime, spectral)
- Productivity Tests: formation tester, drill stem tests, and production tests.

### 1.12.1The Importance of Formation Evaluation

Formation Evaluation is one of the most important process in oil and gas industry. This process is usually required to:

1. To locate the potential zones and determine its lithology
2. Evaluate hydrocarbons reservoirs and predict oil recovery.
3. Perform measurement of in situ formation fluid pressure and acquisition of formation fluid samples.
4. Provide the reservoir engineers with the formation's geological and physical parameters necessary for the construction of a fluid-flow model of the reservoir.
5. Generally, in petroleum exploration and development, formation evaluation is used to determine the ability of formations to produce petroleum.

All mentioned above can be done using data from different sources such as drilled cuttings, well logs, cores, and test results[7].

The field of geology that is of most importance to the oil industry and can help evaluate the subsurface formation is sedimentology. It entails a precise and detailed study of the composition, texture and structure of the rocks, the color of the constituents, and identification of any traces of animal and plant organisms. This enables the geologist to perform the following:

a) To identify the physical, chemical and biological conditions prevalent at the time of deposition.

To describe the transformations that the sedimentary series has undergone since deposition. He must also consider the organization of the different strata into series, and their possible deformation by faulting, folding, and so on. The geologist depends on rock samples for this basic information. On the surface, these are cut from rock outcrops. Their point of origin is obviously precisely known, and in principle a sample of any desired size can be taken, or repeated. Sampling from the subsurface is rather more problematic. Rock samples are obtained as cores or cuttings.

Cores obtained while drilling (using a core-barrel), by virtue of their size and continuous nature, permit a thorough geological analysis over a chosen interval. Unfortunately, for economic and technical reasons, this form of coring is not common practice, and is restricted to certain drilling conditions and types of formation.

“Sidewall-cores”, extracted with a core-gun, sample-taker or core-cutter from the wall of the hole after drilling, present fewer practical difficulties. They are smaller samples, and, being taken at discrete depths, they do not provide continuous information. However, they frequently replace drill coring, and are invaluable in zones of lost-circulation.

Cuttings (the fragments of rock flushed to surface during drilling) are the principle source of subsurface sampling. Unfortunately, reconstruction of a lithological sequence in terms of thickness and composition, from cuttings that have undergone mixing, leaching, and general contamination, during their transportation by the drilling-mud to the surface, cannot always be performed with confidence. Where mud circulation is lost, analysis of whole sections of formation is precluded by the total absence of cuttings. In addition, the smallness of this kind of rock sample does not allow all the desired tests to be performed.

Because of these limitations, it is quite possible that the subsurface geologist may find himself with insufficient good quality, representative samples, or with none at all. Consequently, he is unable to answer with any confidence the questions fundamental to oil exploration:

a) Has a potential reservoir structure been located?
b) If so, is it hydrocarbon-bearing?
c) Can we infer the presence of a nearby reservoir?

An alternative, and very effective, approach to this problem is to take in situ measurements, by running well logs. In this way, parameters related to porosity, lithology, hydrocarbons, and other rock properties of interest to the geologist, can be obtained. The first well log, a measurement of electrical resistivity, devised by Marcel and Conrad Schlumberger, was run in September 1927 in **Pechelbronn** (France). They called this, with great foresight, “electrical coring”. Since then scientific and technological advances have led to the development of a vast range of highly sophisticated measuring techniques and equipment, supported by powerful interpretation procedures.

Well log measurements have firmly established applications in the evaluation of the porosities and saturations of reservoir rocks, and for depth correlations.

More recently, however, there has been an increasing appreciation of the value of log data as a source of more general geological information. Geologists have realized, in fact, that well logs can be to the subsurface rock what the eyes and geological instruments are to the surface outcrop. Through logging this study measures a number of physical parameters related to both the geological and petrophysical properties of the strata that have been penetrated; properties which are conventionally studied in the laboratory from rock-samples. In addition, logs tell us about the fluids in the pores of the reservoir rocks.

Log data constitute, therefore, a “signature” of the rock; the physical characteristics they represent are the consequences of physical, chemical and biological (particularly geographical and climatic...) conditions prevalent during deposition; and its evolution during the course of geological history. Log interpretation should be aimed towards the same objectives as those of conventional laboratory core-analyses. Obviously, this is only feasible if there exist well-defined relationships between what is measured by logs, and rock parameters of interest to the geologist and reservoir engineer.

The descriptions of the various logging techniques will show that such relationships do indeed exist, and that the study may assume:

a) A significant change in any geological characteristic will generally manifest itself through at least one physical parameter which can be detected by one or more logs.
b) Any change in log response indicates a change in at least one geological parameter.

# CHAPTER TWO

# 2. LITERATURE REVIEW

## 2.1. Introduction

A literature review is a piece of academic writing demonstrating knowledge and understanding of the academic literature on a specific topic and it evaluates the relevant previous literature within a particular field of research then it highlighting what has already been done and find the gaps related to them.

## 2.2. Petrophysical Properties

The study of the properties of rocks and their relationship to the fluids they contain in both static and flowing states facilitate the understanding the rservoir behaviour and suggest the best approch for reservoir exploitation. Petrophysics emphasizes those properties relating to the pore system and its fluid distribution and flow characteristics. These properties and their relationships are used to identify and evaluate:

- Hydrocarbon reservoirs
- Hydrocarbon sources
- Seals
- Aquifers

The petrophysicist or formation evaluation engineer practices the science of petrophysics as a member of the reservoir management team. The petrophysicist provides answers on products needed and used by team members, as well as physical and chemical insights needed by other teammates[8].

The reservoir and fluid characteristics to be determined are:

- Zoning/ Thickness (bed boundaries)
- Lithology (rock type)
- Shale volume
- Porosity
- Formation Resistivity
- Fluid identification and characterization
- Fluid saturations and pressures
- Permeability (absolute)
- Fractional flow (oil, gas, water)

## 2.3. Shaly Sand

**Shale** is a collective term , defined and used slightly different among the disciplines . For a geologist , shale can be defined as a fine - grained , sedimentary clastic rock with grain size below 0.031 mm and with > 35 % clay minerals and silt grains . From a geomechanic point of view , shale would be a rock where the clay minerals contribute significantly to load bearing parts of the formation . For a reservoir engineer , shale can generally be characterized as low permeability formations , with little regard to the mineral composition . For Petrophysicist shales can cause complications because they are generally conductivity and may therefore mask the high resistance characteristics of hydrocarbons[9]

The volume of shale in a formation will affect almost all the logs. The most common curves used to estimate shale volume is the GR and neutron - density . As a shale indicator , one value for clean sand and one value for shale are determined , and the volume of shale is distributed between the endpoints . A linear relationship can be assumed , but is often found to be too pessimistic and overestimate the volume of shale in the formation . Some non-linear relationships can be used to reduce the uncertainty related to determining volume of shale .

Shale can be distributed across a reservoir sand body as a combination of three different modes : laminar , structural or dispersed .The distribution is closely related to how the shale was deposited and will have great influence on the determination and effect of volume shale ( V ) . A volume of shale in laminar mode may prove helpful in reducing water coning . while the same amount of shale in dispersed mode may influence permeability significantly reduce production.

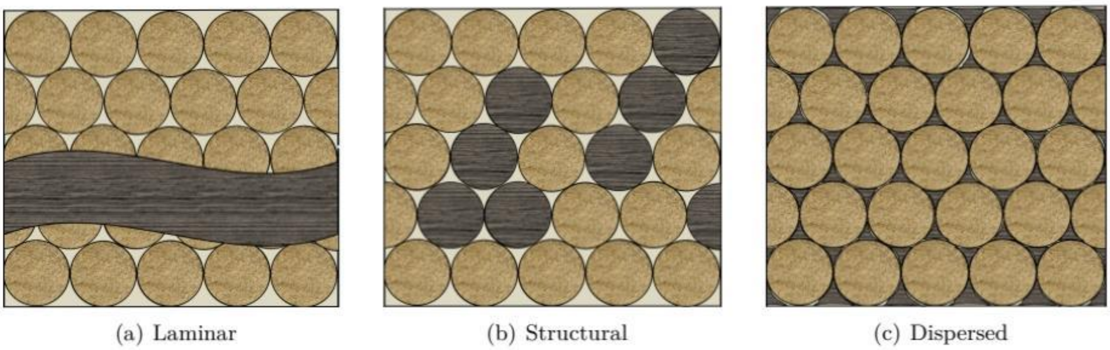


*Figure2- 1 Shale distribution modes*

One difference between grains of sand ( quartz ) and shale is that shale has its own porosity . The pores can either be filled with bound water , or some organic content as kerogen or vitrinite making them a potential source of hydrocarbons.

In the laminar case , shale is distributed as layers . In a given bulk volume of sand grains , some have to be removed to make space for the shale .

In the structural case , shale is present as grains within the sand . Since shale has its own porosity , the total porosity in this case increases compared to clean sand.

Dispersed shale is a term for shale distributed inside the pores of the sand . The clay minerals can be precipitated from moving pore fluids , or be a result of sand and silt grains transforming into clay minerals . Since the pore volume and pore throats are reduced as a result of this , the permeability in the formation will be reduced.

The effects of the presence of clay materials in reservoir rocks have been recognized for almost forty years as being perhaps the most complex problem encountered in formation evaluation. Attempts to solve the interpretation problems have resulted in the establishment of various empirical techniques. At the same time, numerous attempts have been made to establish a conceptual model to predict the conductive behavior of shaly sand.

Clay crystals attract water that is adsorbed onto the surface, as well as cations (e.g sodium) that are themselves surrounded by hydration water. This gives rise to an excess conductivity compared with rock, in which clay crystals are not present and this space might otherwise be filled with hydrocarbon.

The most difficult problem facing the log analyst lies in the identification of potential zones and the proper quantification of the amounts of hydrocarbons they contain. The quantitative evaluation of the commercial potential of a prospective formation is mainly achieved by estimating its water saturation, Sw.

It is recognized that the electrical conductivity properties of clean i.e. clay free, porous rocks depend on the amount and conductive characteristics of the fluids saturating its pore space. Since hydrocarbons are poor electrical conductors, then a formation partially containing either oil or gas should exhibit lower conductive response than that of an otherwise clean rock, of the same porosity, whose pore space is completely filled by the same brine. Both the qualitative and quantitative evaluation of clean formations are easily accomplished.

Qualitative interpretation in such formation is based on the existance of sharp resistivity contrasts between water filled and hydrocarbon bearing zones.

The evaluation of water saturation follows from the application of simple petrophysical model that relate the water content to the resistivity of formation water Rw, the formation resistivity factor F, and the recorded electrical resistivity of the potential zone, Rt.

Using Archie's equation in shaly sands results in values of water saturations, Sw, that are too high, and may lead to potentially hydrocarbon bearing zones being missed. Many equations have been proposed in the past for accounting for the excess conductivity resulting from dispersed clays in the formation, which can have the effect of suppressing the resistivity and making Sw, calculated using Archie too pessimistic.

## 2.4.Well Logging Overview

Well logging plays a central role in the successful development of a hydrocarbon reservoir. Its measurements occupy a position of central importance in the life of a well, between two milestones: the surface seismic survey, which has influenced the decision for the well location, and the production testing. The traditional role of wireline logging has been limited to participation primarily in two general domains: Formation Evaluation and completion evaluation[10].

The goals of formation evaluation can be summarized by a statement of four questions of primary interest in the production of hydrocarbons:

- **Are there any hydrocarbons, and if so, are they oil or gas?**

First, it is necessary to identify or infer the presence of hydrocarbons in formations traversed by the wellbore.

- **Where are the hydrocarbons?**

The depth of formations which contain accumulations of hydrocarbons must be identified.

- **How much hydrocarbon is contained in the formation?**

An initial approach is to quantify the fractional volume available for hydrocarbon in the formation. This quantity, porosity, is of utmost importance. A second aspect is to quantify the hydrocarbon fraction of the fluids within the rock matrix. The third concerns the areal extent of the bed, or geological body, which contains the hydrocarbon. This last item falls largely beyond the range of traditional well logging.

- **How producible are the hydrocarbons?**

In fact, all the questions really come down to just this one practical concern. Unfortunately, it is the most difficult to answer from inferred formation properties.

Formation evaluation is essentially performed on a well-by-well basis. A number of measurement devices and interpretation techniques have been developed. They provide, principally, values of porosity and hydrocarbon saturation, as a function of depth, using the knowledge of local geology and fluid properties that is accumulated as a reservoir is developed. Because of the wide variety of subsurface geological formations, many different logging tools are needed to give the best possible combination of measurements for the rock type anticipated. Despite the availability of this rather large number of devices, each providing complementary information, the final answers derived are mainly three: the location of oil-bearing and gas-bearing formations, an estimate of their producibility, and an assessment of the quantity of hydrocarbon in place in the reservoir.

## 2.5. Formation Evaluation Data Origins

Data needed for formation evaluation has many sources such as:

### 2.5.1. Mud Logging

**Mud logging** is the creation of a detailed record (well log) of a borehole by examining the cuttings of rock brought to the surface by the circulating drilling medium (most commonly drilling mud). This provides well owners and producers with information about the lithology and fluid content of the borehole while drilling. Historically it is the earliest type of well log.

The practice of mud logging relies heavily on the mud circulation system. High pressure mud pumps draw mud or drilling fluid, from surface tanks and direct it downhole through the drill-pipe. The mud exits the drill- string through nozzles in the bit. As a bit drills through the subsurface, the rock it grinds along with water, oil or gas in the formation is carried back up the hole by the drilling fluid. Upon reaching the surface the liquid portion of the drilling fluid falls through the screens to the mud pits, ready to be pumped back into the well; the rock cuttings on the shaker screen provide the basis for determining down-hole lithology and oil shows.

### 2.5.2. Conventional and Sidewall Coring

Rock cores provide essential data for the exploration, evaluation and production of oil and gas reservoirs. Physical rock samples allow geoscientists to examine first hand the depositional sequences penetrated by a bit and offer direct evidence of the presence, distribution and deliverability of hydrocarbons. Cores provide ground truth for calibration of well logs and can reveal variations in reservoir properties that might be undetectable through down-hole logging measurements alone. Operators are better able to characterize pore systems in the rock and model reservoir behavior to optimize production based on the analysis of core porosity, permeability, fluid saturation, grain density, lithology and texture. These analyses are carried out in core laboratories around the world. Cores can be cut and collected by different techniques such as conventional and sidewall coring. Coring entails taking core samples from the well and examining the presence of oil or gas.

### 2.5.3. Measurement While Drilling (MWD)

Some Measurements are required to be recorded while drilling. This is called measurement while drilling (MWD). Tools are run as an integral part of the drill string. When real-time information is required for operational reasons, such as steering a well (e.g., a horizontal trajectory-to record inclination and azimuth) in a particular formation, and to pick formation tops, coring points, and/or casing setting depths (GR, Resistivity).

Although many measurements are taken while drilling, the term MWD is more commonly used to refer to measurements taken down-hole with an electromechanical device located in the bottom-hole assembly (BHA). The definition of MWD was again broadened to include data that was stored in tool memory and recovered when the tool was returned to the surface.

### 2.5.4. Logging While Drilling (LWD)

Logging While Drilling or LWD is the general term we use to describe the systems and techniques for gathering down-hole data while drilling a well. A more specific definition is the acquisition of petrophysical data. Generally, LWD offers the same measurements as wireline, with some differences in quality, resolution and/or coverage.

Traditionally, petrophysicists were concerned only with wireline logging, that is, the data acquired by running tools on a cable from a winch after the hole had been drilled. However, advances in drilling/logging technology have allowed the acquisition of log data via tools placed in the actual drilling assembly. These tools may transmit data to the surface on a real-time basis or store the data in a down-hole memory from which it may be downloaded when the assembly is brought back to the surface.

LWD tools present a complication for drilling, as well as additional expense. However, their use may be justified when:

- Real-time information is required for operational reasons, such as steering a well (e.g., a horizontal trajectory) in a particular formation or picking of formation tops, coring points, and/or casing setting depths.
- Acquiring data prior to the hole washing out or invasion occurring
- Safeguarding information if there is a risk of losing the hole
- The trajectory is such as to make wireline acquisition difficult (e.g., in horizontal wells).

Some of the data recorded may be usable only if the tool string is rotating while drilling, which may not always be the case if a steerable mud motor is being used. In these situations, the petrophysicist may need to request drilling to reacquire data over particular intervals while in reaming/rotating mode. This may also be required if the rate of penetration (ROP) has been so high as to affect the accuracy of statistically based tools (e.g., density/neutron) or the sampling interval for tools working on a fixed time sampling increment. Another important consideration with LWD tools is how close to the bit they may be placed in the drilling string. While the petrophysicist will obviously want the tools as close to the bit as possible, there may be limitations placed by drilling, whose ability to steer the well and achieve a high ROP is influenced by the placement of the LWD tool string. LWD data that may typically be acquired include the following:

- GR: natural gamma ray emission from the formation
- Density: formation density as measured by gamma ray Compton scattering via a radioactive source and gamma ray detectors. This may also include a photoelectric effect (Pe) measurement.
- Neutron porosity: formation porosity derived from the hydrogen index (HI) as measured by the gamma rays emitted when injected thermal or epithermal neutrons from a source in the string are captured in the formation
- Sonic: the transit time of compressional sound waves in the formation

- Resistivity: the formation resistivity for multiple depths of investigation as measured by an induction-type wave resistivity tool.

### 2.5.4.1. Open-Hole Logging

As a matter of fact, most logs are run in open or cased holes.

**Open-hole logging** refers to logging operations that are performed on a well before the well-bore has been cased and cemented. In other words, the logging is done through the bare rock sides of the formation. This is the most common type of logging method because the measurements are not obstructed and it is done after the well has been drilled[11].

Open hole logging devices are used to characterize subsurface formations. Common formation attributes that may be characterized include:

- **Capacity Storage** of the formation, which normally includes porosity and fluid saturations,
- **Fluid properties**, which include density, gas to oil ratio, API gravity, water resistivity and salinity, temperature, and pressure.
- **Geological setting**, which may include structural or stratigraphic dip, facies characteristics, and reservoir heterogeneities.

The basic open hole wireline logging devices can be divided into four general groups, as shown in **Table 2-1**. The correlation and lithology devices are used primarily to correlate between wells and to discriminate reservoir from nonreservoir rocks. The resistivity devices are used to determine formation resistivity at varying distances from the wellbore, which is used for correlation and the determination of water saturation. The lithology and porosity devices are used to determine both lithology and porosity.

A variety of auxiliary tools is used to make special logging measurements.

| Type | Device |
|---|---|
| **Correlation and lithology** | Spontaneous potential |
| | Gamma ray |
| | Photoelectric effect |
| **Resistivity** | Induction |
| | Laterolog |
| | Microresistivity |
| **Porosity and Lithology** | Density |
| | Compensated Neutron |
| | Sonic |
| | Photoelectric effect |
| **Auxiliary** | Caliper |
| | Formation Tester |
| | Dimeter |
| | Borehole Televiewer |

*Table2- 1 Basic open hole tools*

#### 2.5.4.1.1 Correlation and Lithology

Correlation devices are used to identify common formations between wells and their lateral extension and to distinguish potential reservoir rocks from non-reservoir rocks. These devices make use of three different physical phenomena: spontaneous potential, gamma rays, photoelectric effect, density and sonic travel time.

**Spontaneous potential**

Spontaneous potential (SP) is a natural voltage or electrical potential that arises due to differences in the ionic activities (relative saltiness) of the drilling mud and the formation waters. This potential can be used to correlate formations between wells, to indicate permeability, and to estimate formation water resistivity. No SP occurs when oil-based mud is used in the borehole. Hydrocarbons and shaliness in the formation suppress the SP. The magnitude of the SP decreases as the resistivity of the mud filtrate and formation waters approach a common resistivity. The direction of SP deflection reverses as the ratio of the resistivity of the mud filtrate ($R_{mf}$) to that of the formation water ($R_w$) reaches 1.0 or more. If there is no contrast in the mud filtrate and formation water salinities, there is no measurable SP.

**Gamma ray**

Gamma rays' tools measure the natural radioactivity of the formation. This radioactivity is emitted primarily from potassium in the structure of clay minerals, radioactive salts in the formation waters, radioactive salts bound to the charged surfaces of clay minerals, potassium associated with feldspars, and radioactive minerals associated with igneous rocks and rock fragments. The gamma ray response is used for correlation of formations between wells and for estimating volume shale and/or volume clay minerals.

An advanced version of the gamma ray tool, called the spectral gamma ray, breaks down or segments the detected gamma rays by their different energies using spectral analysis techniques. These segments correspond to the radioactive families of potassium, uranium, and thorium. Uranium frequently occurs as a precipitated salt deposited in a formation from waters having flown through that formation. When this occurs, the uranium counts disguise radioactivity due to mineralogy. The use of the spectral tool allows the removal of gamma ray counts caused by uranium, typically permitting more accurate use of the remaining gamma rays for determining lithology, volume shale, or volume clay. In some local areas, ratios of potassium to thorium have been successfully used to determine some clay types. However, this clay typing has not proven particularly universal and should be attempted with much caution.

**Photoelectric effect**

The photoelectric effect, or Pe, measures a formation's ability to absorb gamma rays. The absorptive abilities of formations vary with lithology. The photoelectric absorption is recorded as a supplementary measurement to the formation density measurement, using common detectors and radioactive sources.. The Pe measurement is not valid in muds weighted with barite. The recording can be used both for correlation of formations between wells and for determining lithology.

Knowledge of lithology significantly improves the accuracy of interpretation of all the porosity measurements.

| Tool | Vertical Res tion | Radius of Investigation | Applications | Limitations |
|---|---|---|---|---|
| **Spontaneous potent (SP)** | 6–10 ft | N/A | Well-to-well correlation, es mate $R_w$, and indicate perm bility | Does not work in oil-based mud and $R_{mf}$ and $R_w$ must contrast |
| **Gamma ray** | 2 ft | 12 in | Well-to-well correlation and estimate $V_{sh}$ | Sensitive to hole size ch es |
| **Spectral gamma ray** | 3 ft | 16 in | Well-to-well correlation and estimate $V_{sh}$ | Sensitive to hole size ch es |
| **Photoelectrical effec (Pe)** | 2 in | 2 in | Identify lithology and well-t well correlation | Does not work in barite mud, is a pad device, and uses a radioactive source |

*Table2- 2 Resolution and applications of correlation and lithology measurements*

## 2.5.4.1.2 Resistivity

Resistivity tools are primarily used for correlation and to determine the volume of the pore space saturated with water. Resistivity tools can be divided into three tools types: induction, laterolog, and microresistivity tools [12].

### Induction

This principle of exciting magnetic fields allows induction tools to measure resistivity without the requirement of a direct electrical connection to the formation. This feature permits the tool to be used in nonconductive muds (OBM). Different transmitter and receiver arrays allow focusing of the measurement for different vertical resolution and depths of investigation.

### Laterologs

The laterolog device measures the voltage and current magnitudes associated with a series of current electrodes mounted on the surface of the logging sonde, such tools operate in salty mud and measure the resistivity of uninvaded zone. These measurements require direct electrical contact with the formation, which is normally provided by the drilling mud. This characteristic does not allow this measurement to be made in oil-based muds. The focusing of the laterolog measurement is accomplished through the placement of the electrodes. Generally, laterologs exhibit very good vertical resolution.

**Microresistivity**

Microresistivity devices are used to estimate the resistivity of the flushed zone immediately adjacent to the borehole. This shallow investigation can result in mudcake being a significant influence. Hole size and mudcake corrections are commonly required. Like laterologs, these devices require a direct electrical contact with the formation. For this reason, microresistivity devices cannot be used in oil-based muds. Formation resistivity is typically profiled with three resistivity measurements of different depths of investigation to characterize the influence of the invading mud filtrate upon apparent formation resistivity. This characterization permits the influence of the flushed zone to be separated from the reading of the deep device for a more accurate determination of the true formation resistivity ($R_t$).

## 2.5.4.1.3 Porosity

Each of the porosity tools density, compensated neutron, and sonic, can be used to estimate porosity when lithology and fluid properties are known.

**Table 2.3**. shows the resolution and applications of porosity devices.

**Density**

The density tool measures the apparent density of the formation using a radioactive source that bombards the formation with high energy gamma rays and then measures the number of lower energy gamma rays returning to the detectors. The detectors and source are mounted in a pad that is forced against the borehole wall. The measurement attempts to correct automatically for the effects of mudcake and minor hole rugosity. The measurement is sensitive to significant borehole wall rugosity and pad standoff, which cause the tool to read too low of a density.

**Compensated neutron**

Compensated neutron devices measure the hydrogen index of the formation using a radioactive neutron source that bombards the formation with fast-moving neutrons. Neutrons collide with atoms of the formation, transferring their energy through these collisions. The most efficient transfer of energy occurs with hydrogen atoms because the mass of hydrogen is approximately the same as the mass of a neutron. Two detectors count the number of deenergized (thermal) neutrons returning from the formation. The ratio of the detector count rates is primarily related to the hydrogen index or the apparent water-filled porosity.

This measurement is very sensitive to tool standoff, hole size, temperature, and salinity. Environmental corrections are highly recommended before attempting to interpret results. Gas has a very low hydrogen index compared to water, which causes the tool to report abnormally low porosities in gas-bearing formations. When used in conjunction with density measurements, gas-bearing intervals are often easy to identify.

| Tool | Vertical Resol tion | Radius of Inve tigation | Applications | Limitations |
|---|---|---|---|---|
| **Compensated density** | 18 in. | 8 in. | Estimate porosity | Pad contact device |
| **Compensated neutron** | 2 ft | 10 in. | Estimate porosity and id tify presence of gas | Needs environmental correc tions; sensitive to standoff f wall |
| **IPL* (Integrated Porosity Lithology)** | 1 ft | -- | Estimate porosity and ide fy presence of gas, thin evaluation, shalt sand eval tion | Needs environmental correc- tions; sensitive to standoff f wall |
| **Sonic** | 2 ft | Typically, 6 in. | Measure compressional velocity and estimate p rosity | Sensitive to compressibility |
| **FWS (monopole)** | 4 ft | Typically, 6 in. | Measure compressional and shear velocities and estimate porosity | Cannot measure shear velocity when shear velocity > mud vel ty |
| **Dipole sonic** | 4 ft | Typically, 12 in. | Measure shear velocity | — |
| **CMR*(Combinable Ma netic Resonance)** | 6 in. | 1 in. | Porosity, pore size distribu tion, permeability | Minimum 6.5 in. wellbore |
| **Photoelectrical effect (Pe)** | 2 in. | 2 in. | Identify lithology and corr tion | Does not work in barite mud and pad contact tool |

*Table2- 3 The Resolution And Applications Of Porosity Devices*

**Sonic**

Sonic devices measure the velocity of various acoustic waves, most notably compressional, shear, and Stoneley waves. The velocity of the waves is a function of the elastic properties and the density of the formation. Logs normally present the inverse of velocity, called the interval transit time or delta t (Δt).

Shear velocities are used to determine mechanical properties of the formations and to determine Poisson's ratio for use in interpreting seismic data. Shear velocities can be determined from the FWS (monopole), the dipole sonic, or the quadrupole sonic. The monopole sonic is not able to measure shear velocities when the shear velocity of the formation is slower than the compressional velocity of the mud.

Mud interval transit times are typically in the 190 μsec/ft range.

**Calper Log**

The caliper log is a well logging tool that provides a continuous measurement of the size and shape of a borehole along its depth and is commonly used in hydrocarbon exploration. The measurements that are recorded can be an important indicator of wash-outs, caving or shale swelling in the borehole, which can affect the results of other well logs[13].

There are five cases of relationship between bit size and caliper rading which can cause differing in logging readings.

1. Bit size = caplier called normal case .
2. Caliper > bit size resulting caving .
3. Caliper >> >> bit size over scale causing washing out .
4. Caliper < bit size due to mudcake build up .
5. Caliper << bit size called tight spot case.

## 2.5.4.2. Cased Hole Logging

**Cased-hole logging** involves retrieving logging measurements through the well casing, or the metal piping that is inserted into the well during completion operations. Cased-hole logging is performed more rarely, but still provides valuable information about the well.

In some cases, the decisions must be made to plug and abandon the well or recomplete it, and the cased-hole log will help identify what lies beyond the casing of the well.

Cased-hole logging can be used to evaluate the formation and completion of the well, as well as, determine the state of the cement, corrosion, and perforation. Both gamma ray and neutron porosity logs can be run through the casing of a well, and better ideas of thermal decay and interval transit time can be achieved through porosity, hydrocarbon saturation, and producibility measurements.

When a hole has been cased and a completion string run to produce the well, certain additional types of logging tools may be used for monitoring purposes. These include:

- **Thermal decay tool (TDT):** This neutron tool works on the same principle as the neutron porosity tool, which is, measuring gamma ray counts when thermal neutrons are captured by the formation. However, instead of measuring the HI, they are specifically designed to measure the neutron capture cross-section, which principally depends on the amount of chlorine present at formation brine. Therefore, if the formation water salinity is accurately known, together with the porosity, $S_w$ may be determined. The tool is particularly useful when run in time-lapse mode to monitor changes in saturation, since many unknowns arising from the borehole and formation properties may be eliminated.
- **Gamma ray spectroscopy tool (GST):** This tool works on the same principal as the density tool, except that by measuring the contributions arising in various energy windows of the gamma rays arriving at the detectors, the relative proportions of various elements may be determined. In particular, by measuring the relative amounts of carbon and oxygen a (salinity independent), measurement of $S_w$ may be made.
- **Production logging Tool**: This tool, which operates using a spinner, does not measure any properties of the formation but is capable of determining the flow contributions from various intervals in the formation.
- **Cement bond log:** This tool is run to evaluate the quality of the cement bond between the casing and the formation. It may also be run in a circumferential mode, where the quality around the borehole is imaged. The quality of the cement bond may affect the quality of other production logging tools, such as TDT or GST.
- **Casing collar locator (CCL):** This tool is run in order to identify the positions of casing collars and perforated intervals in a well. It produces a trace that gives a “pip” where changes occur in the thickness of the steel.

## 2.6. Quicklook Log Interpretation

Once the section TD (total depth) of the hole has been reached, the petrophysicist will be expected to make an interpretation of the open-hole logs that have been acquired. Before starting the log interpretation, the petrophysicist should have:

- All the relevant daily drilling reports, including the latest deviation data from the well, last casing depth, and mud data.
- All the latest mud-log information, including cuttings description, shows, gas reading, and ROP (rate of penetration).
- Logs and interpretations on hand from nearby wells and regional wells penetrating the same formations, in particular where regional or field-wide values of m, n, $R_w$, $\rho_g$ and fluid contacts are available.

### 2.6.1. Identifying The Reservoir

Well log interpretation is one of the most methods for identifying the reservoir and it must be done in several steps and it is not recommended for the user to analyze them randomly because the result might be a total error figure 2-4 shows the steps for reservoir identification and characterization.

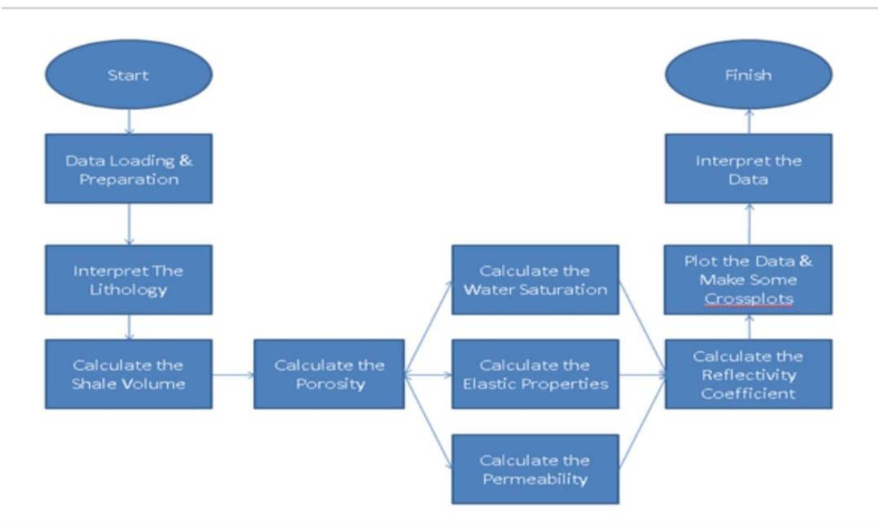


*Figure2- 2 Steps for reservoir identification and characterization.*

## 2.6.2.Interpret the lithology

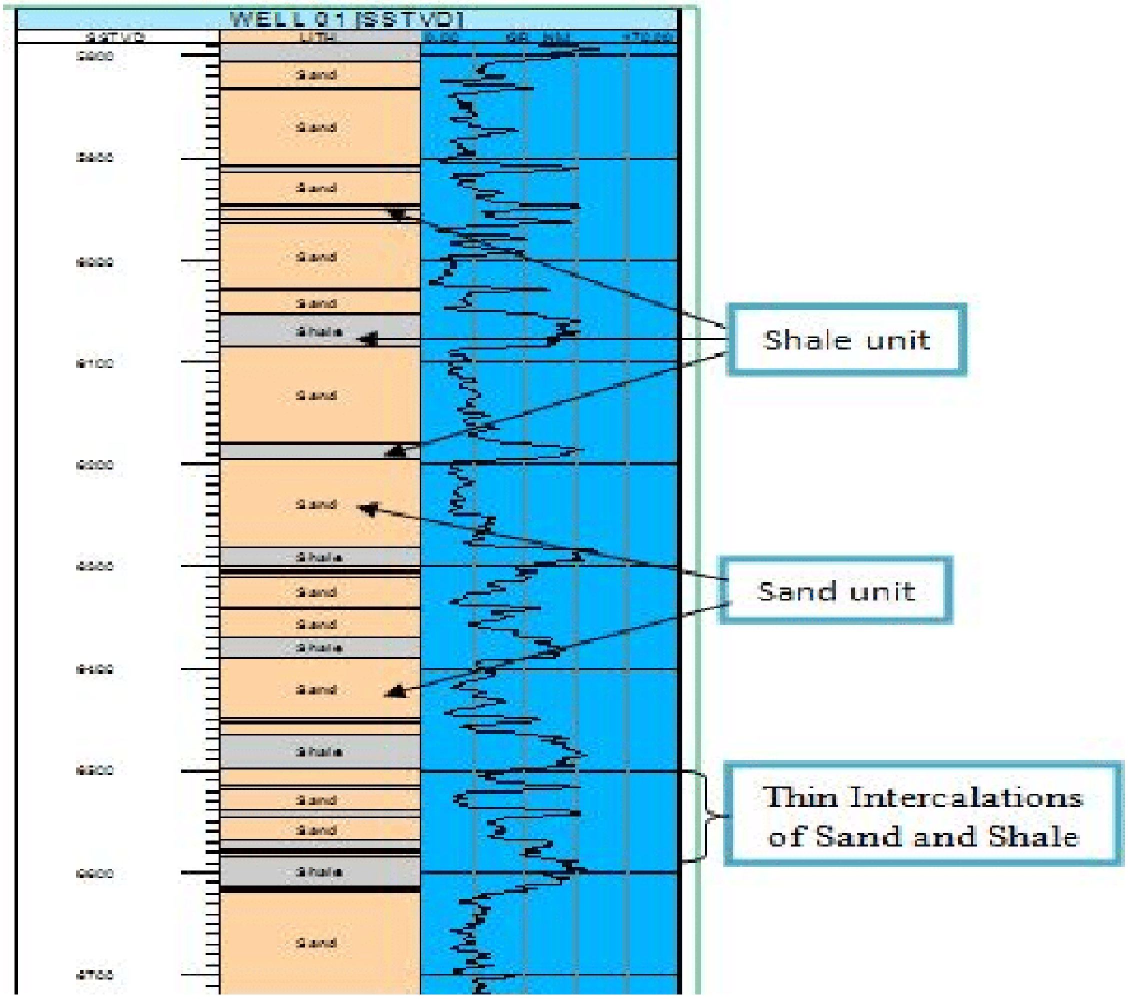


*Figure2- 3 Use of gamma ray log to determine the lithology.*

The user will be able to interpret the lithology by using several logs, there are gamma ray, spontaneous potential, resistivity, and density log. Basically, a formation with high gamma ray reading indicates that it is a shaly or shale, when the low gamma ray reading indicates a clean formation (sand, carbonate, evaporite, etc.), lithology interpretation is very important in reservoir characterization because, if the lithology interpretation is already wrong, the other steps such as porosity and water saturation calculation will be a total mess.

## 2.6.3.Calculating the Shale Volume

This second step could be done by using gamma ray log, Larionov (1969) proposed two formulas Equ 2-1,and Equ 2-2 to calculate the shale volume, those formulas are:

**Larionove (1996) tertiary rocks :**

$$Vsh = 0.083(23.7 \times IGR - 1) \quad \text{(Equ 2-1)}$$

**Larionove (1996 ) for older rocks :**

$$Vsh = 0.33(22 \times IGR - 1) \quad \text{(Equ 2-2)}$$
$$IGR = \frac{GRlog - GRmin}{GRmax - GRmin}$$

where IGR is the gamma ray index, Vsh is the shale volume, GR log is the gamma ray reading, GR max is the maximum gamma ray reading, and GR min is the minimum gamma ray reading.

Calculating shale volume is an important thing to do because, it can be useful to calculate the water saturation, if the reservoir has shale within its body (shaly) such as in delta, that reservoir may has higher water saturation because, shale has the ability to bound together with water which will increase the water saturation. Shale volume could also be used as an indicator of zone of interest or not, many users usually will not classify a formation with high shale volume as a reservoir because of its low permeability.

### 2.6.4. Calculating the Porosity

Porosity is the void or space inside the rock, they are very useful to store fluids such as oil, gas, and water, they are also able to transmit those fluids to a place with lower pressure (probably surface) if they are permeable. Porosity calculation is the third step of well log analysis and it could only be done correctly if the first step (lithology interpretation) is correct. There are many methods that can be used to calculate the porosity, the user may use density log, sonic log, neutron log, or combination between them, but the most common one is neutron-density log combination. The user may use the formulas below Equ 2-3 and Equ 2.4 to calculate the neutron-density porosity:

$$\Phi nd = \frac{\Phi d + \Phi n}{2}$$ (Equ 2-3)

for non-gas reservoir, or

$$\Phi nd = \sqrt{\frac{\Phi d^2 + \Phi n^2}{2}}$$ (Equ 2-4)

for gas reservoir

φd value:

$$\Phi d = \frac{\rho matrix - \rho log}{\rho matrix - \rho fluid}$$ (Equ 2-5)

where **ρ** matrix is the matrix density (the value depends on the lithology, see table 2 for the value reference), **ρ** fluid is the fluid density (see table 2 for the value reference), **ρ** log is the density log reading, φd is the density-derived porosity, φn is the neutron porosity (from neutron log reading), and φnd is the neutron-density porosity. If the lithology interpretation has been wrong from the start, the density-derived porosity will also show the wrong result which means that the neutron-density porosity will also be wrong, so the ability to interpret the lithology correctly is an important asset for the user.

| Lthology | value (gr/cm$^3$) |
|---|---|
| **Sandstone** | 2.644 |
| **Limestone** | 2.710 |
| **Dolomite** | 2.877 |
| **Anhydrite** | 2.960 |
| **Salt** | 2.040 |

| Fluid | Value (gr/cm$^3$) |
|---|---|
| **Frish Water** | 1.0 |
| **Salt Water** | 1.15 |
| **Methane** | 0.423 |
| **Oil** | 0.8 |

*Table2- 4 Matrix density and fluid density reference table (Halliburton, 1991) with some additions.*

## 2.6.5. Calculating Hydrocarbons Saturation Frome water Saturation

There are so many methods to calculate water saturation, the user may use Archie's,[14] Simandoux's (1963), etc. which will use different formula for every one of them, Below is Simandoux's (1963) method, to calculate the water saturation by using the following formula:

$$\frac{1}{Rt} = \frac{Sw^2}{F \times Rw} + \frac{Vsh \times Sw}{Rsh} \qquad \text{(Equ 2-6)}$$

$$\mathrm{Rw} = \frac{Rwe + 0.131 \times 10\left(\frac{1}{\log\left(\frac{BHT}{19.9}\right)}\right)^{-2}}{-0.5 \times Rwe + 10\left(\frac{0.0426}{\log\left(\frac{BHT}{50.8}\right)}\right)} \qquad \text{(Equ 2-7)}$$

$$\mathrm{Rwe} = Rmf \times 10^{\frac{SP}{61+0.133\times BHT}} \qquad \text{(Equ 2-8)}$$

$$\mathrm{F} = \frac{a}{\Phi m}$$

where Rt is the true resistivity of the formation (deep resistivity), Rw is the formation water resistivity, Vsh is the shale volume, Rsh is the resistivity of shale, Rwe is the formation water resistivity (without thermal effect), BHT is the bottom hole temperature , Rmf is the mud filtrate resistivity, SP is the spontaneous potential log reading, F is the formation volume factor, a is the tortuosity factor, m is the cementation exponent, φ is the porosity, and Sw is the water saturation. To acquire the value of a and m, the user will need to create a pickett plot, but according to Asquith, the reference value is shown in table 2-5.

| Lithology | A(tortuosity factor) | M(cementaion expone |
|---|---|---|
| **Carbonate** | 1.0 | 2.0 |
| **Consolidated sandstone** | 0.81 | 2.0 |
| **Unconsolidated sandsto** | 0.62 | 2.15 |
| **Average sand** | 1.45 | 1.54 |
| **Shaly sand** | 1.65 | 1.33 |
| **Calcareous sand** | 1.45 | 1.70 |
| **Carbonate(carothers,19** | 0.85 | 2.14 |
| **Pliocene sand** | 2.45 | 1.08 |
| **Miocene sand** | 1.97 | 1.29 |
| **Clean ,granular formati** | 1.0 | Phy(2.05-phy) |

*Table2- 5 Tortuosity factor (a) and cementation exponent (m) reference table*

### 2.6.6. Presenting the Results

Having calculated the Ø, and $S_w$ curves, it is usually required to provide averages over various formation zones. This should be done as follows. First of all, determine over which depths the results should be broken up. Apart from the formation boundaries as agreed upon with the geologist, further subdivision should be made for any possible changes in fluid type or zones where the data are of particularly poor quality, or at any points where there is marked change in log character.

Note that the average porosity is given by:

$$(\emptyset)\ \text{Average} = \sum \emptyset_{,i} / h \qquad \text{(Equ 4-9)}$$

where h is the net thickness.

The average value of $S_w$ is given by:

$$(S_w) \text{ Average} = \sum \emptyset_i * S_{wi} / \sum \emptyset \qquad \text{(Equ 4-10)}$$

Where a permeability transform is available, the average permeability over each major sand body should also be presented.

## 2.7 Case study 1 :

COMPARATIVE ANALYSIS OF HYDROCARBON POTENTIAL IN SHALY SAND RESERVOIRS USING ARCHIE AND SIMANDOUX MODELS: A CASE STUDY OF "X" FIELD, NIGER DELTA, NIGERIA

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The aim of this study is evaluate four wells in a typical Niger Delta field using the Archie and Simandoux models and compare them estimate the petrophysical parameters with a view to determining the hydrocarbon potential in shaly sand reservoirs .

Where the interpretation difficulties arise whenever the portions of clay minerals in formation are high.

These clay minerals contribute to the increase of the overall conductivity. In a large quantity, their conductivity becomes as important as the conductivity of the formation water.

Where the volume of shale calculation from logs has made because of its further influence on the computation of important petrophysical properties such as porosity and water saturation it is applied to most widely used shale sand Smit and Dual water to characterize excess conductivity . The most frequently used technique for deriving volume of shale in Niger delta, is from gamma ray ,and neutron density logs (Adeoti eta; 2009).

The data were loaded ,processed and interpreted with the use of Geology software . The reservoir of interest were delineated using a combination of lithology, resistivity, and porosity logs .

The clay volume and volume of shale are used interchangeably in the study .

The volume of shale from natural gamma ray was calculated using the formula

expressed in equation (1)

$$V_{sh}\ \text{linear} = \frac{GR - GR_{cl}}{GR_{sh} - GR_{cl}} \quad (1)$$

**Where :**

**GR** is the gamma ray log reading in the zone of interest.

**$GR_{cl}$** is the gamma ray log reading 100% clean zone.

**$GR_{sh}$** is the gamma ray log reading in 100% shale zone.

The volume of shale from neutron -density combination was calculated by using the relation in equation (2)

$$V_{sh}\ \text{neutron-density} = \frac{\Phi_n - \Phi_d}{\Phi_{nsh} - \Phi_{dsh}} \quad (2)$$

**Where:**

**Ød =** density porosity in the sand.

**Øn =** neutron porosity in the sand **.**

The volume of shale from resistivity was calculated by applying the formula expressed in equation (3)

$$V_{sh}\ \text{resistivity} = \frac{\log(RESD) - \log(RESD\_CLN)}{\log(RESD\_SHL) - \log(RESD\_CLN)} \quad (3)$$

**Where:**

RESD = resistivity log reading from zone of interest.

RESD – CLN = resistivity log reading from clean sand .

RESD-SHL = resistivity log reading from shale.

The volume of shale total was estimated from the combination of volume of shale from the gamma , resistivity and neutron-density logs .

Water saturation analyses were carried out using water saturation from Archie and Simandoux equations . The Archie equation is presented in equation (4)

$$S_w = \sqrt{\frac{F \times R_W}{R_t}} \qquad (4)$$

**Where:**

Rw = resistivity of formation water.

Rt = true formation resistivity.

F= formation factor.

The Simandoux equation for water saturation is presented in equation (5)

$$S_w = \frac{C.R_W}{\phi_e^2}\left[\sqrt{\frac{5\,\phi_e^2}{R_W\,.\,R_t} + \left(\frac{V_{sh}}{R_{sh}}\right)^2} - \frac{V_{sh}}{R_{sh}}\right] \qquad (5)$$

The effective porosity used in Simandoux model was determined from equation (6)

$$\text{Effective Porosity} = \sqrt{\frac{\Phi_{dc^2} + \Phi_{nc^2}}{2}} \qquad (6)$$

**Where:**

Ødc and Øcn represent density and neutron porosities corrected for shale given by equations .

Hydrocarbon saturation was determined from this equation:

$$\mathbf{S_h = 1 - Sw} \qquad (7)$$

The results of petrophysical values of this case study are shown in tables 1 and 2

| WELL | ZONE | TOP DEPTH (m) | BASE DEPTH (m) | NET (m) | PHT AVG | VSH AVG | PHIE AVG | BVW_SIMA AVG | SW_ SIMA AVG | F |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1099.57 | 1128.52 | 28.96 | 0.31 | 0.22 | 0.27 | 0.02 | 0.07 | 13.7 |
| | 2 | 1172.57 | 1203.05 | 30.48 | 0.32 | 0.17 | 0.29 | 0.03 | 0.11 | 11.9 |
| | 3 | 1274.37 | 1291.59 | 17.22 | 0.31 | 0.35 | 0.24 | 0.03 | 0.09 | 17.4 |
| | 4 | 1554.18 | 1583.89 | 29.72 | 0.27 | 0.21 | 0.23 | 0.06 | 0.22 | 18.9 |
| 2 | 1 | 1074.27 | 1138.13 | 63.86 | 0.32 | 0.3 | 0.28 | 0.03 | 0.1 | 12.8 |
| | 2 | 1144.68 | 1236.27 | 91.59 | 0.38 | 0.14 | 0.36 | 0.06 | 0.15 | 7.72 |
| | 3 | 1295.71 | 1357.89 | 62.18 | 0.32 | 0.2 | 0.29 | 0.05 | 0.17 | 11.9 |
| | 4 | 1465.03 | 1486.06 | 21.03 | 0.27 | 0.4 | 0.21 | 0.05 | 0.17 | 22.7 |
| | 5 | 1570.79 | 1593.96 | 23.16 | 0.3 | 0.19 | 0.27 | 0.03 | 0.11 | 13.7 |
| 3 | 1 | 1086.42 | 1127.11 | 40.69 | 0.34 | 0.28 | 0.31 | 0.02 | 0.05 | 10.41 |
| | 2 | 1153.78 | 1215.35 | 61.57 | 0.32 | 0.27 | 0.29 | 0.03 | 0.09 | 11.89 |
| | 3 | 1304.81 | 1341.23 | 36.42 | 0.3 | 0.21 | 0.27 | 0.04 | 0.14 | 13.72 |
| | 4 | 1548.65 | 1584.92 | 36.27 | 0.32 | 0.3 | 0.28 | 0.05 | 0.15 | 12.76 |
| 4 | 1 | 1311.6 | 1329.1 | 17.5 | 0.29 | 0.29 | 0.25 | 0.04 | 0.13 | 16 |
| | 2 | 1426.3 | 1436.8 | 10.5 | 0.27 | 0.37 | 0.22 | 0.05 | 0.19 | 20.7 |
| | 3 | 1534.5 | 1572.2 | 37.6 | 0.29 | 0.23 | 0.26 | 0.04 | 0.15 | 14.8 |
| | 4 | 1587.7 | 1593.2 | 5.49 | 0.3 | -0.2 | 0.32 | 0.05 | 0.16 | 9.77 |
| | 5 | 1620 | 1630.9 | 11 | 0.3 | -0 | 0.31 | 0.05 | 0.17 | 10.4 |

Table 1 – Petrophysical Analysis (Archie ) of Wells (1 – 4 )

| WELL | ZONE | TOP DEPTH (m) | BASE DEPTH (m) | NET (m) | PHIT AVG | VSH AVG | PHIE AVG | BVW_ARC AVG | SW_ARC AVG | F |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1099.57 | 1129 | 28.96 | 0.31 | 0.2 | 0.27 | 0.05 | 0.15 | 13.7 |
| | 2 | 1172.57 | 1203 | 30.48 | 0.32 | 0.2 | 0.29 | 0.06 | 0.18 | 11.9 |
| | 3 | 1274.37 | 1292 | 17.22 | 0.31 | 0.4 | 0.24 | 0.07 | 0.23 | 17.4 |
| | 4 | 1554.18 | 1584 | 29.72 | 0.27 | 0.2 | 0.23 | 0.09 | 0.33 | 18.9 |
| 2 | 1 | 1074.27 | 1138.13 | 63.86 | 0.32 | 0.3 | 0.28 | 0.07 | 0.21 | 12.8 |
| | 2 | 1144.68 | 1236.27 | 91.59 | 0.38 | 0.14 | 0.36 | 0.07 | 0.2 | 7.72 |
| | 3 | 1295.71 | 1357.89 | 62.18 | 0.32 | 0.2 | 0.29 | 0.08 | 0.25 | 11.9 |
| | 4 | 1465.03 | 1486.06 | 21.03 | 0.27 | 0.4 | 0.21 | 0.09 | 0.35 | 22.7 |
| | 5 | 1570.79 | 1593.96 | 23.16 | 0.3 | 0.19 | 0.27 | 0.05 | 0.18 | 13.7 |
| 3 | 1 | 1086.4 | 1127.1 | 40.69 | 0.34 | 0.28 | 0.31 | 0.03 | 0.1 | 10.4 |
| | 2 | 1153.8 | 1215.4 | 61.57 | 0.32 | 0.27 | 0.29 | 0.05 | 0.15 | 11.9 |
| | 3 | 1304.8 | 1341.2 | 36.42 | 0.3 | 0.21 | 0.27 | 0.06 | 0.21 | 13.7 |
| | 4 | 1548.7 | 1584.9 | 36.27 | 0.32 | 0.3 | 0.28 | 0.06 | 0.21 | 12.8 |
| 4 | 1 | 1311.6 | 1329.1 | 17.5 | 0.29 | 0.29 | 0.25 | 0.06 | 0.2 | 16 |
| | 2 | 1426.3 | 1436.8 | 10.5 | 0.27 | 0.37 | 0.22 | 0.07 | 0.28 | 21 |
| | 3 | 1534.5 | 1572.2 | 37.6 | 0.29 | 0.23 | 0.26 | 0.06 | 0.2 | 15 |
| | 4 | 1587.7 | 1593.2 | 5.49 | 0.3 | -0.2 | 0.32 | 0.04 | 0.13 | 9.8 |
| | 5 | 1620 | 1631 | 11 | 0.3 | -0 | 0.31 | 0.05 | 0.18 | 10 |



Table 2 – Petrophysical Analysis (Simandoux ) of Wells (1 – 4 ) .

| Sw by Archie | Sw by Simandoux |
|---|---|
| 0.15 | 0.07 |
| 0.18 | 0.11 |
| 0.23 | 0.09 |
| 0.33 | 0.22 |
| 0.21 | 0.1 |
| 0.2 | 0.15 |
| 0.25 | 0.17 |
| 0.35 | 0.17 |
| 0.18 | 0.11 |
| 0.1 | 0.05 |
| 0.15 | 0.09 |
| 0.21 | 0.14 |
| 0.21 | 0.15 |
| 0.2 | 0.13 |
| 0.28 | 0.19 |
| 0.2 | 0.15 |
| 0.13 | 0.16 |
| 0.18 | 0.17 |

Table 3- water saturation using both Archie's equation and simandoux model.

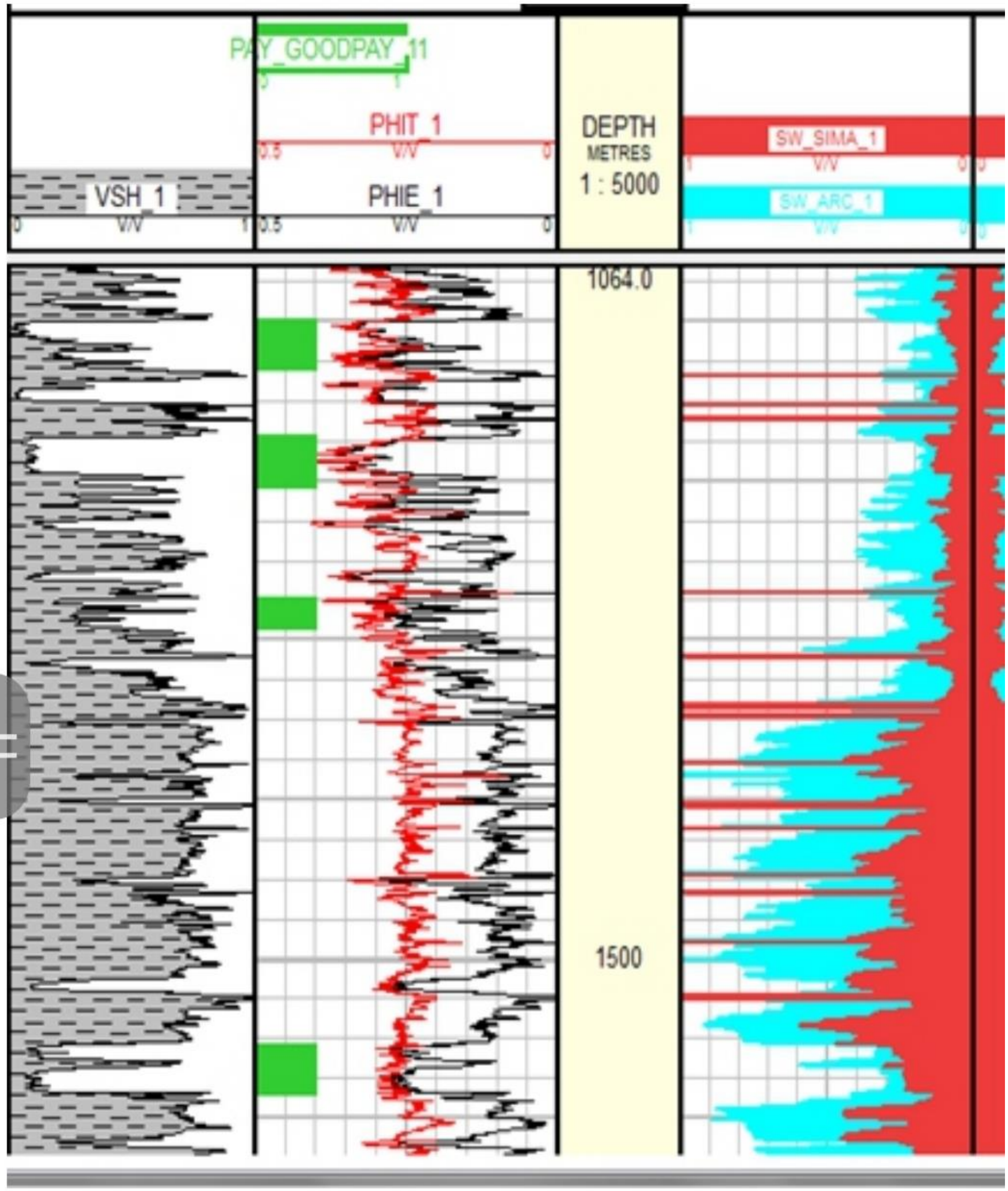



Figure 1: Comparative between Archie and Simandoux models for Sw calculation

## 2.8 Case study 2:

*Petrophysical interpretation in shaly sand formation of gas field in Tanzania* An onshore gas .

field called R field is in the southeast coast of Tanzania. An exploration well R-x was drilled vertically using water-based mud to total measured depth at 3489m in sand formation . The commercial , sweet, dry gas was detected in the well R-x as confirmed by resistivity logs and drill stem tests .This was the target formation for petrophysical properties interpretation .However , minor oil shows were detected during drilling further down at the bottom of the well.

The target formation in the stratigraphy of the area can be categorized as shaly sand .

Petrophysical properties such as porosity, water saturation, and reservoir thickness are fundamental to reserves estimation and production forecast . This properties can be derived from well logs, formation pressure test or cores through formation evaluation test ,or combined cores with wireline logs .

Properties accounting for and included in models to compute water saturation are resistivity, porosity, formation water salinity , lithology-dependent fitting parameters

( cementation or porosity exponent m , and saturation exponent n) and temperature.

Established methods ware used in evaluation of the properties considered .

The equation of Clavier et al was used to compute shale volume from gamma ray. Density and neutron-density methods were used to calculate total and effective porosities . Water saturation in the sand was computed using the model of Poupon and

Leveaux.  The model include shale resistivity and shale volume to account shale effect .

Methodologies used were implemented in **Techlog** software  .

## Shale volume computation :

Shale volume was computed using Clavier Equation1 and neutron-density equation 2.

**Clavier equation for shale volume**

$$V_{\text{shale}} = 1.7 - \sqrt{3.38 - \left(\text{GR}_{\text{index}} + 0.7\right)^2}. \quad (1)$$

Where $\text{GR}_{\text{index}} = \frac{\text{GR}_{\text{log}} - \text{GR}_{\text{ma}}}{\text{GR}_{\text{shale}} - \text{GR}_{\text{ma}}}$

Properties of 100% shale ware taken at a depth interval between 1413 and 1485

The mean of the volume oh shale that was obtained for zonze is range from 0.2 to 0.4 $m^3/m^3$ .

$$V_{\text{shale}} = \frac{\text{NPHI}_{\text{log}} - \text{NPHI}_{\text{ma}} + M_1\left(\rho_{\text{ma}} - \rho_{\text{log}}\right)}{\text{NPHI}_{\text{shale}} - \text{NPHI}_{\text{ma}} + M_1\left(\rho_{\text{ma}} - \rho_{\text{shale}}\right)}.$$

**(2)**

Where $M_1 = \frac{\text{NPHI}_{\text{f}} - \text{NPHI}_{\text{ma}}}{\rho_f - \rho_{\text{ma}}}$ "which is a slop of a line"

## Total and effective porosity :

Bulk total porosity and effective porosity of each zone were computed using density 3 and neutron-density 4 equations .

**Density porosity equation**

$$\phi_t = \frac{\rho_{ma} - \rho_{log}}{\rho_{ma} - \rho_f}. \quad (4\text{-a})$$

$$\phi_{t\_shale} = \frac{\rho_{ma} - \rho_{log}}{\rho_{ma} - \rho_f}. \quad (4\text{-b})$$

$$\phi_e = \phi_t - (\phi_{t\_shale} V_{shale}). \quad (4\text{-c})$$

**Algorithm calculate porosity from neutron- density cross-plot**

$$\text{If } \rho_{mf} < \rho_{sand}, \rho_{mf} \langle \rho_b \text{ and } \rho_b \rangle 0$$

$$\phi_d = \frac{\rho_b - \rho_{lim}}{\rho_{mf} - \rho_{lim}}. \quad (5)$$

The mean value of total porosity was 21.8% , and effective porosity was 15.6%

## Computation of water saturation :

Water saturation was computed by using Archie and Poupon and Leveaux 6,7 equations.

**Archie equation**

$$S_w = \left( \frac{aR_w}{\phi_t^m R_t} \right)^{\frac{1}{n}}, \quad (6)$$

**Where:**

a = tortuosity factore . n = saturation exponent .

m = cementation exponent. Rt = formation resistivity.

Rw = formation water resistivity.

**Poupon and Leveaux equation (Indonesia model)**

$$S_w = \left[ (V_{\text{shale}})^d \sqrt{\frac{R_t}{R_{\text{shale}}}} + \sqrt{\frac{\phi_e^m R_t}{aR_w}} \right]^{\frac{-2}{n}}, \qquad (7)$$

Where d = 1- 0.5 * Vshale

**Formation water resistivity**

$$R_w = \frac{R_{\text{mf}} R_t}{R_{\text{xo}}}, \qquad (8)$$

**Where:**

Rmf = resistivity of mud filtrate .

Rxo = resistivity of invaded zone .

Average water saturation by using Archie was range from 32% to49% and by using Poupon and Leveaux was range from 19% to 45% .

Archie equation doesn't take in account the shale volume so it give higher value of water saturation , In shaly sand reservoir models such as Poupon and Leveaux must be used .

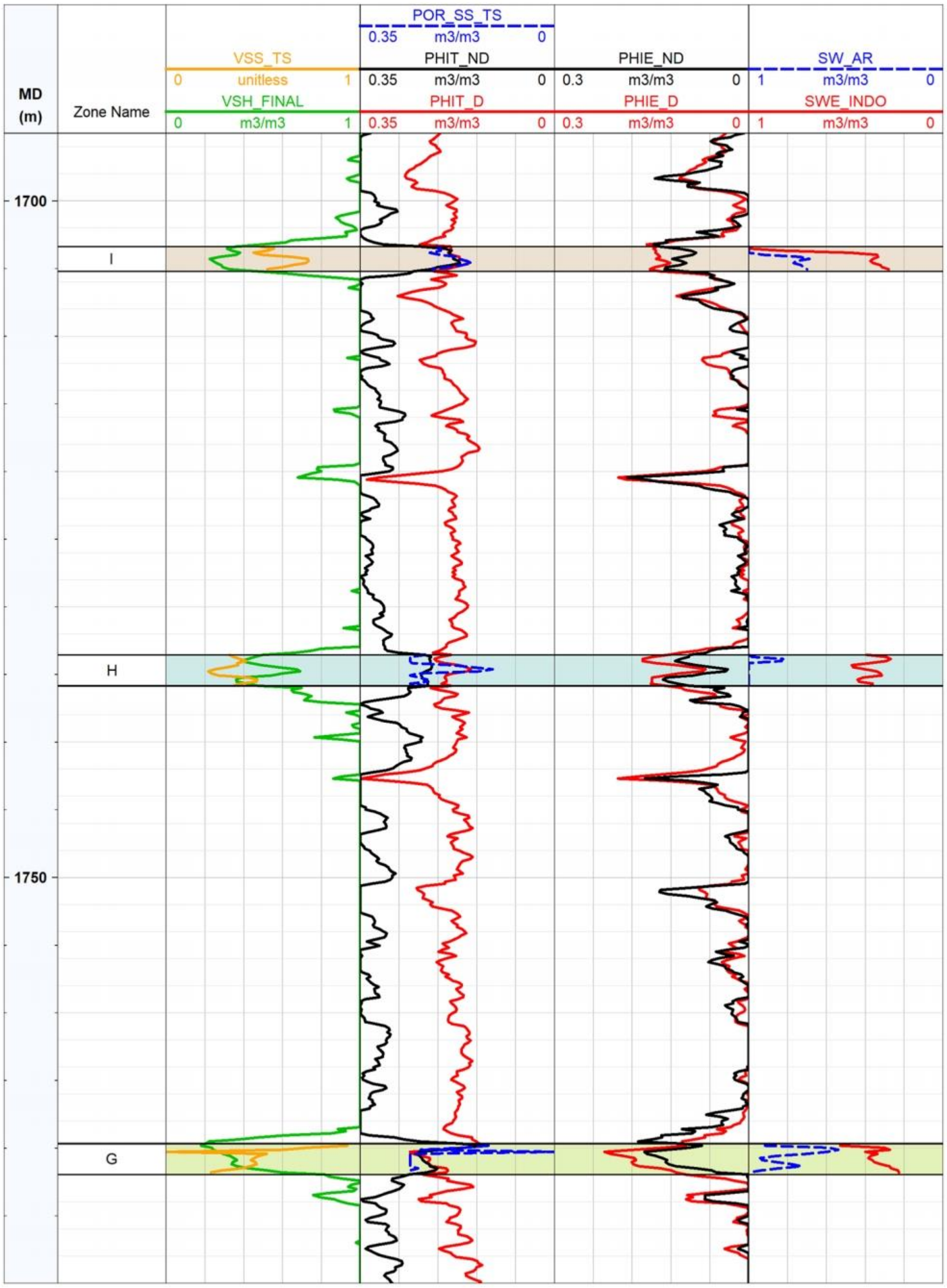



Figure.1 Display the results of water saturation by Archie and Indonesian models.

# CHAPTER THREE

# 3. METHODOLOGY

## 3.1. Introduction

This project is focused on the impact of uncertainty in petrophysical evaluation of shaly sand reservoirs of Sharyoof field in block-53 (Say'un Masila basin) by using TECHLOG software.

## 3.2. Types of Data Needed for The Project

The data required for ideal interpretation is shown in **Table. 3-1**

| No | Data Required |
|---|---|
| 1 | Geological Report |
| 2 | Drilling data |
| 3 | Mud Logging Data |
| 4 | Core report |
| 5 | Well Logs Data |
| 6 | Cut Off values of Say'un Masila basin. |
| 7 | Petrophysical Report |
| 8 | Production Report |

*Table3- 1Data required for the Project*

## 3.3. Data Collection Methods

The Petroleum Exploration and Production Authority and DPDB were approached to get the required data to work and perform the project. This was organized by the HOD and faculty dean by preparing and sending an official letter to provide the related data. Only limited volume of data was provided concerning Sharyoog 2& 9 wells mainly related to wireline logs data, no core or production or petropysical report data are available.

## 3.4. ANALYSIS APPROACH

Analysis approach for the available data is Qualitative and Quantitative (Analytical and Descriptive approach). **Techlog Software 2015.3** will be used.

The data will be checked for the quality, corrected and presneted, folowing by traditional steps for logs interpretation.

### 3.4.1. TECHLOG 2015.3

Techlog is a Schlumberger owned Windows based software platform intended to aggregate all the wellbore information. It allows the user to interpret any log and core data. It addresses the need for a single platform able to support all the wellbore data and interpretation integration workflows, reducing the need for a multitude of highly specialized tools. By bringing the whole workflow into a single platform risk and uncertainty can be assessed throughout the life of the wellbore.

With the Techlog Quanti module, you can perform log quality control and precomputations of fluid properties followed by a full petrophysical analysis. This workflow can be saved and reused for future work, incorporating Monte Carlo for uncertainty analysis.

Using the module for interactive log interpretation, it is possible to

- Design your own petrophysical workflow
- Save and quickly reapply workflows to new data
- Easily transfer workflows to other projects
- Resample on-the-fly, allowing variables from different datasets to be input to a workflow
- Add your own scripts to further extend your workflows.
- Log quality control

Multiwell control of petrophysical parameters can be achieved by setting defaults for well, dataset, and zone combinations. With graphical and tabular, multiwell and multizone parameter management, users have control at all times. Plots are dynamically linked to parameter tables, allowing graphical selection of equation parameter values. Using the cascade function, parameter values can be edited and effects monitored on subsequent results.

**Petrophysical computations**

A comprehensive list of petrophysical computations (lithology, porosity, saturation, productivity, etc.) is available in the Quanti module. Parameter defaults can be defined at project, well, and zone levels and hierarchical parameter management facilitates scenario comparison. Users may insert scripts into the Quanti workflows for instant multiwell, multizone applications. Monte Carlo uncertainty modeling can also be performed.

**Workflow design**

Quanti workflows enable users to

- Apply cutoffs to determine reservoir and pay quality rock
- Calculate sums and averages over discriminated intervals
- Create report quality tables by zone or by layer
- Investigate sensitivities to the choice of cutoffs and uncertainties in results.

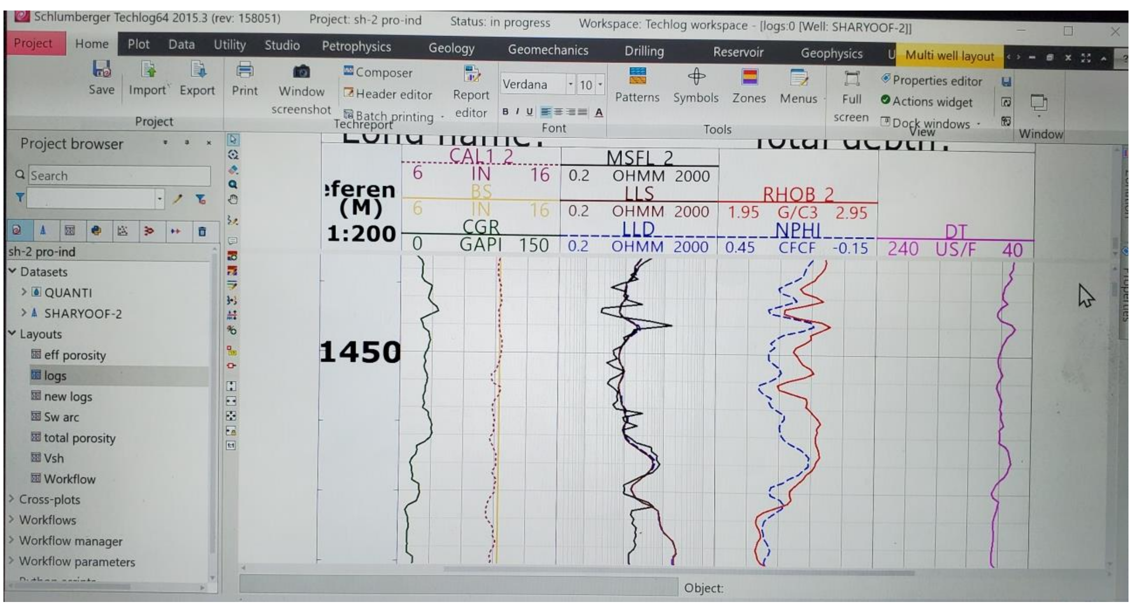



*Figure 3- 1 Techlog Interface*

## 3.5. Expected Results

After the analysis for the data, and evaluating a shaly sand reservoir by known different techniques, we expect to find out the effect of shale presence on the calculated petrophysical parameters such as porosity and saturations and to reduce the uncertainty of petrophysical analyss results for Shatyoof field in block 53 in (Say'un Masila basin ). Analysis will be done by evaluating the well logs for two wells in the field.

Different results using an Archi equation and Simandoux,or Indonesian equation will be shown in the outputs plots and time tables.

# CHAPTER FOUR

# 4. PETROPHYSICAL INTERPERTATION

## 4.1. Introduction

In this chapter well log interpretation and analysis are carried out using Techlog software for two wells ( Sharyoof-2 & Sharyoof-9) in Sharyoof field,block-53. A log database was created for Sharyoof -2 & Sharyoof-9 in Techlog , the petrophyical analysis software. Net pay, shale volume, porosity and water saturation were calculated.

The comparative of two wells ( Sharyoof-2 & Sharyoof-9) in block-53 was taken using Archie and Indonesian models. Many types of logs and calculations had been recorded to estimate the effects of present of shale in saturation values in sand reservoirs.

This chapter will debate the interpretation to find uncertainties in determination of water saturation and figure out the best method to minimize the uncertainties.

Based on the analysis, the main target is S1A Sand as well as S1C which are oil-bearing. All other intervals were water-bearing.

The applied cutoff values and parameters used for petrophysical analysis and properties calculatios are listed in Tab. 4-1. and 4-2.

| Net Sand and Net Pay Cut-offs | | | |
|---|---|---|---|
| **Zone** | **VSh cutoff** | **Porosity-Cuto** | **Sw Cut-off** |
| **S1A** | 0.35 | 0.1 | 0.5 |
| **S1B** | 0.35 | 0.1 | 0.5 |
| **S1C** | 0.35 | 0.1 | 0.5 |
| **S2** | 0.35 | 0.1 | 0.5 |
| **S3** | 0.35 | 0.1 | 0.5 |

*Table4- 1 shown the cut-offs that were used in the analysis*

The parameters listed in table 4-2 were used in calculation which are cementation factor (m), tortuosity factor (a) , saturation exponent (n) , and formation water resistivity (Rw).

| | |
|---|---|
| **a** | 1 |
| **m** | 1.8 |
| **n** | 2 |
| **Rw** | 0.95 |

*Table4- 2 Factors Used For Sw Calculations*

The main logs that had been used in the interpretation are gamma ray (GR) , caliper log ( CALI),Compensated Neutron (NPHI), Corrected Bulk Density ( RHOB), Soinc travel time log (DT), Resistivity logs which include Deep Lateralog (LLD), Shallow Lateralog (LLS) , and Micro-Spherical Focused Log (MSFL).

## 4.2 . Basis of Petrophysical Analysis of Sharyoof-2 & Sharyoof-9 Wells

There are different well logging tools that were used in Sharyoof-2 & sharyoof-9 wells which are divided into three tracks. The first track included Gamma ray log (GR) used to deleneate formations tops (zonation), and to determine the shale volume "Vsh", Caliper log (CALI) to determine hole diameter. The second track included Deep resistivity Lateralog (LLD) to determine the formation true resistivity "Rt" , Shallow Lateralog (LLS), and Micro-Spherical Focused Log (MSFL) to determine the resistivity of shallow zones (Flushes and invaded zones). The third track included Compensated Neutron (NPHI) , and Corrected Bulk Density (RHOB), to determine both the total and effective porosity from crossplots.

The combination of (Vsh), (Øeffe) and (Rt) were used to determine water saturation (Sw).

The Qishn formation delineated reservoir zones are listed below in Table 4-3.

<table>
<tr><td rowspan="8">Qishn Formation</td><td colspan="2">Qishn Carbonates</td></tr>
<tr><td colspan="2">Red Shale</td></tr>
<tr><td rowspan="5">Upper Qishn Clastics</td><td>S1A</td></tr>
<tr><td>S1B</td></tr>
<tr><td>S1C</td></tr>
<tr><td>S2</td></tr>
<tr><td>S3</td></tr>
<tr><td colspan="2">Lower Qishn Clastics</td></tr>
</table>

*Table4- 3 Zonation of Qishn Clastic Formation*

### 4.2.1.Lithology Determination

Lithologies were determined over the interval from Red Shale to lower Qishn based on analysis of the gamma ray and photoelectric log responses and confirmed by data from density, lithology and mud logs.

### 4.2.2.Volume of Shale Calculation

The volume of shale (Vsh) was calculated from the gamma ray log using two methods that are Linear method and Larionov methods to see the impact of shale volume on water saturation. Shale parameters were picked from intra-Qishn Formation shales.

Because shale is usually more radioactive than sand or carbonate, gamma ray logs are used to calculate volume of shale in porous shaly reservoirs .

The volume of shale expressed as a decimal fraction or percentage is called Vshale. This value can then be applied to the analysis of shaly sands .

Calculation of gamma ray index is the first step needed to determine the volume of shale from a gamma ray log **.**

This is important as a threshold value of shale volume (cutoff value ) is often used to help discriminate between reservoir and non- reservoir rocks **.**

Estimating the rock's shale volume Vsh linearly from the gamma ray log still remains the first preferred approach to become with a preliminary shaliness indicator. The procedure is easy and straightforward, and might give reasonable results for some deep reservoirs. The first equation is shown below defines an $I_{GR}$ shaliness index (linear method ) as a function of the GR gamma ray log reading.

**Shale index ($I_{GR}$) = GR log - GR clean / GR shale - GR clean** (Equ-4.1)

**Where;**

$I_{GR}$ = gamma ray index

GR log = gamma ray reading of formation of interest

GR clean = minimum gamma ray ( clean sand or carbonate)

GR shale = maximum gamma ray (in front of shale layer)

It is required to record the response of the gamma ray log for a nearby known shale body and a nearby known clean rock**.**

However, quite often the linear $I_{GR}$ shaliness indicator yields an over-estimation of rock's volume of shale (specially for shallow, young reservoirs), producing higher water saturation and an overall pessimistic scenario of the reservoir quality. To overcome this, several empirical formulations have been developed to correct and reduce the rock's shale volume (Vsh) as a direct functions of shale index ($I_{GR}$), that is Vsh = f ($I_{GR}$), trying to adjust the clay minerals total radioactive response**.**

The Larionov ( 1969) equation for older rocks below (eq 4-2) is used for the calculation of shale volume.

$$VSH_{\text{LarionovOldRocks}} = 0.33\ (2^{(2\ IGR)} - 1)$$

(Equ 4-2)

**Where؛**

$I_{GR}$ is the gamma ray index.

Vsh is the shale volume of the formation of interest.

### 4.2.3.Porosity Determination.

Total and effective porosity were calculated from the Neutron-density log using Vshale over the Qishn Formation.

The Netron-Density crossplot of Sharyoof-2 & Sharyoof-9 are used for the calculation the porosity .

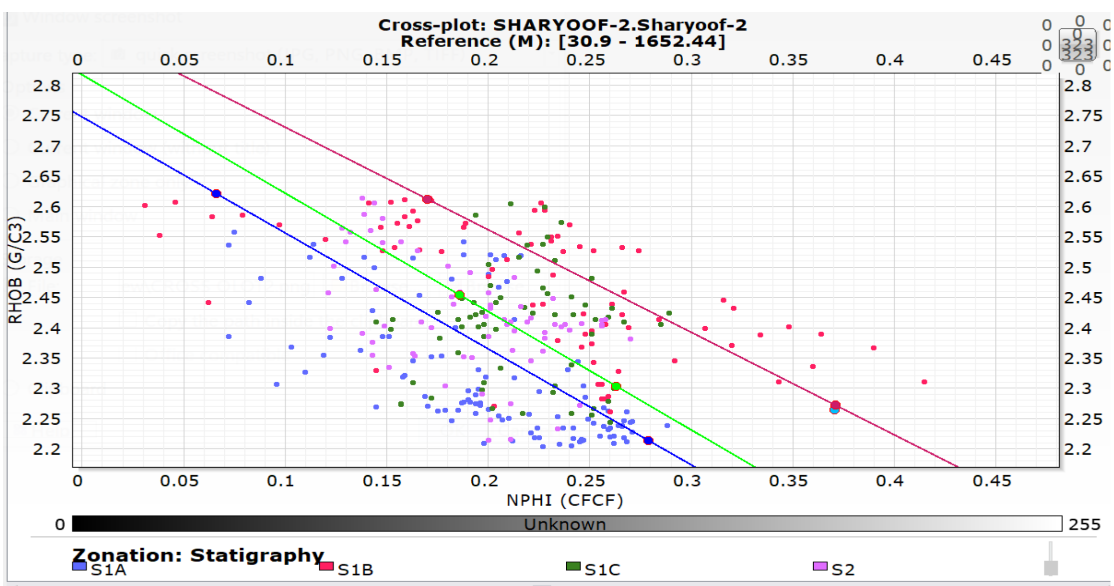



*Figure4- 1 Sharyoof-2 Netron – Density crossplot*

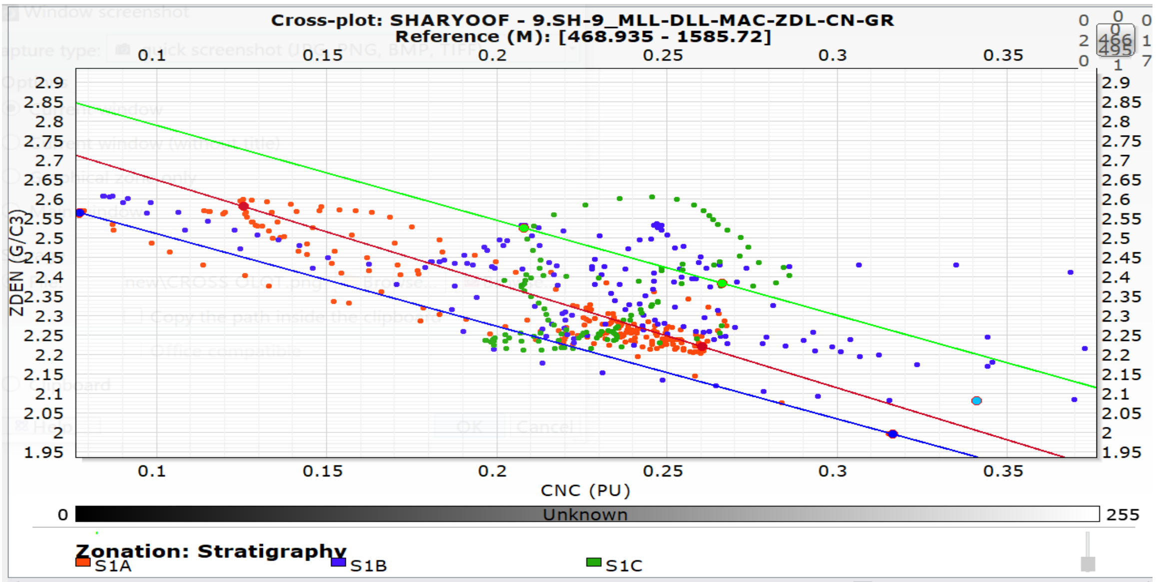



*Figure4- 2 Sharyoof-9 Netron-Density crossplot*

## 4.2.4.Water Saturation Determination

Water Saturation (Sw) was determined by means of two methods Archie ,and Indonesian, to find out the the difference in their ouputs and the effect of shale content on such differences.

Evaluation of the amount of hydrocarbons present in the reservoir is based on the ability of the log analyst to estimate the volume of water present in the pore space .

As the hydrocarbon saturation of the pores increases ( as the water saturation decreases ), the formation's resistivity increases, and as the salinity of the water in the pores decreses (as Rw increses ), the rock's resistivity also increases.

This requires the solution of some form of Archie equation for the water saturation parameter Sw in uninvaded zone.

If the sand contains petroleum, the true resistivity Rt will increase, whereas the formation factor FR will remain the same because it is a function of the formation porosity only.

Model studies of the first Archie equation, which relates the formation resistivity factor and porosity specifically for effectively clean (shale-free) porous media, have quantified the changes to this relationship caused by latent shale effects .

A geologist / Petrophysicist, by knowing (or determining) several parameters (a, n, m, Rw), and by determining from logs the porosity (Φ) and formation bulk, or true, resistivity (Rt), can determine the formation's water saturation (Sw) for clean formation as per the Archie equation below:

$$S_w = \left(\frac{a \ x \ R_w}{R_t \ x \ \phi^m}\right)^{\frac{1}{n}} \qquad \text{(Equ4.3)}$$

**Where ;**

Sw = total water saturation؛

n = saturation exponent؛

m = cementation exponent؛

a = tortuosity factor؛

Φ =porosity fraction؛

Rw = formation water resistivity Ω.m (Resistivity of connate wate)؛

Rt = true formation resistivity as derived from a deep reading resistivity log Ω.m؛

When the rock matrix has some electrical conductivity , the resistivity is not only a function of the water resistivity ( Rw ) , but also depends upon the matrix rock minerals beside the non conductive quartz and calcite matrix grains . The most common cases happen on clastic shaly rocks with important content of clay minerals .

In these shaly rocks the Archie law over-estimates the water saturation . Many models consider the shale volume in the matrix to account for the excess of conductivity such as Simandoux and Indonesian models .

Even though numerous other relationships have been developed over the years, the Archie equation remains the most flexible and generally useful approach. Yet its proper application requires knowledge of its limitations such as, it doesn't take into account the presence of shale that will cause over-estimation in the calculation of the water saturation . The equation was empirical in origin and therefore needs modification in rock–fluid combinations different from Archie's experiments.

Simandoux equation of 1963 was one of the first models to successfully incorporate and correct the excess of conductivity in the matrix due to the presence of shale .

$$SW_{\text{Simandoux}} = \frac{a\,.\,Rw}{2\,.\,\phi^{m}} \left[ \sqrt{\left(\frac{Vsh}{Rsh}\right)^{2} + \frac{4\,\phi^{m}}{a\,.\,Rw\,.\,Rt}} - \frac{Vsh}{Rsh} \right] \quad \text{(Equ 4.4)}$$

**Where;**

Rt is formation resistivity ،

Rw is formation water resistivity ،

Rsh is shale resistivity ،

φ is the porosity,

a, n, m are Archie equation constants،

Vsh is fraction of shale (shale volume) ،

Sw is water saturation .

Simandoux equation is usually the default option to work with shaly rocks when the water resistivity (Rw) is low . Many clastic reservoirs with " fresh" salinities of less than 20.000 PPM equiv. NaCl " high water resistivity " behave better with Indonesian equation.

As a general rule, we recommend to consider the use of Indonesian Equation for areas with large amounts of dispersed shale , and reservoirs with fresh formation water, Simandoux equation for salty reservoirs. .

The Indonesian water saturation equation by Poupon- Leveaux (1971), is one of the best models to estimate Sw in shaly rocks especially in dispersed shale. The Indonesian model is a closed mathematical formula easy to apply, that uses the regular parameters, a toruosity, m porosity cementation exponent, and n water saturation exponent.

$$SW_{\text{Indonesia}} = \left\{ \frac{\sqrt{\frac{1}{Rt}}}{\left(\frac{Vsh^{(1-0.5Vsh)}}{\sqrt{Rsh}}\right) + \sqrt{\frac{\phi_e^m}{a.Rw}}} \right\}^{(2/n)} \quad \text{(Equ 4.5)}$$

With Archie exponents m and n which are usually set to 2, a can vary between 0.6 to 1

Zone parameters :

a =1 , m= 1.8 , n = 2 , Rw = 0.95 Ω-m.

Statistically, Indonesian equation gives better results than the Simanduox equation when dispersed shale fractions are high **.**

### 4.2.5. Archie Equation Parameters Used for Sw Calculation in The Upper Qishn Formation in Sharyoof Field.

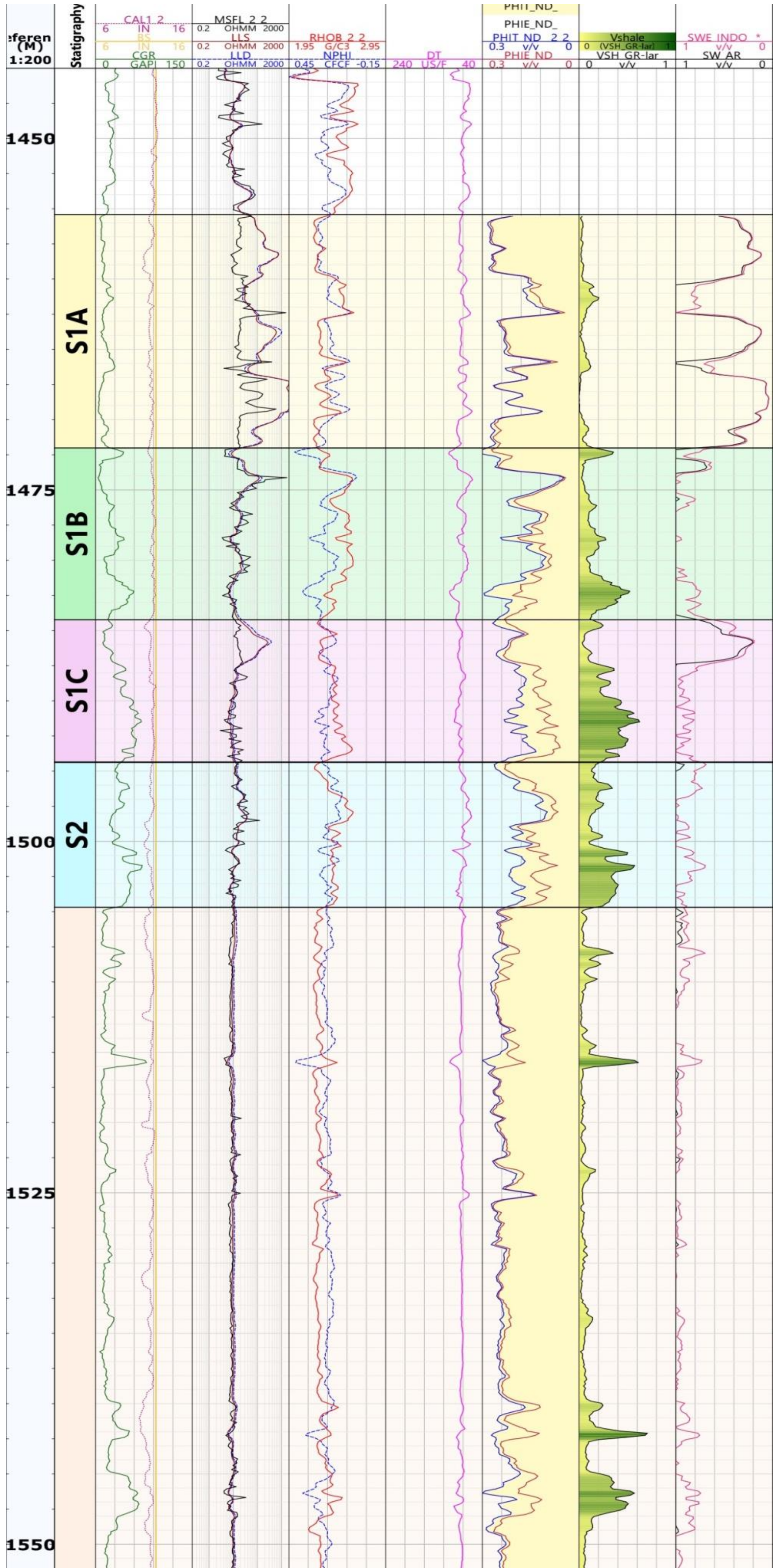
As stated aerlier in table 4-2, the following parameters are used in the calculation: value of the tortuosity factor, a, was selected as 1.0. The cementation and saturation exponents, m and n, were given values of 1.8 and 2 in the Qishn Formation , Rw value of 0.95 ohm-m was calculated using Arcie equation in ront of 100% water saturated zone , and average porosity value Ø ware used.
The true formation resistivity (Rt) was calculated from the deep laterolog tool (LLD).

## 4.3. Petrophysical Analysis of Clastic Qishn Formation in Sharyoof Field

### 4.3.1 Sharyoof-02-Well logs Interpretation

As it is mentioned, the Qishn clastic was taken as a study area which contains five layers: Qishn S1A, Qishn S1B, Qishn S1C, Qishn S2, Qishn S3 as a resrvoir targets (productive and non-productive zones) which will be analyzed below with comparing the values of shale volume using Linear and Larionov methods and the values of water saturation by means of using Archie and Indonesian equations.

The volume of shale (Vsh) calculation from logs become critical because of its further influence on the computation of important petrophysical properties such as porosity and water saturation.



eferen (M)
1:200
Statigraphy
CAL1_2
6 IN 16
BS
6 IN 16
CGR
0 GAPI 150
MSFL_2_2
0.2 OHMM 2000
LLS
0.2 OHMM 2000
LLD
0.2 OHMM 2000
RHOB_2_2
1.95 G/C3 2.95
NPHI
0.45 CFCF -0.15
DT
240 US/F 40
PHIT_ND_
PHIE_ND_
PHIT_ND_2_2
0.3 v/v 0
PHIE_ND
0.3 v/v 0
Vshale
0 (VSH_GR-lar) 1
VSH_GR-lar
0 v/v 1
SWE_INDO
1 v/v 0
SW_AR
1 v/v 0
1450
1475
1500
1525
1550
S1A
S1B
S1C
S2

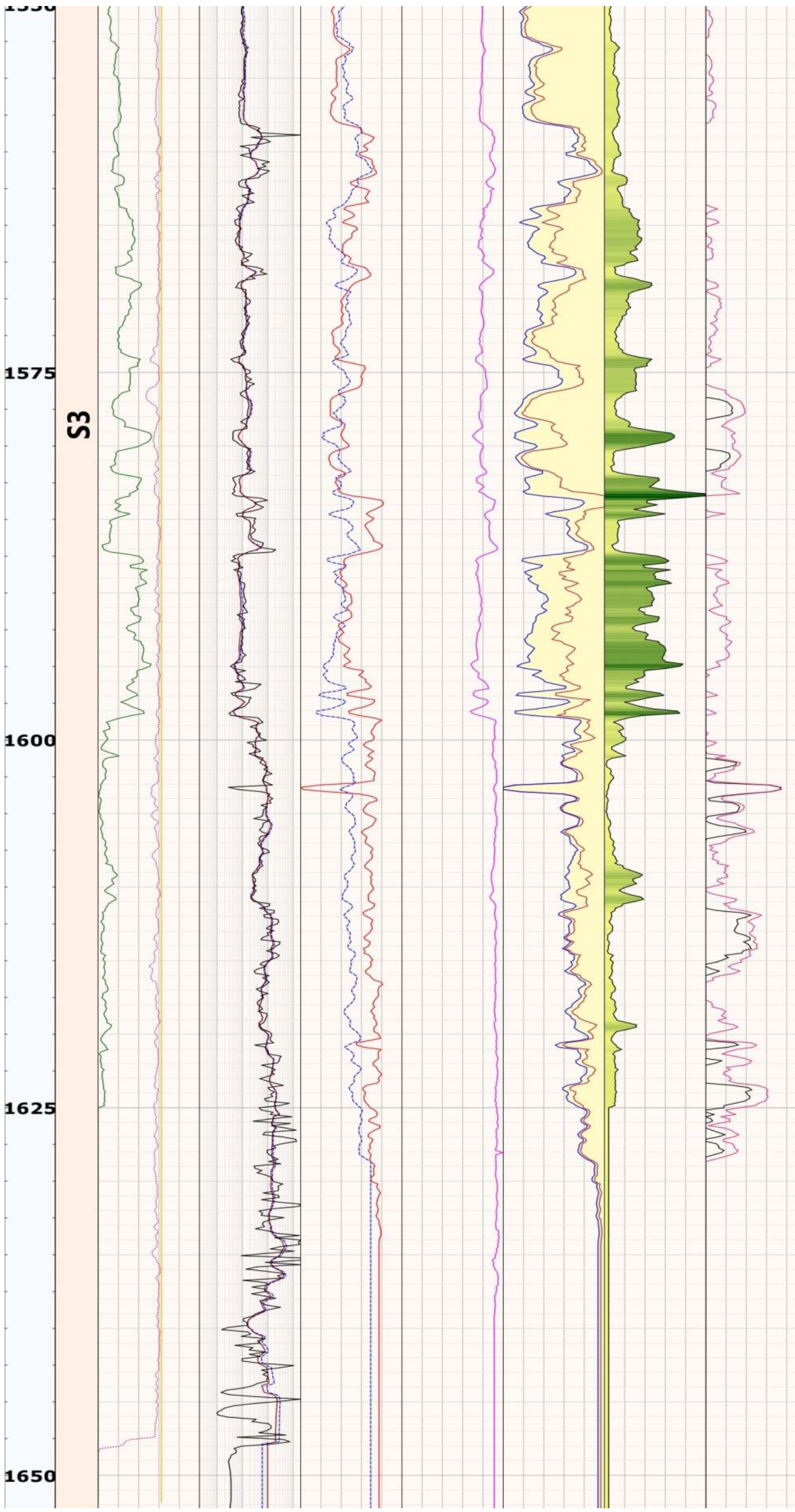



*Figure4- 3 Sharyoof-2 log analysis*

### 4.3.1.1Qishn S1A Zone

At the beginning, we've made a correction for the zonation depth of this well to separate evidently the layers.

As it is known ,the gamma ray classify the lithology of the formation into shale, nonshale,( shaly zones), and in the section below it points that the reading of gamma ray is low identifying sand presence in combination with others data.

Zone S1A is located in a depth from 1455.41 to 1472.016 m which might be signalized to be a productive reservoir. The logs ( Gamma Ray, Resistivity, and porosity) indicate that sand is the dominant formation, in addition to some amount of shale.

The resistivity of this layer is high and it might be an indicator for hydrocarbon presence.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about 16.606, 15.7, 12.19 respectively.

The zone contains 6.8% of average shale volume using Linear method "Vsh" and 3.3% by Larionov , 23.3% of average effective porosity "Φeff" , and 21.7 % of averge water saturation using Indonesian "Sw" while by Archie's equation Sw is 23.2% .

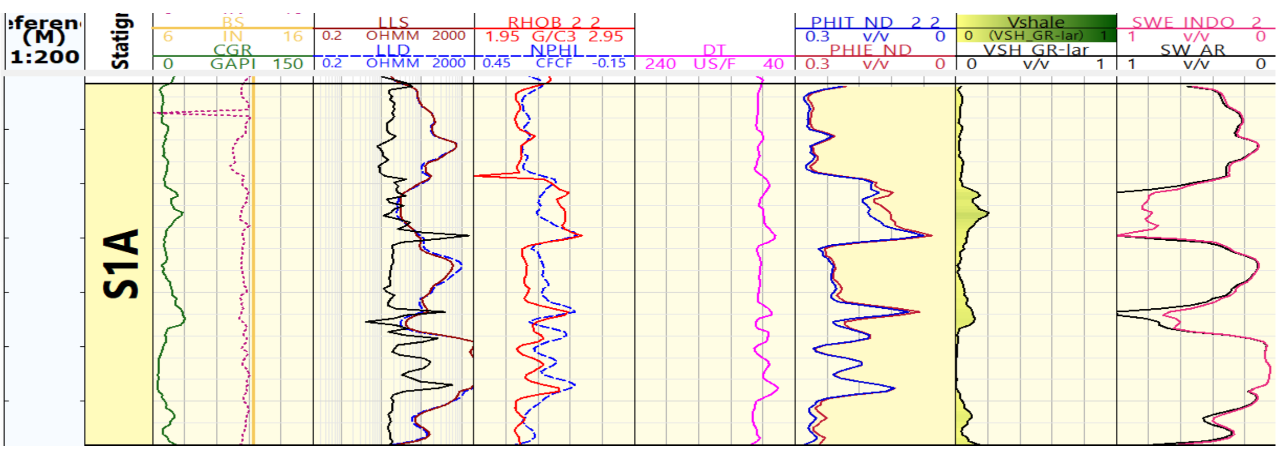



*Figure4- 4 Qishn S1A Interval in Sharyoof-2*

### 4.3.1.2 Qishn S1B Zone

This zone is located in a depth from **1472.016** to **1484.242**m. The logs reading ( Gamma Ray, Resistivity, and porosity) points that, the shale is tremendously considerable compared to the sand, with more clean top part of the layer.

In the log below, the layer is charcterized by high gamma ray reading because of the increase of shale content, and by low resistivity log readings because of water present and shale content.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about **12.226, 8.363, 0 m** respectively.

The zone contains 27.4% of average shale volume "Vsh" using Linear method 16% using Larionov, 16.4% of average effective porosity "Φeff", and 85.8% of average water saturation "Sw" using Indonesian while by using Archie Sw is 94.6%. So, the layer has no potential.

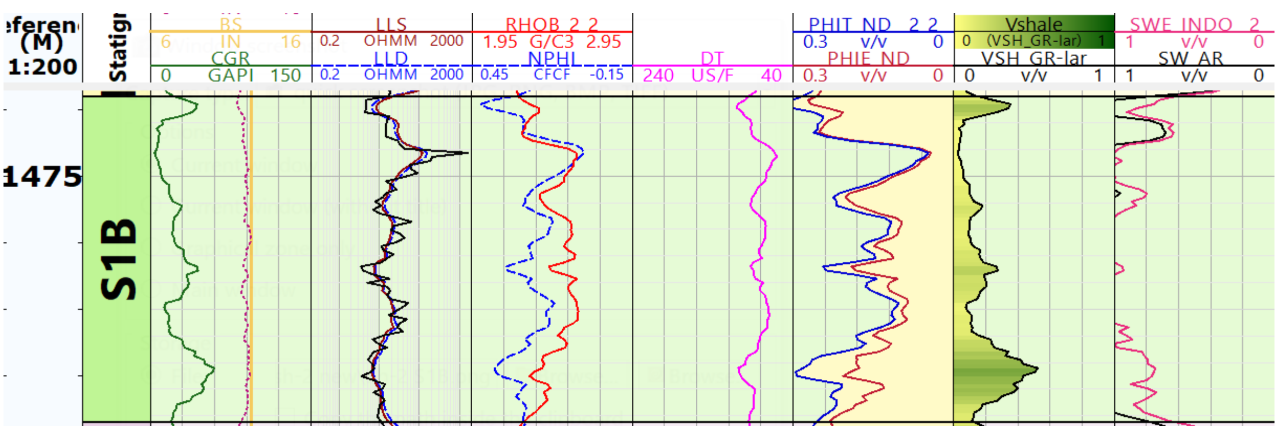



*Figure4- 5 Qishn S1B Interval in Sharyoof-2*

### 4.3.1.3 Qishn S1C Zone

This zone is located in a depth from **1484.242** to **1494.35** m. At the top of this layer, the gamma ray reading is lower which points out more clean sand .Then gamma ray did increased at the bottom of the same layer to point for shale content increase .

The logs interpretation ( Gamma Ray, Resistivity, and porosity) point out that, S1C zone has a slight to no potential at the top clean part of sand.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about **10.101, 5.529, 1.**67 **m** respectively.

The zone contains 14.4% of average shale volume "Vsh" by using Linear method whereas7.4% by using Larionov, and has 21.5% of average effective porosity "Φeff" , and 26% of averge water saturation "Sw"by using Indonesian however in Archie equation is 31% .

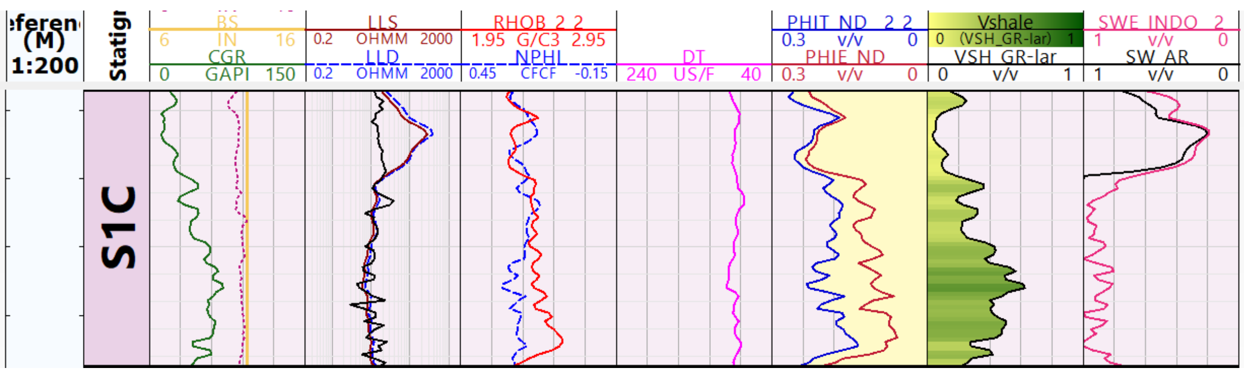



*Figure4- 6 Qishn S1C Interval in Sharyoof-2*

### 4.3.1.4 Qishn S2 Zone

This zone is located in a depth from **1494.35** to **1504.69 m.** The logs interpretation ( Gamma Ray, Resistivity, and porosity) indicate that the formation is highly shaly formation and water saturated.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about **10.4, 5.5, 0 m** respectively.

The zone contains 34.5. of average shale volume "Vsh" by using Linear method and 20.7% using Larionov, and has 15.8 of average effective porosity "Φeff" , and 84.5% of averge water saturation "Sw" by using Indonesian, and 99.1% using Archie's equation.

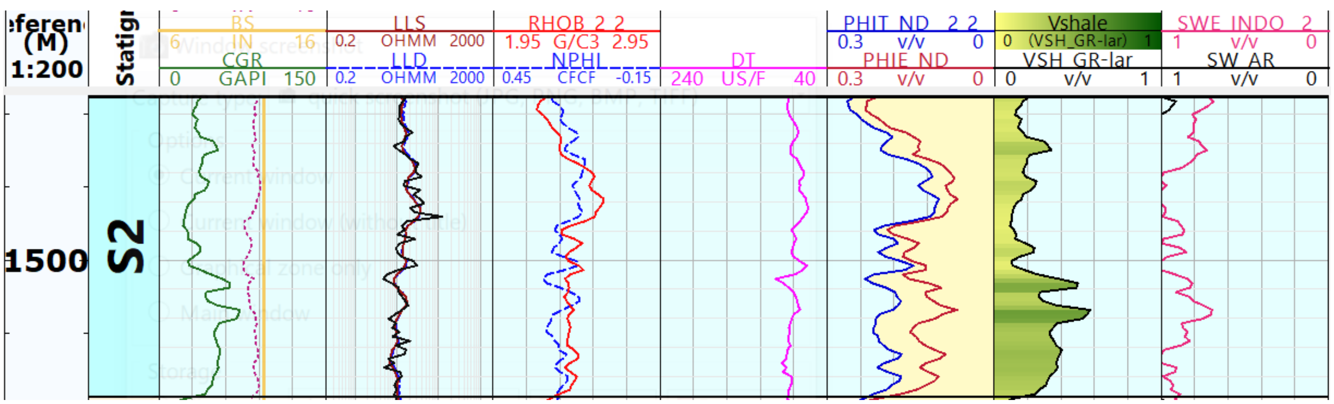


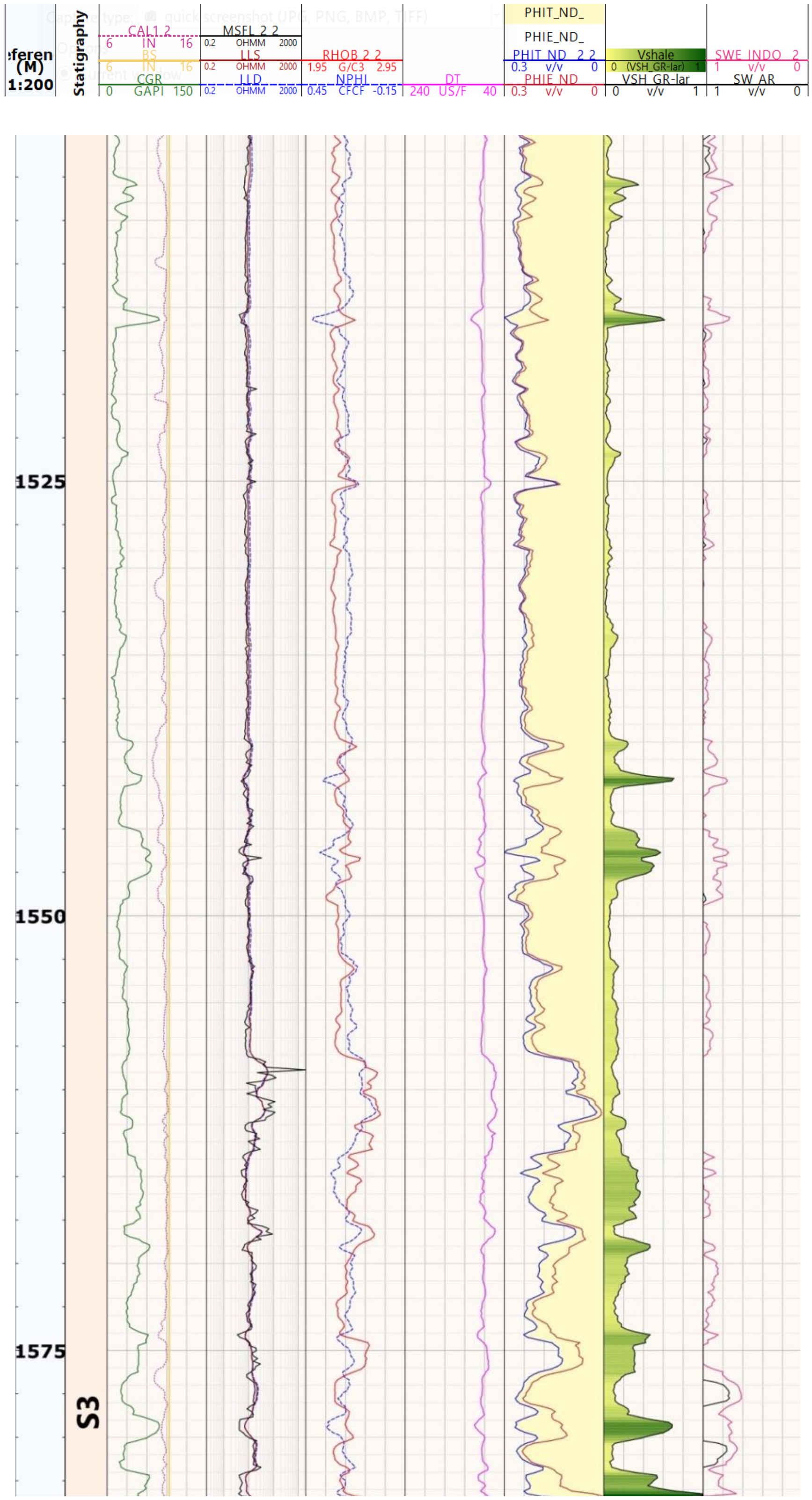

*Figure4- 7 Qishn S2 Interval in Sharyoof-2*

### 4.3.1.5 Qishn S3 Zone

This zone is located in a depth from **1504.69** to **1652.436 m** The logs interprettain ( Gamma Ray, Resistivity, and porosity) show that S3 zone is clean with low shale content in some parts, with no potential as it is water saturated.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about **147.74,0,0 m** respectively.

The zone contains7.5% of average shale volume "Vsh" by using Linear method and 5.2% using Larionov, and it has 25% of average effective porosity "Φeff" , and 100% of averge water saturation "Sw" by using Indonesian, and 100% Archie's equation.



Referen (M) 1:200
Statigraphy
CAL1 2
6 IN 16
BS
6 IN 16
CGR
0 GAPI 150
MSFL 2 2
0.2 OHMM 2000
LLS
0.2 OHMM 2000
LLD
0.2 OHMM 2000
RHOB 2 2
1.95 G/C3 2.95
NPHI
0.45 CFCF -0.15
DT
240 US/F 40
PHIT_ND_
PHIE_ND_
PHIT ND 2 2
0.3 v/v 0
PHIE ND
0.3 v/v 0
Vshale
0 (VSH_GR-lar) 1
VSH GR-lar
0 v/v 1
SWE INDO 2
1 v/v 0
SW AR
1 v/v 0
1525
1550
1575
S3

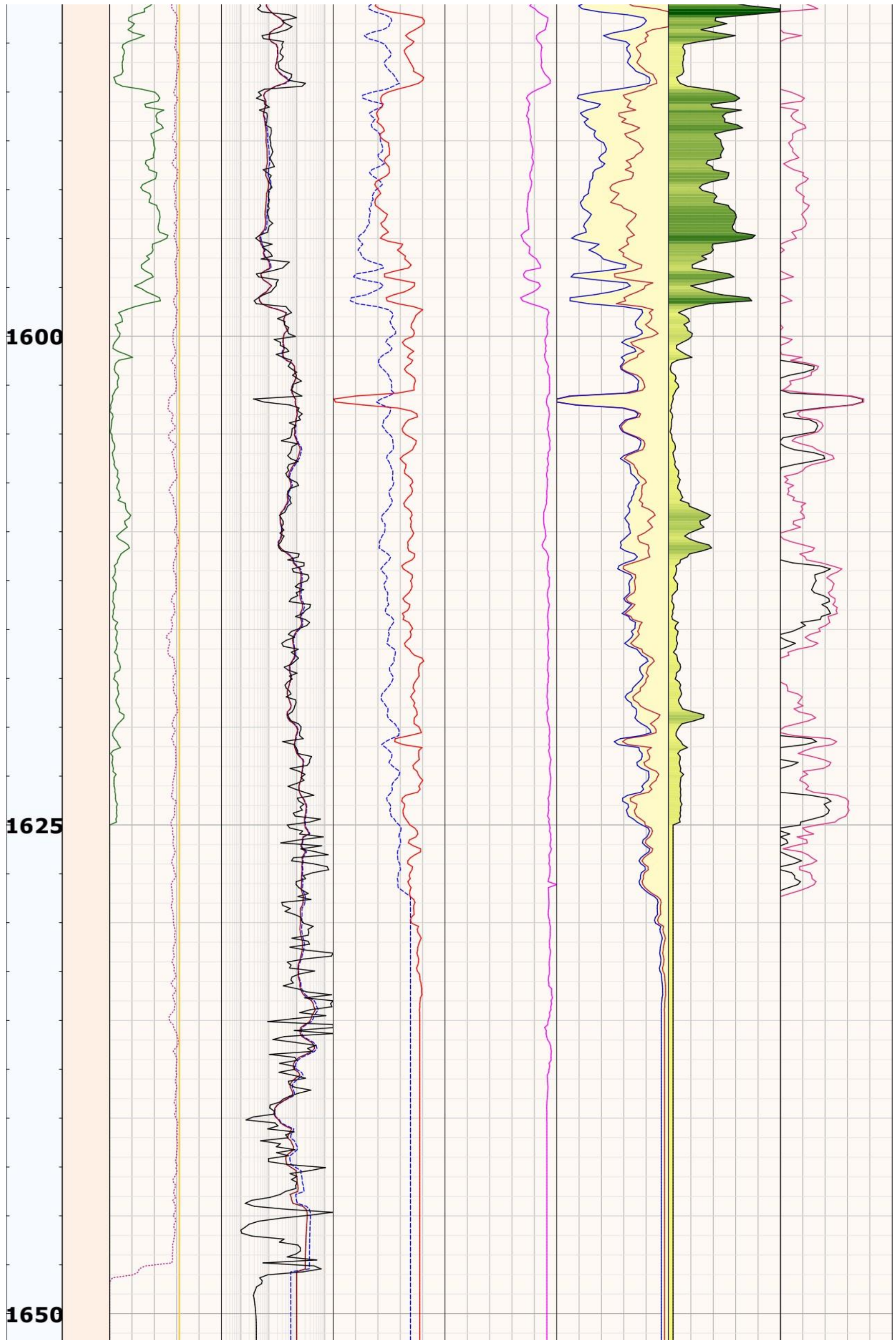



*Figure4- 8 Qishn S3 Interval in Sharyoof-2*

Tables 4.4, summarize the average reservoir values of the different estimated petrophysical parameters for Sharyoof-2. Two scenarios are listed below show effect of calculation method of shale volume and water saturation on petrophysical properties and on each other .

| Zone | Top | Bottom | Gross | Net reservoir | Net pay | GR | POR.N | POR.D | DT | Rt | Vsh Linear % | Vsh Larionove % | POR eff % | Sw Total % | Sw eff % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1A | 1455.41 | 1472.016 | 16.60 | 15.7 | 12.19 | 15.4 | 0.21 | 2.272 | 83.4 | 1272 | 6.8 | 3.3 | 23.3 | 23.2 | 21.7 |
| S1B | 1472.061 | 1484.242 | 12.22 | 8.36 | 0 | 38.5 | 0.23 | 2.449 | 58.8 | 17.3 | 27.4 | 16 | 16.4 | 94.6 | 85.8 |
| S1C | 1484.242 | 1494.35 | 10.10 | 5.52 | 1.67 | 23.9 | 0.20 | 2.293 | 87.6 | 194.4 | 14.4 | 4.7 | 21.5 | 31 | 26 |
| S2 | 1494.35 | 1504.69 | 10.4 | 5.5 | 0 | 46.4 | 0.19 | 2.371 | 79.9 | 15.4 | 34.5 | 20.7 | 15.8 | 99.1 | 84.5 |
| S3 | 1504.69 | 1652.436 | 147.74 | 0 | 0 | 17.6 | 0.22 | 2.281 | 84.3 | 12.2 | 7.5 | 5.2 | 25 | 100 | 100 |

*Table4- 4 summarize the average reservoir values of the different estimated petrophysical parameters for Sharyoof-2*

According to this petrophysical analysis, two hydrocarbon -bearing zones have been identified. One zone is identified in the S1A unit while the other zone is recognized at the upper of S1C.

However, the lower part of the S1C is mainly water- bearing. No hydrocarbon-bearing zones are detected at S1B unit, S2, and S3 in this well.

The presence of clay minerals in shale leads to overestimate in water saturation. Archie and Indonesian equations are applied in the study in order to compare the result of both models (Indonesian &Archie).

| Zone | Vsh-linrar % | Vsh-larionov % |
|---|---|---|
| **S1A** | 6.8 | 3.3 |
| **S1B** | 27.4 | 16 |
| **S1C** | 14.4 | 4.7 |
| **S2** | 34.5 | 20.7 |
| **S3** | 7.5 | 5.2 |

*Table4- 5 Summarizing the values of shale volume using linear and non-linear (larionov) methods in Sharyoof-2.*

Reffering to the table 4-5 above, all nonlinear relationships (Larionov) produce a shale volume value lower than that from the linear equation.

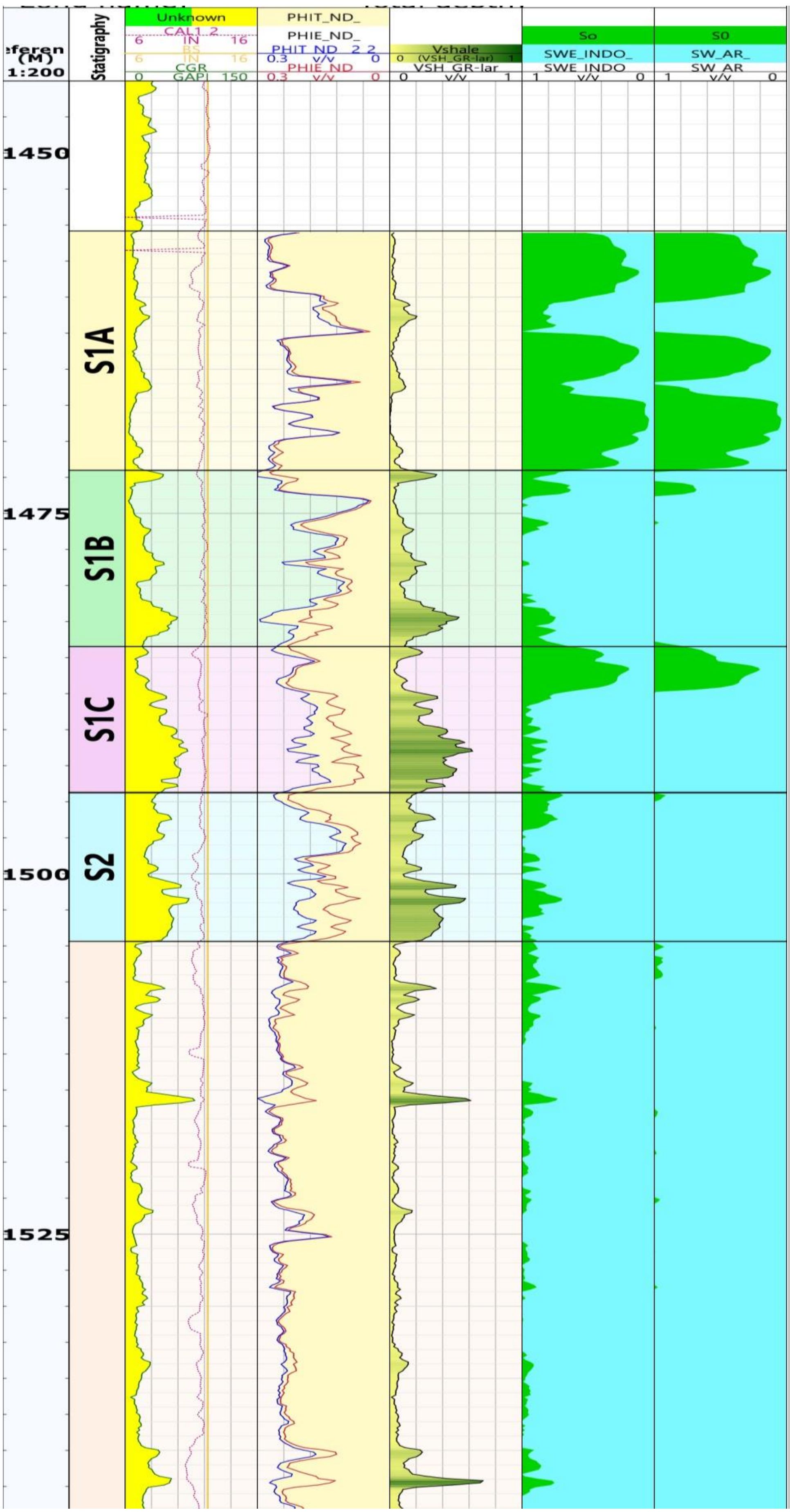
For a first order estimation of shale volume, the linear response, where Vshale = IGR, should be used**.**

| Zone | POR.eff % | Sw-total % | Sw-eff % |
|---|---|---|---|
| **S1A** | 23.3 | 22.7 | 21.5 |
| **S1B** | 16 | 93.9 | 88.2 |
| **S1C** | 20.4 | 32.1 | 31.5 |
| **S2** | 20.7 | 99.1 | 90 |
| **S3** | 25 | 100 | 100 |

*Table4- 6 Values of effective porosity and water saturation using both Archie's equation and Indonesia model in Sharyoof-2.*

This table 4.6 summarizes the values of effective porosity, total water saturation using Archie's equation, and effective water saturation using Indonesian model for the five layers of Sharyoof-2. ( The focus is on HC zones)

As it is shown, total and effective water sautration values are not similar to each other, the difference is that Sw-eff values are performed with taking into account the shale volume. S1A and S1C are the layers which have low water saturation compared with the other layers unit.



Statigraphy
Unknown
CAL1_2
IN
BS
CGR
GAPI
PHIT_ND_
PHIE_ND_
PHIT_ND_2
PHIE_ND
v/v
Vshale
(VSH_GR-lar)
VSH_GR-lar
So
SWE_INDO_
SWE_INDO
S0
SW_AR_
SW_AR
1:200
1450
1475
1500
1525
S1A
S1B
S1C
S2

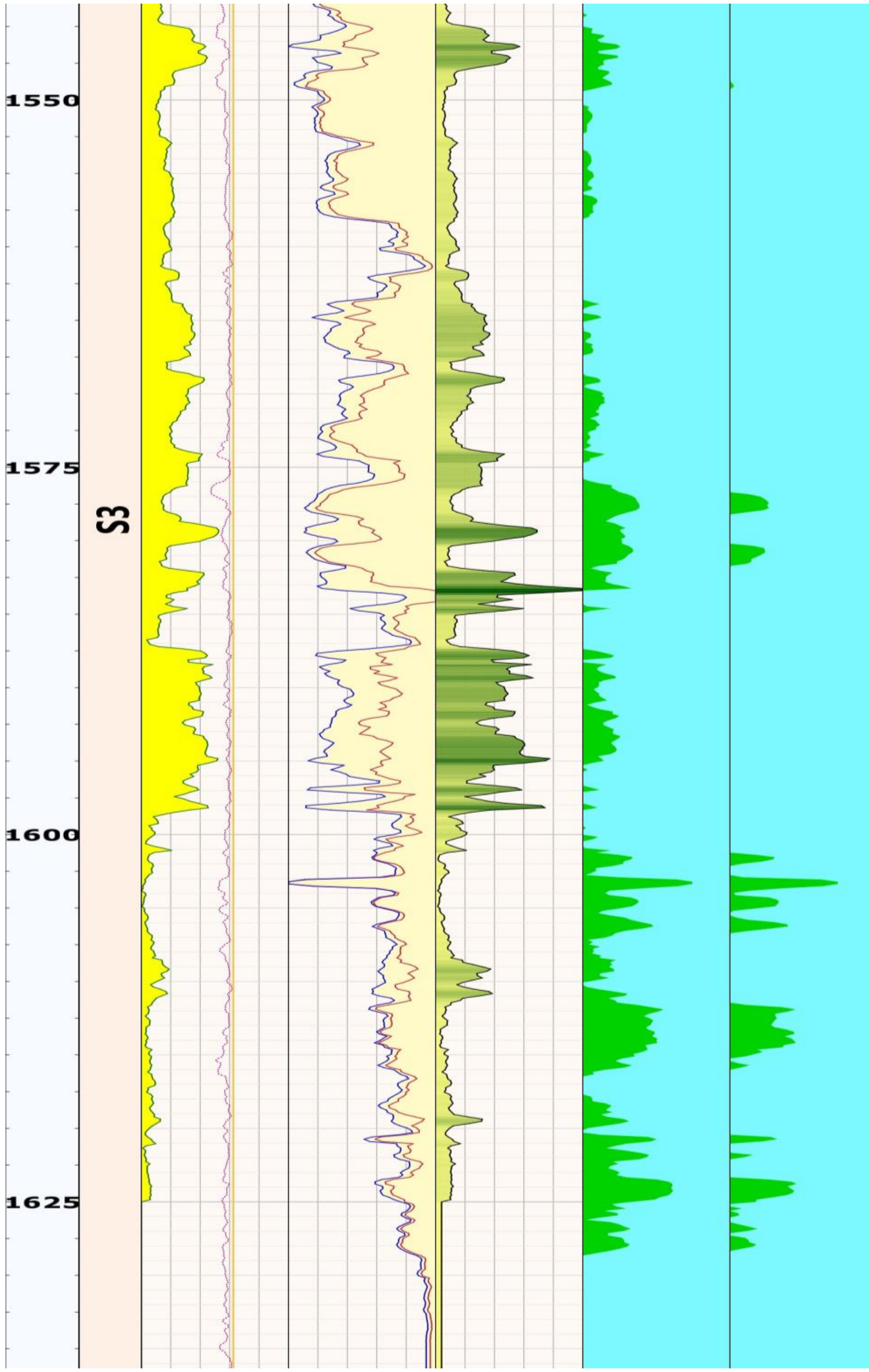



*Figure4- 9 Comparison of water saturation by using Archie & Indonesian models in Sharyoof-2*

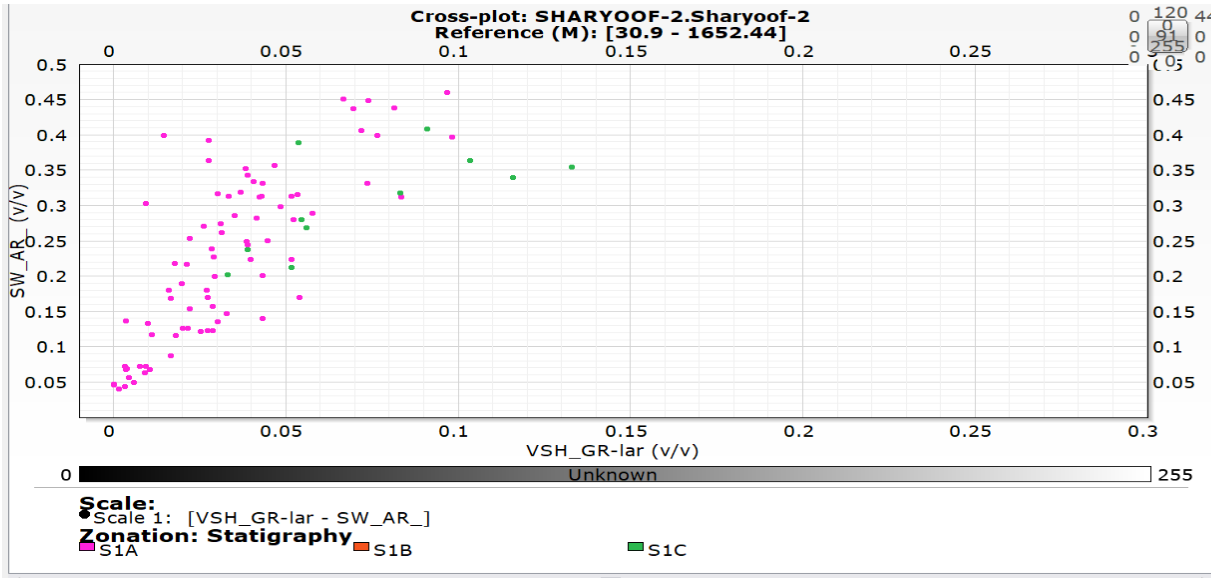



*Figure4- 10Total Water Saturation And Volume of Shale Relationship in Sharyoof-2*

This figure illustrates that, with the increase of shale content, the water saturation incresaed which is due to clay bound water effect.

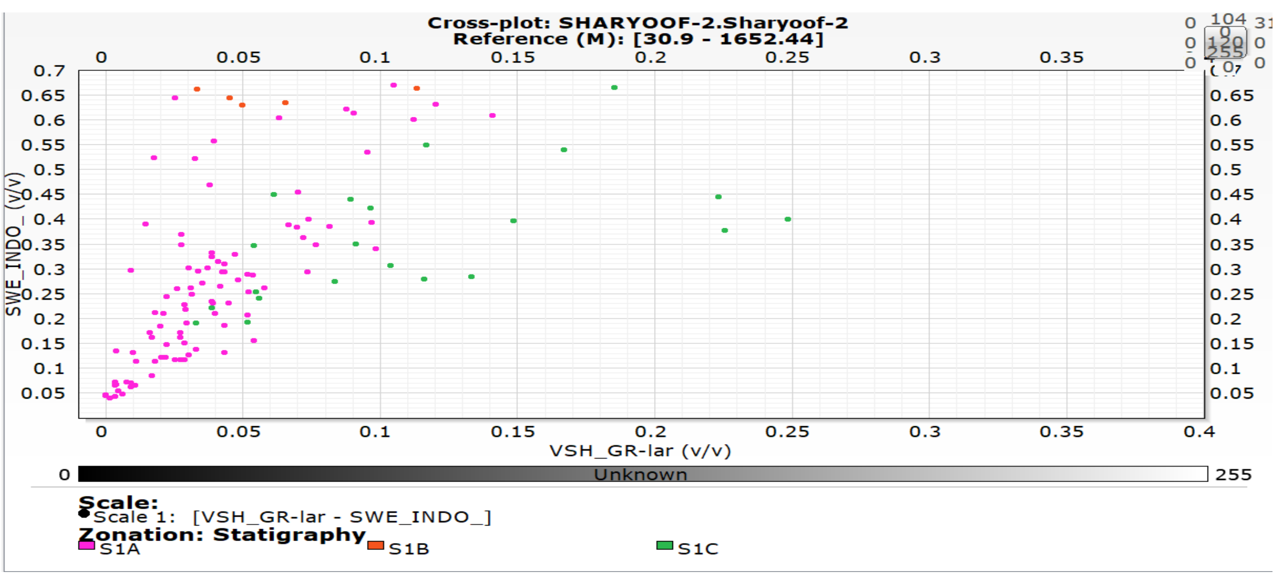



*Figure4- 11 Effective Water Saturation And Shale Volume in Sharyoof-2*

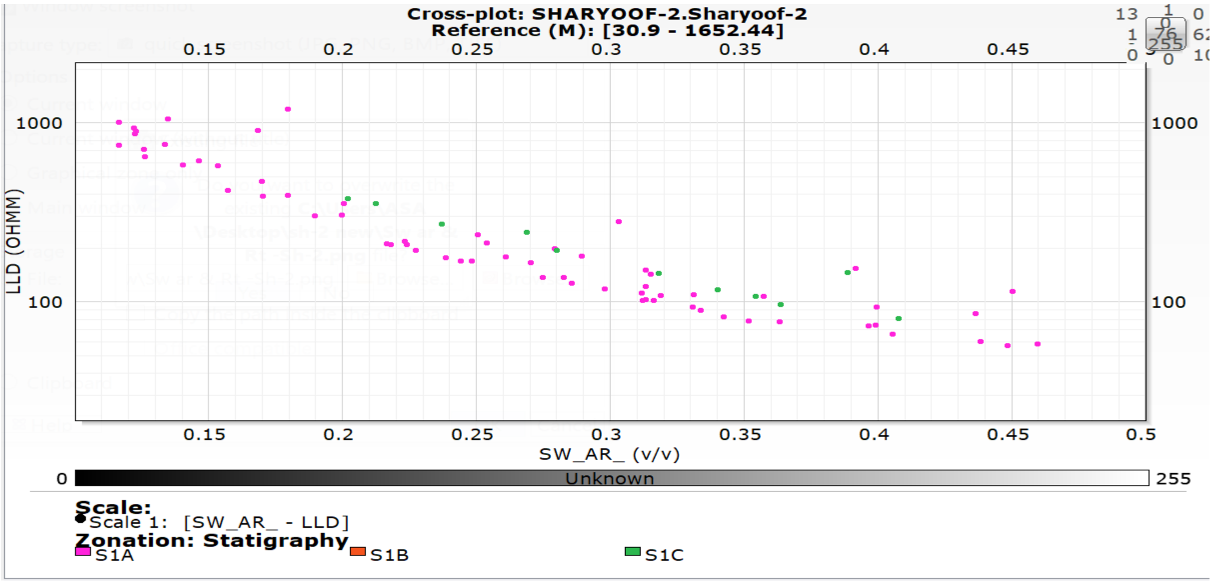



*Figure4- 12 Total Water Saturation And true Resistivity Relationship in Sharyoof-2*

A water saturation -resistivity relationship shows that, total water saturation is inversely proportional with resistivity. When Sw is decreasing , saturation of hydrocarbon is increasing ,thus resistivity is increasing.

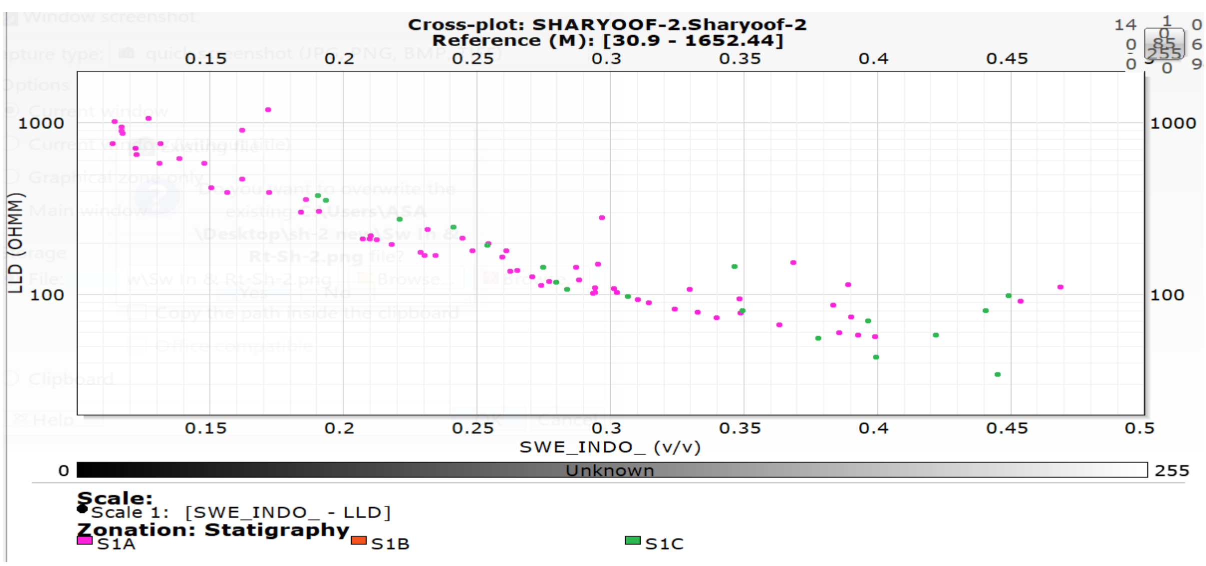



*Figure4- 13 Effective Water Saturation and true Resistivity in Sharyoof-2*

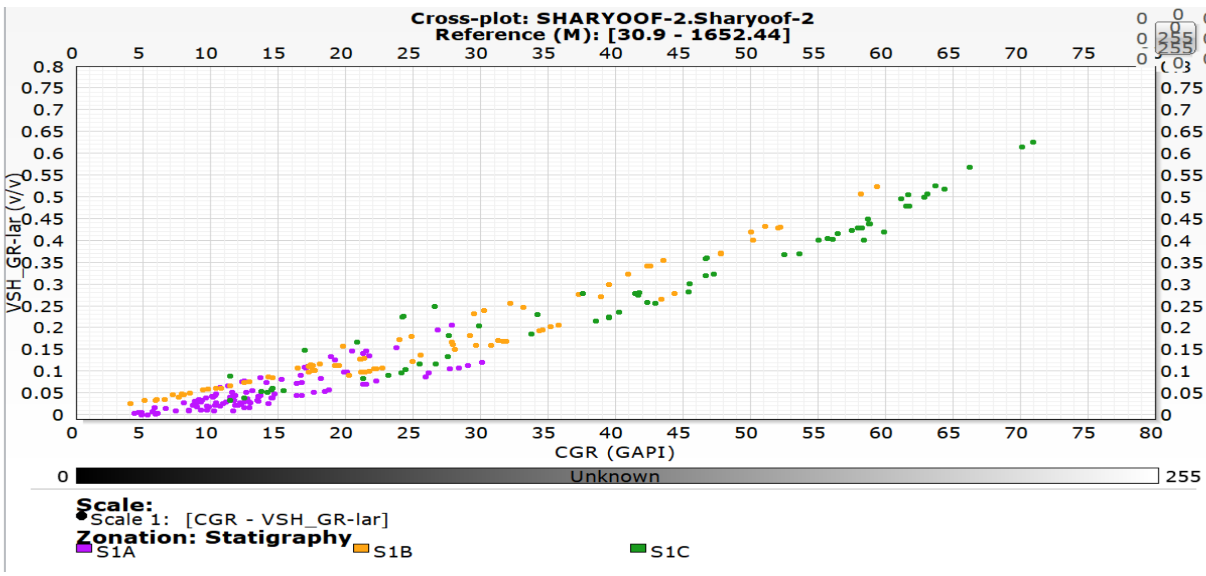



*Figure4- 14 Shale Volume By larionove and Gamma Ray in Sharyoof-2*

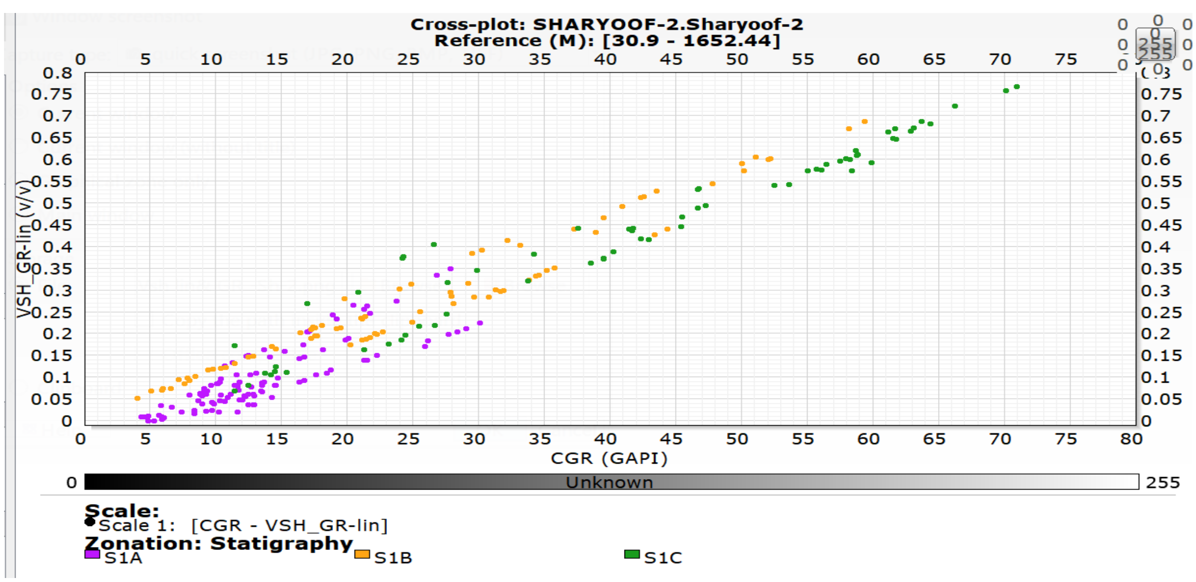



*Figure4- 15 Shale Volume By linear and Gamma Ray in Sharyoof-2*

The GR -shale volume relationship confirm the propertional relation between these two parameters.

### 4.3.2 Sharyoof-09-Well logs Interpretation

As it is shown Qishn clastic was taken as a study area which contains five layers : Qishn S1A, Qishn S1B, Qishn S1C, Qishn S2, Qishn S3 as a reservoir targets ( productive and non-productive zones) which will be interpreted below with comparing the values of shale volume using Linear and Larionov methods and the values of water saturation by means of using Archie and Indonesian equations.

The volume of shale (Vsh) calculation from logs become critical because of its further influence on the computation of important petrophysical properties such as porosity and water saturation.

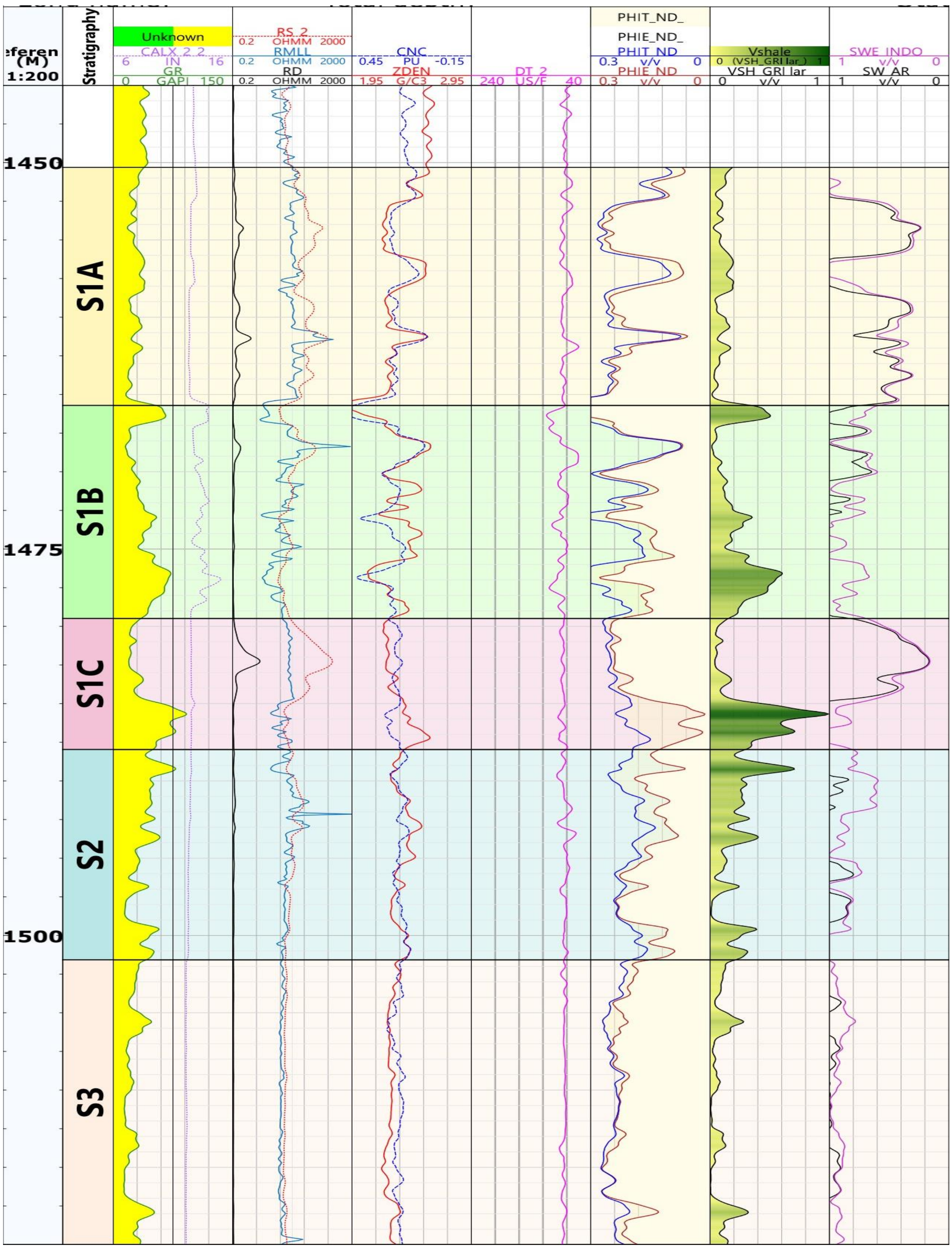



*Figure4- 16 Sharyoof-9 log analysis*

### 4.3.2.1Qishn S1A Zone

At the beginning, we've made a correction for the zonation depth of this well to separate evidently the layers.

As it is known ,the gamma ray classify the lithology of the formation into shale, nonshale, and shaly zones and in the section below it points that the reading of gamma ray is low identifying sand presence in combination with others data.

Zone S1A is located in a depth from 1450.31 to 1465.71 m which might be signalized to be a productive reservoir. The logs ( Gamma Ray, Resistivity, and porosity) indicate that sand is the dominant formation, in addition to some amount of shale.

The resistivity of this layer is high and it might be an indicator for hydrocarbon presence.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about 15.4 , 12.8 , 6.9 respectively.

The zone contains 14.3% of average shale volume using Linear method "Vsh" and 7.4 % by Larionov , 24.7 % of average effective porosity "Φeff" , and 35% of averge water saturation using Indonesian "Sw" while by Archie's equation Sw is 39% .

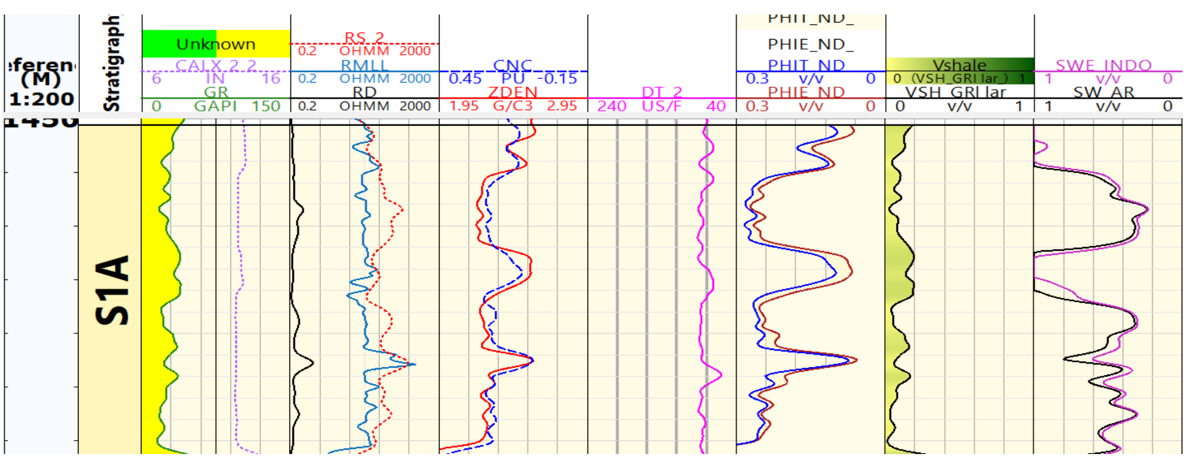



*Figure4- 17 Qishn S1A Interval in Sharyoof-9*

#### 4.3.2.2Qishn S1B Zone

This zone is located in a depth from **1465.71** to **1479.49** . The logs reading ( Gamma Ray, Resistivity, and porosity) points that, the shale is tremendously considerable compared to the sand, with more clean top part of the layer.

In the log below, the layer is characterized by high gamma ray reading because of the increase of shale content, and by low resistivity log readings because of water present and shale content.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about **13.78 , 9.59 , 0 m** respectively.

The zone contains 28.8 % of average shale volume "Vsh" using Linear method 17% using Larionov, 18% of average effective porosity "Φeff", and 80% of average water saturation "Sw" using Indonesian while by using Archie Sw is 90%. So, the layer has no potential

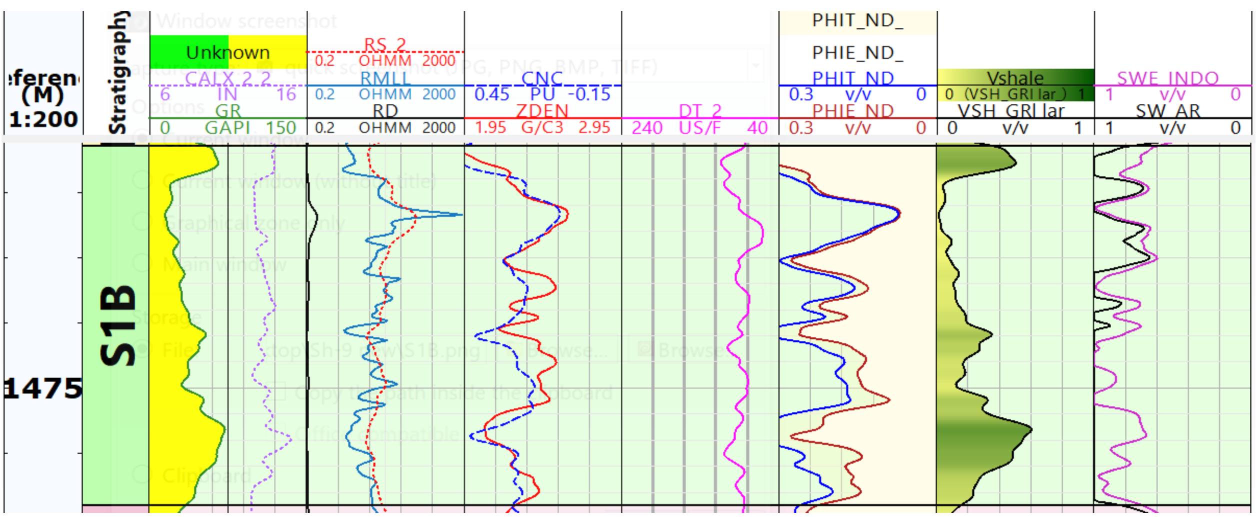



*Figure4- 18 Qishn S1B Interval in Sharyoof-9*

### 4.3.2.3Qishn S1C Zone

This zone is located in a depth from **1479.49** to **1487.97** m. At the top of this layer, the gamma ray reading is lower which points out more clean sand .Then gamma ray did increased at the bottom of the same layer to point for shale content increase .

The logs interpretation ( Gamma Ray, Resistivity, and porosity) point out that, S1C zone has a slight to no potential at the top clean part of sand.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about **8.47 , 5.96 , 3.4 m** respectively.

The zone contains 13.5 % of average shale volume "Vsh" by using Linear method whereas 7 % by using Larionov, and has 23.7% of average effective porosity "Φeff" , and 29 % of averge water saturation "Sw"by using Indonesian however in Archie equation is 32 % .

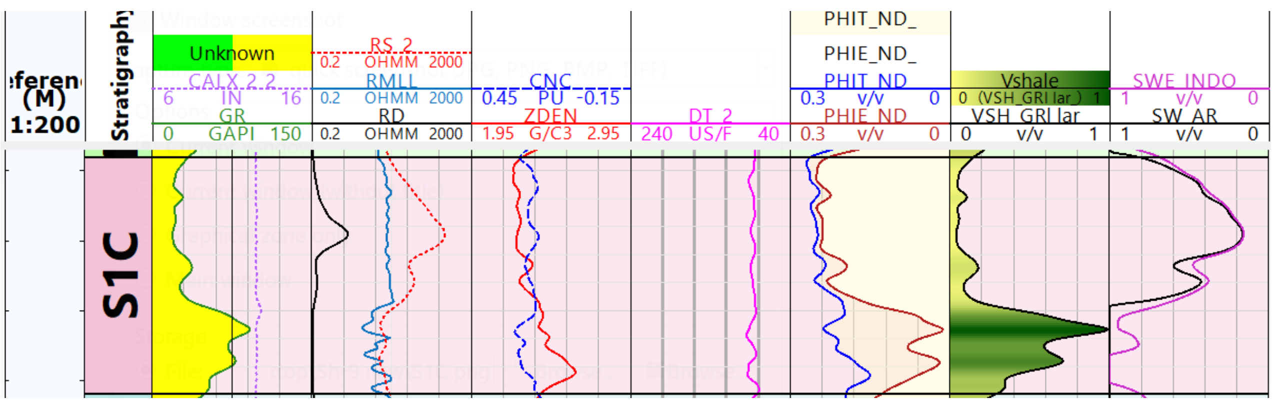



*Figure4- 19 Qishn S1C Interval in Sharyoof-9*

### 4.3.2.4 Qishn S2 Zone

This zone is located in a depth from **1487.97** to **1501.58 m.** The logs interpretation ( Gamma Ray, Resistivity, and porosity) indicate that the formation is highly shaly formation and water saturated.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about **13.4 , 11. 1 , 0 m** respectively.

The zone contains 29..4 % of average shale volume "Vsh" by using Linear method and 17.6 % using Larionov, and has 16.3 % of average effective porosity "Φeff" , and 82.5 % of averge water saturation "Sw" by using Indonesian, and 94% using Archie's equation.

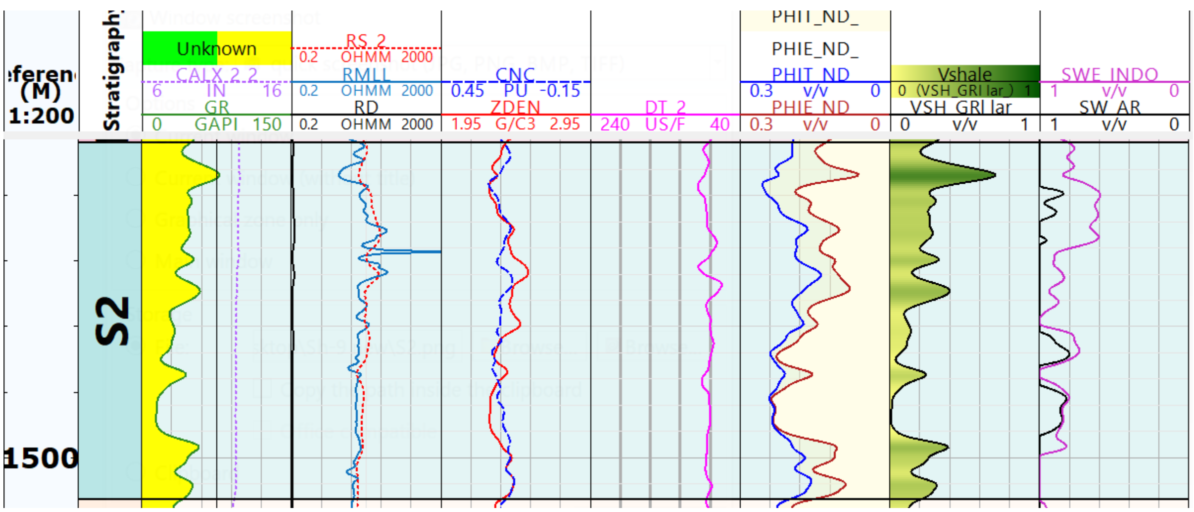



*Figure4- 20 Qishn S2 Interval in Sharyoof-9*

## 4.3.2.5 Qishn S3 Zone

This zone is located in a depth from **1501.58** to **1585.69 m** The logs interprettain ( Gamma Ray, Resistivity, and porosity) show that S3 zone is clean with low shale content in some parts, with no potential as it is water saturated.

The summary of this zone is that, it has total gross thickness, net reservoir, and net pay about **84.11, 0 , 0 m** respectively.

The zone contains 13.3 % of average shale volume "Vsh" by using Linear method and 8.7 % using Larionov, and it has 23% of average effective porosity "Φeff" , and 100% of averge water saturation "Sw" by using Indonesian, and 100% Archie's equation

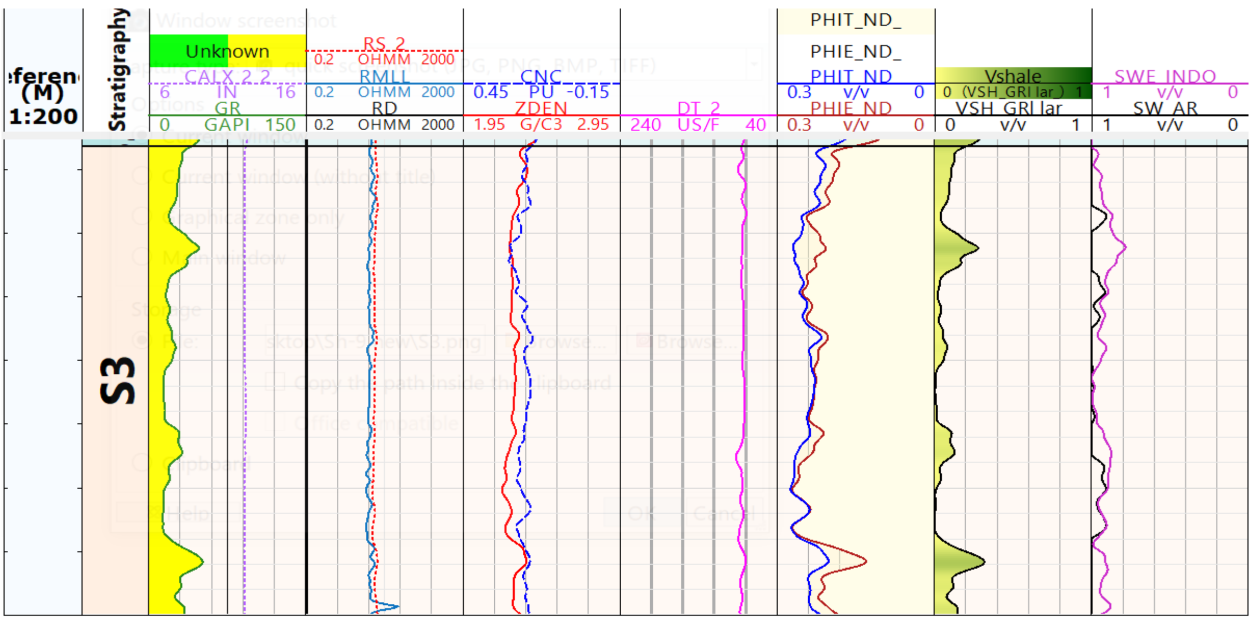



*Figure4- 21 Qishn S3 Interval in Sharyoof-9*

Tables 4.7, summarize the average reservoir values of the different estimated petrophysical parameters for Sharyoof-9.Two scenarios are listed below show the effect of the calculation method of shale volume and water saturation on the petrophysical properties and on each other.

| Zone | Top | Bottom | Gross | Net reservoir | Net pay | GR | POR.N | POR.D | DT | Rt | Vsh Linear % | Vsh Larionove % | POR eff % | Sw Total % | Sw eff % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1A | 1450.31 | 1465.71 | 15.4 | 12.8 | 6.9 | 24.3 | 23.9 | 2.238 | 85.65 | 91.3 | 14.3 | 7.4 | 24.7 | 39 | 35 |
| S1B | 1465.71 | 1479.49 | 13.788 | 9.59 | 0 | 35.7 | 23.7 | 2.373 | 86.9 | 23.4 | 28.8 | 17 | 18 | 90 | 80 |
| S1C | 1479.94 | 1487.97 | 8.47 | 5.69 | 3.4 | 23.6 | 21.9 | 2.247 | 86.8 | 127.5 | 13.5 | 7 | 23.7 | 32 | 29 |
| S2 | 1487.97 | 1501.58 | 13.4 | 11.1 | 0 | 36.2 | 20.4 | 2.37 | 83.2 | 22.7 | 29.4 | 17.6 | 16.3 | 94 | 82.5 |
| S3 | 1501.58 | 1585.69 | 84.11 | 0 | 0 | 27.6 | 22.8 | 2.281 | 84.3 | 19.2 | 13.3 | 8.7 | 23 | 100 | 100 |

*Table4- 7 summarize the average reservoir values of the different estimated petrophysical parameters for Sharyoof-9*

According to this petrophysical analysis, two hydrocarbon -bearing zones have been identified. One zone is identified in the S1A unit while the other zone is recognized at the upper of S1C.

However, the lower part of the S1C is mainly water- bearing. No hydrocarbon-bearing is detected at S1B unit, S2, and S3 in this well.

The presence of clay minerals in shale leads to overestimate in water saturation. Archie equation is applied in the study in order to compare the result of both models (Indonesian &Archie).

| **Zone** | **Vsh Linrar %** | **Vsh Larionov%** |
|---|---|---|
| S1A | 14.3 | 7.4 |
| S1B | 28.8 | 17 |
| S1C | 13.5 | 7 |
| S2 | 29.4 | 17.6 |
| S3 | 13.3 | 8.7 |

*Table4- 8Table 4.8 Summarizing the values of shale volume using linear and Larionove methods in Sharyoof-9*

Reffereing to the table 4-8 above, all nonlinear relationships ( Larionov) produce a shale volume value lower than that from the linear equation.Tab 4.8

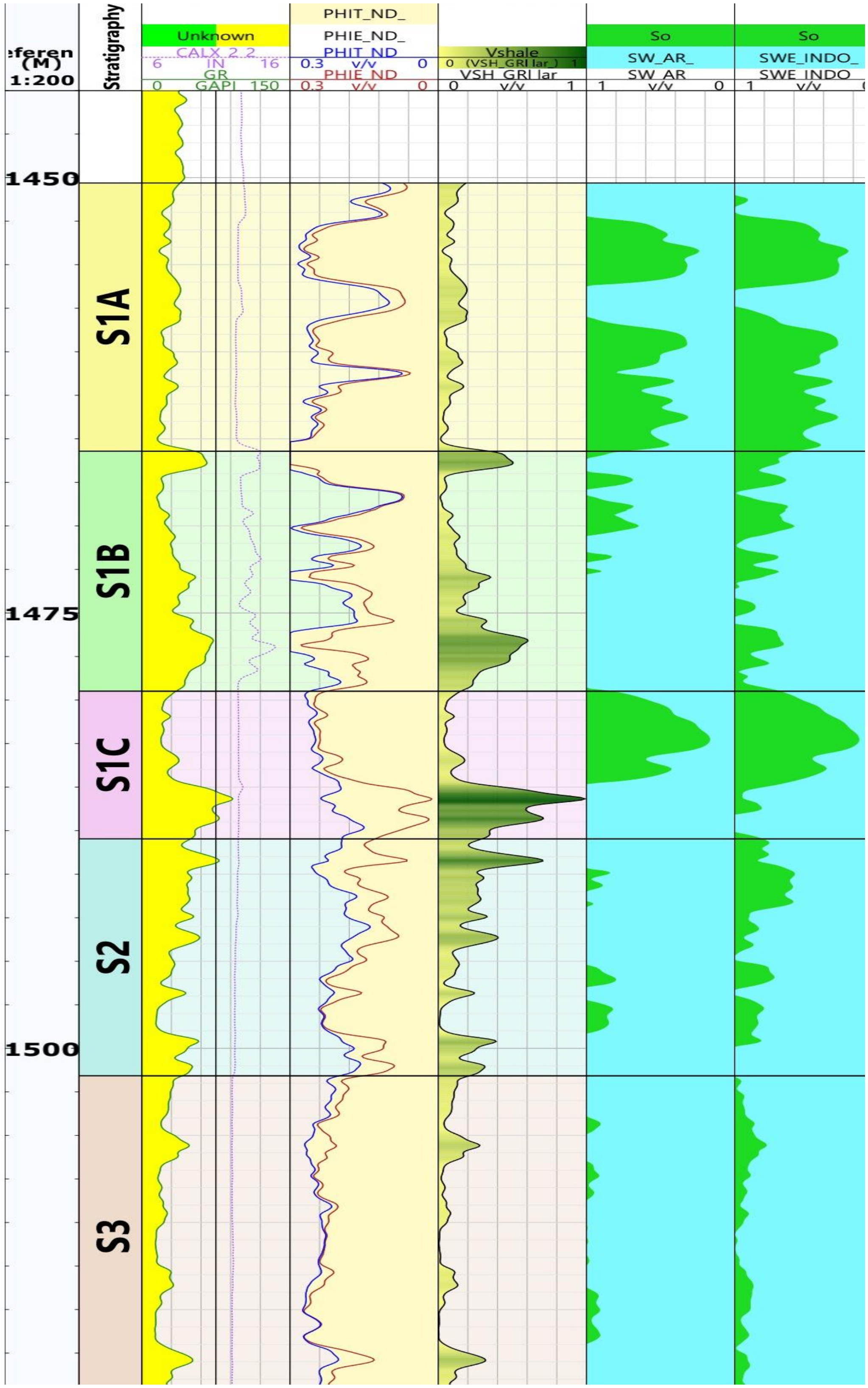
For a first order estimation of shale volume, the linear response, where Vshale = IGR, should be used.

| Zone | POR.eff | Sw-total | Sw-eff |
|---|---|---|---|
| S1A | 24.7 | 39 | 35 |
| S1B | 18 | 90 | 80 |
| S1C | 23.7 | 32 | 29 |
| S2 | 16.3 | 94 | 82.5 |
| S3 | 23 | 100 | 100 |

*Table4- 9 Values of effective porosity and water saturation using both Archie's equation and Indonesian model in Sharyoof-9*

This table 4.9 summarizes the values of effective porosity, total water saturation using Archie's eauation, and effective water saturation using Indonesian model for the five layers of Sharyoof-09.( The focus is on HC zones) .

As it is shown, total and effective water sautration values are not similar to each other, but the difference is that Sw-total values are performed without taking into account the shale volume. S1A and S1C are the layers which have low effective water saturation compared with the other layers unit.



eferen (M) 1:200
Stratigraphy
Unknown
CALX 2.2
6 IN 16
GR
0 GAPI 150
PHIT_ND_
PHIE_ND_
PHIT_ND
0.3 v/v 0
PHIE_ND
0.3 v/v 0
Vshale
0 (VSH_GRl lar ) 1
VSH_GRl lar
0 v/v 1
So
SW_AR_
SW_AR
1 v/v 0
So
SWE_INDO_
SWE_INDO
1 v/v
1450
1475
1500
S1A
S1B
S1C
S2
S3

*Figure4- 22 Comparison of water saturation by using Archie & Indonesian models in Sharyoof-9.*

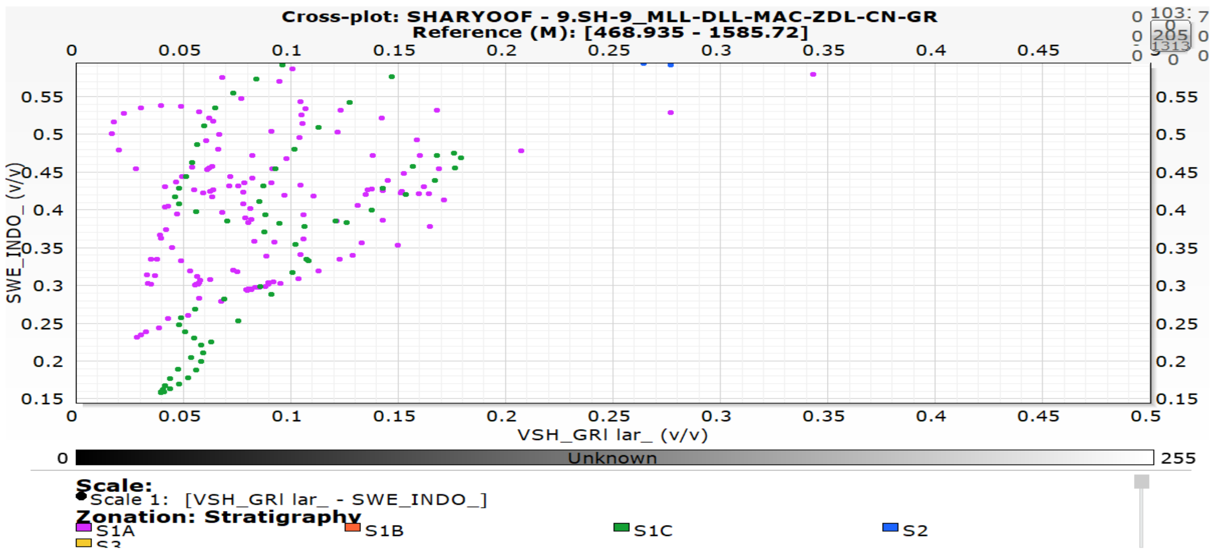



*Figure4- 23 Effective Water Saturation And Volume of shale in Sharyoof-9*

None typical relatioship between Sw and Vsh seens to be due to poor input data quality..

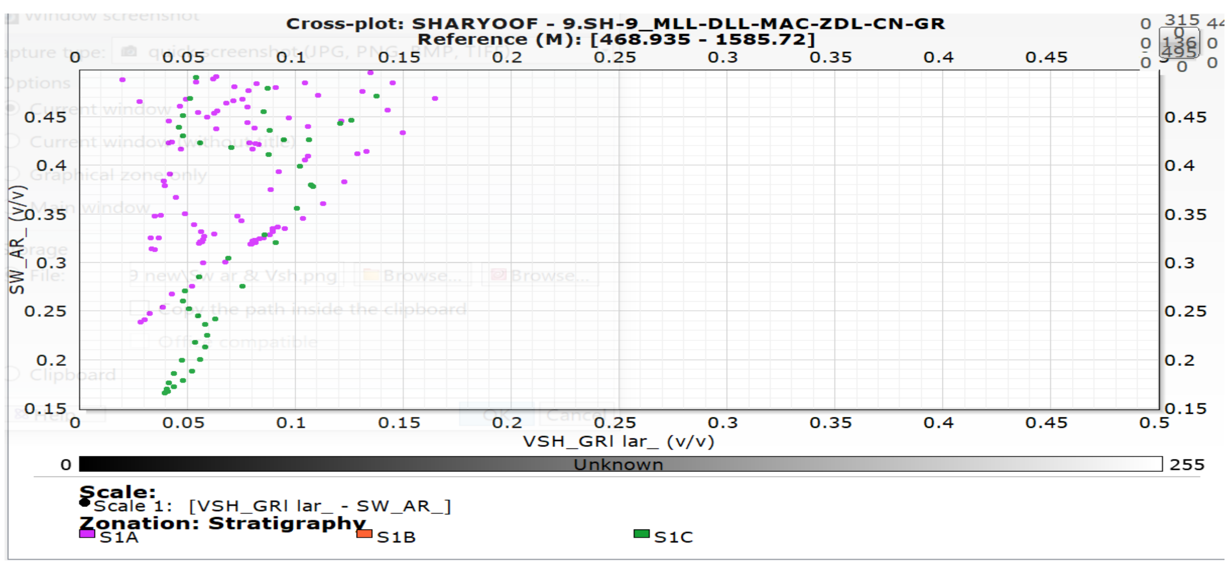



*Figure4- 24 Total Water Saturation And Volume of shale in Sharyoof-9*

This figure illustrates that, with the increase of shale content, the water saturation incresaed which is due to clay bound water effect, however some random none typical relathioship is observed due to poor inputs data.

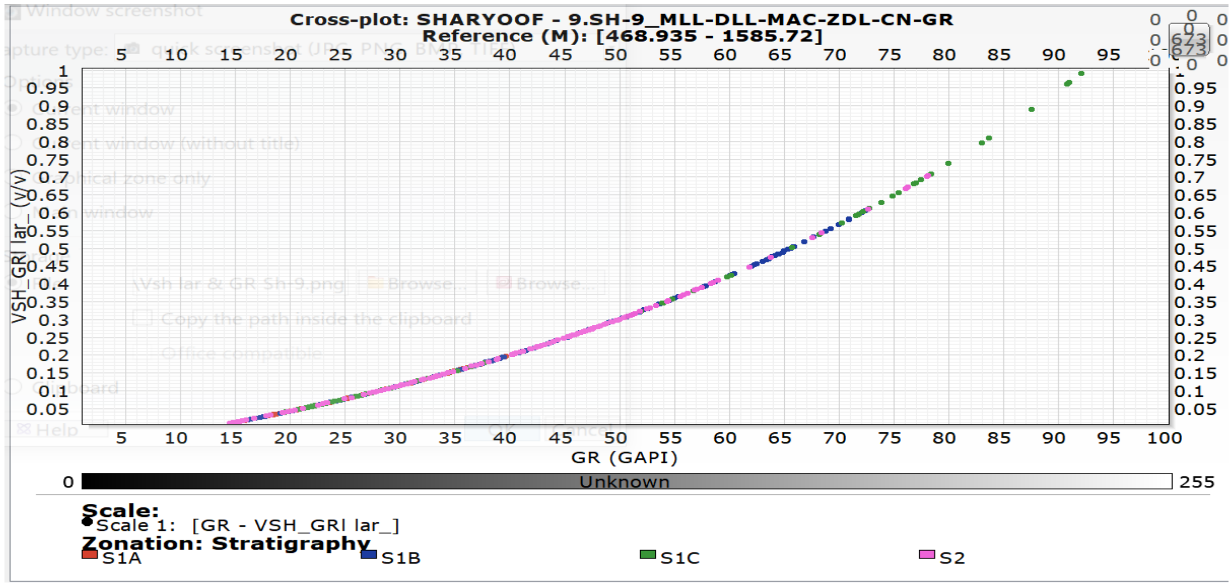



*Figure4- 25 Shale volume By Larionove And Gamma Ray in Sharyoof-9*

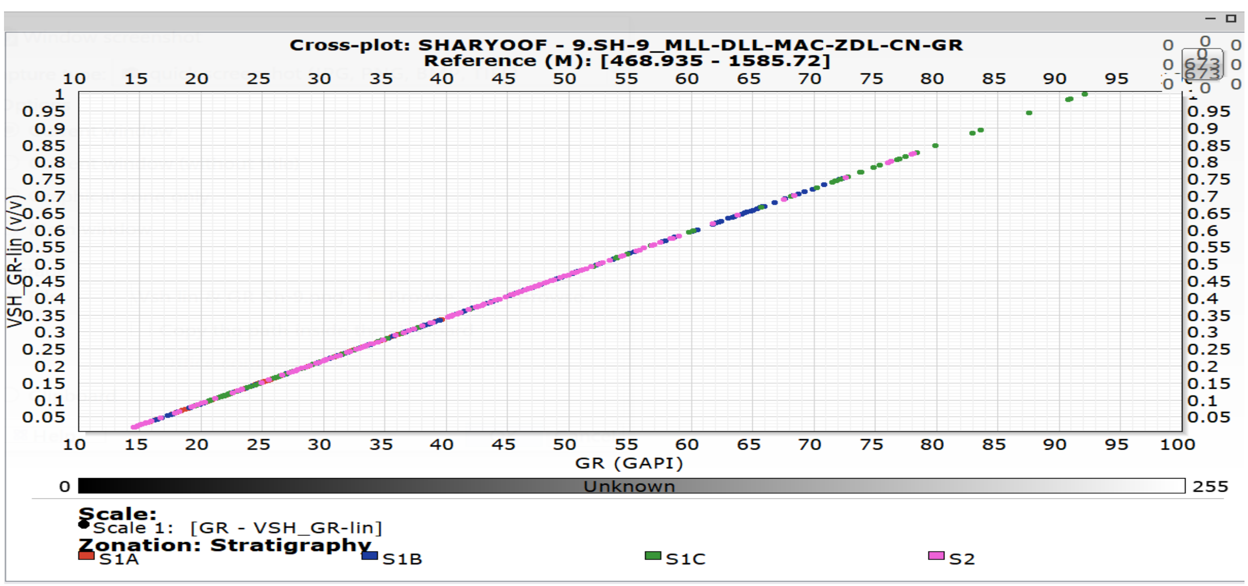



*Figure4- 26 shale volume By linear method And Gamma Ray in Sharyoof-9*

The GR -shale volume relationship confirm the propertional relation between these two parameters.

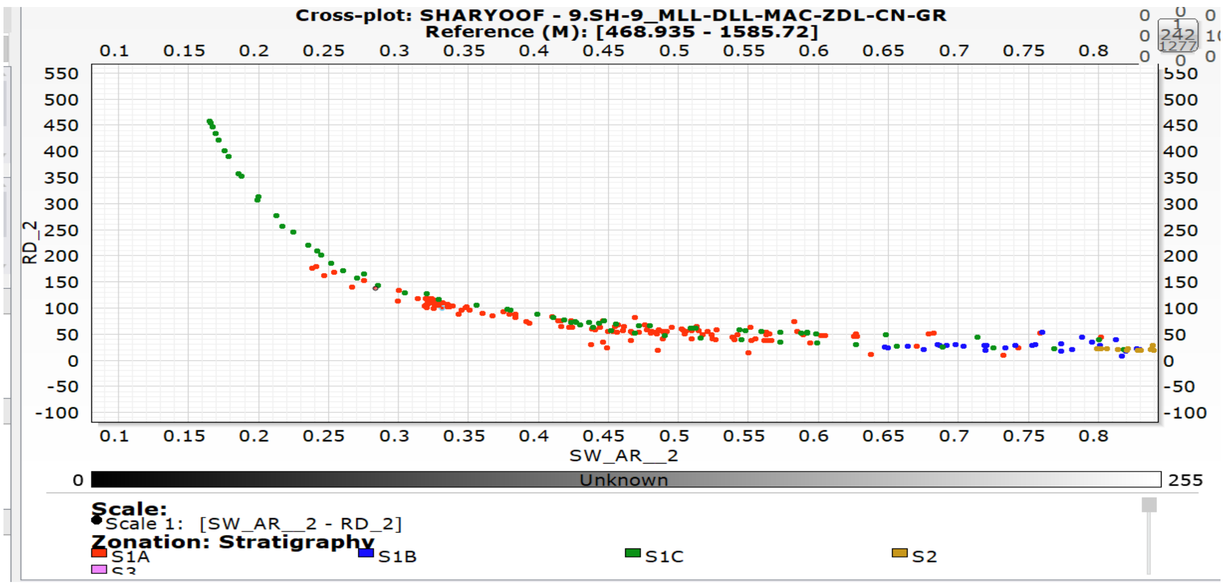



*Figure4- 27 Total water saturation and true resistivity relationship in Sharyoof-9*

The water saturation -resistivity relationship shows that, total water saturation is inversely proportional with resistivity. When Sw is decreasing , saturation of hydrocarbon is increasing ,thus resistivity is increasing.

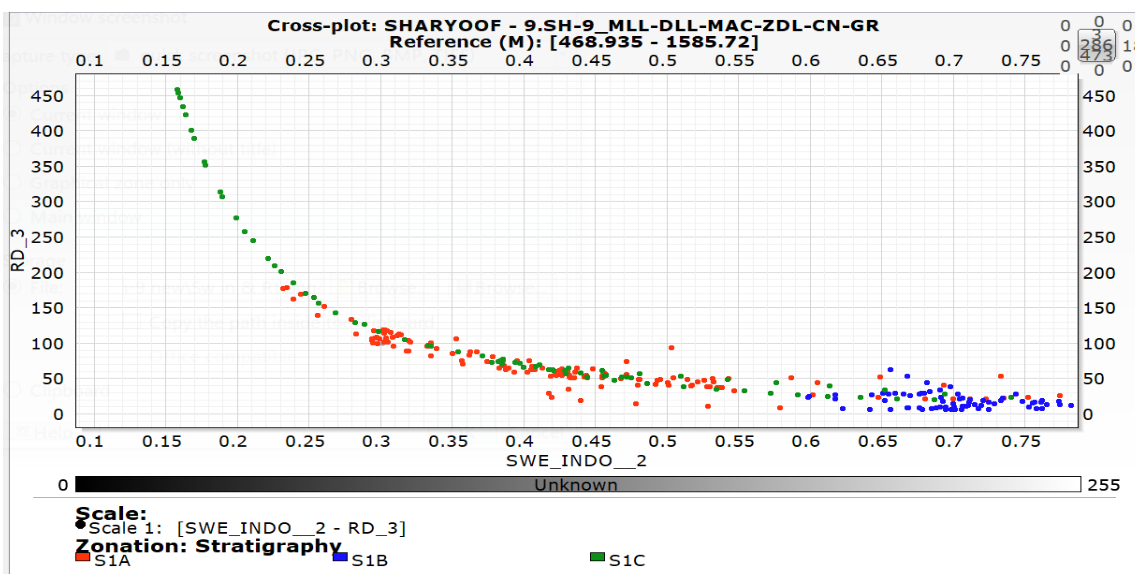



*Figure4- 28 Effective water saturation and resistivity relationship in Sharyoof-9*

# STOIIP CALCUALTION

STOIIP is stock tank oil initially in place that can be determined for both wells ( Sharyoof -02 & Sharyoof-09 )by means of using volumetric calculation (noting that the volumetric equation is used only at the early stage in field life). The more wells you have , the more accurate determination will be.

$$\text{STOIIP} = \frac{7758 * A * h * \Phi\ (1 - Sw)}{Boi} \qquad \text{( Equ 4.6)}$$

**Where :**

STOIIP : Stock Tank Oil Initially In Place

A = area of interest (acre)

h = thickness of net pay (feet)

Sw = water saturation ( fraction)

Ø = Average porosity ( fraction)

Boi = FVF = Oil Formation Volume Factor. (bbl/STB)

**STOIIP for S1A (Using Archie' Equation for Determining Water Saturation)**

Average Porosity = 0.24

Average Net Pay = 9.563 m * 3.28 to convert to feet

Average Water Saturation = 0.310 (From Archie)

Area = 1600 acre

Oil FVF = 1.078 bbl/STB

STOIIP = 59782724.45 STB = 59.78 MMSTB

**STOIIP S1C values**

Average Porosity = 0.226

Average Net Pay = 2.553 m * 3.28 to convert to feet

Average Water Saturation = 0.3115

Area = 800 acre

Oil FVF = 1.04 bbl/STB

STOIIP = 7777762.178 STB = 7.77 MMSTB

**STOIIP S1A (Using Indonesian Model for Determining Water Saturation )**

Average Porosity = 0.24

Average Net Pay = 9.563 m * 3.28 to convert to feet

Average Water Saturation = 0.288

Area = 1600 acre

Oil FVF = 1.078 bbl/STB

STOIIP = 61733574.78 STB = 61.733 MMSTB

**STOIIP S1C values**

Average Porosity = 0.226

Average Net Pay = 2.553 m * 3.28 to convert to feet

Average Water Saturation = 0.2785

Area = 800 acre

Oil FVF = 1.04 bbl/STB

STOIIP = 8150552.522 STB = 8.150 MMSTB

Table 4.10 Values of STOIIP Calculating for both wells ( Sharyoof -02 & Sharyoof -09 )

| Zone | STOIIP Archie | STOIIP Indonesian |
|---|---|---|
| S1A | 59.78 MMSTB | 62.73 MMSTB |
| S1C | 7.77MMSTB | 8.150 MMSTB |

*Table4- 10 demonstrates the values of OIIP which are determined by volumetric calculations*

Archie's equation values are overestimated in determining water saturation, thus STOIIP results would certainly be less due to the increasing of water saturation. In contrast, Indonesian equation values are not overestimated in calculating water saturation, consequently STOIIP results would be more accurate because of the reasonable values of water saturation. For this reason, it is required to have more models to compare the values ,when the shale is taken into account for calculating Sw or when it is neglected.

# CHAPTER FIVE

# 5. Conclusions and Recommendations

## 5.1. Introduction

In this research, the impact of uncertainties in petrophysical evaluation of shaly-sand reservoirs of Sharyoof field in block -53 (Say'un Masila basin) on the water saturation calculation was done by applying the petrophysical log analysis using TECHLOG 2015.3.2 Software for two wells ( Sharyoof-02 and Sharyoof-09).

## 5.2. Conclusions

1- The uncertainity water saturation (Sw) results from many factors including deviation of the constant m, and n from the average values 2 and inacurate measurement of Rw, Rt, Vsh, and φ.

2- In conclusion, the petrophysical analysis in Sharyoof-02 could be summarized that, it has two hydrocarbon-bearing zones which are S1A and the upper of S1C. However, no hydrocarbon-bearing is revealed at S1B, S2, and S3. Similarly in Sharyoof-09, S1A and the upper of S1C have hydrocarbon-bearing. In contrast to S1B, S2, and S3, no hydrocarbon-bearing is detected.

3- Archie equation results in higher SW values in shaly sand, and it is more accurate in clean sand fomation.

4- Archie equation results in higher Sw comparing with Indonesian formula.

5- Compared to the linear response, all nonlinear relationships (Larionov) produce a shale volume value lower than that from the linear equation.

6- According to this petrophysical analysis, two hydrocarbon -bearing zones have been identified. One zone is identified in the S1A unit while the other zone is recognized at the upper of S1C.

7- However, the lower part of the S1C is mainly water- bearing. No hydrocarbon-bearing is detected at S1B unit, S2, and S3 in this well.

8- The presence of clay minerals in shale leads to overestimate in water saturation. Archie equation is applied in the study in order to compare the result of both models (Indonesian &Archie).

9- One of the best approach to make sure about the Sw calculation is to apply different calculations models.

10- Petrophysical relationships built for Sharyoof-9 units showed poor relation probably due to poor inputs or lack of experience to work with software.

11- Resistivity values ware incorrect , so it cause complication during the interpretation .

## 5.3. Recommendations

1-Redefining process of the layers boundaries (S1A, S1B, S1C, S2, S3) should be done again (correction) so as to ensure the petrophysic analysis to be more precise as a result perform a new petrophysical evaluation .

2-Using models that take volume of shale in account when calculating water saturation to reduce the uncertainty and to obtain results that are close to reality.

3- Recalculating STOIIP values based on equatios that take into account the presnece of shale such as Indenosian or Simandoux equations to reduce the uncerinity of reserve volume due to the Sw overestimation as a result of shale content

4- Recommend to perform logs data quality check before analysis .

## 5.4. Limitations

1- Difficulties while gathering the data led to delay in accomplishing this project on the exact time.

2- The limited volumes of logs data, the method of plots which are displayed on, and relationships might prevent the comprehension of the field analysis.

3- Absence of coring and mud logging reports led to put a recommendation for Rw without comparing with the company.

4- Incorrect values of the resistivity that cause complication in the interpretation.

5- Formation water resistivity (Rw) is not available form filedl water samples or report or any other reliable source, so it was calculated using Archie equation within water bearing zone and pickett method.
6- Spectral Gamma Ray log is not available to identify clay types.
7- No reference petrophysical reprts is avai;able to compare the results.
8- No completion and production data are available to validate the analysis results in terms of wells productivity.

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