SAHAND HALGURD MUSHEER

PETROPHYSICAL ASSESSMENT OF AVANAH RESERVOIR IN KHURMALA DOME OF THE KIRKUK FIELD, IRAQ

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
SAHAND HALGURD MUSHEER

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Petroleum and Natural Gas Engineering

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Approval of Director of Institute of Graduate Studies

Prof. Dr. K. Hüsnü Can BAŞER

We certify that this thesis is satisfactory for the award of the degree of Masters of Science in Petroleum and Natural Gas Engineering

Examining Committee in Charge:

Prof. Dr. Cavit ATALAR — Committee Chairman, Petroleum and Natural Gas Engineering Department, NEU

Prof. Dr. Salih SANER — Supervisor, Petroleum and Natural Gas Engineering Department, NEU

Assist. Prof. Dr. Süleyman AŞIR — Materials Sciences and Nanotechnology Engineering Department, NEU

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name: Sahand Halgurd Musheer

Signature: 

Date: 28.06.2021

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To my Parents…

ABSTRACT

Petrophysics is the study of physical rock properties and their relations with reservoir fluids. It is one of the principal subjects in the petroleum industry to evaluate a reservoir. The study of disparity of the petrophysical properties gives a good idea on how to manage the reservoir in an accurate way. The detailed lithological and petrophysical descriptions of the rocks from different logging tools are the most important parameters that are taken into consideration in the reservoir description. Through well log data Avanah Formation lithology described and level by level porosity, permeability and water saturation determined. Log data integrated with core data and extrapolated to un-cored wells for finding hydrocarbon pay thickness and volume.

Data for the study was provided by the Kar Company. Processing was realized using TECHLOG software of Schlumberger. Geological correlations between wells have been used to demonstrate the directional changes in reservoir properties and defining and determining where to drill production wells in the future.

In this study, Avanah Formation has been divided into two parts: The upper part of Avanah Formation consists mainly of limestone while the lower part consists mainly of dolomite with some limestone interlayers. Mapping distributions showed that average porosity and average permeability increase toward the NW of the field in both Avanah limestone and Avanah dolomite. Water saturation in the NW area and dome area was less compared to SE wells. Due to mentioned reservoir characteristics Middle and NW part of the field indicated to be the best location for drilling new wells in the future production plan.

Keywords: Avanah Formation; Kirkuk Field; Khurmala Dome; Formation Evaluation; Iraq.

ÖZET

Petrofizik, fiziksel kaya özelliklerinin ve bunların rezervuar sıvıları ile ilişkilerinin incelenmesidir. Bir rezervuarı değerlendirmek, petrol endüstrisindeki temel konulardan biridir. Petrofiziksel özelliklerin eşitsizliğinin incelenmesi, rezervuarın doğru bir şekilde nasıl yönetileceği konusunda iyi bir fikir verir. Kayaların çeşitli kuyu loglarindan elde edilen detaylı litolojik ve petrofiziksel açıklamaları, rezervuar açıklamasında dikkate alınan en önemli parametrelerdir. Bu çalışmada kuyu log veriler kullanılarak Avanah Formasyonu litolojisi tanımlandı, gözeneklilik, geçirgenlik ve su doyum luluğu her veri seviyesine göre belirlendi. Hidrokarbon üretim zonu kalınlığı ve hacmini bulmak için log verileri karot verileriyle entegre edilmiş ve karot bulunmayan kuyulara ekstrapolasyonlu uygulan miştir.

Çalışma için veriler Kar Company tarafından sağlanmıştır, işlemler Schlumberger'in TECHLOG yazılımı kullanılarak gerçekleştirilmiştir. Rezervuar özelliklerindeki yönsel değişimleri göstermek ve gelecekte üretim kuyularının nerede delineceğini tanımlamak ve belirlemek için kuyular arasında jeolojik korelasyonlar yapilmıştır.

Bu çalışmada, Avanah Formasyonunun üst kısmı ağırlıklı olarak kireçtaşından, alt kısım ise bazı dolomitik kireçtaşı ara tabakalc dolomitten oluşmaktadır. Haritalama dağılımları, hem Avanah kireçtaşı hem de Avanah dolomitinde sahanın KB'sine doğru ortalama gözeneklilik ve ortalama geçirgenliğin arttığını göstermiştir. KB alanı ve kubbe alanındaki su doygunluğu GD kuyularına göre daha azdı. Bahsedilen rezervuar özelliklerinden dolayı, sahanın orta ve kuzeybatı kısmı, gelecekteki üretim planında yeni kuyular açmak için en iyi yer olarak belirtilmiştir.

Anahtar Kelimeler: Avanah Formasyonu; Kerkük Sahası; Khurmala Domu; Formasyon Değerlendirmesi; Irak

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LIST OF SYMBOLS AND ABBERVATIONS

a:	Tortuosity factor
BS:	Bit Size
CAL:	Caliper
CPI:	Computer Process Interpretation
DTCO:	Compressional Sonic
GR:	Gamma Ray
K:	Permeability
K core	Core permeability
LLD:	Latero Log Deep
m:	Cementation exponent
N:	Number of samples
n:	Saturation exponent
NPHI:	Neutron Porosity
PEFZ:	Photoelectric Factor
PERM_from Empirical Method:	Permeability calculated from empirical method
PERM_Morris and Biggs:	Permeability calculated from Morris and Biggs method
PHIT:	Total porosity
PHIT-ND:	Total porosity from Neutron and Density
RHOB:	Bulk density from China national oil cooperation company
RHOZ:	Bulk density from Schlumberger company
RLA3:	Resistivity shallow lateral log
Rm:	Resistivity of mud
Rmc:	Resistivity of mud cake
Ri:	Resistivity of invaded zone
Rmf:	Resistivity of mud filtrate
RT:	True formation resistivity
RXOZ:	Flushed zone resistivity
Rw:	Formation water resistivity

Rxo:	Formation resistivity at flushed zones
Sw:	Water saturation
Sw-QE:	Water saturation calculated from Quanti Elan
Swb:	Bound water saturation
Swf:	Free water saturation
Swi:	Irreducible water saturation
Sxo:	Water saturation in the invaded zone
Tmf:	Mud filtrate temperature
TNPH:	Neutron Porosity
Δt:	Transit time
Δtmaa:	Apparent matrix transit time
ρb:	Bulk density
ρh:	Hydrocarbon density
ρmata:	Apparent matrix density
ρmf:	Density of mud filtrate
φ:	Porosity
φc:	Core porosity
φD:	Porosity from density log
φN:	Neutron porosity
φS:	Sonic porosity
φt:	Total porosity

CHAPTER 1
INTRODUCTION

1.1 Preface

Formation evaluation is a technique used to analyze physical properties of reservoir rocks through subsurface wellbore such as cores, well logs and well tests. The reservoir is a rock layer under high pressure and temperature having porosity that holds hydrocarbons and permeability that allows fluids to pass through. Studies of this type give a clear figure about the commercial value hydrocarbons before developing oil and gas fields (Bateman, 1985).

Reservoir engineering virtually relies on Formation evaluation to manage the production capacity of the studied field and estimate the Oil Initially In Place (OIIP). Reservoir modeling is based on correct subsurface properties of the rocks and fluids and production optimization could not result in realistic data without using correct data from the Formation. Field development plan (FDP) of a field, starts with the analysis of Formation parameters (Asquith et al., 2004).

The Kirkuk field is 100 km long and 4 km wide including three domes from NW to SE such as Avanah, Baba and Khurmala dome (Al-Rawi, 2015). The Kirkuk field is one of the important oil field in Iraq. It is estimated that the reserve of the field is about 10 billion barrels. Recently, the maximum production capacity of the field is one million barrels per day. From 1934 to 1961, the Kirkuk field produced about 2 billion barrels of oil with the natural reservoir pressures. With the start of water injection from 1961 to 1971, the oil production increased up to 3.2 billion barrels of oil in 1971 (Al-Naqib et al., 1971).

Khurmala dome located around 34 km west of Erbil and is about 80 km NW of Kirkuk as shown in Figure 1. The length of this dome is about 22 km, and width is around 3 to 3.5 km. Hydrocarbons are produced from two main Formations, the first one on the top is the Paleocene – Upper/Middle Eocene age Avanah Formation, which is predominantly a recrystallized fore reef type limstone with some mudstone interbeds. The rock is porous, vuggy, fractured and locally stylolitic. The second one below Avanah Formation is

Paleocene – early Eocene age of Khurmala Formation, the whole rock is dolomitic, with all gradations of recrystallization, which have good porosity and permeability practically, also described by natural fracture. Reservoir potential of Avanah Formation has been investigated in this study.

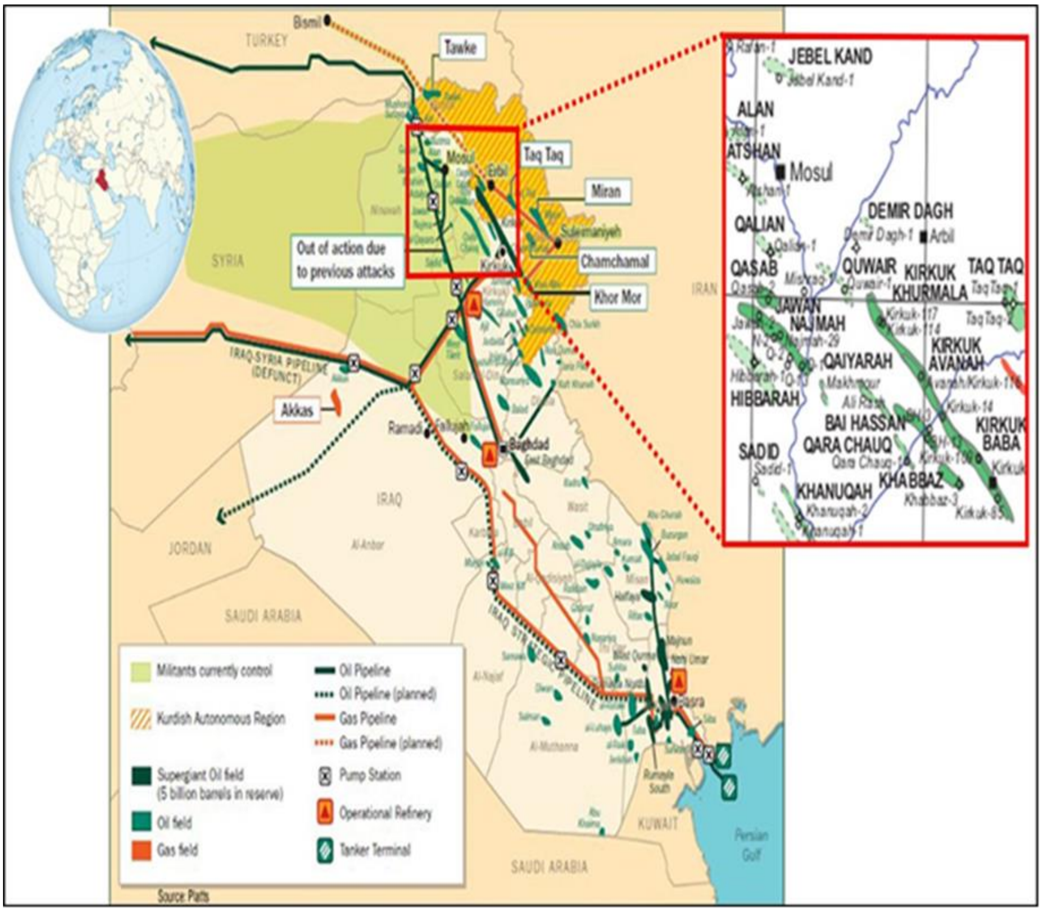


Figure 1.1: Location map of the Khurmala dome (Al-Rawi, 2015)

1.2 Stratigraphic Sequence

Reservoirs are associated with Tertiary sequence from Palaeocene to Miocene age as shown in Figure 1.2. Stratigraphic column in the drilled wells from surface to reservoirs zones include Upper - Middle Fars Formation, Lower Fars Formation subdivided into a number of units as shown in Figure 1.3, Avanah Formation, Khurmala Formation and Kolosh Formation.

1.2.1 Avanah Formation (U-M. Eocene)

The Fars Formation on the top is divided into two parts Upper and Lower Fars Formation. The upper part of this formation is primarily composed of siliciclastic sediments. It comprises an alternating series of sandstone, reddish brown, partly grey, fine to medium grains, interbedded with reddish to red brown claystone. The lower part of Fars Formation consists of an alternation of gypsum, anhydrite, lagoonal limestone markers, marls, and siltstone with occasional halite rocks (salts) layers. It can be said that, Fars Formation is overlying Avanah reservoir and evaporates are forming the cap rock.

The main pay zones of this area include Avanah Formation and Kurmala Formation. Avanah Formation in the Kirkuk field has been described by McGinty in 1953 (Bellen et al., 1959). Based on his description, Avanah rocks are porous, vuggy, fractured and locally stylolitic. This formation is composed of recrystallized fore – reef and contains some marly rocks. Fauna includes Nummulites spp. Discocyclina sp., Miliolids, Textularids, Alveeolina spp. Orbitolites sp., shell fragments, echinoid debris, and algae. The rock is frequently pyritic and contains abundant calcite growths (Jassim and Goff, 2006). Estimated thickness is about 140 m (KAR Company, 2014). Avanah reservoir divided by Kar company into two parts such as Avanah dense, Avanah porous and their estimated thicknesses are 80 m and 60 m, respectively. In this research Avanah dense is named as Avanah limestone and Avanah porous is named as Avanah dolomite.

Khurmala Formation is consists of dolomite with some limestone interbeds as shown in Figure 1.3 and interfinger with Kolosh Formation from the bottom of the Formation (Jassim and Goff, 2006). Actually, the thickness of Khurmala Formation is not the same in all wells. Khurmala Formation thickness is about 173 m in the Kirkuk area, while the thickness increases to 262 m in Atshan 1, but in Jabar Kand 1 the thickness of Kurmala reach the maximum value which is about 606 m (Jassim and Goff, 2006).

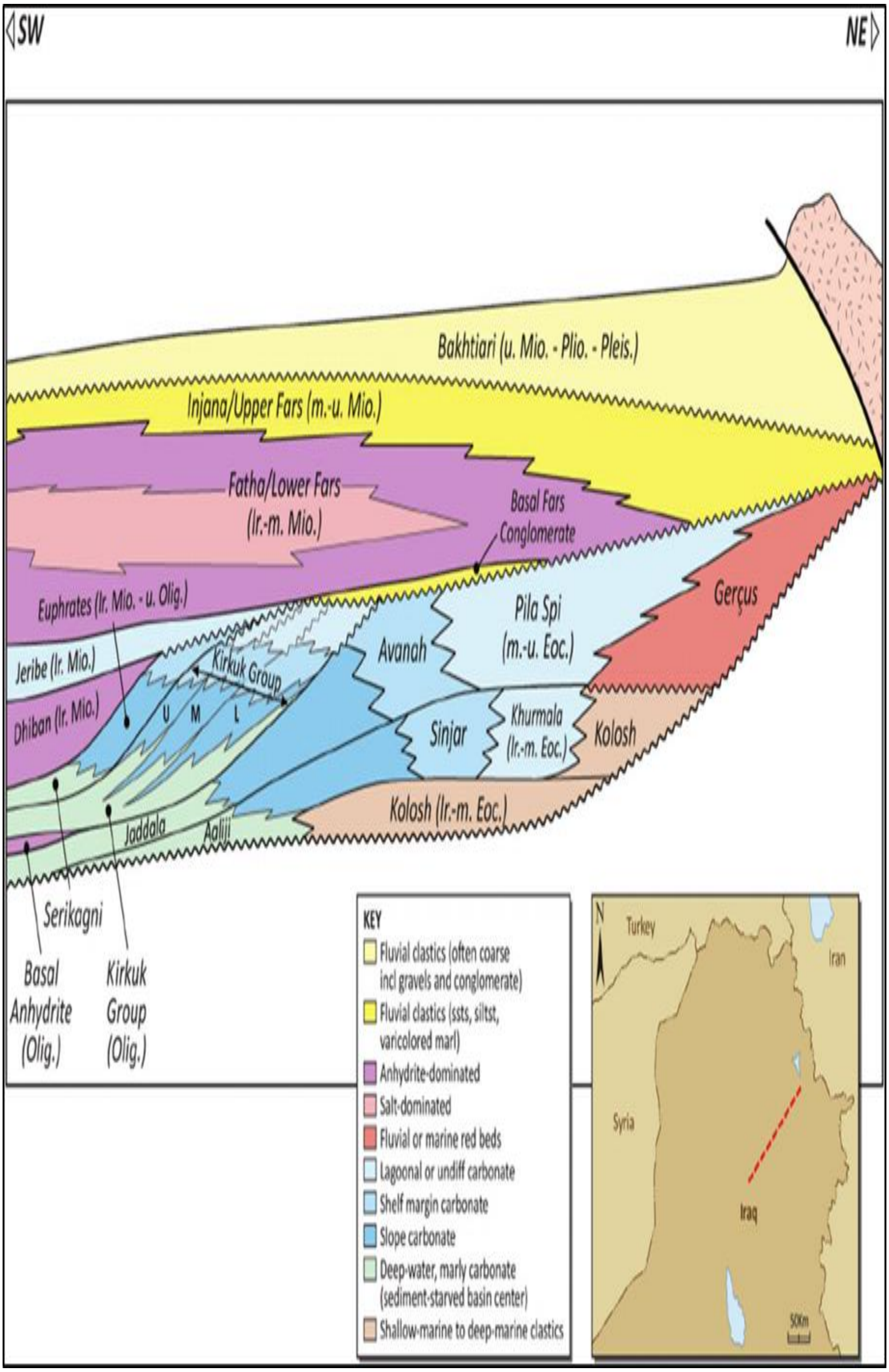


Figure 1.2: Stratigraphic cross section showing Kirkuk Group Formations (After Aqrawi et al., 2010).

Stratigraphic column in the Khurmala dome is shown in Figure 1.3

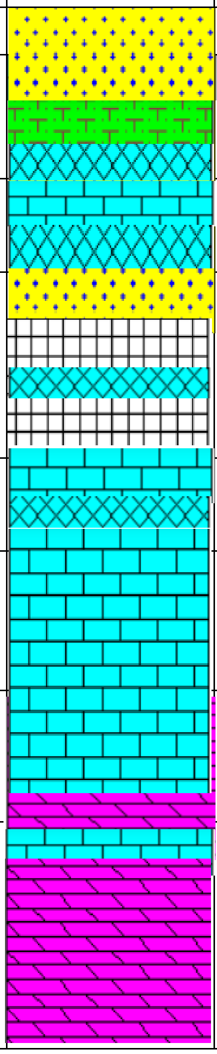
FORMATION	THICKNESS (m)	LITHOLOGY	SYMBOLS
Upper- Middle Fars	580		Sand
Lower Fars (Upper Red Bed)	56		Sand Claystone Anhydrite
Lower Fars (Seepage Beds)	33		Limestone Anhydrite
Lower Fars (Saliferous Beds)	102		Claystone Salt Anhydrite Salt
Lower Fars (Transition Beds)	34		Limestone Anhydrite
Avanah Limestone	83		Limestone
Avanah Dolomite	79		Dolomitic
Khurmala	+ 122		Dolomitic Limestone

Figure 1.3: Drilled stratigraphic column in Khurmala dome

1.3 Objective of the Research

The main objective of this research is to estimate reserves in the Avanah reservoir using well log data from six wells through emphasizing specifically on the following points

1. Identification of the lithology.
2. Study lateral changes constructing geological cross sections.
3. Determination of effective porosity from porosity logs.
4. Determination of water saturation from resistivity logs.
5. Evaluating the hydrocarbon zones and hydrocarbon types (oil or gas).
6. Integrating core and well logs data to estimate the permeability in un-cored wells.
7. Determining net-pay thickness in wells applying porosity and water saturation cut-offs.

1.4 Problem Statement

More than 10 wells have been drilled in Khurmala dome. The production rate from number of wells is not good enough in the south part of the dome compared to the rest of the wells. Most of the time, changing physical properties and reservoir characteristics are the main factors decreasing well production. In this research, improving production from the field has been investigated through subsurface well data mainly using wireline logging data and core data. Understanding the reasons behind decline of production is always great achievement to increase production by drilling more productive wells.

CHAPTER 2
LITERATURE REVIEW

This part covers the review of previous studies related with this thesis topic and study area.

2.1 Overview

Qadir (2008) used two methods for studying Formation evaluation in the upper Qamchuqa reservoir in the Khabbaz oil field (Kirkuk area), which was wire-line logs data, and core data. Lithology was classified into three lithological units, A, B and C. Furthermore, among these three, Unit A was defined as the best reservoir unit.

Harrison and Jing (2001) reconsidered the most common saturation height methods and their effect on volumetric hydrocarbons in place approximations. This paper reconsidered some of the most common saturation-height methods such as Leverett, Johnson, Cuddy (1941) and Skelt (1995) methods which are commonly used by the oil and gas industry. A comparison between all these methods has been determined to select the most representative method. Therefore, for this aim two wells which have predictable core data, SCAL and a full set of electric logs were used. The research concluded that Cuddy's technique was the humblest to appliance. Leverett's SCAL-based J-Function, whereas Johnson's and Skelt's SCAL-based methods were extremely inconvenient for the analysis. To observe the effect on the estimated oil in place, the considered methods were compared on a well basis, through which the resultant saturation height applied as a relationship to the reservoir structure.

Sahib (2003) evaluated the permeability of sandstone rock in southern Iraqi oil fields using well logs focusing on the geological factors such as, nature of the porosity and grain properties. He used different methods to calculate permeability by integrating core and log data. He also compared his result with porosity permeability direct correlations, the irreducible water saturation method, improved log derived permeability by pore throat radius and cementation exponent parameters, the resistivity ratio method, and the transform approaches method.

Finally, it was concluded that each Formation has its own character to apply a method in order to calculate permeability in the un-cored wells with approximate results. He concluded that only porosity was insufficient to clarify the permeability variations.

Nordahi (2004) studied petrophysical evaluation of the Tilje Formation in the Heidrun field, located in mid Norway. Estimation of porosity and permeability of a challenging reservoir type was studied through an integrated reservoir study for having a precise estimation of the interested petrophysical properties. In this study the core interval samples were analyzed to find the more effective parameters on petrophysical properties. Furthermore, evaluation of the near wellbore region in the same field was carried out using a process-based numerical modelling tool. This tool is relied on correlation of the core analysis data including with the surrounding wells. For better convincing the results of two methods; first process-based model a second method is brought into consideration that its basics are on how mud and mud contents can be used for calculating the near wellbore porosity and permeability.

Obeida et al. (2005) applied various techniques to calculate fluid saturation which was a case study on a huge complex carbonate reservoir in the Middle East. This study was adjusted using MIPCs and J Functions obtained from core tests. The reasons behind using the J Function model were that in one area the results for matching irreducible water saturation were not good, and a capillary pressure curve for each reservoir rock type was used. Again, the results of this method were not satisfactory, especially when picking up an average from a single capillary pressure test. Eventually log derived J-function and the results were used.

Abdulkareem (2011) studied petrophysical properties of the Jribe, Dihban, Euphrates, and Bajwan Formations in an Iraqi gas field. In his study, Archie parameters were determined from well logs analysis. It was concluded that the lithologies of these Formations were mostly limestone while it was partially dolomitized and contained some shale. Moreover, clay volume was calculated using combination of gamma ray log method, resistivity log method, neutron log method, density neutron cross-plot method, density - acoustic cross-plot method and neutron - acoustic cross-plot method.

Furthermore, porosity was determined from sonic log, density log and neutron logs, and also secondary porosity index which occur due to diagenetic process was determined. Crystallization, dolomitization, and recrystallization are the diapenetic processes determined. In addition, the following formation related parameters were determined:

• Formation water resistivity was determined from the apparent water resistivity method using spontaneous potential log.

• Fluid saturation was determined by using Archie equation, Dual water model and Indonesian model.

• Irreducible water saturation was calculated through plotting water saturation versus porosity in a linear scale.

• From empirical equations permeability was estimated.

• Distribution of porosity and permeability were mapped using the SURFER software.

Tixier (1949) studied evaluation of permeability through electric-log resistivity gradients in oil/water transition zones with regards a deep investigation resistivity tool. Although the investigations were the existing empirical relationships between resistivity and water saturation, water saturation and capillary pressure were employed for that purpose. Therefore, using the resistivity gradient from the corresponding layers resulted in the calculation of the average permeability.

2.2 Petrophysical Analysis of Several Fields

Al-Hilali (2006) evaluated carbonate reservoirs in the eastern Baghdad oil field by using a CORIBAND model, which is used for complex reservoir interpretation. The author performed pre-interpretations from the available open-hole logs to acquire the values of total porosity and apparent matrix identifiers. Therefore, the value of resistivity for uninvaded zone (Rt) and invaded zone (Rxo) were determined for each level. Cross-plot technique were used to select clay parameters and study the lithology types for each formation.

Moreover, Archie's parameters were determined through using two criteria. Firstly, for each formation and secondly, for each level using cross-plots methods. For each level in crossed interval the types and values of the secondary porosity were studied using a method developed by Schlumberger. Furthermore, the Indonesia equation was used to calculate water saturation in flushed and uninvaded zones for each level. Saturation results were evaluated using the Repeat Formation Tester log (RFT).

Abdulsattar (2007) studied the impacts of using fixed and variable petrophysical parameters on hydrocarbon saturation evaluation and the discovery of the missing pay zone by the dual water model for the East Baghdad oil field. This study enclosed the factors that affect the change of the Archie parameters and obtained them using well log interpretation, so the water saturation can be computed precisely. Moreover, water saturation in the invaded zone was calculated by using the Electromagnetic Propagation Technique (EPT), and the author reviewed the factors that affect permeability. As a result, the best relationship to determine permeability was discovered, and the highest hydrocarbon saturation was obtained when using variable porosity exponent (m), which was computed via Electromagnetic Propagation Technique (EPT).

Al-Jahlawe (2007) studied Formation evaluation of Iraqi reservoirs in the West Qurna oil field, prepared a computer program to evaluate the reservoir using logs data. This program was comparable with the Schlumberger's Global processing program. First, the Global technique was modified by calculating the actual values for Archie's parameters. The Pickett and Gomez method was used to determine those parameters, while those parameters are constant in the original Global program. The type of matrix lithology was determined by using matrix identification cross plots, apparent density matrix and apparent sonic matrix.

The volume of clay is calculated through the following methods: spontaneous potential log method, neutron log method, resistivity log method, density – neutron cross-plot method and density – acoustic cross-plot method. In addition, apparent formation water resistivity and apparent resistivity of mud filtrate and spontaneous potential log versus flushed zone resistivity / true formation resistivity ratio were used to calculate formation water resistivity and mud filtrate resistivity. Moreover, the invaded and non-invaded zone resistivities and invasion diameter were calculated using RtGlobal method.

It was concluded that the porosity and moved hydrocarbon saturation values are higher if the value of parameters are not constant. This was confirmed by comparing results with flow test and drilling steam test result.

Richrdson (2009) performed a petrophysical analysis of the Lance Formation Washakie basin in Wyoming. In this study logs and core data were used. By using Gamma ray and density porosity curves the lithology of the reservoir was identified. From those curves the lithology was found to be composed of mainly porous sandstone with shale and coal. The amounts of shale were calculated by using the Gamma Ray (GR) log.

Porosity was determined from the density and neutron porosity logs and core data analysis. Gas bearing zones were predicted in the lower part of the lance Formation using petrophysical data. Moreover, the Formation water resistivity was calculated by using Pickett Plot and core data. Then, water saturation was determined using Archie's equation of average water saturation. Finally, core data was used to estimate the permeability.

Mimonitu (2010) studied petrophysical evaluation of the O-M field offshore gas bearing sandstone reservoir in Southern Africa. The log data was used for Formation evaluation and results were correlated with core analysis. Core data and Gamma Ray curve were employed to identify the lithology of the reservoir, and the volume of shale was calculated using various logs and methods (linear and nonlinear gamma ray method, spontaneous potential log, neutron log method resistivity method and double clay indicators).

Furthermore, porosity was determined by using core data and density log, neutron log and sonic log and effective porosity was calculated. The Formation water resistivity was computed using the spontaneous potential method and Pickett Plot method.

In addition, Darcy's law was used for core data to calculate permeability. Gas oil and water contacts were determined using slick line pressure data and wireline logs. Consequently, the study provided to scale transition matters in a complex gas bearing sandstone reservoirs and helps as a base for analysis of petrophysical properties in a multi-scale system.

Abed (2011) evaluated permeability of non-fractured carbonate reservoir in the North Rumaila oil field, Sothern Iraq using well logs and core data. Interactive petrophysics and a Fortan program were used for interpretations and environmental corrections. Petrel program was used for creating plots and cross plots. First, the raw data were corrected for evaluating carbonate rock of the Mishrif Formation, and the corrected log sets were used as input data. Moreover, Archie's parameters (tortuosity factor, cementation exponent and saturation exponent) were calculated using well log data.

Additionally, from well log measurements in un-cored sections of the wells the porosity correlations were used to calculate permeability. Finally, regression methods between the Flow Zone Indicator (FZI) from well logs and core data were applied to develop a statistical model of each reservoir unit.

Abdulzahara (2011) studied the characterization of carbonate reservoirs via flow units. This study characterizes a petrophysical-based technique that well logs and core plugs data were used to illustrate flow units within the productive carbonate reservoir of the Mishrif Formation in the west Qurna field which is located in southern Iraq. The Petrel program was used to plot well locations and to create a structure map. Interactive Petrophysics program was employed for the interpretation log data. For the determined parameters needed for this program several logs and core data were used. Matrix identification cross plot were used for lithology determination. Volume of shale was calculated using gamma ray log.

Jaafar (2012) studied the properties of the Mishirif Formation and created an accurate geological model for the Buzurgan oil field in Iraq. For this purpose, the author used a precise petrophysical evaluation of reservoir, by using an Interactive Petrophysical model, and also discussed the factors that affect the variation of Archie's parameters. The study showed the methods to compute the factors and obtained them through core reports and well log interpretation. Moreover, the gamma ray curve and density-neutron plot were applied to compute the volume of shale, and porosity was determined by using acoustic log, density log and neutron log. Therefore, water saturation was calculated from resistivity logs. Additionally, well correlation was created and divided Formation into 38 layers. The Mishirif structure was separated into three segments: saddle, south dome and north dome, also it was divided into 2121768 fine cells to contribute clear and perfect petrophysical distribution along Formation. Initial oil water contact was evaluated and compared with the final oil water contact which determined from the new drilled wells. Finally, oil initial in place was estimated and differentiated with oil initial in place which was previously calculated in other studies.

Niepsuj and Krakowska (2012) studied petrophysical parameters of the main dolomite Formation in Poland by well logging and seismic data. The following logs were used in the study: gamma ray, total porosity, bulk density, and resistivity and P-wave velocity. For this study a number of software programs such as GEOWIN, HAMPSON--RUSSELL and GEOGRAPHIX DISCOVERY were used. The study determined three zones in the main dolomite that have different parameters based upon statistical computations and parameters described by 2D cross-plots.

Miah (2014) studied Formation evaluation of the Bakhrabad gas field via logging data, Natural (NGR) and Spectral Gamma Ray logs (SGR) were used to identify the lithology of the pay zone, and the results showed mostly sand with laminated shale.

The volume of shale was calculated using the true resistivity method and gamma ray curve. Additionally, density-neutron combination was used to determine porosity. Due to the presence of shally sand in the pay zone, sonic log was used to determine porosity.

Furthermore, the following parameters were determined: Formation water resistivity was estimated by using inverse Archie's method, water saturation due to Archie's equation, the Indonesia and Simandoux models, and permeability through using Wyllie and Rose's equation.

CHAPTER 3
METHODOLOGY

This chapter discusses all required steps and introduces methodology to complete this project.

3.1 Description

The first task to initiate the study was data procurement from KAR Company. Data includes analog and digital well logs, core data and geological information from six wells in the study area. Upon receiving data was inspected, processed and checked for quality. Right at start extracting the top depths of Avanah Formation in obtained wells and geological interpretation were performed.

Well log data were analyzed by using TECHLOG software to determine the main petro physical properties (porosity, water saturation, and permeability) and characterizing the hydrocarbon fluids. This task was achieved through integrating well logging data with core data for generalization and interpretation of non-cored intervals. Also was used for making cross section planes and correlating between the wells in the study.

Log data used in this study include Gama ray log, Sonic log, Neutron-Density log, Caliper log, photo electric factor log (PEF), and resistivity logs. Subsurface contour maps of the Khurmala dome using Petrel Software were also prepared.

3.2 Logging tools:

Common logging tools that used to extract petrophysical properties are introduced briefly below.

3.2.1 Gamma Ray Log (GR)

The radioactivity of the formations measured or evaluated through utilizing Gamma ray log, because there is the presence of radioactive elements in shale formations. Thus, the Gamma-Ray typically identifies shale formation or presence of shale in the formation. The Gamma-Ray log (GR) is usually illustrated in the first track on a linear grid and is scaled in

American Petroleum Institute (API) unit from (0 to 100 or 0 to 150). Radioactivity with high readings causes a deflection of the curve to the right and low radioactivity causes a deflection to the left; thus high readings indicate shale and lower readings indicate less shale or shale free formations called clean sandstone, clean limestone or clean dolomite. However, when there is mica, uranium feldspar, glauconite presence in the clean sandstone formations, Gamma ray may show high readings (Asquith et al., 2004).

So, with having Potassium (K), Thorium (Th) and Uranium (U) content in sandstone formation, Spectral Gamma Ray should be run to separate each radioactive elements with different readings as seen in Figure 3.1. Other three common simple uses of Gamma-ray are the correlation of stratigraphic units, mineral analysis and shale volume calculation which is important for calculating water saturation in shale bearing formations (Dewan, 1983).

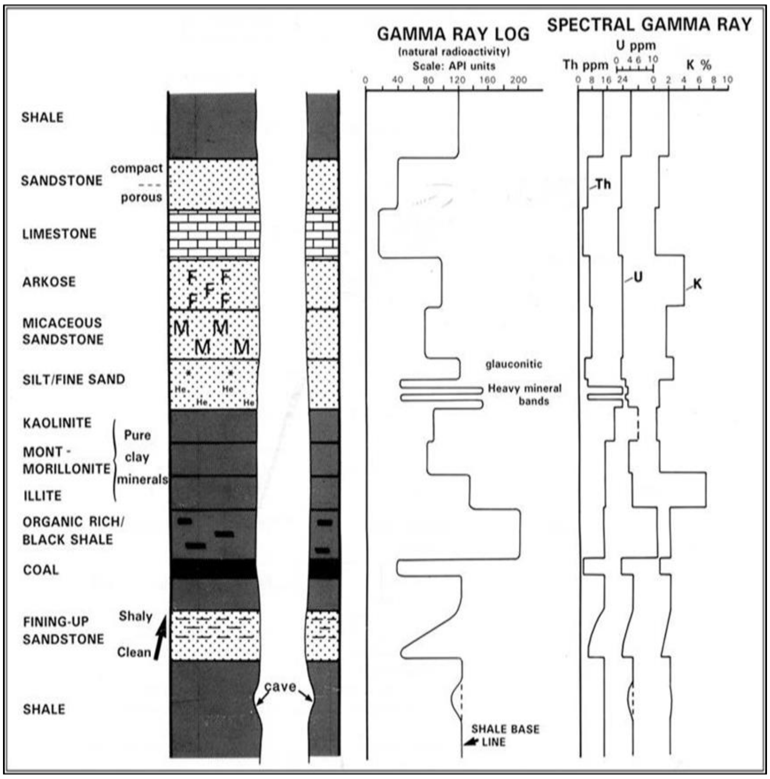


Figure 3.1: Comparison of total Gamma Ray and Spectral Gamma Ray curves opposite different lithologies (After Rider, 1986).

3.2.2 Sonic Log

The whole process of sonic log could be mentioned as the operation of sending and receiving sound pulses by the end of the tool. The simplest one comprises of one transmitter and a pair of receivers. Usually sonic curve is plotted in Track 2 or 3 ranging from 40 – 140 µsec/ft. The time that need for cross the sound wave on the formation recorded by sonic log, called as slowness and obtainable in microseconds per foot (µsec/ft) and it rely on the formation lithology and its porosity value (Figure 3.2). In addition, increasing porosity lead to increase interval transit time (Oghenekohwo, 2010).

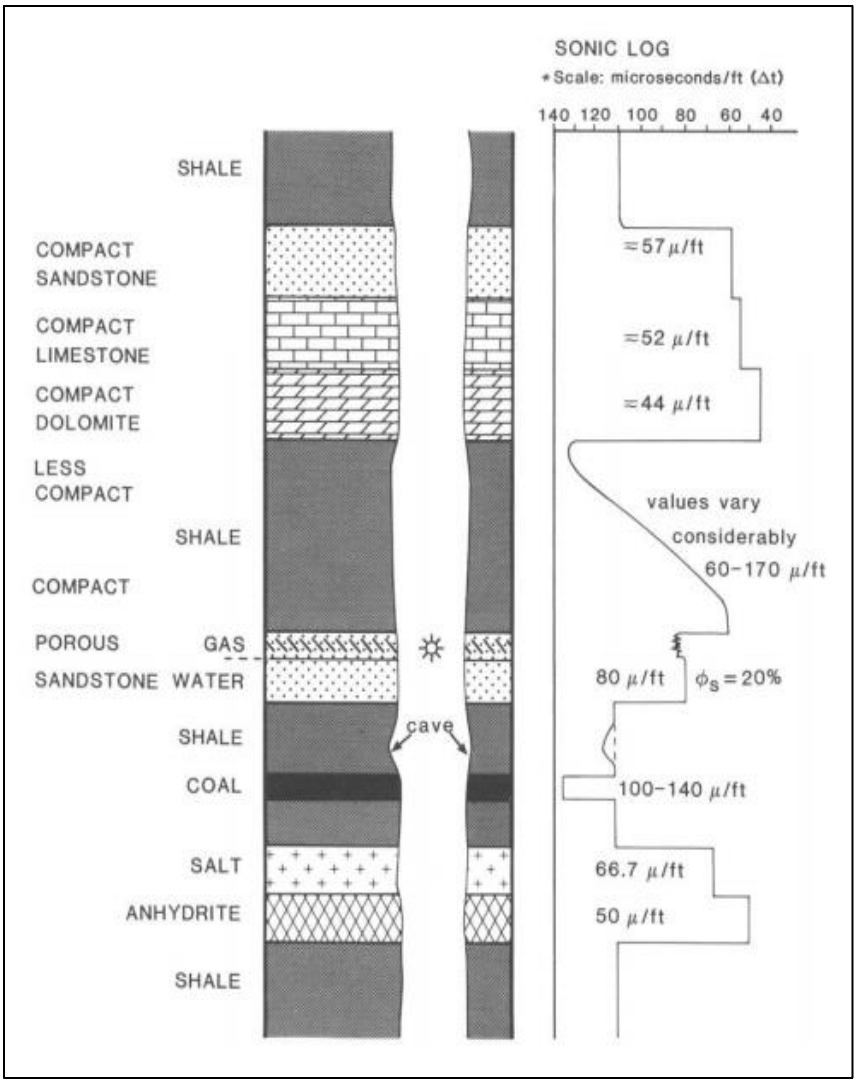


Figure 3.2: Sonic log records in various lithologies (After Rider, 1986).

3.2.3 Neutron Log

The Neutron log responds primarily to hydrogen atoms in the formation. The two substones in the formation with the greatest concentration of hydrogen atoms are water and liquid hydrocarbons that occupy the pore spaces. In clean formations the tool reflects the amount of liquid filled porosity. Neutron porosity readings are computed automatically and displayed as a curve scaled in linear porosity units similar to the density porosity display. Neutron readings are affected to some extent by the lithology of the rock matrix, therefore a matrix setting must be chosen prior to logging the well. Neutron logs, however, usually calibrated for a limestone matrix and if actual lithology coincides with the chosen matrix setting porosity may be read directly from the log. Porosity for the lithology other than limestone may be determined from a chart if the lithology is known (Asquith et al., 2004).

3.2.4 Density Log

The Formation density tool radiates gamma rays into the formation from the source and measures gamma rays returning at the detectors. By introducing the known amount of radioactive energy into the formation and monitoring its loss while transit, a good approximation of rock density can be obtained. Gamma rays are emitted continuously from the source and the passed through the mud cake into the rock, where they are scattered or absorbed some are returned back through the mud cake to the detectors and counted. In the formation density tool source and receiver detectors spacing is so close, so the device evaluates invaded zone close to the bore wall. The loss of gamma ray energy that occurs during transit from source to detector is used to interpret porosity of the formation (Asquith et al., 2004).

3.2.5 Resistivity Log

Formation resistivity is very important because it is inversely related to water saturation (Sw). In a reservoir rock as water saturation increase electrical resistivity of the formation decreases. Consequently, from resistivity measurements water saturation and therefore hydrocarbon saturation could be determined. The simple measuring system has a pair of current electrodes and a pair of voltage electrodes. The resistivity logs could be used in differentiating hydrocarbon bearing zone from water-bearing zone. When porosity logs are not available it could be used for porosity determination and could be used to indicate permeable zones. Resistivity is measured in ohm-meters (Asquith et al., 2004).

The resistivity logs are normally illustrated on a logarithmic scale ranging from 0.2 - 2000 ohm-meters in Tracks 2 or 3, the values increase from left to right. In electrical logging several factors control the measure of electrical response. These are: water saturation, salinity, porosity and pore interconnections sometimes referred to as tortuosity. The first two of these factors are fluid dependent while the third one is rock dependent. As the salinity of the sample is changed you can observe a change in the voltage reading. As salinity increases current flows between the current electrodes and there is a potential or voltage drop measured in logging terms the resistivity of the formation decreases, resistivity also decreases as water saturation increases and as porosity increases (Krygowski, 2003).

3.2.6 Caliper Log

A caliper is an auxiliary tool which is used for measuring borehole diameter. This tool usually consists of (2, 4 up to 30) extendable arms. The caliper curve generally schemed in Track 1 with the bit size for reference scaled range (6 – 16) based on the bit size. If the caliper log reads a constant hole size, this phenomenon is called on gauge. This happens if has non-permeable Formation or well consolidated formation like massive sandstones, metamorphic rock and igneous rock. If caliper read more than bit size its mean we have caving, weak formation or soluble formation like (unconsolidated sand or salt formation) in this case called over gauge, inversely if caliper read less than bit size its means there is swelling or mudcake development, where swilling happens in shale layers and mudcake develops in pours and permeable sandstone layers. This is called under gaue (Figure 3.3). The caliper logs have more applications as follows (Parsons, 1943):

Caliper information is useful in lithological identifications, indicate porous permeable zones, computing thickness of the mudcake, calculation volume of borehole, calculation of cement volume and hole characteristics.

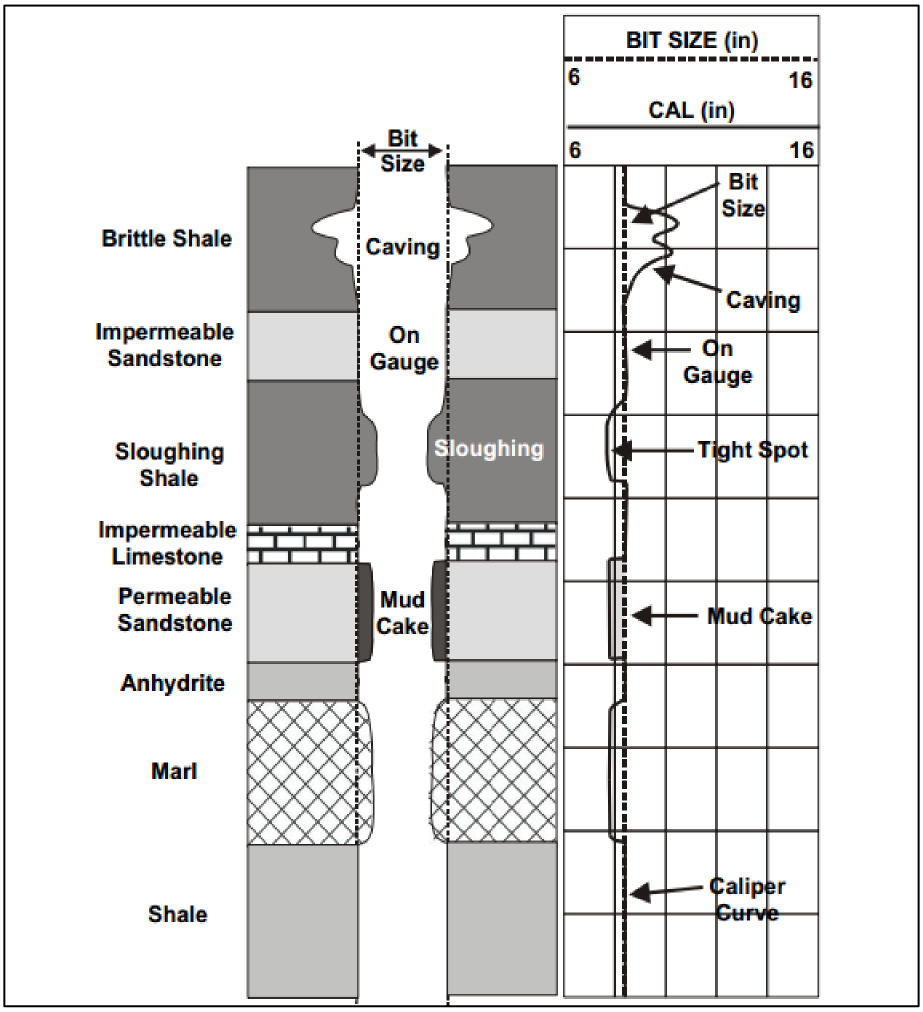


Figure 3.3: Caliper log readings in numerous lithologies (After Ahammod et al., 2014)

3.3 Techlog Software

TECHLOG software is a Schlumberger software platform to identify and collect all well bore information. In addition, through using this software we will be able to interpret logs and core data. In this research study, TECHLOG software has been used in order to find and identify porosity, water saturation and hydrocarbon and gas zones. Utilizing and identifying mentioned reservoir characteristics depend on the collected data from Avanah Formation in Khurmala dome.

3.4 Petrel Software

As it is well-known, PETERL software could be used as a petroleum software platform for exploration purposes as well as the production sector in oil and gas industry. In this project Petrel software has been used to prepare subsurface contour maps of Khurmala dome.

3.5 Determination of Lithology

Determination of the lithology is one of the important components for formation evaluation of a reservoir. There are many techniques used to accomplish this task. In this project Density versus Neutron cross plot technique was used for lithology determination; this method consists of plotting corrected neutron porosity (φ_N) versus corrected bulk density (ρ_b) on a standard plot.

3.6 Porosity Determination

Porosity can be calculated from sonic log through the following equation;

$$\varphi_S = \frac{\Delta t - \Delta t_{ma}}{189 - \Delta t_{ma}} \quad (3.1)$$

Where,

φ_S=prosity from sonic log.

Δt_{ma}=is the matrix transit time, *µsec/ft*

Δt=is the transit time from sonic log, *µsec/ft*

Prosity also can be calculated from density log through the following equation;

$$\varphi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{mf}} \quad (3.2)$$

φ_D=porosity from density

ρ_{ma}=is the matrix density, *gm/cc*

ρ_b=is the bulk density, *gm/cc*

ρ_{mf}=is the density of mud filtrale, *gm/cc*

Finally porosity can be calculated directly from neutron porosity log and denoted as φ_N.

Total porosity is calculated as follows:

For oil reserviors:

$$\varphi t = \frac{\varphi_N + \varphi_D}{2} \tag{3.3}$$

For gas reservoirs:

$$\varphi t = \sqrt{\frac{\varphi_{N2} + \varphi_{D2}}{2}} \tag{3.4}$$

φt= is the total porosity from Neutron and Density

φ_N= neutron porosity

φ_D=porosity from density

3.7 Water and Hydrocarbon Saturation Determination

After calculating porosity, it is possible to calculate water saturation. The Archie equation is adopted to achieve this task as in the following equation for non-invaded zone:

$$Sw^n = \frac{aRw}{\emptyset^m Rt} \tag{3.5}$$

Where,

Sw = water saturation.

R_w= formation water resistivity

m= cementation factor.

a= tortuosity factor.

n= saturation factor.

Rt= formation true resistivity.

For flushed zone this equation is used;

$$Sxo^n = \frac{aRmf}{\emptyset^m Rxo} \tag{3.6}$$

Where,

Sxo = water saturation of the flushed zone

Rmf = resistivity of mud filtrate at formation temperature

Rxo = shallow resistivity from Micro Spherically Focused Log (MSFL)

$$movable\ hydrocarbon = \varphi_t(S_{xo} - S_w) \quad (3.7)$$

The volume of residual hydrocarbon can be calculated as:

$$residual\ hydrocarbon = \varphi_t(1 - S_{xo}) \quad (3.8)$$

3.8 Permeability Determination

Permeability is defined simply as the ability of the rock to transmit fluids through it. There are many methods to estimate permeability. Two methods have been used to calculate permeability in this project:

3.8.1 Porosity Correlation Method (Empirical Method)

Permeability values in un-cored wells can be estimated from cross-plotting method by plotting core porosity on the x-axis in linear scale and core permeability on the y-axis on a log scale. Permeability versus porosity for core data of all units and generated best fit line of each line expressed with an equation as: (Desbrandes and Brace, 1985).

$$K = b\ e^{a\,ø} \quad (3.9)$$

Where,

a and b = are constants

ø = porosity (fraction)

k = permeability (md)

3.8.2 Morris and Biggs Method

Morris and Biggs estimated the permeability through presenting the following two expressions for oil and gas reservoirs (Morris and Biggs, 1967).

For oil reservoirs:

$$k = 62.5 \left(\frac{\emptyset^3}{Swc}\right)^2 \tag{3.10}$$

For gas reservoirs:

$$k = 6.2 \left(\frac{\emptyset^3}{Swc}\right)^2 \tag{3.11}$$

Where,

k = absolute permeability, (D)

Ø = porosity, (fraction)

Swc = connate water saturation, (fraction)

3.9 Cut-off Determination

Identification of petrophysical property of the formation units could be proposed or intended through using cut-off determination, when the formation contains poor reservoir zones. Because, formation volume accumulations should not contain poor reservoir zones during assessing formation recovery (Worthington, 2008).

More clearly, cut-off determination process begun with identifying the reference parameter which become a factor to evaluate or differentiate between intervals that do not contain reservoir potential and intervals that contain reservoir potential. Based on the researches, there is no any reliable method to cut-off evaluation (Worthington and Cosentino, 2005). Cut- off identification is require to determine volume of hydrocarbon in reservoir. Due to that, net pay that identified by cut-off determination hold hydrocarbon in the reservoir.

Flow rate utilized to define net pay and recovered fluids; formations with having proper permeability that allow good hydrocarbon movement are categorized as net reservoir or net sandstone. So that, net pay zones means ability to produce fluids or hydrocarbons with acceptable water and hydrocarbon ratio (Suzanne and Robert, 2004).

3.9.1 Porosity Cut Off Determination

A plot of porosity on the linear scale versus permeability on the log scale was used for determination of cut off porosity. The intersection of a straight line drawn from 0.1md with the best fit line between core permeability and core porosity determines the cut off core porosity. Conventionally, a permeability of 0.1md is the accepted minimum value for conventional oil production.

3.9.2 Water Saturation Cut-Off Determination

As previously has been mentioned porosity cut-off is selected based on core permeability and core porosity, then water saturation cut-off was achieved through plotting the porosity against water saturation in linear scale and drawing the hyperbolic best fit line through the data to determine water saturation cut off corresponding the porosity cut-off as shown in Figure 3.4.

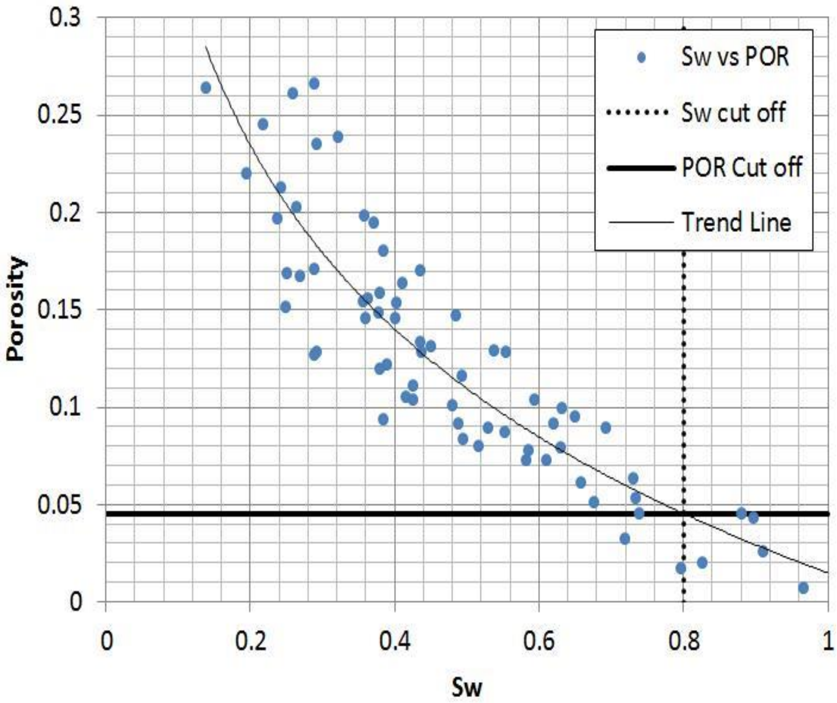


Figure 3.4: Water saturation cut off determination plot (Worthington, 2008).

CHAPTER 4
RESULTS AND DISCUSSION

In this chapter petrophysical parameters calculated from well log such as lithology, porosity, water saturation, and permeability are discussed.

4.1 Lithology Determination of Avanah Formation

Density versus neutron cross plot technique was used to determine lithology of six wells in Avanah Formation. This method consists of plotting corrected neutron porosity (φN) vs. corrected bulk density (ρb) on a standard plot (Figure 4.1). The result of determination process shows that the upper Avanah data points are aligned on limestone line whereas, the Lower Avanah data are on the dolomite line in all wells. There are several interbeds of limestone in the Lower Avanah Formation in some wells.

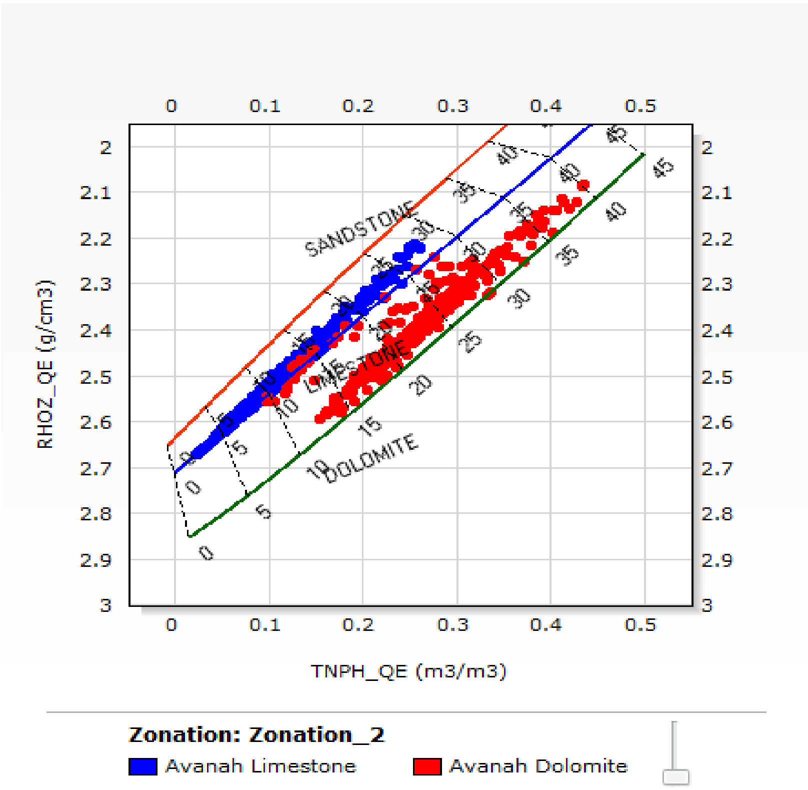


Figure 4.1: φN vs. ρb cross plot for Avanah Formation in Well A

Based on data of Well A in Figure 4.1 blue points represent Avanah limestone and red points represent Avanah dolomite. Lithology cross plots of other wells are shown in Appendix 1.

In addition, interpretation of all wells has been done through using TECHLOG software. Interpretation of Well A has been reproduced through using excel as well. So, the aim of using Excel software was to determine and identify several important things from Avanah Formation such as lithology, gas zone, fracture and secondary porosity. The result shows that gas zone of Well A located in upper part of Avanah. Lithology in Well A identified by using photoelectric factor PEF, Gama ray (GR) and neutron- density logs. Figure 4.2 represents gas zone from 822 m to 860 m in Well A, from 860 to 880 no gas due to porosity is zero, also from 880 to 895 represents gas in Well A.

In addition, high Gama ray log indicate shale zone and in Figure 4.2 have high Gama ray reading in lower part of Avanah Formation but it not an indication for shale zone because PEF reading is 3 without any deviation it is an indication for dolomite, also density and neutron curve showing dolomite and the points of porosity located over dolomite line as shown in Figure 4.1 then the result has been compared to ″Cutting Master Log″ data which support that same result, which mean cause of high gamma ray in Avanah Dolomite is existence of radioactive element, not shale.

Figure 4.3 illustrates fractures and secondary porosity of Avanah Formation. Secondary porosity index has been calculated from the difference between Density-Neutron cross plot porosity (φDN) and sonic porosity (φS). Fracture detection is based on low reading of sonic log, high reading of neutron-density log and high reading of caliper log from well log data.

Fracture located in both upper and lower part of Avanah Formation it is based on high reading of caliper log compared to bite size. Secondary porosity located in lower part of Avanah formation it is based on low reading of sonic log and high reading of neutron-density log. It is clearly seen that secondary porosity is dominant in Avanah limestone.

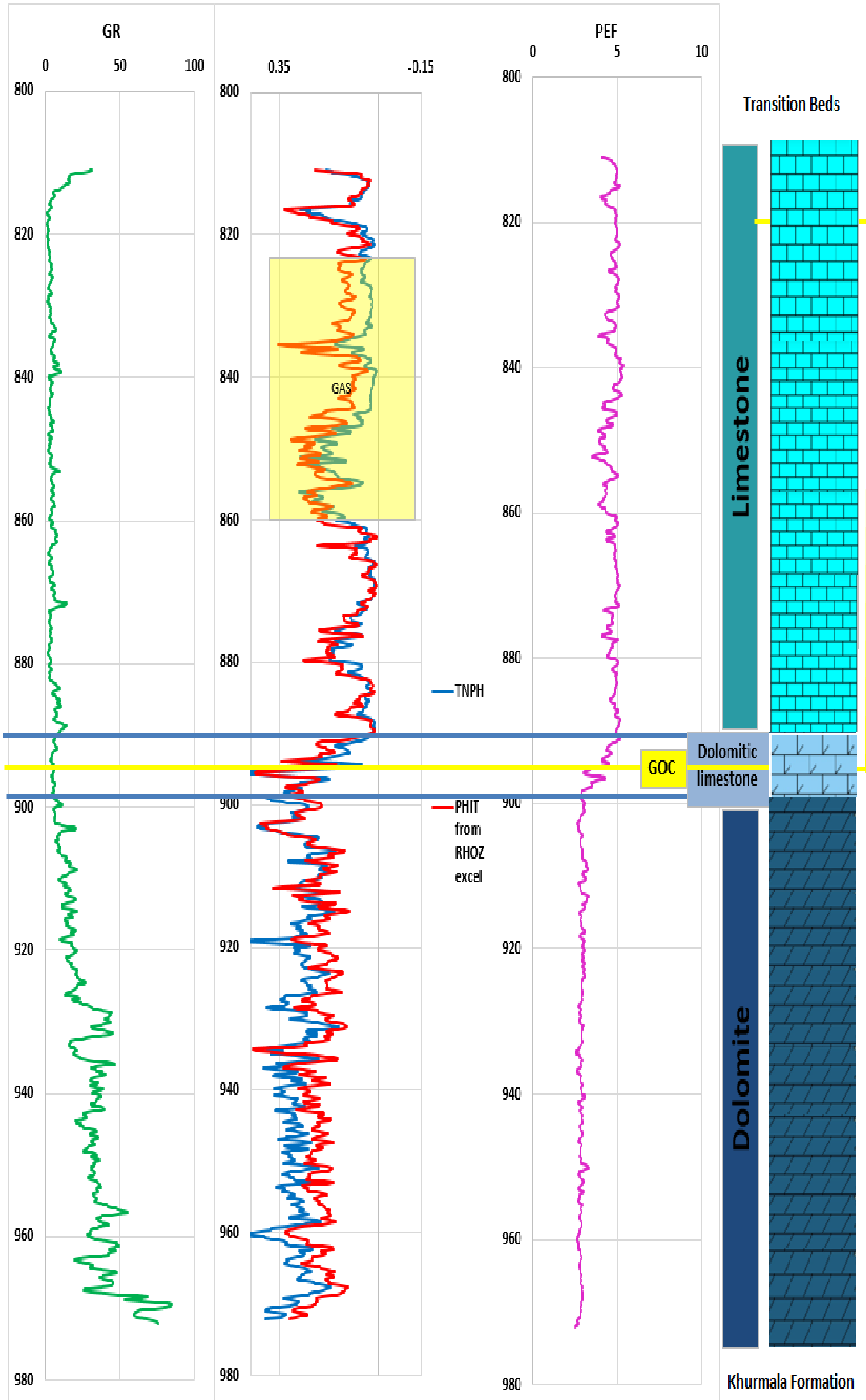


Figure 4.2: Lithology and gas zone in Well A

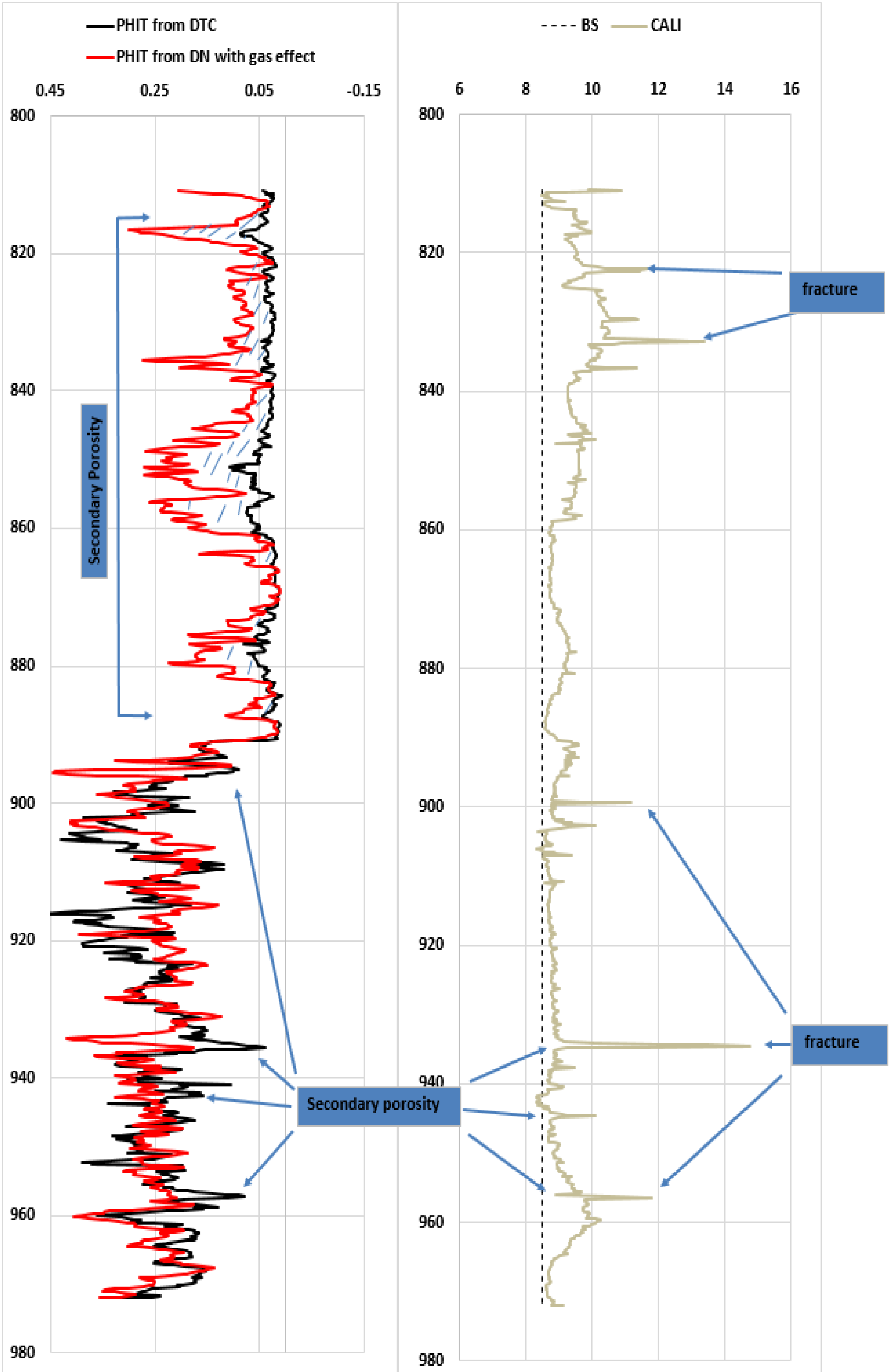


Figure 4.3: Secondary porosity and fractures in Well A

4.2 Porosity Calculation of Avanah Formation

Porosity of Avanah Formation has been calculated through density and neutron log. The details of this method has been explained in Chapter 3.

Figure 4.4 represents log porosity distribution in Well A. It is seen clearly that porosity of Avanah dolomite is higher than Avanah limestone due to the dolomitization which increase porosity, the average porosity of Avanah limestone in well A is 0.1 while the average porosity of Avanah dolomite is 0.245. From a quick look of the results of this method and comparing them with core results, it is clear that the core and log porosity values are not greatly differ from each other. The results of other wells are shown in Appendix 2 interpretation of wells.

4.3 Calculation of Water and Hydrocarbon Saturation

After level by level porosity determination, water and hydrocarbon saturations are calculated. The Archie equation is adopted to achieve this task. Water saturation of both Avanah limestone and dolomite determined through using Archie equation inserting number of real data including n, m and a which are all constant, Rw is equal to 0.1 ohm-m at 40°C due to having average salinity of 50 kppm in the Khurmala dome area.

Well A located in NW part of Kurmala dome, this well recognized by having good porosity and it leads to provide high level of hydrocarbons. Also water saturation level of this well is low, average water saturation of Avanah limestone is 0.33 while the average water saturation of Avanah dolomite is 0.2 as shown in Figure 4.6. which is considered as a good reservoir characteristic. Moreover, this well has a gas in upper part of the formation, while oil in lower part of the formation as shown in Figure 4.6. Interpretation of other wells showed in Appendix 2.

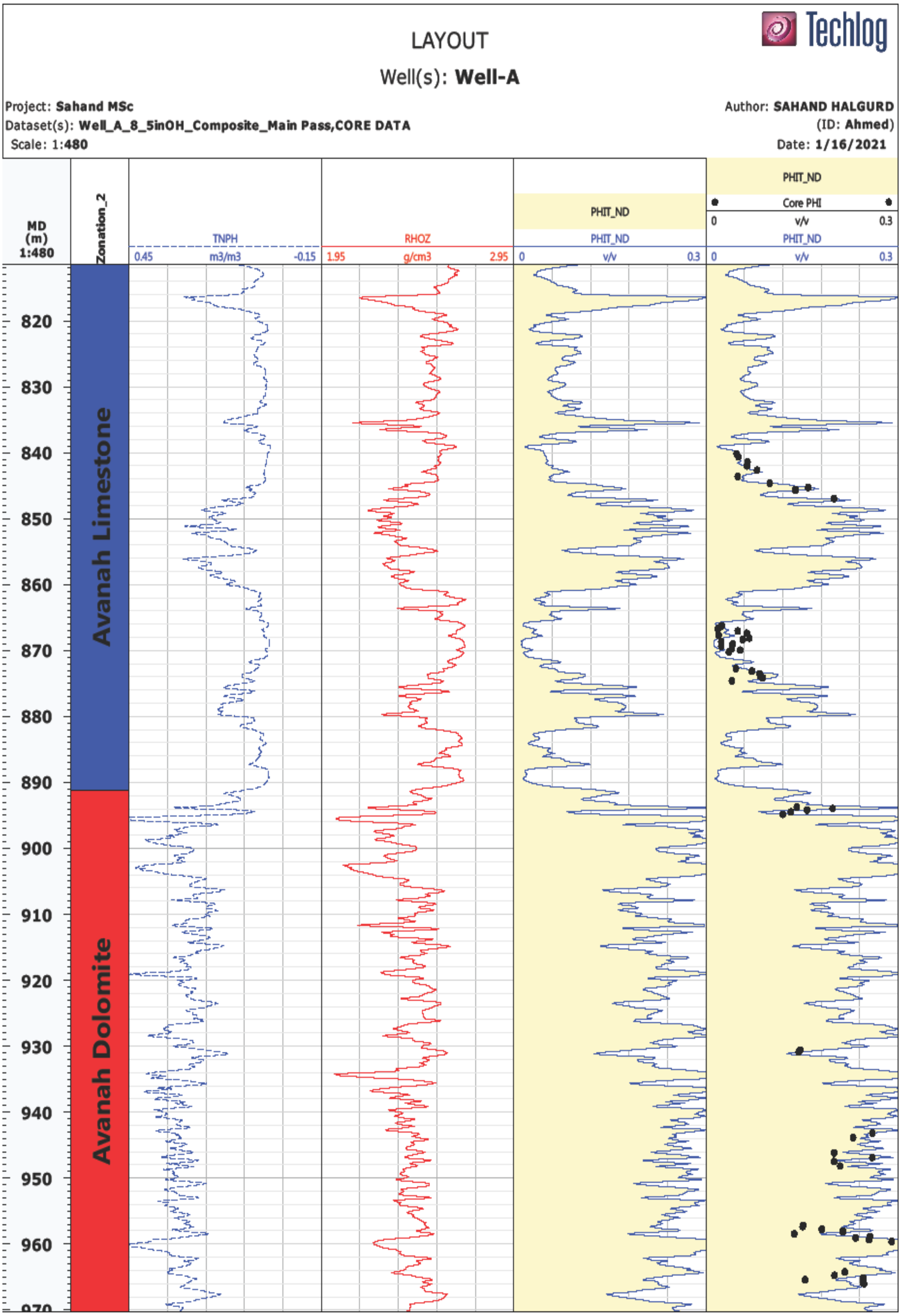


Figure 4.4: Log and core porosity comparison in Well A

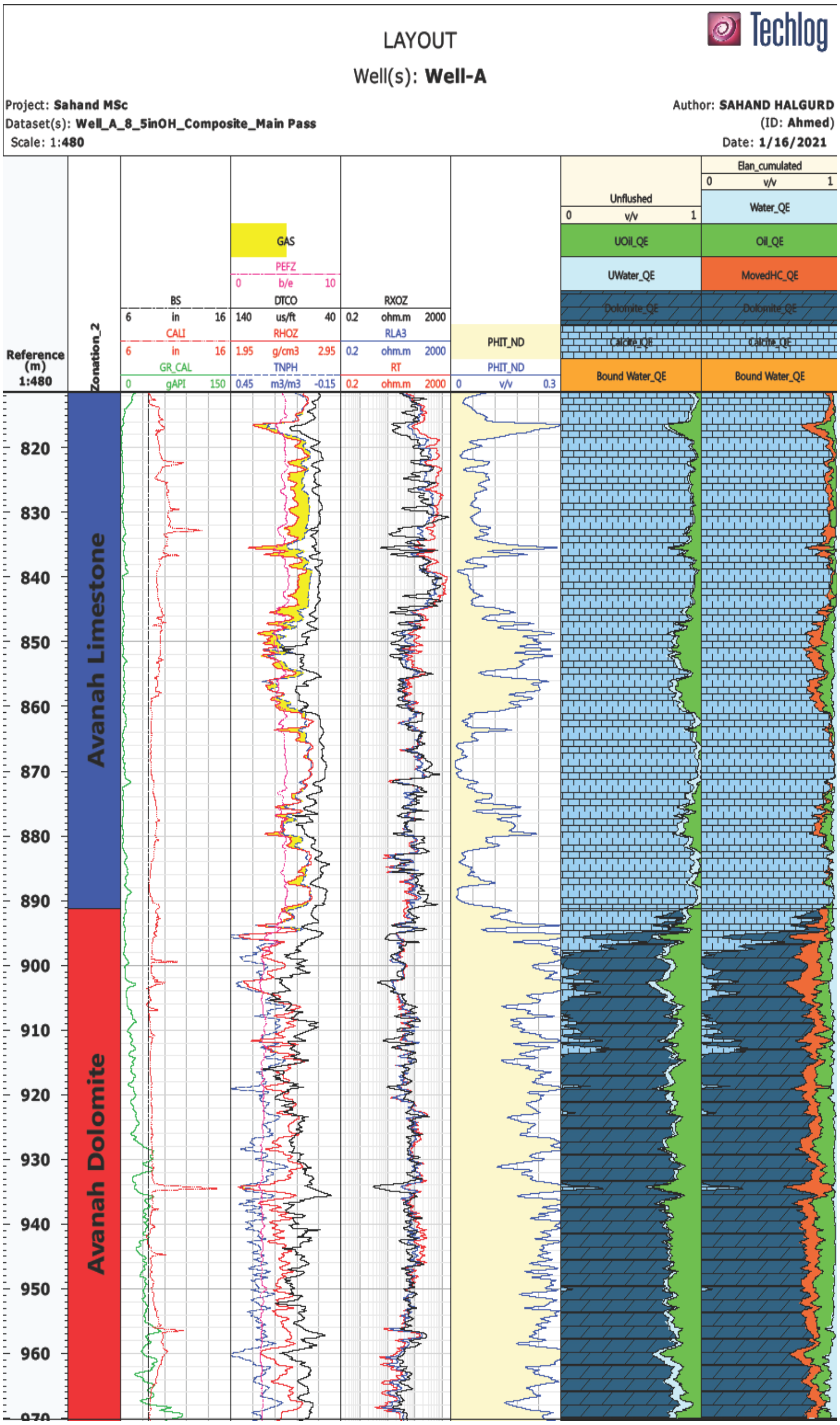


Figure 4.5: Water and hydrocarbon saturations in Well A

4.4 Permeability Estimation of Avanah Formation

Two different methods were used to calculate permeability of Avanah Formation.

4.4.1 Permeability Estimation from Porosity correlation method (empirical method)

Permeability values in un-cored wells and intervals are estimated though using relationship obtained from porosity-permeability trend line analysis. A plot of core porosity on the x-axis in linear scale and core permeability on the y-axis in log scale is constructed and trend line analyses were performed. As it's well-known, the level of accuracy for selecting porosity and permeability rely on regression coefficient (R2) value. R2 value equal to 0.7447 for Avanah limestone and 0.8232 for Avanah dolomite. Equations obtained through porosity and permeability data plotted in Figures 4.6 and 4.7 are given in Table 4.1**.**

Table 4.1: Equations generated from porosity versus permeability correlation of core data From Wells A, G and H.

Unit	General equation	R^2 value
Avanah limestone for all wells	$Y = 0.0112\ e^{45.826\ x}$	0.7447
Avanah dolomite for all wells	$Y = 0.0598\ e^{23.022\ x}$	0.8232

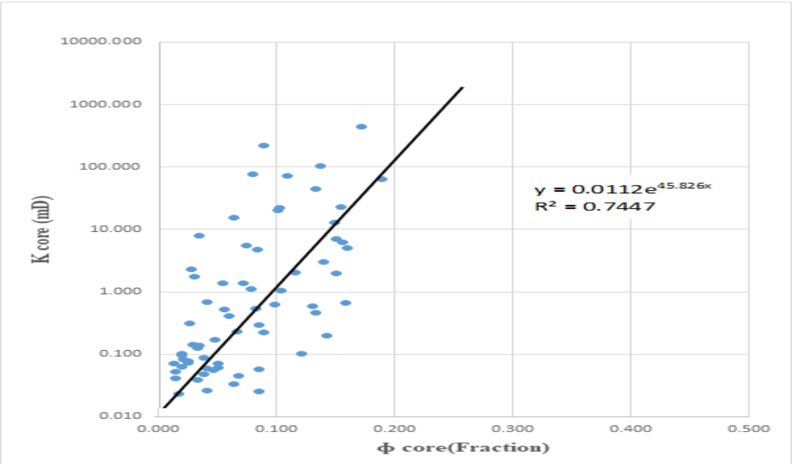


Figure 4.6: Permeability versus porosity cross plot using core data of Avanah limestone from Wells A, G and H.

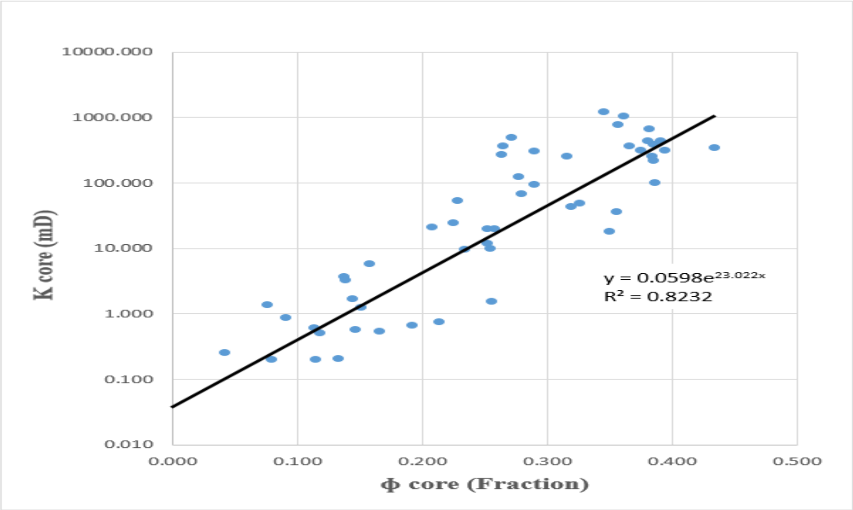
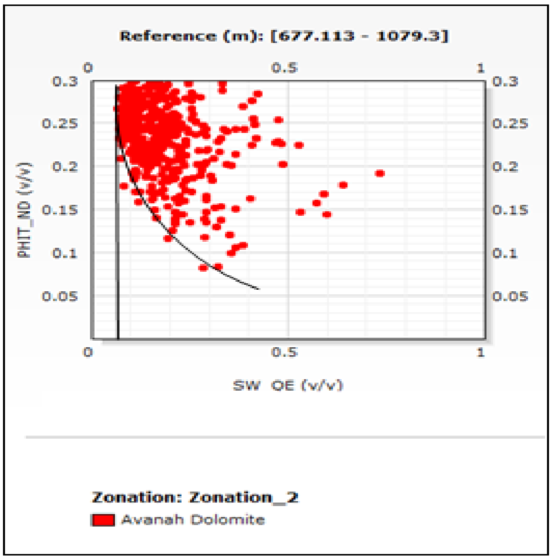


Figure 4.7: Permeability versus porosity cross plot using core data of Avanah dolomite from Wells A, G and H.

4.4.2 Permeability Estimation from Morris and Biggs method

The detail of this method has been mentioned in Chapter 3. Here permeability estimated based on the data of porosity which is extracted from well log data and irreducible water saturation (Swi). Figure 4.8 shows Swi of Avanah limestone and dolomite in Well A. Results for all wells are shown in Table 4.2. The Swi Figures for other wells are given in Appendix 3.



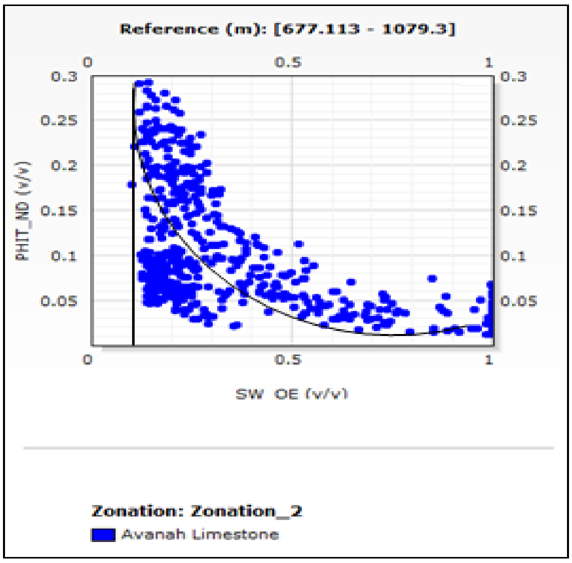


Figure 4.8: Swi calculation in Avanah dolomite and limestone in Well

Table 4.2: Values of Swi estimated from φ vs. Sw using Morris and Biggs method.

Well name	Swi Avanah Limestone %	Swi Avanah Dolomite %
Well-A	10	6
Well-B	16	8
Well-C	16	34
Well-D	6	3
Well-E	22	12
Well-F	15	20

Permeability estimation through using Morris and Biggs method as well as imperical method is shown in Figure 4.9 for Well-A and then it is compared to permeability of core data. Based on mentioned comparison result that has been collected is very close to each other which are a proper indication for getting a correct result, it is important to note that the relationship from porosity-permeability trend line analysis method was selected to the permeability estimation in this study because the result of this method is accurate and close to permeability of core data more than Morris and Biggs method as shown in Figure 4.9.

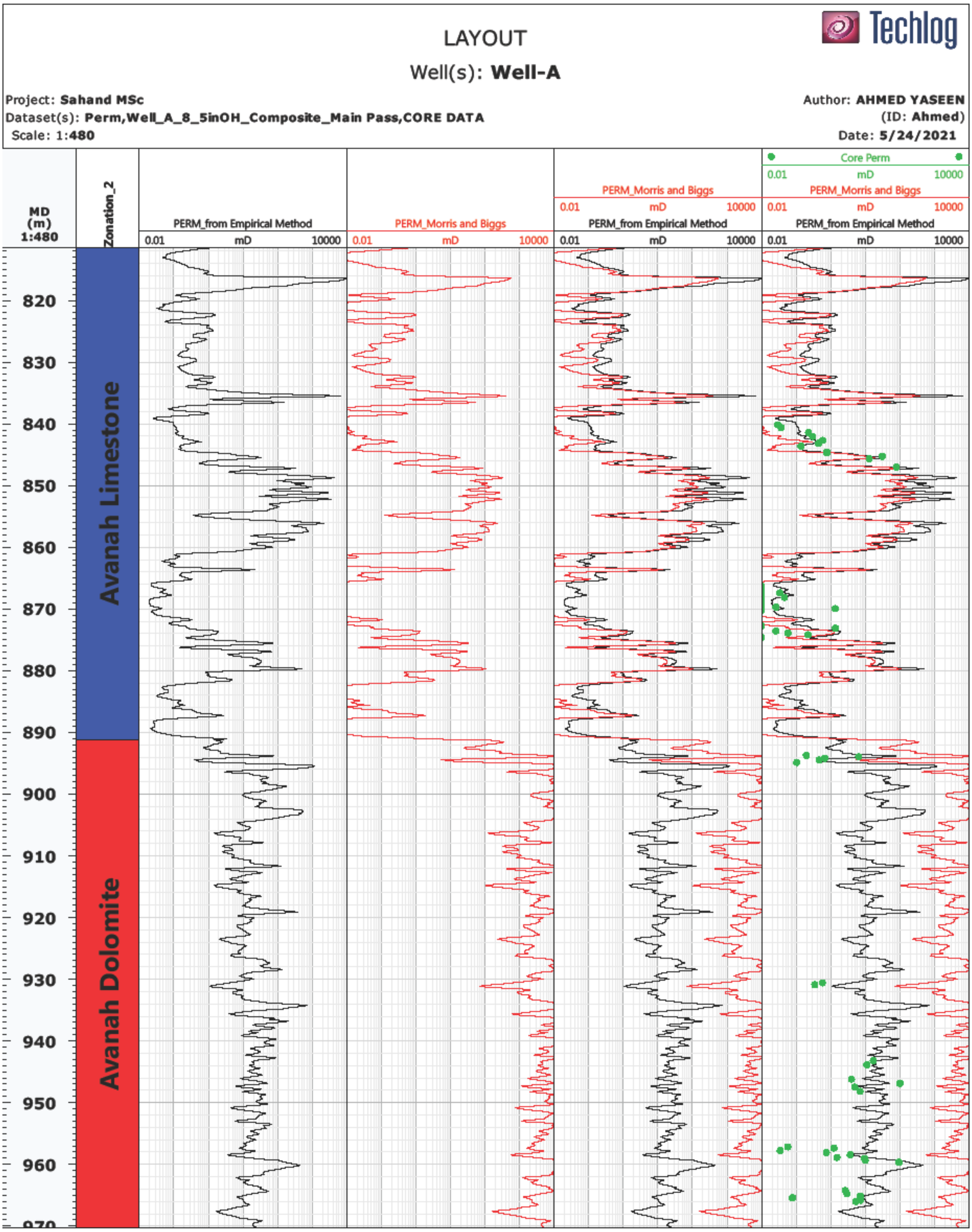


Figure 4.9: Calculated permeability values in Avanah Formation for Well A

4.5 Correlation cross section, interpretation and Contour Map of Avanah Formation

Figure 4.10 represent the level of hydrocarbon in each well which are found through inserting their resistivity logs data to clarify the outcomes and to differentiate between wells. In addition studied wells are not very close to each other and due to that their reservoir characteristics including porosity, permeability, water saturation are not the same, Even the production rate change from one well to another, So all wells can be divided into three parts.

Average porosity, permeability and water saturation of Well A- and Well-D which are located in the NW of the Khurmala dome: average porosity in Well A (0.1 in Avanah Limestone and 0.245 in Avanah Dolomite) and average water saturation (0.33 in Avanah limestone and 0.2 in Avanah Dolomite). Also average porosity and water saturation of Well-D include: average porosity (0.118 in Avanah Limestone and 0.254 in Avanah Dolomite) also average water saturation of mentioned well is (0.2 in Avanah Limestone, 0.1 in Avanah Dolomite), as well as based on estimation permeability of mentioned wells Well A- and Well-D both wells have a good permeability.

While Well- B and Well- E located in the middle part of the khurmala dome are good as well but less reservoir characteristics compared to Well- A and Well-D due having moderate permeability and average porosity of Well- B and Well- E, water saturation level is quite high compared to Well-A and Well-D as shown in Table 4.3.

On the other hand, the rest wells including Well-C and Well-F located in the SE having poor reservoir characteristics and the level of hydrocarbon is not good enough as illustrated in Figure 4.11. Due to that, wells that located in the NW of the Khurmala dome found to be better than other part of the location. In addition for all mentioned wells as shown in Figure 4.10 and Figure 4.11 Gas oil contact located in -595 m subsea level and Oil water contact located in Khurmala Formation.

Table 4.3: Calculated average porosity and average water saturation in Avanah Formation

Well name	Average porosity (fraction)		Average water saturation (fraction)	
	Avanah limstone	Avanah dolomite	Avanah limstone	Avanah dolomite
Well-D	0.118	0.254	0.2	0.1
Well-A	0.1	0.245	0.33	0.2
Well-E	0.095	0.201	0.48	0.285
Well-B	0.084	0.164	0.45	0.46
Well-F	0.068	0.157	0.76	0.68
Well-C	0.064	0.149	0.84	0.82

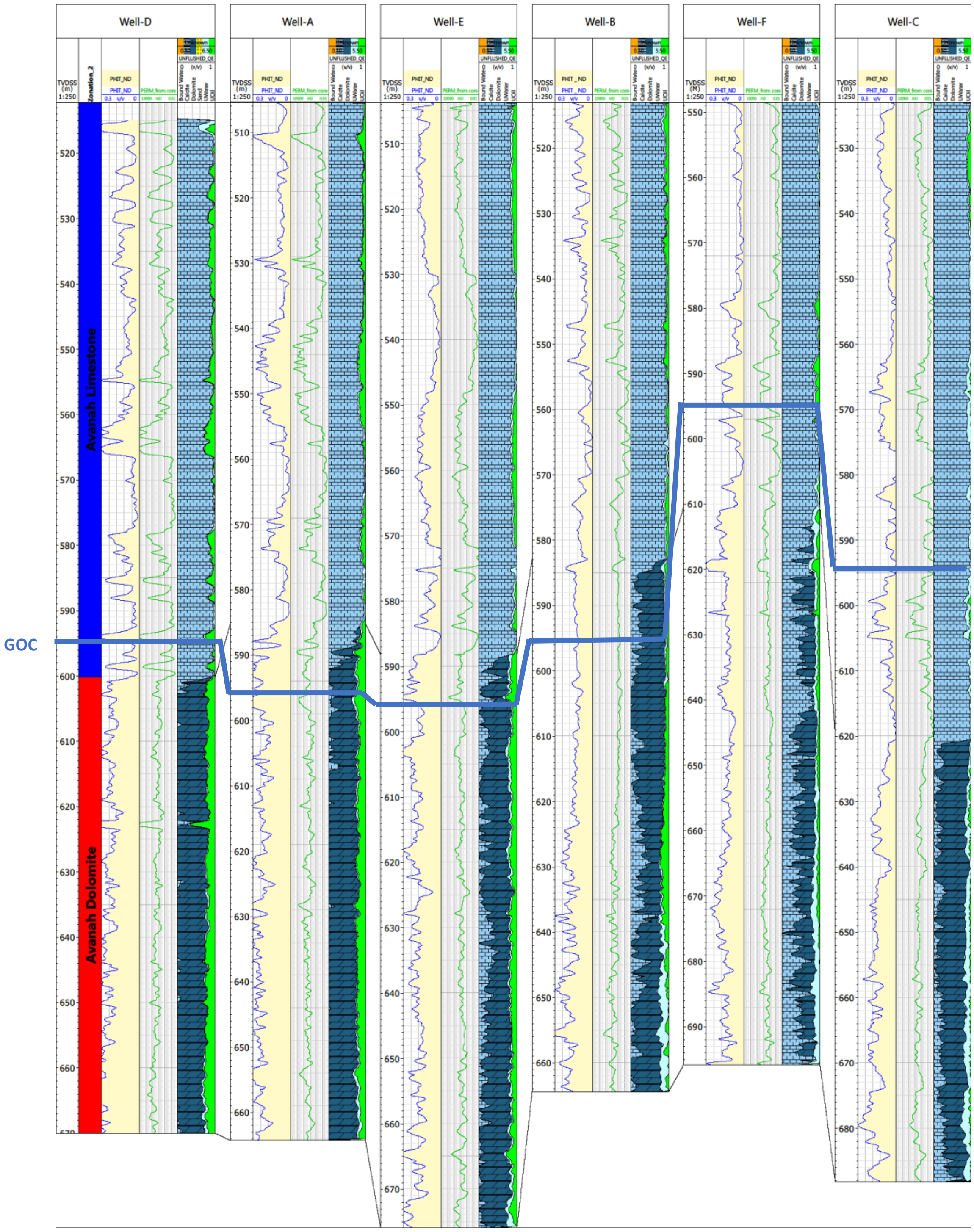


Figure 4.10: Correlation cross sections between six wells showing the changes in the porosity, permeability and saturations

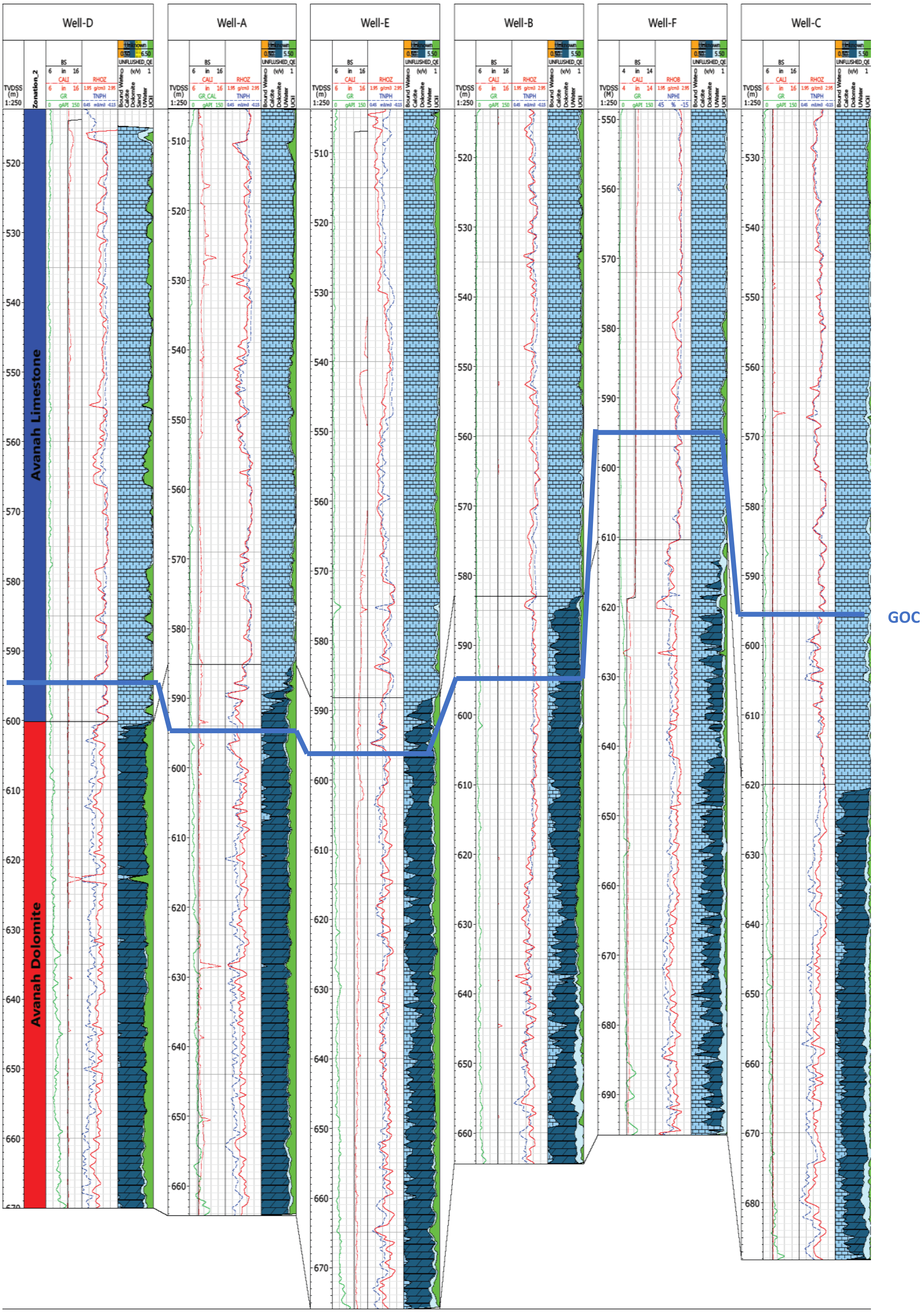


Figure 4.11: Correlation cross sections between six wells that hanging logs showing the changes in the lithology and hydrocarbon

As it's shown by contour map in Figure 4.12, green line represents gas oil contact at -595 m sub sea level and blue line represents oil water contact at -680 m sub sea level.

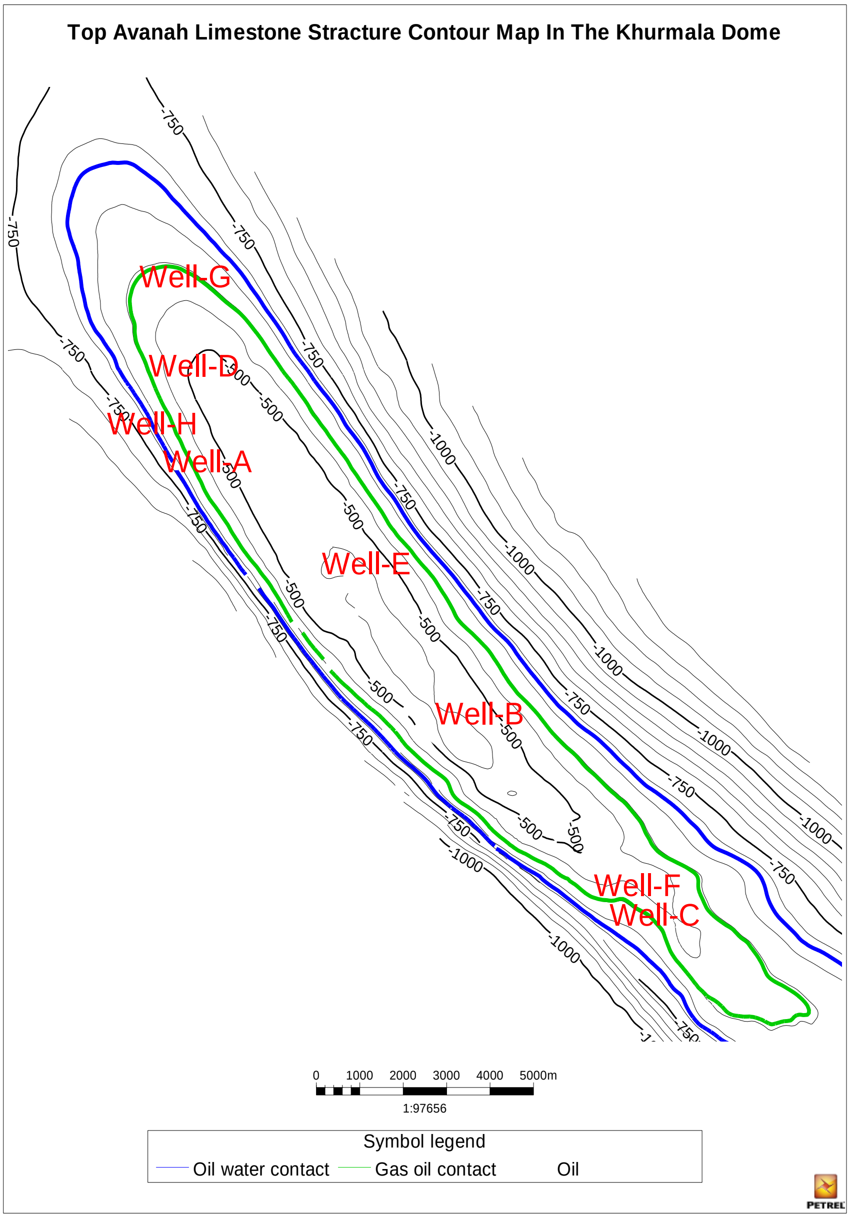


Figure 4.12: Top Avanah Limestone structure contour map in the Khurmala dome

As it's interpreted before depending on reservoir characteristics Well-A and Well-D have good reservoir characteristics compared to other wells that located in NW of the Khurmala dome as shown in Figure 4.13, but Well-B and Well-D have moderate reservoir characteristics and the rest are poor. So, in case of having a new plan for drilling new wells in this Area, based on the data Middle to NW of the dome can be considered as good area.

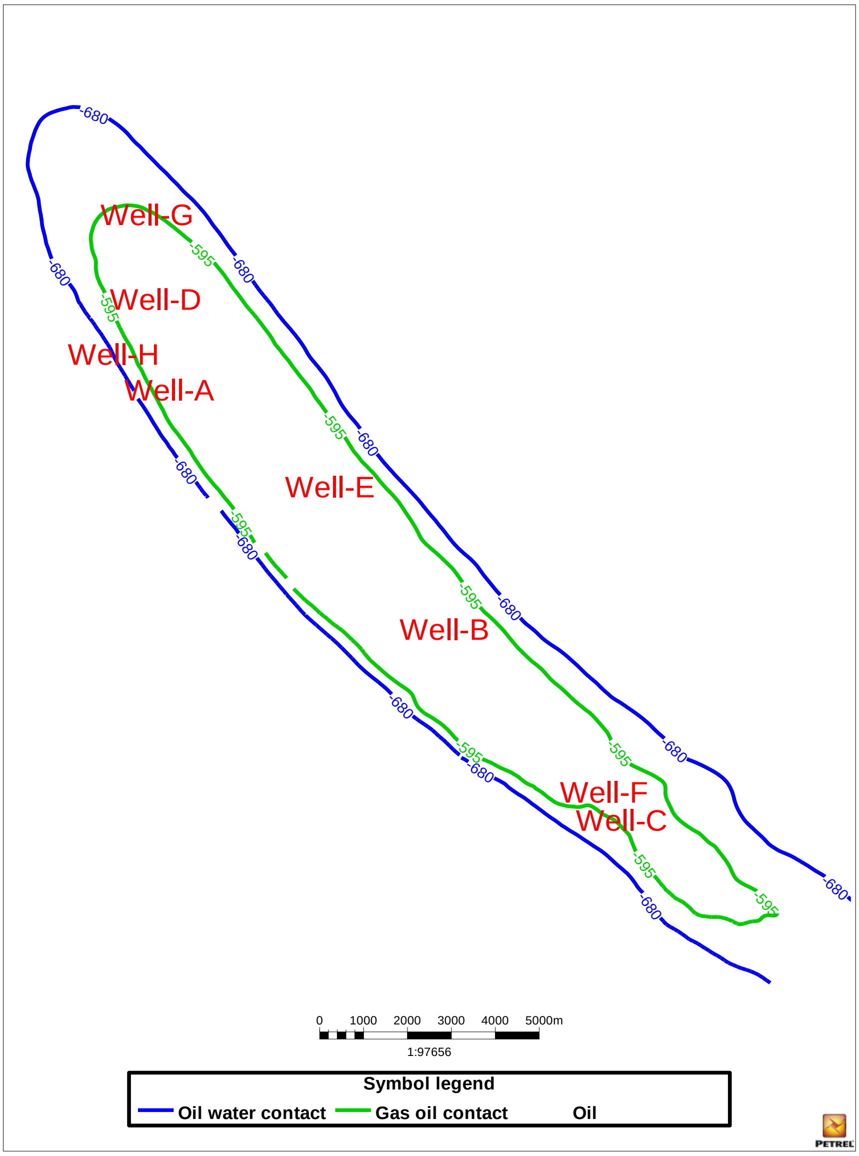


Figure 4.13: Simple map showing Wells location and contacts

4.6 Porosity Cut-Off Determination

A plot of porosity on the linear scale versus permeability on the log scale is used for determination of cutoff porosity. The intersection of a straight line that drawn from 0.1md with the best fit line between core permeability and core porosity determines the cutoff core porosity. Conventionally, a permeability of 0.1 md is measured minimum value for oil production. As demonstrated in Figure 4.14 and 4.15 The core porosity cut-off for Avanah limestone is 0.045 and Avanah dolomite is 0.04.

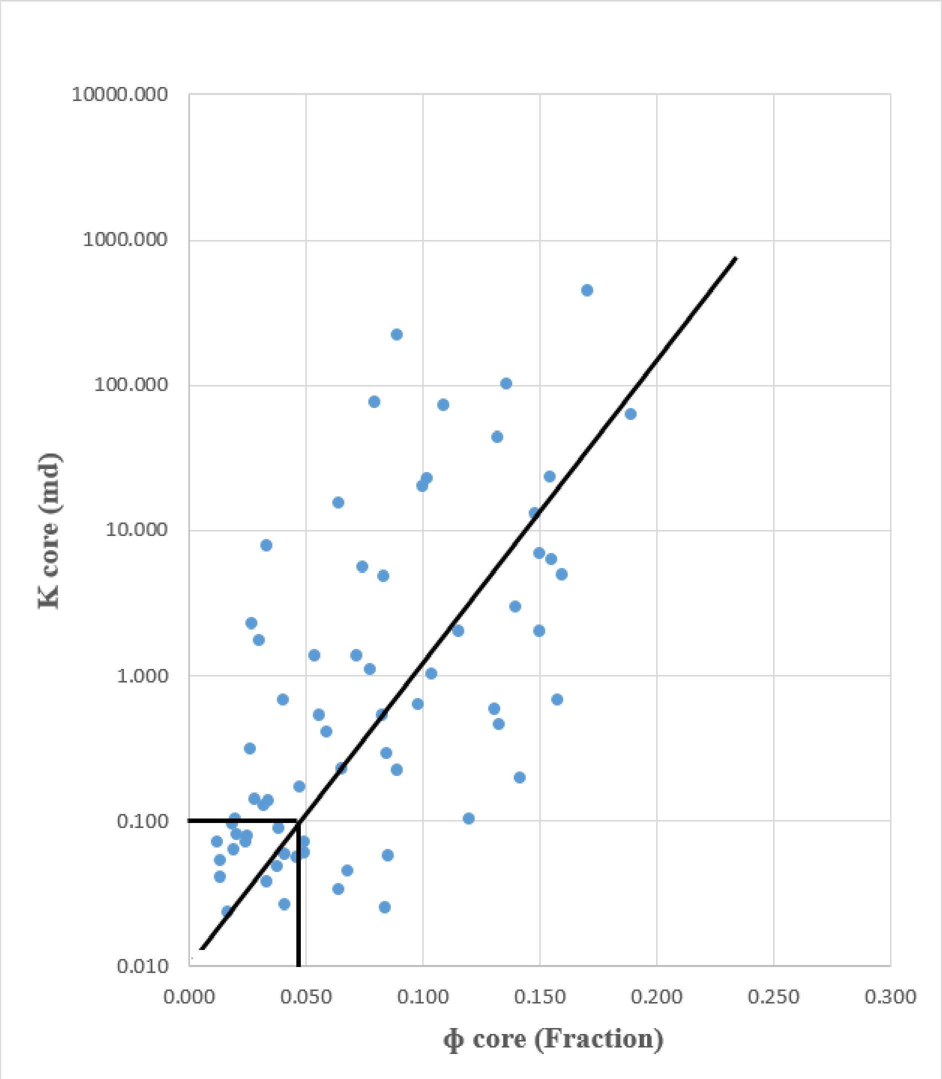


Figure 4.14: Core permeability versus core porosity plot used in determination of cut-off value in Avanah limestone

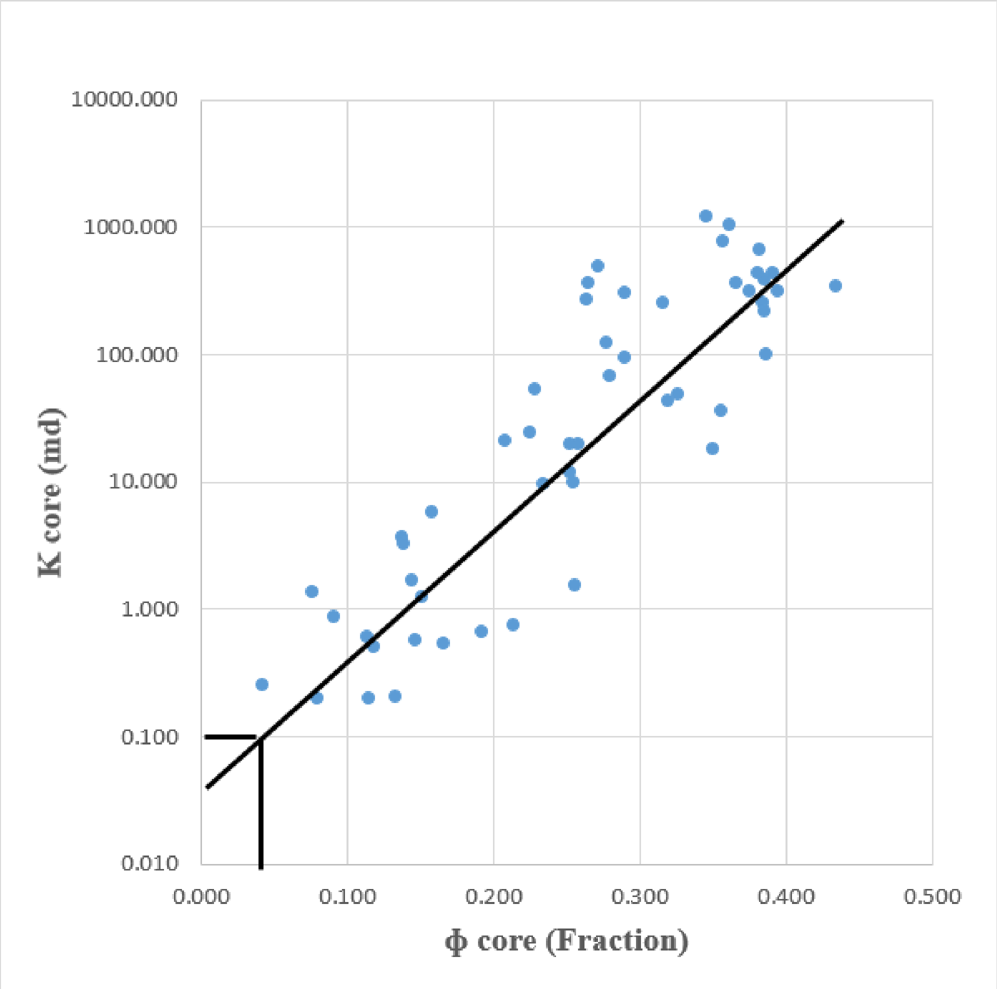


Figure 4.15: Core permeability versus core porosity plot used in determination of cut-off value in Avanah dolomite

4.7 Water Saturation Cut-off Determination

Water saturation cut off is achieved through plotting the porosity and water saturation on a linear scale and drawing best fit a hyperbolic line through the data to determine water saturation cut off. Porosity cut-off of Avanah limestone is 0.045 and this value has been used to detect and determine water saturation cut-off which is equal to 0.6 as illustrated in Figure 4.16.

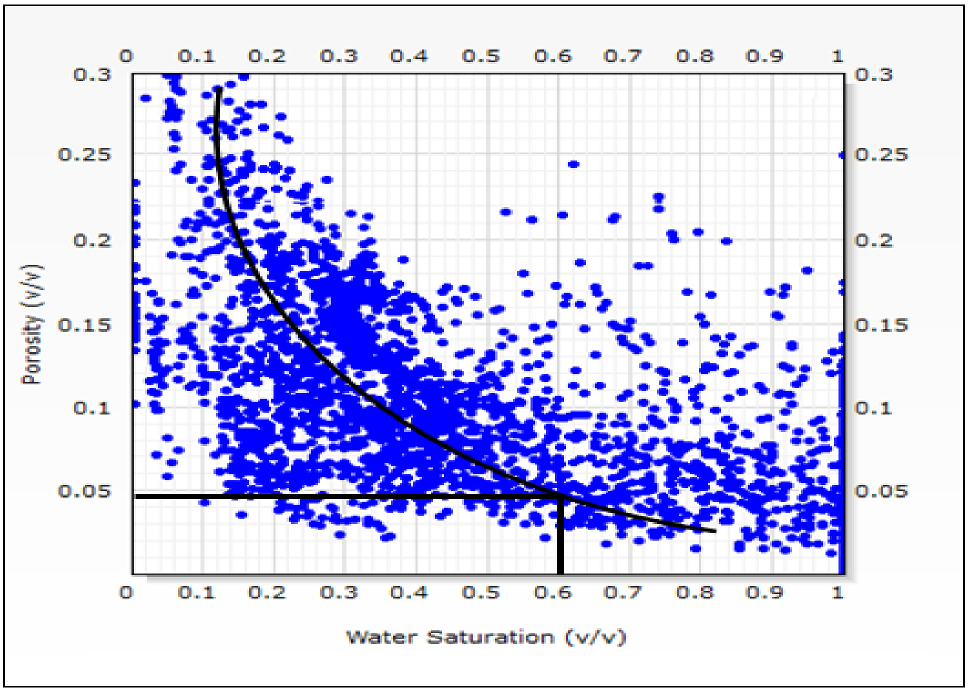


Figure 4.16: Multi well water saturation cut off determination plot of Avanah limestone

On the other hand, porosity cut-off of Avanah dolomite was 0.04 and due to that water saturation cut-off found to be 0.65 as shown in Figure 4.17.

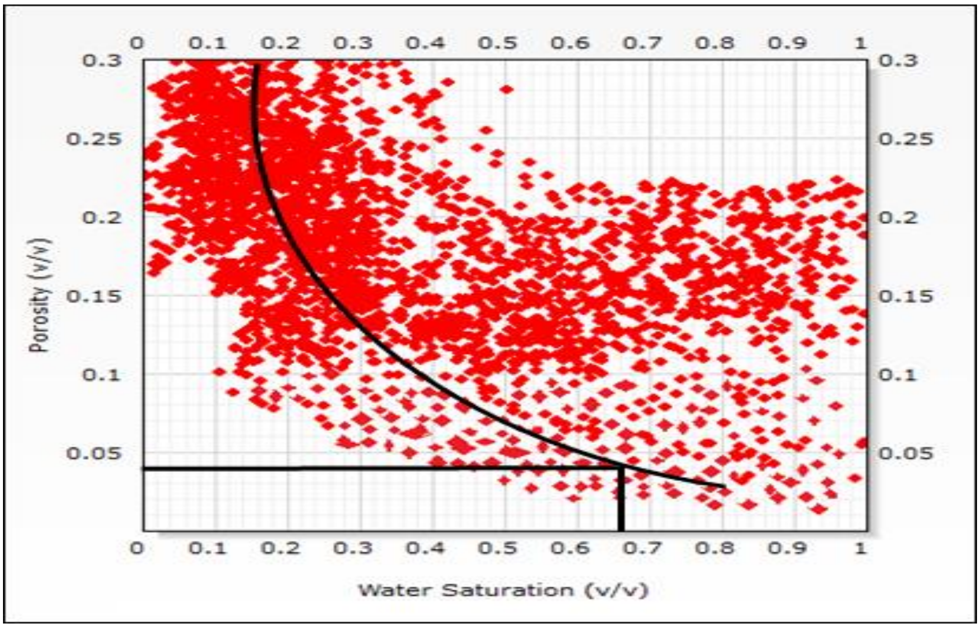


Figure 4.17: Multi well water saturation cut off determination plot of Avanah dolomite

4.8 Net Pay Thickness Determination

Net pay thickness is the part of a reservoir from which hydrocarbons can be produced at an economic rate. The gross is considered as the thickness of the reservoir interval that covers zones of which hydrocarbon can be produced and intervals which do not favor the production of hydrocarbon.

Furthermore, net pay is used to calculate volumetric hydrocarbon in place and to estimate moveable hydrocarbons and non-moveable hydrocarbons. Also net pay is used to determine the probable amount of hydrocarbons obtainable by secondary recovery methods (Cobb and Marek, 1998).

The difference between gross and net is completed through implementing cut off values in the petrophysical analysis. In this case, cut off values of porosity is 0.045 and water saturation is 0.6 in Avanah limestone and cut off porosity is 0.04 and water saturation is 0.65 in Avanah dolomite. These parameters were used to recognize pay intervals. That is, intervals with porosity greater than 4.5 % and water saturation less than 60 % were considered as net pay intervals in Avanah limestone also porosity greater than 4% and water saturation less than 65% were considered as net pay intervals in Avanah dolomite. The net to gross ratio is the thickness of net reservoir divided by the thickness of gross reservoir, which is frequently used to signify the quality of a reservoir zone. Tables 4.4 demonstrate the calculated net pay summary for all wells.

Net to gross calculation has been based on PHIT and Sw which stand for porosity and water saturation. Pay-Net flag interval in the Figure 4.18 produced due to applying water saturation cut off and porosity cut off. Based on cut off range that mentioned above, water saturation and porosity in this range is calculated as pay zone Figure 4.18 shown the calculation of net pay in Well A, other wells calculation showed in Appendix 4.

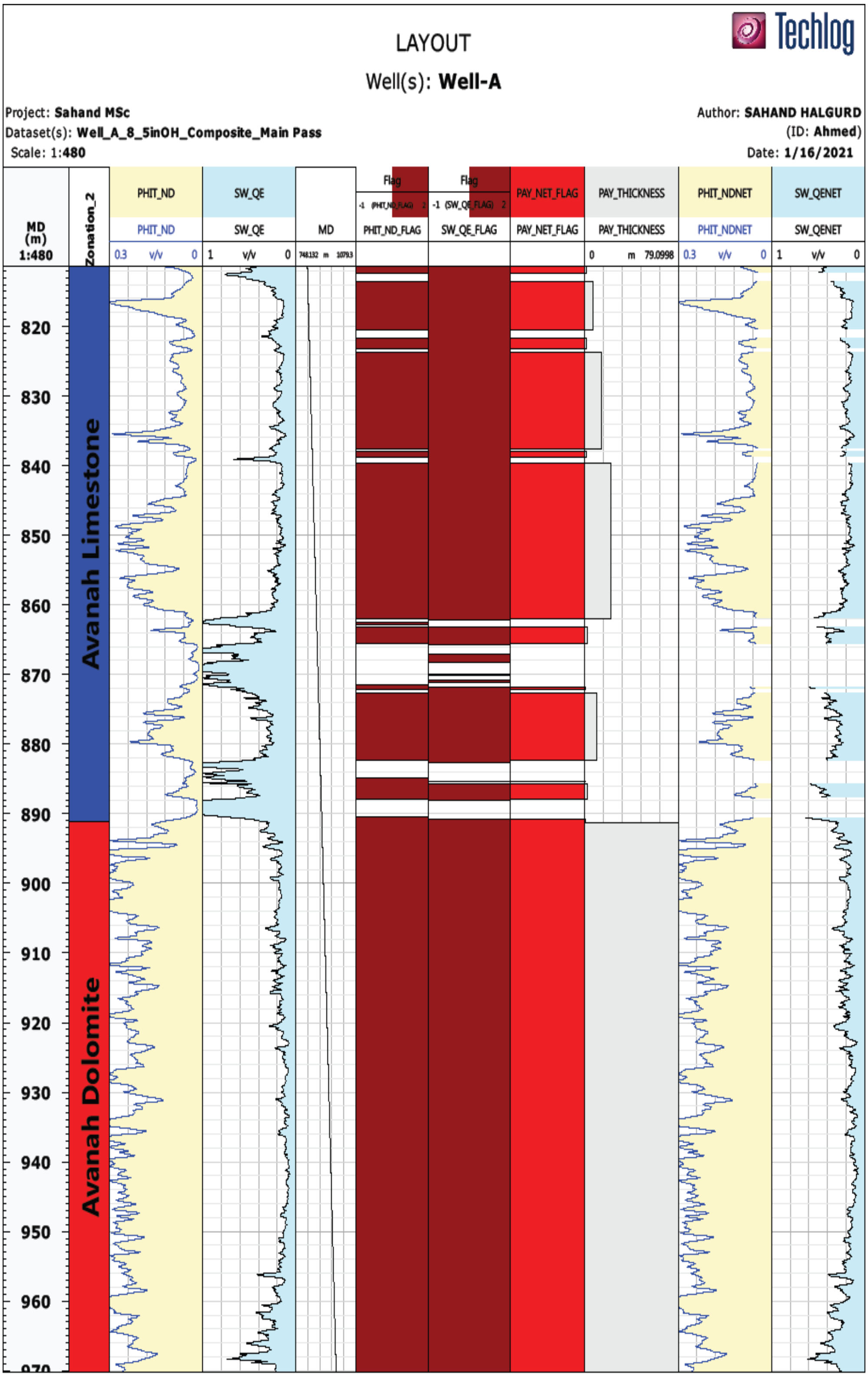


Figure 4.18: Net pay calculation for Well A

Table 4.4: Calculated net and gross pay summary for six wells in Avanah Formation

Well	Zones	Top Drilled depth (m)	Bottom Drilled depth (m)	Gross (m)	Net (m)	Net to Gross (%)	Av.Porosity (fraction)	Av.Water Saturation (fraction)
Well-A	Avanah Limestone	811.4	891.2	79.8	61.817	0.775	0.121	0.226
	Avanah Dolomite	891.2	970.3	79.1	79.1	1	0.245	0.197
Well-B	Avanah Limestone	803	873	70	51.812	0.74	0.102	0.354
	Avanah Dolomite	873	954.5	81.5	61.112	0.75	0.152	0.276
Well-C	Avanah Limestone	928	1025	97	17.069	0.176	0.105	0.362
	Avanah Dolomite	1025	1093.2	68.2	6.588	0.097	0.136	0.559
Well-D	Avanah Limestone	827.2	915.2	88	62.979	0.716	0.14	0.148
	Avanah Dolomite	915.2	985	69.8	69.19	0.991	0.25	0.124
Well-E	Avanah Limestone	788.7	873.2	84.5	55.239	0.654	0.143	0.357
	Avanah Dolomite	873.2	961	87.8	87.072	0.992	0.2	0.279
Well-F	Avanah Limestone	951.5	1013.4	61.9	18.898	0.305	0.129	0.349
	Avanah Dolomite	1013.4	1098.8	85.4	44.849	0.525	0.151	0.509

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this work, petrophysical properties of the Avanah Formation in the Khurmala dome were determined. The study is based on well logs from six wells, core analyses from three wells, which are deliberated to represent this study. Through performing this study the following conclusions are reached.

1. High Gamma ray log indicates shale zone, but the cause of high gamma ray in Avanah Dolomite is the existence of radioactive elements, not shale.
2. Secondary porosity index has been calculated from the difference between Density-Neutron cross plot porosity (φDN) and sonic porosity (φS). It is clearly seen that secondary porosity is dominant in Avanah limestone.
3. Fracture detection is based on low reading of sonic log, high reading of neutron-density log. Fracture located in both upper and lower part of Avanah Formation it is based on high reading of caliper log compared to bite size.
4. From the porosity determination it was concluded that the porosity of Avanah dolomite higher than Avanah limestone due to the dolomitization effect on the Avanah dolomite.
5. Water saturation and hydrocarbon results shows that gas zone of all wells located in upper part of Avanah Formation and oil zone in all wells are located in lower part of Avanah Formation.
6. Based on petrophysical analysis of studied wells from correlation cross section, Middle part to NW of the field could be mentioned as a good location for drilling new wells due to having good porosity, good permeability, low water saturation and high hydrocarbon content.
7. From net pay determination porosity values greater than 4.5 percent in the Avanah limestone and greater than 4 percent in the Avanah dolomite interval were used.
8. From net pay determination water saturation less than 60 percent in the Avanah limstone and less than 65 percent in the Avanah dolomite interval were used.

5.2 Recommendations

- Any oil producer well is recommended to be drilled from the middle part of the Avanah reservoir toward the NW direction of the structure due to having a higher porosity, permeability and hydrocarbons.
- Based on the interpretation process for selected wells in Khurmala dome, there is no shale content in the wells. So, using spectral gamma Ray will be useful to be more specific about the shale content in the area.
- Recommended to use data from all wells for study of an accurate OOIP estimation and producible reserve estimation.
- Recommended to study gas reserves in the field.
- Recommended to construct all necessary subsurface maps.

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APPENDICES

APPENDIX 1

LITHOLOGY DETERMINATION

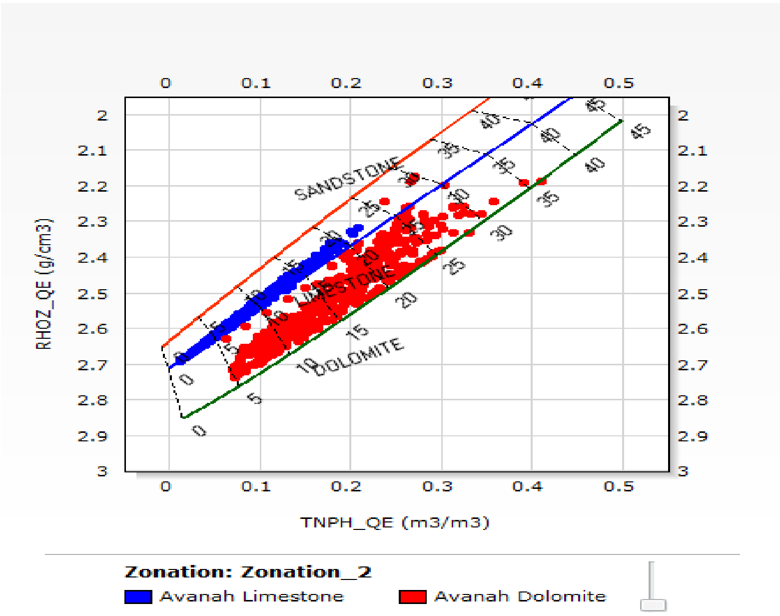


Figure 1.1: φN vs. ρb cross plot for Avanah Formation in Well B

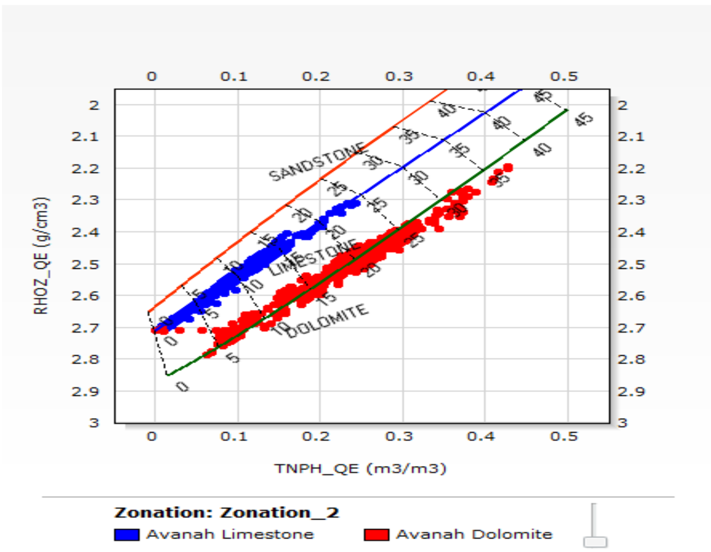


Figure 1.2: φN vs. ρb cross plot for Avanah Formation in Well C

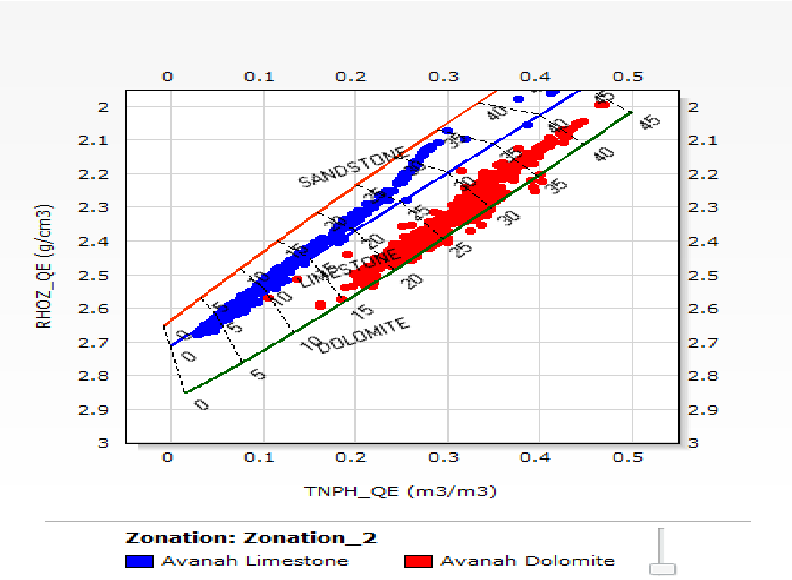


Figure 1.3: φN vs. ρb cross plot for Avanah Formation in Well D

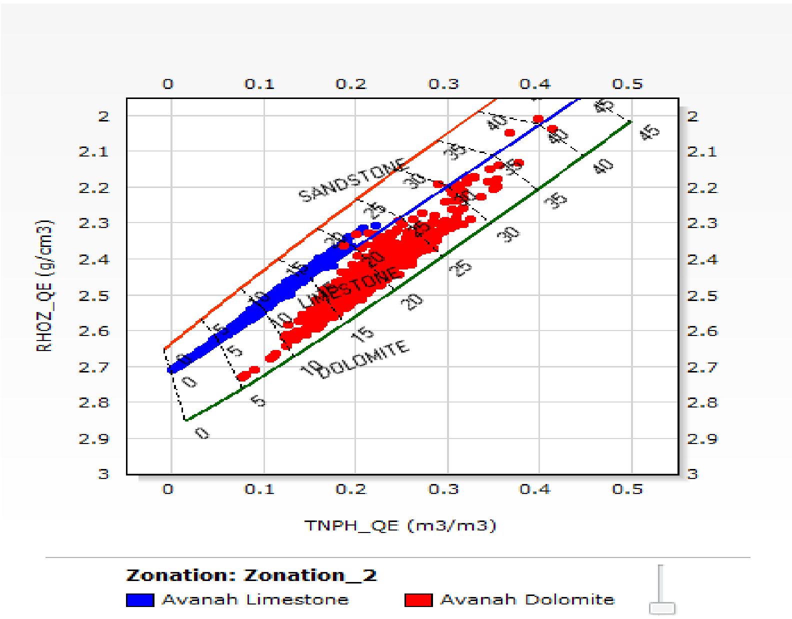


Figure 1.4: φN vs. ρb cross plot for Avanah Formation in Well E

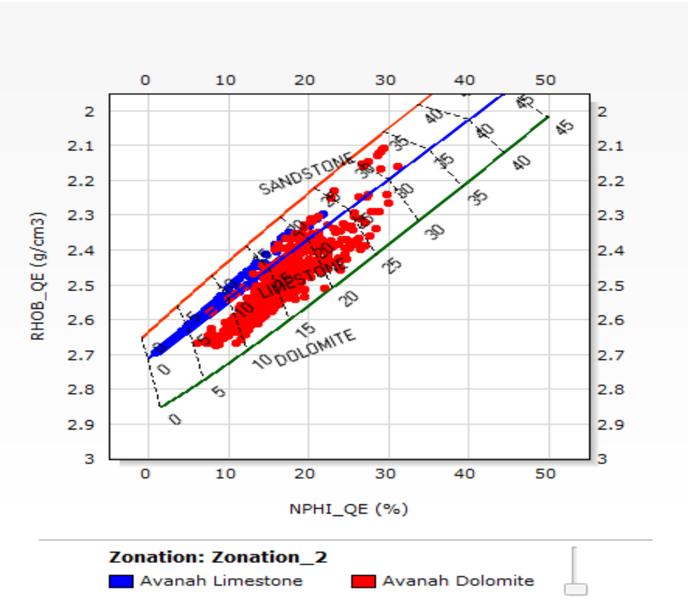


Figure 1.5: φN vs. ρb cross plot for Avanah Formation in Well F

APPENDIX 2

WELLS INTERPRETATION

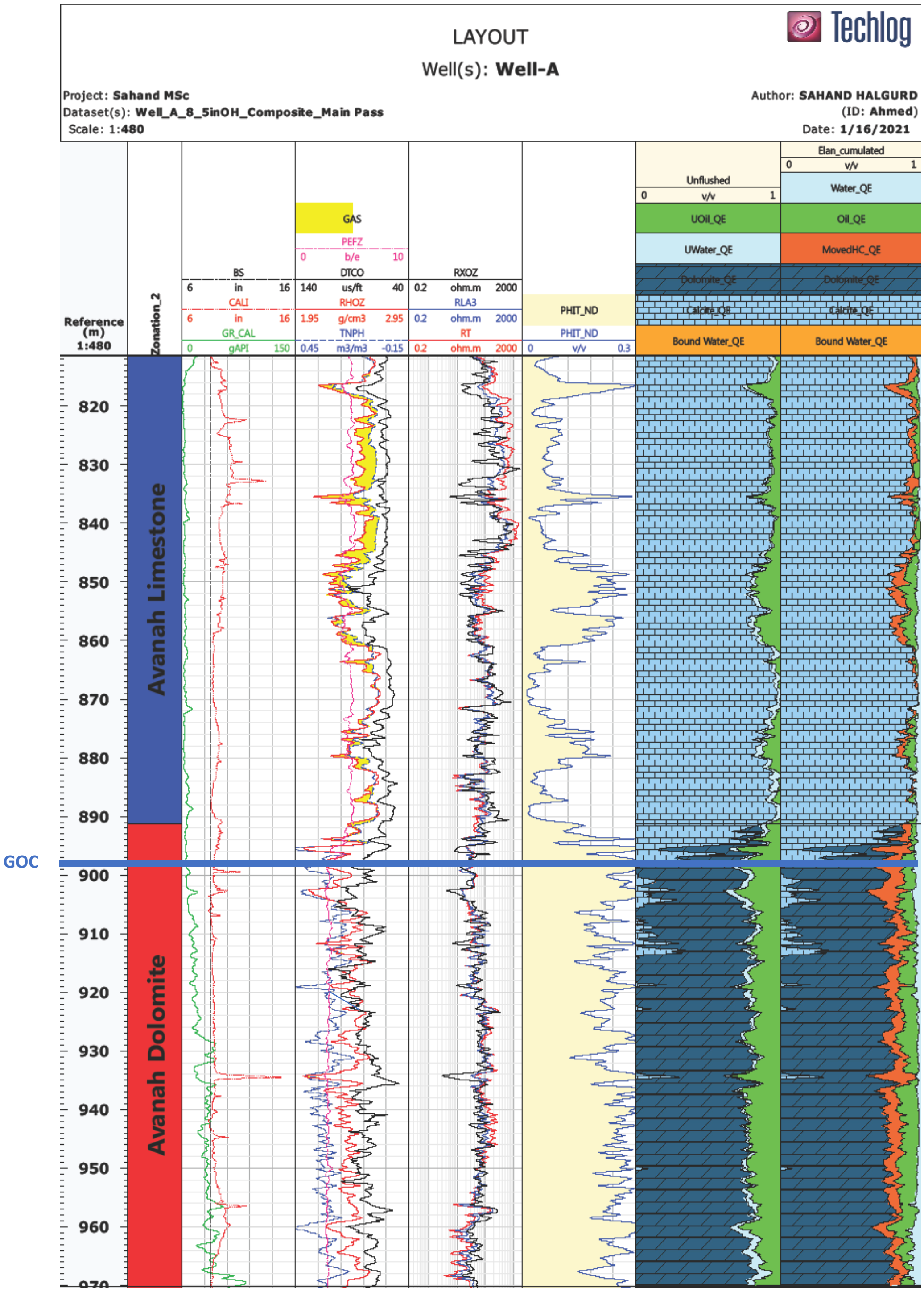
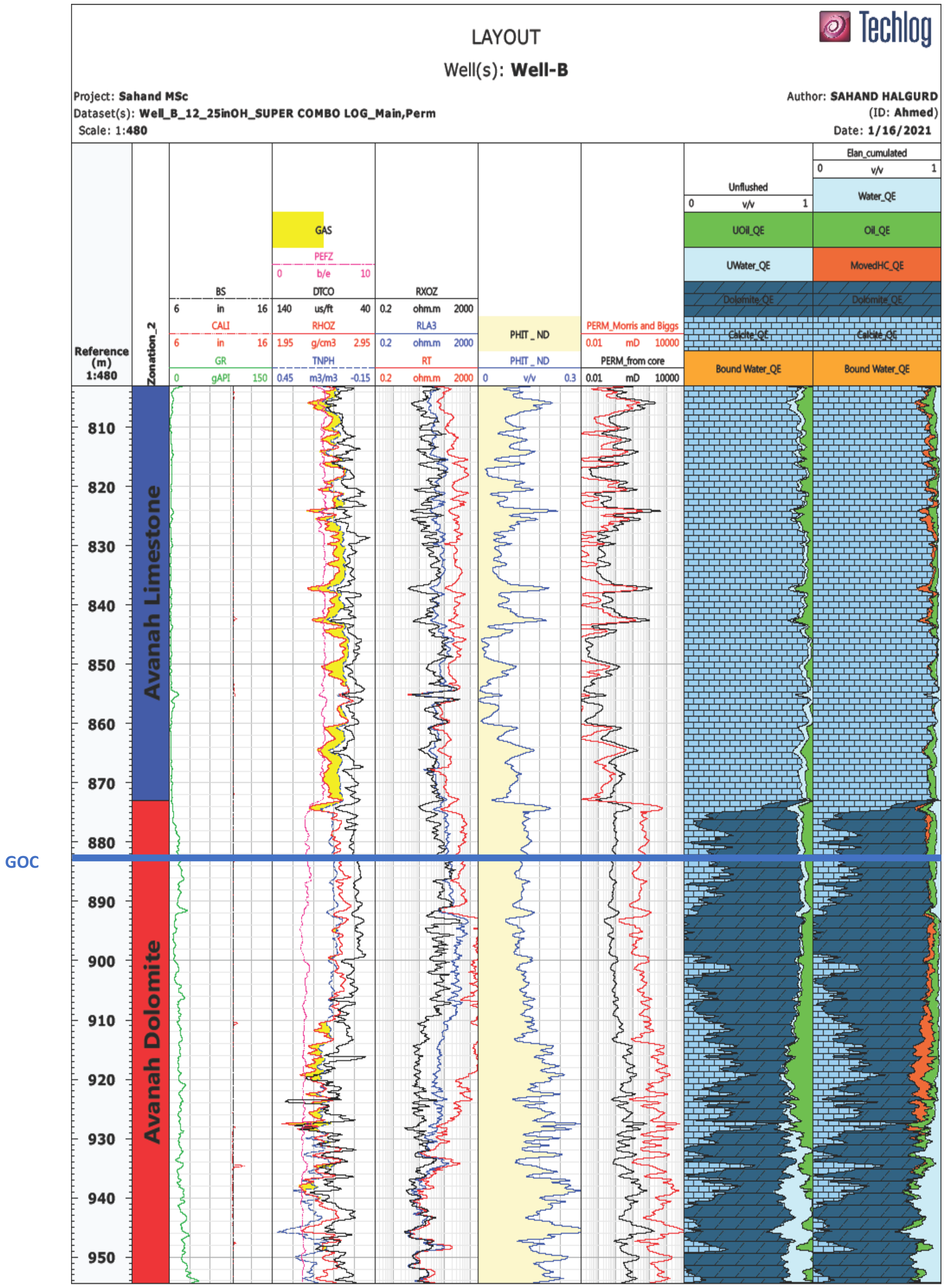


Figure 5.1: Interpretation in Well A



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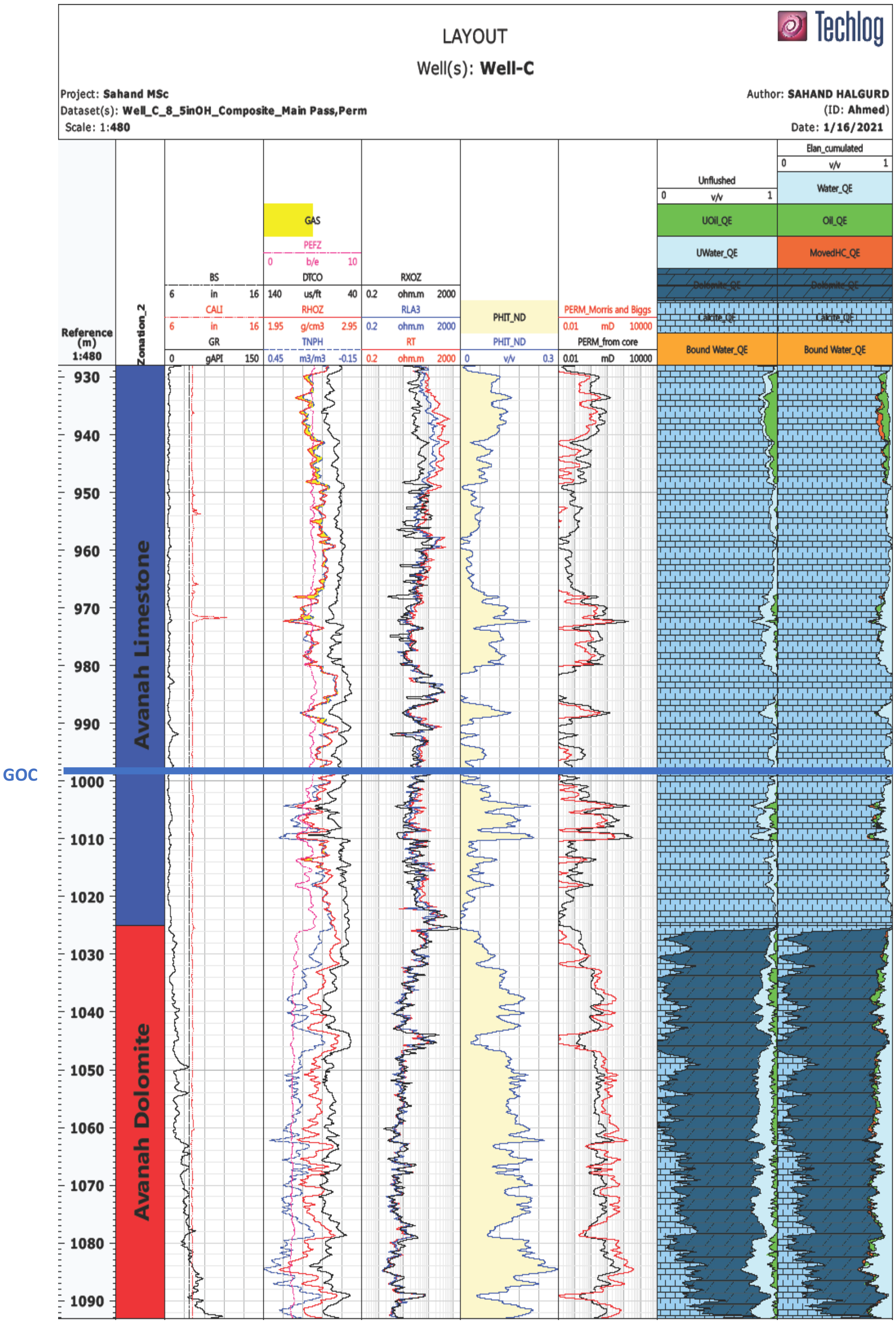


Figure 5.3: Interpretation in Well C

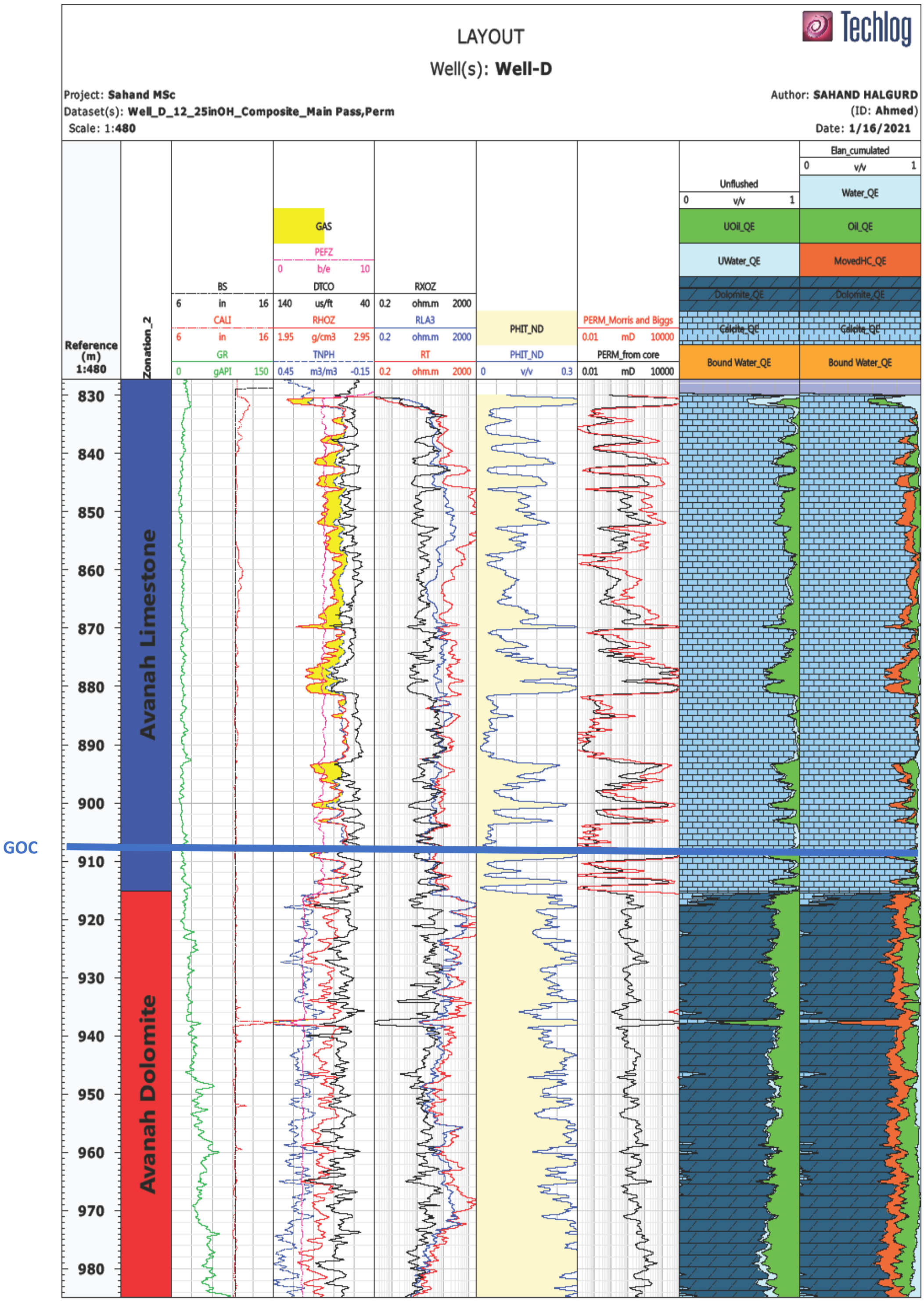


Figure 5.4: Interpretation in Well D

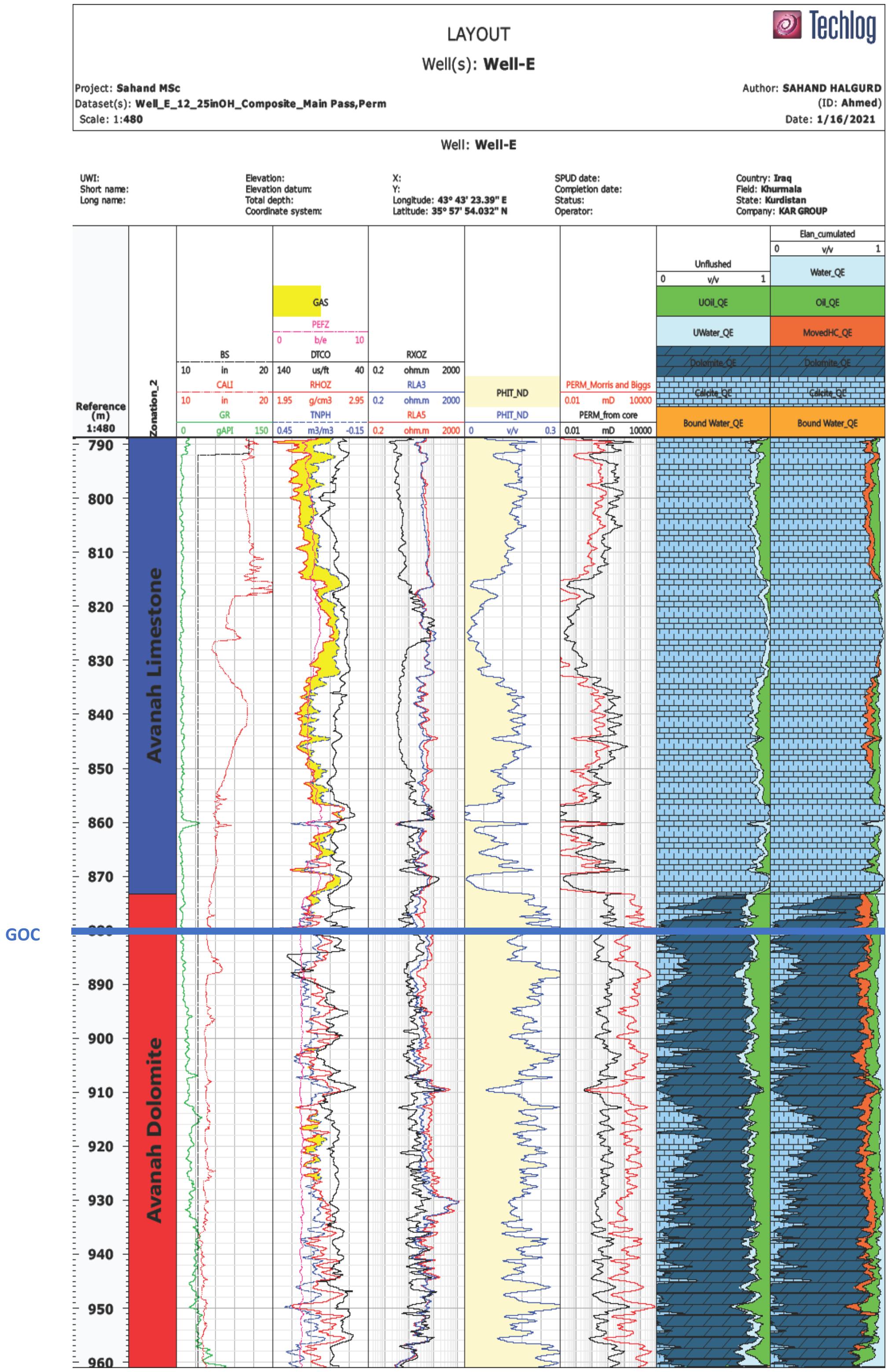


Figure 5.5: Interpretation in Well E

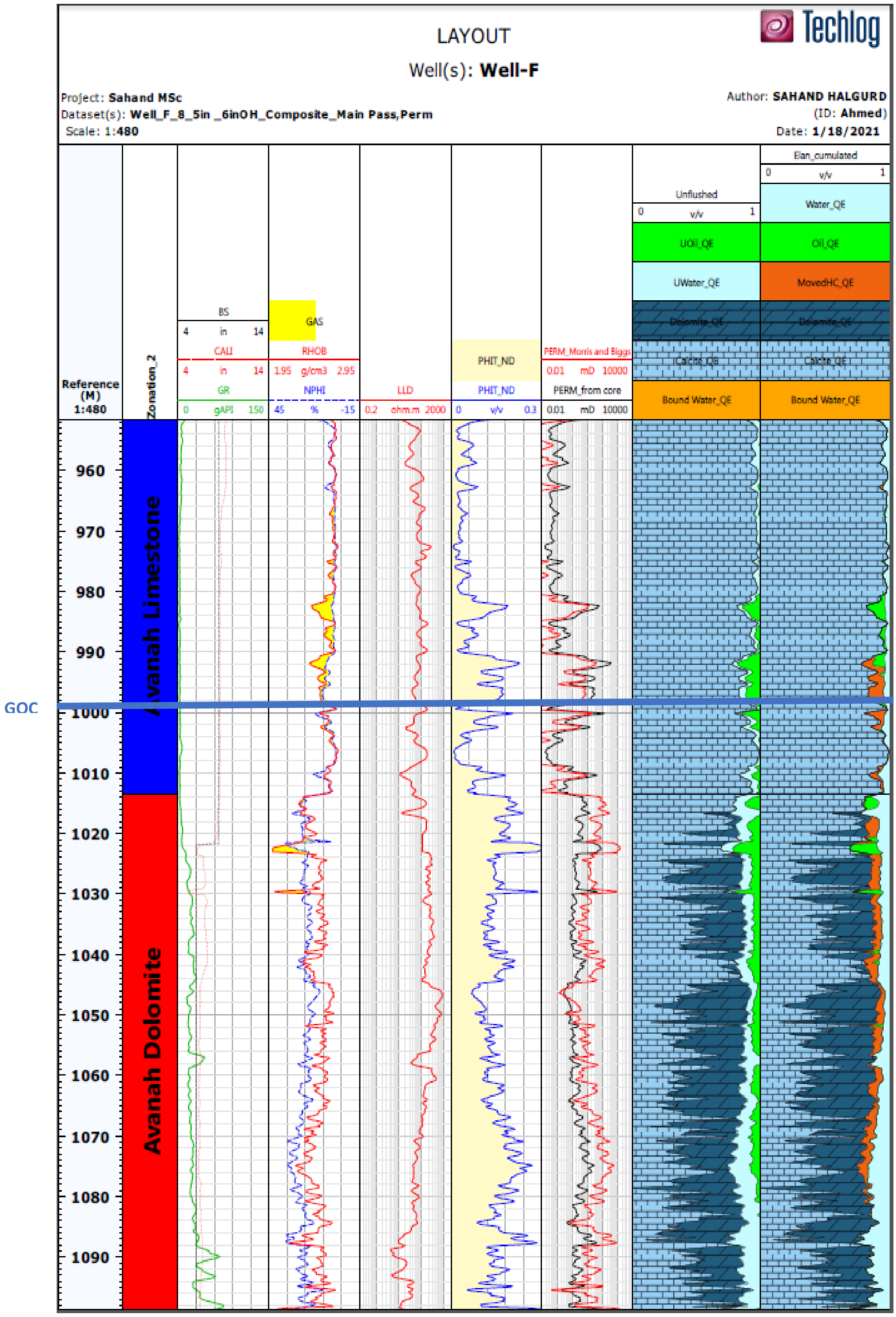


Figure 5.6: Interpretation in Well F

APPENDIX 3

POROSITY VERSUS WATER SATURATION PLOTS FOR SWI DETERMINATION

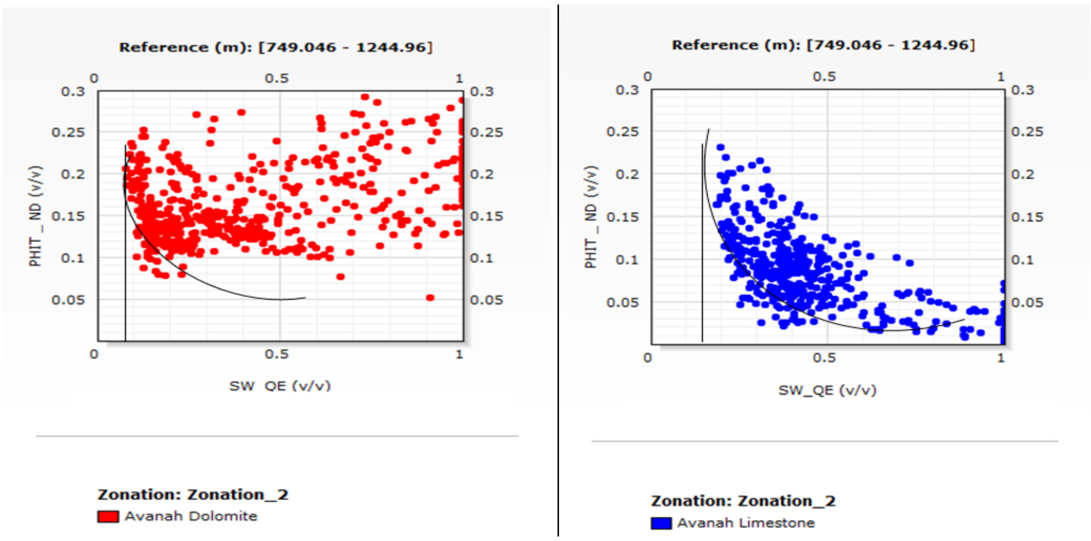


Figure 3.1: Swi calculation in Avanah dolomite and limestone in Well B

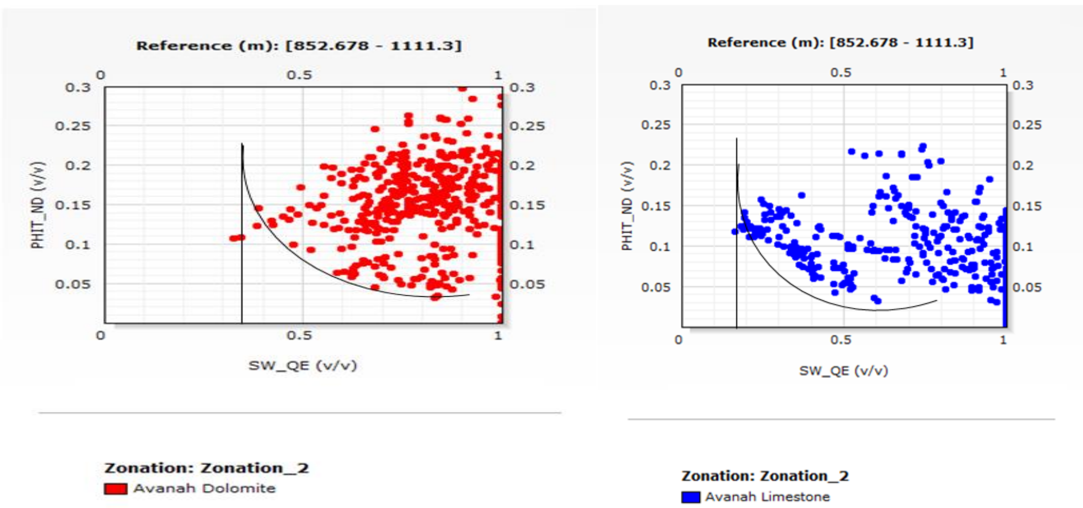


Figure 3.2: Swi calculation in Avanah dolomite and limestone in Well C

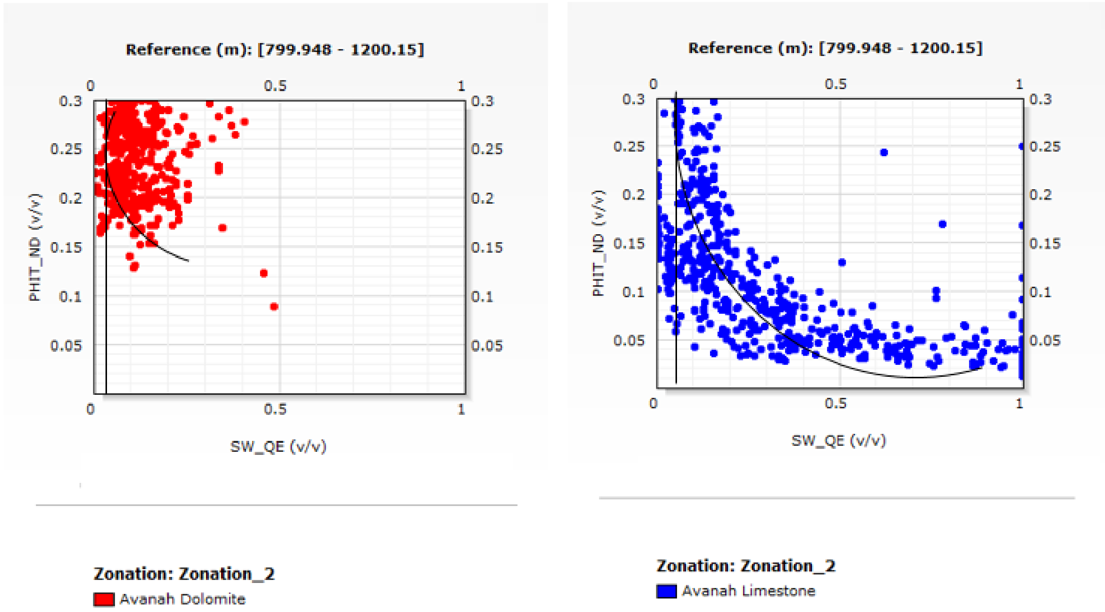


Figure 3.3: Swi calculation in Avanah dolomite and limestone in Well D

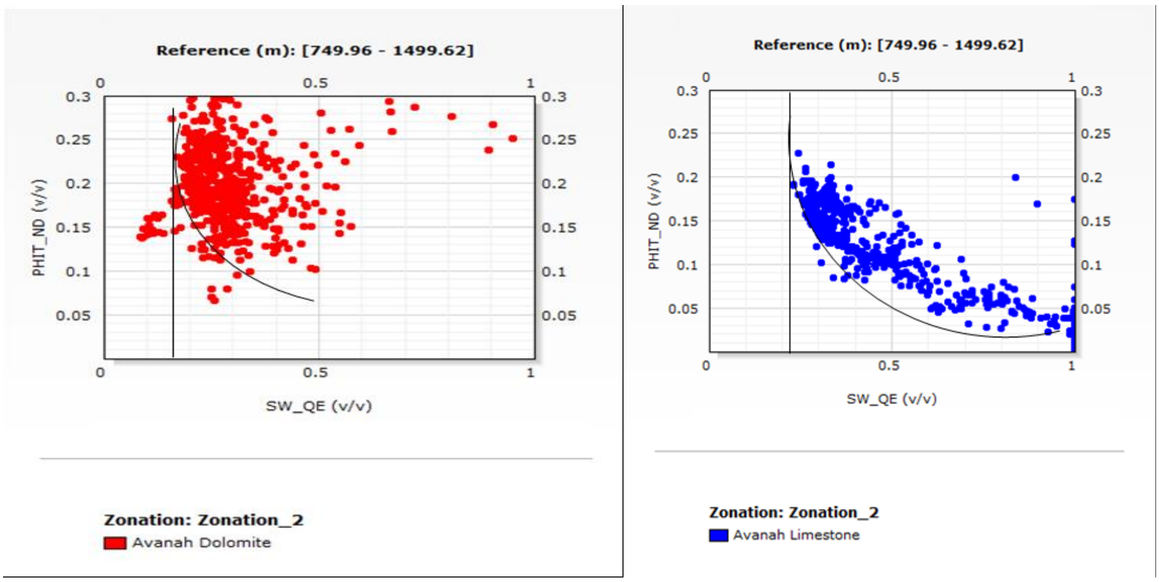


Figure 3.4: Swi calculation in Avanah dolomite and limestone in Well E

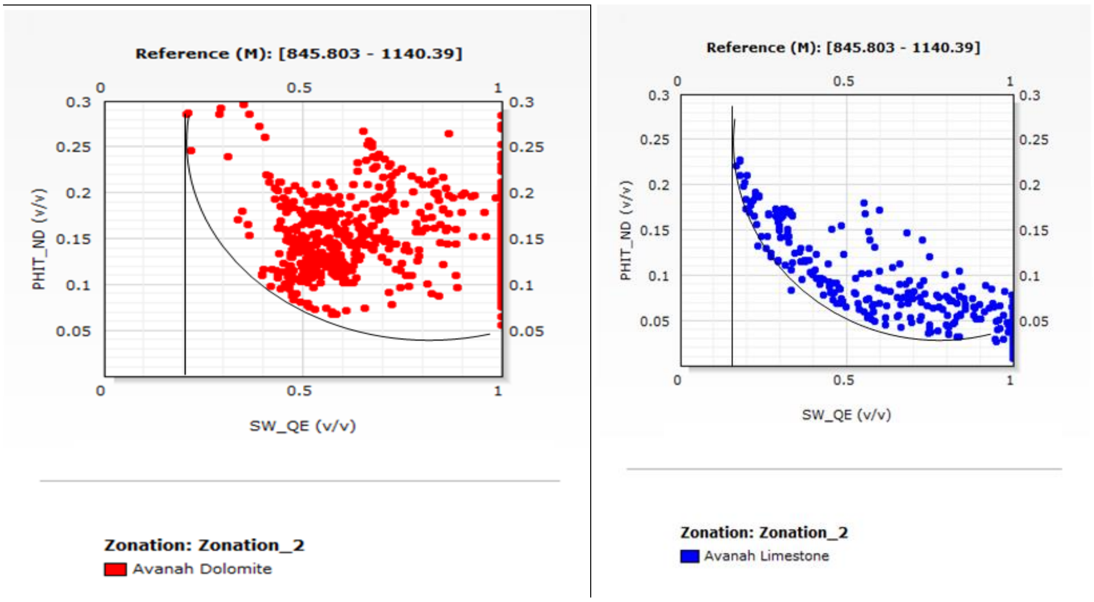


Figure 3.5: Swi calculation in Avanah dolomite and limestone in Well F

APPENDIX 4

NET PAY CALCULATION

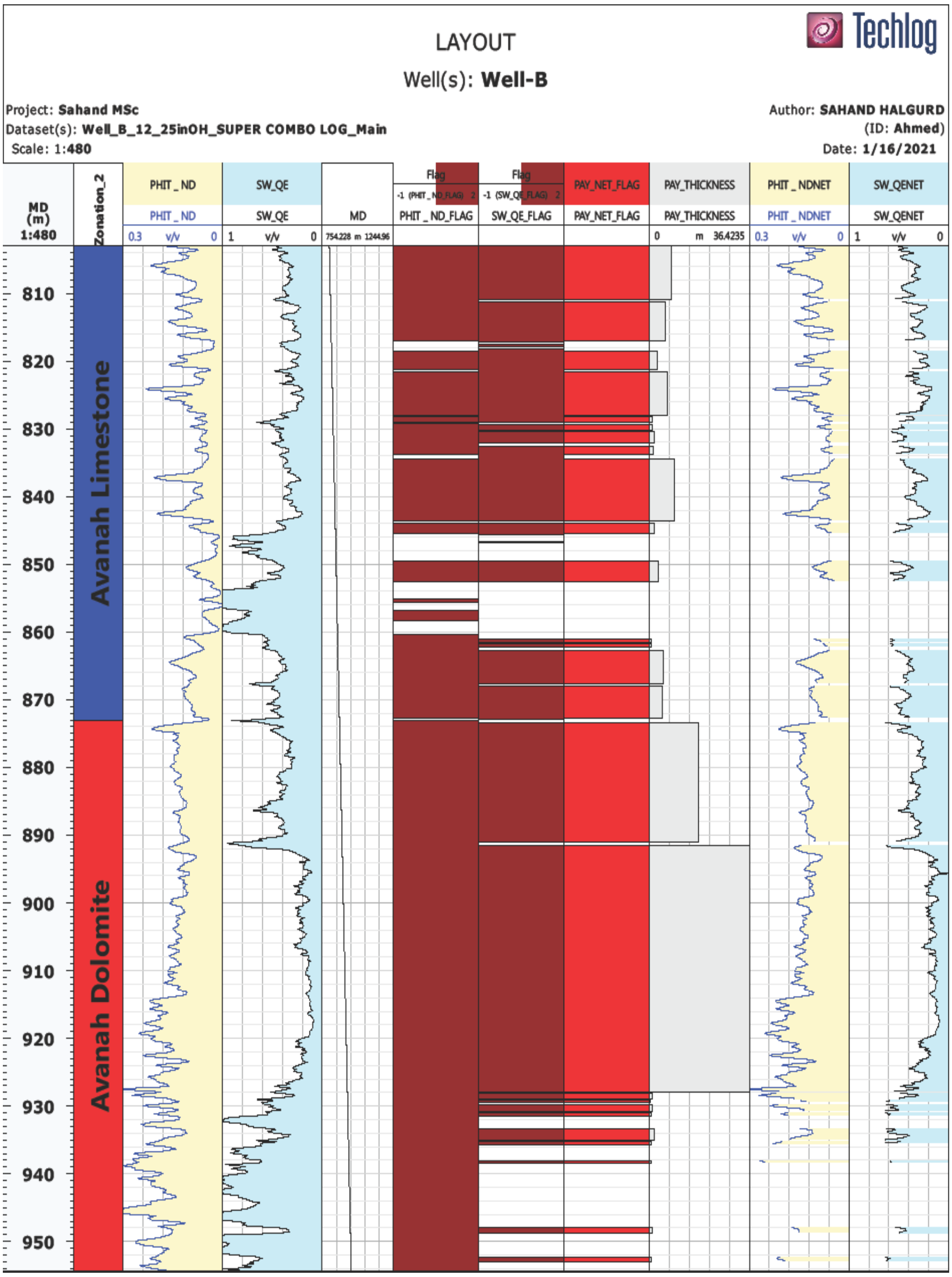


Figure 4.1: Calculation of net and gross pay thicknesses in Well B

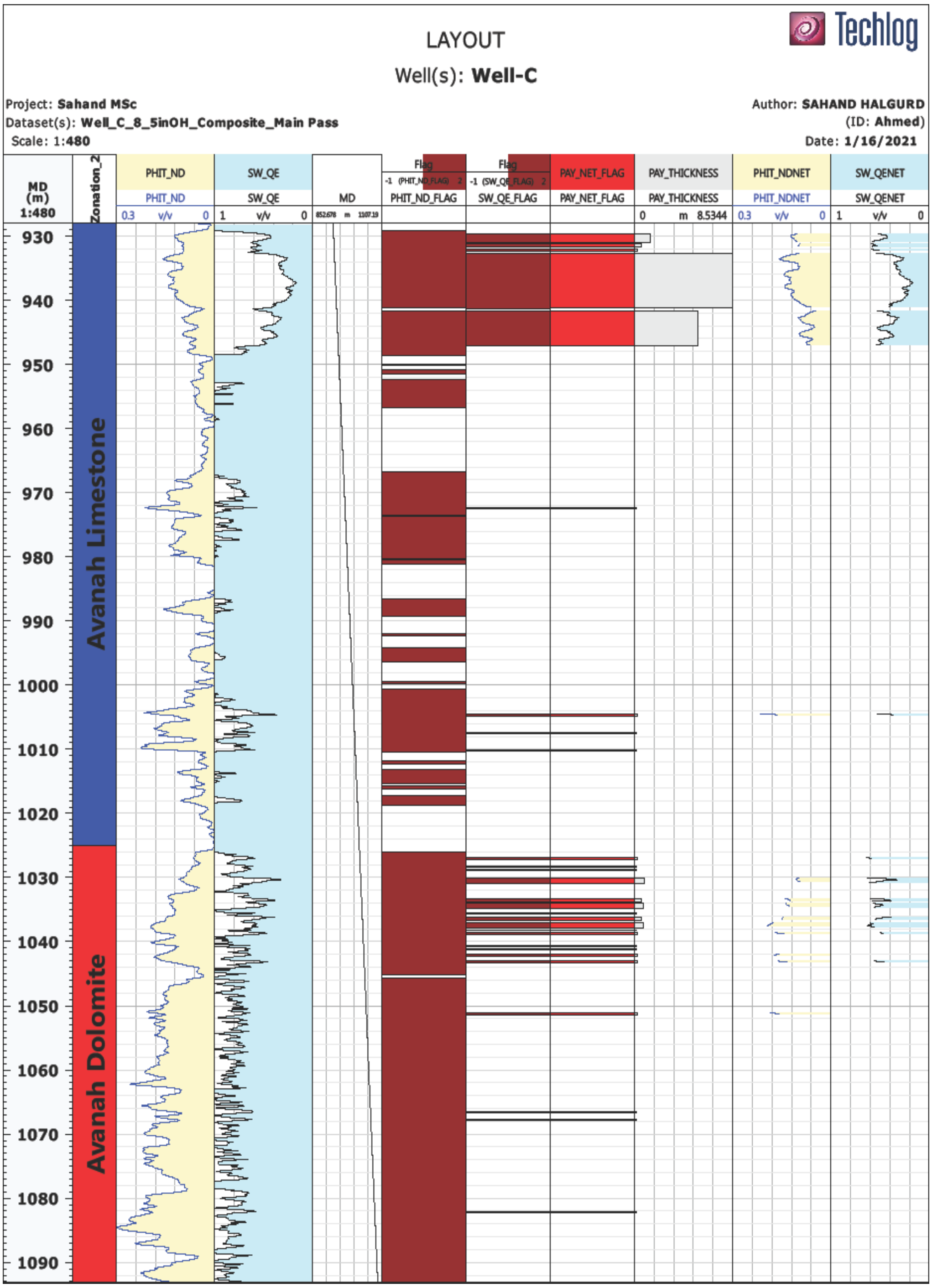


Figure 4.2: Calculation of net and gross pay thicknesses in Well C

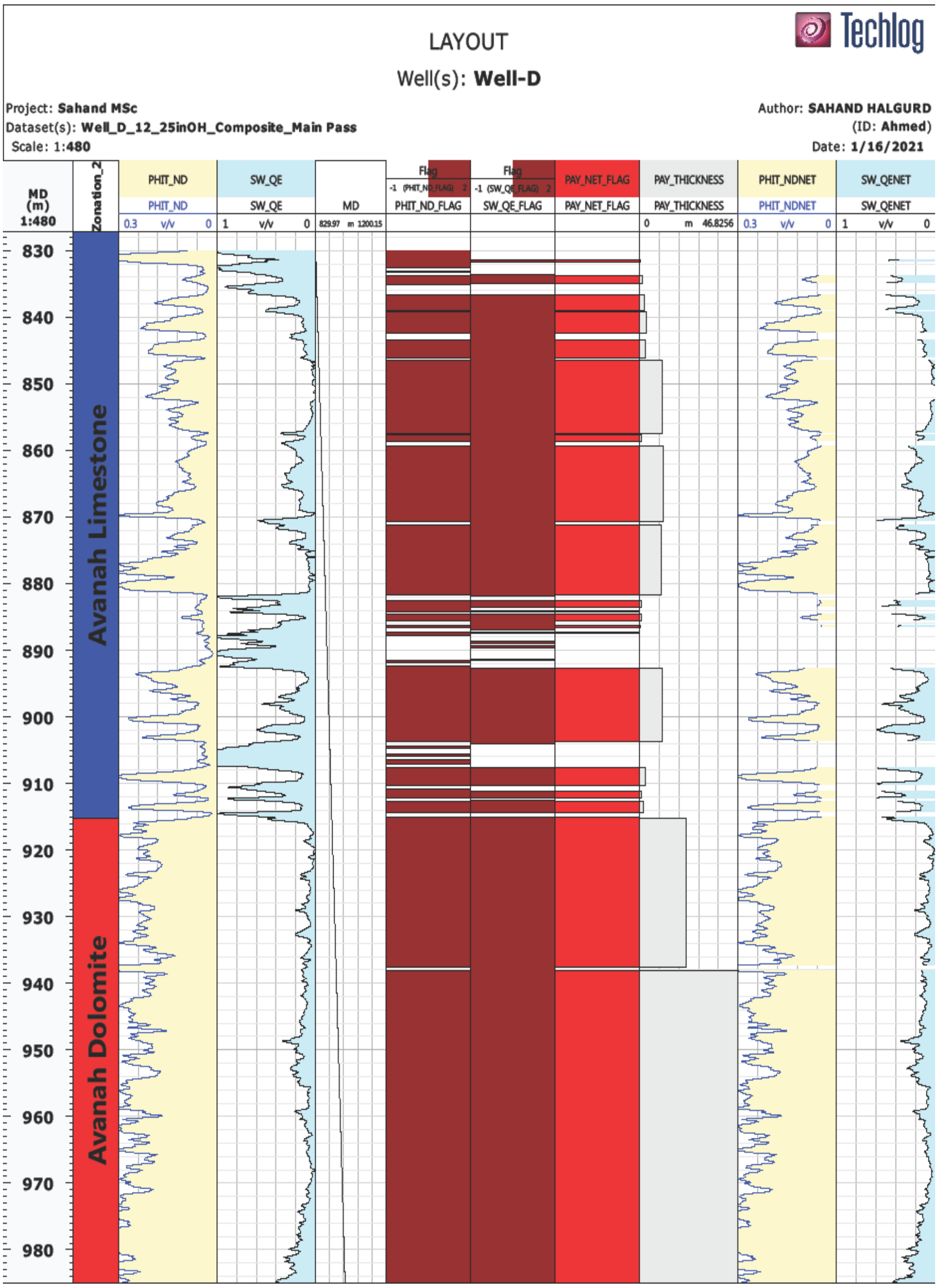


Figure 4.3: Calculation of net and gross pay thicknesses in Well D

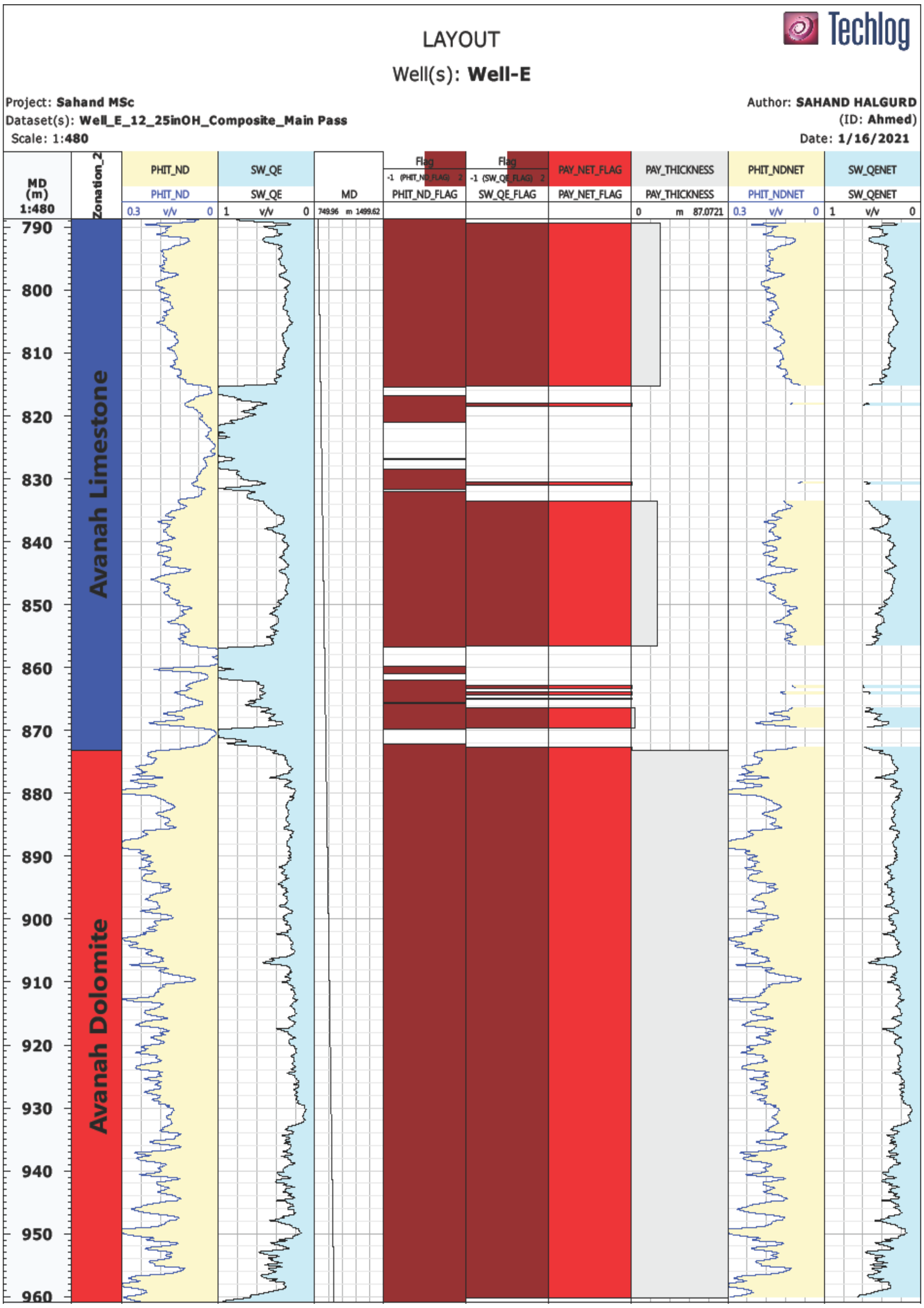


Figure 4.4: Calculation of net and gross pay thicknesses in Well E

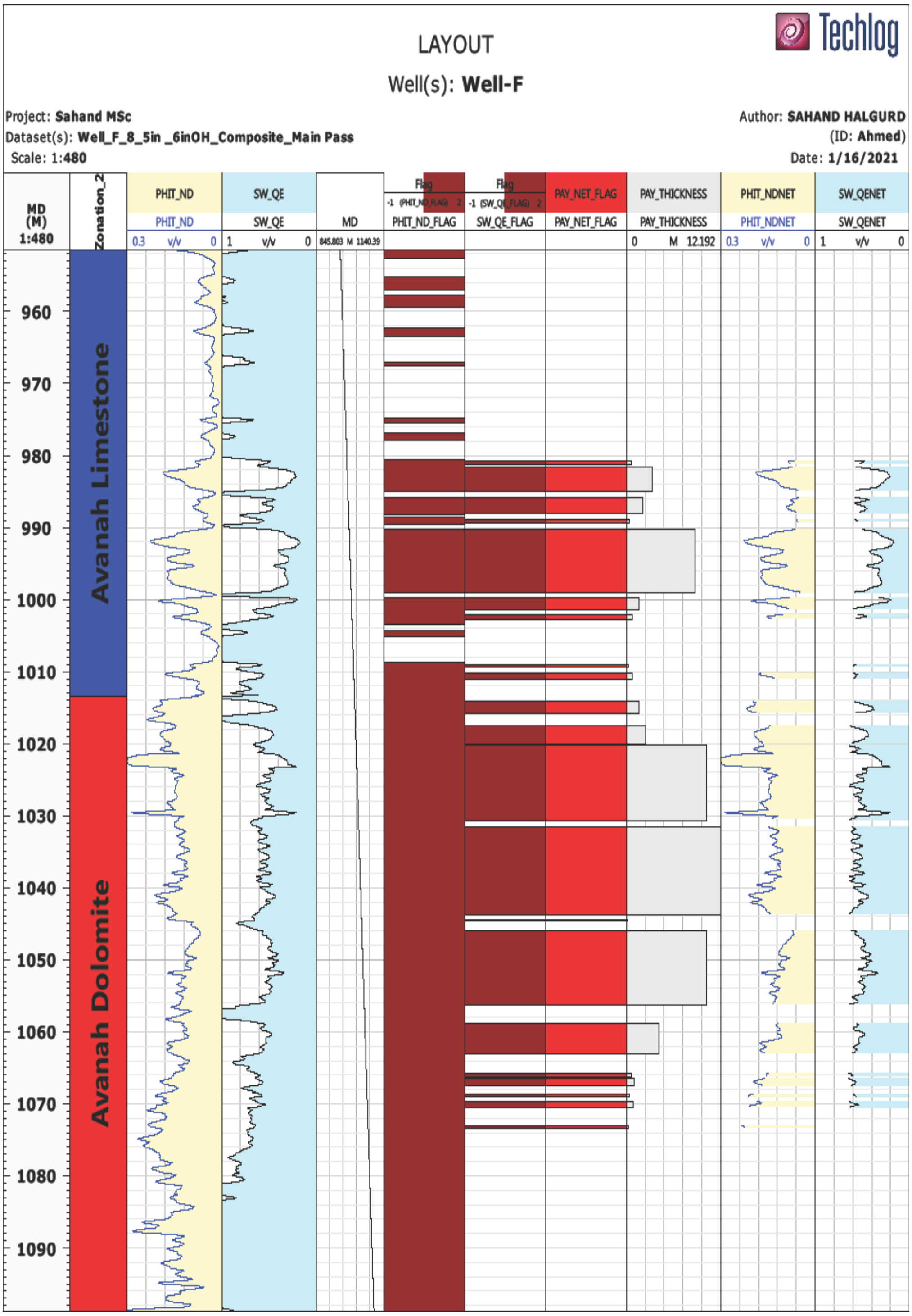
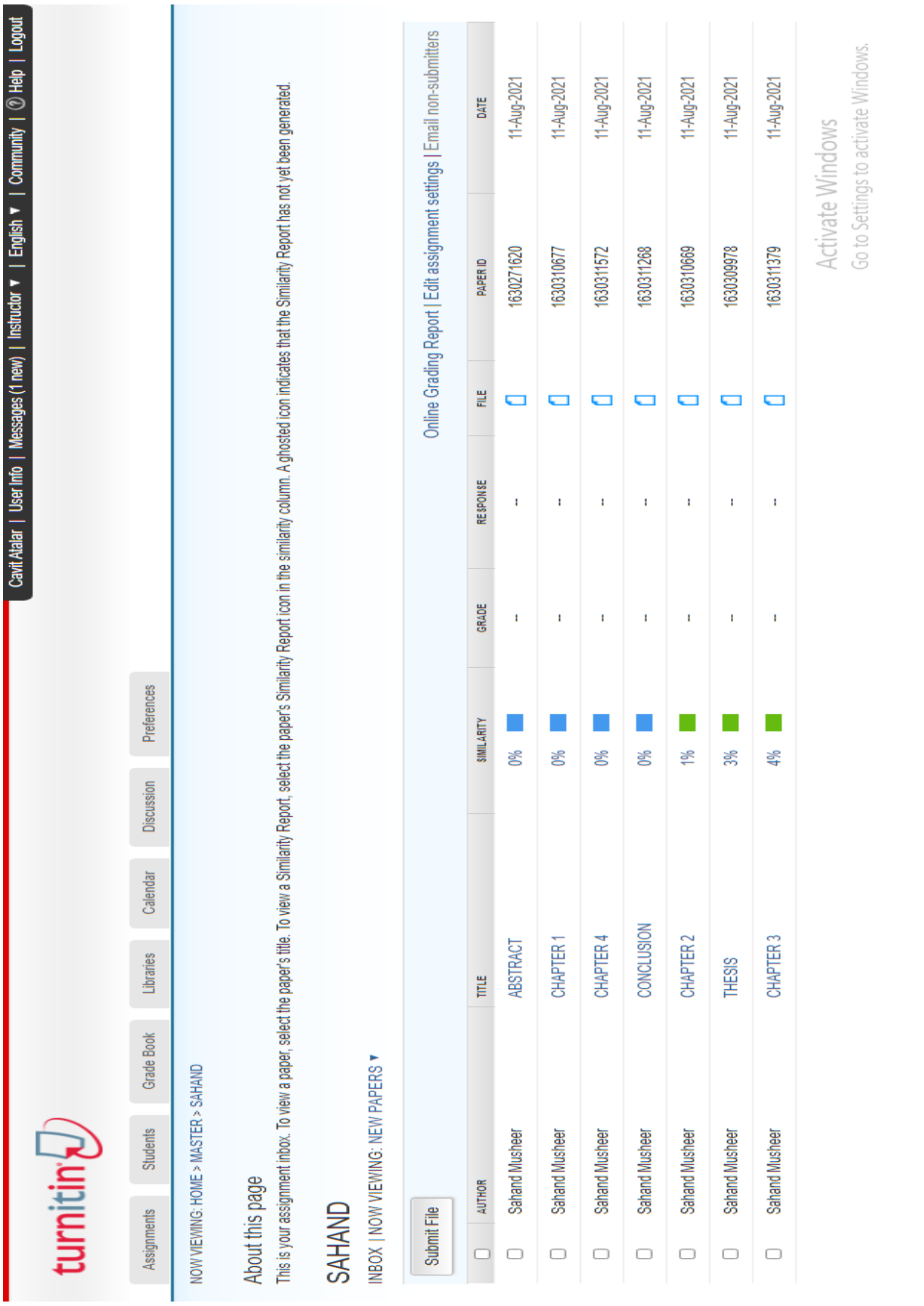


Figure 4.5: Calculation of net and gross pay thicknesses in Well F

APPENDIX 5

SIMILARITY REPORT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Prof. Dr. Salih SANER

Thesis Supervisor

APPENDIX 6

ETHICAL APPROVAL LETTER

YAKIN DOĞU ÜNİVERSİTESİ

ETHICAL APROVAL DOCUMENT

Date: 28/06 /2021

To the **Institute of Graduate Studies**

The research project titled “**PETROPHYSICAL ASSESSMENT OF AVANAH RESERVOIR IN KHURMALA DOME OF THE KIRKUK FIELD, IRAQ**’’ has been evaluated. Since the researcher will not collect primary data from humans, animals, plants or earth, this project does not need through the ethics committee.

Title: **Prof. Dr.**

Name Surname**: Salih SANER**

Signature**:** 

Role in the Research Project**: Supervisor**