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Application of python in the estimation of petrophysical properties,Sarir Field

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Abstract— **This paper investigates the application of python programming in the field of petrophysics, specifically in the estimation of lithology, shale volume, porosity, and water saturation. During this study, wire-line logs data from two wells (well-1 and well-2) in the sarir oil field were used. The percentage of shale, porosity, and water saturation in the rock is an important input parameter for some petrophysical and reservoir calculations (e.g., estimation of original oil in place and oil reserve). In this work, python 3, Jupyter notebook, and python libraries (Pandas, Matplotlib and NumPy) were used to carry out a solid computation of petrophysical characteristics and then provide summaries of the result.**

Keywords—Petrophysical interpretation, Python Programming, Shale Volume, Porosity, Fluid Saturation.

I. INTRODUCTION

Well logging is the method of obtaining a detailed record of the subsurface geological formations. In the petroleum industry, petrophysical interpretation is being used for many reasons, such as a base to understand the geology of the wellbore at high resolution and to estimate the producible hydrocarbon reservoir. One of the most useful ways to perform a petrophysical interpretation is by use of well logs because they can contain key information about the formation sampled by different petrophysical measurements. Python is high-level interpreter, and most popular programming language for data science and specifically for data analytics. Python is an open-source and free software development language with the most impressive library of Artificial Intelligence and Machine Learning algorithms. Python has proven to be the most useful platform for highly sophisticated Petroleum Data Analytics tools[1]. Its objective is the automation of processes to save both compilations and time, fundamental for the optimization in the labor field [5]. Python is a general-purpose scripting language. Scripting languages are routinely used to solve small tasks, but Python is an exception. Python is a flexible language with a minimalist syntax. This programming language is interpreted, which means that code in Python is not converted into machine code but executed by an interpreter program. Hence, we conclude that Python is a practical platform. Any code in Python will run wherever there is an interpreter. Python can also be used as a regular calculator. The Python programming language was found to have the following advantages, namely: simple syntax as the code is easy to write, read and maintain; large standard library and a great number of alternate libraries; support for object-oriented programming and other paradigms; cross-platform and support for nearly all modern systems. Its integrative ability. The software interface is user-friendly, thus making it easily used for creating software products for the oil and gas industry [6]. Jupyter Notebook, or simply a notebook, provides an interactive way to write and execute Python code in a web-based interface. This process of executing Python code can be thought of as a hybrid between the Python interpreter and Python scripts. Some of the added advantages provided by Jupyter Notebook include a convenient means of sharing work via rich computational and data-driven narratives that mix code, figures, data, and text [2]. An additional advantage of this web-based environment is that it combines all the different pieces like code, text, images, equations, and visualization plots, together in one document. The notebooks are easily shareable and could be edited on the go since they do not have too much dependency on the associated system [1]. This process aims to analyze well logs and estimation of reservoir properties that are needed to understand and quantify potential risks, that could impact our hydrocarbon presence and consequently in wrong decisions being made. In this present work python and jupyter notebook performed petrophysical interpretation using well data to determine and analyze the petrophysical properties in the Nubian reservoir of the study area in the Sarir field in the southeastern Sirt basin. The objective of this study is to develop well logs data analysis to estimate reservoir properties, including lithology, shale volume, porosity, and fluid saturation, based on a common set of well logs, including gamma ray, bulk density, neutron porosity, resistivity, and sonic. The goal is to build a triple-combo to display the log data that helps qualitative interpretation. Following that, the quantitative interpretation to calculate the reservoir properties based on the well-log data.

II. GEOLOGICAL BACKGROUND

The Sarir or, more specifically, the Sarir "C" field lies on the western edge of the Calanscio Sand Sea in southern Cyrenaica and is the largest oil field in Libya. It occurs at the southeastern margin of the Upper Cretaceous-Tertiary Sirte basin or embayment that contains all the major oil fields of Libya and is the most prolific oil-producing basin in North Africa.

The Sarir "C" field, which is part of a complex of three fields, is 35 mi (56 km) long and 25 mi (40 km) wide covering approximately 146 mi2 (378 km2). To its north lies the Sarir "L" accumulation, which covers approximately 15 mi2, and is situated approximately between the two, a much smaller Sarir North pool. The estimated ultimate recovery from the "C" field is 6.5 billion bbl of oil and, from the "L" field, 1.2 billion bbl, ranking them as the 51st and 201st largest fields in the compilation of Carmalt and St. John (1986)[3].

The Nubian formation in the SE Sirt basin is composed of four members, which can be correlated regionally using a lithostratigraphic framework. Within the Sarir Sandstone are two sandstone-dominated members, each reflecting a rapid drop in base level, which are important oil reservoirs in the study area.

Between these sandstones are thick shales of continental origin, which define the architecture of the reservoir units. This four-fold lithostratigraphic subdivision of the Sarir Sandstone contrasts with previous schemes, which generally only recognized three members. The sandstones below the top Sarir unconformity host more than 20 billion barrels of oil-in-place. The dominant traps are structural (e.g. Sarir C field), stratigraphic (e.g. Messla field), hanging-wall fault plays (e.g. UU1-65 field), and horst-block plays (e.g. Calanscio field) [4].

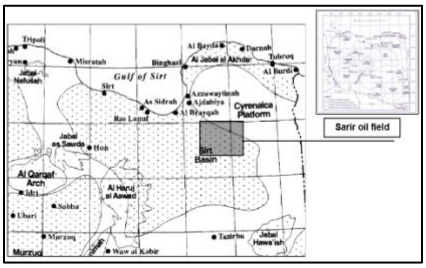

Fig. 1. *Map of field in the study area.*

III. MATERIAL AND METHODOLOGY

A. Methodology

Python 3 was used to display and analysis of well logging data. The Python programs were run in the Jupyter Notebook interactive environment. This study used a different python library. NumPy which is used for working with array and mathematical functions while Pandas are package built on top of NumPy and provides an efficient implementation of a DataFrame [2]. Pandas are used for data analysis as there is flexibility to deal with different data structures. Matplotlib includes capabilities for a flexible range of data visualization in python, which is used to build a variety of plots (histograms, scatter plots, bar charts, etc.) [2]. These libraries were used to create petrophysical algorithms. These Python libraries can be installed using the operating system command prompt (terminal) window by typing "pip install <package name>".

The petrophysical interpretation workflow that concentrate in this work is describe in following section:

- Firstly, import python libraries. Secondly, load well data and read data from CSV files. Before the analysis, a data quality check and data cleaning were performed on each set of well logs. Once well data cleaning is completed start viewing and working on the well data.
- Display triple-combo curves which consist of Gamma-ray, Spontaneous potential, and Caliper log at the first track. The resistivity log (deep and shallow resistivity) is shown in the second track. And the third track is consisting of a porosity log (Neutron, Density and Sonic log).
- Calculate the shale volume which is the first step in quantitative interpretation. The gamma-ray and spontaneous log are also employed in establishing the volume of shale for each of the gross sand zones delineated.

$$V_{sh} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (1)$$

  Where, V_{sh} is shale volume (%), GR_{log} is gamma ray reading, GR_{min} is gamma ray reading in clean sand and GR_{max} is gamma ray reading in shale.

- Estimation of porosity by using neutron, density, and sonic log. The effective porosity is determined from the corrected porosity by adjusting the calculated porosity for the volume of shale present.

$$sonic\ \Phi = \frac{\Delta t_{\log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}} \quad (2)$$

Where, sonic Φ is sonic porosity (%), Δt_{log} is interval transit time in the formation, Δt_{ma} is interval transit time in matrix and Δt_{fl} is interval transit time in the fluid in the formation.

$$Density\ \Phi = \frac{\rho_{ma}-\rho_b}{\rho_{ma}-\rho_{fl}} \qquad (3)$$

Where, Density Φ is density porosity (%), ρma is matrix density, ρ_b is bulk density and ρ_{fl} is fluid density.

$$\phi_e = total\Phi * (1 - V_{sh}) \qquad (4)$$

Where, ϕ_e is effective porosity (%), total Φ is average total porosity.

- The resistivity as well as density and neutron logs are used in triple combo log-view to obtain zones of hydrocarbons and delineate OWC. These logs are used to establish the zones of hydrocarbons. The zones with hydrocarbons are recognized due to their higher resistivities. This is especially so when the deep resistivity log reading is relatively higher than the shallow resistivity reading.
- The water saturation in reservoir zone is calculated based on Simandoux equation.

$$Sw = \frac{c.Rw}{\phi_e^2}\left[\sqrt{\frac{5\ \phi_e^2}{Re.Rt} + \left(\frac{Vsh}{Rsh}\right)^2} - \frac{Vsh}{Rsh}\right] \qquad (5)$$

Where, C = 0.40 for sand and 0.45 for carbonate, Vsh is lowest of the various shale indicators sh, Rt is deep resistivity (corrected for invasion), Rsh is deep resistivity reading in adjacent scale, ϕ_e is effective porosity.

- The permeability within the gross sand zone is calculated from Timur equations.

$$K = a\frac{\Phi^b}{SWi^c} \qquad (6)$$

Where, K= permeability md. Ø = porosity, fraction. Swi = irreducible water saturation. a = 8581.0 (constant). b = 4.4 (constant). c = 2.0 (constant).

- The cutoffs are established as a deterministic cutoff that is fixed at one value and the probabilistic cutoff, which ranges from a lower limit to an upper limit. Table 1 shows cut-off parameters.

TABLE I. CUT-OFF PARAMETERS.

Parameters	Cut-offs		
	Vsh %	***Φ%***	***Sw%***
Value	**35**	**10**	**50**

B. Well Data

In this study, several data must be available for the purposes of petrophysical interpretation, these data provided by AGOCO, and these data are well logging data which are many types of logs are available to determine the well-tops, sequence of the layers and the properties of the rocks. The well logging is Caliper log (CALI), Gamma ray (GR), Spontaneous Potential (SP), Density (RHOB), Neutron (NPHI), Medium resistivity (ILM), Deep resistivity (ILD), Micro spherical focused log (MSFL). Table II show the well logging available for each well.

TABLE II. TYPES OF LOG DATA FOR EACH WELL.

well	Well data							
	CALI	***GR***	***SP***	***RHOB***	***NPHI***	***ILM***	***ILD***	***MSFL***
Well-1`	√	√	√	√	√	√	√	√
Well-2	√	√	√	√	√	√	X	√

IV. RESULT AND DISCUSSION

The well-logging data were plotted and analyzed using python-3 where code writing and run through Jupyter notebook. It is important to interpret well logs in both qualitative and quantitative manners. The conventional logs were used as a source for getting information about lithology, shale volume, porosity, and saturation. The following sections will describe the results of logs data interpretation. Figs 2 and 3 exhibit the triple combo plot of two selected wells in the Sarir field (well-1 and well-2). Well -1 extends from 8200ft to 9310ft while well-2 covers depth from 8220 to 9310. Based on changes in Gamma-ray, Spontaneous potential, Neutron, Density, Sonic and Resistivity logs well-1 and well-2 split into eight zones. The qualitative part of the interpretation was determining the lithology and reservoir zone.

The lithology was interpreted using a gamma-ray and the neutron and density cross plot. From the log responses, it was clear that the lithology of the studied wells has the same distribution and was divided generally into two main zones; the upper zone of shaly dominant lithology which extend from zone 1 to zone 4 and the lower zone from zone 5 to zone 8 with sandstone dominant lithology with some percentage of shale interbedded. Figs 6 and 7 shows the neutron density cross plot which displays the distribution of lithology based on the gamma-ray reading. Figs 8 and 9 show the main lithology in the zone-5 and zone-6 which shows the main lithology is sand with some percentage of shale.

Figs 2 and 3 illustrate the triple combo. From neutron density, the log shows that yellow shading is the reservoir zone and green shading is the non-reservoir zone. From the log response, zone 5 and zone 6 show low gamma ray and yellow shading for neutron-density which is indicated as reservoir zone. zone-5 covers the interval from 8642.5 to 8700 ft while zone-6 extend from 8700 to 8857 ft for well-1. However, in well-2 zone-5 extend from 8658.5 to 8728ft while zone-6 extend from 8728 to 8974ft.

From resistivity logs, the evidence of oil and water was observed in zone (5 & 6), in which the resistivity response is high and the separation between resistivity responses are present. According to these results, the OWC line was plotted at a depth of 8795.5ft at the end of zone-6, while the end of zone-5 is defined as a transitional zone, where the shale percentage increased. However, in well-2 the oil is observed at the beginning of zone-5 whereas the rest of the zone is non-reservoir according to neutron-density response with high resistivity and high-water saturation due to the shale effect. On the other hand, in zone-6 oil is observed in the middle of the zone whereas the beginning of the zone is non-reservoir according to neutron density response with high resistivity and high-water saturation and OWC is plotted at 8903.5ft of zone-6.

The next part of log interpretation was determining the petrophysical properties. Figs 4 and 5 show the interpretation plot which according to cut-off parameters two targets were identified along each well which is the zone (5 &6). For a zone (5&6) in well-1 the net pay was about 11.5ft for zone-5 and 95ft for zone-6. The shale volume was about 8% and 10% respectively. However, in well-2 the net pay was about 25.5ft for zone(5) and 87.5ft for zone-6. The shale volume was about 16.3% and 8%. The porosity in the studied wells was interpreted using the porosity logs. The porosity logs show that the porosity in the upper zones is mainly total porosity due to shale porosity, while effective porosity was noticed in the lower zones. For zone-5 the effective porosity was about 19.6% in well-1 and 18.8% in well-2 while the effective porosity in zone-6 was about 14.6% in well-1 and 14.6%. The permeable zones were identified by the separation between shallow and deep resistivity. Timur equation was used to calculate the permeability, which ranged between 3 md to 1000 md at the lower zones. From the saturation log, in a zone (5&6), The saturation response decreases gradually from top to bottom, in which, at top of these zones the oil saturation increases and water saturation decrease. The average water saturation is about 12.3% for zone-5 and 24.7% for zone-6 in well-1 while in well-2 the water saturation was about 20.1% in zone-5 and about 23% in zone-6. The tables below show the reservoir result.

TABLE III. RESERVOIR PROPERTIES FOR WELL-1.

Zone No	Reservoir properties well-1					
	litholog y	***Net pay ft***	***Vsh%***	***Φ%***	***K md***	***Sw%***
Zone-5	Shalysa nd	11.5	8	19.6	346.8	12.3
Zone-6	Shalysa nd	97	10	14.6	65	24.7

TABLE IV. RESERVOIR PROPERTIES FOR WELL-2.

Zone No	Reservoir properties well-2					
	litholog y	***Net pay ft***	***Vsh%***	***Φ%***	***K md***	***Sw%***
Zone-5	Shalysa nd	25.5	16.3	18.8	278	20.1
Zone-6	Shalysa nd	87.5	8	14.6	42.7	23

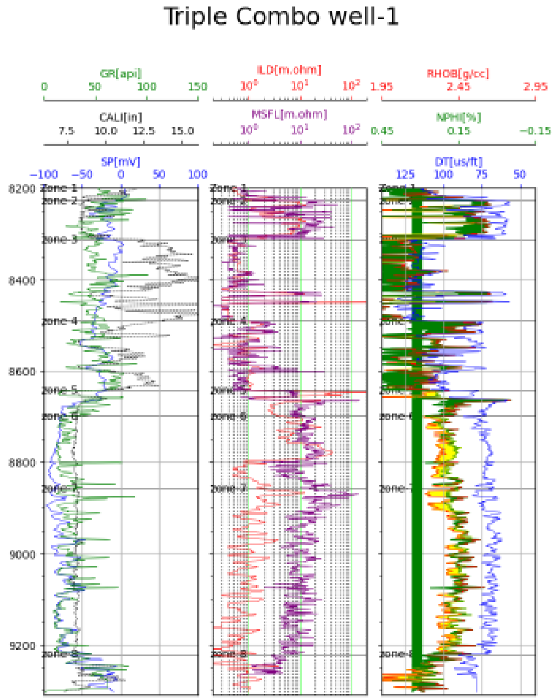

Fig. 2. *Triple combo of well-1.*

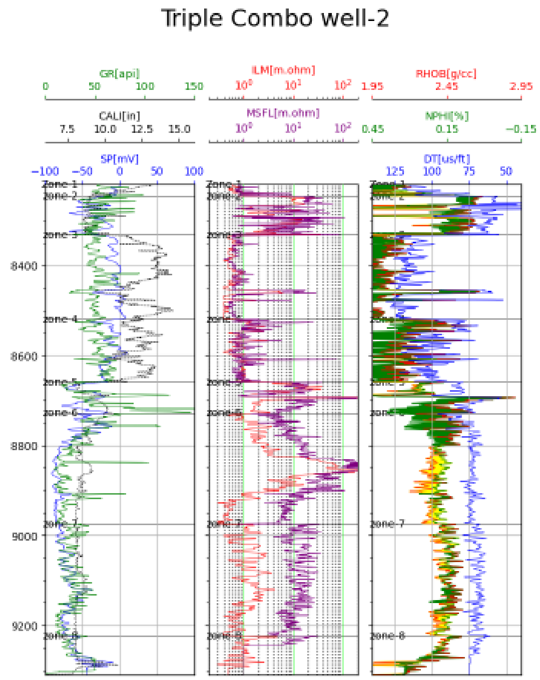

Fig. 3. *Triple combo of well-2.*

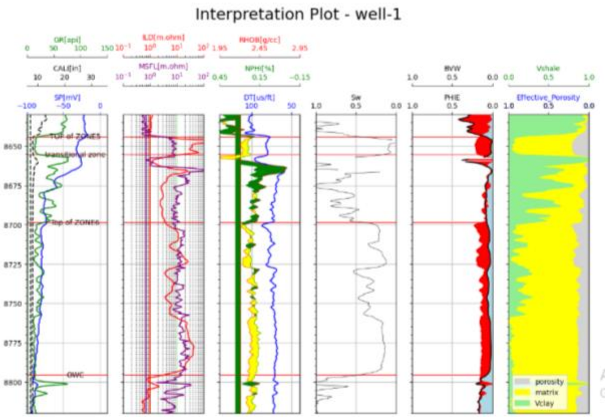

Fig. 4. *Interpretation plot of reservoir zone (5&6) well -1.*

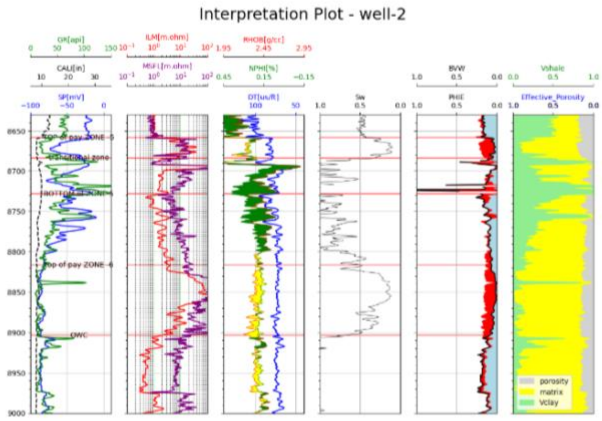

Fig. 5. *Interpretation plot of reservoir zone (5&6) well -2.*

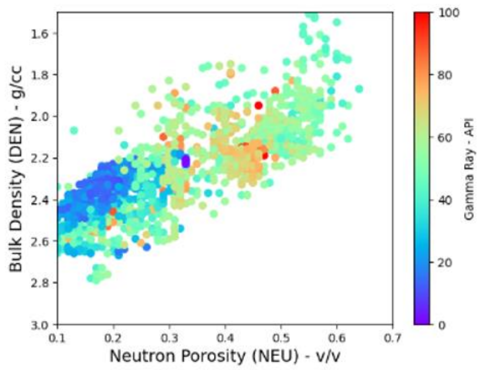

Fig. 6. *Neutron- Density and gamma ray crossplot well-1.*

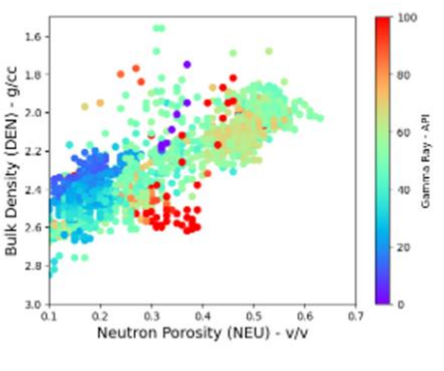

Fig. 7. *Neutron- Density and gamma ray crossplot well-2.*

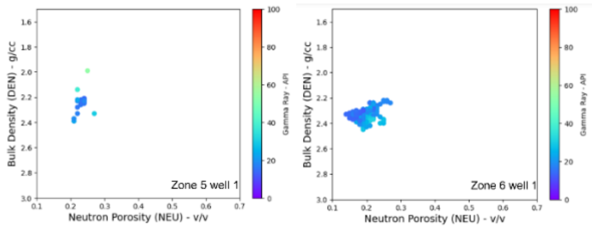

Fig. 8. *Neutron- Density and gamma ray crossplot zone (5&6) well-1.*

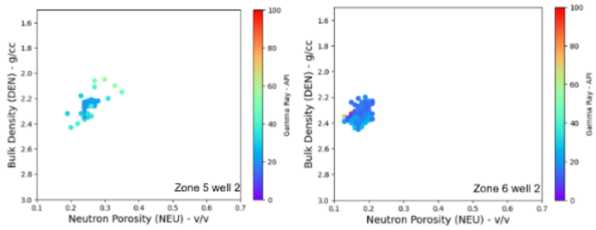

Fig. 9. *Neutron- Density and gamma ray crossplot zone (5&6) well-2.*

V. CONCLUSION AND RECOMMENDATION

The present study deals with applying python 3 as a data analysis tool to analyze well logging data and calculate petrophysical parameters shale volume, porosity, and water saturation as well as prediction of lithology. The different logging data of two wells from the sarir field are interpreted to provide the necessary petrophysical information. Python open-source libraries (pandas, NumPy and Matplotlib) are used in the interpretation process. This work is started by building a triple combo plot for studied wells and then split zones based on log response. Based on gamma ray, resistivity, neutron, and density log response identify zone 5 and 6 as reservoir zone. The lithology of the studied wells was interpreted using gamma ray and neutron and density log which the main lithology of the upper zone was shaly for the first four zones and shaly sand for the lower zone. According to the cut-off value, the net pay for zone 5 in well -1 was about 11.5 ft and zone 6 was about 97ft while zone 5 in well 2 was about 25.5 ft and zone 6 was about 87.5ft. The shale volume ranged from 8 % to 16 % and porosity was about 14% to 19% while the water saturation ranged from 12% to 24.7%. The interpretation shows the good result for each well.

For future work, it is essential to use machine learning open-source libraries such as Scikit-learn and TensorFlow. Develop well-logging interpretation to plot lithology on the interpretation plot and predict a more accurate result. In order to obtain precise results, particularly in the calculation of the permeability, core data are required.

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