Identification of Barriers and Productive Zones Using Reservoir Characterization

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Abstract: The most common complication faced by petroleum engineers is the description of a reservoir, both accurately and efficiently. Inadequate and insufficient reservoir characterization lead most enhanced oil recovery and secondary recovery projects to fail and also makes it difficult to deal with heterogonous reservoir. An accurate description of a reservoir is vital to the reservoir management and achieving maximum oil recovery. Reservoir characterization plays a very important role in descripting the storage and flow capacity of a reservoir and also plays a decisive role in reservoir simulation. The main objective of this research is to identify reservoir barriers and productive zone using reservoir characterization, in this study some of the most useful methods such as Flow Zone Indicator (FZI), Discrete Rock Type (DRT), Winland R35 methods were applied to 4 different wells to identify the rock types and flow units developing a static reservoir characterization model. To achieve the objective of this research the static model is transformed into a dynamic model by introducing graphical method such as stratigraphic flow profile (SFP), stratigraphic modified Lorenz plot (SMLP) and modified Lorenz plot (MLP) to easily quantify reservoir flow units based on physical structure, storage capacity, flow capacity, rock type and reservoir process speed. The physical structure permits the flow units to be interpreted in a stratigraphic model arrangement, determining well-to-well correlation schemes; the main aim of understanding the flow unit's characterizations is to identify the barriers, speed zones and baffles.

Keywords: Flow Zone Indicator (FZI), Discrete Rock Type (DRT), Winland R35 methods, Flow unit (FU), Reservoir Quality Index (RQI), Hydraulic Flow Unit (HFU) stratigraphic flow profile (SFP), stratigraphic modified Lorenz plot (SMLP) and modified Lorenz plot (MLP).

I. INTRODUCTION

Reservoir characterization plays a fundamental part in all oil and gas industry, the understanding of the reservoir rock properties such as porosity; permeability and pore throat assists engineers improve reservoir characterization. Reservoir characterization is described as the manner of quantitatively character reservoir using the available data. Heterogeneous reservoirs usually present high challenges to engineers and geologist in acquiring accurate of the hydraulic flow unit, rock typing, barriers and productive zone performance and recovery predictions, because of its tendency of being tight and heterogeneous.

For numerous ages petroleum engineers and geoscientists have studied and introduced methods to advance the reservoir characterization as it has remained a difficult encounter, reservoir characterization methods are entirely valued because they bring a much better-quality and exact characterization of the storage and flow capacity of an oil and gas field and consequently offerings a foundation for developing a simulation model.

Hydraulic flow unit (HFU) defines the division of reservoir channels towards different zones with the same flow and bedding characterization, thereby integrating factors like porosity and permeability towards a solo magnitude that defines a formation, indicating flow zones and rock typing.

Rock type is a key concept in improving the reservoir description of straddles multiple scales and bridges multiple disciplines. Reservoir rock classification (rock typing) has been a fundamental tool for reservoir characterization, several techniques introduced by several authors has been used to identify rock types in a formation such as FZI, DRT and winland (35), that indicates different flow zones (HFU) for each dissimilar rock type.

Parameters involved in these techniques are usually obtained from core data analysis, well logs and well tests, thus in this studies the core data analysis is being used. However, it is difficult predicting properties for uncored well.

Flow unit is described as stratigraphic uninterrupted interval of the same reservoir process speed that respects the physical structure and retains characteristics of the rock type. Graphical method is a tool using to determine flow units using techniques such as stratigraphic flow profile (SFP), stratigraphic modified Lorenz plot (SMLP) and modified Lorenz plot (MLP) to quantify reservoir flow units based on physical structure, rock and pore throat types, reservoir speed process and flow and storage capacity of the reservoir creating stratigraphic model correlation.

The key purpose of this research is to describe the rock type, flow zones and flow unit characterization to identify barriers (seals), baffles (zones control fluid flow) and speed zones from 4 wells of an Egyptian reservoir. Provided an enhanced characterization of the reservoir.

II. BACKGROUND THEORY

A. HYDRAULIC FLOW UNIT

This method describes the quality of an entire reservoir rock in which the geological properties (texture, mineralogy, sedimentary structure, bedding) and petrophysical properties (porosity, permeability, capillary pressure) that affect fluid flow are surely predictable and certainly dissimilar from properties of different rocks. Each flow unit/zone in the reservoir represents a continues lateral, vertical and similar flow and bedding characteristic. In this approach rock types are classified based on the equation below:

$$RQI = 0.0314\sqrt{\frac{K}{\varphi_e}}$$

Where φ_e is effective porosity (fraction), K is permeability (md) and RQI is rock quality index (μm). Additionally, core derived porosity must convert to normalize one as shown below:

$$\varphi_z = \frac{\varphi_e}{1-\varphi_e}$$

Where φ_z is normalized porosity. Lastly Flow zone indicator can be calculated by the equation below:

$$\log RQI = log\emptyset_z + \log FZI$$

On a log-log plot of RQI versus $\emptyset_z$ will be plotted, core samples with the same pore and grain size characteristics will lie on a straight line with a unit slope, while core samples with dissimilar FZI will lie on different parallel lines. To assist in simplifying the use of rock type in a recreation model, continued FZI values are transformed to discrete rock type (DRT) by equation using the equation below, so as to assist calculate the permeability of each geological model using permeability-porosity relationship of each discrete rock type.

$$DRT = Round\ (2\ln(FZI) + 10.6)$$

B. Winland Method (R35)

For several years' scientist have made experiments using capillary pressure curve by mercury injection to estimate pore throat sizes. In this approach , developed an experimental correlation that relates porosity, permeability and pore throat radius from mercury intrusion tests. The experimental connection of the maximum numerical relationship was attained at the 35% of the cumulative mercury saturation curve, which is donated as (R35). R35 has been considered to estimate the point where the model pore aperture happens, and it is referred to as the point where the pore system is connected creating an on-going route through the core sample. The winland equation is:

$$\log(R35) = 0.732 + 0.588\log(K) - 0.864\log(\emptyset)$$

Where K is the permeability, $\emptyset$ is the porosity and R35 is the calculated pore throat radius at 35% mercury saturation.

With this in mind confirmed that this case is only correct if the pore throat size is equivalent to the point of inflexion of the pore throat size verse mercury saturation. R35 of a particular rock type will always have the same values. Below are the five-petrophysical flow units with distinctive reservoir performance differentiated by the extension of the R35 standard:

- Mega-porous units, expressed by R35 greater than 10 microns.
- Macro-porous units, expressed by R35 between 2.5 and 10 microns
- Meso-porous units, expressed by R35 between 0.5 and 2.5 microns
- Micro-porous units, expressed by R35 between 0.2 and 0.5 microns
- Nano-porous units, expressed by R35 smaller than 0.2 microns

C. Graphical Methods

These methods introduce tools which support easy description of reservoir flow units established based on storage capacity, flow capacity, flow unit speed with relation to determined rock types using techniques such as winland R35, FZI, and DRT. Determined rock types are transformed to petrophysical established flow units, which can be entered in a statistical flow simulator. Application of these methods begins by determining the rock types within a physical structure; the physical structure permits the flow units to be interpreted in a stratigraphic model arrangement, determining well-to-well correlation schemes. The main aim of understanding the flow unit's characterizations is to identify the barriers, speed zones and baffles. The three graphical tools used to determine flow units are:

1. Stratigraphic Modified Lorenz Plot (SMLP)

This tool is a plot of computed percent flow capacity versus percent storage capacity in a stratigraphic sequence, which display a shape illustrating the flow performance of each zone.

2. Stratigraphic Flow Profile (SFP)

In this tool a flow profile is created, displaying the correlation of an interpreted flow unit consisting of Gamma ray (GR), porosity and permeability (core data), winland R35, K/Phi, percent flow capacity and percent storage capacity. This flow profile is the foundation that compares flow units from different techniques to develop a 3 dimensional flow unit reservoir description and a flow unit interval can be developed in respective to winland R35 and K/Phi ratio.

3. Modified Lorenz Plot (MLP)

This tool is a plot of percent flow capacity versus percent storage capacity that is computed from flow unit interval obtained from SFP, sorted and plotted in descending order of the flow unit speed. This plot is uncertain to maintain similar traces as the original un-interpreted Lorenz plot .

Furthermore, the shapes of this curve indicates a predictable flow performance of the reservoir, the shape of the curve can be classified into three segment as mentioned below:
- Speed Zone Unit (SZU): These are a steep slope segments that indicates a high degree of percentage of flow capacity corresponding to storage capacity of reservoir.

- Baffles: These are segments having relatively flat slope indicating very high degree of storage capacity with small amount of flow capacity, which is also referred to zone that control formation fluid movement.

Barriers: These are segments that neither have flow nor storage capacity in the reservoir.

III.DATA USED

The following data is a core sample extracted from 4 different wells of an Egyptian field, consisting of gamma ray (GR), porosity and permeability with depths of each well. Before running this research, the quality of all the samples were checked, a few samples were broken or unavailable due to miss handling of core samples; therefore, they were not included in our calculations to ensure accurate readings only.

FIG 1(A, C, E, G) shows the plot of RQI and normalized porosity based on FZI value. As illuminated in this figure, all data laying in the same colour presents accurate straight-line correlations with unit slope of equal FZI value as shown in Table 1.

According to the data in this figure, the well (A10, A11, A12 and A13) display 16, 7, 18 and 14 FZI respectively that confirms the number of HFU in each well; this could be because of the heterogeneity of the reservoir. It is also due to know that rock type with the highest FZI value has the better quality of fluids flow in the pore spaces of the reservoir rock.

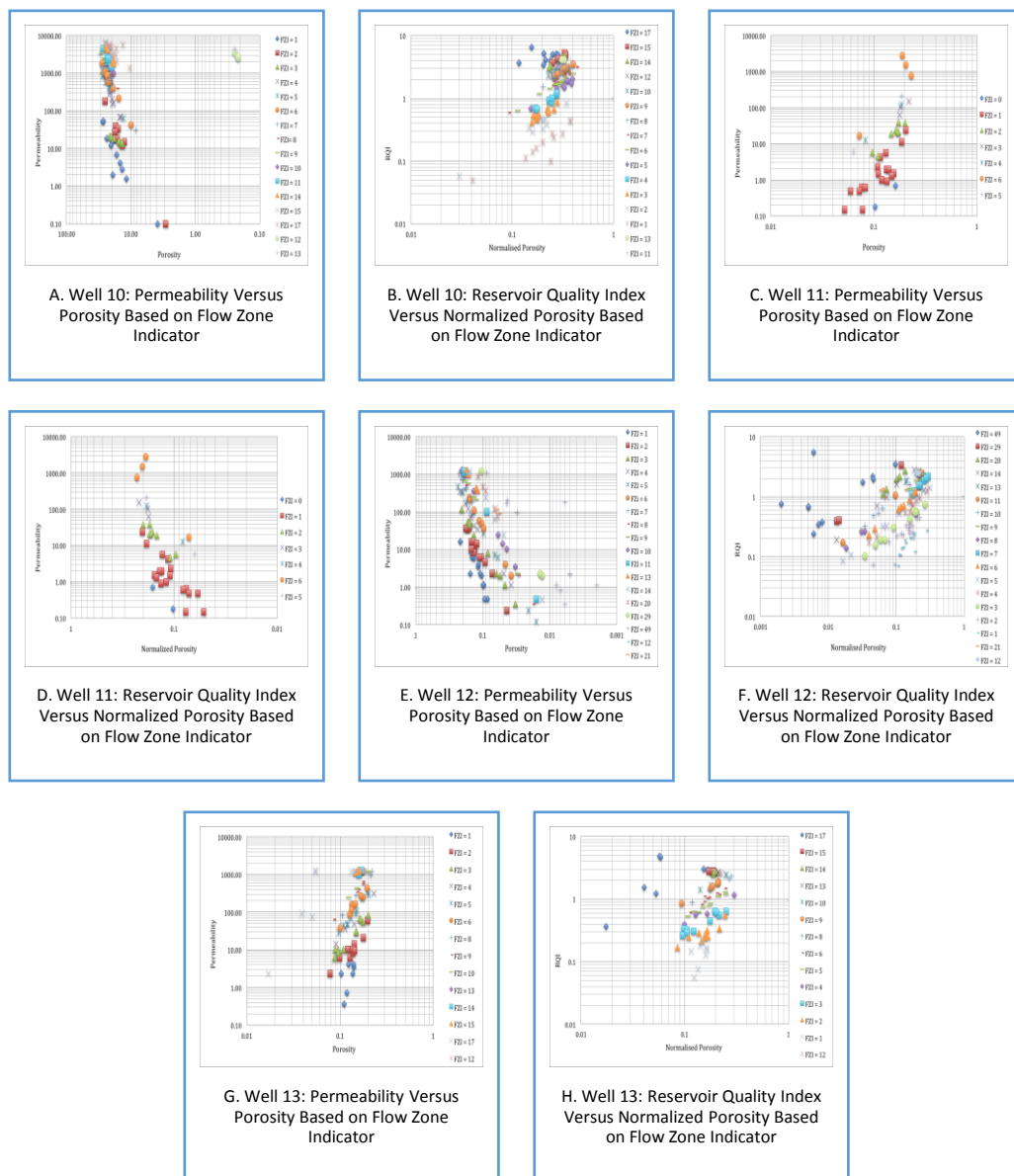Fig. 1(B, D, F, H) illustrates the plot of permeability versus porosity classified based on FZI.

A. Well 10: Permeability Versus Porosity Based on Flow Zone Indicator

B. Well 10: Reservoir Quality Index Versus Normalized Porosity Based on Flow Zone Indicator

C. Well 11: Permeability Versus Porosity Based on Flow Zone Indicator

D. Well 11: Reservoir Quality Index Versus Normalized Porosity Based on Flow Zone Indicator

E. Well 12: Permeability Versus Porosity Based on Flow Zone Indicator

F. Well 12: Reservoir Quality Index Versus Normalized Porosity Based on Flow Zone Indicator

G. Well 13: Permeability Versus Porosity Based on Flow Zone Indicator

H. Well 13: Reservoir Quality Index Versus Normalized Porosity Based on Flow Zone Indicator

Figure 1: Flow Zone Indicator Results For All Wells

IV.RESULTS AND DISCUSSION

A. *FLOW ZONE INDICATOR (FZI)*

B. *DISCRETE ROCK TYPES*

Fig 2 (A, B, C D) shows a plot of permeability versus porosity based on DRT values for all wells, according to

the data in this figure, the well (A10, A11, A12 and A13) display 9, 6, 10 and 9 DRT respectively.

consuming results. Also, the DRT values have a correlation in each well with similar DRT values that indicates the connection of all 4 wells.


A. Well 10: Permeability Versus Porosity based on Discerte Rock Type

B. Well 11: Permeability Versus Porosity based on Discerte Rock Type

C. Well 12: Permeability Versus Porosity based on Discerte Rock Type

D. Well 13: Permeability Versus Porosity based on Discerte Rock Type

Figure 2: Discrete Rock Type Results for All Wells

C. WINLAND METHOD

Routine core data gathered for each well was calculated using winland equation, winland R35 plot of the entire 4 wells shown in Figure 3 (A, B, C, D), illustrates the core data covers two parts of the plot surface that means the existence of separate rock types. Following the winland categories, the 4 wells where classified into two (Marco-porous and Meso- where classified into two (Marco-

porous and Meso-where classified into two (Marco-porous and Meso-of R35 (1, 2, 3, 4) as shown in this figure, as observed in both FZI and DRT, rock types with the highest value of pore throat radii have the better quality index to flow fluids through porous media. In addition to winland, Figure 10 illustrates the plot of permeability and porosity based on winland R35 category method.

As illustrated in this Figure DRT simplifies the flow units in order to make an easier application of rock type in the simulation models for a more accurate and less time
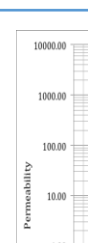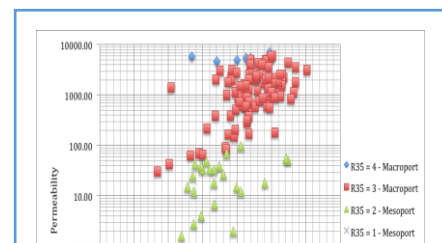
D. GRAPHICAL TOOLS: STRATIGRAPHIC FLOW PROFILE (SFP), STRATIGRAPHIC MODIFIED LORENZ PLOT (SMLP) AND MODIFIED LORENZ PLOT (MLP)

1. Stratigraphic Flow Profile (SFP)

Figure (4, 5, 6, 7), demonstrates a stratigraphic flow profile showing the correlation and inter-relationship between Gamma ray (GR) logs, porosity and permeability (core data), winland R35, K/Phi ratio and percent of both flow and storage capacity. This profile is the foundation for comparing flow units to balance wells within a prepared stratigraphic framework to develop a 3 dimensional flow unit reservoir description for simulation. Furthermore, flow units' interval is defined in respect to K/Phi ration and winland R35 for each well
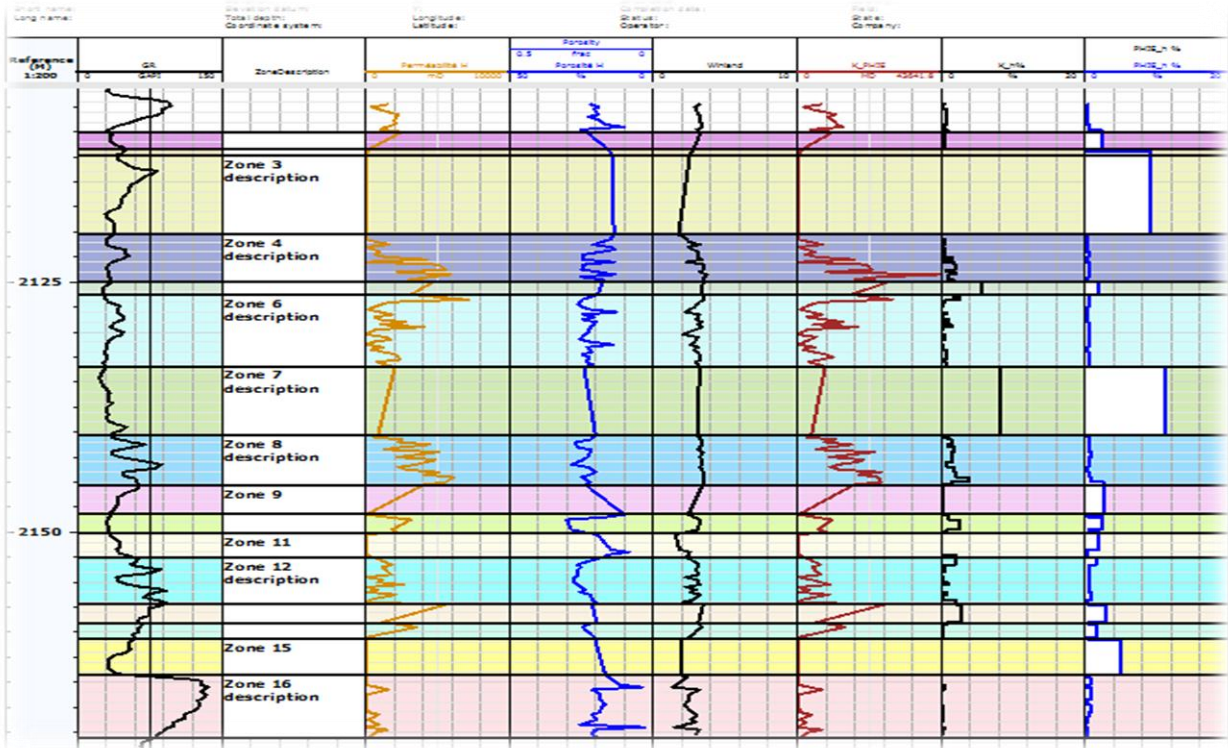
Figure 4: Well 10 Stratigraphic Flow Profile (SFP)
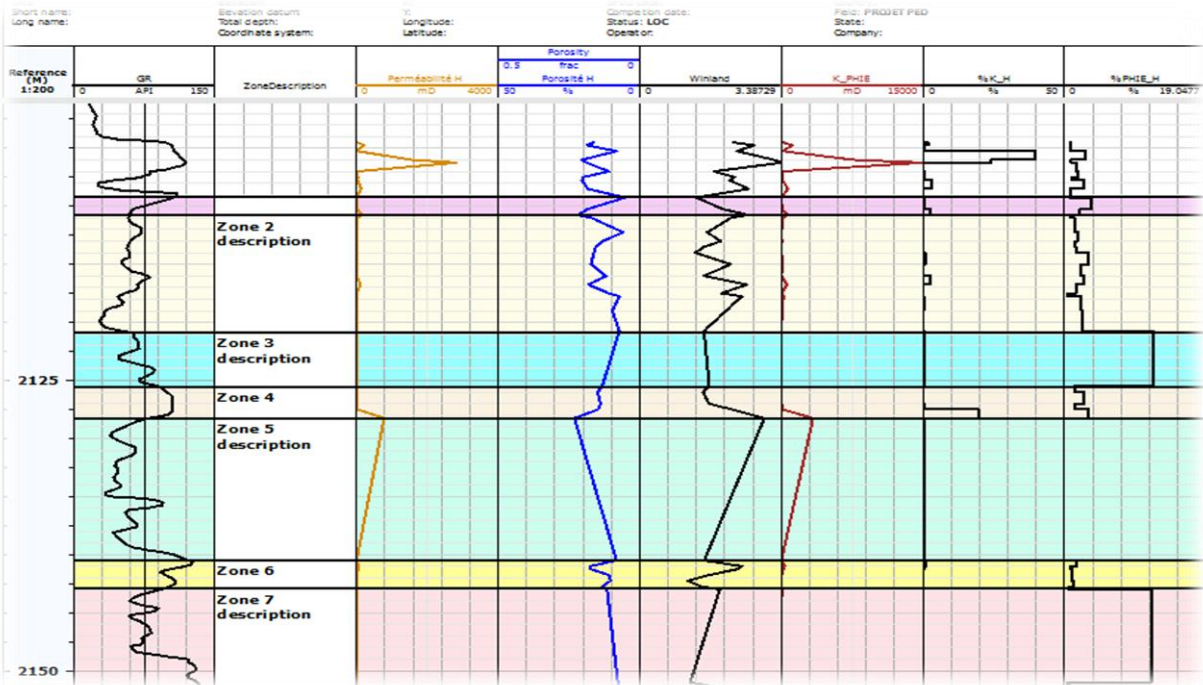
Figure 5: Well 11 Stratigraphic Flow Profile (SFP)
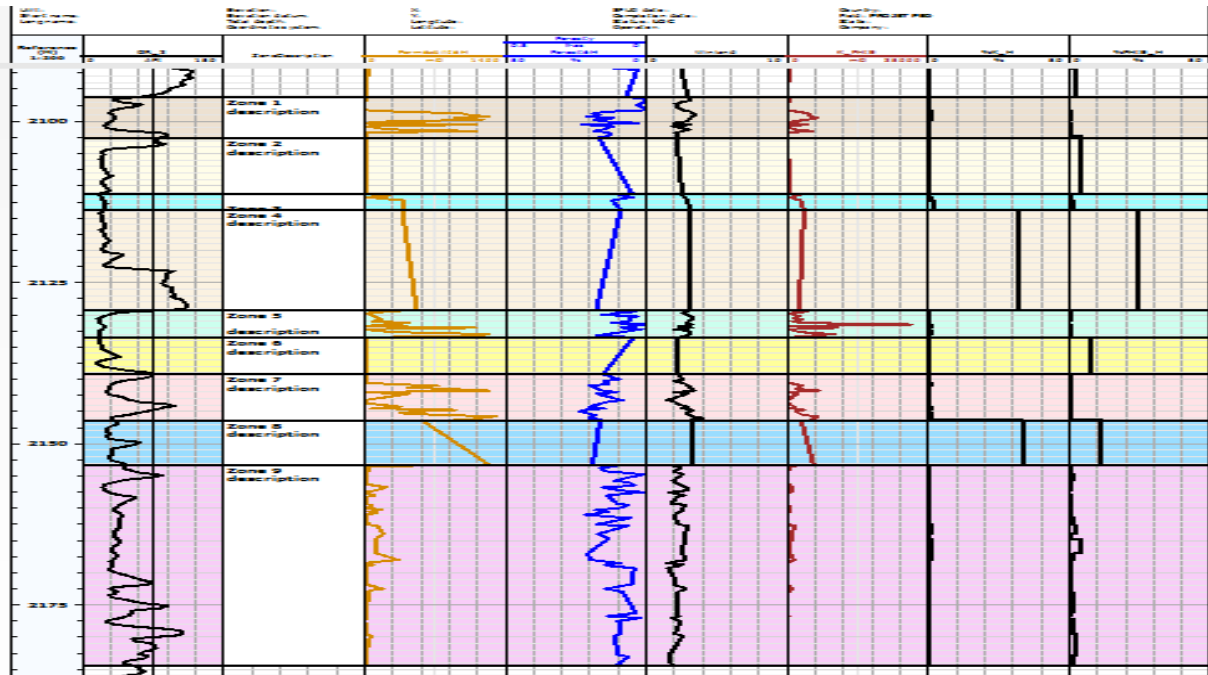
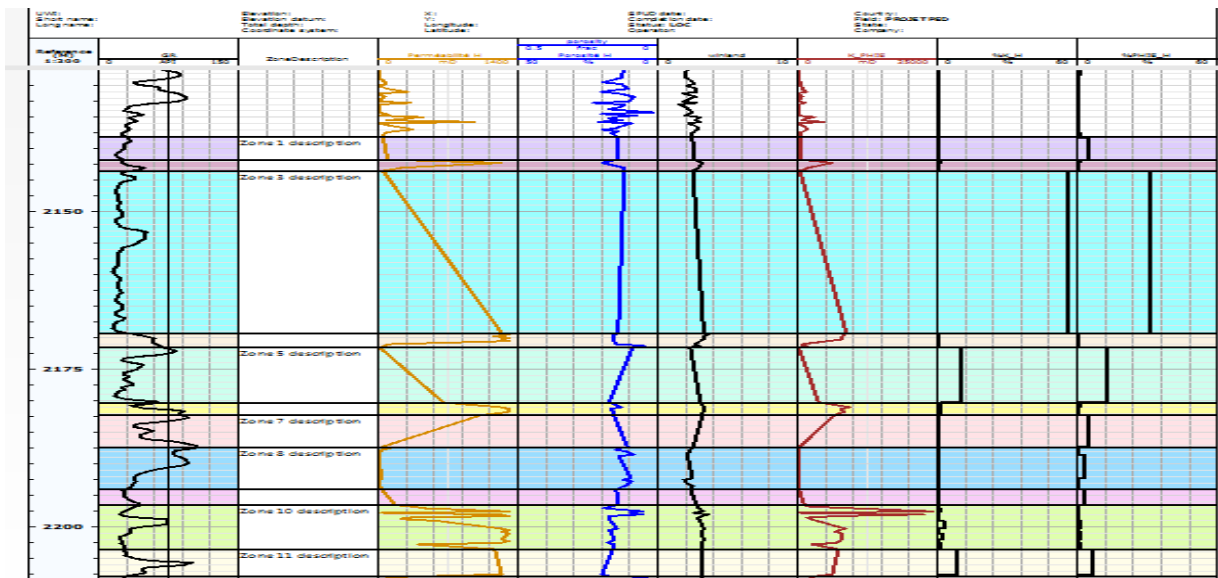Figure 6: Well 12 Stratigraphic Flow Profile (SFP)

Figure 7: Well 13 Stratigraphic Flow Profile (SFP)

2. Stratigraphic Modified Lorenz Plot (SMLP)

Figure (8a, 9a, 10a, 11a), demonstrates a plot of an un-interpreted stratigraphic modified Lorenz plot (SMLP), the shape of this figures identify the flow performance of each particular well. Segments' having a steep slope indicates very high percentage of reservoir flow capacity with relation to the storage capacity, which also represents the highest processing speed referred to as speed zones.

Segments' having relatively flat slope indicates a very high percentage of reservoir storage capacity with respect to small amount of flow capacity also known as baffles (Zones that control formation fluid movement) and finally zones or segments that are neither flow or storage reservoir are referred to as barriers (seal to flow) such as faults.
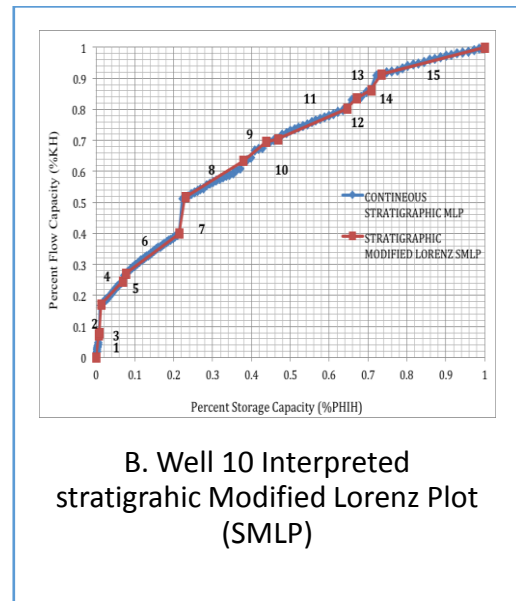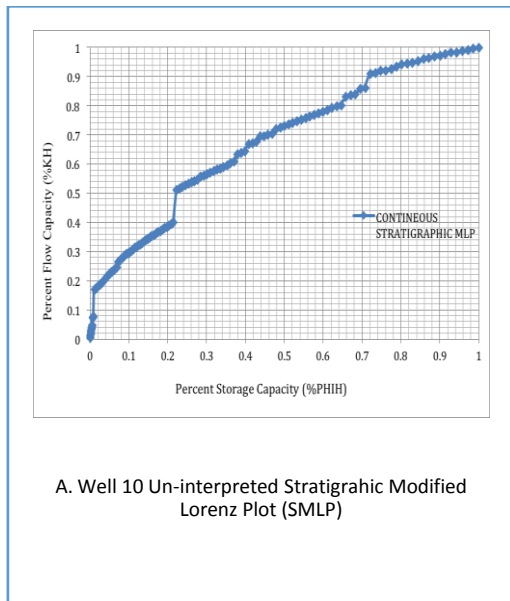
A. Well 10 Un-interpreted Stratigrahic Modified Lorenz Plot (SMLP)

B. Well 10 Interpreted stratigrahic Modified Lorenz Plot (SMLP)

Figure 8: Stratigraphic Modified Lorenz Plot (a) Un-Interpreted (b) Interpreted

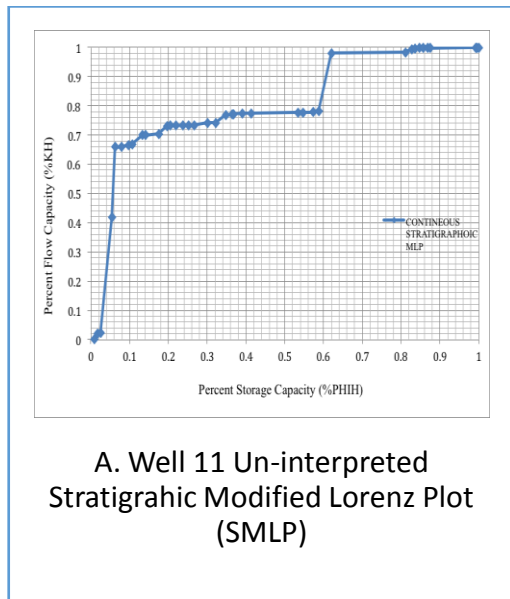A. Well 11 Un-interpreted Stratigrahic Modified Lorenz Plot (SMLP)

B. Well 11 Interpreted stratigrahic Modified Lorenz Plot (SMLP)
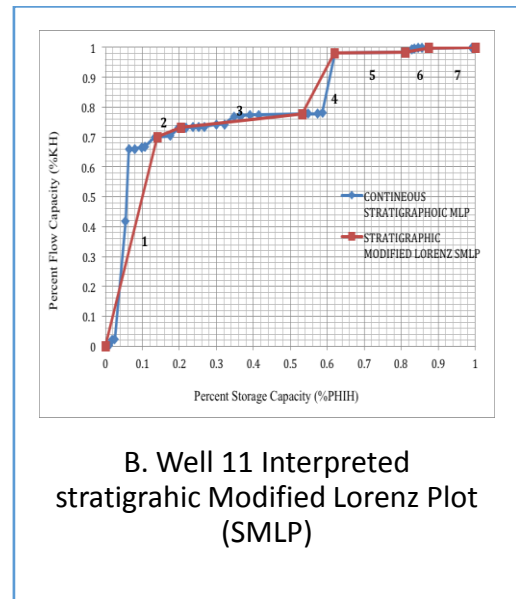
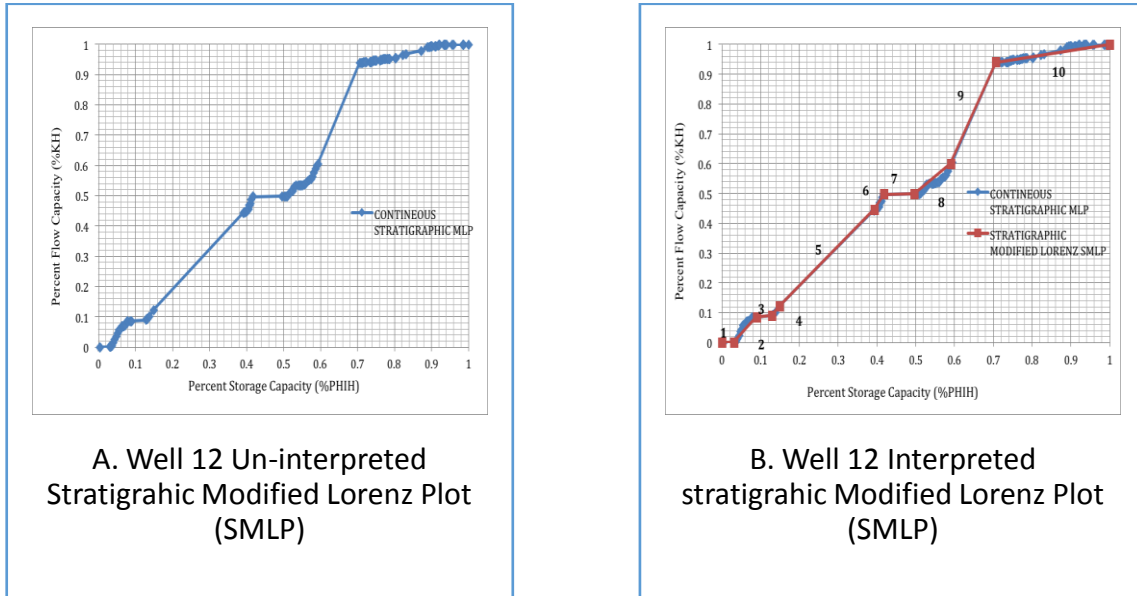Figure 9: Stratigraphic Modified Lorenz Plot (a) Un-Interpreted (b) Interpreted

A. Well 12 Un-interpreted Stratigrahic Modified Lorenz Plot (SMLP)

B. Well 12 Interpreted stratigrahic Modified Lorenz Plot (SMLP)

Figure 10: Stratigraphic Modified Lorenz Plot (a) Un-Interpreted (b) Interpreted

A. Well 13 Un-interpreted Stratigrahic Modified Lorenz Plot (SMLP)
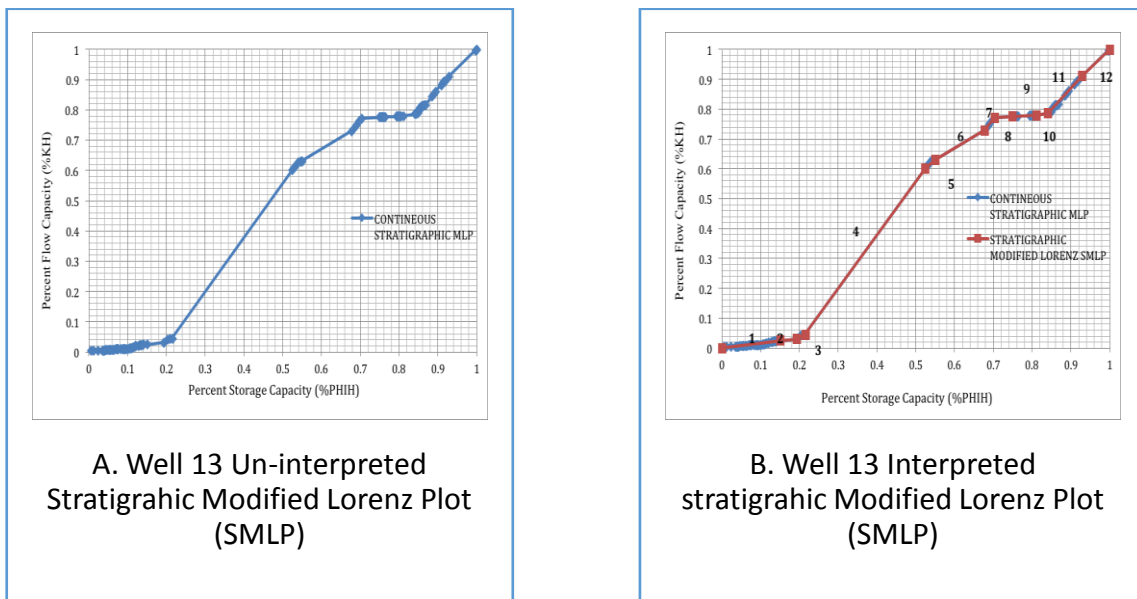
B. Well 13 Interpreted stratigrahic Modified Lorenz Plot (SMLP)

Figure 11: Stratigraphic Modified Lorenz Plot (a) Un-Interpreted (b) Interpreted

Figure (8b, 9b, 10b, 11b), demonstrates a plot of an interpreted stratigraphic modified Lorenz plot (SMLP), the developed exploratory flow unit in figure (4, 5, 6, 7), are used to compute the flow and storage capacity for each unit to interpreted the original Lorenz plot which provides an exceptional technique for recognizing speed zones, baffles and barriers. It is important to know that the interpreted plot should retain similar shape to the un-interpreted plot. The table below shows a well description of the numbers of flow units for each well based on interpreted (SMLP).

Wells	No. of Flow Units	Flow Units Characterizations		
		Speed Zones	Baffles	Barriers
Well 10	15	1, 2, 4, 8	3, 5, 6, 7, 15, 12, 13, 14, 11, 10, 9	
Well 11	7	1, 4	2, 3, 6	5, 7
Well 12	10	5, 6, 4, 2, 8	10	7, 1, 3
Well 13	12	4, 7, 11, 12	6, 3, 10, 1, 2	8, 9

3.Modified Lorenz Plot (MLP)

Figure 12 demonstrates a plot of percent flow capacity versus percent flow capacity, for a definitive prediction of the flow unit performance. This is computed using the developed exploratory interval flow unit sorted and plotted in descending flow unit speed. In the figure, unit (1, 2, 4, 8) shows to be the speed zones that happen to have the highest flow unit speed (FUS) as shown in table 1. Unit (3, 5, 6, 7, 15, 12, 13, 14, 11, 10, 9) illustrates to be baffles, which happen to have high storage capacity and lower flow capacity. This well does not have a seal.
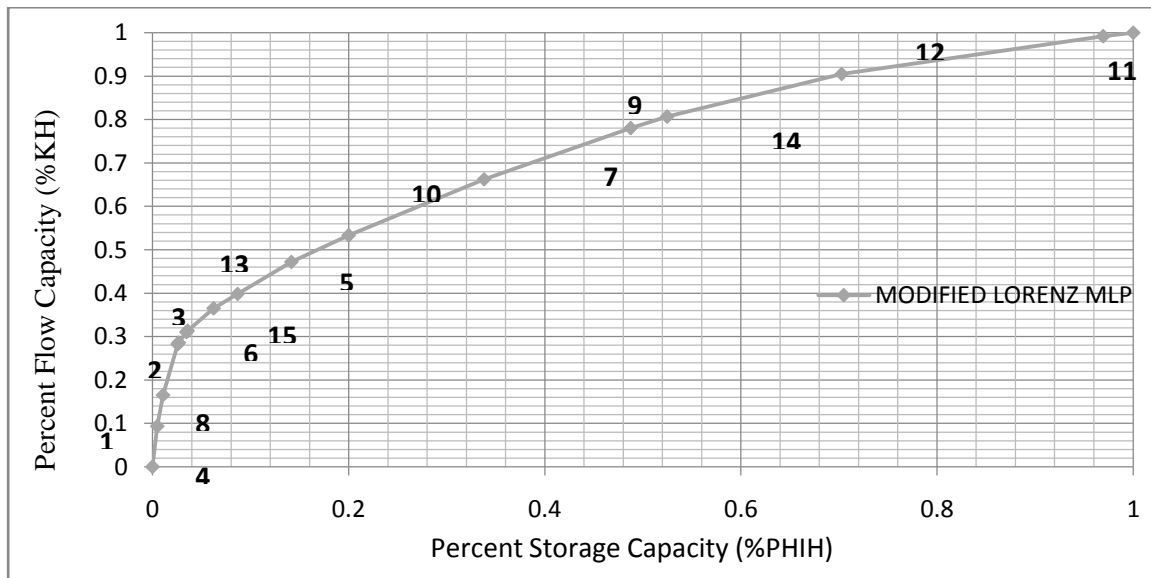

Figure 12: Well 10 Modified Lorenz Plot

Figure 13 demonstrates a plot of percent flow capacity versus percent flow capacity, for a definitive prediction of the flow unit performance. This is computed using the developed exploratory interval flow unit sorted and plotted in descending flow unit speed. In the figure, unit (1, 4) shows to be the speed zones that happen to have the highest flow unit speed (FUS) as shown in table 2. Unit (2, 3, 6) illustrates to be baffles, which happen to have high storage capacity and lower flow capacity. Finally unit (5, 7) illustrates a neither flow or storages capacity indicating a seal.
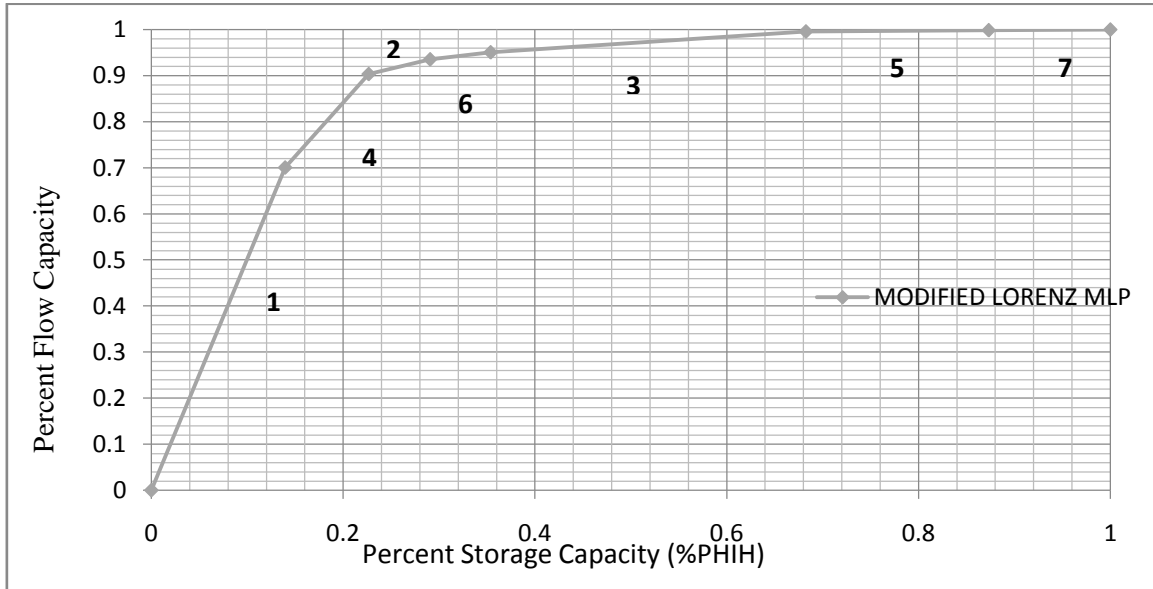
Figure 13: Well 11 Modified Lorenz Plot

Figure 14 demonstrates a plot of percent flow capacity versus percent flow capacity, for a definitive prediction of the flow unit performance. This is computed using the developed exploratory interval flow unit sorted and plotted in descending flow unit speed. In the figure, unit (5, 6, 4, 2, 8 shows to be the speed zones that happen to have the highest flow unit speed (FUS) as shown in table 3. Unit (10) illustrates to be baffles, which happen to have high storage capacity and lower flow capacity. Finally unit (7, 1, 3) illustrates a neither flow or storages capacity indicating a seal.
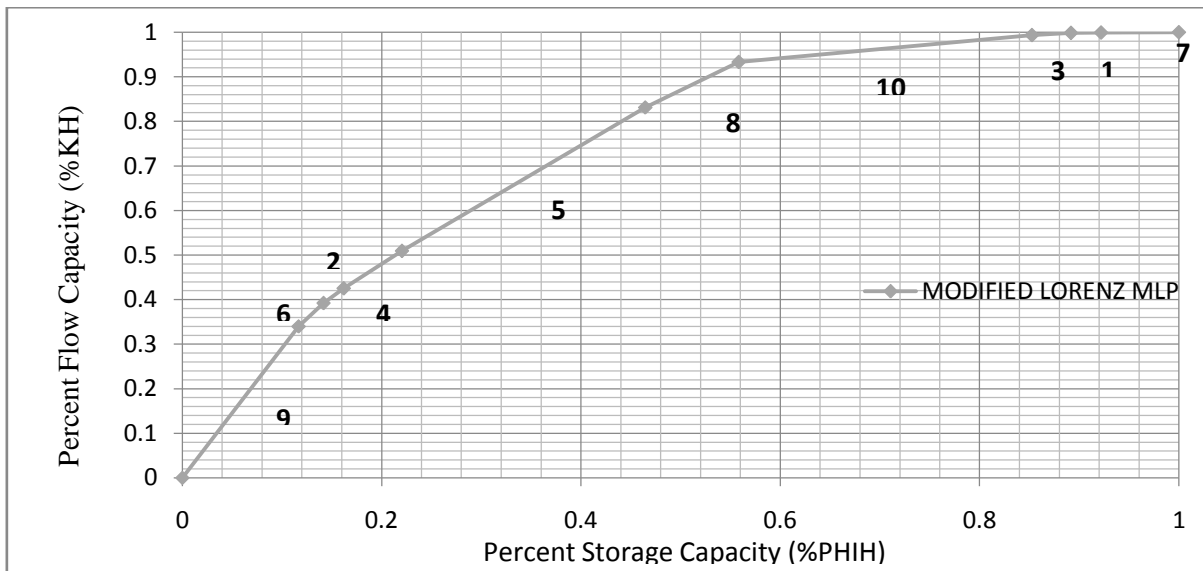

Figure 14: Well 12 Modified Lorenz Plot

Figure 15 demonstrates a plot of percent flow capacity versus percent flow capacity, for a definitive prediction of the flow unit performance. This is computed using the developed exploratory interval flow unit sorted and plotted in descending flow unit speed. In the figure unit (4, 7, 11, 12) shows to be the speed zones that happen to have the highest flow unit speed (FUS) as shown in table 4. Unit (6, 3, 10, 1, 2) illustrates to be baffles, which happen to have high storage capacity and lower flow capacity. Finally, unit (8, 9) illustrates a neither flow or storages capacity indicating a seal.
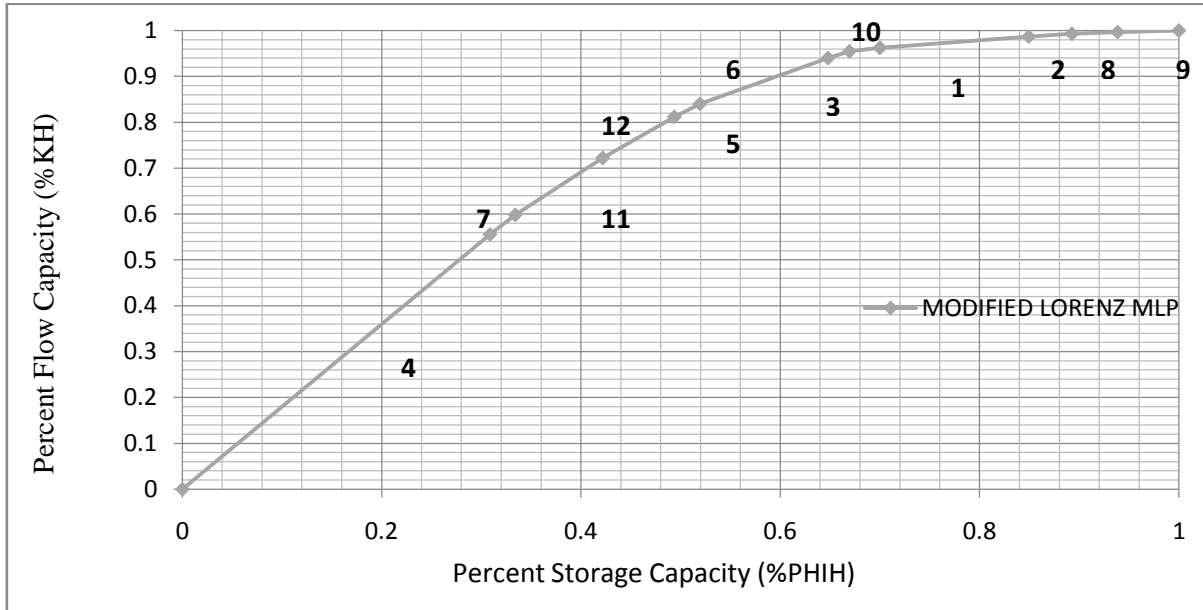
Figure 15: Well 13 Modified Lorenz Plot

E. WELLS CORRELATION WITH TECHNIQUES

Fig 16 shows well correlation, created using tech-log. This figure illustrates zones classification based on GR reading indicating shale and sand stone zone with correlation to Winland R35 method, FZI and DRT. This figure indicates 9 unit zones in this well having zone (2, 4, 5, 6, 8) are sand stone and proven to be a productive zones with relation to low Gamma ray and relatively high range of DRT, FZI and winland R35 that has better quality of fluids flow in the pore spaces of the reservoir rock. While zone (1, 3, 7, 9) are shale zones, in relation to relatively high gamma ray and know as barriers (seals).
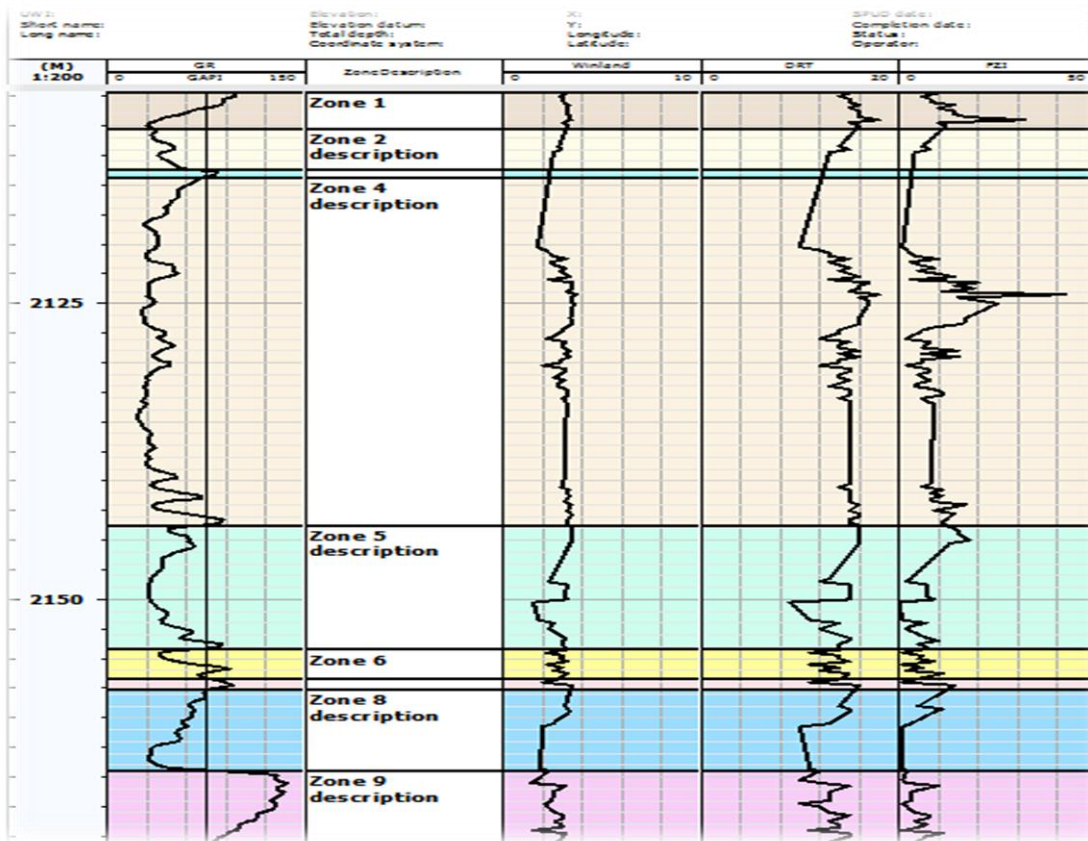

Figure 16: Well 10 Correlation with Techniques

Fig 17 shows well correlation, created using tech-log. This figure illustrates zones classification based on GR reading indicating shale and sand stone zone with correlation to Winland R35 method, FZI and DRT. This figure indicates 9 unit zones in this well having zone (1, 3, 5, 7) are sand stone and proven to be a productive zone with relation to low Gamma ray and relatively high range of DRT, FZI and winland R35 that has better quality of fluids flow in the pore spaces of the reservoir rock. While zone (2, 4, 6, 8, 9) are shale zones, in relation to relatively high gamma ray and know as barriers (seals).
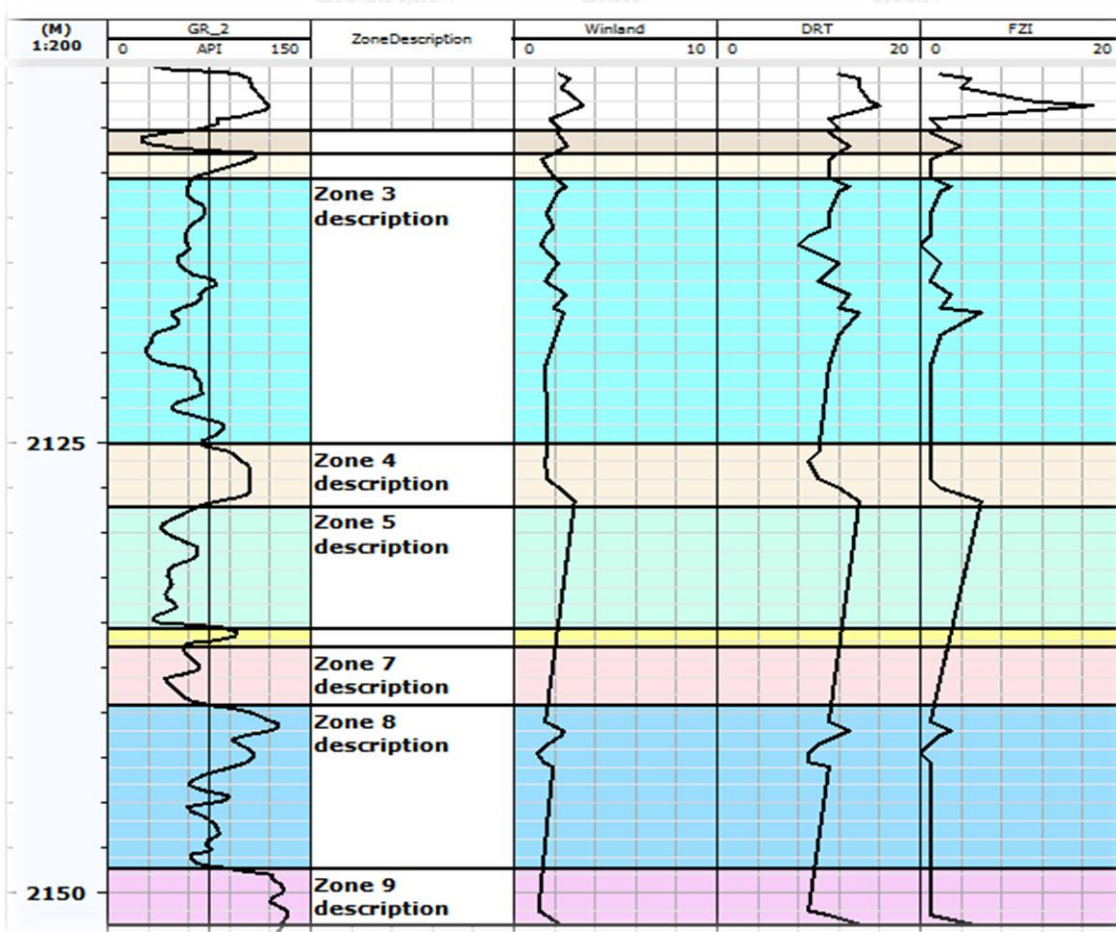

Figure 17: Well 11 Correlation with Techniques

Fig 18 shows well correlation, created using tech-log. This figure illustrates zones classification based on GR reading indicating shale and sand stone zone with correlation to Winland R35 method, FZI and DRT. This figure indicates 13 unit zones in this well having zone (1, 3, 5, 7, 9, 11, 13) are sand stone and proven to be a productive zones with relation to low Gamma ray and relatively high range of DRT, FZI and winland R35 that has better quality of fluids flow in the pore spaces of the reservoir rock. While zone (2, 4, 6, 8, 10, 12) are shale zones, in relation to relatively high gamma ray and know as barriers (seals).
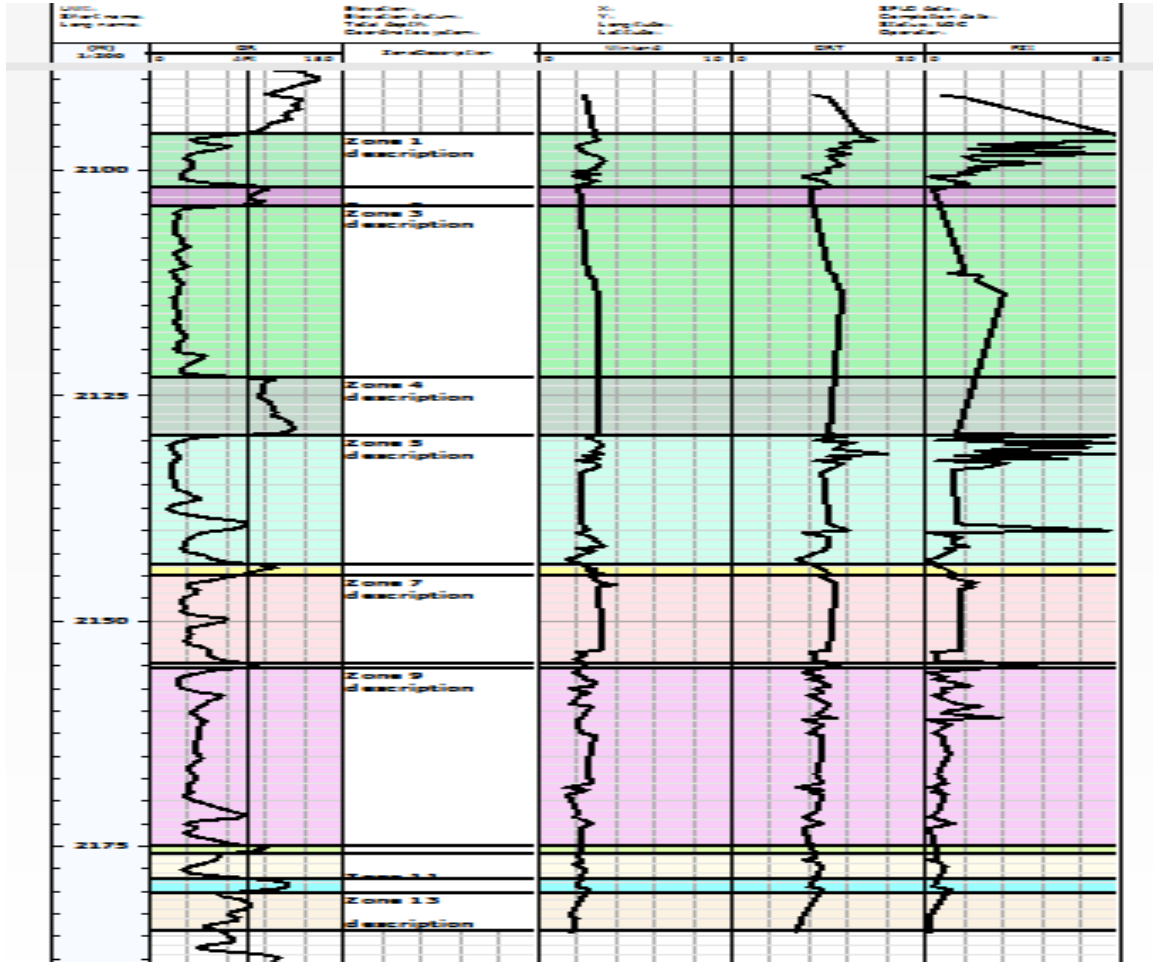
Figure 18: Well 12 Correlation with Techniques

Fig 19 shows well correlation, created using tech-log. This figure illustrates zones classification based on GR reading indicating shale and sand stone zone with correlation to Winland R35 method, FZI and DRT. This figure indicates 10 unit zones in this well having zone (2, 4, 6, 8, 10) are sand stone and proven to be a productive zones with relation to low Gamma ray and relatively high range of DRT, FZI and winland R35 that has better quality of fluids flow in the pore spaces of the reservoir rock. While zone (1, 3, 5, 7, 9) are shale zones, in relation to relatively high gamma ray and know as barriers (seals).
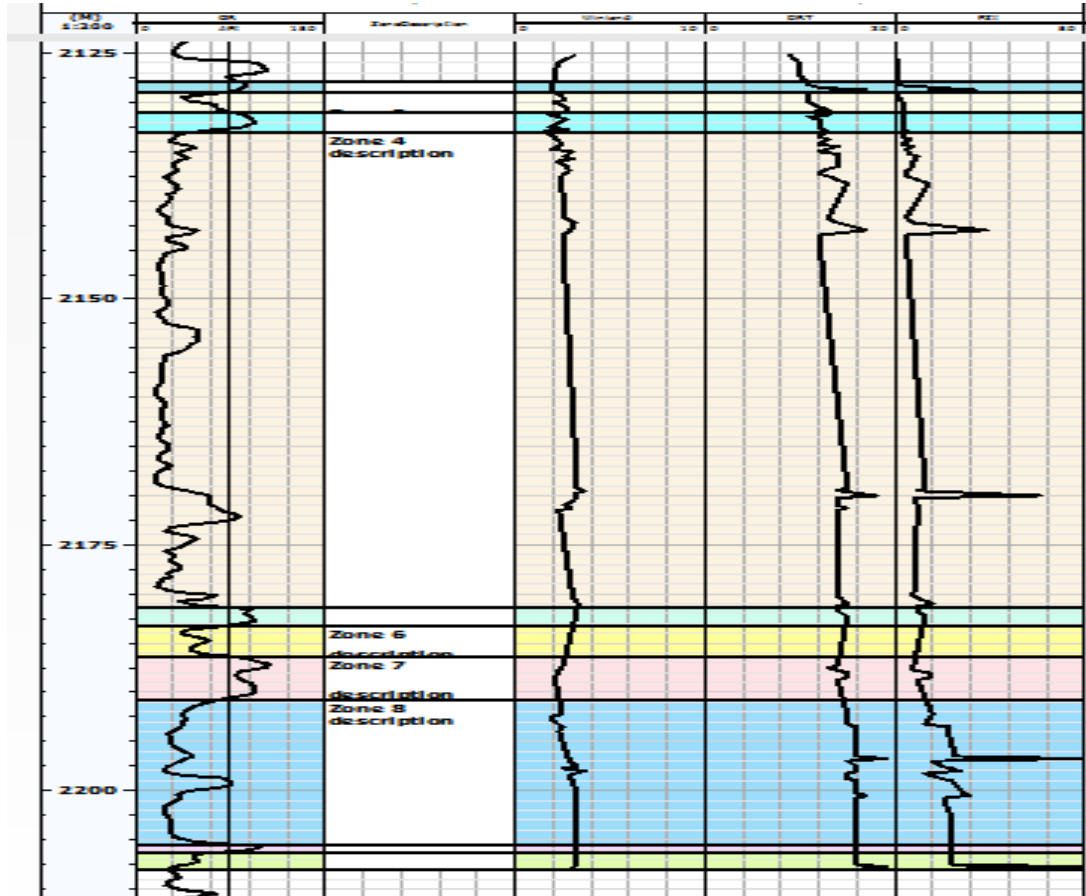
Figure 19: Well 13 Correlation with Techniques

V. CONCLUSION

Reservoir characterization is the first time step before any field development or any enhanced recovery project; efficient reservoir characterization provides a comprehensive description of the entire reservoir, which minimizes the failure of enhanced oil recovery and secondary recovery. The most common approaches for characterizing reservoir and analysing the reservoir rock type and flow units characterization were investigated in this research for a heterogeneous reservoir; including Flow Zone Indicator, Discrete Rock Type, and winland R35 method, storage capacity, flow capacity, stratigraphic flow profile (SFP), stratigraphic modified Lorenz plot (SMLP) and modified Lorenz plot (MLP). In accordance to the result the methods characterize the reservoir flows units, rock types, potential productive zones and barriers because it integrates and acknowledges various parameter that are regularly omitted. The geologic method is a major improvement over determining rock types and flow zone to identify barriers and potential productive zones; which provides a good image about the reservoir and creates a better descriptive reservoir model that can be applicable to any reservoir simulation.

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Table 3: Well 12 Flow Unit Speed

No. of Units	FUS	DKH	▢ PhiH
9	2.9164	0.3401	0.1166
6	2.0803	0.0519	0.0249
4	1.6234	0.0330	0.0203
2	1.4453	0.0843	0.0583
5	1.3200	0.3222	0.2441
8	1.0818	0.1016	0.0939
10	0.2048	0.0602	0.2942
3	0.1292	0.0050	0.0391
1	0.0260	0.0007	0.0301
7	0.0069	0.0005	0.0781

Table 1: Well 10 Flow Unit Speed

NO. of Units	FUS	DKH	▢ PhiH
4	18.8111	0.0937	0.0049
1	12.4940	0.0718	0.0057
8	7.7833	0.1168	0.0150
2	3.1653	0.0034	0.0011
6	3.1272	0.0244	0.0078
3	2.6098	0.0029	0.0011
15	1.9455	0.0517	0.0266
13	1.3700	0.0333	0.0243
5	1.3382	0.0736	0.0550
10	1.0436	0.0608	0.0582
7	0.9380	0.1293	0.1379
9	0.7874	0.1176	0.1494
14	0.7052	0.0263	0.0373
12	0.5538	0.0984	0.1777
16	0.3244	0.0865	0.2667
11	0.2792	0.0085	0.0306

Table 4: Well 13 Flow Unit Speed

No. of Units	FUS	DKH	▢ PhiH
4	1.8000	0.5557	0.3087
7	1.6726	0.0422	0.0252
11	1.4164	0.1243	0.0877
12	1.2400	0.0892	0.0720
5	1.1269	0.0289	0.0256
6	0.7752	0.0996	0.1285
3	0.6805	0.0144	0.0212
10	0.2438	0.0074	0.0306
1	0.1671	0.0249	0.1493
2	0.1303	0.0056	0.0434
8	0.0859	0.0039	0.0460
9	0.0527	0.0032	0.0613

Table 2: Well 11 Flow Unit Speed

No. of Units	FUS	DKH	▢ PhiH
1	5.0148	0.7003	0.1396
4	2.3300	0.2030	0.0871
2	0.5031	0.0321	0.0638
6	0.2402	0.0151	0.0632
3	0.1375	0.0452	0.3288
5	0.0133	0.0025	0.1904
7	0.0118	0.0015	0.1268