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# PETROPHYSICAL EVALUATION FOR DEVELOPMENT OF A MARGINAL OIL FIELD IN THE ONSHORE NIGER DELTA, NIGERIA

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## ABSTRACT

*Petrophysical evaluation was conducted on an onshore marginal field in Niger Delta with the aim of evaluating the rock and fluid properties to boost hydrocarbon production in the field. Five well logs suite from five wells and core log data for two wells were utilized for this study. Petrophysical properties evaluated included; porosity, net to gross, formation factor, irreducible water saturation, permeability, water saturation, hydrocarbon saturation and pay thickness. The well logs suite contained the following logs: Gamma ray log for lithology identification; Resistivity log for fluid type discrimination and determination of water saturation; Density log for porosity determination; and Neutron log in combination with density log for hydrocarbon types. A total of seven reservoir sands (, Sand A, B, C, D, E, F and G) were identified and correlated across all five wells on the basis of gamma ray and resistivity log motifs. The reservoir gross thicknesses ranged from 62.55 to 228.50 ft, shale volume from 7.0 to 24.60%, net to gross from 0.76 to 0.93%, effective porosity from 20.78 to 26.22%, water saturation from 35.80 to 62.30% and permeability ranged from 545.94 to 2821.97 mD. This shows that the reservoirs are of good quality for hydrocarbon productionacross the field.*

**Keywords:** Petrophysics, Shale Volume,Porosity, Permeability, Reservoir,Well Logs, Hydrocarbon

## INTRODUCTION

A reservoir is one which by virtue of its porosity and permeability is capable of containing a reasonable quantity of hydrocarbon if entrapment conditions are right, and can also release hydrocarbon at a satisfactory rate when the reservoir is penetrated by a well (Etu-Efeotor, 1997).

Reservoir quality analysis is the application of available data in the description of the reservoir in terms of its cleanliness (shale volume), amount of fluid it can hold (porosity) and produce (permeability), fluid saturation (oil, gas, water), net-to-gross, etc. Reservoir quality assessment at the well scale is often accomplished through petrophysics.

Petrophysics is the study of the physical and chemical properties of rocks and their contained fluids (Canon, 2017). Defining petrophysical properties such as permeability, fluid saturation, areal extent, thickness of reservoir and porosity is very vital to the oil and gas industry. Majority of hydrocarbons produced in the Niger Delta is gotten from the accumulations in the pores of porous and permeable rock bodies. These ‘spaces’ are a function of the porosity of the rock which is a very important petrophysical parameter. Fluid saturation is how much of oil, water or gas is present in the pore spaces of the rock and is very essential to determine the distribution of fluids in the reservoir (Darling, 2005).

The porosity along with hydrocarbon saturation determines the quantity of hydrocarbon reserves enclosed in the reservoir. Thickness is also a significant petrophysical parameter in the estimation of hydrocarbon volume. In some reservoirs, the thickness of some rock beds such as shale which has almost no recoverable oil due to their low permeability must be calculated and removed from the gross thickness to get the thickness of the productive beds (Canon, 2017). Areal extent is also required in the estimation of hydrocarbon volume. It is considered as the areal extent of the reservoir and it is determined from seismic. All these show that the determination of these petrophysical parameters is a crucial process in the evaluation of hydrocarbon volume. These properties depend on a host of other properties such as the mineralogy of the rock, pore size and the nature of the fluid itself.

The objectives of the research include: the evaluation of the petrophysical properties of reservoirs in UPX field and the identification of fluid types and their saturations levels within the hydrocarbon bearing reservoirs.

The well data utilized for this study includes well header, well deviation, well logs (gamma ray, resistivity, neutron and density logs). Well headers were used to define the locations of the wells. Well Deviations were used to show the trajectory of the individual wells. Gamma ray log was used for lithology identification and correlation as well as estimating shale volume. Resistivity log was used for fluid discrimination and estimating water and hydrocarbon saturation. Density log was used for total porosity estimation. Total porosity and shale volume were used for estimating effective porosity. Permeability was calculated using water saturation, effective porosity, formation factor and irreducible water saturation. Density and Neutron logs were used in combination for discriminating between types of hydrocarbons. The software utilized for visualization and interpretation is Schlumberger Techlog.

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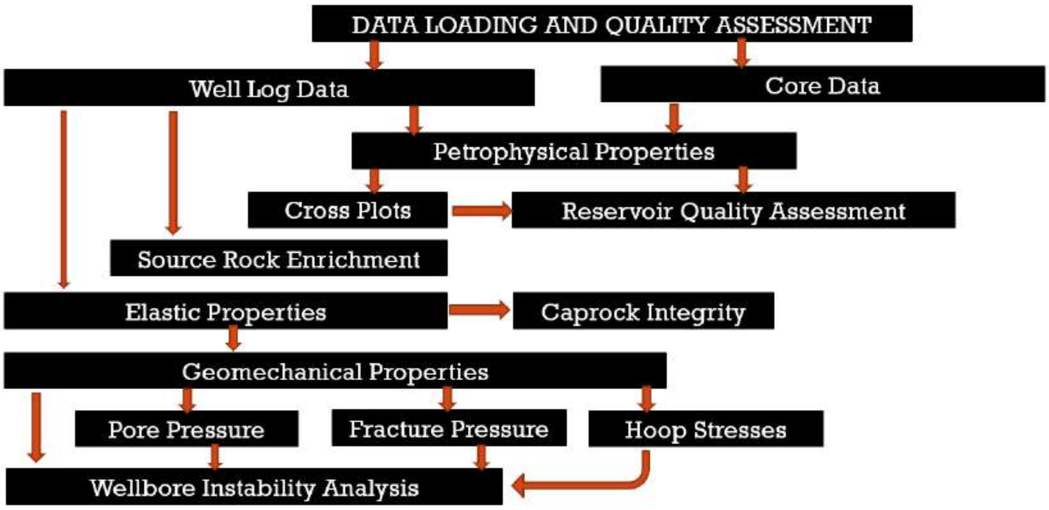


Figure 1: Methodology Flowchart adopted for formation evaluation in UPX Field

**Petrophysical Analysis**

Four main petrophysical parameters are important in defining any reservoir quality, which include: shale volume (Larinov, 1969), total and effective porosity (Dresser Atlas, 1979), Net to Gross (NTG), permeability (Owolabi et al., 1994) and water saturation ($S_w$). Various equations applicable to the Niger Delta formations were utilized for their computation and are presented as follows;

$$\mathrm{Vsh} = 0.083 \times (2^{(3.7 \times GR_{index})} - 1) \quad (1)$$

$$\mathrm{GR_{index}} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \quad (2)$$

$$\Phi t = \frac{\rho_{ma} - \rho_{log}}{\rho_{ma} - \rho_{fl}} \quad (3)$$

$$\emptyset_E = (1 - Vsh) \times \emptyset_T \quad (4)$$

$$Net - to - gross = \frac{NH}{GH} \quad (5)$$

$$S_w = \sqrt{\frac{R_o}{R_t}} \quad (6)$$

$$K(mD) = 307 + 26552(\emptyset_e^2) - 34540\ (\emptyset_e \times S_{wirr})^2 \quad (7)$$

$$S_{wirr} = \left[\frac{F}{2000}\right]^{1/2} \quad (8)$$

$$F = \frac{0.62}{\emptyset^{2.15}} \quad (9)$$

$GR_{log} = GRlogreadingofformation$

$GR_{min} = GRsandbaseline$

$GR_{max} = GR\ shale\ baseline$

$\rho ma = density\ of\ the\ rock\ matrix$

$Density\ of\ sand = (2.65g/cm^2)$

$\rho log = formation\ bulk\ density\ from\ log$

$\rho fl = Density\ of\ contained\ fluid$

$\emptyset_E = Effective\ porosity$

$\emptyset_T = Total\ Porosity$

$Vsh = Volume\ of\ shale$

$NH = Net\ thickness$

$GH = Gross\ thickness$

$S_w = water\ saturation$

$R_o = Resistivity\ of\ the\ oil\ leg$

$R_t = True\ resistivity\ reading$

$K(mD) = permeability\ in\ milliDarcy$

$S_{wirr} = irreducibe\ water\ saturation$

$F = Formation\ Factor$

## RESULTS AND DISCUSSION

Petrophysical properties (total porosity, effective porosity, water saturation and permeability) calculated using various empirical models defined within the Schlumberger Techlog environment. The results showing derived petrophysical properties for reservoir sands A, B, C, D, E, F and G are presented in Table 1.0 and summarized in Table 2.0. Figure 3.0 is a histogram plot showing the average reservoir petrophysical properties for reservoir sands identified across UPX field. Porosity and permeability results provided from special core analysis for UPX-01 and UPX-05 wells were compared with log derived porosity and permeability results obtained from empirical modelling using various equations and presented in Table 4.0 and Figures 4.0 and 5.0 respectively.

### Shale Volume

As a reservoir rock become shalier, it will be more difficult to store and produce hydrocarbons. On average, shale volumes recorded are 7.0%, 10.8%, 8.8%, 4.8%, 24.6%, 7.6% and 10.0% in Sand A, B, C, D, E, F and G reservoirs respectively (Table 2.0). High shale volume lowers the quality of a reservoir and prevents flow of hydrocarbons to a well. Generally, all reservoir sand bodies have less than 25% shale volumes (on average) which signify that there is less resistance to the flow of fluids within the reservoir rock. This shows that only a minor amount of the reservoir sands are dirty, hence, about 70% of the reservoir sands are clean and can be produced of hydrocarbon.

### Net to Gross

On average, net to gross ratio are; 93% 89%, 91% 95%, 75%, 92% and 90% in Sand A, B, C, D, E, F and G (Table 2.0).

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These results show that all identified reservoir sand packages have >70% clean sand volumes, indicating that the reservoirs are clean enough for hydrocarbon production, provided they are hydrocarbon bearing.

**Total and Effective Porosity**

On average, total porosities are 26.84%, 25.46%, 26.22%, 24.56%, 25.16%, 21.52% and 21.22% accordingly (Table 2.0). The porosity that is responsible for flow and accumulation in a reservoir is the effective porosity. The average effective porosities derived from density log are 26.22%, 24.64%, 25.8%, 24.12%, 24.68%, 21.16% and 20.78%. According to Levorsen (1967), rocks have negligible porosity when < 5%, poor porosity when >5-10%, good porosity when >10-20%, very good when >20-30%, and excellent when >30. Based on this classification scheme, the average total effective porosity recorded for all reservoir rock units in UPX field are classed as having very good porosities for hydrocarbon production. The results of effective porosity obtained from special core analysis conducted on UPX-01 (at a depth ranging from 5002.30 to 5048.60 ft) and UPX-05 (at a depth ranging from 5539.60 to 5562.20 ft) ranged from 20.40% to 22.50% and 24.41% to 27.50% respectively. Results of effective porosity obtained from density logs for UPX-01 and UPX-05 at same cored depth intervals ranged from 19.22% to 22.28% and 21.44% to 25.56% respectively. The error difference between core derived porosity and log derived porosity ranged from 0.45 to 3.23%. A plot of depth against core and log derived porosities for UPX-01 and UPX-05 wells revealed similar trends with minimum differences. The low difference between these porosity values suggests that the density tool is a very good tool for porosity determination in UPX field.

**Permeability**

The results of permeability obtained from special core analysis conducted on UPX-01 (at a depth ranging from 5002.30 to 5048.60 ft) and UPX-05 (at a depth ranging from 5539.60 to 5562.20 ft) ranged from 920.54 to 1045 mD and 4105 to 5022 mD respectively (Table 2.0). Results of log permeability obtained using Owolabi et al (1994) empirical model for UPX-01 and UPX-05 at same cored depth intervals ranged from 2895 to 6430 mD and 6223 to 8955 mD respectively. Results of log permeability obtained using Wylie and Rose (1950) empirical model for UPX-01 and UPX-05 at same cored depth intervals ranged from 853 to 1677 mD and 4098 to 5354.87 mD respectively. Results of log permeability obtained using Timur (1968) empirical model for UPX-01 and UPX-05 at same cored depth intervals ranged from 85.67 to 365.80 mD and 293.51 to 694.56 mD respectively.

A plot of depth against core and log derived permeability using various empirical models for UPX-01 and UPX-05 revealed that Owolabi's model greatly overestimated permeability values by approximately 206%, Timur's model underestimated permeability values by approximately 84%, whereas Wylie and Rose's model exceeded core permeability values by approximately 7%. Bear in mind that permeability is the most difficult reservoir property to be estimated using empirical models. Surprisingly, Wylie and Rose's empirical model gave reasonable permeability values which closely match permeability values obtained from special core analysis. Hence, Wylie and Rose's empirical model was used for determination of permeability values across UPX field.On average, the results of reservoir permeability calculated using Wylie and Rose mathematical model are 2821.97 mD, 2475.18 mD, 2405.98 mD, 1829.13 mD, 2184.7 mD, 831.09 mD and 545.94 mD for sand A, B, C, D, E, F and G. Both Levorsen (1967) and Rider (1986) classified reservoir quality based on permeability values as follows; < 10 mD (poor to fair), >10-50 mD (moderate), >50-250 mD (Good), >250-1000 mD (very good) and >1000 mD (excellent). Based on this classification scheme, reservoir Sand A, B, C, D, E, F and G are classed as having very good to excellent reservoir quality. These values are typical of Niger Delta reservoirs. Hence, fluid flow within these reservoir units will occur with ease because of the relatively high permeability values.

**Fluid saturation**

Water saturation obtained from hydrocarbon bearing reservoirs are 99.72%, 41.20%, 98.94%, 62.30%, 34.80%, 40.45% and 48.75% for Sand A, B, C, D, E, F and G accordingly. This leads to a corresponding hydrocarbon saturation of 0.28%, 58.8%, 0.6%, 37.70%, 65.20%, 59.55% and 51.25% for Sand A, B, C, D, E, F and G respectively. Sand A and sand C are predominantly water with very little or no hydrocarbons present. These hydrocarbon saturation values are good for reservoir development.

## CONCLUSION

This study has shown that the reservoir intervals evaluated in UPX fields have the necessary requirement to be termed good reservoir rocks for production. The reservoir rocks are of good to excellent quality and can be produced with minimum stress because of low shaliness, high net to gross, good to excellent effective porosity and permeability, good hydrocarbon saturation values.

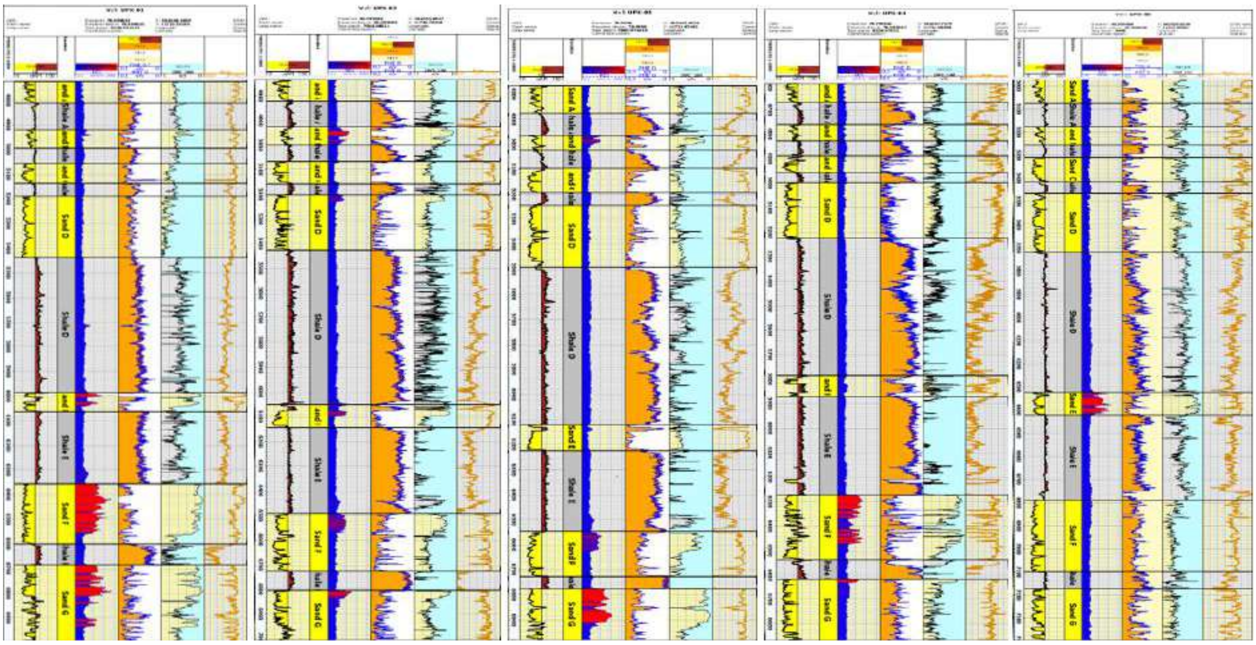

Figure 2: Results of petrophysical evaluation conducted on five wells in UPX field

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Table 1: Results of petrophysical evaluation conducted on five wells in OPX oil field

| Well | Reservoir | Top (Ft) | Base (Ft) | Gross (Ft) | Net (Ft) | NTG | Vsh (%) | Total Porosity (%) | Effective Porosity (%) | Water Saturation (%) | Permeability (mD) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| UPX-01 | Sand A | 4801.67 | 4890.51 | 88.84 | 85.80 | 0.96 | 4.00 | 25.80 | 25.20 | 99.90 | 1598.39 |
| UPX-02 | Sand A | 4801.67 | 4887.45 | 85.78 | 78.75 | 0.92 | 8.00 | 29.00 | 28.40 | 99.80 | 3356.37 |
| UPX-03 | Sand A | 4844.56 | 4954.85 | 110.29 | 100.08 | 0.91 | 9.00 | 26.20 | 25.70 | 99.50 | 1916.00 |
| UPX-04 | Sand A | 4669.94 | 4749.59 | 79.65 | 75.89 | 0.95 | 5.00 | 26.30 | 25.80 | 99.50 | 2984.63 |
| UPX-05 | Sand A | 5037.56 | 5141.72 | 104.16 | 94.44 | 0.91 | 9.00 | 26.90 | 26.00 | 99.90 | 4254.44 |
| UPX-01 | Sand B | 4997.73 | 5071.26 | 73.52 | 70.52 | 0.97 | 3.00 | 24.30 | 23.50 | 57.60 | 998.28 |
| UPX-02 | Sand B | 4991.61 | 5065.13 | 73.52 | 58.41 | 0.79 | 21.00 | 29.20 | 28.30 | 22.50 | 6530.70 |
| UPX-03 | Sand B | 5043.69 | 5101.89 | 58.21 | 53.42 | 0.92 | 8.00 | 24.80 | 24.30 | 43.50 | 1371.27 |
| UPX-04 | Sand B | 4838.43 | 4905.83 | 67.40 | 64.88 | 0.96 | 4.00 | 23.30 | 22.50 | 98.10 | 876.30 |
| UPX-05 | Sand B | 5242.81 | 5322.46 | 79.65 | 65.50 | 0.82 | 18.00 | 25.70 | 24.60 | 97.20 | 2599.36 |
| UPX-01 | Sand C | 5135.59 | 5215.24 | 79.65 | 73.65 | 0.92 | 8.00 | 22.70 | 22.30 | 97.80 | 669.76 |
| UPX-02 | Sand C | 5132.53 | 5224.43 | 91.90 | 86.16 | 0.94 | 6.00 | 28.70 | 28.30 | 99.90 | 3043.65 |
| UPX-03 | Sand C | 5175.42 | 5270.38 | 94.97 | 88.46 | 0.93 | 7.00 | 24.80 | 24.50 | 98.80 | 1456.02 |
| UPX-04 | Sand C | 4967.10 | 5037.56 | 70.46 | 62.37 | 0.89 | 11.00 | 26.70 | 26.30 | 98.70 | 2195.65 |
| UPX-05 | Sand C | 5374.54 | 5481.76 | 107.22 | 94.22 | 0.88 | 12.00 | 28.20 | 27.60 | 99.50 | 4664.83 |
| UPX-01 | Sand D | 5267.32 | 5515.46 | 248.14 | 237.32 | 0.96 | 4.00 | 20.40 | 20.00 | 99.30 | 289.27 |
| UPX-02 | Sand D | 5267.32 | 5490.95 | 223.63 | 213.76 | 0.96 | 4.00 | 25.20 | 24.80 | 62.30 | 1278.47 |
| UPX-03 | Sand D | 5322.46 | 5570.60 | 248.14 | 239.74 | 0.97 | 3.00 | 24.40 | 24.00 | 99.90 | 1039.32 |
| UPX-04 | Sand D | 5077.38 | 5304.08 | 226.70 | 220.45 | 0.97 | 3.00 | 25.30 | 25.00 | 98.80 | 1547.22 |
| UPX-05 | Sand D | 5530.78 | 5785.04 | 254.27 | 228.27 | 0.90 | 10.00 | 27.50 | 26.80 | 98.20 | 4991.36 |
| UPX-01 | Sand E | 6063.82 | 6143.47 | 79.65 | 56.50 | 0.71 | 29.00 | 29.80 | 29.30 | 33.60 | 6534.36 |
| UPX-02 | Sand E | 6115.90 | 6210.87 | 94.97 | 77.27 | 0.81 | 19.00 | 26.10 | 25.70 | 51.70 | 1520.13 |
| UPX-03 | Sand E | 6198.61 | 6302.77 | 104.16 | 87.42 | 0.84 | 16.00 | 26.40 | 26.20 | 99.70 | 1734.79 |
| UPX-04 | Sand E | 5864.69 | 5950.47 | 85.78 | 44.19 | 0.52 | 48.00 | 21.40 | 20.80 | 99.10 | 542.24 |
| UPX-05 | Sand E | 6388.55 | 6486.58 | 98.03 | 87.00 | 0.89 | 11.00 | 22.10 | 21.40 | 19.10 | 592.00 |
| UPX-01 | Sand F | 6434.50 | 6679.58 | 245.08 | 230.00 | 0.94 | 6.00 | 25.00 | 24.70 | 22.30 | 2067.26 |
| UPX-02 | Sand F | 6557.04 | 6792.92 | 235.89 | 221.37 | 0.94 | 6.00 | 22.60 | 22.20 | 55.30 | 762.07 |
| UPX-03 | Sand F | 6624.43 | 6805.18 | 180.75 | 168.59 | 0.93 | 7.00 | 18.90 | 18.60 | 51.40 | 236.35 |
| UPX-04 | Sand F | 6351.78 | 6615.24 | 263.46 | 220.65 | 0.84 | 16.00 | 21.40 | 21.00 | 32.80 | 680.09 |
| UPX-05 | Sand F | 6854.19 | 7163.60 | 309.41 | 301.91 | 0.97 | 3.00 | 19.70 | 19.30 | 99.40 | 409.68 |
| UPX-01 | Sand G | 6762.29 | 7126.84 | 364.55 | 306.15 | 0.84 | 16.00 | 23.00 | 22.40 | 37.90 | 775.83 |
| UPX-02 | Sand G | 6869.51 | 7077.82 | 208.31 | 181.48 | 0.87 | 13.00 | 22.40 | 22.00 | 56.90 | 687.85 |
| UPX-03 | Sand G | 6854.19 | 7059.44 | 205.25 | 190.63 | 0.93 | 7.00 | 22.30 | 21.90 | 30.80 | 588.33 |
| UPX-04 | Sand G | 6694.89 | 6952.22 | 257.33 | 248.83 | 0.97 | 3.00 | 17.90 | 17.70 | 69.40 | 265.70 |
| UPX-05 | Sand G | 7237.13 | 7460.76 | 223.63 | 200.00 | 0.89 | 11.00 | 20.50 | 19.90 | 99.10 | 412.01 |

Table 2: Average petrophysical properties for reservoir rocks in UPX field

| Reservoir Interval | Gross (Ft) | Net (Ft) | NTG (Ft) | Vsh (%) | Total Porosity (%) | Effective Porosity (%) | Sw (%) | Permeability (mD) |
|---|---|---|---|---|---|---|---|---|
| Sand A | 93.74 | 86.99 | 0.93 | 7.00 | 26.84 | 26.22 | 99.72 | 2821.97 |
| Sand B | 70.46 | 62.55 | 0.89 | 10.80 | 25.46 | 24.64 | 41.20 | 2475.18 |
| Sand C | 88.84 | 80.97 | 0.91 | 8.80 | 26.22 | 25.80 | 98.94 | 2405.98 |
| Sand D | 240.18 | 227.91 | 0.95 | 4.80 | 24.56 | 24.12 | 62.30 | 1829.13 |
| Sand E | 92.52 | 70.48 | 0.75 | 24.60 | 25.16 | 24.68 | 34.80 | 2184.70 |
| Sand F | 246.91 | 228.50 | 0.92 | 7.60 | 21.52 | 21.16 | 40.45 | 831.09 |
| Sand G | 251.82 | 225.42 | 0.90 | 10.00 | 21.22 | 20.78 | 48.75 | 545.94 |

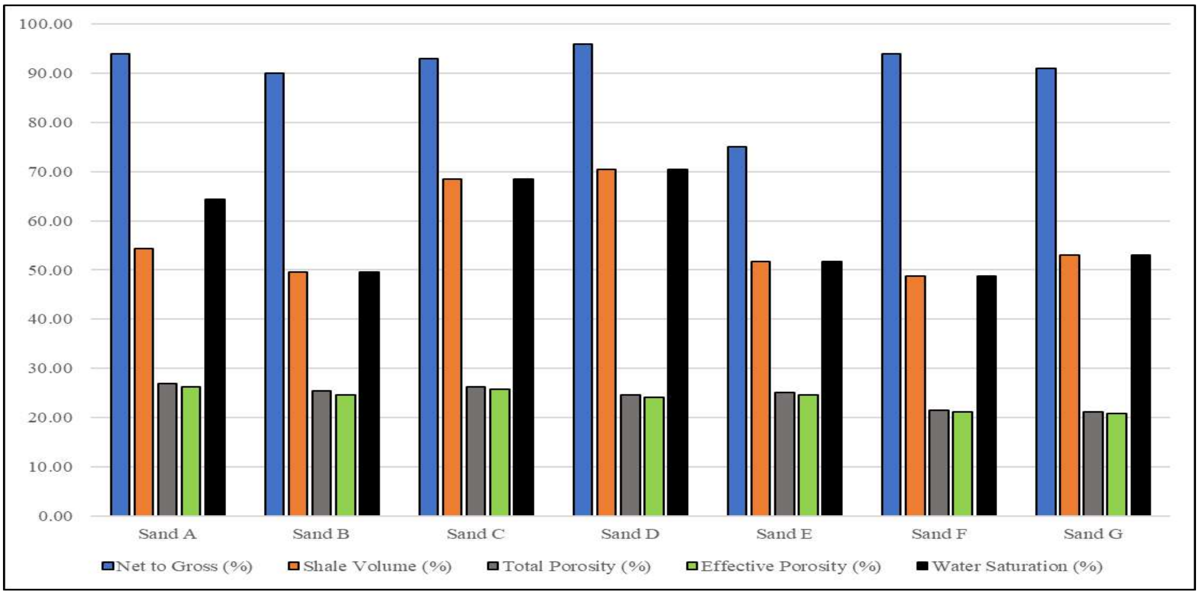


Figure 3: Histogram plot showing reservoir petrophysical properties across UPX field

Table 3: Results of routine core analysis compared with log analysis using empirical models

| Well | Depth (m) | Core Effective Porosity (%) | Well log Effective Porosity (%) | Core Permeability (mD) | Permeability (Owolabi et al, 1994) | Permeability (Wylie and Rose, 1950) | Permeability (Timur, 1968) |
|---|---|---|---|---|---|---|---|
| UPX-01 | 5002.30 | 21.40 | 20.34 | 1023.43 | 6430.00 | 1387.00 | 325.40 |
| UPX-01 | 5008.40 | 22.30 | 21.55 | 1050.66 | 5920.00 | 1677.00 | 223.67 |
| UPX-01 | 5011.60 | 22.50 | 22.28 | 920.54 | 3986.00 | 853.00 | 114.65 |
| UPX-01 | 5023.40 | 20.40 | 19.22 | 1045.00 | 3548.00 | 1137.00 | 365.80 |
| UPX-01 | 5034.80 | 21.80 | 20.67 | 935.54 | 2895.00 | 1020.00 | 85.67 |
| UPX-01 | 5048.60 | 20.66 | 20.12 | 1034.60 | 4043.41 | 1022.00 | 169.87 |
| UPX-05 | 5539.60 | 25.56 | 24.56 | 5022.00 | 8435.00 | 4098.00 | 694.56 |
| UPX-05 | 5543.30 | 24.67 | 21.44 | 4830.20 | 6223.00 | 4558.00 | 449.56 |
| UPX-05 | 5549.50 | 26.22 | 24.89 | 4453.60 | 8130.00 | 4128.00 | 613.65 |
| UPX-05 | 5553.40 | 27.50 | 25.56 | 4105.00 | 7940.00 | 4562.00 | 445.87 |
| UPX-05 | 5558.70 | 24.41 | 24.86 | 4645.55 | 8955.00 | 4362.00 | 329.40 |
| UPX-05 | 5562.20 | 25.92 | 24.76 | 5160.00 | 7320.00 | 5354.87 | 293.51 |

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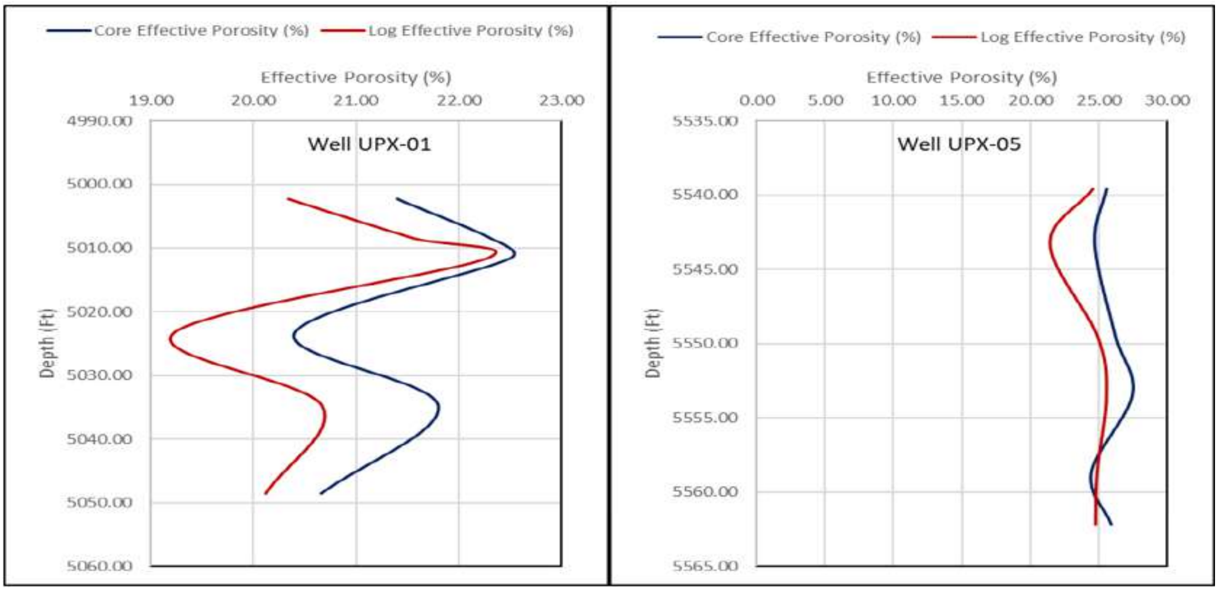


Figure 4: Results of core derived porosity vs density log porosity for UPX-01 and UPX-05 wells

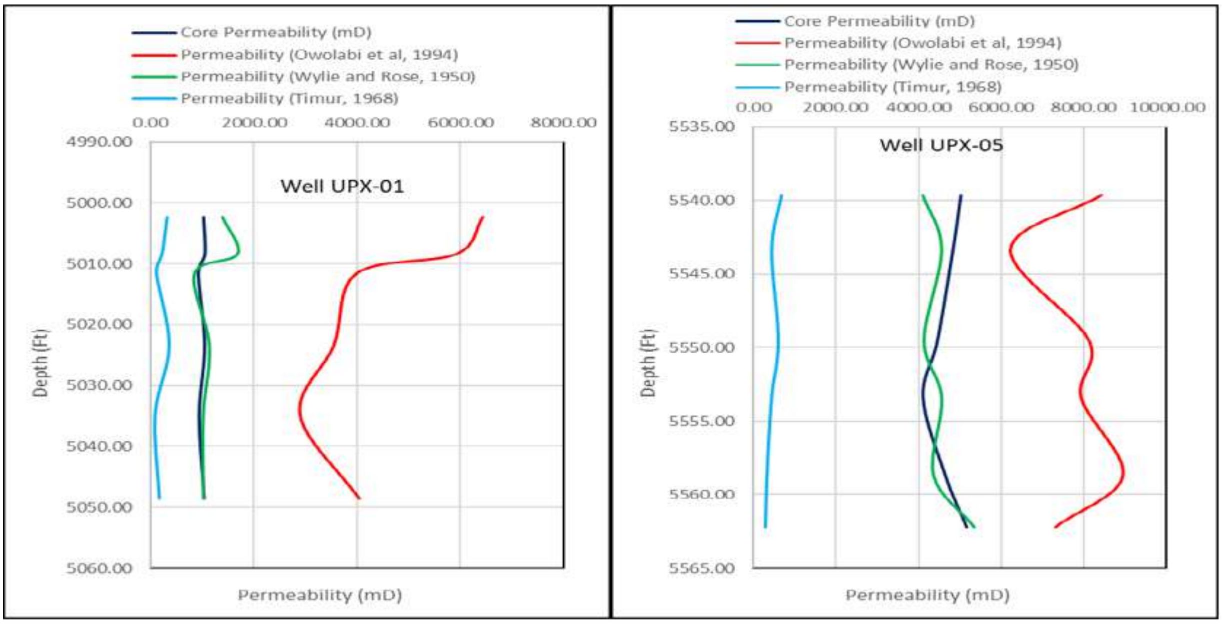


Figure 5: Results of core permeability versus log permeability for UPX-01 and UPX-05 wells

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