# Reservoir Characterization of the Pre-Cenomainian Sandstone: Central Sinai, Egypt

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*Abstract*

Fifty-one sandstone core samples obtained from wadi Saal area. They are belonging to the Pre-Cenomanian age. These samples were subjected to various laboratory measurements such as: density, porosity, permeability, electrical resistivity, grain size analysis and ultrasonic wave velocity. The parameters describing reservoir properties are outlined. Packing index, reservoir quality index, flow zone indicator and pore throat radius (R35 and R36) were calculated. The obtained interrelationships among these parameters allowing to improve petrophysical knowledge about the Pre-Cenomanian reservoir information. The obtained rock physics models could be employed with some precautions to the subsurface existences of the Pre-Cenomanian sandstone reservoirs especially in the surrounding areas.

*Keywords: reservoir, sandstone, porosity, permeability, Egypt*

## Introduction

Wadi Saal area is in Central Sinai Peninsula at 4 km northeastern Sant Katrine religion compound. The petrophysical properties stratigraphy and bio-facies of the Paleozoic rocks in Sinai have been studied by different authors as [1-5] and others. It is subdivided in central Sinai into four zones from basement upward as: a- Araba Formation (Carboniferous). b- Naqus Formation (Cambrian – Early Carboniferous). c- Durba Formation (Early Carboniferous), and d- Ataqa Formation (Early Carboniferous). They consist of mainly sandstones sometimes intercalated with shale. The environments of deposition of these deposits especially in Wadi Saal are mainly fluvial distributary mouth bar, channels, and barrier island rock types [4] The X-ray diffraction analysis of the bulk sample side by side with SEM reveals that the whole clay types presented in Wadi Saal sandstone are only Kaolinite appeared as pore lining and pore filling [5].

## Methodology

Rock density, porosity and permeability were measured [6-8] in petrophysical laboratory of Ain Shams University (PRU). Porosity is measured using matrix cup Helium Porosimeter. Gas permeability is measured using Ruska gas permeameter. Electrical resistivity has been performed using the Universal bridge (TF-2700).

## Results and Discussion

### Porosity Vertical Profile

The porosity value changes 26.2% up to 35.44% across the studied section. The highest values are recorded at 18m; 33m; 43.5m; and 90m from the sea level (Fig. 1). The porosity lowest values (15.17%, 16.21%and 16.45%) are recorded at 36m, 104m and 6.0m from sea level respectively due to the occurrence of kaolinite clay as pore filling sandstone. Porosity vertical profile displays increasing up to 43.5m and decreasing up to 142m. This behavior indicates two depositional cycles.

### Permeability Vertical Profile

The vertical profile of permeability (Fig. 2) is generally in consistence with the porosity profile. The permeability highest values (1291.09µm$^2$; 3272.74µm$^2$; 5289.42µm$^2$ and 2861.93µm$^2$) are located at 8m,24.5m, 33m and 145m respectively. The permeability of the studied samples has a wide range from 0.11µm$^2$ up to 5289. 42µm$^2$.The permeability profile displays two depositional periods as indicated from porosity behavior. The first cycle started from the base of the section up to 36 m wherever the second depositional cycle started. This behavior can utilize in understanding zonation of the subsurface occurrences of the oil producing Pre-Cenomanian sandstone deposits in the Gulf of Suez area.

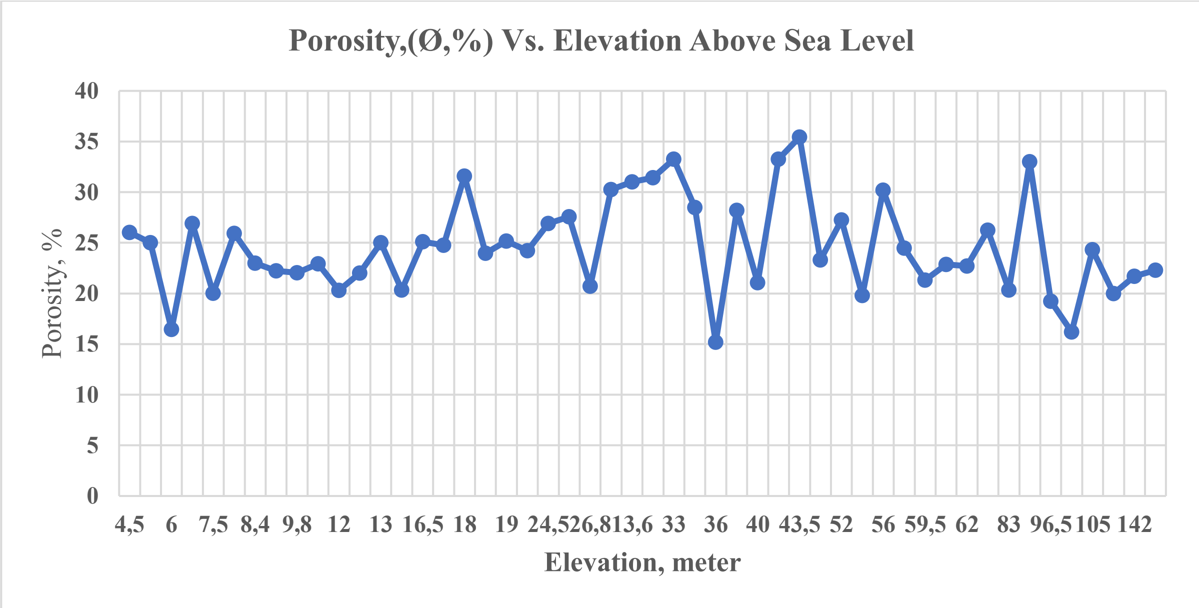


Fig. 1. Porosity vertical Profile

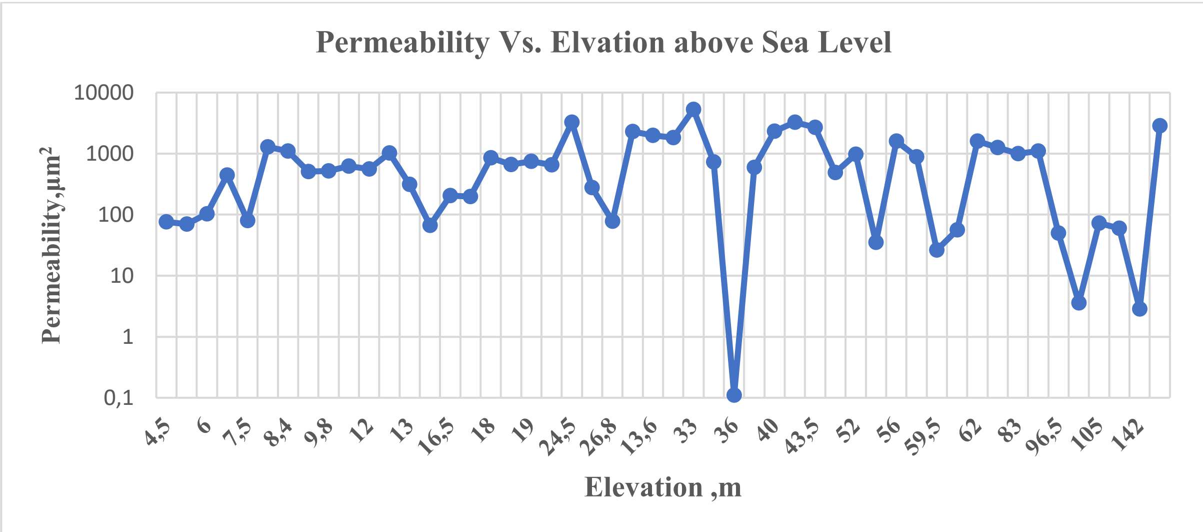


Fig. 2. Permeability Vertical Profile

**Formation Factor-Porosity Relation**

The formation factor -porosity relations (Fig. 3) show two linear trends measured at two brine concentrations (Rw1= 2.0 ohm.m. and 0.20 ohm.m.) each of which is controlled with a regression line equation as.

$$F1 = 6.3561Ø - 1.067 \quad , \quad R^2 = 0.2814 \quad (1)$$

$$F2 = 12.939Ø - 0.737 \quad , \quad R^2 = 0.436 \quad (2)$$

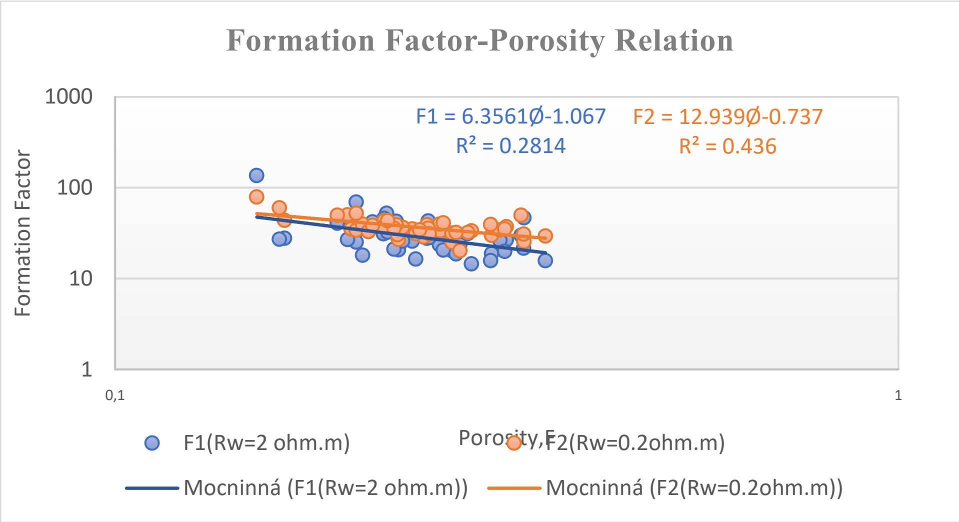


Fig. 3. Formation Factor – Porosity Relation

Eq. (1&2) are characterizing by fair coefficient of correlation ($R^2 = 0.28$ and 0.44) for the first and second brine concentration respectively. The calculated cementation exponents (m- value) in both concentrations is lower than that of the Archie's equation. This is most likely due to the high porosity and permeability values (Ø = 35.55% and K = 5289.42μm$^2$).

**R35 (Winland) Versus R36 (El Sayed)**

The Calculated Winland - R35 [9] is plotted against R36 [10] in Fig. 4. It displays negligible differences in the pore throat radius although to calculate R35 you need both porosity and permeability data. In contrast R36 calculation only needs either porosity (Ø) or permeability (K) as the following equations:

$$Log\, r35 = 0.732 + 0.588\, Log\, Kair - 0.864\, Log\, Ø \qquad Winland \qquad (3)$$

where r35 is the pore aperture radius corresponding to the 35th percentile, $K_{air}$ is uncorrected air permeability (md), and Ø is porosity (%).

$$r36 = 466.82\, e\, 0.193\, Ø \qquad El\ Sayed\ and\ El\ sayed\ (2021) \quad from\ Ø \qquad (4)$$
$$r36 = 2277.5\, K0.542 \qquad El\ Sayed\ and\ El\ sayed\ (2021) \quad from\ K \qquad (5)$$

where r36 in A° (Angstrom), porosity (Ø in %) and K is uncorrected air permeability (mD).

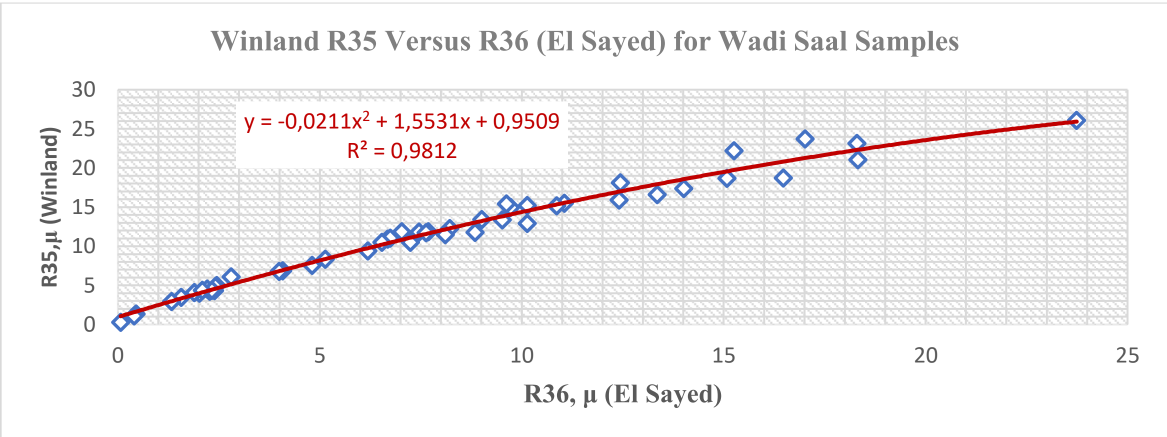


Fig. 4. Pore Radius R35 Versus R36 Relationship

Fig. 4, displays a polynomial relationship characterizing by a very high coefficient of correlation ($R^2$= 0.98) and controlling by the following equation:

$$R35 = -0.0211 R36^2 + 1.5531 R36 + 0.9509 \qquad , R^2 = 0.9812 \qquad (6)$$

The high coefficient of correlation of equation (6) allows to calculate R35 from R36 and vice versa with high accuracy. The pore throat radius (R35 & R36) of the Pre-Cenomanian sandstone in Wadi Saal area are ranged as (0.0 up to > 25 μm). Both give a complete agreement that Pre-Cenomanian sandstone reservoirs have a pore aperture size < 0.5 μm (5000 A°) are fluid dry (at elevation 36m; 104m and 142m) and not producing even they were in a charged interval. It means that the Pre-Cenomanian sandstone in its subsurface occurrences have a great opportunity to be a fluid producing (Fig. 5).

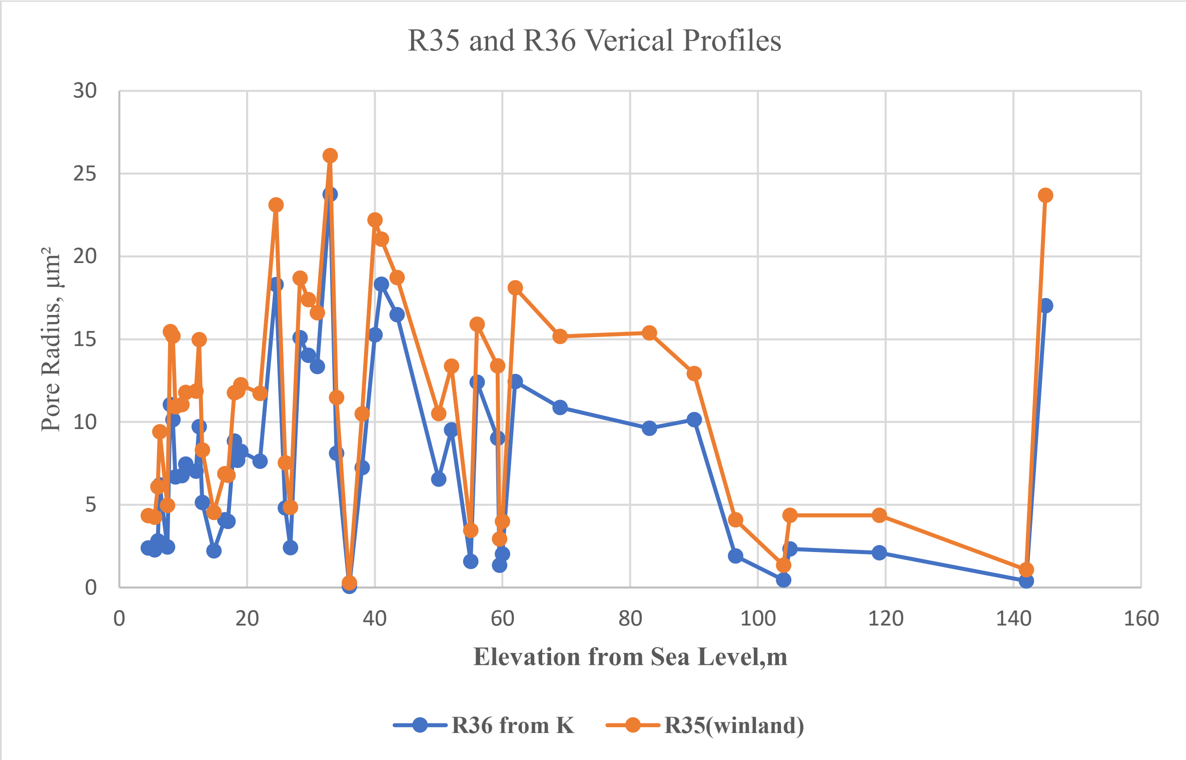


Fig. 5. Pore Throat Radius (R35&R36) Vs. Elevation from S.L., m.

**R36 Versus RQI, FZI, AND HT**

The pore throat radius R36 is plotted (Fig. 6) against three important reservoir parameters as reservoir quality index (RQI), fluid zone indicator (FZI) and Tiab flow unit characterization factor (HT). The reservoir quality index is firstly defined by [11] as:

$$RQI = 0.0314 \sqrt{k} / \text{Ø} \quad (7)$$

If permeability (K) is expressed in millidarcies and porosity (Ø) as a fraction, then RQI is expressed in micrometers or µm. The reservoir flow zone indicator (FZI) is calculated from RQI and $Ø_z$ as:

$$log\ (RQI) = log\ (\text{Ø}\ z) + log\ (FZI) \quad (8)$$

where Ø z is the ratio of pore volume to grain volume:

$$\text{Ø}\ z = \text{Ø} / 1 - \text{Ø} \quad (9)$$

The FZI is a unique parameter that includes the geological attributes of the texture and mineralogy in the structure of distinct pore geometrical facies.

The Tiab flow unit characterization factor HT [12] clearly combines all the petrophysical and geological properties and assessed from equation:

$$HT = 1 / FZI2 \quad (10)$$

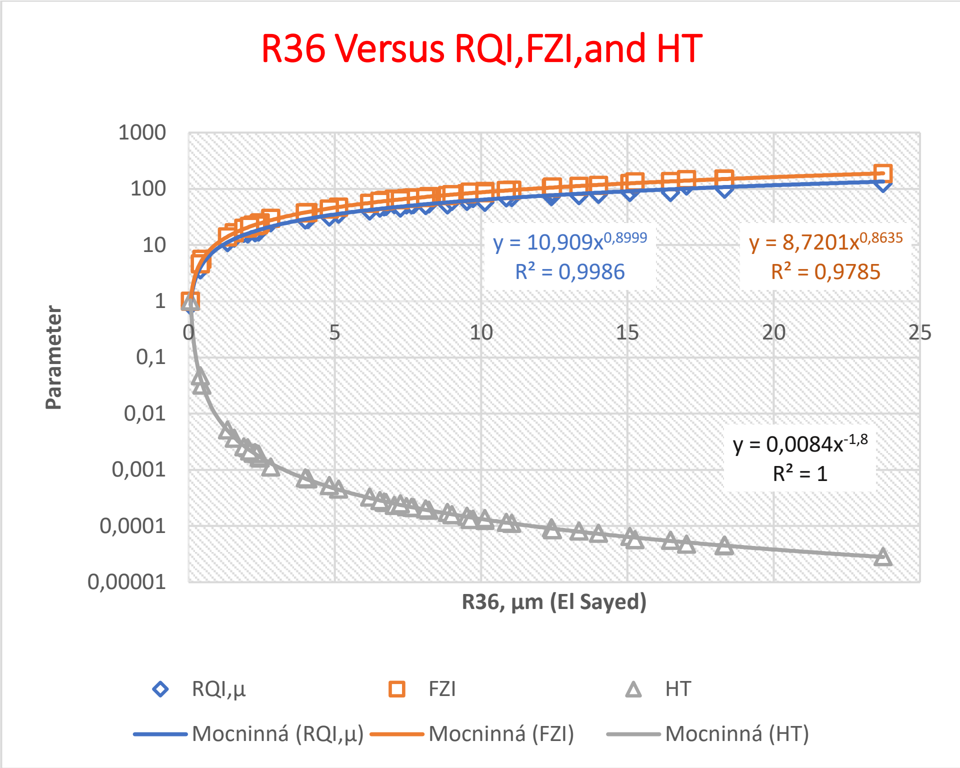

Fig. 6. R36 Versus RQI, FZI AND HT

The relationships (Fig. 6) among R36 and RQI, FZI and HT are characterizing by very high close coefficients of correlation ($R^2$ = 0.9986, 0.9785 and 1.0) respectively. Both RQI and FZI have positive linear trend with R36, while HT has negative trend. The high coefficients of correlation obtained allow calculation of RQI, FZI and HT from R36 with very high accuracy and vice versa by using the following equations:

$$RQI = 10.909\,(R36)^{0.8999} \quad , \quad R^2 = 0.9986 \qquad (11)$$

$$FZI = 8.7201\,(R36)^{0.8635} \quad , R^2 = 0.9785 \qquad (12)$$

$$HT = 0.0084\,(R36)^{-1.8} \quad R^2 = 1 \qquad (13)$$

**R36 Versus Swi**

The irreducible water saturation (Swi) is estimated by using [12] equations (14&15):

$$RQI = 3.14\,(FFI/Ø - FFI).\sqrt{Ø3} \qquad (14)$$

$$FFI = Ø\,(1 - Swi) \qquad (15)$$

Where FFI is the free fluid index.

Fig. 7 exhibits the relationship between R36 and Swi. The exponential relationship is characterized by a very high coefficient of correlation ($R^2$ = 0.9942) permits Swi calculation from the R36 according to the equation:

$$R36 = 91.071e^{-57.49\,Swi} \quad , R^2 = 0.9942 \qquad (16)$$

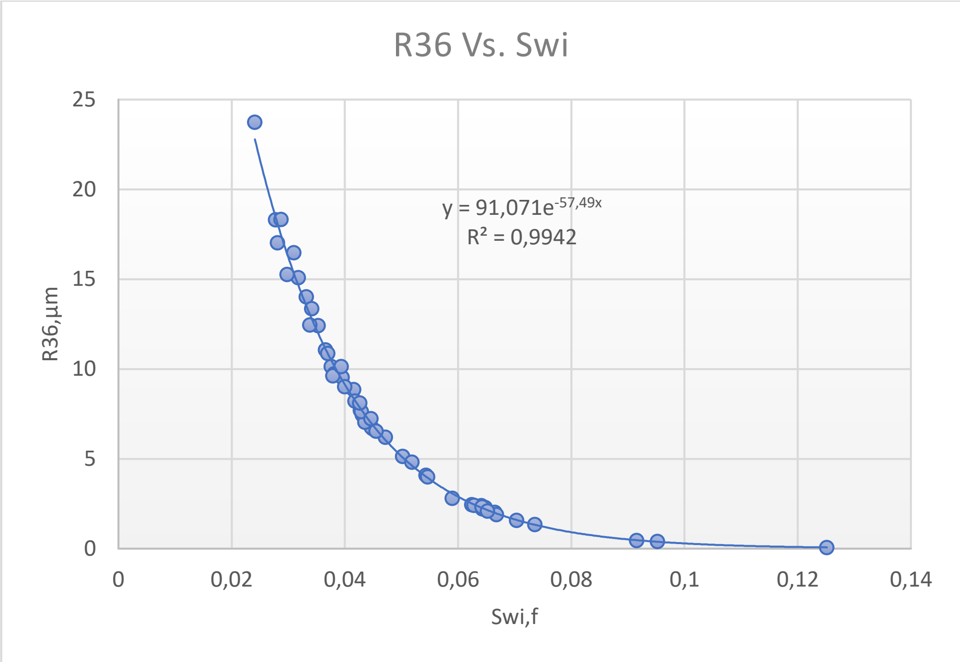


Fig. 7. R36 Versus Swi

**Conclusions**

a. The studied section is divided into two petrophysical zones according to porosity and permeability vertical profiles which can utilize in understanding zonation of the subsurface occurrences of the hydrocarbon bearing Pre-Cenomanian sandstone deposits in the Gulf of Suez area.
b. The calculated cementation exponents (m- value) in both concentrations is lower than that of the Archie's equation. This is most likely due to the high porosity and permeability values (Ø = 35.55% and K = 5289.42µm2).
c. The high coefficient of correlation of equation (6) allows to calculate R35 from R36 and vice versa with high accuracy.
d. the Pre-Cenomanian sandstone in its subsurface occurrences have a great opportunity to be a fluid producing.
e. The high coefficients of correlation obtained among R36 and petrophysical parameters allow calculation of RQI, FZI and HT from R36 with very high accuracy and vice versa.
f. The exponential relationship between R36 and Swi is characterized by a very high coefficient of correlation (R2 = 0.9942) permits Swi calculation from the R36.

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