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# Assessment of Reservoir Potentiality for Abu Madi Formation, Southwest Disouq Field, Onshore Nile Delta, Egypt

**Afife M.[1], Abdelhady A.[2], Abdel Aziz M.[2] and Wafaa Elshahat[1]**

[1] Geophysics Department, Faculty of Science, Benha University, Benha, Egypt.

[2] Exploration Department, Disouq Petroleum Company, Fifth Settlement, Cairo, Egypt.

**Corresponding author: E-mail address: mohamed.aziz@Disouco.com**

## Abstract:

Disouq area is located on the onshore western part of the Nile Delta (N.D.); which is one of the most important gas provinces, as its sedimentary succession hides high gas potentiality. The study area is divided into five fields that is: Disouq, Sidi Salem Southeast, South Sidi Ghazy, North Sidi Ghazy, and Northwest Sidi Ghazy. The main reservoir in Disouq field is Abu Madi Formation, a significant reservoir made up of Miocene rock. Through advanced petrophysical techniques and well logging data from specific wells like Disouq-1X, Disouq-2X, Disouq-1-3, Disouq-1-4, Disouq-1-5 and Disouq-1-6 in addition to core data of SSSE-1X well for calibration. Lithologically Abu Madi Formation is composed of sandstone, shale, limestone, and anhydrite layers.

Lithology and reservoir deriving mechanisms of Abu Madi reservoir is determined by using the available well-log and pressure data to construct many types of cross plots to reveal the different conditions that control the behavior of fluids within Abu Madi Formation.

The evaluation of the reservoir's potential is determined by integrating geological and petrophysical studies, revealing the Abu Madi reservoir's classification into two cycles: each of which represents one phase of reservoir development in the Disouq field tentatively related to Lower and Upper Abu Madi reservoirs. The lower reservoir boundary separates Lower Abu Madi sand from the underlying Qawasim Formation. The hydrocarbon potential is distributed through the higher part of the Upper Abu

Madi reservoir in Disouq field. Results of petrophysical analysis are represented vertically in the form of Litho-saturation cross plots and horizontally as Iso-Parametric maps, (hydrocarbon, water saturation, effective porosity, clay volume, net pay thickness), aiding in locating optimal areas for hydrocarbon accumulation and understanding the basin's characteristics.

**Key Words:** Disouq, Abu Madi, Petrophysics, Lith-saturation, cross plot, Reservoir potentiality.

## Introduction

The Disouq concession is located on the onshore part of the Delta. It spreads over an area of 305 km2. Disouq concession comprises the declared commercial gas discoveries by the exploration wells of NSG-1x, SSG-1x, NWSG-1x, SSSE-1x and DSQ-2x located at north of Tanta city in Egypt's cultivated Nile Delta belt that expands towards the Mediterranean Sea. Most gas discoveries are some 35 – 50 km away from existing gas infrastructure except the Northwest Khilala field at the eastern edge of the Disouq concession.

The six discoveries except NW Khilala are known traditionally as the Disouq field lies between Latitude 31◦ 09′ 48″ and 31◦ 14′ 45″ N and Longitude 30◦ 45′ 00″, and 30◦ 54′ 36″ E. In 2008, the latter was the first gas discovery in the Disouq concession. This was followed by three successful wells where two gas-bearing sand intervals more than 50m thick were encountered in the Late Miocene Abu Madi Formation. The production of the Disouq field is derived nowadays from the proper Disouq discovery of the Disouq -1X well which is developed with five wells and the other six surrounding discoveries (Fig.1).

The present work concerns the Southwest of the Disouq concession which includes the proper DSQ-1X, DSQ-2X, DSQ-1-3, DSQ-1-4, DSQ-1-5, and DSQ-1-6. Some confusion is derived by referring to each discovery as a separate field in addition to the initial concession name after the well DSQ-2X.

The study focuses on evaluating the gas potential and reservoir quality of Abu Madi Formation in the Southwest Disouq area by analyzing rock parameters like lithology, porosity, and fluid content.

### Previous work on the Nile Delta province:

The exploration activities started in 1947 by the Standard Oil Company of Egypt (SOE), However, the actual exploration activities have started in 1963 when the first exploration concession (about 28,125 sqkm) was granted to the International Egyptian Oil Company (IEOC).

In 1966 IEOC drilled Mit Ghamer-1 well which is the first exploratory well to be drilled in the onshore Nile delta although gas shows was detected in the Miocene sequences, the well was plugged and abundant (P&A) as a dry hole. In 1967 IEOC achieved the first gas discovery from the late Miocene Abu Madi Formation in the northeastern part of the onshore Delta in Abu Madi area by drilling the Abu Madi -1 well. This well encouraged IEOC to drill six more wells to appraise the discovered structure.

Through the period from 1966 to 1971, IEOC drilled six more exploratory wells; these are Kafr el sheikh, Abu Hammad, El Wastani, Sidi Salim, S.W.Bilqas and Sheibin El Kom. Gas shows were recorded in the Pliocene clastics of El Wastani, Sidi Salim, and S.W.Bilqas wells. Oil shows were also reported in the Upper Cretaceous and Upper Jurassic succession of Shebin El Kom Well.

In 1973 the development of Abu Madi field was started. In the same year the acquisition of two large offshore concessions was granted by Esso after which two deep water wells were drilled. Mobil drilled other five wells; two of them were Temsah -1 and Temsah-2 which tested high rates of gas and condensates from the M. Miocene sequence (Lower Miocene clastics) and CONOCO which commenced a drilling campaign in the Mid Delta onshore area. In 1975 WEPCO drilled Abu Qir-3 well as a dry hole in the onshore part of Abu Qir Bay.

From 1981 to 1982 IEOC extended its exploration success to offshore east Nile delta and discovered Tineh (Oligocene), Port Fouad Marine, Wakar, Kersh and El Qara (Miocene).

Since 1994, the Nile Delta has witnessed rapidly increasing intensive exploration due to improved exploration techniques such as 3D seismic acquisition, bright spots and flat spot analysis combined with using the AVO technique to the new prospects in the offshore Nile Delta. In 1997 British gas drilled Rosetta-3 well located about 25 km east of the Abu Qir concession. The well discovered the upper Pliocene El Wastani Formation sand. The increase resulted from the drilling success of the El Wastani-3 well drilled on the El Wastani Production Lease located in the onshore Nile Delta region of northern Egypt and produced from the second target Abu Madi Formation.

Extensive exploration occurred in the last 20 years by IEOC, Rashpetco/Burullus, BP, Shell, and TOTAL in the offshore of the Nile Delta revealing considerable gas discoveries of which IEOC Zohr gas field.

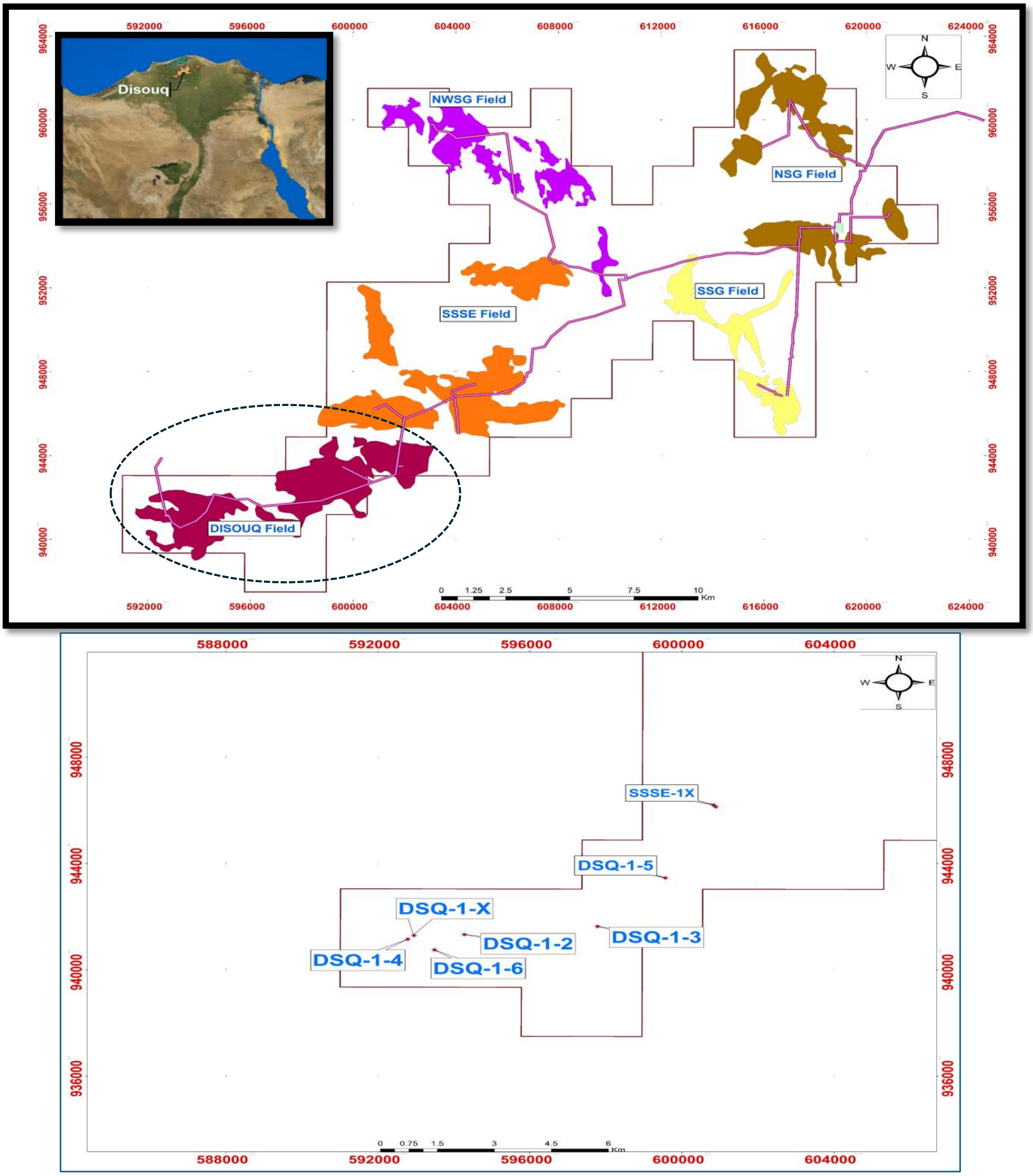



**Fig.1**: Location Map of Study the Area (Southwest Disouq Field) in the Onshore N.D. of Egypt (Disouco, 2014)

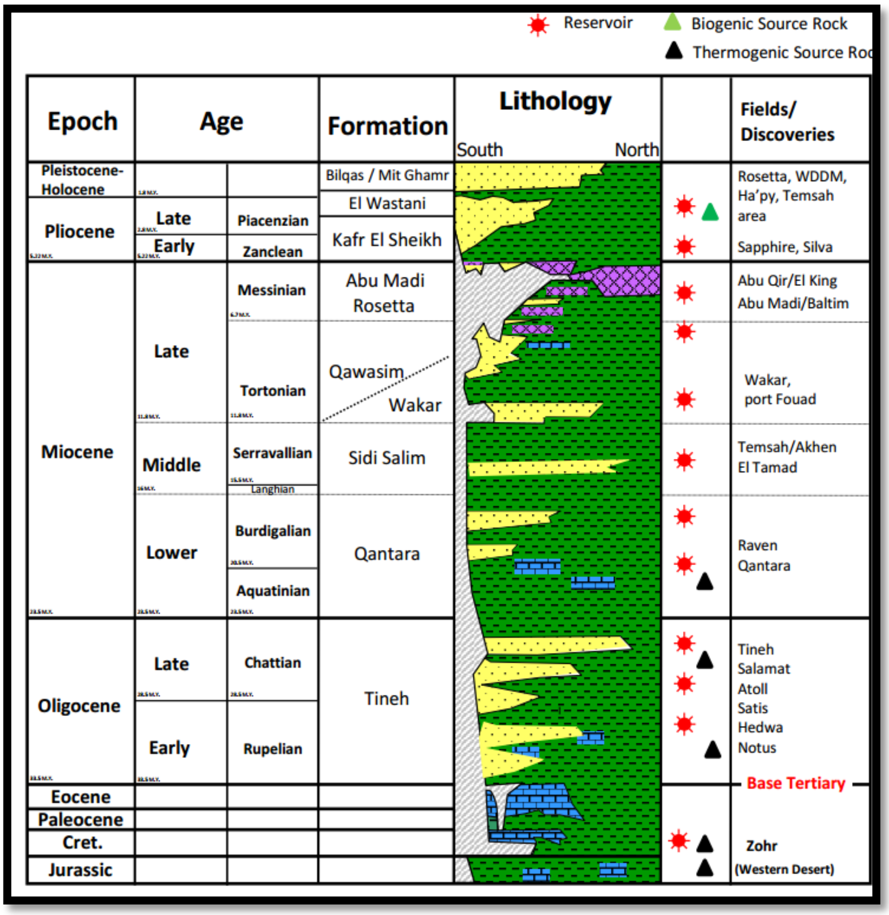
## GEOLOGIC SETTING

Figure (2) reveals the stratigraphy of Disouq field from bottom to top. The Abu Madi Formation (Messinian) is the key reservoir in the Disouq Field; it is composed mainly of sandstone with shale intercalation. These sands are rounded to sub-rounded and poorly cemented with medium grain size and poorly to moderately sorted grains, **Lila (2012).**

Structurally, The N.D.has been subdivided into 4 sedimentary provinces including: the south Delta province, the north delta basin, The Nile cone and The Levant platform **(Sestini, 1984; Ross and Uchupi, 1977)**. There is a pronounced flexure zone developed, extend East-West across the middle part of the Delta district separate between the south block and northern subsided basin affecting Pre-Miocene formations and known as the structure Hinge zone (Fig.3); a number of East-West trending fault system that continue into the other region of Northeast Egypt. These structures are dated to the Jurassic crustal breakup of the southern Neo Tethys, **(Kamel et al. 1998)**. The hinge line has shown a predominant effect in the tectonic and stratigraphic settings of the N.D. **(Said, 1981).**

DSQ field in general is a lobate-shaped W–E trending 4-dip closure with fault dependency at some reservoir levels especially along the northern and eastern margin (Fig.4). The structure is detached, independent and north of the hinge line fault system. The structure is an inverted feature at the Top Messinian and Pliocene formed by mild compression at the junction of NW-SE and NNE-SSW trending fault components along the 'Nile Delta' hinge line. Strike-slip motion is evident on the NNE-SSW fault trend (Fig.4).

**Fig. 2:** General Stratigraphic Column of Nile Delta after EGPC (1994)



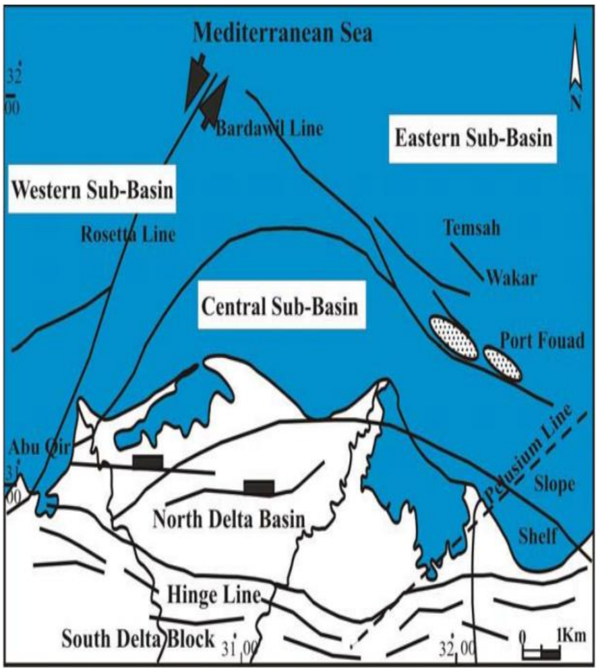




**Fig. 3:** North Nile Delta Sub-Surface Structural Pattern (Kamel et al. 1998)

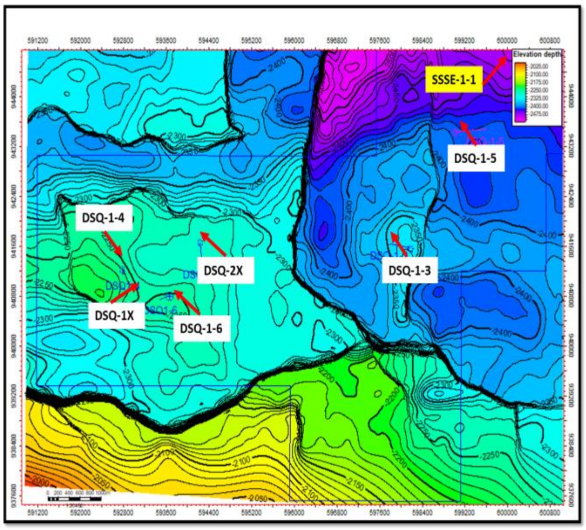



**Fig. 4:** Structure Contour Map on Top of Abu Madi in the Study Area (DISOUCO, 2014)

## DATA AND TECHNIQUES

A complete set of well logs covering the Abu Madi reservoir is available in digitized form (i.e., LAS files) for six wells in the study area; (DSQ-1X, DSQ-2X, DSQ-1-3, DSQ-1-4, DSQ-1-5, and DSQ-1-6). Logging data include resistivity logs (deep and shallow), porosity logs (sonic, density and neutron) and gamma-ray log.

Petrophysical analyses are conducted using an IP program and various wireline logging tools to determine important parameters like porosity, shale volume, fluid saturation, net pay, and gross thickness for potential reservoir characterization. The study involves evaluating these properties for the Abu Madi formation, creating graphical representations of the data, and calibrating the analysis using core data from a nearby field, Sidi Salem Southeast-1X well.

## RESULTS

## AND INTERPRETATION

## Petrophysical Investigation

Wireline quantitative and qualitative techniques are important in the evaluation of petrophysical characteristics and formation evaluation for any reservoir; including the evaluation of Formation water resistivity (Rw), shale volume (Vsh), total porosity (Φt), effective porosity (Φeff), water saturation (Sw), and hydrocarbon saturation (Sh), as well as the determination of the lithologic composition of Abu Madi reservoir.

## Lithologic Identification

Lithologic constituents for the study formation are determined using Neutron-Density and the M-N Crossplots, **(Crain, 1986 and Schlumberger, 1991)**.

The matrix components of Abu Madi reservoir will be defined according to the availability of the data obtained through the area under investigation.

(Fig. 5 & 6) show crossplots of M-N and Neutron-Density for the Abu Madi Formation in the DSQ-1X well. The data points cluster around the sandstone trend with some points shifting towards the dolomite and limestone lines due to the presence of shale and hydrocarbons, respectively. Overall, the description indicates fine to very fine-grained sandstone with low shale content and some calcareous cement, suggesting a promising reservoir with porosity values ranging from 15% to 35%.

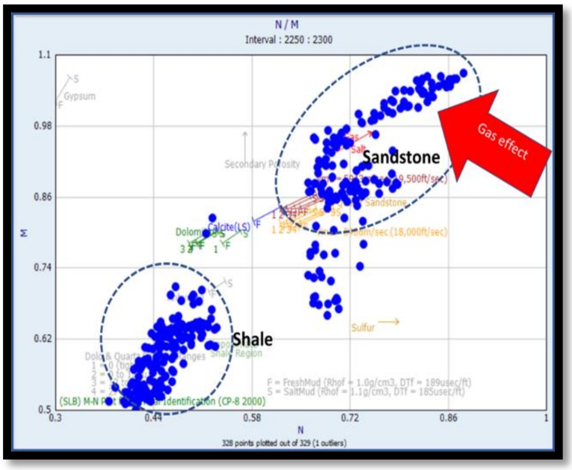



Fig.5:M-N Crossplot of Abu Madi in DSQ-1X Well.

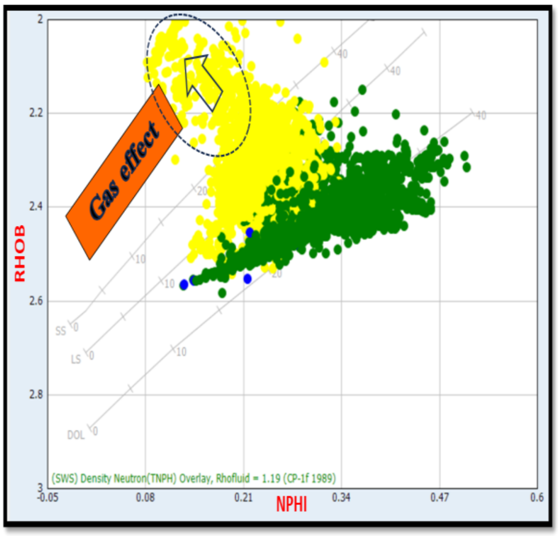



Fig.6: Neutron-Density Crossplot of Abu Madi in DSQ Wells.

## Salinity and Rw determination.

From picket plot (cross plot between effective porosity and deep resistivity in a clear water zone), Abu madi salinity is 48,000 ppm and Rw value is 0.0754 ohm's (Fig.7).

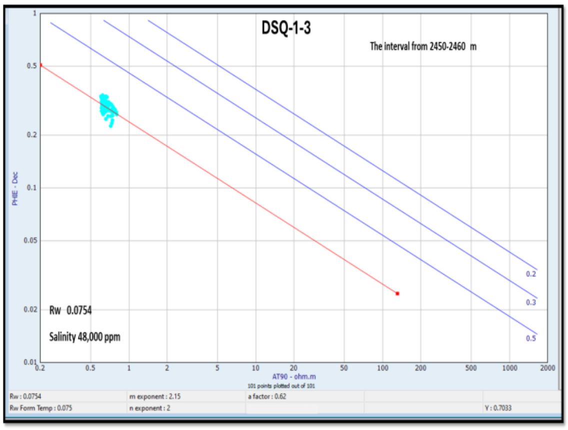



**Fig.7**: Rw Determinations by the Pickett Method for Abu Madi Formation.

## Determination of Shale Content (Vsh)

Gamma-ray tool is sensitive to the radioactive materials, which are usually concentrated in shaly rocks. The tool is used traditionally for identifying and determining shale volume, applying **Dresser Atlas 1983**, equation:

$$IGR = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}} \qquad (1)$$

**Where**:

GR is the Gamma-ray index,

$GR_{log}$ is the Gamma-ray reading for each zone,

$GR_{min}$ is the minimum Gamma-ray value (clean sand or carbonate) and,

$GR_{max}$ is the maximum Gamma-ray value (shale)

The shale volume can be calculated from the Gamma-ray index using one of the following formulae, (**Dresser Atlas, 1979):**

**a – Older rocks (Paleozoic and Mesozoic), consolidated:**

$$Vsh = 0.33\,[2^{(2*IGR)} - 1.0] \qquad (2)$$

**b – Younger rocks (Tertiary), unconsolidated:**

$$Vsh = 0.083\,[2^{(3.7*IGR)} - 1.0] \qquad (3)$$

Formula (no. 2) is applied for Abu Madi Formation in the present work.

**Reservoir Grain Density Determination from Core Data**

The grain density value is very important because it has a direct impact on porosity calculation. In case the absence of core data, the standard value used is 2.65 for sandstone reservoir.

From the available core data in well SSSE-1, Abu Madi Formation is a clean sandstone reservoir with grain density value range 2.55 - 2.7 gm/cc with average value 2.65 gm/cc (Fig.8).

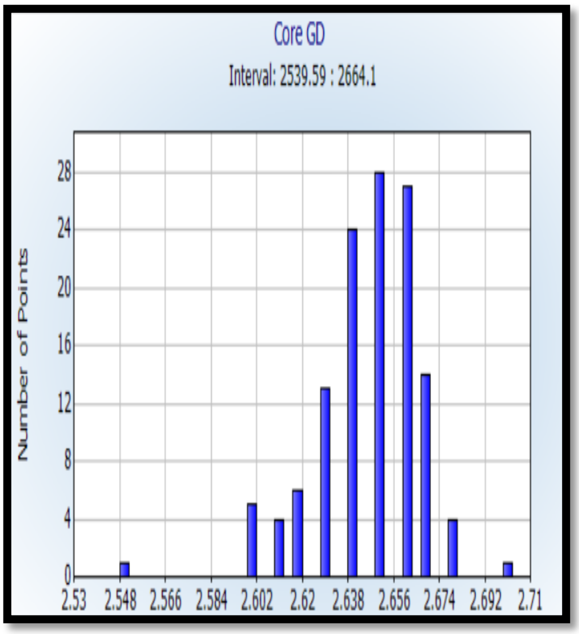



**Fig. 8**: Grain density determination from core data in SSSE-1X well.

## Determination of Porosity Using Density Log

The Density log responds to the electron (bulk) density of the material in the formation. It is used as a porosity indicator in the source rock evaluation, detection, and determination of hydrocarbon density. Porosity is derived from the bulk density, using the following formula **(Wyllie 1963)** from the relation:

$$\Phi_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f} \qquad (4)$$

**Where**:

$\rho_{ma}$ is the matrix density,

$\rho_{log}$ is the density log reading and

$\rho_f$ is the density of mud fluid.

In the present study, the matrix density for Abu Madi unit equals 2.69 gm/cc as determined from core data. This porosity is corrected to eliminate the shale effect using the following equation:

$$\Phi_D = \left[\frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_f}\right] - V_{sh}\left[\frac{\rho_{ma} - \rho_{sh}}{\rho_{ma} - \rho_f}\right] \qquad (5)$$

## Determination of Effective Formation Porosity ($\Phi_{eff}$)

Effective porosity depends largely on the degree of connection between the rock pores with each other forming channels, to facilitate the path of fluids through the lithologic contents. Effective porosities can be calculated by one of the following equations:

$$\Phi_{eff} = \Phi_D - V_{sh}\,\Phi_{Dsh} \qquad (6)$$

$$\varphi_{eff} = \varphi_t * (1 - V_{sh}) \qquad (7)$$

**Where**:

$\Phi_{eff}$ is the effective porosity;

$\Phi_D$ is the porosity derived from the density log.

**Water Saturation ($S_w$)**

"Water saturation ($S_w$) is the fraction of pore volume occupied by the formation water" **(Schlumberger 1972).** The Indonesian model used to calculate water saturation, **(Fertl andHammack 1971)**

$$Sw = \left[\frac{\frac{1}{\sqrt{Rt}}}{\frac{Vsh^{\left(1-\frac{Vsh}{2}\right)}}{\sqrt{Rsh}} + \frac{\phi^{\frac{m}{2}}}{\sqrt{a \times Rw}}}\right]^{\frac{2}{n}}$$

*Rsh* - shale resistivity, ohm.m
*Rw* -formation water resistivity, ohm.m
*Vsh* -shale volume
a,b,m,n -electrical properties

**Rt** is the Resistivity curve from deep log reading,

**Rcl** is the Resistivity of wet clay,

**Øe** is the Effective porosity calculated from equation (6),

**Sw** is the water saturation, fraction,

**Vcl** is the shale volume, fraction,

**Rw** is the formation water resistivity,

**n** is the saturation exponent (equals 2),

a a constant (equals 1), and

**m** is the Cementation factor. In the present study, the Cementation constant is determined from the local experience and pickett's plot data, according to (Disouq Petroleum Company) and m is 2 in DSQ-1-3 for Abu Madi **(Fig. 7).**

**Gas Saturation ($S_g$) Determination**

Is the fraction of pore volume occupied by hydrocarbons. The basic equation for calculating hydrocarbon saturation ($S_h$) is:

$$S_h = 1 - S_w \qquad (9)$$

## Net-Pay Cut-off Calculation

Cut-offs are used in this study for Abu Madi unit, which is considered as a good reservoir, where Vsh must be less than or equal to 35%, Φeff is more than or equal to 10% and Sw is less than or equal to 65%.

## Core-Log integration and permeability prediction

The conventional core analysis is available in the well SSSE-1X which is used for porosity calibration and permeability prediction.

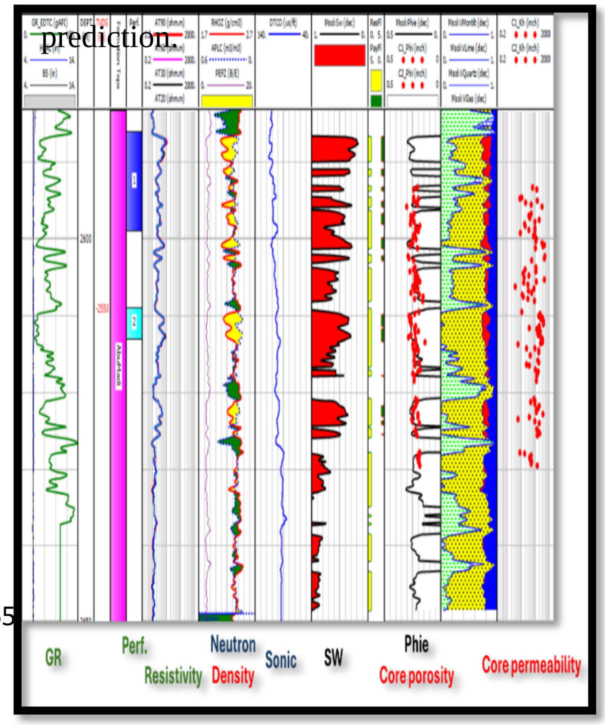


**Fig. 9**: Petrophysical evaluation for well SSSE-1X calibrated with core data**.**

The relation between core porosity-permeability in well SSSE-1X was used to predict permeability in uncored intervals in well SSSE-1X and also in Disouq field.

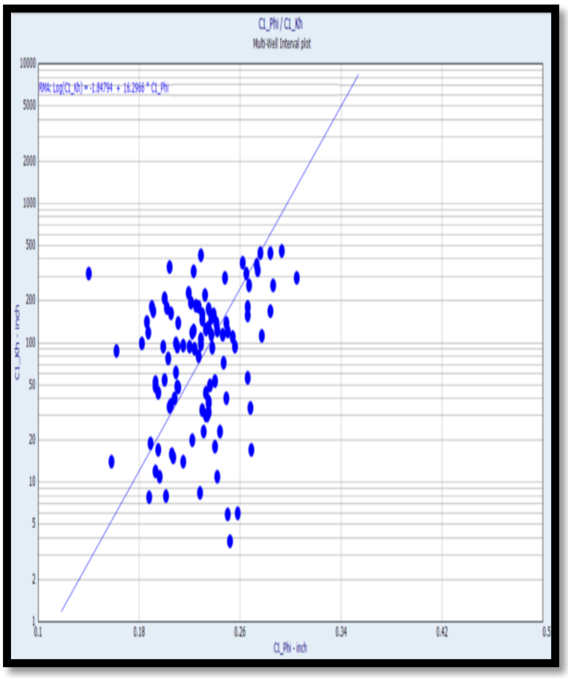


**Fig. 10**: Permeability prediction from core porosity-permeability in well SSSE-1X.

The following equation (1) was used to predict permeability in well SSSE-1X and also to predict permeability in Disouq wells.

**Log(C_Kh) = -1.84794445 + 16.2966 * C_Phi** (10)

The predicted permeability curve is in good match with the measured permeability from core.

Comparison between core data (porosity and permeability) versus log data (Phie and predicted permeability), **(Fig. 11).**

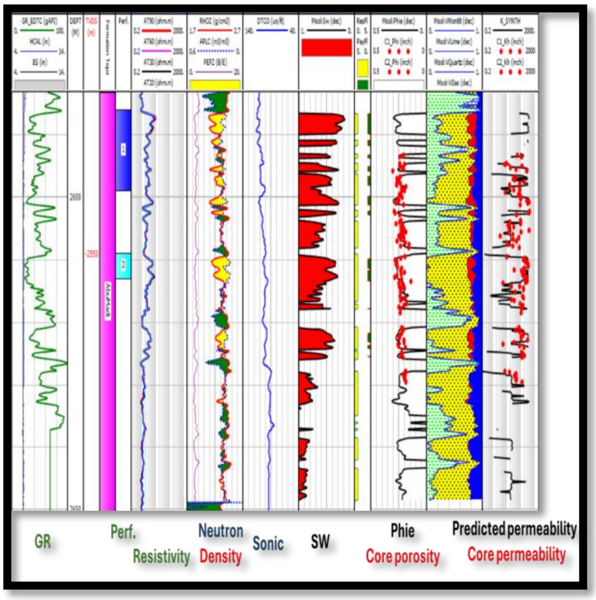



**Fig. 11**: showing the predicted permeability curve versus core data in well SSSE-1X.

## Result and Discussion

In this research, the hydrocarbon potentialities for Abu Madi reservoir have been evaluated by studying the petrophysical characteristics in Disouq area. Petrophysical parameters, which are determined from well-logging analysis, are varied.

The vertical distribution of the petrophysical parameters has been illustrated by litho-saturation cross plots, that are used to reveal the vertical relationship between the different parameters.

A complete image of the study area reached through the construction of a number of maps to show the lateral variation of the different parameters.

## Vertical Distribution of the Petrophysical Parameters

### Litho-Saturation Cross-plot of DSQ-1X Well

The litho-saturation cross plot of Abu Madi reservoir in DSQ-1x well shows that the Abu Madi Formation starts from depth 2256 m to 2348 m, (Fig.12) and consists mainly of sandstone and shale. Abu Madi Formation is subdivided into 2 zones starting with the Upper zone at the top and Lower zone at the bottom. The gross sand interval is about 32 m, with a net pay of 9 m in the upper zone with an average effective porosity value is 26%. Such porosity levels may store commercial quantities of hydrocarbons, with hydrocarbon saturation of 75 % and water saturation of 25%.

### Litho-Saturation Cross-plot of DSQ-1-3 Well

The litho-saturation cross plot of Abu Madi reservoir in DSQ 1-3 well shows that the Abu Madi Formation starts from depth 2412 m to depth 2546 m (Fig. 13) and consists mainly of sandstone and shale. Abu Madi formation subdivided into 2 zones starting with the upper zone at the top and Lower zone at the bottom. The gross sand interval is about 57 m, with a net pay of 15 m and the effective porosity average value is 30%. Such this porosity level may store commercial quantities of hydrocarbons, with hydrocarbon saturation of 53 % and water saturation of 47%.

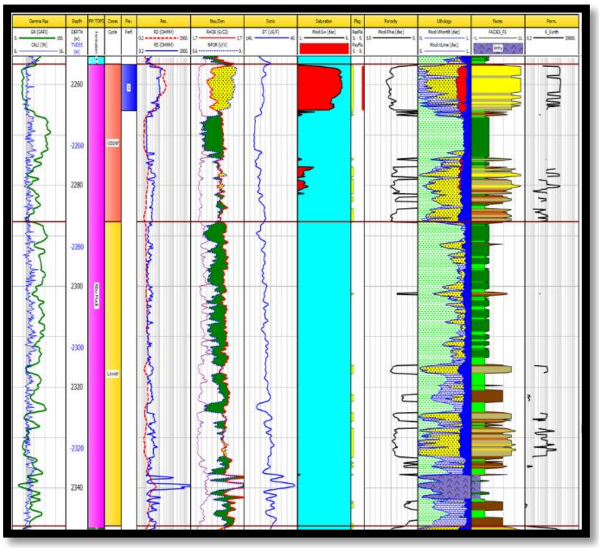


**Fig. 12**: The Litho-Saturation Cross-plot of DSQ-1X Well

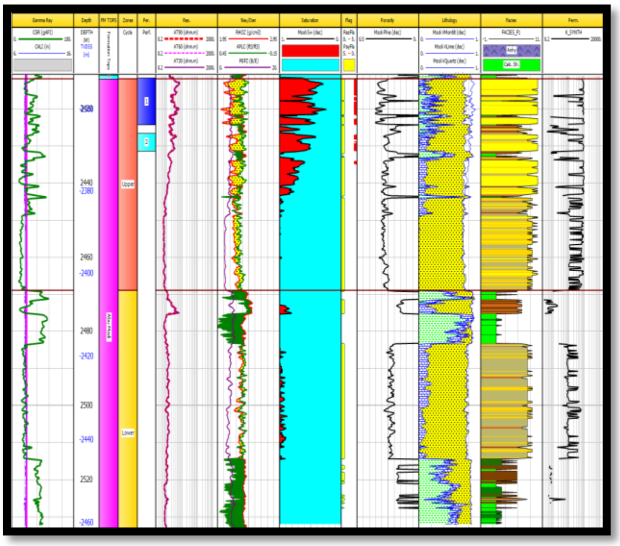


**Fig.13**: The Litho-Saturation Cross-plot of DSQ-1-3 Well

## Fluid Contacts

"The Modular Formation Dynamics (MDT) is an open hole log used for measuring the vertical pressure distribution in a reservoir, the technique of point-by-point evaluation of reservoir pressure is used to determine the pressure profiles, fluid density, fluid contacts, differential depletion, and reservoir inter-communication. MDT is a device capable of providing an estimate of the formation permeability, through the interpretation of pretest pressure data records during drawdown and build-up", **(Stewart and Wittmann, 1979).** In the present study based on petrophysical analysis, the lateral

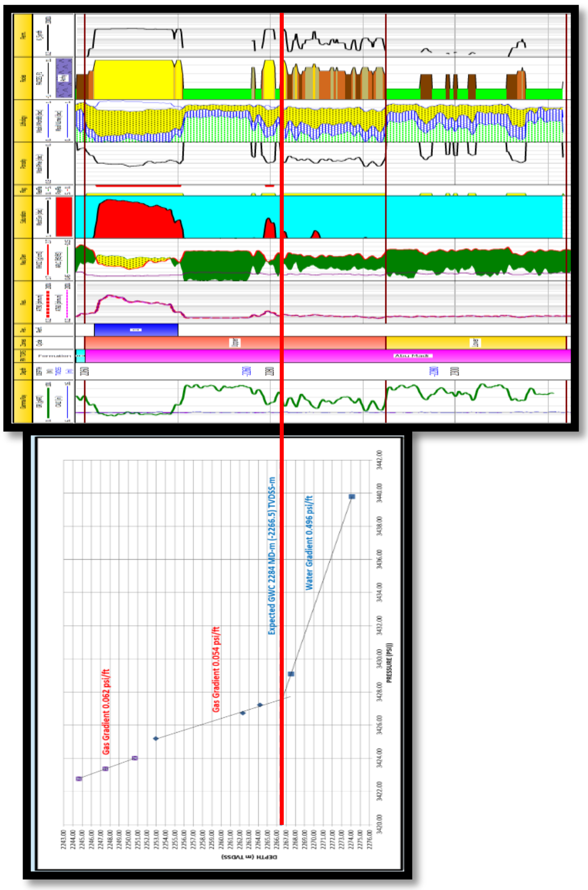



**Fig. 14**: Analysis of Abu Madi Reservoir Pressure Data (MDT), in DSQ 1-4 Well

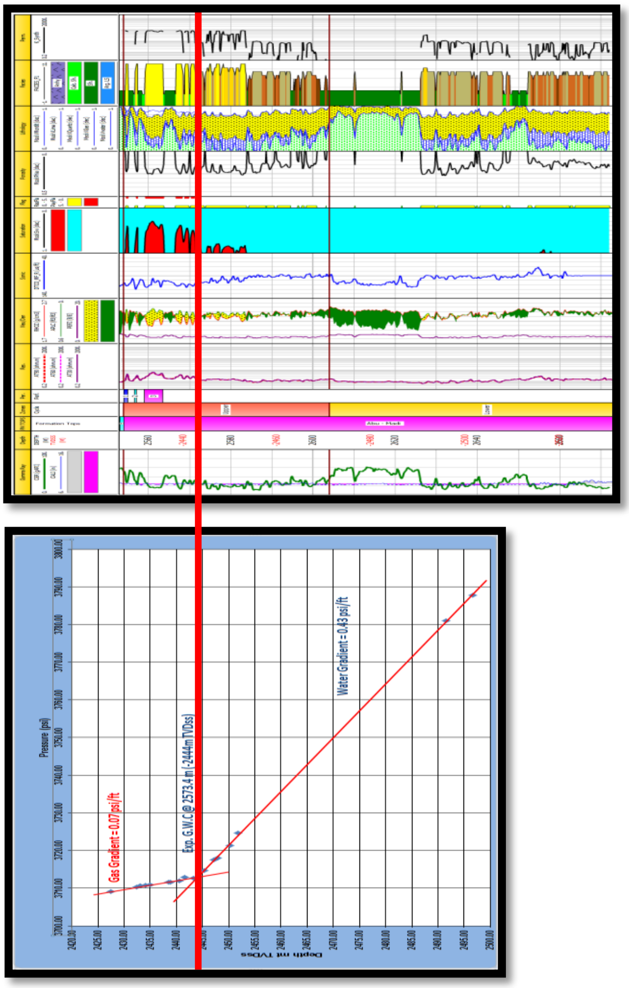



**Fig. 15**: Abu Madi Reservoir Pressure Data (MDT), DSQ 1-5 Well

## Lateral Distribution Maps of Abu Madi Reservoir

The study of the petrophysical results, through the lateral distribution, has been taken by constructing Isopach maps and some iso-parametric maps for the high zone of Abu Madi reservoir. Horizontal distribution of the Petrophysical parameters and hydrocarbon occurrences can be presented and explained through the Petrophysical Iso-parameters maps of Abu Madi Formation. The Iso- parametric maps were constructed for the net-pay (ft.), shale content ($V_{sh}$ %), effective porosity (Φe %), water saturation ($S_w$ %) and hydrocarbon saturation ($S_h$ %). We can figure out the hydrocarbon potentialities and reservoir parameters in the study area by using the standard cut-offs, which encountered in the area as shown in **(Table 1).**

Table 1: Pay Zone parameters of Abu Madi

| Abu Madi Reservoir | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Well | Cycle | Top M. | Bottom M. | Gross M. | Net Pay M. | N/G % | Av. Phi % | Av Sw % | Av. Vcl % | Av. Hc % |
| DSQ-1X | Upper Abu Madi | 2256 | 2287 | 31 | 8.69 | 0.87 | 0.26 | 0.25 | 0.06 | 0.75 |
| DSQ-2X | | | | | | | | | | |
| DSQ1-3 | | 2412 | 2469 | 57 | 13.83 | 0.69 | 0.3 | 0.47 | 0.07 | 0.53 |
| DSQ1-4 | | 2260 | 2293 | 33 | 9.2 | 0.84 | 0.25 | 0.23 | 0.04 | 0.77 |
| DSQ-1-5 | | 2554 | 2604 | 50 | 4.74 | 0.53 | 0.22 | 0.4 | 0.14 | 0.6 |
| DSQ-1-6 | | 2283 | 2315 | 32 | 0 | 0 | — | — | — | — |

## Lateral Distribution Maps of Abu Madi Reservoir (Upper Zone)

### A. Net Pay Map of Upper Zone

This map is constructed to show the variation of thinning and thickening of the vertical thickness of the reservoir rock that contains hydrocarbons (gas, condensate, or both) of the studied rock unit

The net-pay thickness of **Upper Zone (Fig. 16)** is observed within the range of 0-13 m. which is restricted in DSQ-2X and decreases, toward the Eastern part of the field, rapidly to zero at DSQ-1-6 well.

This distribution pattern indicates that the hydrocarbon potential of the Abu Madi Formation is promising at the Southeastern as well as Southwestern directions of the study area.

### B. Shale Content Map of Upper Zone

Shale content an important indicator of the reservoir quality; the lower the shale content the better the reservoir quality.

Shale volume distribution map of Abu Madi Formation **(Fig. 17)** shows that the shale volume percentage graded from a minimum value of 0.07 % at DSQ-1-3 well to a maximum value of 27 % at DSQ-1-6 well. The reservoir rock quality tends to be good in Southeastern and Southwestern parts of the study area.

### C. Effective Porosity Map of Upper Zone

"Effective porosity is the most significant petrophysical parameter in evaluating the hydrocarbon potential. The structural element may not affect the porosity development, but the facies depositional environment, which has a great influence on porosity", **El kadi et al (2002).**

The effective porosity map of Abu Madi Formation **(Fig. 18)** reveals that the Southeastern and Southwestern directions are the best directions for increasing the effective porosity. The lowest value is 22 % at DSQ-1-5 well, while the highest value is 30 % at DSQ-1-3 well. This is matched and conformable with the results of the net-pay thickness map of Abu Madi Formation.

## D. Gas Saturation Map of Upper Zone

The hydrocarbon saturation map of Abu Madi reservoir **(Fig. 19)** reveals that gas saturation have the highest value of 77 %, at DSQ -1-4 well, while the lowest values reach Zero at DSQ-2X and DSQ-1-6 well. In general, gas saturation increase towards the Southeastern and Southwestern directions of the study area

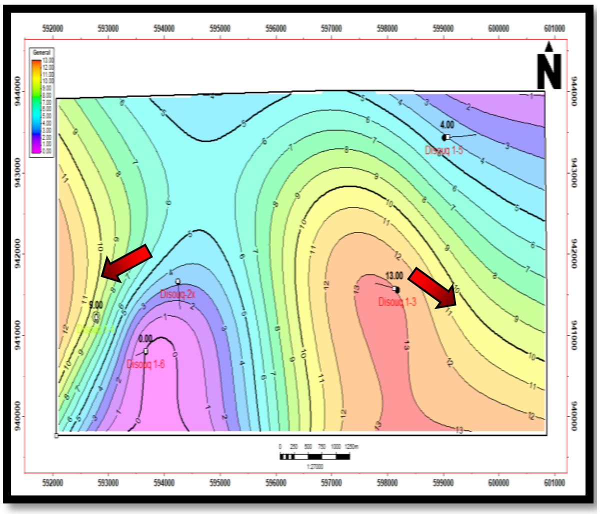


**Fig. 16:** The Net Pay Map for Upper Zone of Abu Madi

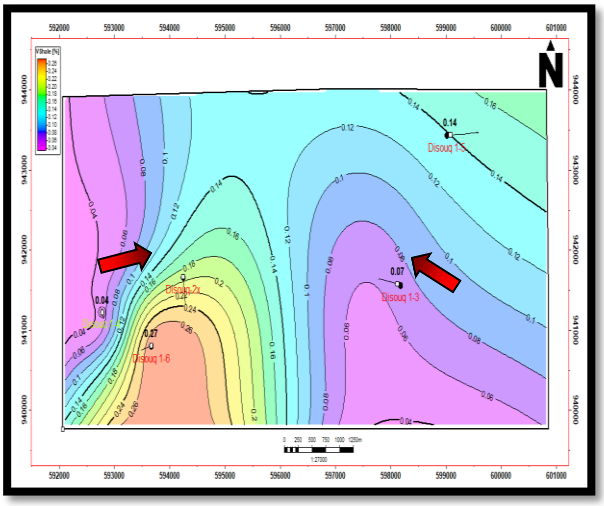


**Fig. 17:** The Shale content Map for Upper Zone of Abu Madi

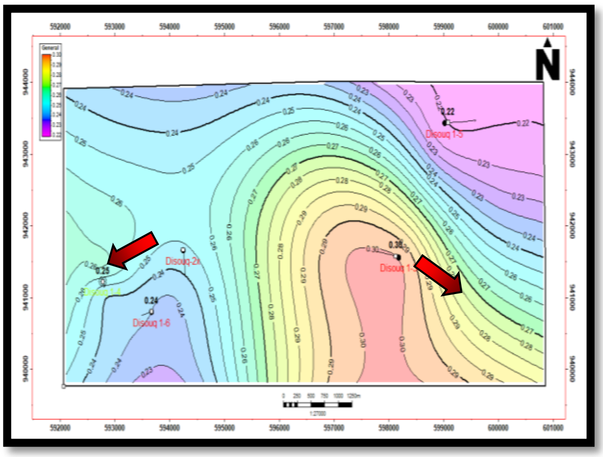


**Fig. 18:** The Effective Porosity Map for Upper Zone of Abu Madi

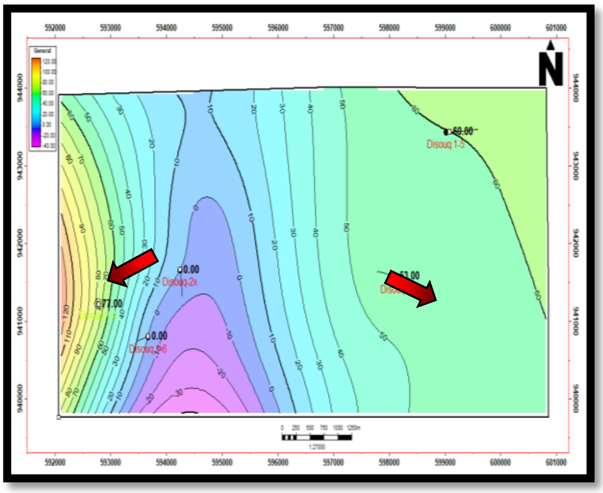


**Fig. 19:** The Gas Saturation Map for Upper Zone of Abu Madi

## CONCLUSION

This investigation aims to make a complete subsurface evaluation of the Disouq Field, in the N.D. of Egypt. In this study a full idea about the petrophysical characteristics of the rock units of interest (**Upper Zone**) through the Messinian Abu Madi Formation is accomplished to evaluate the hydrocarbon potentialities of the study area. Results of the petrophysical evaluation of Abu Madi Formation are established from a complete analysis for Six wells (DSQ-1X, DSQ-2X, DSQ-1-3, DSQ-1-4, DSQ-1-5 and DSQ-1-6) scattered in the study area and represent two cycles of sand sediments from top to base (**Upper and Lower Zones**). Focusing on the **Upper Zone**; with hydrocarbon potentially distributed through 2D cross plots, allows the description of lithology for the **Upper Zone** which is found to be fine Sandstone with more amount of clay content and a slight amount of calcareous cement. **The Upper Zone** is penetrated by four wells by 36.5 m as a net pay and is classified to be a very good reservoir because it has very good porosity ranging from 22% to 30% with a small amount of clay volume of about 7 % and high hydrocarbon saturation around 60 %.

It is recommended to drill more wells into/for the Southeastern direction around DSQ-1-3 and DSQ-1-5 and the Southwestern direction from DSQ-1-4 because these are considered to be good directions for developing the area.

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