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RESERVOIR QUALITY PREDICTION OF THE UPPER MESSINIAN ABU MADI FORMATION, SALMA DELTA FIELD, NILE DELTA, EGYPT

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التنبؤ بجودة الخزان لتكوين أبو ماضي عصر المسيني العلوي
حقل سلمي دلتا – منطقة دلتا النيل – مصر

الخلاصة: يمثل خزان أبو ماضي (المسينيان العلوي) أهمية إقتصادية هامة بدلتا النيل البرية لما يحتويه من كميات واعدة للغازات. يهدف البحث إلي دراسة الخزان الجوفي لمتكون أبو ماضي بحقل سلمي دلتا بغرض التنمية من خلال دراسة المعاملات البتروفيزيقية بإستخدام بيانات القياسات المعملية للعينات اللبية وسجلات الرصد البئري وإيجاد علاقات رياضية يمكن منها التنبؤ بالنطاقات عالية الجودة من الخصائص البتروفيزيقية.

وبالتالي ، من الأهمية بمكان تقدير نفاذية الخزان بدقة مناسبة وقد تم تقييم خزان أبو ماضي في منطقة الدراسة إلى أربع وحدات للتدفق الهيدروليكي. تتميز وحدة التدفق الأولى بالحجر الرملي عالي الجودة ، مع نفاذية عالية تتراوح بين ١٠٠ و ١١٠٠ ملي دارسي والمسامية تتراوح بين ١٨ و ٢٩ ٪ كما تتراوح قيم مؤشر التدفق بين ٣ و ١٠. وتتميز وحدة التدفق الثاني بالحجر الرملي عالي الجودة ، مع نفاذية تتراوح بين ١٠ و ٤٠٠ ملي دارسي ، و المسامية بين ١٦ و ٢٨ ٪ ، و قيم مؤشر التدفق بين ١,٥ و ٣. أما وحدة التدفق الثالثة فهي من الحجر الرملي متوسط الجودة ، وتتميز بنفاذية تتراوح بين ٢ و ٥٠ ملي دارسي ، قيم المسامية بين ١٤ و ٢٦ ٪ و قيم مؤشر التدفق بين ٠,٦ و ١,٥. أخيراً وحدة التدفق الرابعة من الحجر الرملي ذو النوعية الرديئة ، مع قيم نفاذية منخفضة بين ٠,٥ و ٢ ملي دارسي ، قيم المسامية بين ١٤ و ١٨ ٪ ، و قيم مؤشر التدفق بين ٠,٢ و ٠,٦.

وأهمية البحث أنه يمكن من خلال ربط القياسات المعملية والسجلات البئرية بعلاقات رياضية والتعرف علي خصائص الخزان في النطاقات الخالية من العينات الصخرية اللبية. وتعتبر هذه النتائج ضرورية للغاية للمساهمة في عملية تطوير حقل سلمي دلتا، بدلتا النيل، مصر.

ABSTRACT: *The Upper Messinian Abu Madi Formation is a major gas reservoir in the onshore Nile Delta, so the recognition and understanding of the reservoir distributions are essential in exploration, development and production phases. Abu Madi reservoir is the main reservoir in Salma Delta field in the Eastern Onshore Nile Delta. Reservoir quality prediction is the main challenging issue in reservoir studies. Precise estimation of this parameter leads to enhancing the reservoir simulation, reservoir process, and further forecasting the reservoir behavior. Hence, it is of great importance to estimate the permeability of reservoir rocks with, appropriate accuracy.*

Abu Madi reservoir in the study area has been classified into four hydraulic flow units (HFUs). The first flow unit (HFU-1) is characterized by very good quality sandstone, with a high permeability ranging between 100 and 1100 mD, porosity varying from 18 to 29 % and flow zone indicator(FZI) values ranging between 3 and 10.The second flow unit (HFU-2) is characterized by good quality sandstone, with a permeability varying from 10 to 400 mD, porosity values ranging between 16 and 28% and FZI values varying from 1.5 to 3. The third flow unit (HFU-3) is of moderate quality sandstone characterized by a permeability varying from 2 to 50 mD, porosity values ranging between 14 and 26 % and FZI values varying from 0.6 to 1.5. The forth flow unit (HFU-4) is of poor quality sandstone, with low permeability values ranging between 0.5 and 2 mD, porosity values varying from 14 to 18% and FZI values ranging between 0.2 and 0.6.

By Neural network technique, permeability was predicted by using FZI values from the cored wells to the un-cored onces, through the integration between the core and wire line log data for some selected wells covering Abu Madi reservoir. These results are very essential for contributing the development process in the Salma-Delta Field.

INTRODUCTION

The Nile Delta geologic history became known; due to the activities of the oil companies, which started working in the Nile Delta in the early sixties of the last century. This can be attributed to the fact that, this province starts to disclose a part of its hidden hydrocarbon reserves as a direct result of using state of the art exploration techniques in addition to the use of different types of geological, and geophysical modeling techniques (EGPC, 1994).

Salma Delta Filed area is located in West Qantara Concession at the Eastern Onshore Nile Delta and South of Manzala Lake, between Latitudes 31º 3' 00" N, 31º 7' N and Longitudes 31º 55' E, 32º 2' E (Figure 1).

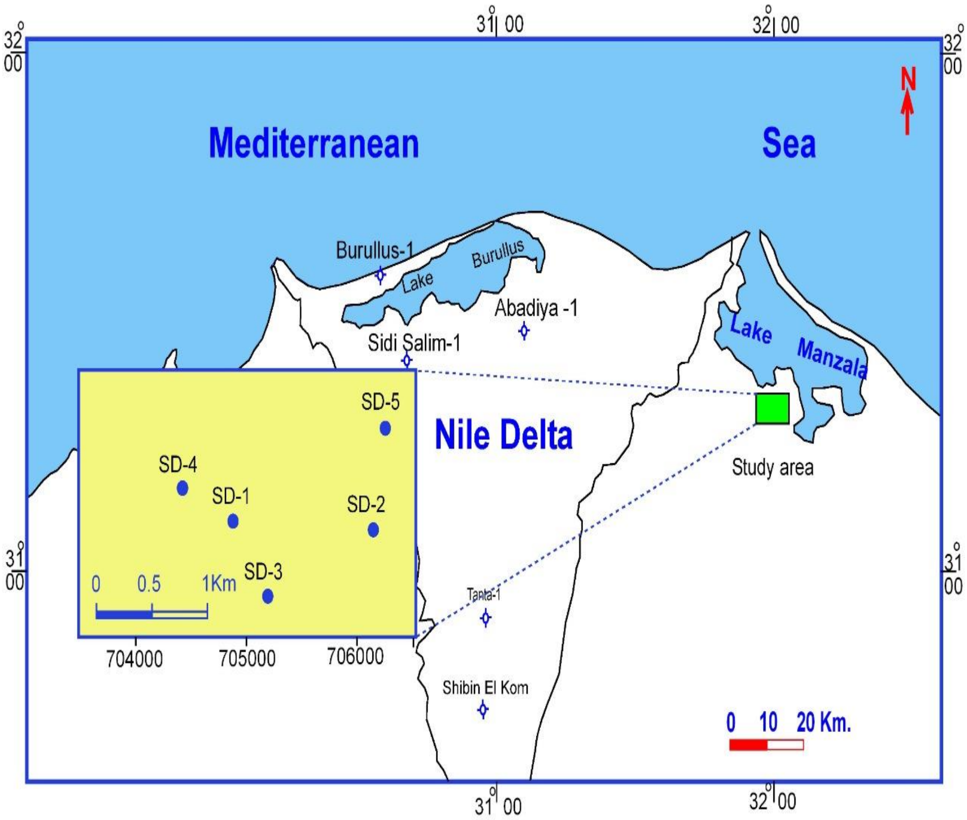

Figure. 1: Location map of Salma Delta field associated with the studied wells.

Salma Delta Filed was discovered by Salma Delta -1 well in December 2008, as a vertical exploratory well to a depth of 2230 m, followed by Salma Delta -2 as an appraisal well targeting the same reservoir level, which was drilled to 1250 m away from the east of Salma Delta-1 to test the Messinian Abu Madi reservoir on the upthrown side of the N-S fault. The well was drilled in May 2009 by WASCO to a total depth of 2180 m, that reached the base of the Qawasim Formation. The field became a mature field and the company began its development strategy by drilling other wells, such as Salma Delta -5, Salma Delta -3 and Salma Delta -4.

Abu Madi Formation is one of the main hydrocarbon reservoirs in the Nile Delta province. The big challenge in the exploration and development phases is the reservoirs compartmentalization and connectivity. Salem et al., (2005) reported that, the main proven reservoirs of the North Nile Delta basin were the Late Miocene sequences (Abu Madi and Qawasim reservoirs).

Because the reservoirs of the Nile Delta are of stratigraphic trap type, they contain high amount of clay minerals, which affect the accuracy of the petrophysical parameters and reservoir characterization leading to inaccuracy in the hydrocarbon reserve estimation. so that, the reservoir characterization has to be implemented in such shaly sand reservoirs, with a high degree of facies heterogenities.

This paper aims to study the hydraulic flow units and flow zone indicators for predicting the permeability of rock from the core and well log data. The concept was applied to some uncored wells/intervals to predict their permeability. Flow zone indicator depends on the geological characteristics of the material and various pore geometries of the rock mass; hence it is a good parameter for determining the hydraulic flow units. The flow zone indicator is a function of the reservoir quality index and void ratio. The flow zone indicator was determined from well log and core data and so the reservoir, can be divided into various hydraulic flow units.

Geological Setting

The Abu Madi Formation consists of a sequence of thick layers of rarely conglomeratic sandstone and interbedded with shale layers, which repeated and became thicker in the upper part. The sand is composed of quartz, that varies in grain size and almost loose. The conglomeratic levels in the sandy matrix represent the lower part of Abu Madi Formation, indicating the lower unconformity. The Abu Madi reservoir proved to be the best reservoir in the Nile Delta, having good porosity. The overwhelming gas fields in the Nile Delta had been produced from Abu Madi Formation (Schlumberger, 1984). These sandstones were considered as the main gas producing zone in the Nile Delta fields. The main reservoir in the study area is the Abu Madi Formation, that composed of well-defined fluvial sandstone channels with interbeds of shale and silt, favoring a very good quality reservoir.

During the Messinian age (from 7.24 to 5.33 My), the Mediterranean was isolated gradually from the Atlantic Ocean, leading to the wide extension precipitation of gypsum (from 5.96 to 5.6 My), massive salt deposition (from 5.6 to 5.5 My) and a sudden falling in sea level, followed by the creation of brackish water environments from "Lago-Mare" (Lake Sea) facies (Roveri et al., 2014). This sea-level severe drop caused a huge fall in the Mediterranean Sea water level, which is followed by wide erosion and the formation of large canyons incisions expanded around the Mediterranean, in addition to the spreading of salt deposits in the depocenter of the basin (Dolson et al., 2005). The Mediterranean's Messinian salinity crisis triggered the development of 5 major Paleo-drainage systems along the northern coastline of Egypt. The major canyons were filled with deposits of Qawasim and Abu Madi Formation (Pigott and Abdel-Fattah, 2014).

At the start of the Pliocene, a great sea transgression has flooded all the Nile Delta basins, producing Kafr El Sheikh Formation, which is characterized by the deposition of thick marine shales with thin layers of interbedded sandstones. A sudden sea level drop at the Early Pleistocene age led to the deposition of El Wastani Formation, which is a low stand deltaic system to shelf-margin deposits. The Oligocene - Neogene stratigraphic succession within the Nile Delta area, El Heiny and Enani, 1996 and Vandre´et al., 2007.is shown in Fig. (2).

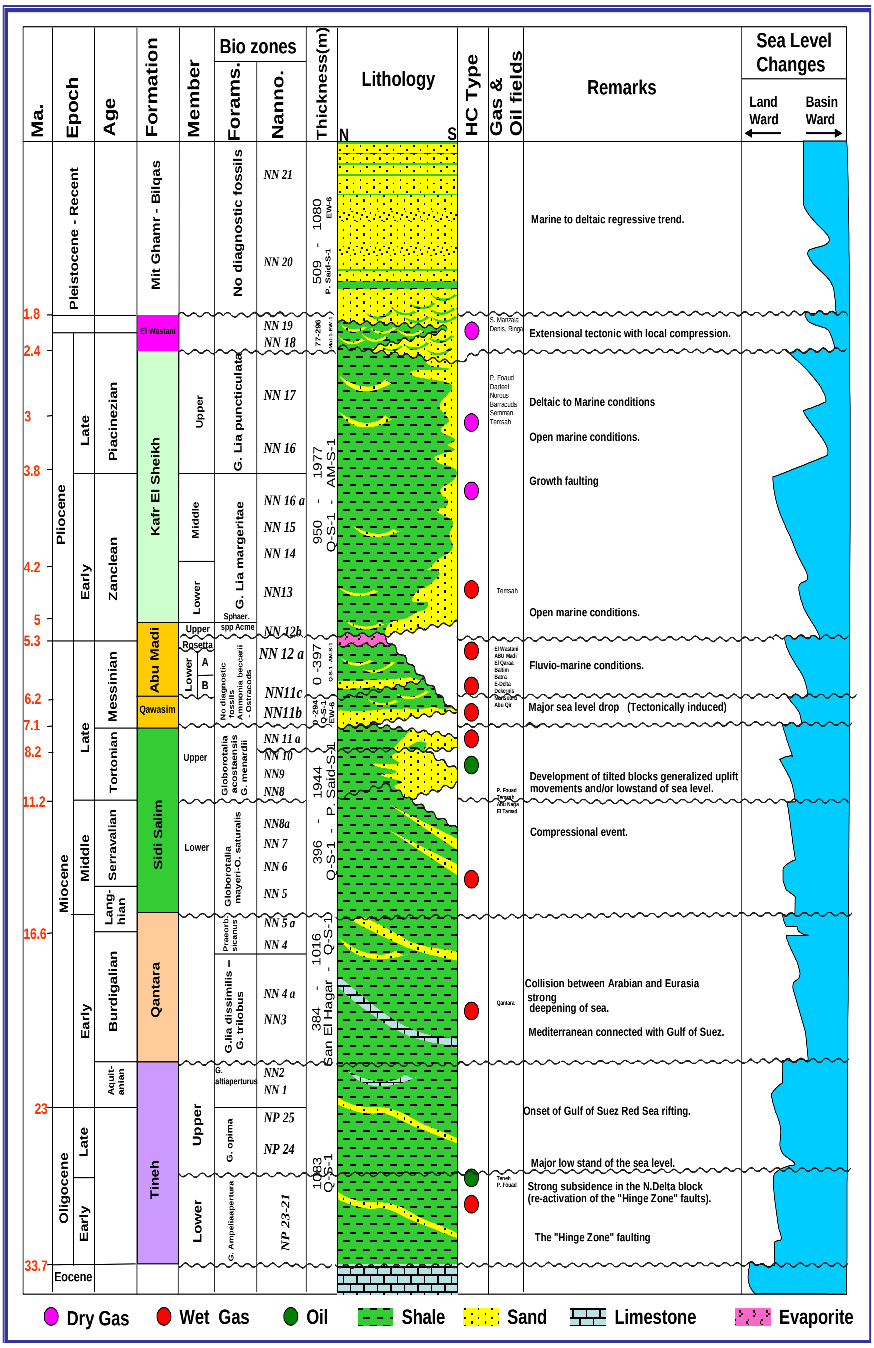

Figure 2: Generalized stratigraphic column of the Salma Delta Field (WASCO, 2016).

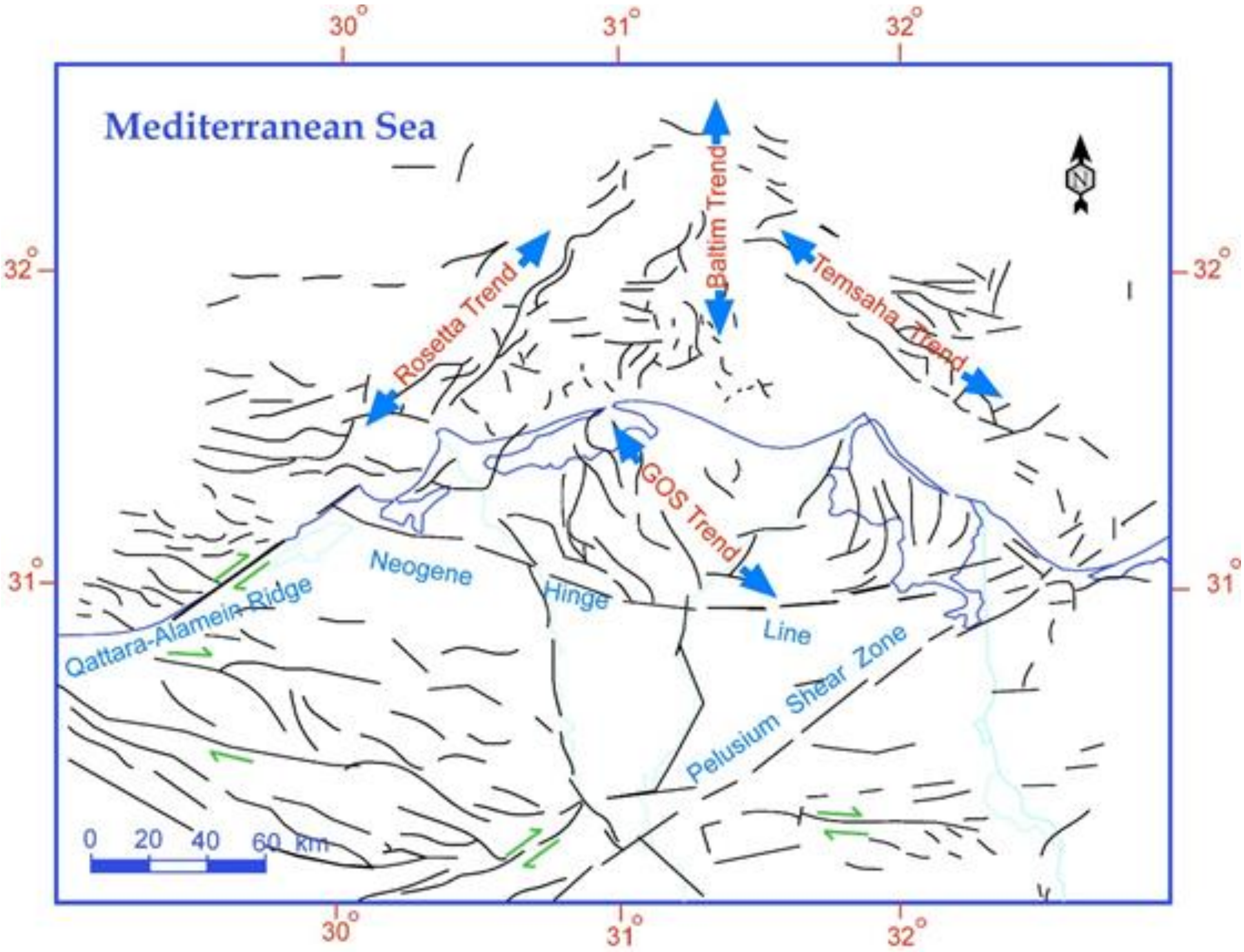

Figure 3: Nile Delta tectonic setting map (Abdel Aal, et al., 1994).

During the Late Cretaceous-Miocene, the Jurassic-Early Cretaceous rift basins were inverted with the development of the Syrian arc series of large northeast-southwest oriented folds south of the Nile Delta and Eastern Mediterranean regions (Darwish, 1996, and Kusky, 2003). The tectono-stratigraphic evolution of the eastern Nile Delta is shown in fig. (3). The "hinge line" is an Upper Cretaceous carbonate shelf edge, that forms the southern boundary of the thick Neogene sediments in the Nile Delta. It is an essential element, that affected the overall stratigraphic and tectonic evolution of the Nile Delta basins. A subsequent rifting phase (Gulf of Suez rift) occurred during the Oligo-Miocene with a dominant extension orientated in northwest faults due to divergence of the African plate away from the Arabian plate. The Oligo-Miocene or older E-W and NW trending faults in the Nile Delta were suggested to be related to the initial rifting phases of the Gulf of Suez. The gross seismic stratigraphic framework of the study area is described, concerning the main representative seismic section, perpendicular to the depositional direction of the Messinian depositional system. is shown in fig. (3).

1. Dataset

The available data of the studied area are well-logging data, including composite log, Gamma-Ray, Density, Neutron, Resistivity and Sonic logs. provided by El Wastani Petroleum Company in LAS and ASCII formats. In addition to core analysis results for Salma Delta-4 well for Abu Madi reservoir.

2. Methodology

To achieve the work, correlation and integration of core and log data, were carried out using linear and non-linear regressions, to build relevant relationships between the log and core data, and to determine the individual reservoir parameters, such as shale volume, porosity, fluid saturation, permeability, and hydraulic flow units (HFUs) of the reservoir litho-facies.

Finding a relationship between the core and log data is the best solution to predict the reservoir parameters in the un-cored wells, as indirect methods for plotting data of several wells and generate a correlation between the variables, to estimate the rock types and permeability in un-cored wells.

The rock-typing techniques, as (Leverett's, 1941) reservoir quality index RQI and (Winland , 1972) and flow zone indicator FZI (Amaefule, 1993) were used to define the reservoir into different hydraulic flow units (HFUs) and predict the reservoir permeability.

Core Permeability:

Permeability is generally defined as the ability of rock porous media to allow the passage of fluid (Friedman, 1977). Permeability is determined by the dimensions of the connected pores and the flow capacity of the formation to transmit fluids. The rock permeability (k) is a very important rock property, because it controls the directional movement and the flow rate of the reservoir fluids in the formation. The permeability of the core samples represents a wide range between 0.1 mD and 1000 mD.

Permeability Calculation

The length of the sample was measured using calipers and the bulk volume measured by mercury displacement. These values, along with the upstream-downstream pressures, flow rate, viscosity of nitrogen and barometric pressure temperature were entered in Darcy's equation for gas permeability (below), and the permeability (mD) of the sample is calculated, through the equation: (Darcy equation, 1856).

$$Kg = \frac{2{,}000 \times P_O \times Q_O \times \mu \times L}{\left(P_1^2 - P_O^2\right) \times A}$$

Where:

Kg = Gas-permeability (millidarcy)

Po = Barometric-pressure (atm)

Qo = Gas flow rate (cc/sec)

μ = Gas viscosity (cp)

L = Core length (cm)

P1 = Upstream pressure (atm)

A = Core cross-sectional area perpendicular to the direction of flow (cm²)

4. RESULTS AND DISCUSSIONS

a- Core gamma depth correction:

The natural gamma radiation of the cores was measured and the maximized smoothed gamma emission intensity of cores and the spectral gamma are plotted against the core depth, to detect the core depth shift.

b- Core Data to Reservoir Condition Correction:

To estimate the valid reservoir parameters from the well logs, they first have to be calibrated to the available core data. The most important parameter that affects the porosity and permeability of any reservoir, is the net of overburden pressure. It is the difference between the overburden and internal pore pressure. The plot between the core porosity, at reservoir condition (2350 psi) and ambient condition (400 psi) is shown in fig. (4).

The relation is given by the following equations:

$$y = 0.9449x + 0.5027 \qquad \text{eq.(1)}$$

where

y is the core porosity at reservoir condition of (2350psi).

X is the core porosity at ambient condition of (400psi).

The relation between the core permeability at reservoir condition at 2350 psi and ambient condition at 400 psi, is shown in Fig. (5).

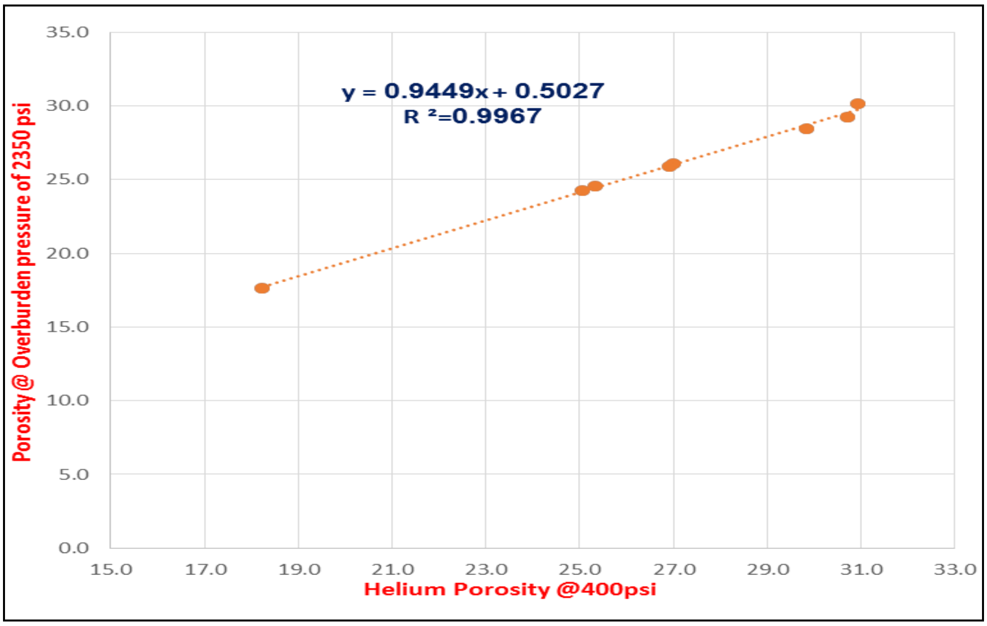

Figure 4: Core porosity as a function of overburden pressure, with the ambient condition.

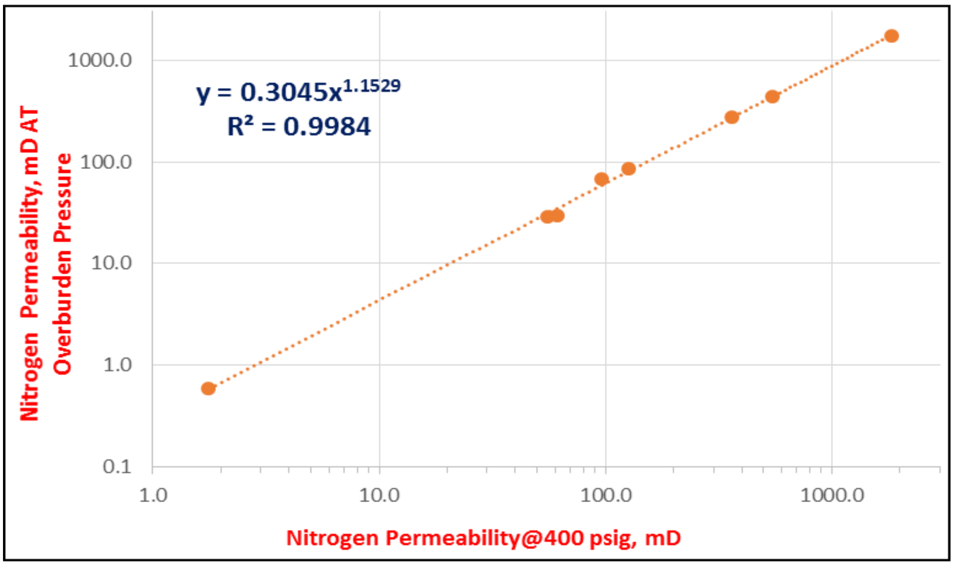

Figure 5: Nitrogen permeability as a function of overburden pressure, with the ambient condition.

The relation resulted into the following equations:

$$y = 0.3045\, x^{1.1529} \qquad \text{eq.(2)}$$

where

y is the core permeability at reservoir condition at 2350psi.

X is the core permeability at ambient condition at 400psi.

Hydraulic flow characterization

The rock typing is a process for reservoir rock classification into units, it is

characterized by a unique set of petrophysical properties e.g. porosity-permeability

relationship and electric properties. The Porosity and permeability data are available from the core analysis.

Several semi-empirical equations have subsequently been proposed to improve the estimation of rock permeability, as subjected to various loading conditions (Panda and Lake, 1994; Bernabé et al., 2003; Costa, 2006; and some modified KC models are listed here.

Bayles et al. (1989) proposed a porosity-permeability relationship based on the fractal pore cross-sectional area, which can be formulated as follow:

$$K = C\frac{\emptyset^{z+2}}{(1-\emptyset)^2} \qquad \text{eq.(3)}$$

Where: c is a constant to determine permeability and z is an exponent parameter for porosity.

A similar permeability formulation based on fractal pore space observations developed by Costa (2006) is written as:

$$K = C\frac{\emptyset^{z}}{(1-\emptyset)} \qquad \text{eq.(4)}$$

(R35) (Winland):

Winland of Amoco established an empirical relationship among porosity, permeability and pore throat radius from mercury intrusion tests, The available data were obtained the net pay cut-off values in some clastic reservoirs. Winland defined the flow unit, as a reservoir unit with uniform pore throat size distribution and similar flow performance, and determined by R35 (Winland, 1972). The Winland equation was used and published by Kolodzie (1980), as:

$$\log R35 = 0.732 + 0.588 \log Ka - 0.864 \log \phi \text{ core} \qquad \text{eq.(5)}$$

where: R35 is the pore aperture radius, corresponding to the 35th percentile of mercury saturation, Ka is the air permeability (mD), and ϕ is the porosity (%).

In Winland's empirical relationship, the highest statistical correlation was at the pore throat size, corresponding to the 35th percentile of the cumulative mercury saturation curve, (Gunter et al., 1997). The concept behind the use of R35 is that, once the different flow unit types have been identified and quantitatively characterized, then the wells are subdivided into smaller units having predictable flow characteristics, solving for R35, we get the relation:

$$R35 = 10 \wedge (0.732 + 0.588 \log Ka - 0.864 \log \varphi) \qquad \text{eq.(6)}$$

The ranges of R35 have distinguished five Petrophysical flow units, these are:

1. Mega port: Flow unit with R35, ranging above a threshold of 10 microns.
2. Macro port: Flow unit with R35, ranging between 2 to 10 microns.
3. Mesoport: Flow unites with R35, ranging between 0.5 and 2 microns
4. Micro port: Flow units with R35, values in the range of 0.2 - 0.5 microns
5. Nano port: Flow units with R35, values less than 0.2 microns.

From the porosity-permeability plot, we determined four flow units in the cored interval of Abu Madi Fm (Fig. 6) with Microport (0.2-0.5 mic.), Mesoport (0.5-2 mic.), Macroport,(2-10 mic.) and Megaport (10-50 mic.). Based on Winland flow unit classification, four rock units can be characterized.

Stratigraphic modified Lorenz Plot (SMLP):

The best way, to assess the minimum number of flow units in a reservoir is used a graphical technique based on the stratigraphic modified Lorenz plot (SMLP) (Gunter et al., 1997;and Tiab and Donaldson, 1996). Constructing the SMLP method is a plot of the percent of flow capacity (% Kh) versus percent of storage capacity (%ϕh), in which the partial sums are computed and the totals are normalized to 100%, and arranged in stratigraphic order. The slope of the segments on this plot is indicative of the flow performance. As shown in Fig. 7, the shape of the SMLP curve reflects the flow performance of the reservoir units. Segments with steep slopes are associated with a high percentage of reservoir flow capacity and therefore, a high production potential.

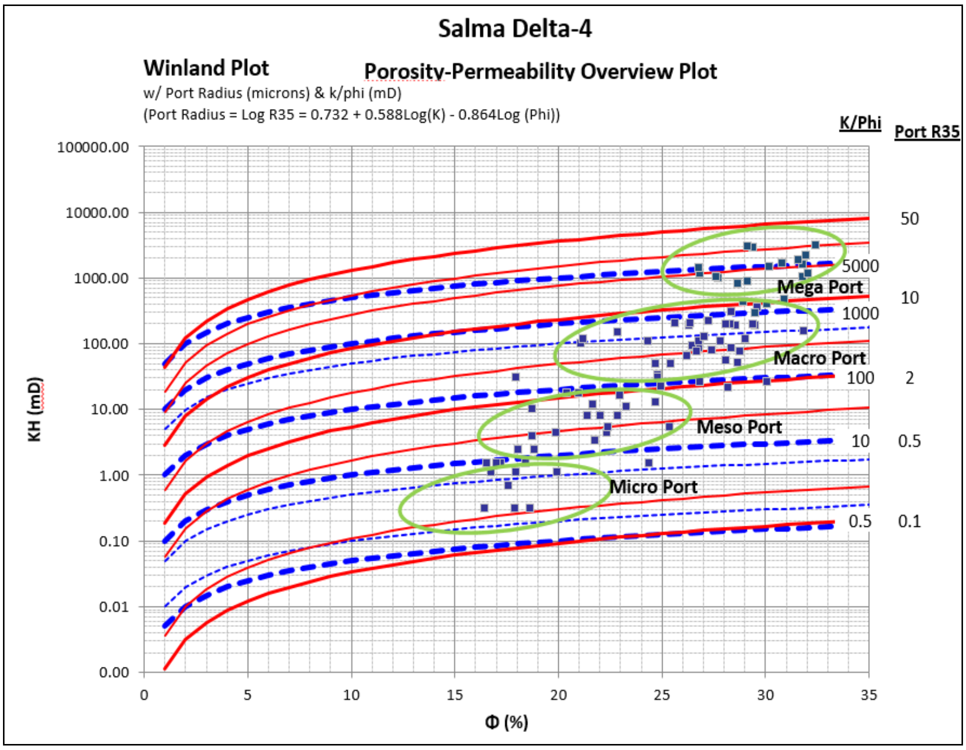

Figure 6: Abu Madi core data porosity –permeability, overlaid by R35 lines.

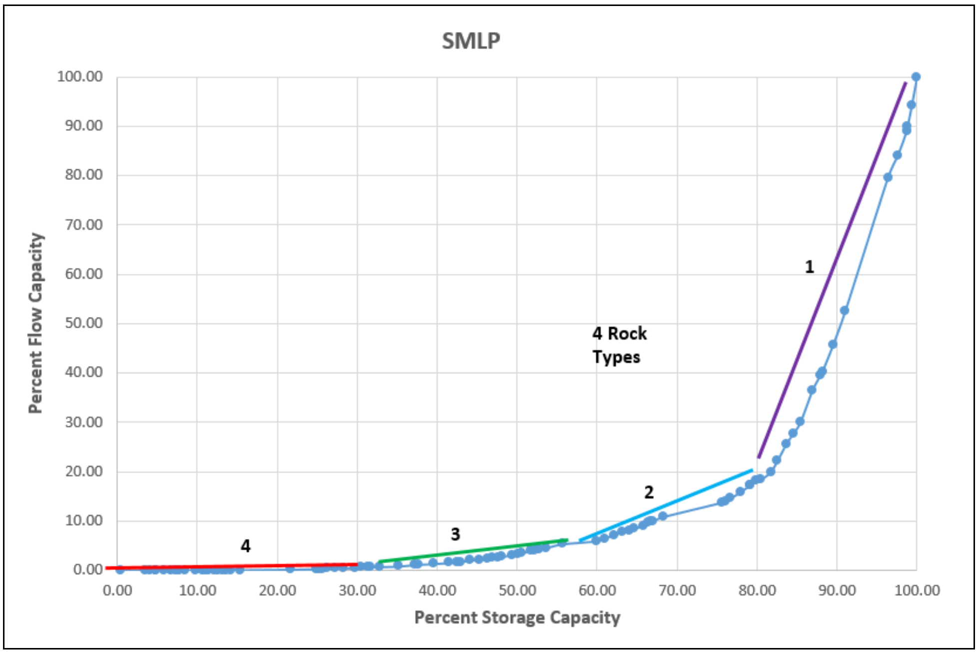

Figure 7: Salma Delta-4 well Stratigraphic Modified Lorenz Plot, sorting by porosity slope changes to define the flow units.

Table 1: Flow unit classification of the Abu Madi reservoir.

	R35 (mic)	PHI (%)	KH (MD)
Megaport	10 - 50	27 -32	500 - 3000
Macroport	2 - 10	21 - 29	10 - 300
Mesoport	0.5 - 2	18 -25	2 - 10
Microport	0.2 – 0.5	16 -20	0.3 -2

On the other hand, segments with flat behavior have storage capacity, but little flow capacity and are typically reservoir baffles. Segments with neither flow nor storage capacity are considered seals (Gunter et al, 1997), (Salazar Luna 2004). Preliminary flow units are interpreted by selecting changes in slope or inflection points in the SMLP curve.

Reservoir Quality Index:

Reservoir Quality Index (RQI) for rock typing classification and the flow properties prediction method, are based on Kozeny-Carmen Equation and the concept of the mean hydraulic radius (Carmen, 1937). The derivative of RQI Equation is based on the assumption that, a porous medium can be represented by a bundle of capillary tubes. Kozeny model (Kozeny, 1927) is one of the earliest models proposed to estimate the permeability from the effective porosity and other relevant parameters by the following equation.(Kozeny, 1927).

$$K = \frac{Ø\, r^2}{8\, t}$$

eq.(7)

where:

K is the permeability in mD, t is the tortuosity

r is the radius of capillary tubes in µm.

In equation (7) r was used by Kozeny and Carmen for realistic porous media and the equation was modified in the generalized by (Carmen, 1937) as:

$$K = \frac{1}{\mathrm{fs}.t^2.\ S^2 gv} * \frac{Ø^3}{(1-Ø)^2}$$

eq.(8)

where:

K in µm^2, fs is the shape factor, Ø in fraction, t is the tortuosity and S^2 gv specific surface area of unit grain volume in µm

RQI addresses variable Kozeny constant and S^2 gv term by the flow zone indicator (FZI), which includes all main geological and geometrical characteristics of the porous media as:

$$FZI = \frac{1}{\sqrt{\mathrm{fs}.t^2.\ S^2 gv}}$$

eq.(9)

$$K = \frac{Ø^3}{(1-Ø)^2} * FZI^2$$

eq.(10)

$$\frac{\sqrt{K}}{Ø} = \left[\frac{Ø}{1-Ø}\right] * FZI$$

eq.(11)

If permeability is expressed in mille Darcie, then, the RQI is defined as follows: (Leverett, 1941).

$$RQI = 0.0314 * \left(\frac{K}{Ø}\right)^{0.5}$$

eq. (12)

Hydraulic flow units:

Hydraulic flow unit (HFU) is defined as a representative reservoir volume practically possesses consistent petrophysical and fluid properties (Amaefule et al., 1993). The hydraulic flow unit concept is used to divide a reservoir into distinct petrophysical types, each of which has a unique flow zone indicator (FZI) value (Al-Ajmi and Holditch, 2000). The hydraulic flow unit (HFU) concept provides a probabilistic approach for combing the geological environments units, with available petrophysical data, to delineate the reservoir into "units" , with similar fluid flow characteristics. Hydraulic flow units are used to rank the dynamic rock-fluid properties, including the saturation-dependent capillary pressure and the relative permeability. Hydraulic units are characterized by the following:

a) Geological attributes of texture (which include mineralogy, sedimentary structure, bedding contacts, and permeability barriers).

b) Petrophysical properties of porosity, permeability, and capillary pressure.

Amaefule et al., (1993) presented the method for the use of hydraulic flow units (HFUs) to divide rock facies as a result of the considerable variation of permeability even in well-defined rock type, and used the concept of a bundle of capillary tubes and gave an equation which was re-arranged to isolate the variable that is constant within a hydraulic flow unit (HFU). According to Amaefule et al., Guo et al. (2005) the flow units in the reservoir are determined using flow zone indicators (FZI) and reservoir quality index (RQI) as follow. (Leverett, 1941).

$$FZI = \frac{RQI}{Øz}$$

eq.(13)

$$Øz = \frac{Ø}{(1-Ø)}$$

eq.(14)

where

K is the permeability mD, Ø is the porosity fraction and

Øz is the normalized porosity.

The relationship between RQI and Øz is used to show that, the samples with similar FZI values lie close together on a log plot of normalized porosity versus permeability (Amaefule et al., 1993).

Log RQI =Log Øz+Log FZI eq. (15)

A plot of RQI versus Øz for data from the cored interval is shown in: Fig. 8, Equation 15 yields a straight line on a log-log plot of RQI versus Øz with a unit slope, The intercept of this straight line at 1 is the flow zone indicator.

The FZI is calculated using equation (13) and equation (14) after the calculation of RQI, where the corrected conventional core analysis data for porosity and permeability were used in the calculation of RQI, then the FZI flow units were defined. Four main hydraulic flow units (HFU's) control the reservoir performance are defined for the cored interval in Salma Delta-4 well. (Fig. 9).

The Hydraulic Flow unit's data are given in table (2).

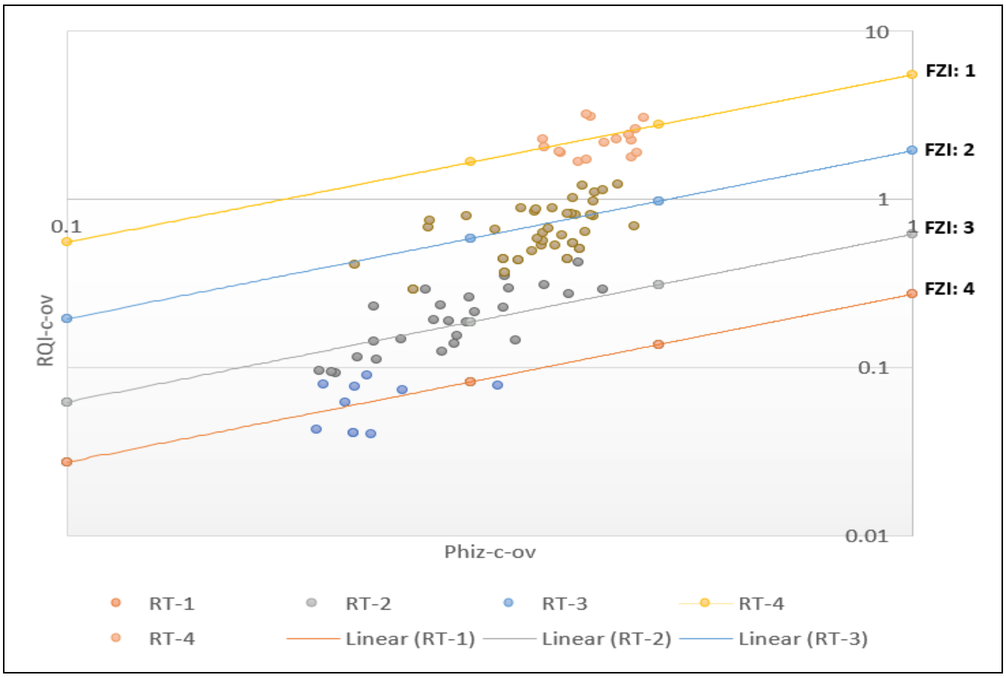

Figure 8: Determination of FZI from PHIZ and RQI.

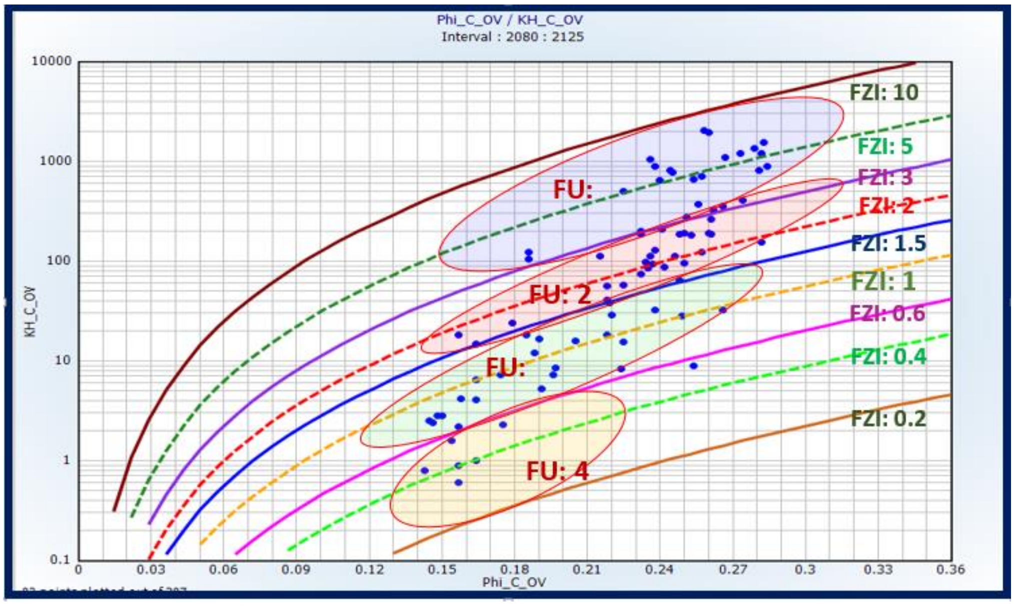

Figure 9: Porosity vs. horizontal permeability X-plot superimposed on flow zone indicator lines and defiend hydraulic flow unit.

Table 2: Summary of Hydraulic Flow unit (HFU's) for Abu Madi reservoir.

Reservoir Quality	HFUs	(FZI)	PHI (%)	KH (MD)
Very good quality sandstone	HFU-1	3 – 10	18 -29	100 - 1100
Good quality sandstone	HFU-2	1.5 – 3	16 - 28	10 - 400
Moderate quality sandstone	HFU-3	0.6 – 1.5	14 -26	2 - 50
Poor quality sandstone	HFU-4	0.2 – 0.6	14 - 18	0.5 - 2

Permeability Prediction

The next step is to predict the permeability for each HFU, depending on the curve of FZI or the average value FZI, using the following equations:

$$K = 1014\,FZI^2 * \frac{Ø^3}{(1-Ø)^2}$$

q.(16).

Using the average FZI related to HFU zones as follows:

$$K\_HFU\#1 = 1014 * 25 * \frac{Ø^3}{(1-Ø)^2}$$

For average FZI= **5** eq.(17)

$$K\_HFU\#2 = 1014 * 4 * \frac{Ø^3}{(1-Ø)^2}$$

For average FZI= **2** eq.(18)

$$K\_HFU\#3 = 1014 * 1 * \frac{Ø^3}{(1-Ø)^2}$$

For average FZI= **1** eq.(19)

$$K\_HFU\#4 = 1014 * 0.16 * \frac{Ø^3}{(1-Ø)^2}$$

For average FZI= **0.4** eq.(20)

Neural network:

The neural network technique was used to reduce the multidimensional data sets to lower dimensions for analysis. This technique can be useful in petrophysics and geology, as a preliminary method of combining the multiple logs into a single or two logs, without losing information.

This method is statistical in nature, but its results are seen to be geologically consistent Statistical modeling, using the effective porosity (PHIE), shale volume (VWCL), and photo-electric curves (PEFZ) to predict the FZI curve using the FZI calculated within cored intervals. Correlation of the predicted FZI and calculated one against the cored intervals reflects similar response and high correlation between the curves, then apply it into other logged wells and predict the FZI in the uncored intervals and other wells.

CONCLUSION

In this study, The flow zone indicator (*FZI*) approach was used to classify the reservoir rock into separate zones, that have similar rock characteristics; which are known as hydraulic flow units (HFU), The prediction of permeability is available from the integration between the core and wireline log data for Abu Madi formation in Salma Delta field. To achieve this study, log and core data are used, well log data include composite log, Gamma Ray, Density, Neutron, Resistivity and Sonic log, provided by El Wastani Petroleum Company in LAS and ASCII formats, and porosity, permeability from core data.

The Abu Madi reservoir in the study area has been defined into four hydraulic flow units, HFU-1 with very good quality sandstone, which have permeability of 100-1100 mD, porosity of 18-29 %, and FZI of 3-10. The second is HFU-2 with good quality sandstone, which have permeability of 10-400 mD, porosity of 16-28 %, and FZI of 1.5-3. The third is HFU-3 with moderate quality sandstone, which have permeability of 2-50 mD, porosity of 14-26 %, and FZI of 0.6-1.5. The forth is HFU-4 with poor quality sandstone, which have permeability of 0.5-2 mD, porosity of 14-18 %, and FZI of 0.2-0.6. By FZI values the permeability can be predicted from the cored wells to the un-cored wells. Neural log analysis using core and log data are reasonably for prediction of permeability in un-cored intervals and un-cored wells.

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