



Investigation of Reservoir Flow Unit and Rock Types of Mishrif Formation in Amara Oil Field and Prediction of Performance

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Abstract

Amara oil field is located at south eastern Iraq in Missan governorate. The Mishrif Formation in Amara field is one of the most important reservoirs in southern Iraq. Identifying and characterizing petrophysical flow units are the key to understanding and improving reservoir description, exploitation, production and predicting the performance of carbonate reservoirs to represent them as combinations of different flow units, each with uniform pore throat size distribution and similar performance. Mishrif Formation in Amara oil field was divided into seven reservoir units (MA, MB11, MB12, MB13, MB21, MC1, and MC2) separated between them barrier beds. The present work is a reservoir flow unit identification for (MA) and (MB11) reservoir units of the Mishrif Formation in two wells ,Amara oil Field (Am-1, and Am-3) using available core data. Also Winland's approach was used to predict pore throat types that corresponds to the R35 value which is a function of entry size and pore throat sorting, and is a good measure of the largest connected pore throats in a rock with intergranular porosity. Determined R35 using Winland's model shows the reservoir rock type of MA unit is better than reservoir rock type in MB11 unit. According to R35 values, the pore throat types of Mishrif Formation in MA unit are mostly of meso, micro, macro, and mega type respectively and negligible existences of nano type, where as MB11 unit consists mostly of meso, macro and micro type respectively with few existences of nano pore type and without any mega type. Application of petrophysical flow unit types approach from routine core analysis indicates that MA unit of Mishrif Formation consists of five hydraulic flow units in wells under study where as MB11 unit has four hydraulic flow units.

Keywords: Amara oil field, Mishrif Formation, petrophysical flow units.

التحقق عن وحدات الجريان المكمنية ونوع الصخور لتكوين المشرف في حقل نفط العمارة والتنبؤ بأدائها

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الخلاصة

يقع حقل العمارة النفطي جنوب شرق العراق في محافظة ميسان. يعتبر تكوين المشرف في حقل نفط العمارة واحد من اهم المكامن في جنوب العراق. أن معرفة وتمييز وحدات الجريان البتروفيزيائية هي بمثابة المفتاح لفهم وتحسين واكتشاف و انتاج المكامن والتنبؤ بأدائية المكامن الكربوناتيية لتمثيلها كمجموعة من مختلف الوحدات الجريانية حيث ان لكل وحدة من هذه الوحدات الجريانية تتميز بتوزيع وحجم مميز لعنق

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المسام وأداء متشابه. تم تقسيم تكوين المشرف في حقل العمارة النفطي الى سبع وحدات مكمنية (MA, MB11, MB12, MB13, MB21, MC1 MC2) يفصل بينها طبقات عازلة. تمثل الدراسة الحالية معرفة الوحدات الجريانية المكمنية للوحدتين المكمنيتين (MA) و (MB11) لتكوين المشرف في بئرين من أبار حقل العمارة (Am-1 و Am-3) بأستخدام معلومات اللباب المتوفرة. كذلك استخدمت طريقة Winland's للتنبؤ بنوع عنق المسام التي تتعلق بقيمة R35 . التي بدورها تعتبر دالة لحجم المسام وتنسيقها وكذلك تعتبر مقياس جيد لمعرفة اتصال اعناق المسام فيما بينها في الصخور المسامية. ان قيمة R35 المحسوبة بأستخدام معادلة Winland's بينت ان نوع الصخور المكمنية للوحدة MA هي افضل من صخور مكن الوحدة MB11. اعتمادا على قيمة R35، ان نوع اعناق المسام في تكوين المشرف للوحدة المكمنية (MA) هي معظمها من نوع meso, micro, macro, mega على التوالي مع تواجد مهمل تقريبا من نوع nano بينما الوحدة (MB11) تتكون معظمها من نوع micro, meso, macro على التوالي مع تواجد قليل من نوع nano وعدم ظهور للنوع mega. ان تطبيق معرفة وحدات الجريان البتروفيزيائية من تحاليل اللباب المتوفرة يدل على ان الوحدة (MA) لتكوين المشرف تتألف من خمس وحدات جريان هايدروليكية بينما الوحدة (MB11) تمتلك اربع وحدات جريان هايدروليكية.

Introduction:

Carbonate reservoir interpretation depends on a wide range of reservoir parameters that need to be identified and characterized before building the reservoir model. To understand reservoir rock / fluid interaction and predict performance, the reservoir may be subdivided into flow units and containers to represent them as combinations of different flow units, each with uniform pore throat size distribution [1]. Flow units in carbonate reservoirs can be defined as reservoir zones that are continuous laterally and vertically and have similar flow and geological properties, such as texture, mineralogy, sedimentary structures, bedding contacts, and the nature of permeability barriers, combined with quantitative petrophysical properties, such as porosity, permeability, capillarity, fluid Saturations, and pore throat properties of the porous media. It represents one or more reservoir quality rock types within that same volume [2].

Each flow unit is characterized by a Flow Zone Indicator (FZI), reservoir zonations with the use of flow zone indicator, and the identification of flow units can be used to evaluate the reservoir's quality based on porosity – permeability relationships; each distinct reservoir type has a unique FZI value [3]. Rock/pore types are units of rock deposited under similar conditions which experienced similar diagenetic processes, resulting in a unique porosity – permeability relationship, capillary pressure profile, and water saturation for a given height above free water in a reservoir .

Well flow rate is a function of the pore type, pore geometry, number and location of the various flow units exposed to the well bore and the pressure differential between the flow units and well bore [4].

Reservoir Description:

The field under study is located at south eastern Iraq in Missan province, about 10 Km south western Amara city and about 25 Km east of Al-Rafedain structure (Abu-Amoud structure), and about 30 Km southeast Al-Kumait structure figure-1. Amara structure is assumed to be a low-relief dome though slightly W-E elongated, having dimensions of approximately 16 Kms width (from west to east side) by 5 Kms length (from south to north) as defined from Amara area 2D seismic lines figure-2 [5]. The Mishrif Formation represents a heterogeneous formation originally described as organic detrital limestones with beds of algal, rudist, and coral-reef limestones, capped by limonitic fresh water limestones [6]. The abundant fauna listed by Bellen et al. [6] indicated that the formation is of Cenomanian- Early Turonian age. The formation was deposited as rudist shoals and patch reefs over growing subtle structural highs developing in an otherwise relatively deeper shelf on which marine sediments of the Rumaila Formation were deposited [7]. The lower boundary of the formation is conformable. The underlying unit is usually the Rumaila Formation. The upper contact is unconformable with the Khasib Formation [8]. The equivalent formations of the Mishrif formation are Gir-bir Formation in the North and the Balambo Formation of the deeper eastern and intrabasinal part of the same basin of the Dokan Formation [9].

Methodology:

A total of more than 150 core permeability and porosity measurements from two wells (Am-1, and Am-3) were attained from archive of Missan Oil Company and were used to calculate the reservoir flow units and pore throat size and type. A data set of laboratory measurements porosity and permeability of core samples were available only in two reservoir units of Mishrif Formation (MA, and MB11) in the wells under study. The upper units of Mishrif Formation (MA, and MB11) represent the principal oil bearing units and were selected in this work to determine the reservoir flow units. Figure-3 illustrates the available intervals of core data for porosity and permeability as well as the units of Mishrif Formation in studied wells of Amara field which divided into seven reservoir units separated by barrier beds.

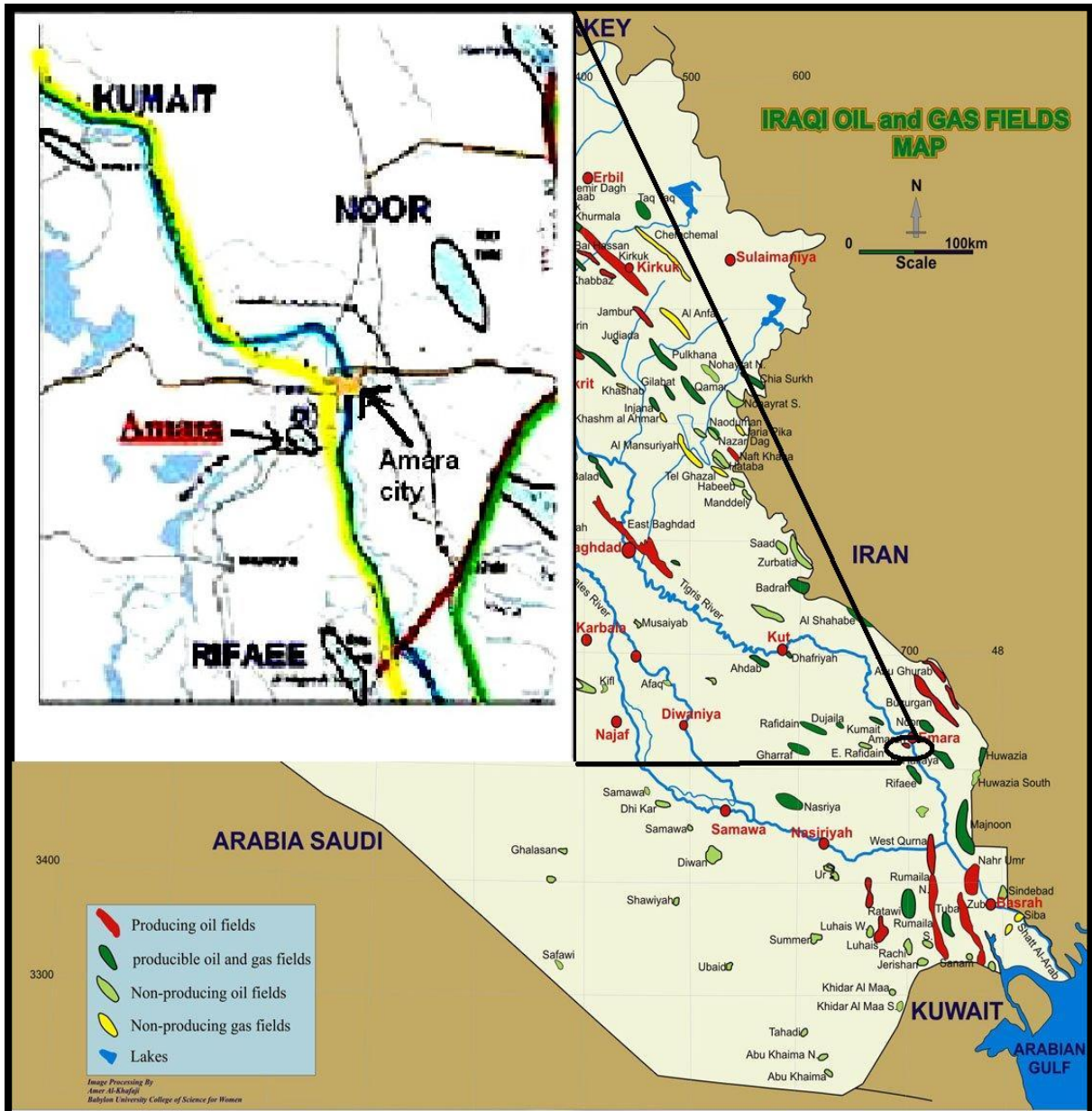


Figure 1- Location map of Amara oil field (modified from Al-Baldawi 2012[10]).

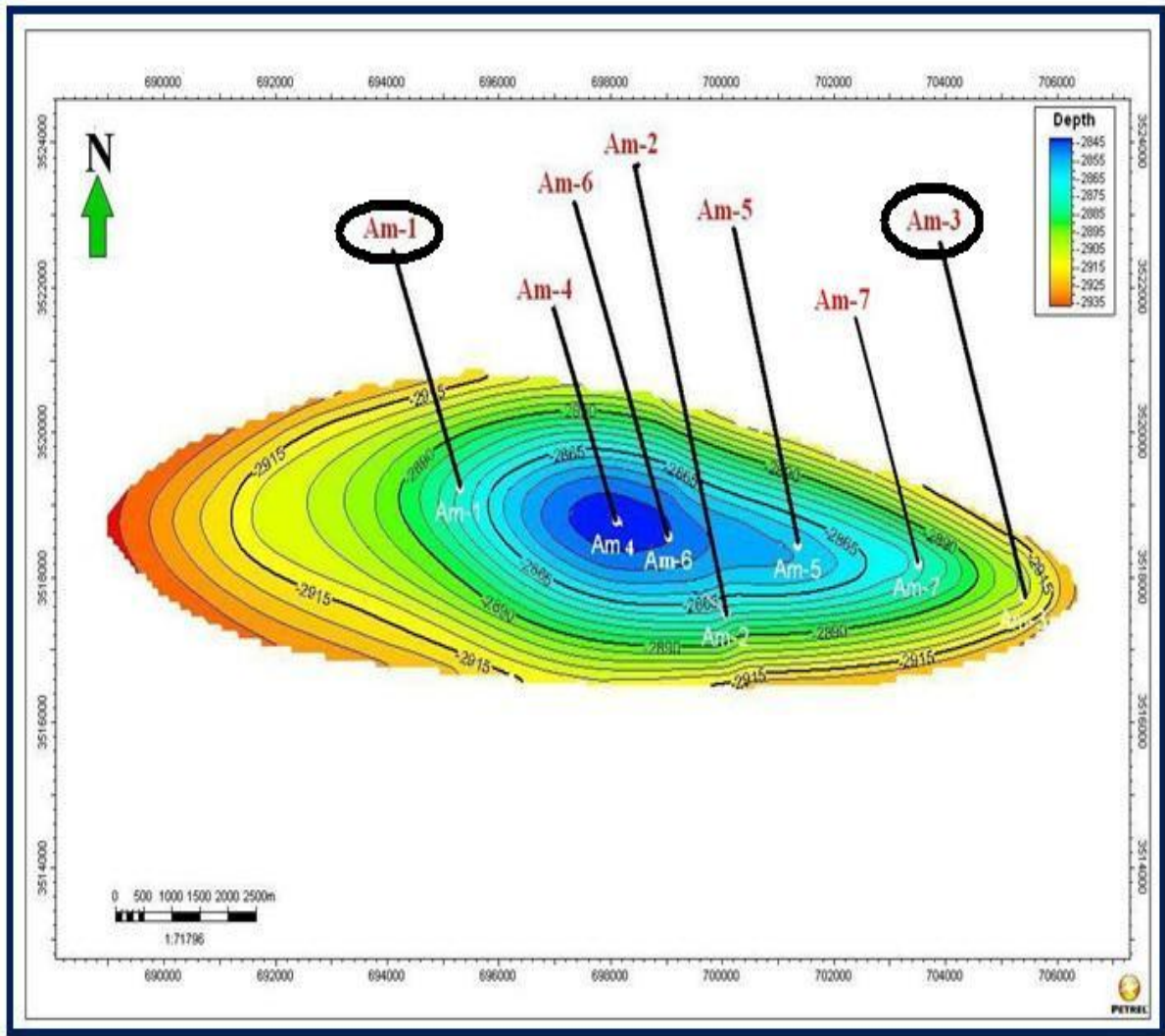


Figure 2- A 3D structure contour map on the top of Mishrif Am-6 with the location of studied wells [10].

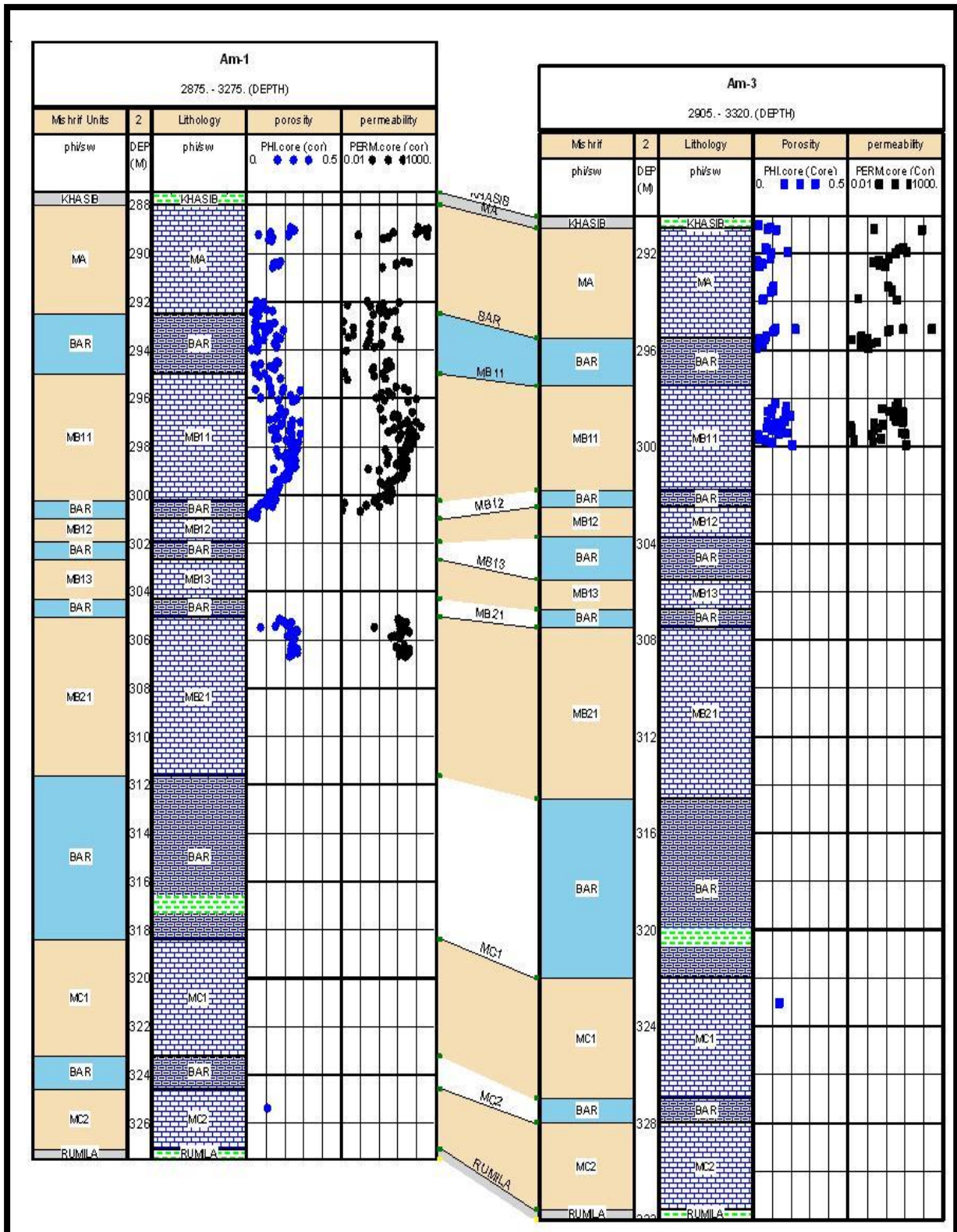


Figure 3- correlation section of Mishrif formation in Amara field that illustrates the Mishrif units with its available porosity and permeability samples in the studied wells.

Derivation of Regression Models for (FZI) and hydraulic flow units Prediction:

A petrophysical flow unit is defined as an interval of sediment with similar petrophysical properties such as porosity, permeability, water saturation, pore throat radius, storage and flow capacity, that are differ from the intervals immediately above and below. Petrophysical flow units are

usually grouped to define containers. Flow units have become popular means of characterizing or zoning a reservoir.

Amaefule, Tiab and others (1993) [11] proposed a new method to identify and characterize flow units. The technique developed is focused at extracting characterization detail at the pore throat level or scale.

Further discussion regarding pore throat analysis is included in the reservoir characterization section. The pore geometry determines the hydraulic quality of the rock. Amaefule, Tiab and others (1993) [11] demonstrated a methodology by which reservoir pore throats are analyzed which results in the ability to identify flow units with similar hydraulic properties. The researchers developed this new methodology by modifying the Kozeny [12]-Carmen [13] equation. This equation expressed permeability in terms of porosity and specific surface area. Three terms must be defined:

Flow Zone Indicator

$$(FZI) = 1 / ((S_{vgr}) (kz)^{0.5}) \dots\dots\dots(1)$$

Reservoir Quality Index

$$(RQI) = 0.0314 (k / \phi_e)^{0.5} \dots\dots\dots(2)$$

Normalized Porosity Index

$$(\phi_z) = \phi_e / (1 - \phi_e) \dots\dots\dots(3)$$

Where S_{vgr} is defined as the specific surface area per unit grain volume, kz is the Kozeny constant, which reflects grain shape, pore shape and tortuosity for the flow unit. The FZI value is considered to be constant within a flow unit. FZI is also defined as:

$$FZI = RQI * \phi_z \dots\dots\dots(4)$$

The derivation from the Kozeny[11]-Carmen[12] equation yields the following logarithmic relationship:

$$\log RQI = \log \phi_z + \log FZI \dots\dots\dots(5)$$

Equations (2) through (4) are used to compute the functions for preparing a log-log plot of RQI versus ϕ_z for Mishrif reservoir of the wells under study. A log-log plot of data from a given flow unit or similar FZI value will be situated on a straight line with a slope of 1.0. The researchers further demonstrated that other flow units will fall on adjacent parallel lines. Each flow unit will have a separate FZI value. The FZI value or indicator will be for a given flow unit having similar pore throat characteristics.

Pore Throat Radius Analysis:

Pore throat size may be estimated from routine core porosity and permeability data. Combining these data with mercury injection capillary pressure results, **Winland (1972) [14]** developed an empirical relationship between porosity, air permeability and pore aperture corresponding to a mercury saturation of 35% (R_{35}). Winland equation was used in this study and is given below:

$$\text{Log} (R_{35}) = 0.732 + 0.588 * \text{Log} (k_{air}) - 0.864 * \text{Log}(\phi) \dots\dots\dots(6)$$

Where:

k_{air} : uncorrected air permeability (md), and

ϕ : porosity (%).

R_{35} : pore throat radius is defined as the pore throat size from mercury injection capillary pressure data where the non wetting fluid (mercury) saturates 35% of the porosity.

R_{35} pore throat radii is a function of entry size and pore throat sorting, and is a good measure of the largest connected pore throats in a rock with intergranular porosity [15].

Determination of Rock Types:

Reservoir rock can be classified based on R_{35} pore throat radius, which is a dominant control on the permeability and flow characteristics of the reservoirs. The reservoir rock can be divided into five petrophysical categories [16]:

Megaporous, defined by pore throat radius > 10 microns

Macroporous, defined by a pore throat radius between 2 and 10 microns

Mesoporous, defined by a pore throat radius between 0.5 and 2 microns

Microporous, defined by a pore throat radius between 0.1 and 0.5 microns

Nannoporous, defined by pore throat radius < 0.1 microns.

Results and Discussion:

In This study Normalized Porosity Index (ϕ_z), Reservoir Quality Index (RQI), Flow Zone Indicator (FZI), and R_{35} have been measured for all core samples of wells under study figure-4 and figure-5. In order to resolve the performance of the different studied Mishrif units, we study the effect of petrophysical flow unit types on the relationship between porosity and permeability as well as on the relationship between normalized porosity Index (ϕ_z) and reservoir quality Index (RQI) for all studied core samples and their influence will be distinguished from crossplots.

Figure 6 and figure-7 show a cross plot of the logarithm of (RQI) versus the logarithm of (ϕZ) for various values of the Flow Zone Indicator (FZI). All the data points that fall on the same (FZI) straight line can be considered to have similar pore throat attributes (i.e., they represent the same hydraulic unit).

Figure-6 shows the existences of five distinct hydraulic flow units within the cored interval of MA unit in studied wells.

Figure-7 shows the existences of four distinct hydraulic flow units within the cored interval for MB11 unit. Each of these hydraulic flow units is characterized by a certain average FZI value.

Figure-8 and figure-9 show a cross plot of the logarithm of permeability vs. porosity data obtained from core analyses. The great scattering in pore throat sizes indicates large variations in particle size and sorting within each rock type; that in turn control permeability.

Figure-10 illustrates the relationship between porosity, permeability and R_{35} for MA unit. This figure shows that the reservoir pore types of Mishrif Formation in MA unit are mostly of meso, micro, macro, and mega type respectively and negligible existences of nano type. The relationships between the porosity and permeability for MA unit samples are improved in the meso, macro and mega flow unit type, indicates that these ranges of R_{35} values affect on the permeability of this unit by increasing the values of R_{35} the connectivity between the pores increases and so fluid flow increase and permeability will be the major controlling factor.

Figure-11 depicts the relationship between porosity and permeability with the R_{35} for MB11 unit. This figure shows that the reservoir pore types of Mishrif Formation in this unit are mostly of meso, macro and micro type respectively with few existences of nano pore type and without any mega type.

Figure-12 and figure-13 and figure-14 show The relationship between porosity and permeability for the MA reservoir unit of micro, meso, and macro flow unit respectably. The sample data points distribution present a strong relationship of high correlation coefficient. The regression equation and correlation coefficient are shown in figures. The relation between the porosity and permeability is improved, that indicates these range of R_{35} values affect on the permeability of our studied samples. Improvement of the porosity permeability relationship is clearly appears on these figures at this range of values of pore throat radii R_{35} of this flow unit type. The permeability values increase with increasing R_{35} values which controlling the permeability and directly related to fluid flow.

Figure- 15 illustrates the relationship between porosity and permeability for studied samples of mega flow unit type. The figure presents a good relationship with a correlation coefficient (R_2) = 0.56. The samples data points of larger values of R_{35} and so permeability and fluid flow values. At this reservoir flow unit type data samples the relation is good but not perfect so the Micro, Meso, and Macro flow unit respectably are direct affect on permeability more than Mega flow unit.

For the studied MB11 unit at the Nano flow unit type as shown in figure- 16. There is no relationship or weak relationship exists between the porosity and permeability. This is plausible, because at this ranges of pore throat radius, R_{35} smaller than 0.1 μm , permeability is too low and no fluid flow exist. The porosity and permeability relationship is very weak at the scale of nano flow unit type because pore throat radii are too small and impede the fluid flow. Figure- 17 and figure-18 and

figure- 19 depict the relationship between porosity and permeability for all studied samples of micro, meso and macro flow unit types. The figures show strong relationship between the the porosity and permeability which indicate these ranges of R35 values affect on the permeability of our studied samples.

However, at the micro, meso and macro flow unit types, the improvement of the relationship is caused by increasing the pore throat size and so the permeability and amount of fluid flow. So by using of the graphically predicted R35 it is able to get real discrimination between reservoir and non reservoir zones which improve the porosity permeability relationship. This is due to the pore throat radii at 35% are directly related to permeability and reservoir performance.

Conclusions:

The parameters that influence fluid flow are mainly pore throat geometrical attributes. The pore geometry is in turn controlled by mineralogy and texture. Various combinations of these geological properties can lead to distinct rock flow units that have similar fluid transport properties. Therefore, an HU can include several rock facies types, depending on their depositional texture and mineralogical content, The analyses of HU that were based on (FZI) showed the existence of five distinct hydraulic flow units within the cored interval of the lithological MA unit of Mishrif reservoir in studied wells. It also showed that only four hydraulic flow units were indicated in the cored interval of the MB11 reservoir unit.

Estimated R35 using Winland's model shows the reservoir rock type of MA unit is better than reservoir rock type in MB11 unit. According to R35 values, the pore throat types of Mishrif Formation in MA unit are mostly of meso, micro, macro, and mega type respectively and negligible existences of nano type, where as MB11 unit consists mostly of meso, macro and micro type respectively with few existences of nano pore type and without any mega type.

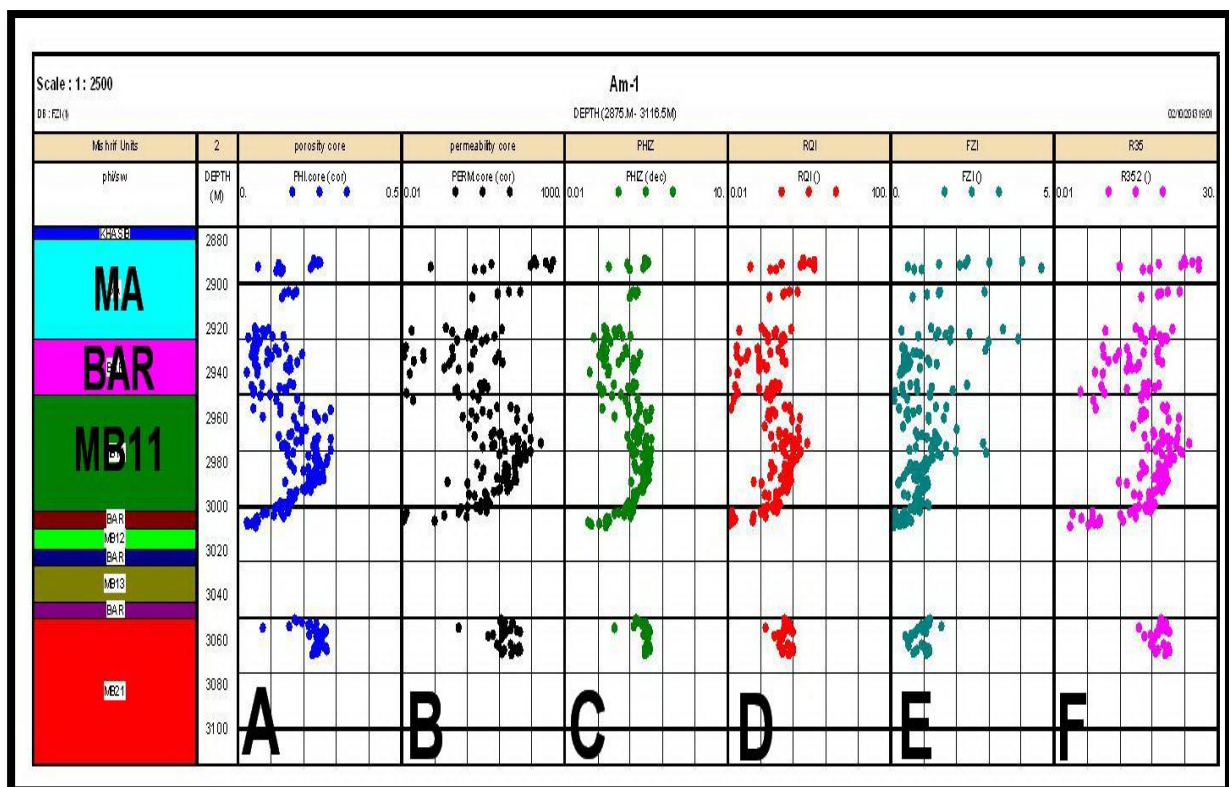


Figure 4- The measurements of (A) porosity (B) permeability (C) ØZ (D) RQI (E) FZI (F) R35 in well Am-1.

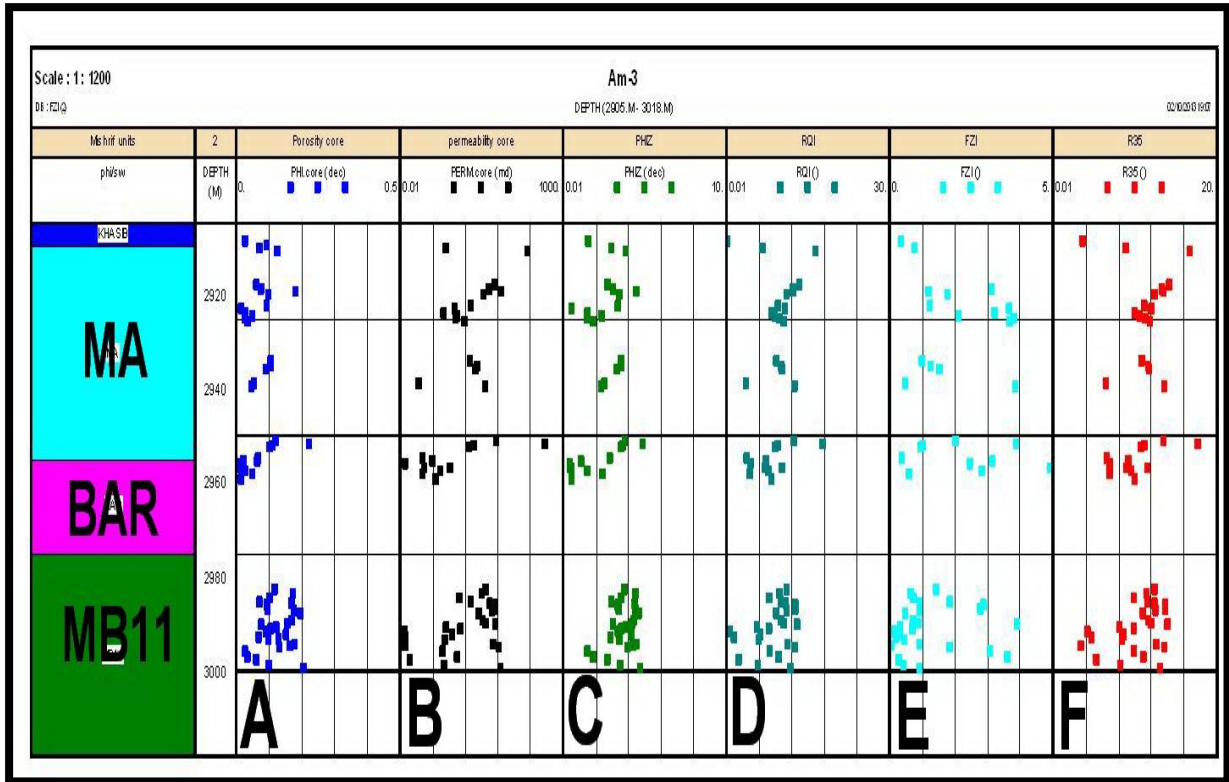


Figure 5- The measurements of (A) porosity (B) permeability (C) ϕZ (D) RQI (E) FZI (F) R35 in well Am-3.

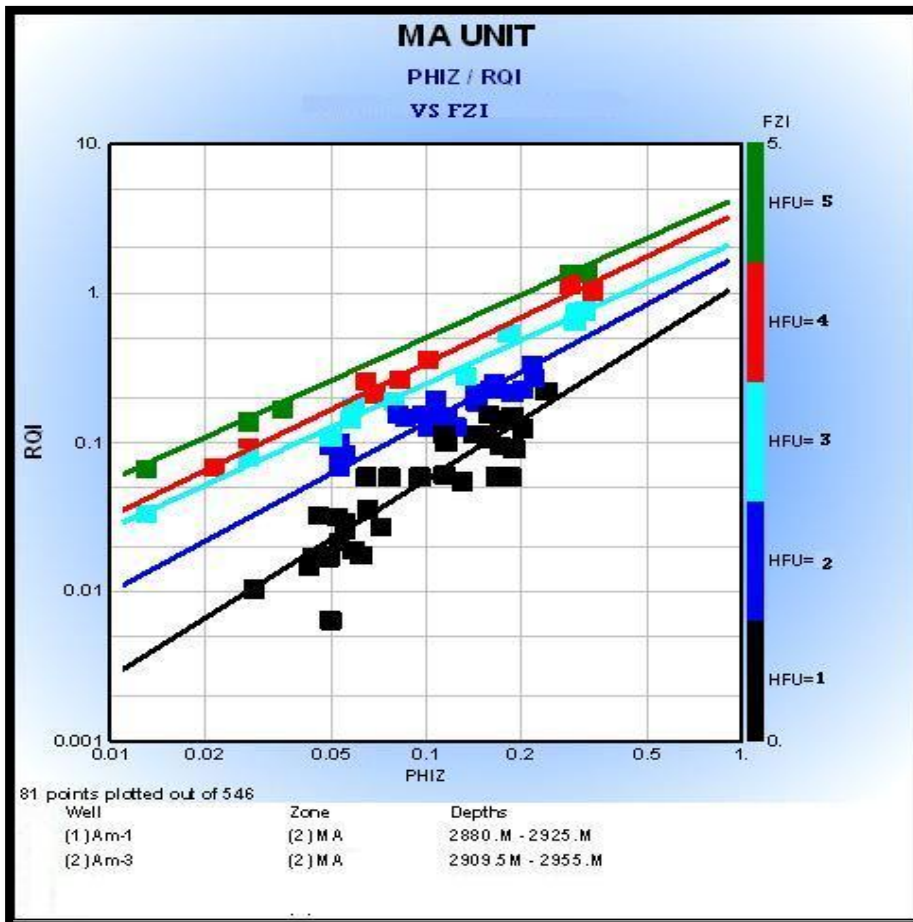


Figure 6- Cross plot of logarithm RQI versus logarithm ϕZ with Flow Zone Indicator (FZI) for MA unit.

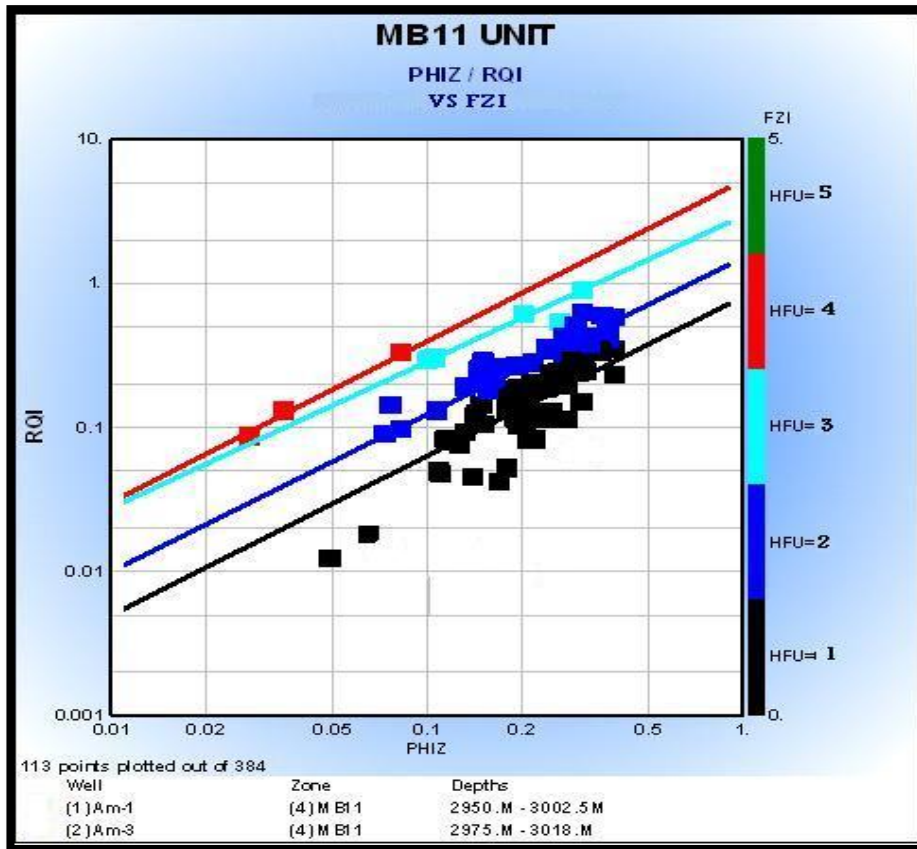


Figure 7- Cross plot of logarithm RQI versus logarithm ϕZ with Flow Zone Indicator (FZI) for MB11 uni

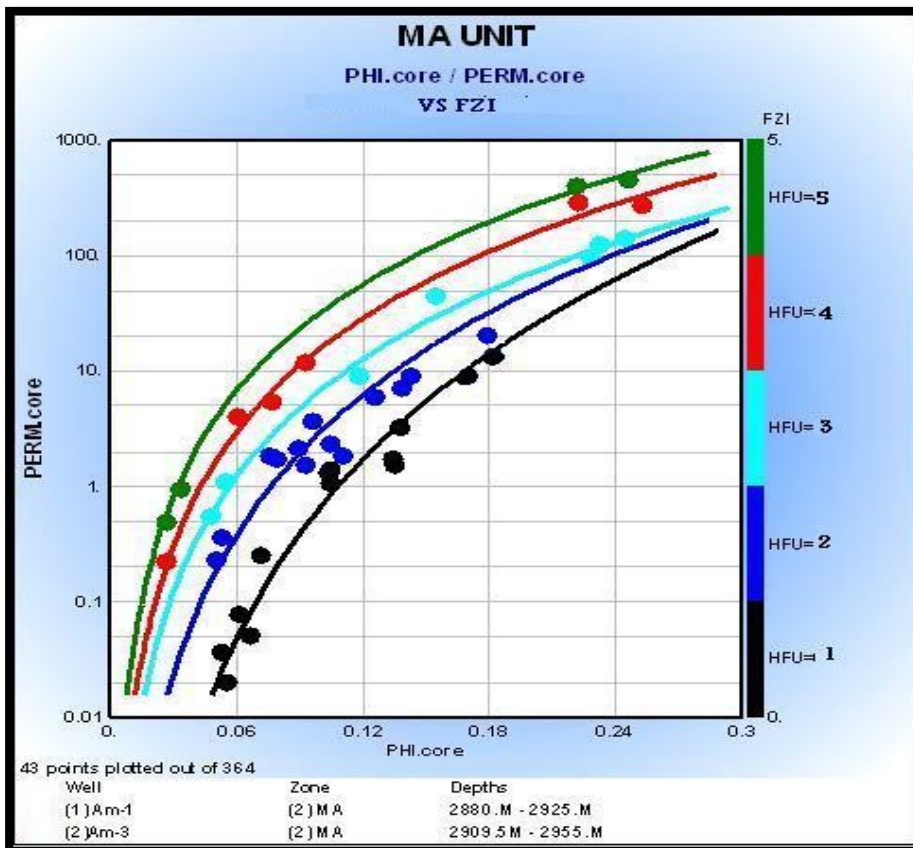


Figure 8- Cross plot of core permeability vs. core porosity with Flow Zone Indicator for MA UNIT

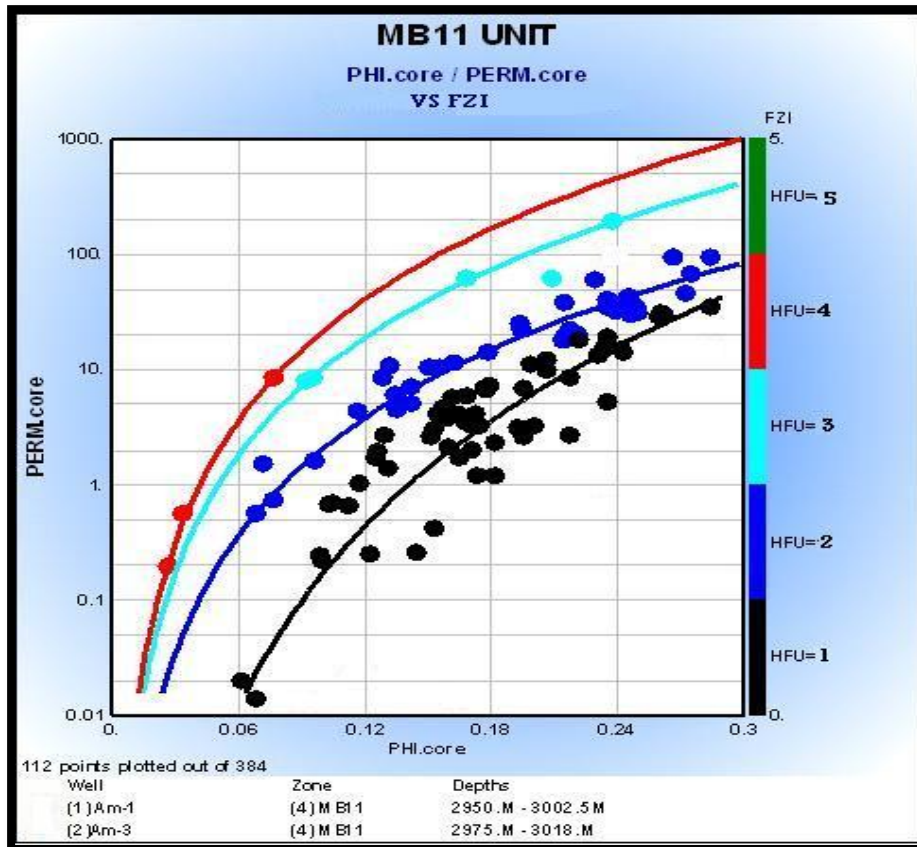


Figure 9- Cross plot of core permeability vs. core porosity with Flow Zone Indicator for MB11 unit.

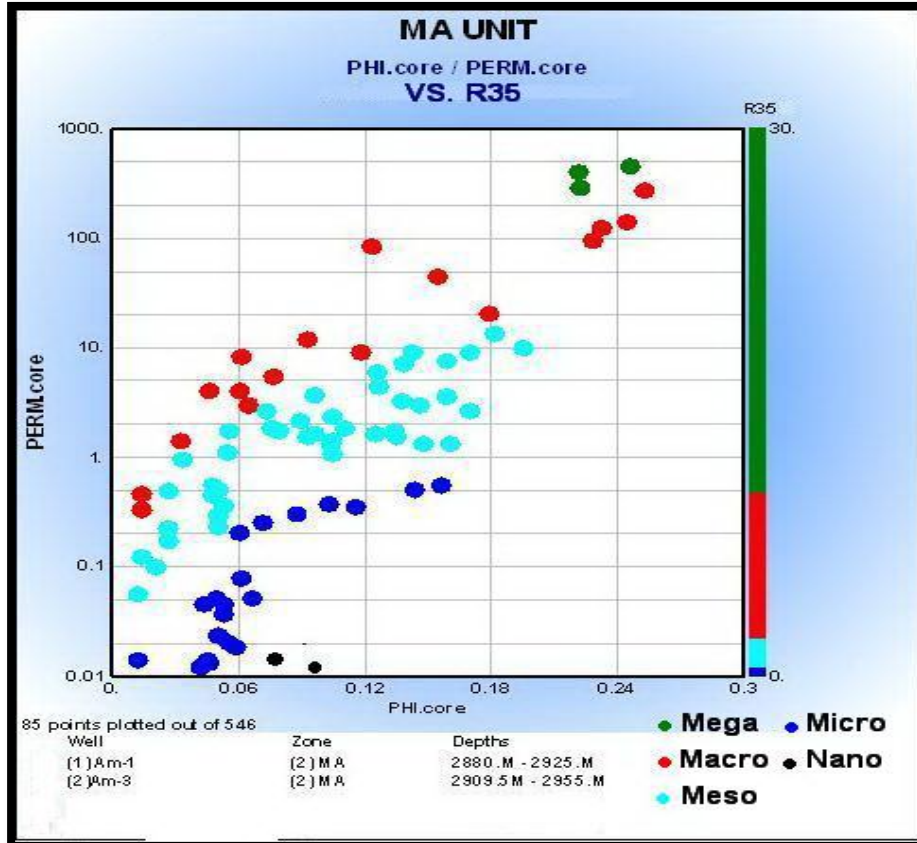


Figure 10- Cross plot of core permeability vs. core porosity with R35 for MA unit.

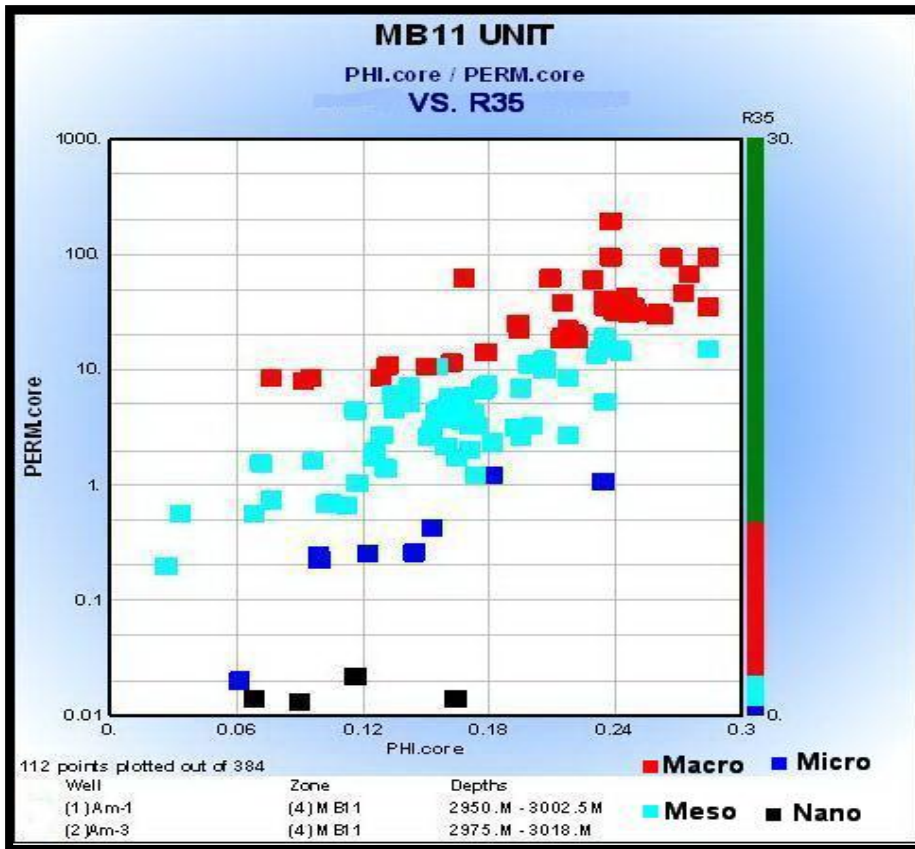


Figure 11- Cross plot of core permeability vs. core porosity with R35 for MB11 unit.

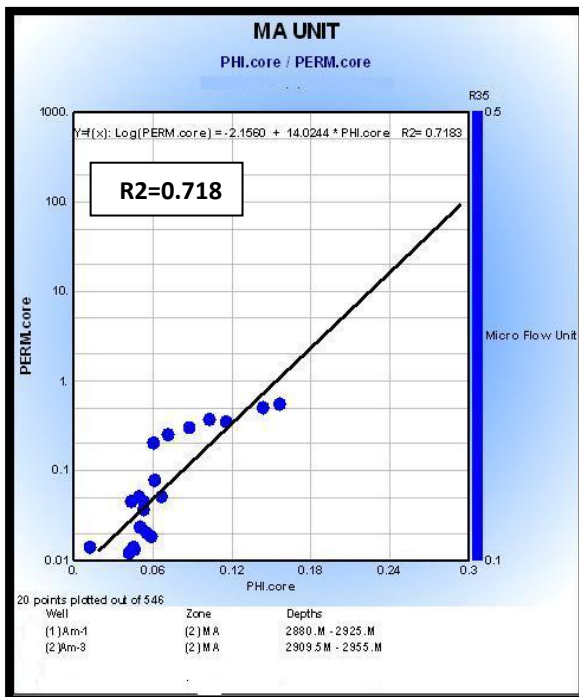


Figure 12- The relationship between Log K vs. Phi for the MA Reservoir Unit samples, R35= (0.1-0.5) (Micro flow unit).

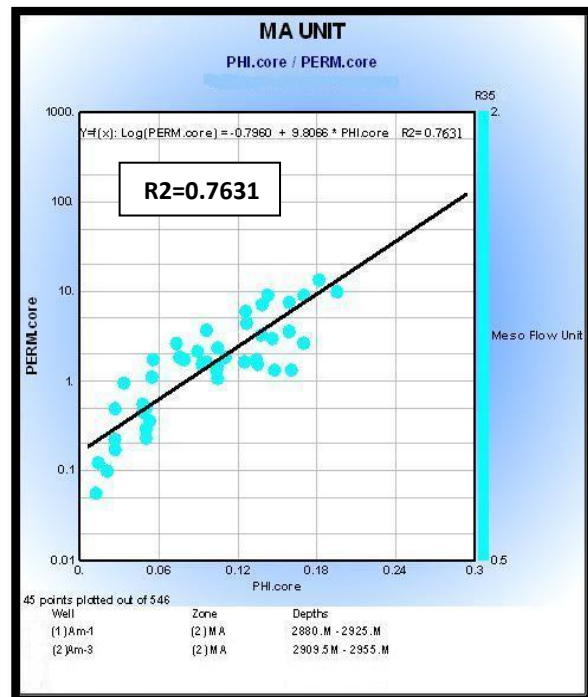


Figure 13- The relationship between Log K vs. Phi for the MA Reservoir Unit samples, R35= (0.5-2) (Meso flow unit).

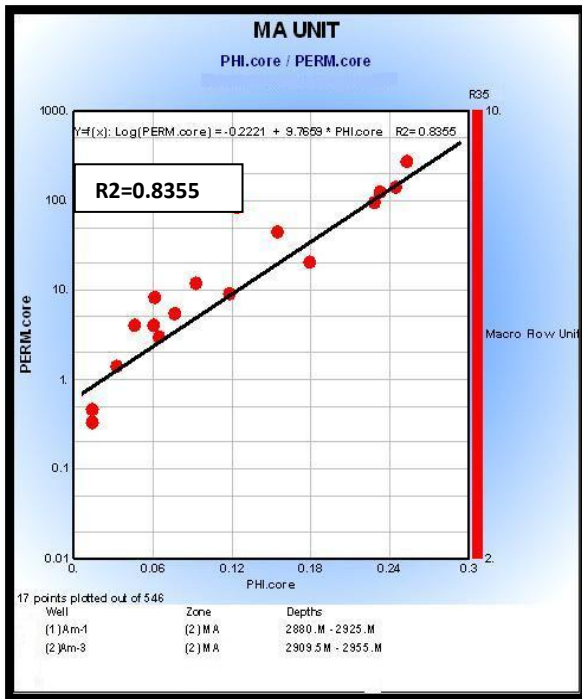


Figure 14- The relationship between Log K vs. Phi for the MA Reservoir Unit samples, R35= (2-10) (Macro flow unit).

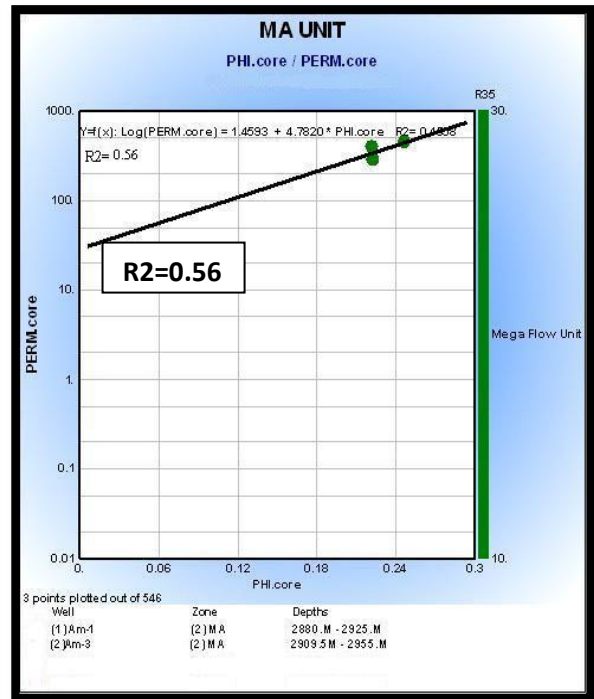


Figure 15- The relationship between Log K vs. Phi for the MA Reservoir Unit samples, R35= > 10 (Mega flow unit).

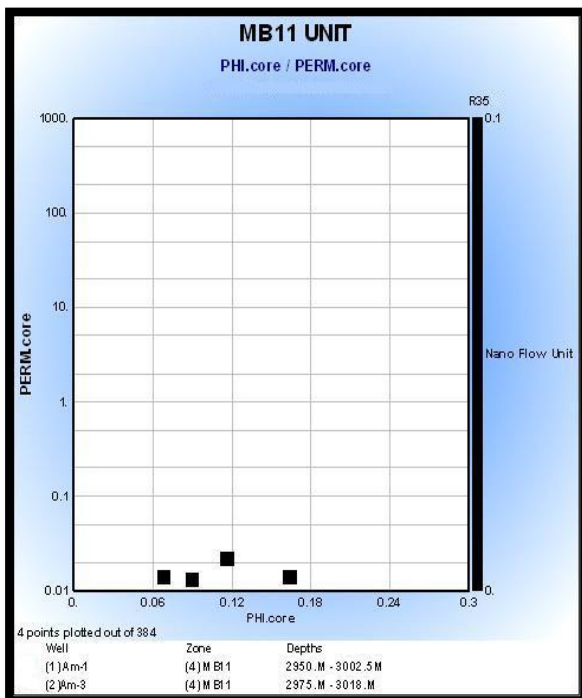


Figure 16- The relationship between Log K vs. Phi for the MB11 Reservoir Unit samples R35= < 0.1 (Nano flow unit).

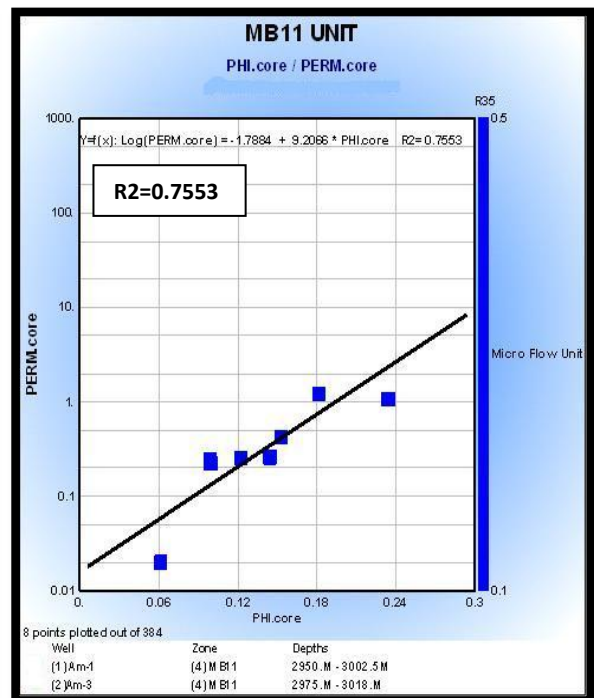


Figure 17- The relationship between Log K vs. Phi for the MB11 Reservoir Unit samples, R35= (0.1-0.5) (Micro flow unit).

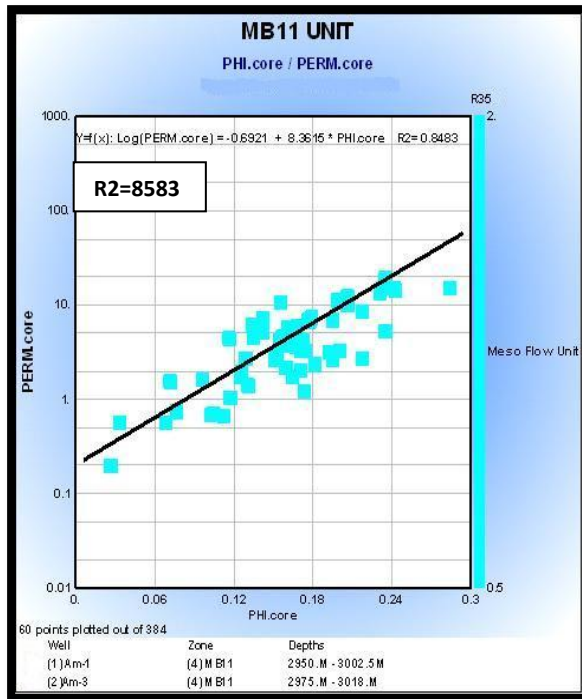


Figure 18- The relationship between Log K vs. Phi for the MB11 Reservoir Unit samples, R35= (0.5-2) (Meso flow unit).

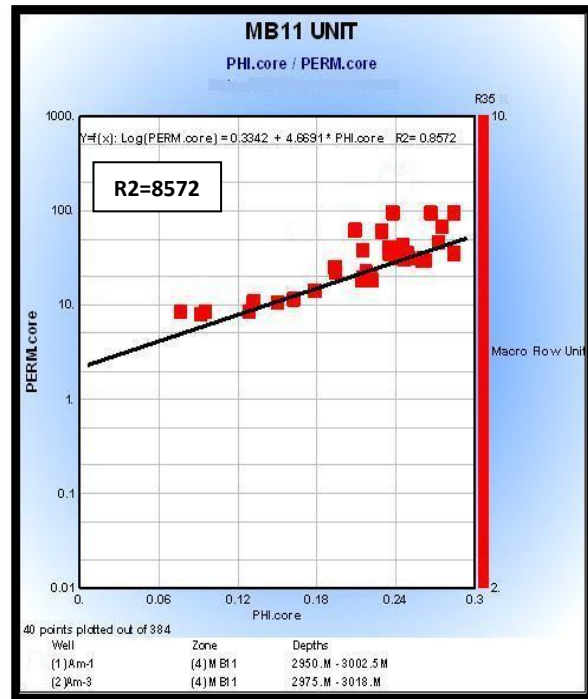


Figure 19- The relationship between Log K vs. Phi for the MB11 Reservoir Unit samples, R35= (2-10) (Macro flow unit)

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