

Reservoir Characteristics from Well Logging Records of Mamuniyat Formation, M Oil Field, NC115 Concession, NW Murzuq Basin, SW Libya

A. A. Kushlaf^{1*}, M. A. Beneesa¹

¹ Department of Engineering Geology, Faculty of Oil and Gas Engineering, University of Zawia, Zawia, Libya

*Corresponding author email: a.kushlaf@zu.edu.ly

Received: 04.11.2023 | Accepted: 18.11.2023 | Available online: 15.12.2023 | DOI:10.26629/uzjest.2023.07

ABSTRACT

This study is concerned with Reservoir characteristics at M field, concession NC-115 in Murzuq basin sw of Libya. Mamuniyat formation is considered the first reservoir in the studied field M-NC115, sourced and sealed by Tanezzuft formation. Well recording operations have developed at the present time to become an essential and important part of drilling conclusions in addition to productive probing operations, which give us information about the well's productivity. Twelve wells were identified for this work scattered in the study area. A petrophysical assessment was achieved with interactive petrophysics software 2018. The results showed that the study Formation consists of sandstones with a small percentage of shale. The results also showed that the upper part of the studied reservoir at ((zones I and II)) is of higher quality than the lower part (zones IV). The reservoir thickness is about 960 ft in the north flank of the study area, and it is completely absent in the southwest flank of the study area. The results also illustrated that the average water saturation is 40%, the porosity is 12%, and the reservoir thickness is 560 ft.

Keywords: Mamuniyat formation, M field, well logging, petro-physical parameters.

How to cite this article:

Kushlaf, A.A.; Beneesa, M.A. Reservoir characteristics from well logging records of mamuniyat formation, M oil field, NC115 concession, NW Murzuq basin, SW Libya. Univ Zawia J Eng Sci Technol. 2023;1:72-89.

الخصائص الخزانة من سجلات تسجيل الآبار لتكوين المامونيات، حقل النفط M، منطقة

امتياز CN 115، حوض مرزق الشمالي الغربي، جنوب غرب ليبيا

عادل كشلاف^{1*}، محمود بن عيسى¹

²قسم الهندسة الجيولوجية، كلية هندسة النفط والغاز والطاقة المتجددة، جامعة الزاوية، ليبيا

ملخص البحث

تهتم هذه الدراسة بخصائص المكمن في الحقل M بامتياز NC-115 في حوض مرزق جنوب ليبيا. يعتبر تكوين المأمونيات الخزان الأول في حقل الدراسة M-NC115، ويعتبر تكوين تانزوفت هو صخر مصدر وغطاء لهذا الخزان. وقد تطورت عمليات تسجيل الآبار في الوقت الحاضر لتصبح جزءاً أساسياً وهاماً من استنتاجات الحفر بالإضافة إلى عمليات الإنتاج

التي تعطي لنا معلومات حول إنتاجية البئر. وقد تم تحديد اثني عشر بئراً لهذه الدراسة منتشرة في منطقة الدراسة. تم إجراء تقييم بتروفيزيائي باستخدام برنامج البتر وفيزياء **IP 2018**. وأظهرت النتائج أن تكوين الدراسة يتكون من الصخور الرملية مع نسبة صغيرة من الطين. كما أظهرت النتائج أن الجزء العلوي من الخزان المدروس في ((المنطقة الأولى والثانية)) أعلى جودة من الجزء السفلي (المنطقة الرابعة). ويبلغ سمك الخزان حوالي 960 قدماً في الجانب الشمالي من منطقة الدراسة، ويغيب تماماً في الجانب الجنوبي الغربي من منطقة الدراسة. كما أوضحت النتائج أن متوسط التشبع المائي 40%، والمسامية 12%، وسمك الخزان 560 قدم.

الكلمات الدالة: تكوين المأمونيات، الحقل M، تسجيل الآبار، المعلمات البتروفيزيائية.

1. Introduction

The Murzuq Basin located on SW Libya forms one of several intracratonic sag basins located on the north African Platform Figure 1, covers an area of some 350,000 km², extending southwards into Niger [1]. The basin borders are defined by erosion resulting from multiphase tectonic uplifts. The Murzuq basin can be considered more accurately as the erosional remnant of a much larger Palaeozoic and Mesozoic sedimentary basin which originally extended over much of North Africa [2]. Its borders consist of Tihemboka high in the west, the Tibesti high to the SE, and the Gargaf and Atshan highs to the north and NW. Most of These uplifts were formed by tectonic events of different ages ranging from middle Palaeozoic to Tertiary times, but the main periods of uplift took place during Middle Cretaceous to Early Tertiary Alpine movements.

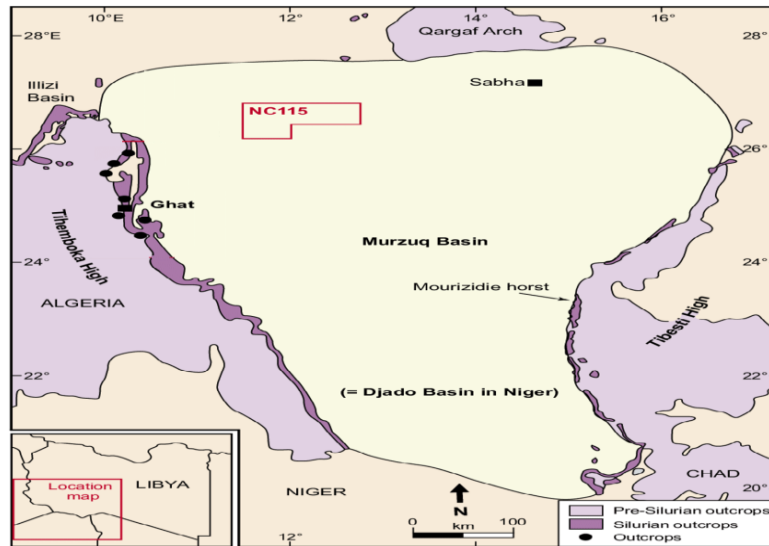


Figure 1 – Geological map of Murzuq Basin showing the location of NC115 Concession [4].

M field is considered one of the oil fields in the NC186 Concession, which contains several exploratory and development wells, distributed in the field on the north and western side of the Murzuq basin, southwest part of Libya Figure 2. It has been affected by the structural and tectonic movements of

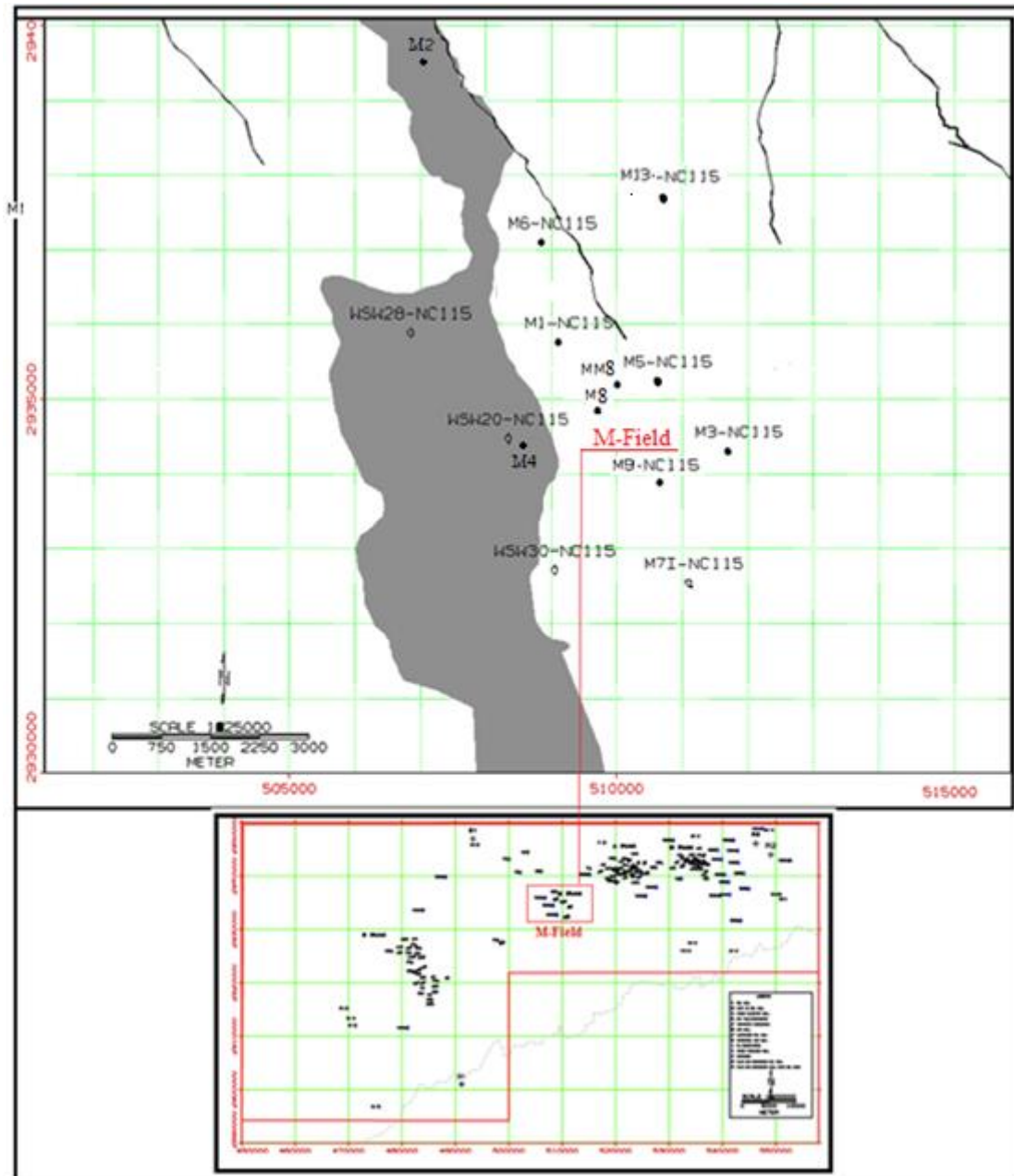


Figure 2 – Location map of M field, Concession 115, Murzuq Basin, Libya.

Murzuq Basin and created paleo-high during the post-Mamuniyat erosional events. This feature of paleo high is clearly represented in the 2-D seismic line shown in Figure 3 by Akakus Oil Operation [3] represented in the area of study. On the other hand, structure contour maps have been carried out for M field and illustrates the same structural feature of paleo-high Figure 4.

The investigated M oil field lies between the latitudes $26^{\circ} 10'$ and $26^{\circ} 40'N$ and longitudes $11^{\circ} 10'$ and $12^{\circ} 50' E$.

Generally, the petroleum system is represented by structural Mamuniyat paleo-high created during the post Mamuniyat erosional event. The basal Silurian Tanezzuft hot shale member acts as seal and source rock in the area of study.

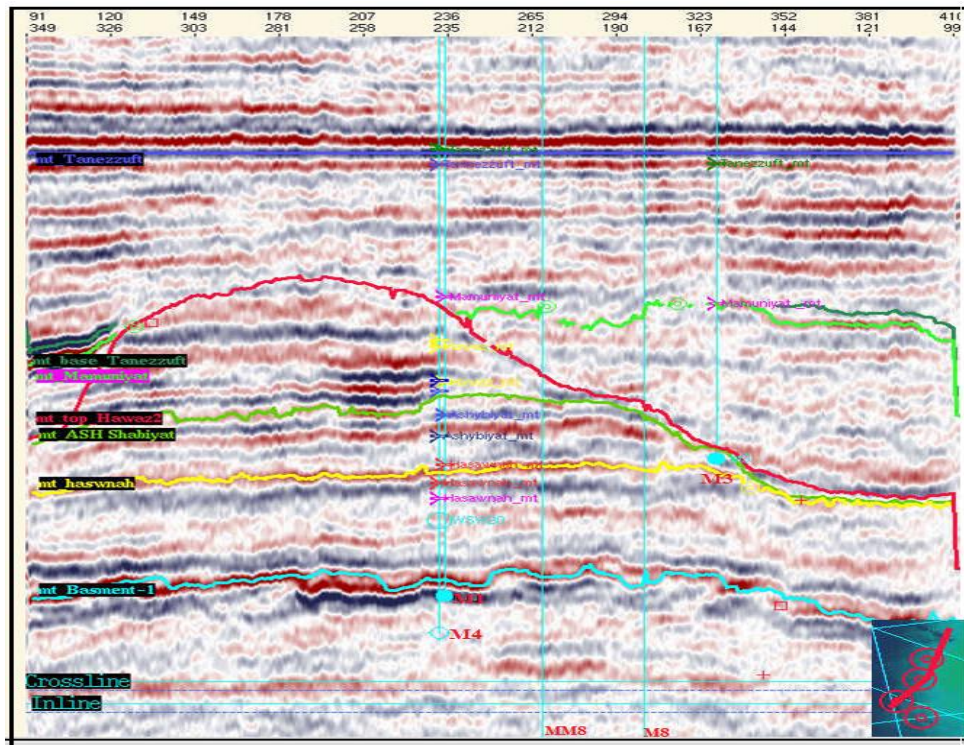


Figure 3 – 2-D seismic line for M1, M4, MM8, M8 and M3, M-field NC115 wells, Murzuq Basin[3].

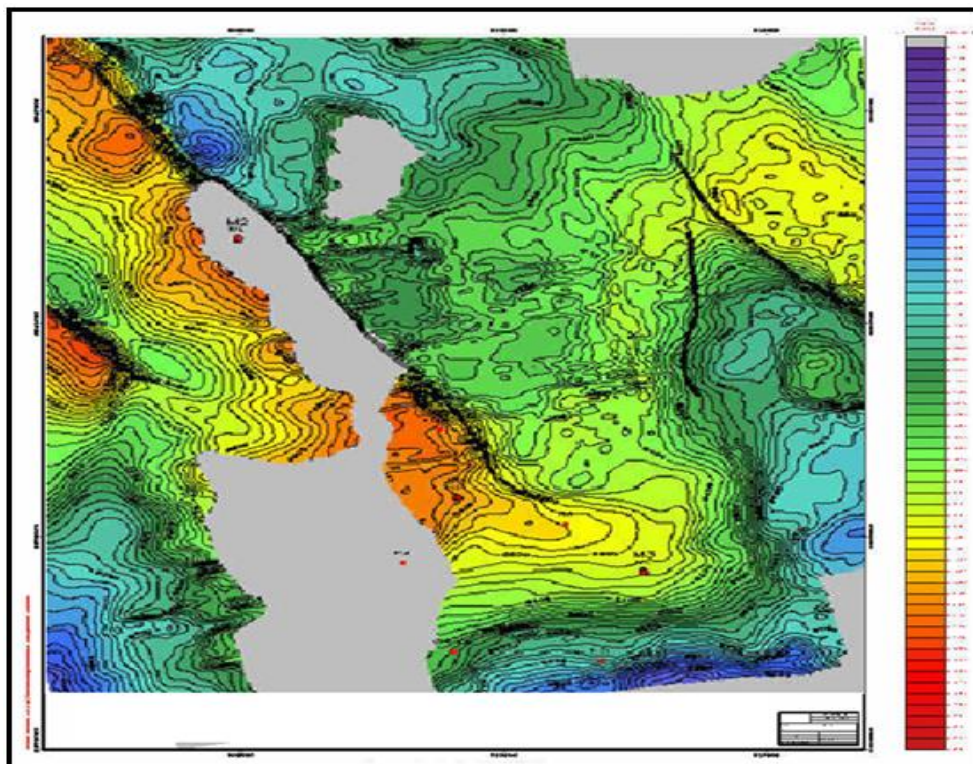


Figure 4 – Structure contour map for Mamuniyat reservoir in M field [3].

This paper is devoted to study the hydrocarbon potentialities of Mamuniyat Formation in M oil field through analysis of the available well log data. A comprehensive analytical formation evaluation has been applied using interactive petro-physics (IP 2018) software parameters [5]. The well records available for this study include the following: resistivity, sonic, neutron, density, nuclear magnetic resonance, spontaneous potential, caliper, gamma ray and natural gamma ray spectrometry logs.

This research paper is carried out as an extension to the previous studies [6],[7] to analyze the petrophysical characteristics of Mamuniyat formation in M oil field, but here we will be interested in this research mainly on the quick look analysis of log curves and plotting crossplots between the petrophysical parameters.

2. General Geologic and Structural Settings

Murzuq Basin is one of the several intracratonic sag basins located on the sw Libya. The structural fabric imparted to the North African continental lithosphere during the late Proterozoic, the structural and stratigraphic evolution of the basin was controlled subsequent by Pan-African event. A series of NNW trending arches and sub-basins across North Africa created during the Early Palaeozoic tectonics, which filled with clastic continental and shallow marine deposits and transgressive open marine facies. Early Palaeozoic tectonism effectively controlled the distribution of late Ordovician reservoirs and distribution of Silurian "Hot Shale" which overlap early-formed fault blocks [8],[9].

The structure of the Murzuq basin is quite simple. The horizontal or gently dipping strata is faulted and the faults are most frequently parallel to the axis. Tectonic movements affected the basin to a greater or lesser degree from middle Palaeozoic (Caledonian) to Post-Oligocene (Alpine) times [9]. Caledonian, Hercynian and Alpine tectonic events affected this basin evolution, especially Caledonian and Hercynian orogenies [9]. Several regions in the south of the Ghadames Basin, Murzuq basin and also in the Kufra basin indicate that the Caledonian orogeny started in the Upper Silurian and persisted through the Lower Devonian.

The stratigraphic column of Murzuq basin started from the Pre-Cambrian to the Pleistocene Figure 5. The maximum thickness in the basin center doesn't exceed 4000 m. The Mamuniyat Formation was defined by Massa and Colombo (1960) after Jabal Al Mamuniyat (West of Qarqaf) [10]. It has been described by [11]. This formation is composed entirely of sandstones, which makes it very prominent and easy to recognize throughout the area. The composition of the Mamuniyat Formation is relatively simple and monotonous. It consists mainly of medium- to coarse-grained and conglomeratic sandstones locally showing high percentages of kaolinitic matrix, with thick-bedded to massive, and less frequently thin bedded quartz sandstones, characterized by a regressive cross-bedded, sandstone unit.

The upper part of the Mamuniyat comprises medium- to coarse-grained sandstone with well-developed wavy cross-bedding [10]. The Mamuniyat formation is characterized by a wide spread under the surface, and its thickness ranges between 20-180 m. It was also noted that it has a regional overlap in the direction of the Qarqaf high [9].

The top part of the Mamuniyat Formation is normally transitional with the transgressive Silurian shales [12]. On the geological map of Libya this formation is included in the "Cambrian and Ordovician rock". In the Murzuq Basin, the main producing reservoir lies in the Mamuniyat quartzitic sandstones. The overall Ordovician sandstone reservoir quality of the Mamuniyat Formation varies greatly. However, porosity as high as 20% has been noted. The clastic deposits of this formation provide the best reservoirs in the northwestern flank of the Murzuq Basin [13],[14].

ERA	PERIOD / SUBPERIOD	EPOCH	AGE My	Main Tectonic Events	Repsol Oil Operations Stratigraphy Based on (IRC) Terminology	
CENOZOIC	Quaternary or Pleistocene	Holocene	0.01	Alpine	Quaternary	
		Pleistocene	1.64		Al Mahruqah Fm.	
	Neogene	Pliocene	5.2		& basalts	
		Miocene	23,3		Mazul Ninah Fm.	
	Paleogene	Oligocene	35.4		Bishima Fm.	
		Eocene	56,5		Sufah Fm.	
Palaeoce	65,0	Zmam Fm.				
MESOZOIC	Cretaceous	Upper	97.0	Austrian	Messak Fm.	
		Lower	145.6	Taouratine Fm.		
	Jurassic	Malm	157.1	Hercynian	Zarzaitine Fm.	
		Dogger	178.0		Tiguentourine Fm.	
		Lias	208.0		Dembaba Fm.	
	Triassic	Upper	235.0		Assedjefar Fm.	
		Middle	241.1		Marar Fm. "Upr. Marar mbr."	
		Lower	245.0		"Lwr. Marar mbr."	
	Permian	Zechstein	256.1		Caledonian	Tahara Fm.
		Rotliegendes	290.0			Awaynat Wanin Fm.
Carboniferous	Upper	Stephanian	303.0		Taconic	Acacus "BDS" Fm.
		Westphalian	318.0			Lowermost Awaynat Wanin Fm.
	Lower	Namurian	332.9	Ouan Kasa Fm.		
		Visean	349.5	Tadrart Fm.		
Devonian	Upper	Tournaisian	362.5	Late Pan African	Akakus Fm.	
		Famennian	377.4		Tanezzuft Fm.	
	Middle	Give./ Couv.			386.0	Hot sh.mbr.
		Lower	Emsian		408.5	Hirmantian sh. Mbr.
Siegenian	Mamuniyat Fm.					
Silurian	Upper	Ludlow./ Prid.	424.0	Pan African	Melez Shuqran Fm.	
	Lower	Wenlock	430.4		Pre-Melez Shuqran ss mbr.	
Ordovician	Upper	Llandoverly	439.0	Hawaz Fm.		
		Ashgillian	443.1		Ash Shabiyat	
	Middle	Caradocian	463.9		Hasawnah Fm.	
		Llanv./ Lland.	476.1			
	Lower	Arenig	493.0		Mourizidie Fm.	
		Tremadoc	510.0			
Cambrian	Upper	517.0	Basement			
	Middle	536.0				
	Lower	570.0				
Pre-Cambrian				Pan African		

Legened Not Present in NC174 Present in NC174 Study Formation

Figure 5- Stratigraphic column of the Palaeozoic, Mesezoic and Cenozoic successions in NC186, NW Murzuq basin, SW Libya, [15].

3. Well Logging Data Analysis Technique

The processing of the well logging data in this study has been carried out utilizing constructing two cross-plots for deriving formation water resistivity (R_w), cementation factor (m) and matrix parameters (P_{ma}). These parameters were used as input parameters for the interactive petrophysics software to evaluate Mamuniyat reservoir. The pay flag was computed using V_{shale} cut-off 40%, Porosity cut off 10% and S_w cut-off 50%. These cut-off percent were determined from the inspection of the logs and cross plots of the porosity versus V_{shale} . The output results are presented in the form of litho-saturation cross plots parameters [5].

4. Results and Discussion

Initially, the well recording data was corrected from different borehole environments. Then these data with core samples recorded have been carried out utilizing quick log interpretation and analytical crossplots for evaluating the petrophysical characteristics of Mamuniyat reservoir.

4.1 Pickett crossplot

The Pickett plot, devised by Pickett [16], represents one of the simplest and most effective methods in use. It solved Archie's equation carefully and plotted deep resistivity and porosity, both on logarithmic scales. The saturation lines are parallel in a Pickett plot. Archie equation solution for water saturation has been replaced and rearranging the relationship becomes:

$$\log \Phi = \log R_t - m \log S_w + \log (aR_w) \quad (1)$$

Figure 6 below, represents Pickett plot for M3-NC115. Points (green, red and brown spheres) represent zone I, II and upper part of zone III plotted on 25% S_w line indicating high oil saturation. Blue spheres of zone IV horizons are plotted between 50% and 100% S_w lines. The slope of the parallel (S_w) lines equals (-1.9) which means that, cementation factor (m) equals 1.9. Lines representing constant ($\rho_{ma} - \rho_b$)(S_w) (i.e BVW) values are parallel to the Y axis, which indicate that (m) is equal to (n) as shown in the Figure. Points plotted on these straight lines denote that, the reservoir is at irreducible state [17][17].

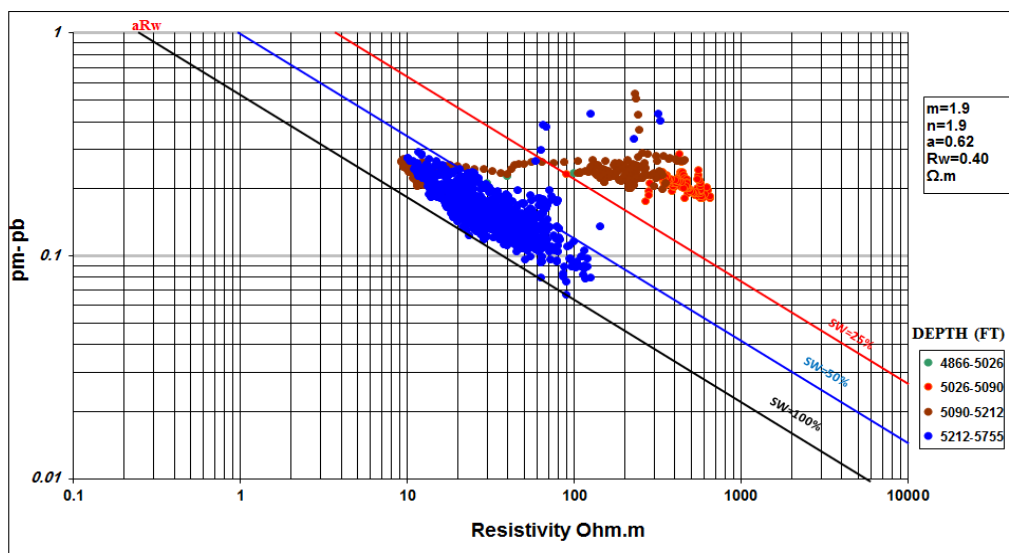


Figure 6 – Pickett plot between ($\rho_{ma} - \rho_b$) versus R_t on log-log plot for M3-NC115 well.

The intercept of the R_0 line with the horizontal axis is at 0.25, which represents (aRw). Accepting the value of 0.62 for (a) gives Rw that is equal to $0.40 \Omega \cdot m$.

4.2 Irreducible Water Saturation

The description estimation of Swirr can be beneficial in extracting valuable of the reservoir parameters, especially in exploratory wells, where core data are not available. It is very important to evaluating relative permeabilities to oil and water (Kro and Krw) and calculating water cut (WC). Many techniques were used to calculate this parameter. Asquith and Gibson [17] have proposed calculating Swirr for each zone depending on formation factor F:

$$Swirr = \sqrt{\frac{F}{2000}} \dots\dots\dots(2)$$

The authors applied the above equation for Mamuniyat formation in M3-NC115 well and displayed the results in a set of cross-plots between Sw, Swirr, and $\Phi N-D$ to give a picture of Krw, Kro, WC and grain size as follows.

4.3 Relative Permeability to Water and Oil

The relationship between Sw and Swirr can be used to evaluate graphically the relative permeability to water (Krw), as illustrated in Figure 7. According to this plot, a set of points (green, red and brown spheres) represent zone I, II and upper part of zone III plotted on and below the zero line reflects no water production. These points reflect the irreducible state of the reservoir (i.e. $Sw = Swirr$). Points plotted on and below the 0.01 line (i.e. 1% water production) belongs also to the lower part of zone III. Points (blue spheres) located on a higher value line represent the deeper zone IV.

The relative permeability of oil (kro) is inversely proportioned to that of water (Krw). This is clear on Figure 8, which represents the relation between Sw and Swirr as a function of (Kro) for M3-NC115 well. Points plotted on and below 0.01 Krw line situated also on and below 0.5 towards higher Kro values. Also points of zero Krw, (green, red and brown spheres) represent zone I, II and upper part of zone III plotted on and around 1.0 Kro line (i.e 100% relative permeability to oil and zero relative permeability to water).

The percent of water which will be produced with oil is of prime importance to describe the reservoir performance. Figure 9 represents the Water Cut (WC) lines in respect to Swirr versus Sw for M3-NC115 well. The WC% must be in correlation with the above Krw and Kro values obtained above. This obvious hence the plotted points around zero WC (green, red and brown points), which related to zone I, II and upper part of zone III, have $Krw=0$ and $Kro=1.0$. Blue points, which belong to zone IV, corresponding to very fine grain size (Fig. 10), maximum $Krw > 0.1$, Figure 7 and Kro less than or equal 0.1 Figure 8.

The crossplot between Sw versus ΦS for this well Figure 10 together with depth ranges represented as color coded. Points clustered below Coarse Grain (CG) line is situated in the upper part of the formation (above 5160 feet). These points represent the best reservoir quality (green, red and brown spheres) represent zone I, II and upper part of zone III. Points belong to depths lower than 5160 (lower part of zone III and zone IV) plotted around and above Very Fine (VF) line. These points related to well-known water bearing zones.

Finally, the graphical technique relating the calculated Swirr with Sw is applied to Mamuniyat formation in this well. The plotted points for this formation indicate scattering on different lines. Points (green, red

and brown spheres) represent zone I, II and upper part of zone III is plotted around zero WC Figure 9, zero K_{rw} Figure 7 and 1 K_{ro} Figure 8 lines confirming the upper part to be at irreducible state and will produce oil free. The lower part of zone III and zone IV) of Mamuniyat formation at depths between (5160-5755 ft) in this well have points scattered below 20% WC line and above 0.01 K_{rw} and 0.5 K_{ro} lines. This indicate that, the lower part of this formation has high relative permeability to water and zero relative permeability to oil and high percentage water cut or in other word it will produce only water.

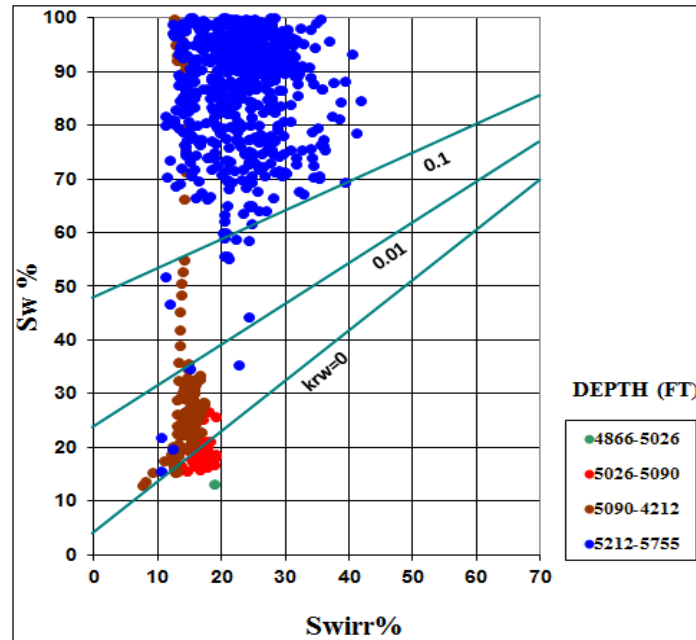


Figure 7. Crossplot between Sw versus Swirr for Mamuniyat Formation, M3-NC115 well showing relative permeability to water(K_{rw}).

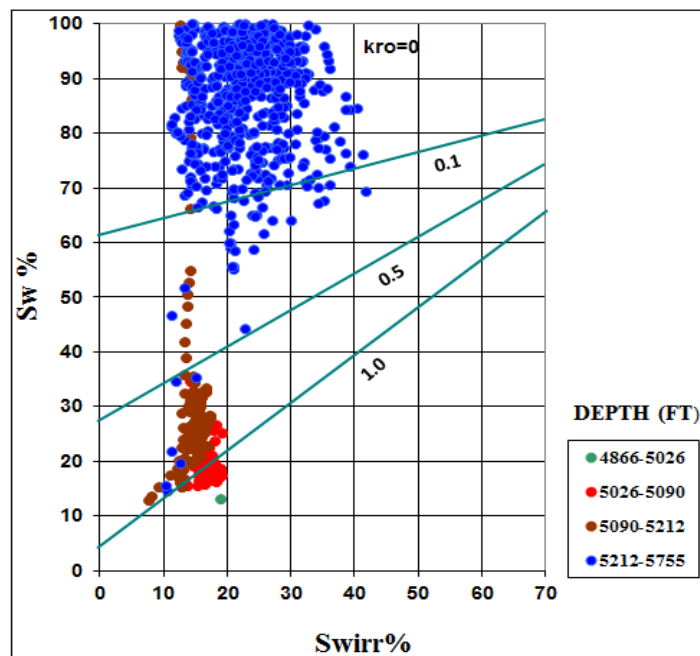


Figure 8. Crossplot between Sw versus Swirr for Mamuniyat Formation, M3-NC115 well showing relative permeability to oil (K_{ro}).

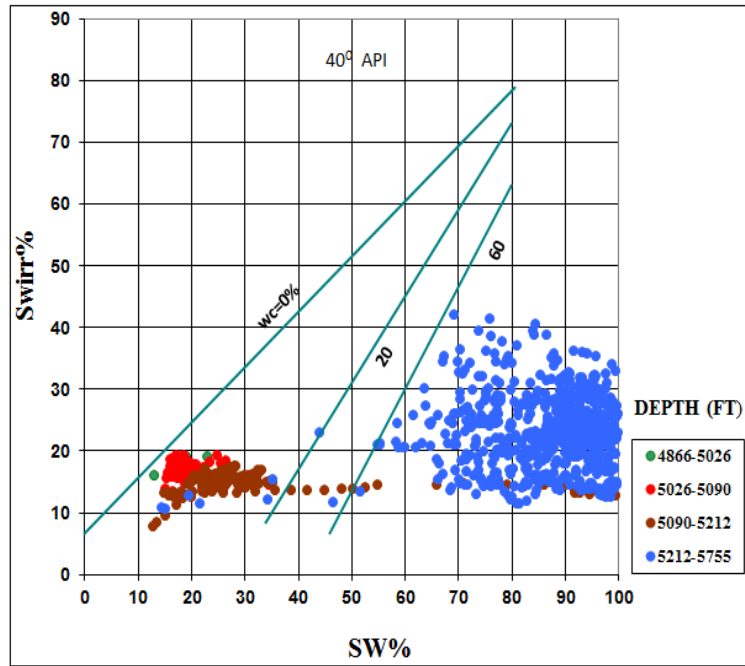


Figure 9. Crossplot between Sw and Swirr for Mamuniyat Formation, M3-NC115 well, illustrating water cut percent.

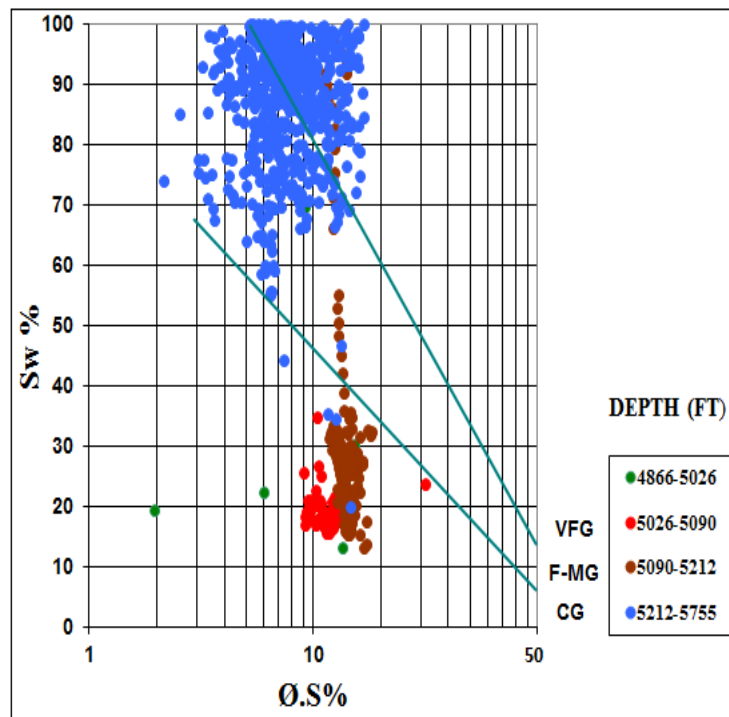


Figure 10. Water saturation vs sonic porosity showing upward coarsening sequence, for MAMuniyat Formation at M3-NC115, M oil Field

4.4 Buckles plot

Porosity-Saturation (Buckle) plot Figure 11 for the zone II (red spheres) of M3 well Mamuniyat formation indicate firmly that this zone is indeed at irreducible state and will produce free water oil as the plotted points track accurately BVW curve of 0.02. This low value, indicate oil production from well sorted and coarse grains as (i.e sorting and grain size increase towards lower BVW direction). The Sw value on this curve represents Swirr (0.11 in this case). Zone IV (blue spheres), represent the water zone thru Mamuniyat Formation in M Field when plotted on Buckle Figure 12 showed wide scattering of points. This scattering feature is characteristic for water producing zones. This zone has very fine grain connected to the presence of shale.

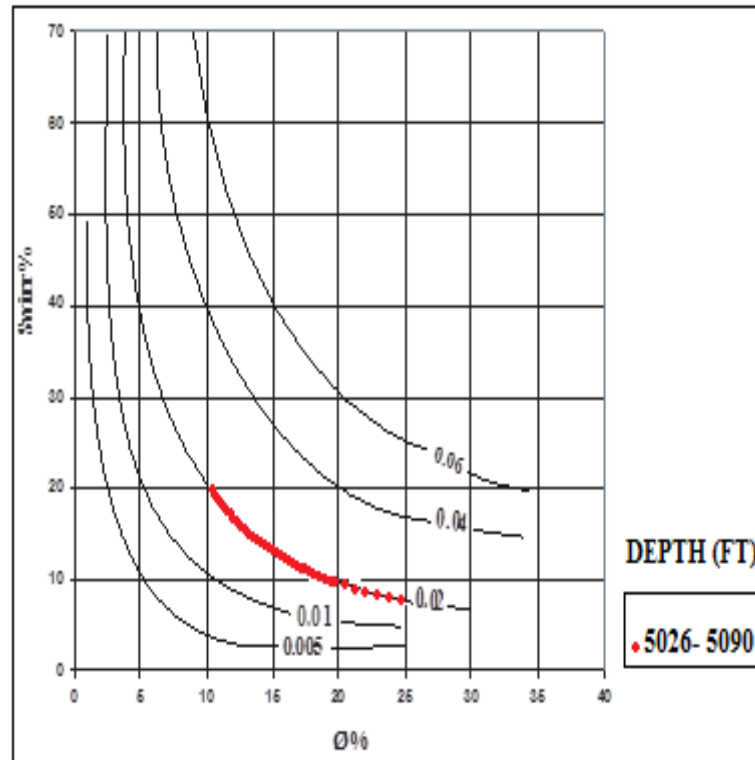


Figure 11 . Porosity Versus Water Saturation (Buckle) Cross-Plot for Mamuniyat Formation (Zone II) In M3-NC115.

4.5 Hydraulic Flow Unit (HFU)

The relation between permeability (K) and porosity (Φ) is not straight forward. Accordingly, there is no well-defined correlation between K and Φ . Different $\Phi - K$ relationships are evidence of the existence of different Hydraulic Flow Units (HFU). This situation is obvious for Mamuniyat Formation in the study area as the reservoir is clean homogeneous Sandstone. Four distinct and clear trend curves are detected between core $K - \Phi$ on a semi-log cross-plot Figure 13 suggesting the possible existence of 4 Hydraulic Flow Units corresponding to these trends.

The plot of RQI versus Φz on a log -log paper yields a straight line representing specific HFU. Other HFU will fall on straight parallel lines with slope unity. Figure 14 represents application of such technique to Mamuniyat Formation in M3-NC115 well. The plotted points fall on 4 parallel lines with slope unity. Each line denotes specific Hydraulic Flow Unit. Note that, these 4 lines can be correlated

with 4 trends noticed on Figure 13. Intercept of these lines with $\Phi_z = 1$ (FZI) are: 12, 18, 23 and 30 for HFU1-HFU4 respectively. All Hydraulic Flow Units in this formation with **FZI** more than one so all of these units represent good to excellent reservoir quality.

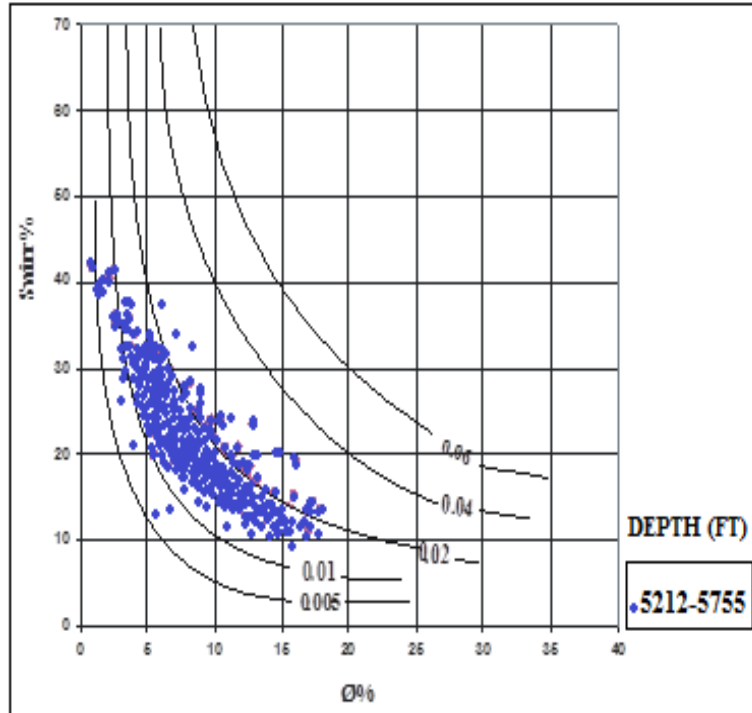


Figure 12 . Porosity Versus Water Saturation (Buckley) Cross-Plot for Mamuniyat Formation (Zone IV) In M3-NC115.

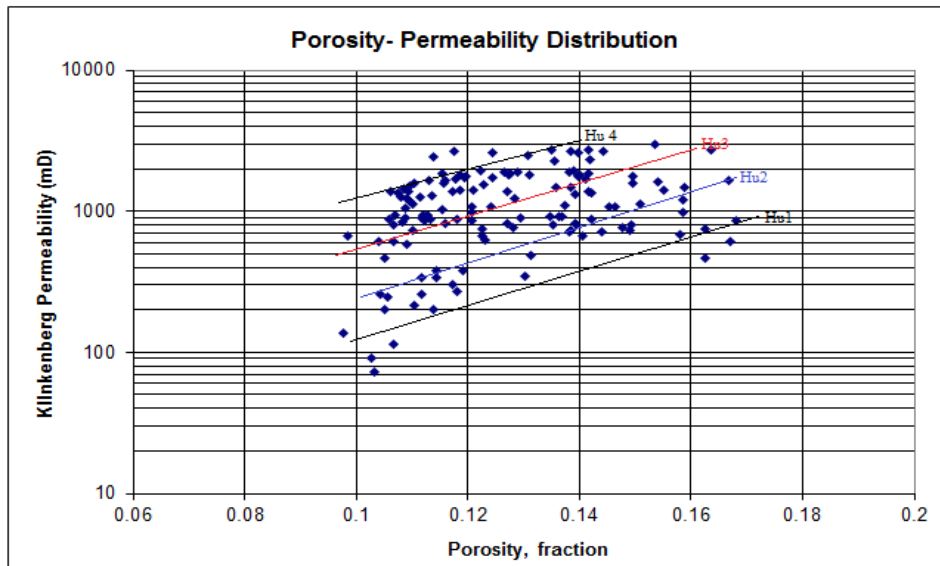


Figure 13 . Core Permeability (Kmd) Versus Porosity (Φ %) for Mamuniyat Formation, M3-NC115 well, Showing Four Distinctive Curve Trends.

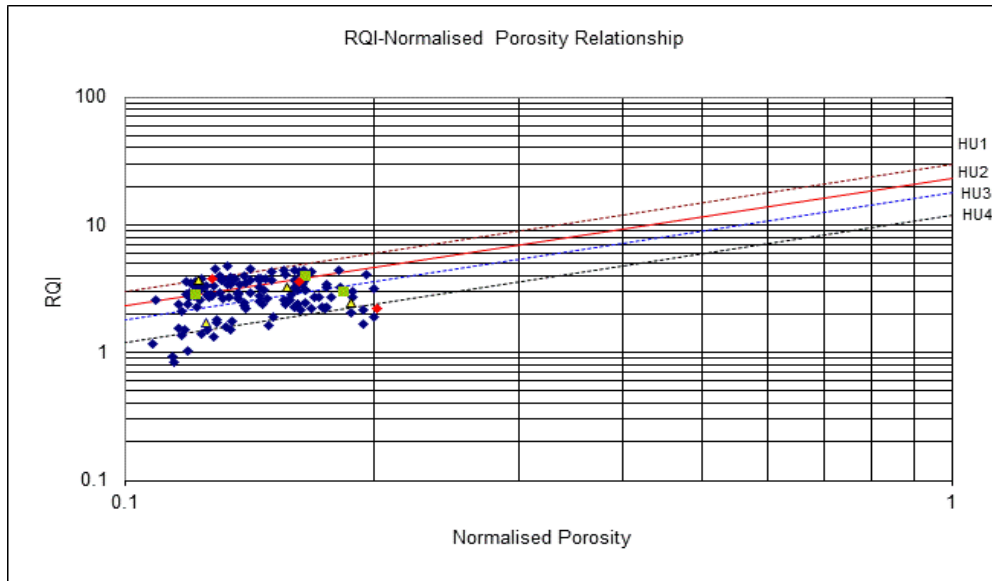


Figure 14 . Log-Log Plot of RQI versus Φ_z for Mamuniyat Formation in M3-NC115 Well Showing Four Parallel Lines Corresponding to Four Hydraulic Flow Units (HFU).

4.6 IP Output Results

The output results of IP-2018 were offered in the form of lithosaturation cross plots for Mamuniyat Formation in the study area. This formation was subdivided into four zones (I, II, III and IV). These zones have its own petrophysical parameters (V_{sh} , S_w , S_h and Φ). The calculated shale volume V_{sh} for Mamuniyat formation in M3-NC186 well Figure 15 ranges from 0.6% to 0.9% with average 0.7%. The effective porosity ranges from 10.2% to 12.4% with average 11.5%. Water saturation ranges from 20.5% to 93.3% with average 54.1 %. The top of Mamuniyat formation is 4866 ft with a gross thickness of 820 ft. and net pay thickness is 302 ft. It is well known that zone I, II and upper part of zone III are potentially the most productive zones.

On the other hand, the calculated shale volume of M13-NC186 well Figure 16 ranges from 0.1% to 0.3% with average 0.2%, the effective porosity ranges from 11.2% to 13.3% with average 12.4%, the water saturation ranges from 21.4% to 44.3 % with average 31 %. The top of Mamuniyat formation is at 5126 ft with a gross thickness of 530 ft. and net pay thickness is 55.5 ft. Zone I is potentially the most productive zone.

4.7 Areal Distribution Of Mamuniyat Reservoir

The deduced petrophysical parameters are represented by a number of isoparametric maps showing the lateral distribution of Mamuniyat Formation. The gross reservoir thickness contour map Figure 17 shows that the maximum recorded reservoir thickness 820 ft at M3-NC186 well, while it decreases gradually south ward recording the minimum value of 200 ft at the M7I-NC186 well.

The effective porosity contour map of the Mamuniyat reservoir shows a regular pattern of distribution with a general increasing towards North of the area Figure 18, recording a maximum value of 12.7% at well M2-NC186. This value decreases gradually towards South of the study area recording a minimum value of 7.3% at well M4-NC186.

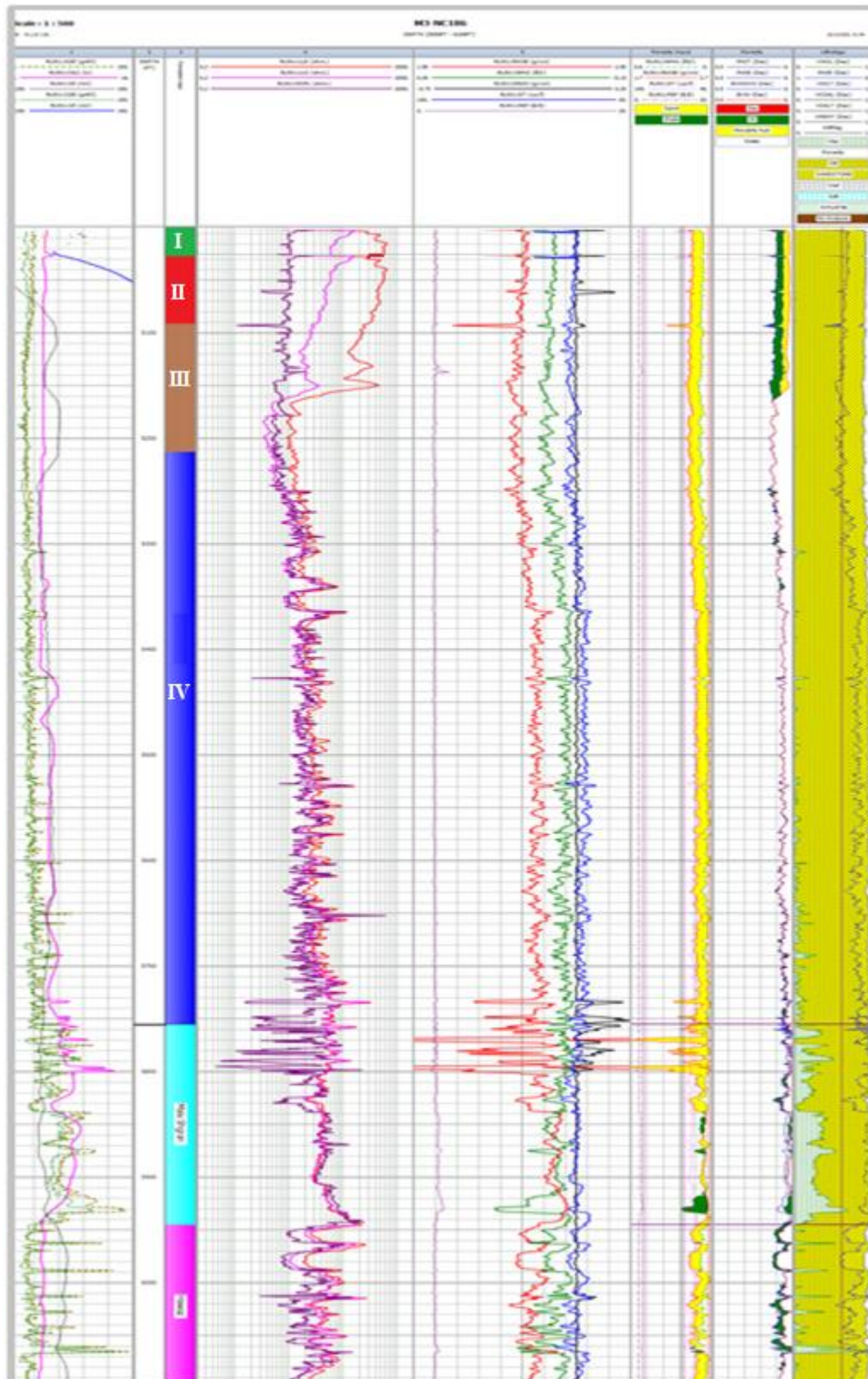


Figure 15 . Selective examples of the IP results for well M3-NC186, M Oil Field

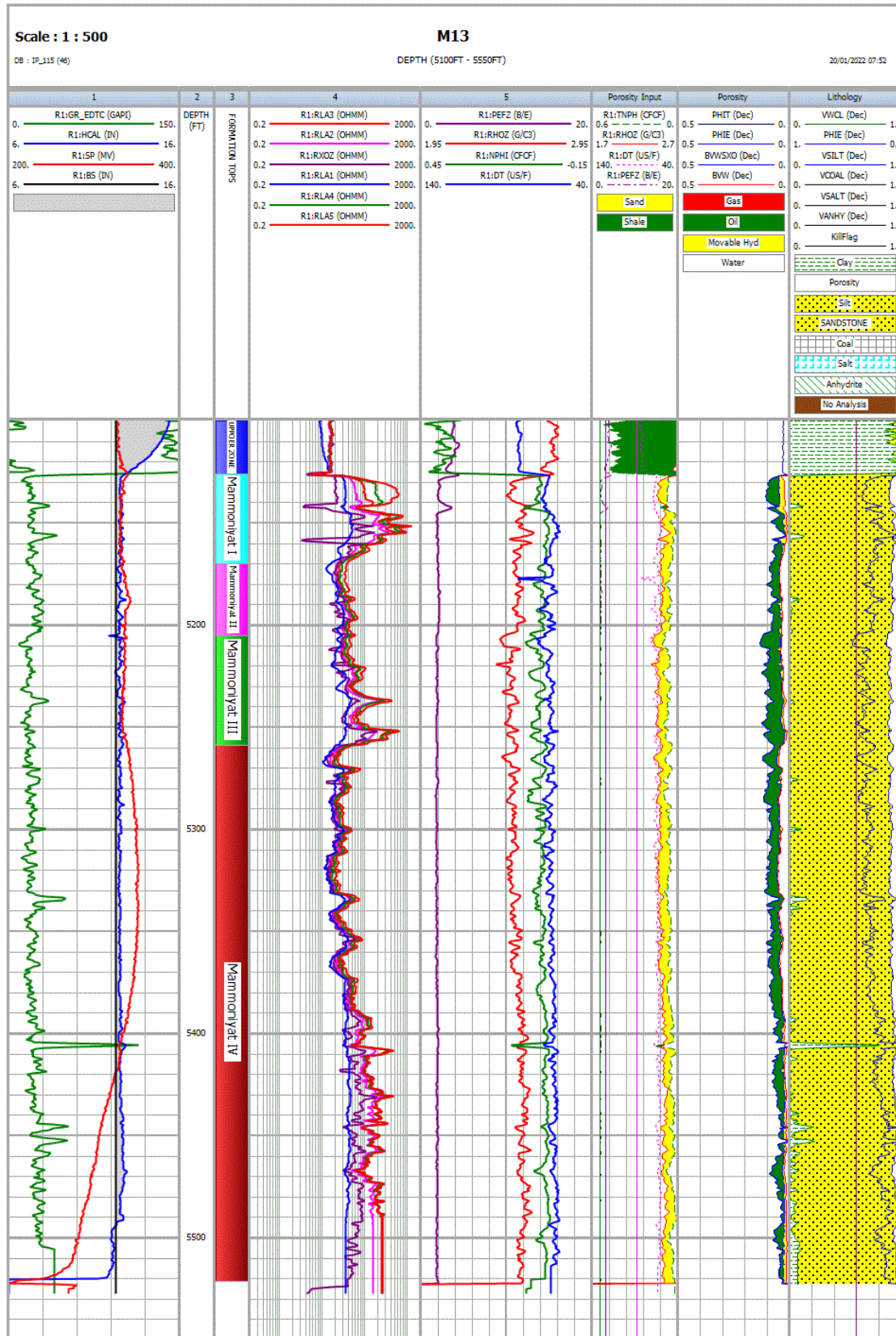


Figure 16 . IP Litho-Saturation Crossplot for M13-NC186 Well.

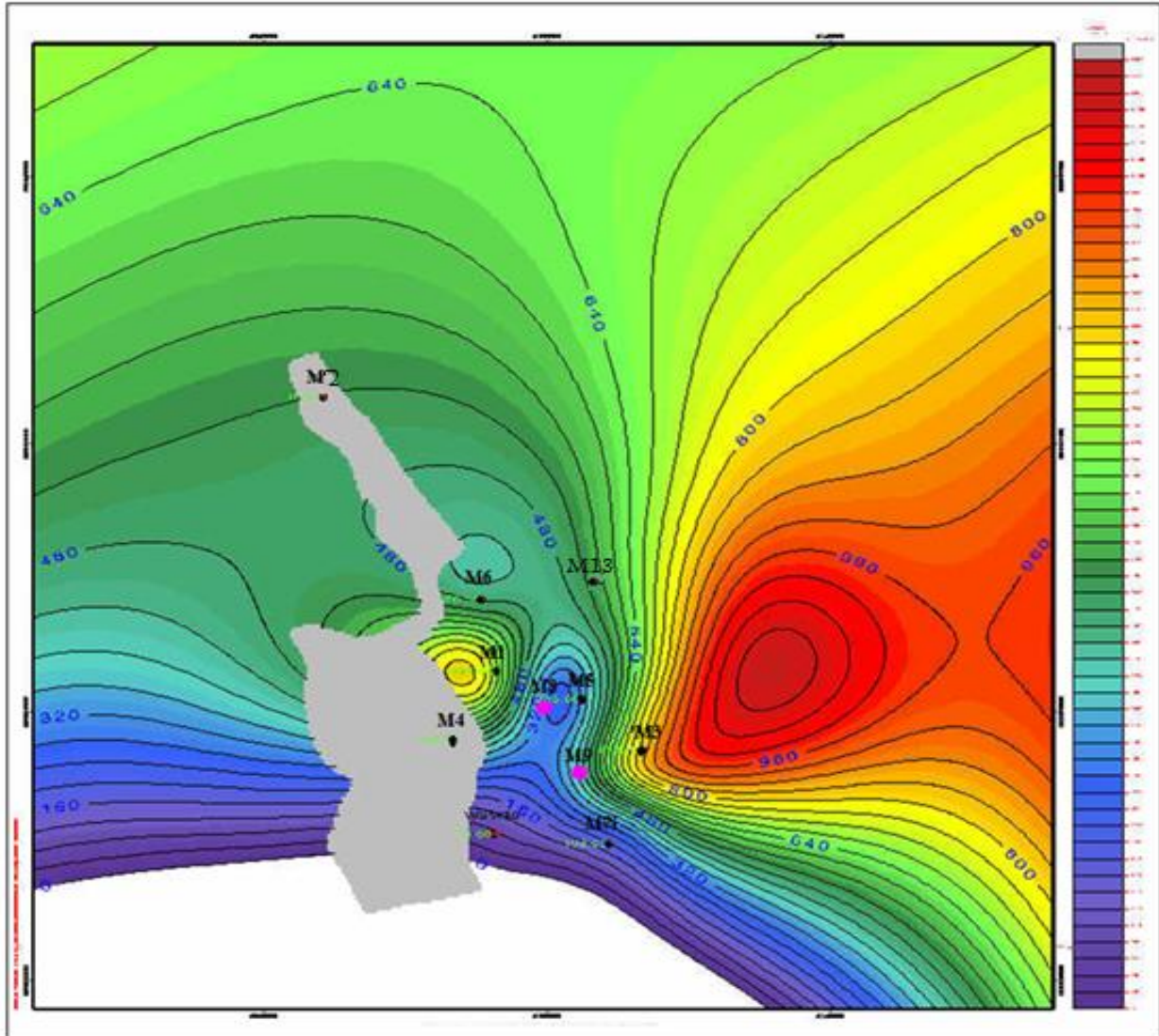


Figure 17 . Gross thickness contour map for Mamuniyat reservoir in M-NC186 Concession

5. Conclusion

The Mamuniyat Sandstone formation of Upper Ordovician age represents the main reservoir in Murzuq basin, sourced and sealed by the Silurian Tanezzuft shale formation. The Silurian Hot shale thanezzuft-upper Ordovician Mamuniyat Sandstone petroleum systems of the Murzuq basin have been studied by boote et al. (1998), Craik et al. (2001). The petroleum system is represented in this study by structural Mamuniyat paleo-high. This study is concentrated to evaluation the petro-physical parameters of Mamuniyat Formation at M oil field, Concession NC115 in Murzuq basin. The formation is informally subdivided into 4 zones, named (Mamuniyat I to IV). Each zone is characterized by its own petrophysical parameters.

The analytical and graphical formation evaluation tells that the reservoir consists mainly of clean Sandstone. This Sandstone is characterized by coarsening upward sequence from zone IV at the bottom level until zone I at the top. The results indicated that the Mamuniyat reservoir is mainly oil-bearing.

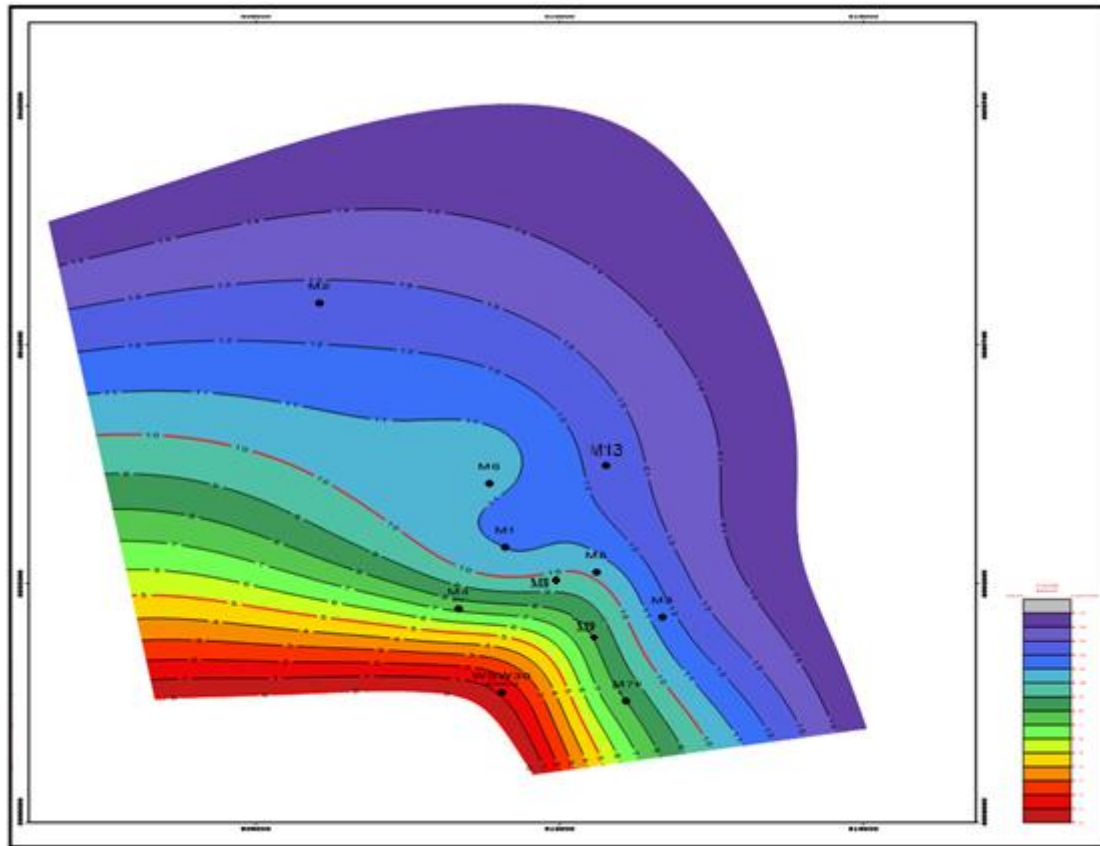


Figure 18 . Average effective porosity contour map for Mamuniyat reservoir in M-NC186 Concession.

The lithosaturation crossplots resulted through (IP -2018) program indicated that zones I and II contain the main oil reservoir. The lithosaturation crossplots and isoparametric maps of Mamuniyat formation showing that the volume of shale is low and the porosity is relatively high as an indication of good reservoir. The relationship between core $K-\Phi$ and also Buckles crossplot suggests the presence of more than one hydraulic flow units of Mamuniyat formation represent very good to excellent reservoir quality.

6. Acknowledgment

We would like to thank Akakus Oil company for providing us the well logging data and the materials for preparing this paper.

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