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Reservior Charactrization of Messinian Abu Madi Sandstone by Incorporating NMR Log with Conventional Logs: a Case Study Nile Delta, Egypt

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Abstract: *The Nile Delta is considered as the earliest known delta in the world. It is an emerging giant gas province in the Middle East and one of the most promising areas for future petroleum exploration in the North East Africa. The present area is the West Al-Khilala Field which is lied NW El Mansoura concession and it is located between Latitude 31o 17' & 31o 12'N and Longitude 31o 13' 52" & 31o 17' E in the North Western part of the Onshore Nile Delta.The main object of this work is the formation evaluation of MessinianAbu Madi reservoir through the interpretation and integration of NMR log data with conventional electrical logs and core analysis.The reservoir Properties such as the lithology, Clay content, porosity, fluid saturation and net pay thickness of the formation has been completed by the available conventional open hole logs. NMR log provide a variety of data set which related to reservoir petrophysics and has high confidence than conventional logs such as porosity, permeability, pore size total and effective water saturation.The art NMR technology with the Conventional logs help to evaluate the Producibility of the reservoir and the fluid characteristics as fluid content, fluid type, free fluid volume (FFV), Bound fluid (BFV) and residual oil saturation (ROS).The integration of the reservoir characteristics and core analyses of Messinian Abu Madi Formation indicates a clastic sandstone reservoir with good petrophysical parameters for production.*

Keywords: *Abu Madi Reservoir, Messinian, NMR, West Al Khilala Field, Nile Delta, and Egypt*

I. Introduction

The Nile Delta is still under discussion in light of the fact that the Nile Delta does not have any exposures of older rocks, where it secured by the Holocene soils. It is still in an early exploration stage [1]. The hydrocarbon capability of the Nile Delta sedimentary sequence is constrained to the Neogene formations, trapped against listric fault planes or by tilted fault blocks.The Nile Delta Basin had turned into the most imperative vitality source in Egypt in the most recent couple of decades in the mid-1960s with the late gas revelations of the West Al Khilala Field. West Al Khilala field is considered a major gas field which discovered within (Messinian) Abu Madi sand in the Nile Delta. The area of study is located between Latitude 31^{o} 17' & 31^{o} 12'N and Longitude 31^{o} 13' 52" & 31^{o} 17' E to the south West of Abu Madi gas field and to the North East of East Delta gas field (Fig. 1). The Abu Madi sandstone consists of fluvial to shallow marine deposits, which fine upwards into marine shale towards the maximum flooding surface at the base of the Pliocene. The generally fluvial and deltaic sandstones of the Abu Madi Formation were deposited in a large SSE-NNW trending valley. This fluvial to estuarine embayment extends for northwards.The area is affected by shallow post–Messinian fault pattern, these are genetically related to sedimentary load of recent sediments at the unstable delta margin where the area of study is located, which caused growth faulting, slumping and normal faults [2]. The area of study is bounded by a normal fault trending NW-SE direction.This paper deals with the formation evaluation of the MessinianAbu Madi sandstone by integrating NMR log data and conventional open hole logs in order to obtain detailed formation evaluation with accurate porosity determination and permeability calculation in order to aid in reservoir modeling after that. A number of wells were drilled within the area but this paper represents only three examples from three wells within the area of study.

II. GeologicalSetting

The Nile Delta which occupies the extreme northern part of Egypt represents the southeastern part of the Eastern Mediterranean basin. The stratigraphy of Nile Delta has been gathered by[3] and elaborated by [4]for construction of sedimentation models of northern Egypt. The stratigraphic chart of Egypt (Fig.2) including subsurface sediment and tectonic sequence from Jurassic to Recent [5] compared with the Nile Delta chart from [6] and the North Sinai, Eastern and Western Desert charts [7].

The northwestern quadrant of the Delta shows a progressive shoaling through the Messinian which probably reflects both - a lowering of the Mediterranean Sea level and progradation of the shelf. At the end of the Messinian interval, global sea level fell significantly, and the isolated Mediterranean Sea was drastically lowered by the 'Messinian salinity crisis' [8].The Upper Miocene (Messinian) Abu Madi Formation are composed of large, thick layers of rarely conglomeratic sands, interbedded with clay layers which become thicker and more frequent in the upper part of the Formation. The sand is quartzitic, variable in grain size and almost loose. The conglomeratic levels in a sandy matrix in the lower part of the Formation exhibit the lower unconformity. The Abu Madi sandstones have consistently proved to be the best reservoirs in the Nile Delta, as they have a high porosity with an average of 21%. The majority of fields produce from Abu Madi Formation [7]. These sandstones are considered as the main gas-producing horizons in the Nile Delta area.The delta is divided into two sub provinces by a faulted hinge line running WNW to ESW acres the area at the latitude of the Kafr El Sheikh city (Fig.3)[9]. This hinge line is the most significant structural feature of the Nile Delta region and is known as the faulted flexure that it separates the south delta province from the north delta basin [10&11]. In the southern delta province, the subsurface structure is complicated by the interaction between tectonic elements of different ages and with different orientation on these structures is superimposed. These are The ENE and NE trending folds of Late Cretaceous to Eocene age (the Syrian arc folds). The Oligocene to Early Miocene NW-SE trending faults which were associated with a major uplift in the south coupled with basaltic extrusion. The Late Miocene and Pliocene delta subsidence was mainly concentrated along the axis of the Nile valley.

III. Material and Methodology

The available data for this study were completed data from three wells (West Al Khilala-1, West Al Khilala-2, and West Al Khilala-5) which are located in West Al Khilala field (Fig.1). The conventional open hole log data (gamma ray, resistivity, neutron porosity and formation density) and NMR log were used in this study.The reservoir evaluation was done by using the interactive petrophysics software (IP software) which aid in fast and accurate calculations of all petrophysical parameters. The porosity measured by NMR tools contains no contribution from the matrix materials and does not need to be calibrated to formation lithology. The conventional resistivity logging tools are being extremely sensitive to the fluid filled space and used to determine the water saturation of the rock. These tools are strongly affected by mineral composition such as conductive minerals as pyrite. For all previous conditions NMR logging is considered as a powerful tool since it can provide three types of information. 1- The Quantities of fluids in the rock. 2- Prosperities of these fluids and it is type (Bulk volume irreducible (BVI), Clay bound water (CBW) & Free fluid (FF). 3- The size of the Pores that contain these fluids. The NMR petrophysical measurements and their applications have been debated by many authors' [12, 13, 14, 15, 16, 17 & 18].

1.1. 3.1 NMR porosity measurements

In NMR logging technology, hydrogen nuclei of the formation fluid is forced to spin and then monitor the rate at which they recover stability. The strength of the NMR signal is proportional to the number of hydrogen atoms in NMR tool-dependent rock volume.The NMR porosity is direct measurement as it reflects the fluids in the pore spaces. The measured porosity doesn't need any type of lithology correction but need fluid hydrogen index correction[18]. The measured porosity of NMR can be divided according to the relaxation time of the fluid after the magnetic field had been released (T_2 distribution). The measured NMR porosity is a total porosity which can be divided into clay bound water (CBW) porosity that represents the water in the internal structure of clay minerals. The amount of clay bound water reflects the volume of clay minerals in the reservoir [19].The effective porosity is the result of the subtraction of CBW porosity from NMR total porosity. This effective porosity can be divided into two types, firstly the pores which contain free fluids and the pores which contain bound fluids which is bounded under capillary forces (Fig. 4).

As the gas reservoirs have low hydrogen index so the magnetic resonance don't make complete polarization to fluid which occupy the pore spaces in the sufficient polarization time. So the measured porosity from NMR is unreliable porosity (underestimated) due to fast relaxation time. In order to solve this problem Hydrogen Index (HI) correction should be done in order to overcome this problem. This correction is done by establishing a relationship between porosity calculated from density and porosity measured from NMR in a clean sand water bearing zone. After that, the relationship on the whole reservoir is applied to correct the HI. After applying the correction we can establish a relation between Density porosity and corrected NMR porosity (DMRP) which shows the compatibility of the relation between two porosities (Fig. 5). The cross plots for work area showed a decent relationship between porosity from conventional log and porosity from NMR logs. This indicates that the previous correction method is a significant correction for raw NMR porosity in this fluid type.

1.2. 3.2NMR permeability calculations

NMR permeability transforms are based on the relationship between the NMR T_2 distribution and pore size distribution. In clastics rocks, this relationship is fairly consistent. The T_2 is the border line between BVI and FFI which differentiate between micro porosity and macro porosity. Both of the two previous parameters are representing the main parts of Coates equation[20], which is used in the calculation of permeability from NMR logs.

$$K= [(\phi/C)^{2} (FFI/BVI)]^{2}$$

The standard cutoff for BVI should be used in case of BVI cutoff not measured from core plugs within the area and in this case the calculated permeability should be compared with core permeability if it available. The standard BVI cutoff is 33 m sec for sandstone and 90 m sec for carbonate reservoir (Fig. 6)[21].

1.3. 3.3NMR pore size distribution

The NMR technology has some limitations of pore size distribution. In case of presence of two fluids within the pore (hydrocarbons and water) it is disturbed the bins distribution which reflects the pore size.

The bins resulted from the NMR tool reflects different decay time of hydrogen presented at the pores 4 m sec, 8 m sec, 16 m sec, 32 m sec, 64 m sec, 128 m sec, 256 m sec and 512 m sec. As the decay time is being short, it reflects a small pore size and as the decay time being longer, the pore size being coarse so each bin is representing a range of pore sizes starting from the smallest 0 m sec and ending by the coarsest 512 m sec[21]. In case of water wet rock, The T_2 value of single pore is proportional to the surface to volume ratio of the pore, which is a measure of the size of the pore. Thus, the observed T_2 distribution of all pores in the rock represents the pore-size distribution of the rock (Figs. 7 & 8).

1.4. 3.4NMR in water saturation calculations

The NMR logging tools are measuring in highly invaded zone in which only residual formation fluids can be traced. The water saturation evaluation depend on many important factors as porosity, formation resistivity and water resistivity so when these factors have low uncertainties, the water saturation value will be very reliable. Using corrected NMR effective porosity in integration with shallow resistivity and deep resistivity the true formation saturations will be determined.

IV. Results and Discussions

1.5. 4.1West Al Khilala-1 well

Over the interval from 9920 ft. Md to 10,050 ft. measured depth the NMR log give good results which enhanced the formation evaluation for the previous intervals. The corrected effective porosity over this interval ranges from 12.7 to 33.6 % with average porosity 21 % which is matched with effective porosity measured by conventional electric logs. The maximum value of permeability over this interval is 1082 md with average value reaches 131 md. The average bound fluid volume which includes the summation of CBW and BVI is 7 % over sand interval but reaches 30 % over shaly intervals. The porosity derived from density used for correction of NMR porosity ranges from 9 to 34.6 % over the interval with average 26 %. The water saturation was calculated based on corrected NMR porosity which reaches 37 % over the reservoir interval but average irreducible water saturation based on CBF reaches to 27% (Fig. 9).The main reservoir interval is divided into two segments according to variety of major grain size. The first interval from 9920' to 9948' the grain size distribution within this interval is mainly medium to coarse grain size silt, very fine to fine sand with low percent of medium sand and very coarse sand with small amount of clay (Fig. 10).The second interval from 9950ft to 10,050ft, the grains which form this interval can be classified into medium silt to coarse silt and very fine to fine grain size sand with minor amount of clay (Fig. 11).

1.6. 4.2West Al Khilala-2 well

For continuing high resolution formation evaluation NMR log was recorded over the reservoir interval in W. Al Khilala-2 well. The corrected NMR porosity over this interval ranges from 14.5 to 27 % with 21.5 % as average value. The permeability over this interval ranges from 0.18 md to 1924 md with average value reaches to 276 md. The average bound volume irreducible ranges from 8 to 12 % over reservoir interval with free fluid volume ranges from 16 to 18 %. The porosity derived from bulk density which used in NMR porosity correction ranges from 8.5 to 33 % with average value reaches 24.5% where the water saturation reaches to 37 % where the average irreducible water saturation reaches to 27%. The previous results of NMR log show a good match with conventional and special core analysis results (Fig.12).The grain size distribution over the reservoir interval is mainly composed of very fine to fine sand with some medium to coarse grain size sand (Figs.13 & 14). The grain size distribution of special core analysis for some selected plugs shows a medium pore size which coincide with the very fine to fine sand size (Fig. 15).

1.7. 4.3 West Al Khilala-5 well

The NMR processed interval over this well is from 10,222ft to 10,280 ft. The corrected effective NMR porosity ranges from 10.7 to 30 % with 21 % as an average value. The calculated permeability started from nil up to 1821 md with average value of 250 md. The density porosity ranges from 5 to 31 % with average value of 22.5 %. The average bound volume irreducible is 6 % where average free fluid of 12 %. The average water saturation reaches to 41 % where irreducible water saturation reaches to 30%.The NMR log results show good match with conventional core analysis porosity, permeability and water saturation of W. Al Khilala-5 (Fig.16).The pore size distribution shows that the interval is composed mainly of very fine to fine sand with medium to coarse grain silt with minor amount of clay (Fig. 17).

V. Figures and Tables

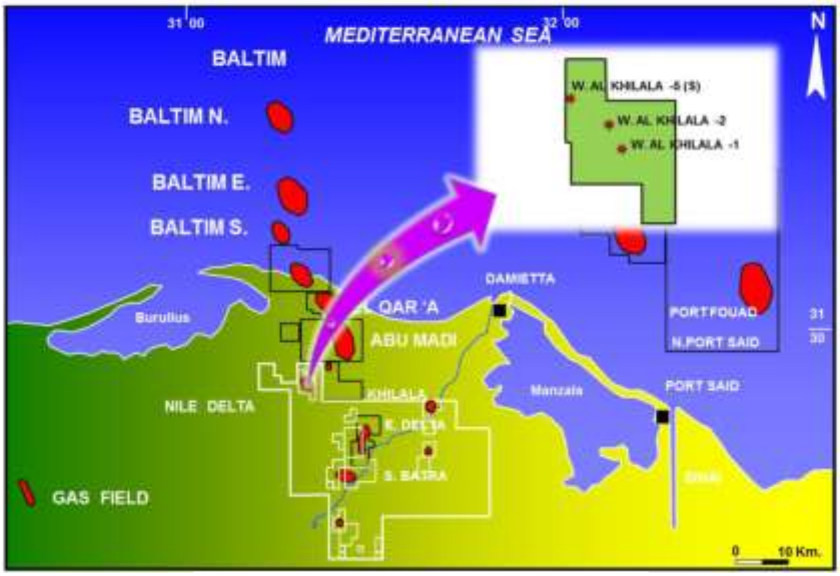


Fig. 1: Location map for the area of study.

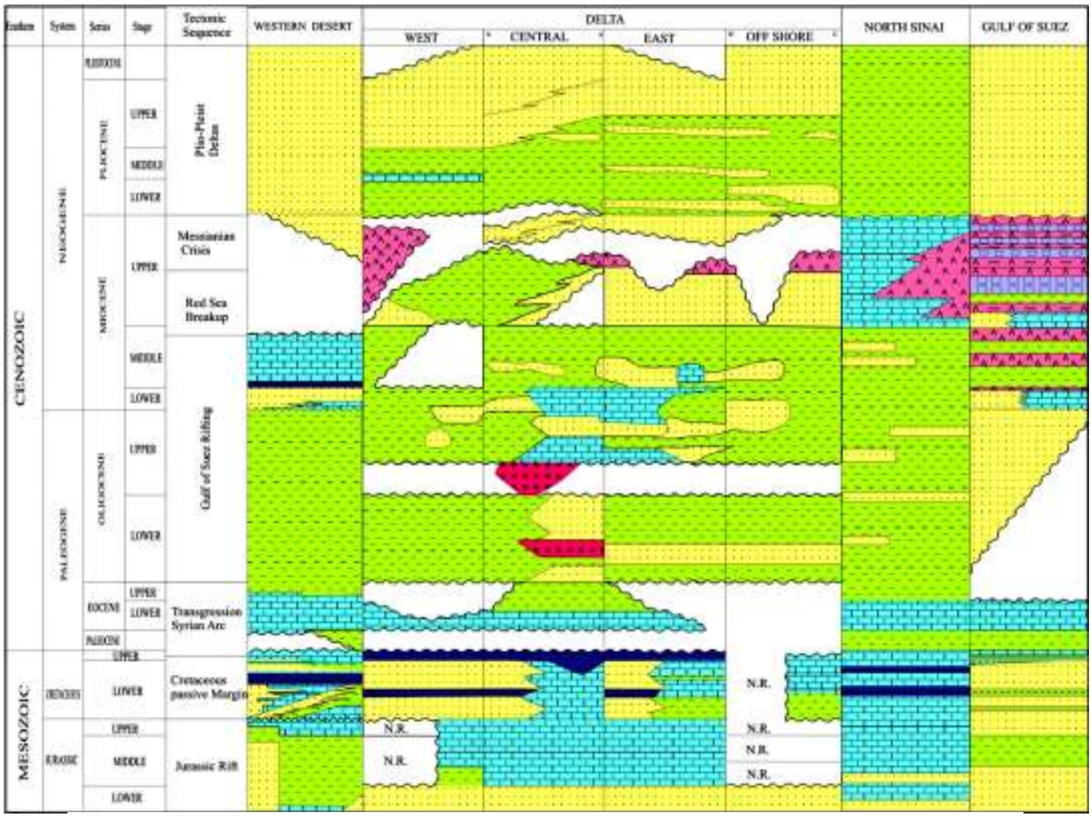


Fig.2: Stratigraphic correlation panel and major tectonic stratigraphic breaks of Egypt[5].

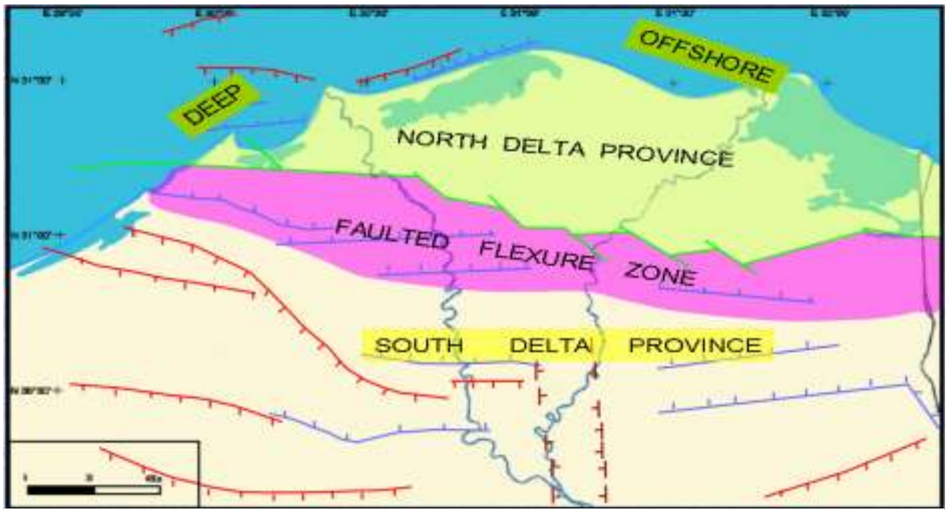


Fig.3: Main subsurface structures of the Nile Delta region (redrawn after Sestini, 1989).

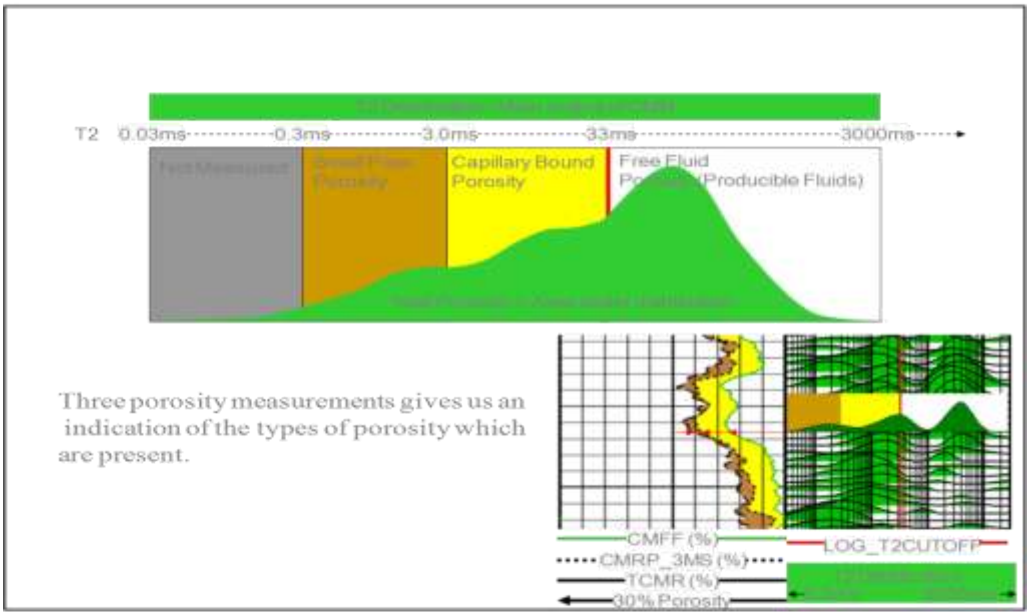


Fig. 4: The Porosity types according to T_2 distribution cutoff.

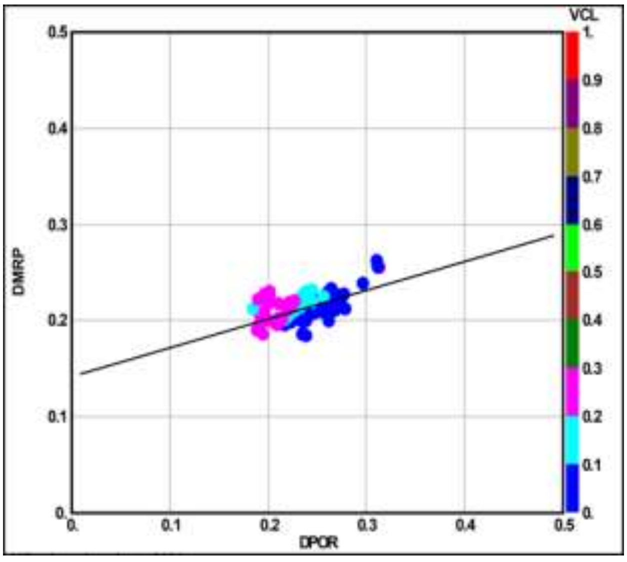


Fig. 5: The relation between density derived total porosity and DMRP of well W. Al Khilala-5well.

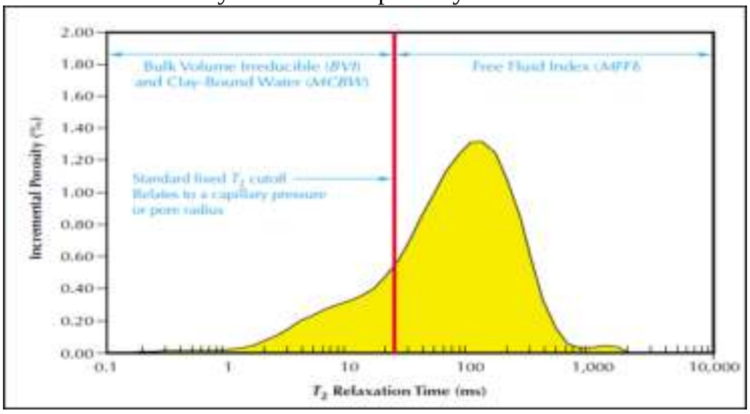


Fig. 6: The Standard fixed T2 cutoff to differentiate between CBW, BVI and FFI [21].

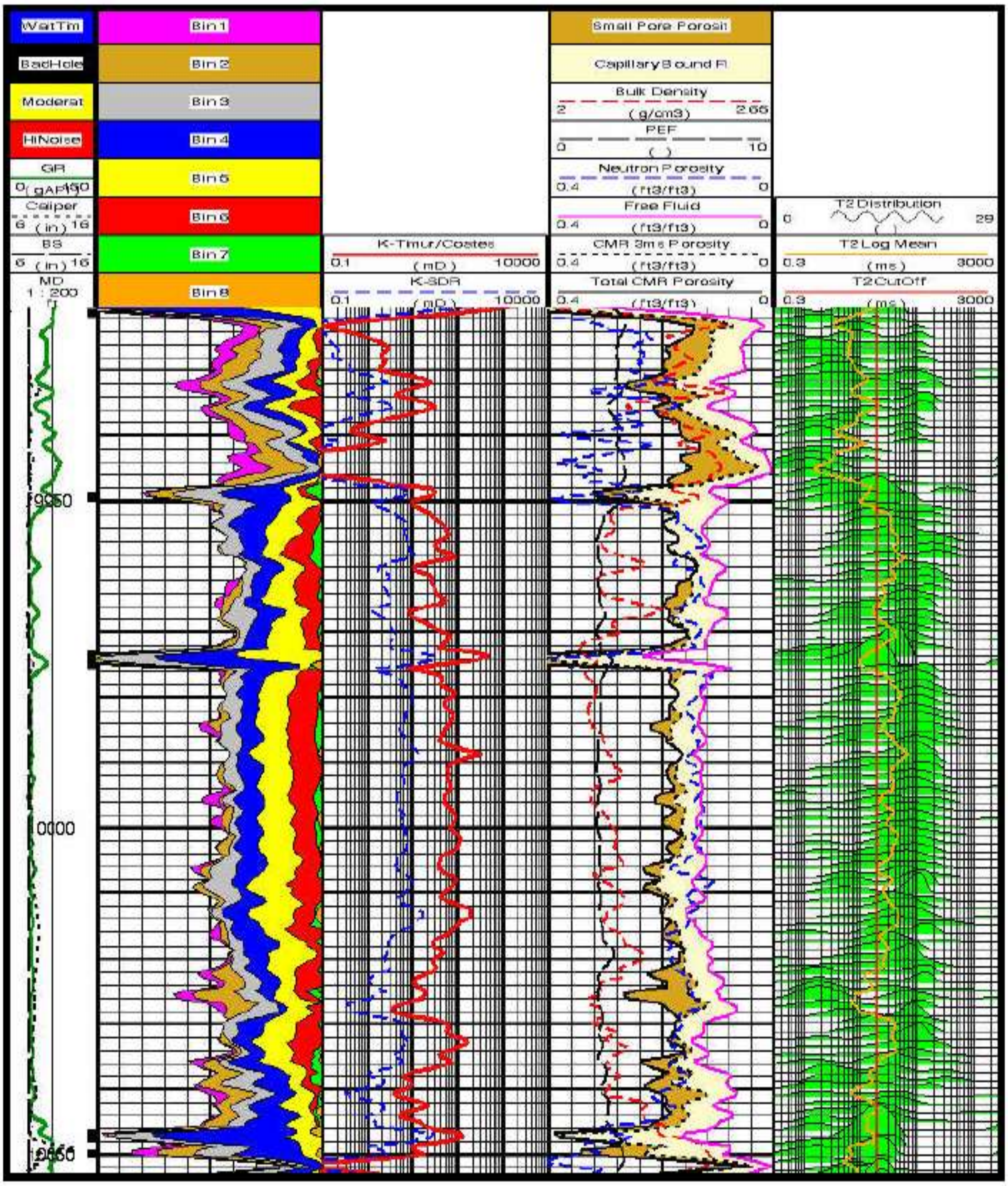


Fig.7: Bin porosity display over interval 9920' – 10,050' for W. Al Khiala-1 Well.

Fig.8: Bin porosity distribution scale for pore size.

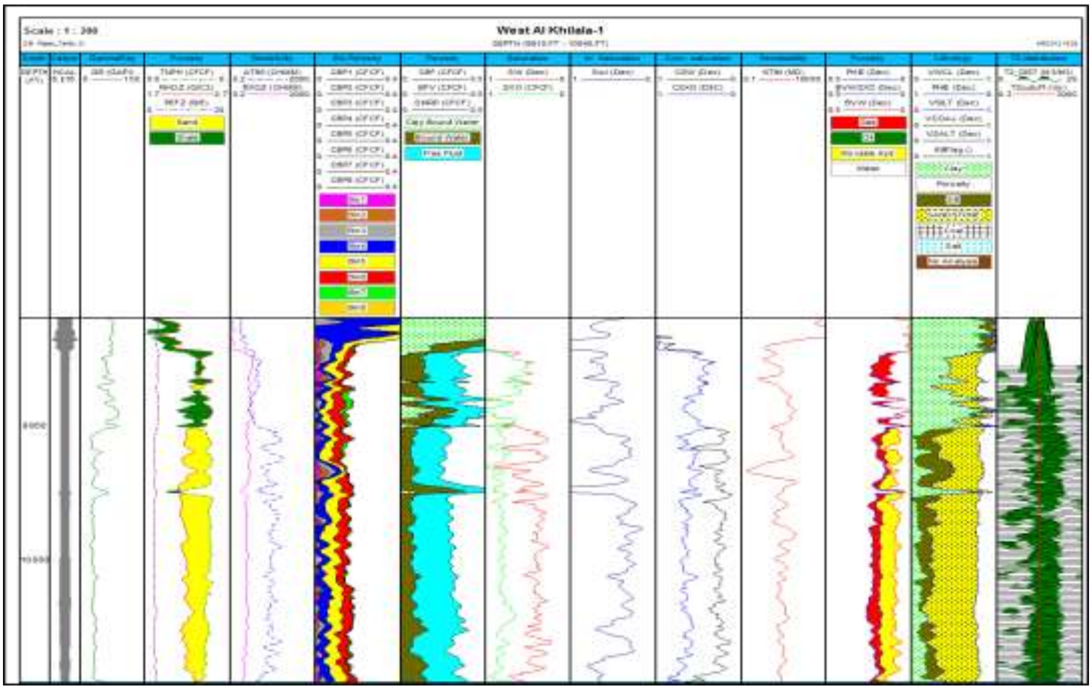


Fig.9: Analog of West Al Khiala-1 well.

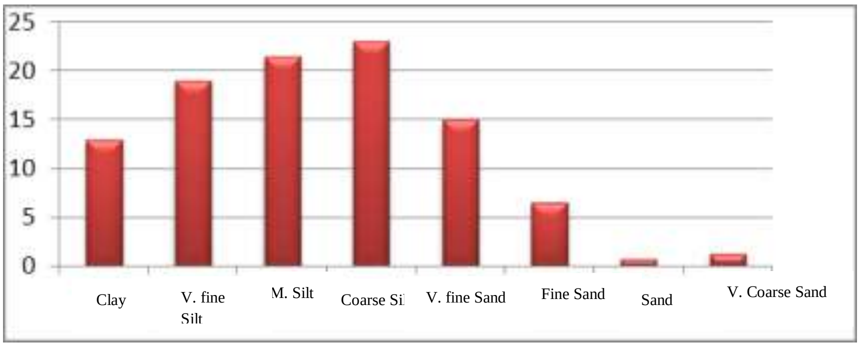


Fig. 10: Pore size distribution over the interval 9920' to 9948' of w. Al Khilala-1

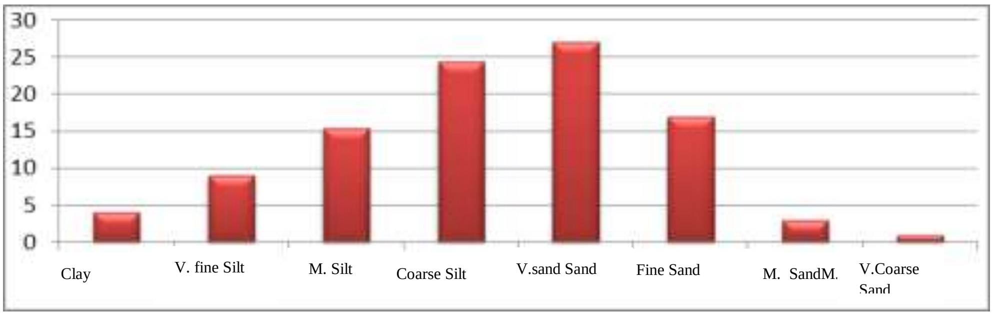


Fig. 11: Pore size distribution over the interval 9950' to 10,050' of W. Al Khilala-1 Well.

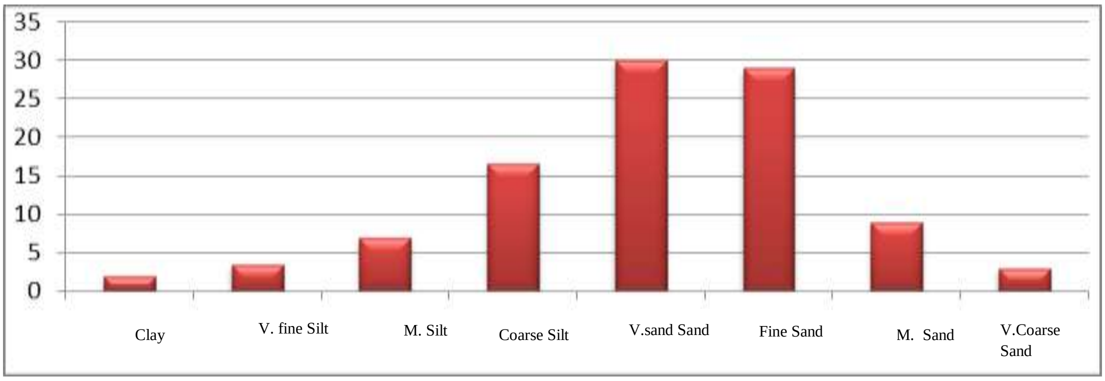


Fig. 13: Pore size distribution over the interval 9930' to 9964' of W. Al Khilala-2 well.

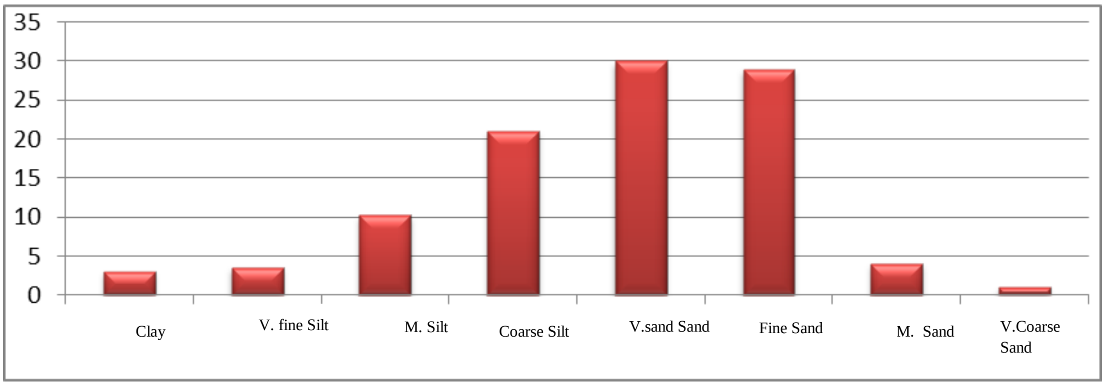


Fig. 14: Pore size distribution over the interval 10,000' to 10,050' of W. Al Khilala-2 well.

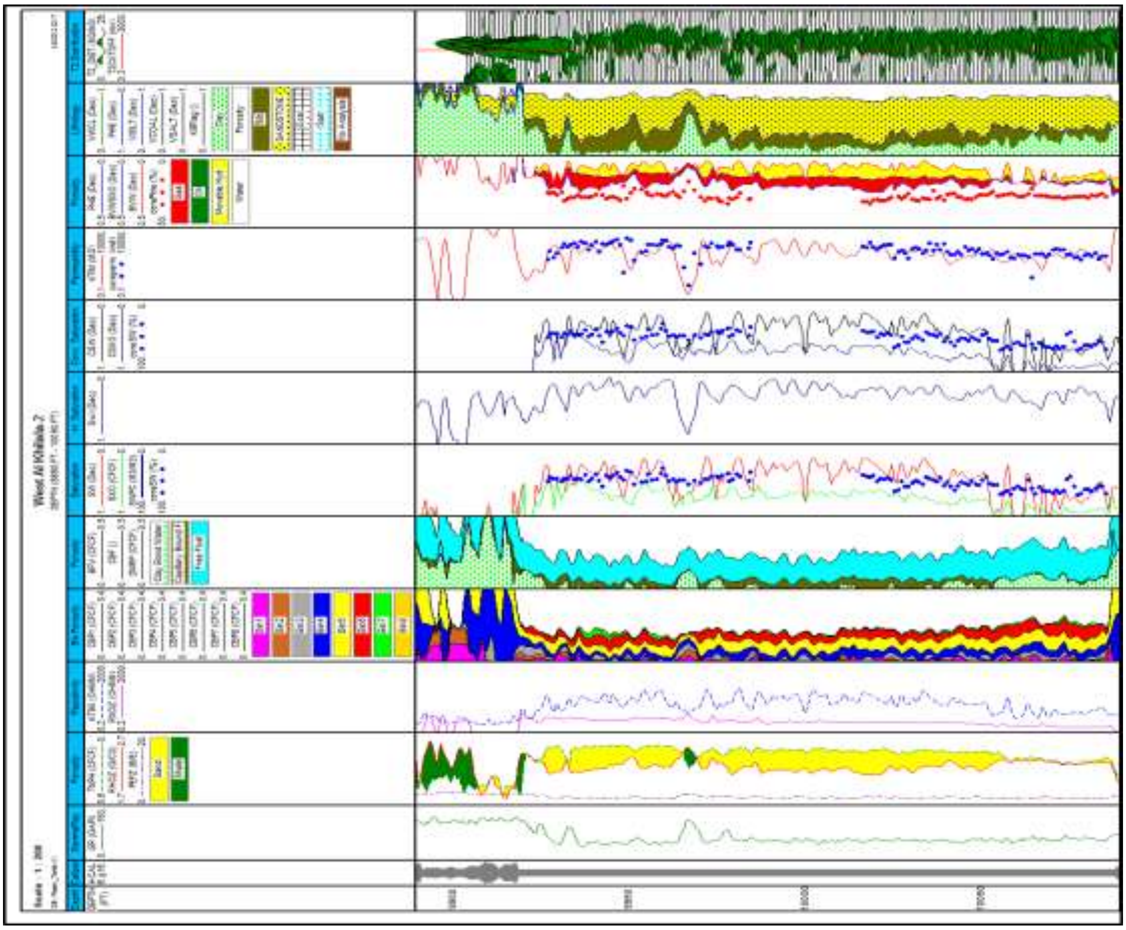
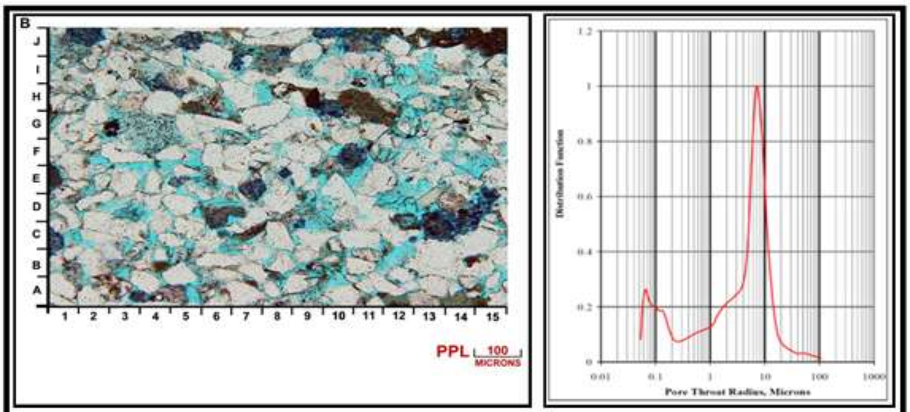


Fig. 15: Analog of West Al Khiala-2 well.



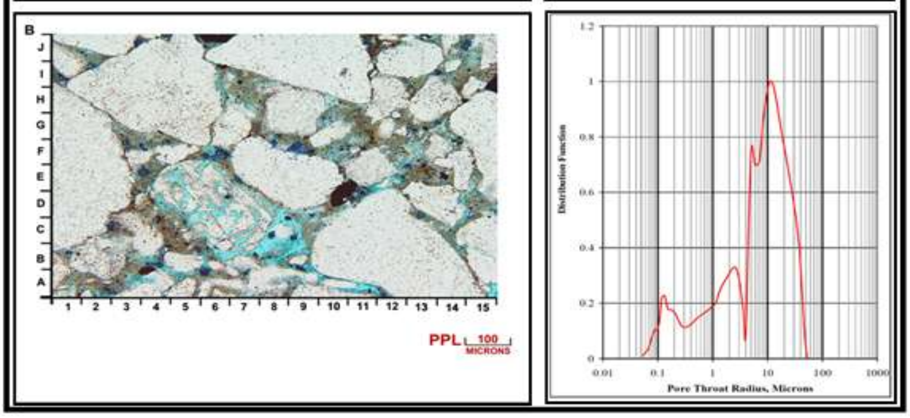


Fig. 16: The pore size distribution of a two samples from core analysis of W. Al Khilala-2 well.

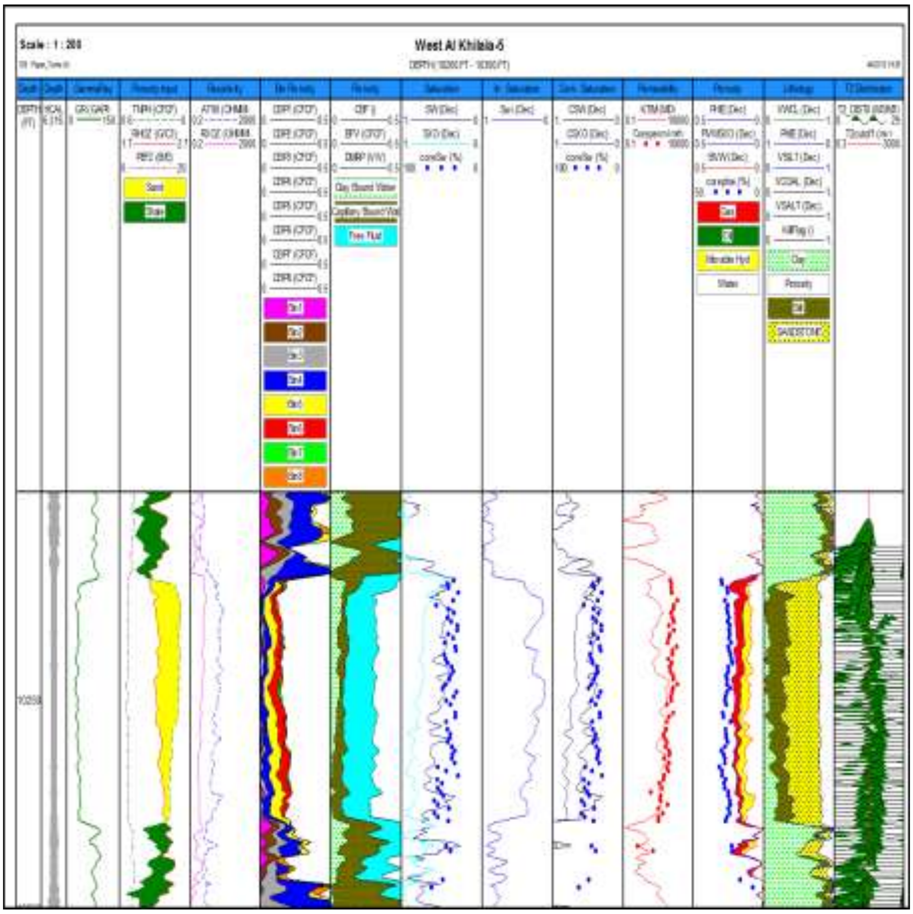


Fig. 17: Analog of West Al Khiala-5 well.

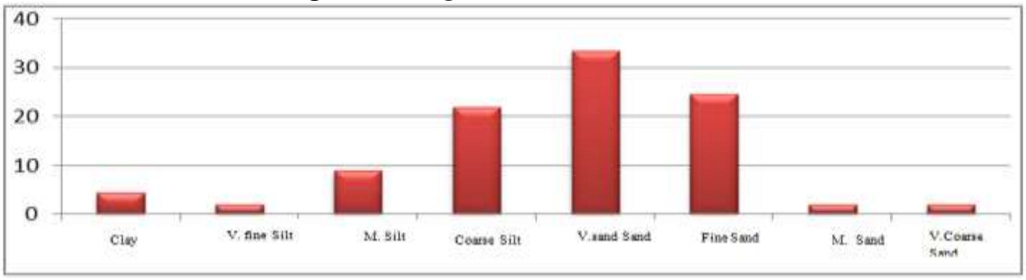


Fig. 18: Pore size distribution over the interval 10,222' to 10,279' of W. Al Khilala-5 well.

VI. Conclusions

The integrating of Nuclear Magnetic Resonance log with conventional open hole log gives an accurate determination of the petrophysical parameters. The NMR derived porosity gives a good result which is best fit with porosity derived from conventional (Density/Neutron) logs and core analysis.The capability of NMR to differentiate between free and Irreducible fluids has helped the log analyses to more accurate estimate of reserves as it contain no contribution from the formation lithology. DMR porosities show much better match with core porosities. NMR porosity in combination with density is a very good tool for gas corrected total porosity calculations.NMR log is powerful tools in Formation evaluation of shaly reservoirs as it differentiate between irreducible water bounded within shale and small porosities and free water within large pores so effective water saturation can be calculated easily to reflect the actual water saturation within large pores.The NMR tool also provides a pore size distribution which depends on T_2 (relaxation time). The size in all wells which have NMR log ranges from medium silt to fine sand except W. Al Khilala-1 well as it's grain size ranges from clay size to very fine sand size with a small amount of fine sand in the interval from 9920 ft to 9948 ft.The interpretation of NMR data requires caution and experience to ensure that the suitable cut-off values are selected and that reliable conclusions are reached from the measured and calculated parameters.The intensive studies of Messinian Abu Madi Formation indicate good petrophysical parameters for production.

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