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INTEGRATION OF PETROPHYSICAL AND GEOLOGICAL DATA WITH OPEN- HOLE LOGS FOR CHARACTERIZATION OF ABU ROASH C RESERVOIR IN BED-15 FIELD, ABU GHARADIG BASIN, WESTERN DESERT, EGYPT

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التنسيق بين نتائج تسجيلات الآبار وكذلك المعلومات الجيولوجية و البتروفيزيقية لتقييم خزان ابو رواش بحقل بدر الدين ١٥ ، صحراء مصر الغربية ، مصر

الخلاصـة: تتناول هذه الدراسة التنسيق بين نتائج تسجيلات الآبار وكذلك المعلومات الجيولوجية والبتروفيزيقية لتقييم أبو رواش بحقل بدر الين ١٥ والذي يعتبرجزء من منطقة امتياز شركة بدر الين للبترول. ويمثل تكوين أبو رواش أهم خزان منتج في الصحراء الغربية حيث يصل سمكه الى ٧٠٠ م ويقسم الى ٧ وحدات من (Aالى G) . وتم التركيز في هذه الدراسة على عضو أبو رواش(C) من تكوين أبو رواش. حيث تبين أن قياسات المسامية لهذا العضو تتراوح بين ١٣% و ٢٣ % بمتوسط ١٨ % وكذلك من تحليل العينات اللبية الأسطوانية أن قيم النفاذية تتراوح من ٣٠٠ ملى دارسى الى ٥٠٠ ملى دارسى . و كذلك تبين أيضاً من دراسة القطاعات الميكروسكوبية لهذا العضو تم التوصل الى أنه يتكون أساسا من الكوارتز الناعم إلى المتوسط بقيم مسامية تصل الى ٢٣% مما يجعله من أهم الوحدات الصخرية التي تحتوي على تجمعات هيدروكربونية تصل درجة التشبع الصخري بها الى أكثر من ٨٥% .

ABSTRACT: *The Abu Gharadig Basin is located in the northern part of the Western Desert of Egypt. It has a great importance as it is considered the most petroliferous basin in the Western Desert as far as hydrocarbon production and potential.The BED-15 field forms part of Badr El Din concession in the Western Desert some 300 km west of Cairo and some 100 km west of the BED-1 producing field. It lies within the Abu Gharadig basin.*

Abu Roash Formation is one of the most producing zones in the western Desert; It is characterized by a cyclic alternation of deltaic flood-plain sandstones, coastal sandstones and shales, and shallow marine shales and limestones. It attain about 700 m in thickness and is divided into seven members (from A to G).Using well log analysis 4 reservoir units are identified within Abu Roash "C": Unit-2, Unit-2A and Unit-3,4. Units 1 and 4 donot contain sands.

From the petrophysical analysis, it was found that, the average porosity is 18% and its value ranges between 13% to 23%, such pores are filled with more than 85% of hydrocarbons. While Core measured permeability confirmed a homogenous distribution through the main reservoir unit in the range of 300 – 500 md.

INTRODUCTION

The BED-15 field forms part of Badr El Din concession in the Western Desert some 300 km west of Cairo and some 100 km west of the BED-1 producing field (Fig.1). several works have been done on Badr El-Din area, among them Bayoumi, T., 1994, El Ghoneimy, 1988, El Gohary, et al. 1986, El Toukhy and El-Beialy, 1994, Helba, 1996, Hendy, et al. 1992 . The oil reservoirs main sand, the Abu Roash "C" is an elongated NNW-SSE tidal channel sandstone at an approximate depth of 3100 mtvdss. The penetrated sand thickness varies between 2m to 32m with high Net to Gross (>95%) and good reservoir quality (porosity ~18%). The reservoir boundary limit is defined to the west by a series of faults and to the east by the channel edge. Oil-water contact has recently been penetrated in BED 15-8 at 3165 & 3220 m.

Field History

The BED-15 field was discovered in 1988 by well BED 15-1 G. A test carried out over the Abu Roash "C" produced oil at a rate of 2288 barrel per day .After Bed 15-1 was put on production in June 1989, the reservoir was further developed by the wells BED 15-3, BED 15-4A, BED 15-7, and BED 15-7 S/T.BED 15-2 did not encounter any sand development and was sidetracked to BED 15-2A, which was equally unsuccessful. BED 15-3 successfully penetrated some 16 m of pay sand. Though BED 15-4 didnot penetrate the Abu Roash "C" due to faulting, its sidetrack BED 15-4A encountered some 32 m of pay sand. BED 15-3 and BED 15-4A came on stream in 1991 and 1993, respectively

Geology

In Abu Gharadig basin, the Abu Roash 'C' was deposited in the Late Cretaceous (Turonian) as part of an overall Transgression, which started in the Cenomanian (Bahariya Formation) and ended in the Maastrichtian (Khoman Formation) (Abdel Al, et al. 1988). The reservoir sand was deposited as a result of the increase of clastic supply from the southern margin of the basin, which was originally covered by huge lagoons (Bakry, 1994). The finer clastics that underlie the reservoir yielded brackish water fauna in BED-1 area reflecting the fresh water supply and benthic forams and ostracods in BED-15 area indicating margial marine to inner neritic environment. This clastic supply was deposited in the form of Minor River Deltas as in BED-1 reservoir sand, then reworked by wave and tide actions forming the back barrier complex as in BED-3 and BED-15 reservoir sand. This sand then changed laterally to be shallow marine shale where BED-2 is located.

Structural Interpretation

The Abu Roash “C” structure is a gentle anticline, plunging to the NNE and dissected by extensional faults oriented predominantly to the NW-SE directions (Figure.2). The faults are generally at low to slightly high angle ($35^o \sim 55^o$). The major faults affecting the area (max. throw 80m) do not follow the usual relation between the fault’s lateral extent and its throw. This relation indicates that the maximum throw of a fault should be located in the centre and the throw decreases laterally towards the tip (Bayoumi,1994). Exceptions to this “rule” may be due to various reasons such as:

1. The slip of the faults is not pure dip slip component, but there is also a strike slip component.
2. Complexity due to intersecting faults.

The above is consistent with the regional dextral wrenching affecting the whole Abu Gharadig Basin at that time. Furthermore, a left -stepping en echelon faults pattern results from the dextral wrenching. The joining of the faults creates blocks that form dip-and-fault closures suitable for hydrocarbons traps.

According to BABETCO classification, the Abu Roash “C” Member can be subdivided into four lithologic units from top to bottom as follows:

Unit 1 (Lower Shale) is composed of calcareous shale with thin shelly intervals

slightly glauconitic, Benthic forams and Ostracods. This unit interpreted to have

been deposited in Brackish Lagoonal environment with fresh water influx. The

thickness of this unit is ranges from 9 to 17m and lies just above the Abu Roash

’D’ expressing the beginning of a short period of sea level fall (LST).

Unit 2 (Active Channel Sand) is composed predominantly of reservoir quality quartz sandstone it overlies sharply the underlying lagoonal deposits with a basal scouring surface enclosing lag deposits suggesting a tidal channel sand in BED-15 and BED-3 areas or Tidal Creek in BED 16-1 (the sand is dominantly fining upward to blocky). The sand is variably developed but always the development is at the expense of the uppermost intervals of the lagoonal shale. The thickness of this unit is varies from 2 to 32 meters.

Unit 2A (Abandoned Channel) is composed of shale with a limestone marker with often thin good quality sandstone reservoir at the bottom part. This zone is representing the abandoned part of the underlying active channel and its top is defined by the coal marker. The fossil content and lithological features of this unit in addition to the Coal bed within the lower part are suggesting deposition in a Marsh to Tidal Flat environment. However, towards the north, where BED-16 is located, the lower shaly part is replaced partly by coarsening upward sandstone interpreted as a barrier bar. This unit infers the beginning of the sea level rise (TST). The thickness of this unit varies between 1 to 10m. This unit marking the top of the reservoir cannot be mapped directly on seismic.

Unit 3 (Wash Over Sequence) consists of shale with fine grained sandstone of low quality if compared to the underlying main sand. The fossil content and lithological features of this unit in addition to the Coal bed within the lower part suggest a deposition in a Marsh to Tidal Flat environment. However, towards the North where BED-16 is located, the lower shaly part is replaced partly by coarsening upward sandstone interpreted as a barrier bar. This unit infers the beginning of the sea level rise (TST). The thickness of this unit is between 1 to 12m.

Unit 4 (Upper Shale) is composed of shale interrupted by few limestone streaks and siltstone at its lower part. Most likely, this unit belongs to the depositional regime of the underlying section, indicated from the same characterized faunal association and accessories. This zone is defined between the Base Lower Limestone marker and the main Abu Roash “C” top boundary and is the mapped seismic marker. The thickness of this unit is ranging from 44 – 54m.

Regional Setting and Tectonics

The Abu Gharadig basin is an elongated asymmetric E-W trending, intra-cratonic half graben system bounded to the North and South by the Qattara Ridge and the Sitra Platform, respectively (Fig. 5).

Stratigraphy

Figure.3 shows the regional stratigraphic column for the Western desert in Abu Gharadig area and the main reservoir source horizons throughout the whole sequence.

The Abu Roash “C” Member in the Abu Gharadig area was deposited during the Late Cretaceous, Turonian age. It is composed mainly of sandstone, shale with some streaks of limestones and can subdivided into four units based on the lithological and sedimentological features as revealed in the cores from wells BED15-3, BED3-7 and BED16-2. Subunits and marker horizons are well defined in all the wells,

a special example is the BED 15-1 log display (Figure.4). These units are (from bottom upwards):

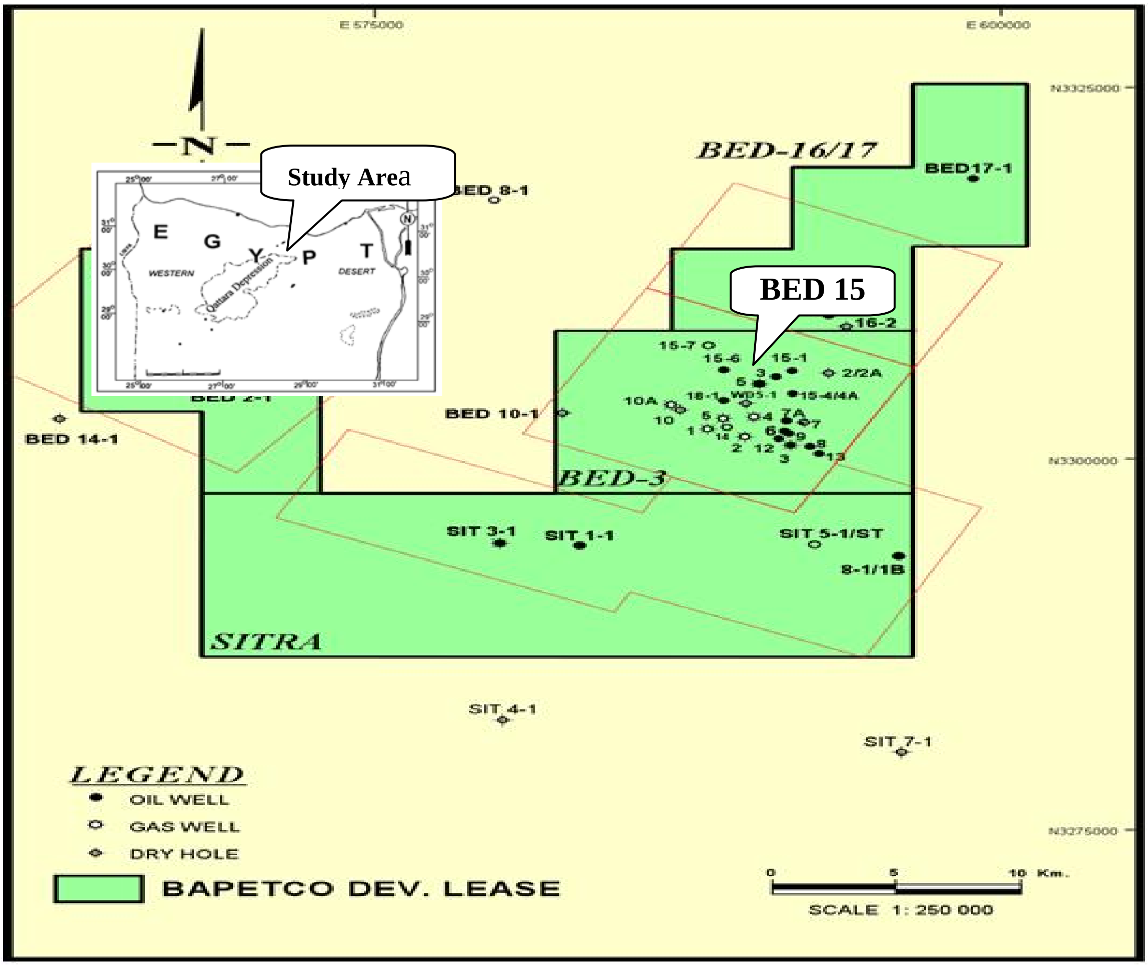

Fig. 1: Location map of the study area.

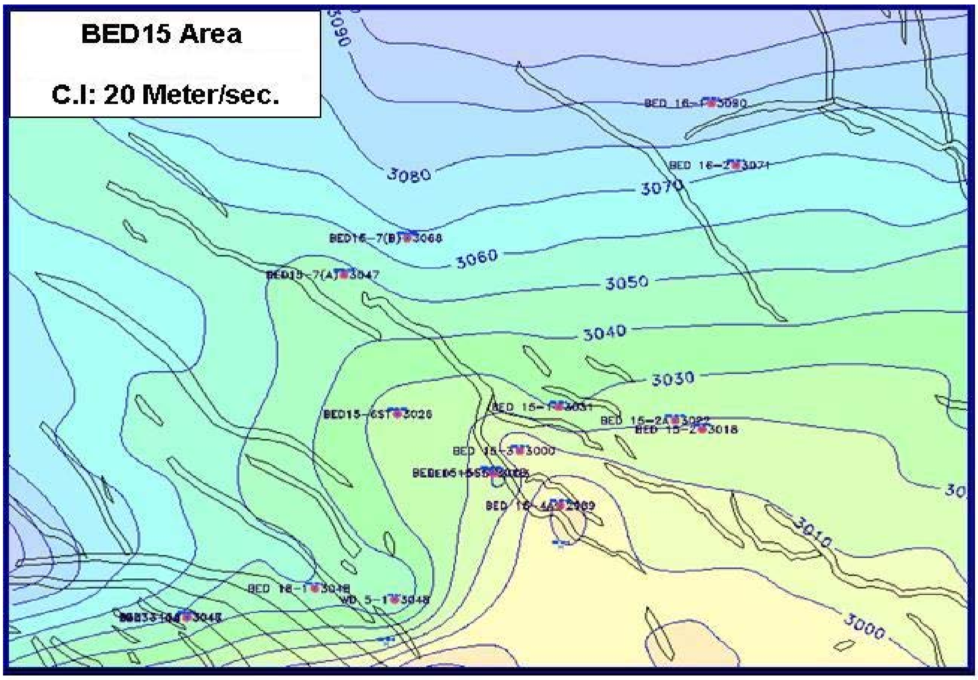

Fig. (2) Structural map on top of Abu Roash "C" Member.

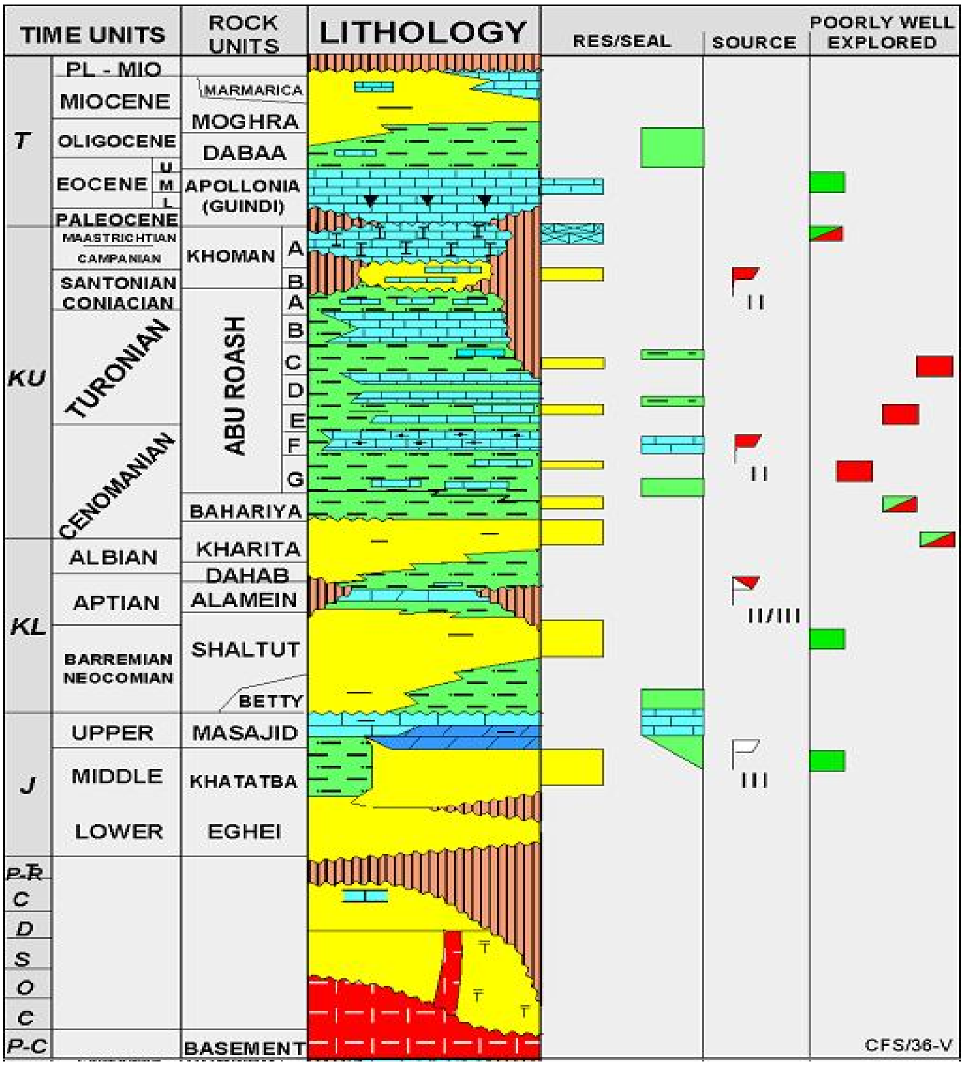

Figure. 3: Litho-Stratigraphic column of Western Desert Area, Egypt.

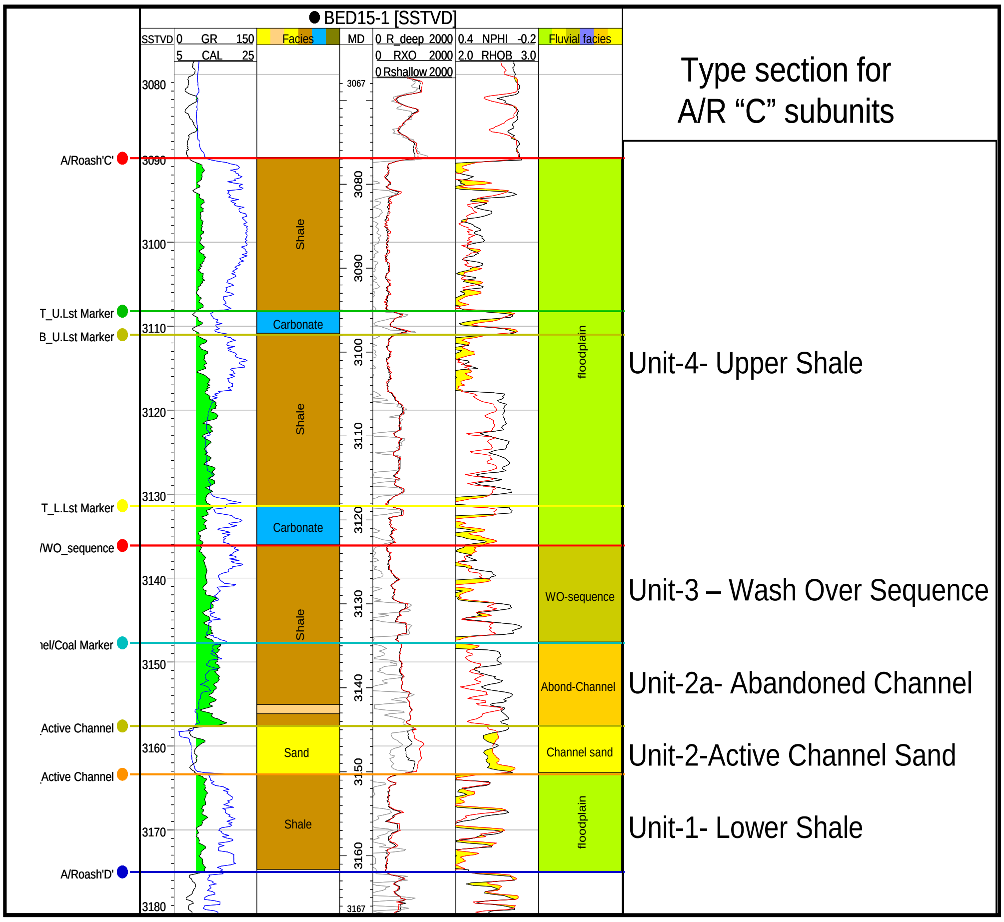

Figure 4: Subunits of Abu Roash "C".

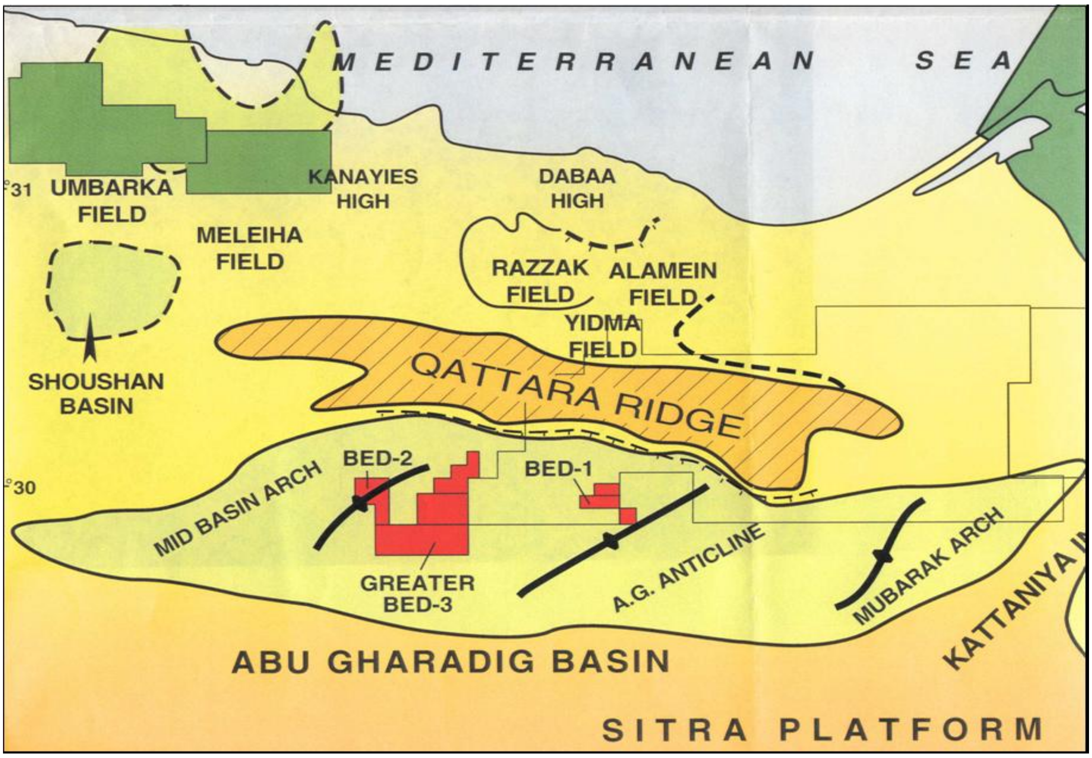

Figure 5: The Abu Gharadig Basin.

Petrophysical Evaluation

Zeidan et al. (1990 – 1994) and 1994 studied the petrophysical properties of the reservoir in Badr El-Din area. All the logging and core data were downloaded on the workstation and validated. Density, neutron, dual laterolog (DLL) and MSFL log data were borehole corrected. From DLL and MSFL data an invasion corrected deep resistivity was obtained. Borehole size, mud resistivity data and bottom hole temperature were taken from the log headers, and confirmed with the daily mud reports in wells which drilled with water base mud. Quality check on the existing data was done including environmental correction for all the available curves and applying depth shift to meet all the logging response at a valid value.

The full field evaluation was followed by computation of sums and averages for each well using porosity and saturation cut-off criteria for the net pay reservoir identification.

Core Data

Cores were acquired over Abu Roash ”C” formation in wells BED 15-3, BED 15-7, 3-6, 3-7 and BED 3-8 and have been incorporated in the study. Conventional core analysis data were carried out by COREX. Some special core analysis such as formation-resistivity factor (FRF), resistivity index (RI), relative permeability measurements and capillary measurements were also done. In total approximately 19 m of Roash ”C” Formation core was recovered.

From the special core analysis the cementation exponent (m) and saturation exponent (n) were obtained, where indicates: a=1, m=2.00 and n=1.85 (Figure.6).

Petrophysical properties

Porosity Evaluation

In the Abu Roash “C” Member porosity was determined using the density with the established grain and fluid density values that reflects the reservoir fluids. The porosity was edited for erroneous readings that were a result of improper contact of the density tool with the borehole wall. The final calculated porosity was in agreement with the core porosity (Figure 7). Due to the overburden pressure the porosity values had to be converted to reservoir condition by using a relation between the confining porosity at 5000 psi and room porosity (for further details see below). In-situ porosity measurements were available on three wells (15-3, 3-7 and 3-8). The measurements showed that the atmospheric porosity is about 1 porosity unit higher than the in-situ porosity.

A core derived matrix density of 2.65 g/cc was used, 1.0 g/cc mud filtrate density for most of wells drilled with water base mud and 0.9 g/cc for oil-base mud.

The equation used to calculate porosity from the density log is as follows:

$\Phi_{density} = rho_{matrix} - rho_{log}/rho_{matrix} - rho_{fluid}$ **(Schlumberger Essentials, 1972)**

where:

$\Phi_{density}$: porosity from density log

rho_{matrix}: is the density log rock matrix (2.65 gm/ cc for sandstone).

rho_{log} : is the density log reading in front of analyzed zone.

rho_{fluid} : is density of the used fluid in the drilled well (1.0 gm/ cc of fresh mud).

Atmospheric to Insitu Core Porosity Correlation

To calibrate the log porosity values to insitu core porosity, a correlation was derived between atmospheric and stressed core porosity. Stressed porosity measurements on core data from BED15-3, BED 3-7 and BED 3-8 have been made under a range of isostatic stresses. In-situ porosity data corresponding to the initial stress conditions in the reservoir have been cross-plotted versus atmospheric core porosity and yield the following transform:

$\Phi_{insitu} = 0.9676*\Phi_{atmospheric}$

This correlation is used to convert atmospheric data to insitu porosity, which used to calibrate the log porosity values.

Permeability Evaluation

Atmospheric to insitu core permeability correlation

A model to estimate the atmospheric air permeability from insitu permeability was developed from porosity and permeability analysis for the cored wells. The first step to correct the air permeability to liquid permeability is to use the Klinkenberg correction as follows:

$K_{air} = K_{\infty} (1+(b/p))$

where

K_{air} apparent gas permeability (mD)

K_{∞} absolute “Klinkenberg” permeability (mD)

P mean absolute pressure (bar)

B Klinkenberg gas slippage correction factor (bar)

Insitu permeability is measured under isostatic stress conditions. Due to the overburden pressure the permeability values have to be converted to reservoir condition by using a relation between the confining permeability at 3000 psi and room permeability via the following transform:

$Perm_{res} = 0.8314*K_{room}-0.986$

$(K_{room} = K_{air})$

Applying all corrections (Klinkenberg and room to reservoir conditions) leads to an overall 20-30 % reduction of the measured air permeabilities (Figure.8). Permeability Calculation

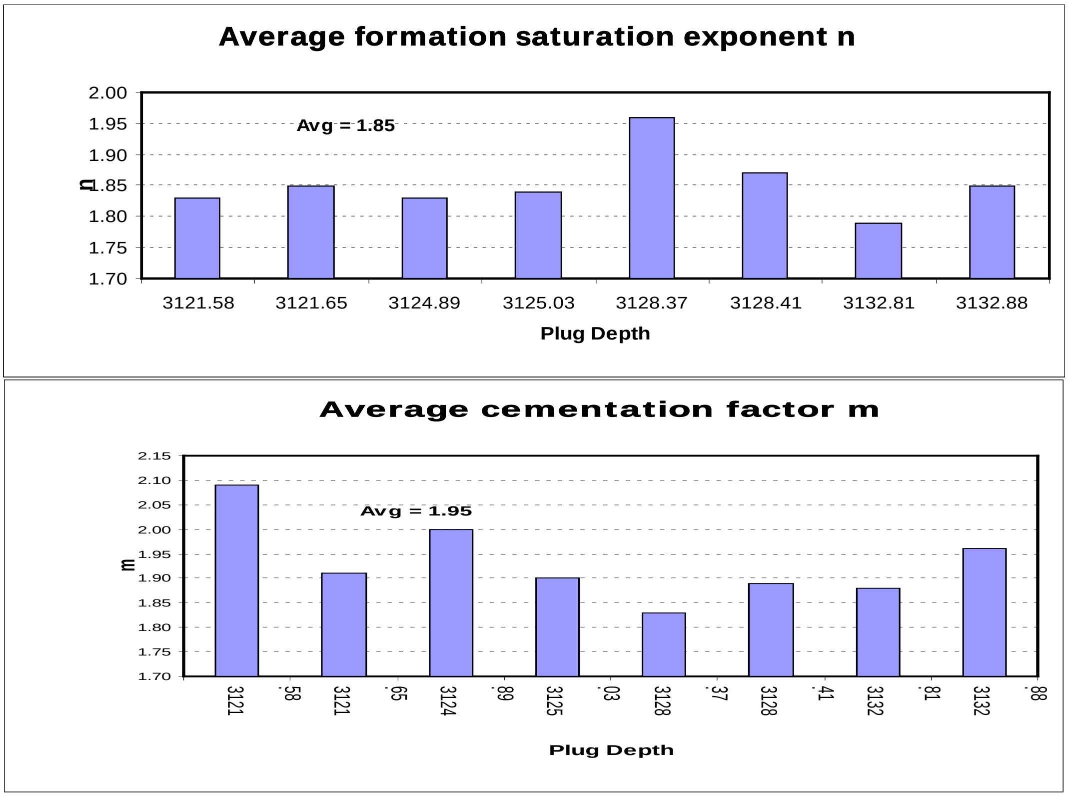

Figure 6: Formation saturation exponent n and cementation factor m.

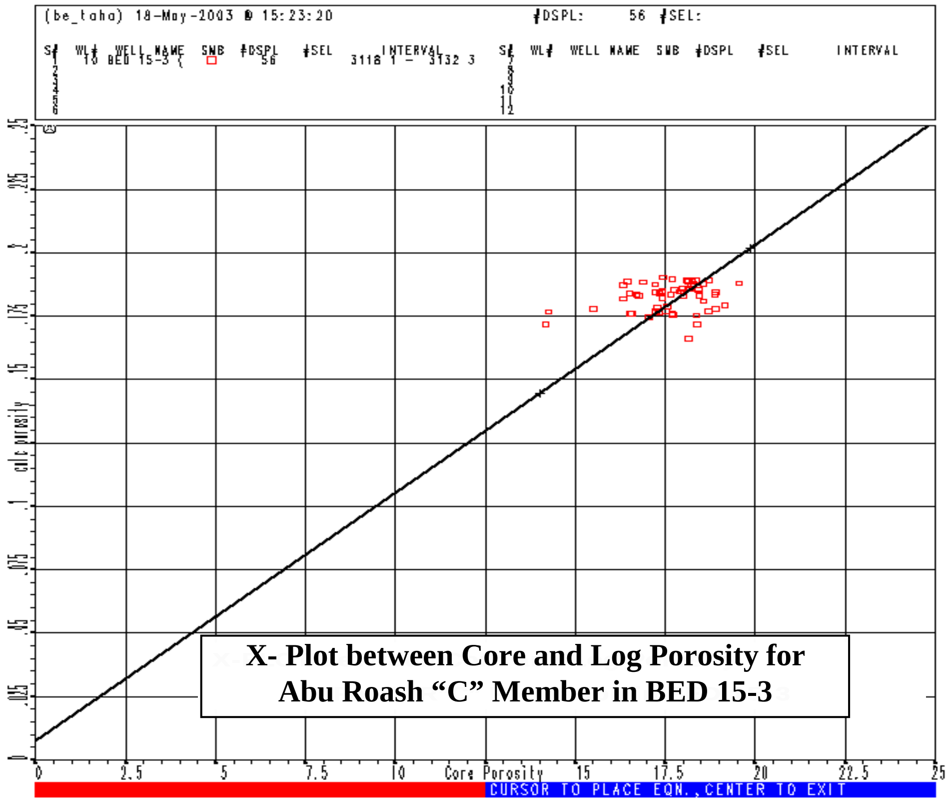

Figure 7: Cross-plot of core and log porosities (BED15-3).

A multivariate statistical model was developed for Abu Roash “C” in BED- 15 area to predict insitu permeabilities from insitu log porosity using the cored well BED 15-3, 3-7 and BED 3-8. The equation was developed to predict the permeability in the various reservoir intervals.

First, a detailed core data review was carried out of all available plug measurements (new Corex, old Geolin, Halliburton). This data check lead to the conclusion that Halliburton results are questionable and should not be used for further evaluation (re-used plugs, no trend recognizable). New Corex permeability data are in line with old Geolin data and were finally used to establish a new Porosity- Permeability relation (Figure. 9).

Several functions were developed and tested to correlate Porosity versus Permeability.

It was derived by using Corex measurements which were correlated in EXCEL:

$$PERM_{insitu}=10\text{^}(0.869+9.4*POR_{insitu})$$

Hydrocarbon Saturation Evaluation

Formation Water Salinity

All water samples obtained from BED-15 Abu Roash “C” during the drilling phase (BED 15-7, BED15-6) were found to be not representative due to contamination with mud filtrate.

A clean water sample from Abu Roash “C” was therefore taken from BED 3-13 well which is completely water flushed. The lab analysis showed a salinity of 50,000-65,000 ppm, equivalent to a resistivity of 0.07 ohm.m. This resistivity value was applied on the log interpretation of the proven water bearing wells BED 3-7 and BED 15-7 and resulted in Sw of 100%. Furthermore, the inititial hydrocarbon saturation calculated with the low salinity (or high resistivity) of about 85% is now also in agreement with the capillary measurements of cores from BED15-3.

This very low salinity of Abu Roash “C” is surprising since other reservoirs in this area show salinities in the range of 190,000 ppm (Kharita).

The impact of the salinity on further log interpretations is significant. Using the salinities as measured from unrepresentative water samples (140,000-250,000 ppm) resulted in calculated initial water saturations of +/- 5%. That does not comply with capillary measurements that show initial Sw of 15-20%. Earlier interpretations of BED-15 Abu Roash “C” wells were based on assumed applicability of high Kharita salinities and resulted ,therefore, in an overestimate of the initial hydrocabon saturation in the order of 10-15% (Table.1).

Table 1: Salinity measurements in BED- 15 Abu Roash “C” Member.

Case	Rw	Salinity, ppm	Remarks
Kharita	0.025	120,000	Assuming Kharita is representative
BED 15-6	0.023	130,000	Contaminated WATER sample (ACS)
BED 15-6	0.046	54,000	Sample corrected for contamination
BED 15-7	0.015	250,000	Contaminated WTR sample (ACS)
BED 15-7	0.04	65,000	Sample corrected for contamination
Final (BED 3-13)	0.07	50-65,000	Sw=1 in 15-7A & 3-7

Hydrocarbon Saturation

The hydrocarbon saturation in the virgin zone was directly calculated using the conventional Archie equation:

$$Sw = [(\varphi^{-m} \times Rw)/Rt]^{1/n}$$

where:

Rw formation water resistivity, ohm.m

Rt true formation resistivity, ohm.m

m cementation exponent

n saturation exponent

Porosity has been established as described in the previous section. In the wells drilled with water base mud the invasion corrected LLD was used as Rt. Rw, m, and n values used in the evaluation are:

$m = 2.0$

$n = 1.85$

Rw corresponding to 50 – 65 kppm NaCl eq. (0.07 ohmm @ 225^0 F)

A shaly sand evaluation technique was not used because of (1) the limited amount of shaly sands present in Abu Roash “C” Member, (2) the availability of insufficient cation exchange capacity (CEC) data to derive a reliable porosity-Qv relationship. As a result of this Rw calculation well BED 3-7 and BED 15-7 S/T are interpreted as 100% water- bearing.

Reservoir total and average properties

The petrophysical evaluation included total and average reservoir properties. Averages have been computed over intervals defined as net reservoir, using the net reservoir identification criteria as described.

Table (2): Reservoir total and average properties BED-15 Abu Roash "C" Member.

WELL	Sand	Top (Mtvdss)	BTM Mtvdss)	Gross	Top (mbdf)	BTM (mbdf)	NET RESERVOIR SAND			HYDROCARBON PAY					
							Net, m	Avg. por	Net/Gross	h, m	Avg. por	Sh	Por*h	Por*h*Sh	perm, MD
BED 15-1	Wshover	3136.2	3147.5	11.3	3123.1	3134.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Abndchanl	3157.1	3238.7	81.6	3134.7	3144.6	8.00	0.20	0.10	0.0	0.00	0.00	0.0	0.0	0.0
	Actvchanl	3070.1	3153.1	83.0	3144.6	3150.3	20.50	0.18	0.25	18.0	0.18	0.80	3.2	2.6	400.0
BED 15-3	Wshover	3110.3	3120.0	9.7	3103.3	3113.0	3.81	0.11	0.39	0.0	0.00	0.00	0.0	0.0	0.0
	Abndchanl	3120.0	3122.9	2.9	3113.0	3115.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
	Actvchanl	3122.9	3141.2	18.3	3115.9	3134.2	18.10	0.18	0.99	18.10	0.18	0.9	3.3	2.9	600.0
BED 15-4A	Wshover	3108.8	3109.8	1.0	3205.8	3206.8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Abndchanl	3109.8	3110.8	1.0	3206.8	3207.9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	500.00
	Actvchanl	3110.8	3142.8	32.0	3207.9	3239.8	31.60	0.20	0.99	26.8	0.20	0.85	5.4	0.91	300
BED 15-7	Wshover	3232.3	3242.3	10.0	3214.3	3224.3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Abndchanl	3242.3	3250.3	8.0	3224.3	3232.3	1.50	0.08	0.19	0.00	0.00	0.00	0.00	0.00	0.00
	Actvchanl	3250.3	3251.4	1.1	3232.3	3233.4	1.10	0.19	1.00	1.0	0.18	0.6	0.00	0.00	200.0
BED 15-7A	Wshover	3338.2	3343.9	5.7	3590.1	3596.8	0.00	0.00	0.00	0.0	0.00	0.00	0.0	0.0	0.0
	Abndchanl	3343.9	3352.2	8.3	3596.8	3607.9	5.90	0.13	0.71	0.0	0.00	0.00	0.0	0.0	0.0
	Actvchanl	3352.2	3363.0	10.8	3607.9	3622.0	10.50	0.18	0.97	0.0	0.00	0.00	0.0	0.0	0.0
BED 3-7	Wshover	3083.6	3093.0	9.4	3076.7	3086.3	5.90	0.07	0.63	0.0	0.00	0.00	0.0	0.0	0.0
	Abndchanl	3093.0	3100.6	7.6	3086.3	3107.0	3.80	0.09	0.50	0.0	0.00	0.00	0.0	0.0	0.0
	Actvchanl	3100.6	3113.6	13.0	3093.9	3153.5	13.00	0.17	1.00	0.0	0.00	0.00	0.0	0.0	0.0

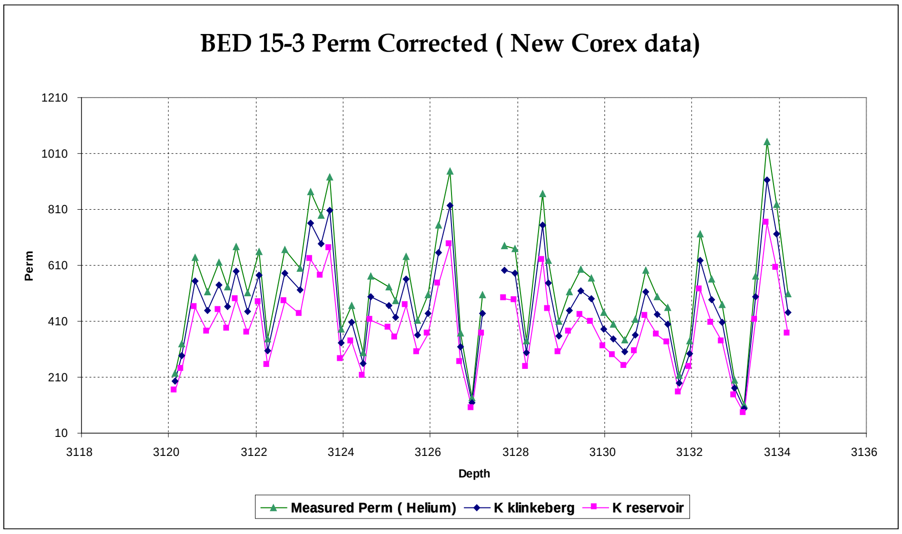

Figure 8: Permeability corrections with Corex data (BED 15-3).

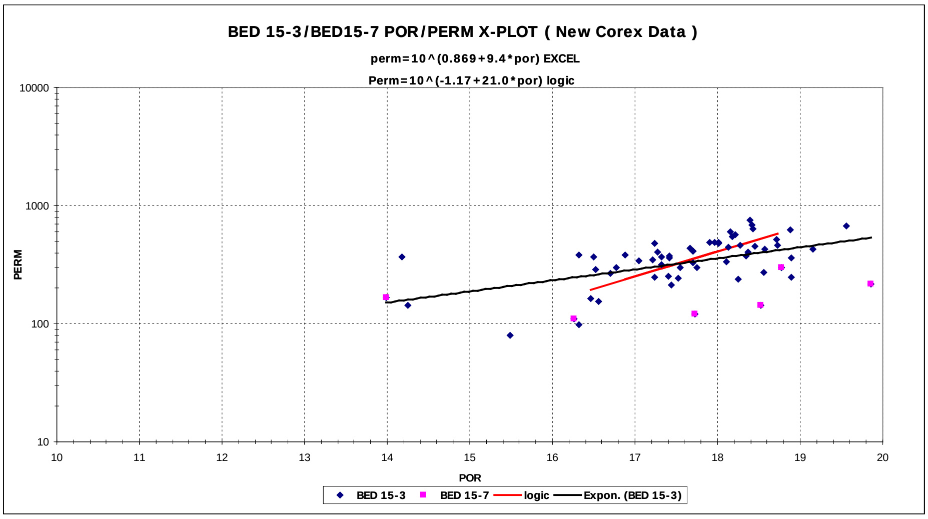

Figure 9: Cross-plot porosity-permeability with Corex data (BED-15)

SUMMARY AND CONCLUSION

1- The Abu Roash "C" reservoir in BED- 15 is a relatively simple homogeneous clean sandstone with good permeability. As such it is appropriate to apply a conventional Archie model and the field does not justify the application of more advanced logging and interpretation techniques.

2- Using well log analysis 4 reservoir units are identified within Abu Roash " C": Unit-2, Unit-2A and Unit-3,4. Units 1 and 4 do not contain sands.

3- Petrophysical analysis indicates a homogenous reservoir, especially for the main active channel sand. Average porosity is 18% (13% – 23%)

4- Core measured permeability confirmed a homogenous distribution through the main reservoir unit in the range of 300 – 500 md.

Therefore, it is highly recommended to carry out further development/ exploration activity to assess the Abu Roash "C "reservoir (Unit 2) for more production from this Member.

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