PETROPHYSICAL ANALYSIS OF NUBIAN RESERVOIR, RIMAL OIL FIELD-SIRTE BASIN

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الملخص

قُسّم تكوين النوبي إلى ثلاث أنطقه وهي النوبي العلوي والطين الصفائحي المتعدد الألوان والنوبي السفلي. يعتبر حقل الرمال النفطي من الناحية التركيبية حاجز متطاول يحده فالقان رئيسيان يتجهان شمال غرب- جنوب شرق.

تمت دراسة خصائص هذا التكوين بتروفيزيائيا وحسبت احتياطياته بالتفصيل باستعمال مجموعة من سرود الجهد الذاتي والمقاومة وأشعة جاما والنيوترون والصوت والكثافة، والتي اختيرت من أثنى عشرة بئرا حفرت بحقل الرمال النفطي. يُنْتَجْ النفط في حقل الرمال من نطاقي مكمن النوبي السفلي والعلوي المكوّنين من الحجر الرملي والعائدين للطباشيري المبكر، حيث وصلت معدلات المسامية الكلية للمكمن السفلي إلى 16% و 18% للمكمن العلوي. وبلغ التشبع المائي في الخزان السفلي إلى ما يقارب الـ25% و 30% للخزان العلوي. كما تم حساب حجم المسام الحاوي على الهيدروكاربون، الذي قدّر بـ 50 قدم للخزان السفلي و45 قدم للخزان العلوي، علاوة على وجود 400 قدم من إلسمك الكلي الصافي للخزان السفلي و 300 قدم للخزان العلوي. ومما سبق فقد قدّرت كمية الهيدروكاربون الأصلية الكلية بـ 97.89 مليون برميل، وكميته المبدئية بالخزان بلغت الـ 59.32 مليون برميل، في حين قدّرت كمية الهيدروكاربون الممكن استخراجها من الخزان بـ 27.54 مليون برميل.

ABSTRACT

The Nubian Formation has been divided into three zones, upper Nubian, varicolored shale and lower Nubian. Structurally, the Rimal oil field is an elongated ridge bounded by two main faults running northwest southeast.

Petrophysical characteristics and fluid reserves of the studied Nubian Formation have been examined in detail according to a complete package of spontaneous-potential resistivity, gamma ray, neutron, sonic, and density logs selected from 12 wells drilled in Rimal oil field. This field is produced from the lower and upper Nubian reservoir sandstones (Early Cretaceous). An average value of total porosity was estimated as 16%

from the lower reservoir and 18% for the upper reservoir. Water saturation is 25% for lower reservoir and 30% for upper reservoir. The hydrocarbon pore volume is 50 feet for lower, and 45 feet for upper reservoir and maximum net pay of the lower reservoir reaches up to 400 feet and 300 feet in upper reservoir. The total original oil in place, initial oil in place and recoverable oil are 97.89 MM barrels, 59.32 MM barrels and 27.54 MM barrels respectively.

KEYWORDS: Petrophysical; Water saturation; Net pay thickness; Hydrocarbon pore volume; Secondary porosity; Initial oil in-place and original oil in-place.

INTRODUCTION

Hallet [1] reported that oil was mostly sourced by Upper Cretaceous shales in the Hameimat Trough and migrated along a series of fairways through the Nubian sandstone, and was trapped in structural and stratigraphic traps. Several of the oil pools have high wax content and it is likely that other source rocks have contributed to these pools. The Turonian and Triassic shales are the, most likely sources of waxy crude. The intra-Nubian shales appear to be too lean to have generated significant volumes of oil, although in local areas they may be richer.

In the Sirte Basin, the Nubian Formation and its correlative strata have yielded major hydrocarbon production, particularly in its southeastern part. Large quantities of hydrocarbons have been accumulated in both structural and combined (structural-stratigraphic) traps in giant oil fields; It contains around 9 billion barrels of original reserves in more than 40 accumulations (Hallet [1]) and it was proven to be a prolific oil reservoir. Rimal oil field of concession-82 is considered one of the major oil fields belonging to Agip Oil Company and National Oil Corporation of Libya. The field is located in the southeastern part of the Sirte basin (Libya), in the Hameimat Trough, between latitudes 28°16' and 28°12' North and Longitudes 22°44' and 22°50' East as shown in Figure (1).

The Lower Cretaceous Nubian (Sarir) sandstone is widespread in the eastern Sirt Embayment and forms the principal oil reservoir of the area. The sandstone was deposited in the principal rifts and troughs of the eastern Sirt Embayment and abrupt thickness variations are characteristic of the Nubian Formation. Nubian sandstones are absent from the intervening horsts. The Nubian sequence is truncated by a sharp unconformity which has removed the upper part of the formation from many areas.

The Rimal oil field was, produced from Lower and Upper Nubian sandstone of Late Jurassic-Early Cretaceous in age by drilling the first wildcat well R1-82**.** The oil in this well was encountered at about 13215 feet in the Lower Nubian sandstone. In the eastern Sirt Basin, Sarir Sandstone and Kalanshiyu (Calanscio) Sandstone formations preferred to indicate Late Jurassic to Early Cretaceous continental clastics (Hallet [1]); as equivalent rock units to Nubian Formation.

The initial production rate was 817 barrels of 33° API and gas oil ratio of 1047 standard cubic feet per barrel. These results encouraged the company to drill more appraisal wells to develop this field. The production from the field started in February 1984 and reached 13,880,000 barrels by 1995.

This study was carried out to further understanding of the structural configuration and to investigate petrophysical characteristics of the Nubian reservoir which include the reservoir porosity, net pay thickness, and reserve estimation of the Nubian reservoir in Concession-82 of Rimal oil field.

METHODS OF STUDY

In an attempt to meet the purpose of this study, the available data were used. These data include spontataneous-potential, resistivity, gamma ray, sonic, neutron, and density logs selected from 12 wells drilled in Rimal oil field Figure (2). These were used in correlation and construction of structural and stratigraphical cross-sections and maps (structural, net pay, porosity, water sat...etc).

The resistivity, sonic, neutron and density logs of the Nubian reservoir interval of each well were read and analyzed every ten feet for estimation of porosity, fluid saturation, net pay thickness, hydrocarbon pore volume, and original oil in place according to the equations of Table (1).

GEOLOGY

The stratigraphic sequence, lithofacies analysis and interpretation of depositional environments have been generally described by many authors such as Sanford [6]; Clifford et al. [7]; Rossi et al. [8]; Ibrahim [9]; and El-Hawat [10].

The Nubian sandstone name originated from the Nile valley. The name reflects exposed non-marine sandstones which characterize the upper Nile valley (Russeger [11]). It's also continued to be in use by Conant and Goudarzi [12] and Barr and Weegar [13].

In the Hameimat Trough a major sedimentary depocentre formed during the deposition of the Nubian sandstone (Hallet [1]). The formation is unconformably overly the basement of Palaeozoic, and-or Triassic/Jurassic graben-fill sediments, and is overlain by the transgressive marine Cretaceous.

Ibrahim [9] divided the formation into three units as shown in Figure (3). Abdulghader [14] identified four basic lithofacies within the Nubian Formation of the eastern Sirt Basin;1) a meandering river facies with point bars, 2) levees and overbank deposits, a relatively high-energy alluvial-plain associated with low-sinuosity braided-streams, 3) swamp facies, and 4) relatively deep-water lacustrine facies. A similar subdivision was made by Rossi et al. [8], they concluded that the lower sand could be assigned to the Tithonian-Valanginian, the middle shale to the Hauterivian-Barremian and the upper sand to the Aptian-Albian. On other hand Ambrose [15] studied in detail the equivalent Sarir Formation and divided it into five units Table (2).

STRUCTURE OF THE STUDY AREA

The Nubian Formation in the eastern Sirt Basin area represents syn-rift deposition as stated by Ibrahim [9], and present in the rift grabens. It has been shown that rifting began as early as the Triassic, following the intensification of rifting which began in the Neocomian (Hea [16]).

The concession 82 is located in the southeast part of Sirte Basin in Hameimat trough Figure (2). Rimal field is structurally formed as an elongated ridge crossed by two main faults running northwest southeast. One is dipping toward southeast and the other toward northwest. However, a third fault cut the ridge in a parallelism with the former faults dipping northwest. Series of normal secondary fault trending north-northwest and south-southeast cut the ridge perpendicular to the main former faults forming series of horsts and grabens. One of these grabens is dividing Rimal field into independent east and west blocks. Due to intense erosion of Al-Jaghbub, Kalanshiyu, and Majid uplifts Figure (4) more than 2500 m of detrital sediments deposited to form a major sedimentary depocentere during the deposition of the Nubian sandstones, with braided fluvial systems entering the basin form all directions (Van Houten [17]). The field is a faulted anticlinal structure Figure (5a), this represented by structure maps of lower and upper Nubian sandstone Formation showing the general structures of the faulted Rimal field anticline.

To understand the structural development of the field where cross sections constructed Figures (5 , 6) through the following wells from the left to right; well R7, R11, R3 , R9 ,R1 ,R8 and R6. The direction of these cross-sections is northeast-southwest following the formations from Lower Cretaceous up to Plio-Pleistocene time Figure (6).

From tectonic point of view these cross-sections show some normal faults numbered from one to eleven. The faults description started from the deep site side (Figures (5a - 5e). The faults number 8 and 9 was only affected the Lower Nubian sandstone (Lower Cretaceous) and variegated shale only and was considered as an old tectonic first phase Figure (5a). The second phase was affected the Lower Nubian, varicolored shale, upper Nubian and Rakb C. This phase might be an old phase but was rejuvenated up to Rakb C involving faults from 1-7 Figures (5a - 5c). This movement formed a type of Horsts shown in cross-section by step faults Figures (5b - 5d). The third phase of tectonic movement was affected by serious of faults number (4, 5, 6 and 7) started form the bottom of the lower Nubian sandstone up to Kheir Formation forming grabens in the middle of the cross-section Figure (5e) and Figure 6). Finally in the right side of the cross-section at the top very recent faults number (10 and 11) were affected the Miocene and Pliocene sediments Figure (6).

PETROPHYSICAL CHARECTERISTICS

Porosity logs; density, neutron, and sonic logs of scale 1:50 were used quantitavely to determine the total porosity of (ØND) and Secondary porosity (Øsec) of the Nubian sandstone reservoirs. The total porosity values were determined according to the reported equations (ØNDcor.) in Table (1). The secondary porosity values were calculated using Øsec equation of Table (1). This equation based on the fact that sonic waves travel through the matrix and void isolated pore spaces. The average porosity values (Øaverage) for lower and upper Nubian reservoir in Rimal oil field were calculated Table (3) according to equation as shown in Table (1). The average porosity maps Figure (7b) present that highest porosity is limited to the south-western part of Rimal field especially for Lower Nubian Member; on the other hand a little increase in porosity is present in northeast part for upper Nubian Member.

The water saturation ($Sw_{average}$) was calculated using Archie [18] and Schlumberger [19] equation of Table (1). The average water saturation was also calculated Table (3) to show the distribution of the water saturation in the studied reservoir. The average water saturation maps were constructed as shown in Figure (7c). It presents a small effect in the Lower Nubian units, but it increased upward as shown in the upper Nubian units.

The net pay thickness of the lower and upper Nubian reservoir Figure (7d) represents intervals that exhibit porosity greater than or equal to the cutoff porosity (7.5-8%). The water saturation is obtained and found to be less than the cutoff water value saturation 60% (Agip Oil Company [20]. The oil water contact (OWC) of the

Rimal oil field for the lower Nubian is located at 13750 ft. SubSea, and the upper Nubian oil water contact is located at 10850ft. subsea [20].

Initial Oil Reserves

The hydrocarbon pore volume of the lower and Upper Nubian reservoirs of each well was calculated Table (3), using equation of Table (1).

The hydrocarbon pore volume (HPV) maps of Rimal oil field was constructed Figure (7e); these generally clarify that HPV decrease upward. Using planimeter the maximum area was determined as 583 acres for Lower Nubian and 970 acres for upper Nubian reservoir. The original oil in place (OOIP, Table (1)) was calculated as 38.507 MM barrels and 59.337 MM for the lower and upper Nubian reservoir respectively (Table (4) left half).

Comparing the above method with the volumetric method, the Upper and Lower Nubian reservoirs were determined as 40.28 MM barrels and 59.76 MM barrels of oil respectively Table (4), right half). The correlation coefficient between the two methods reach 0.99 and this indicate that there is no big difference between the two used methods for estimating OOIP.

The initial oil in place (IOIP) in barrels is equal to the OOIP divided by the formation volume factor (1.65 RB/STB) using equation of Table (1). Therefore the IOIP was calculated and found to be 36.06 MMB and 23.6 MMB for the upper Nubian and lower Nubian reservoir respectively. The recovery factor (RF) of the lower and upper Nubian Formation (17.5% and 25% respectively from the Agip oil company [20]) was calculated giving 6.71 MM barrels of oil. The total recoverable oil is 27.54 MM barrels.

CONCLUSIONS

From the present study the following conclusions can be drawn:

- The average value of total porosity is 16% and 18% for lower and upper Nubian sandstone reservoir respectively, while water saturation is 25% from lower reservoir and 30% from upper reservoir.
- The hydrocarbon pore volume is 50 and 45 feet for lower and upper reservoir respectively and the maximum net pay thickness of lower reservoir found to be 400 feet and 300 feet for upper reservoir.
- The reserve estimates present the initial oil in place (IOIP) and recoverable oil are 97.89 MM Barrels, 59.32 MM Barrels and 27.54 barrels respectively.
- The recovery factor seems to be very low in the lower part 17.5 % and is higher in the upper part (Rf), 35%. This should be reevaluated in some other studies especially the recovery factor belonging to the lower part.

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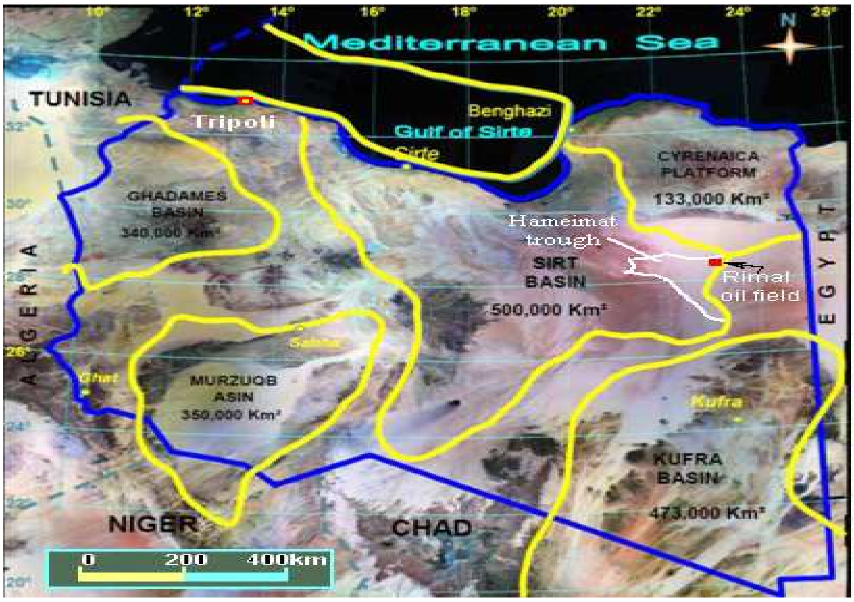

Figure 1: Location map of Rimal Oil Field from concession-82 and Hameimat trough(study area) in Sirte basin.

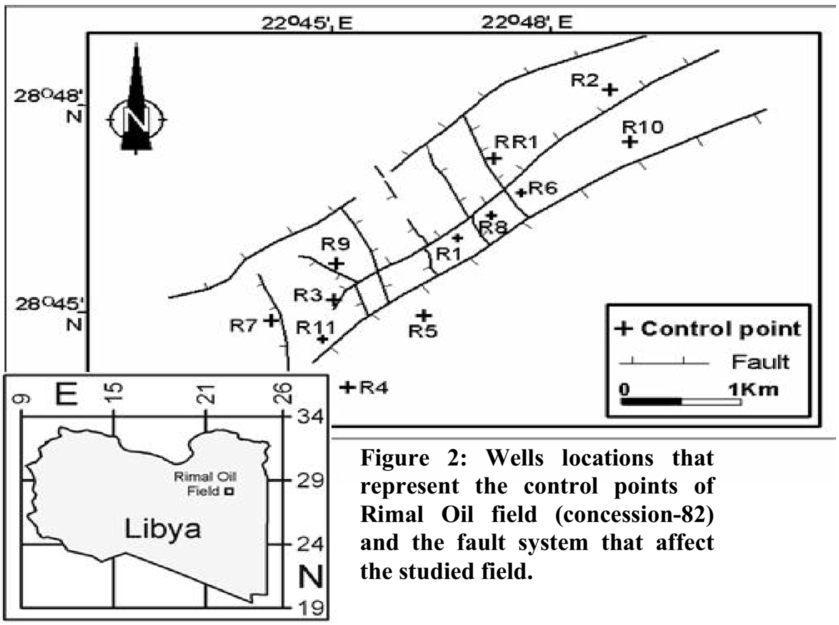

Figure 2: Wells locations that represent the control points of Rimal Oil field (concession-82) and the fault system that affect the studied field.

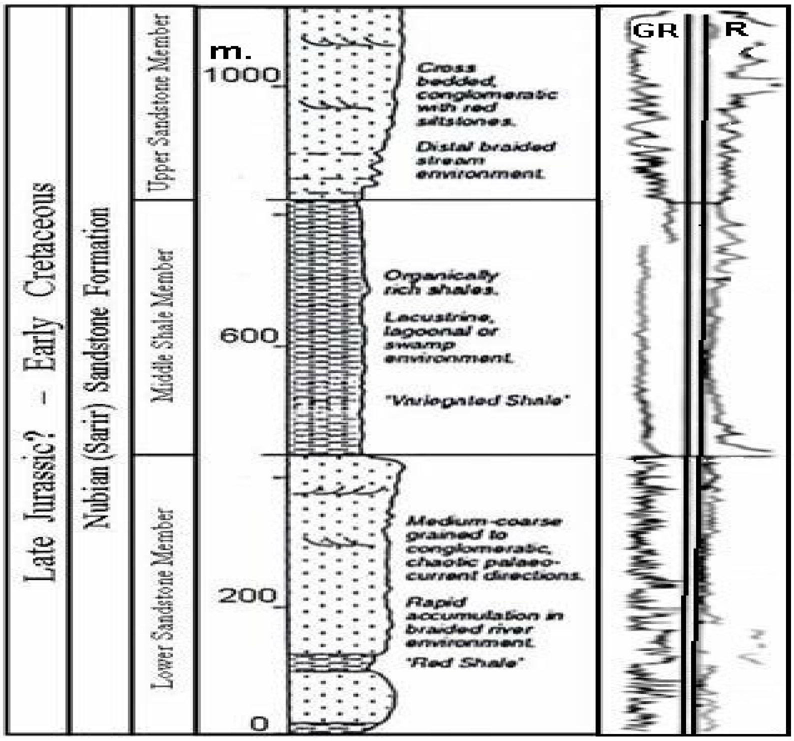

Figure 3: Illustration of informal type section of Nubian Formation units from the R3-82 well (Ibrahim, 1991).

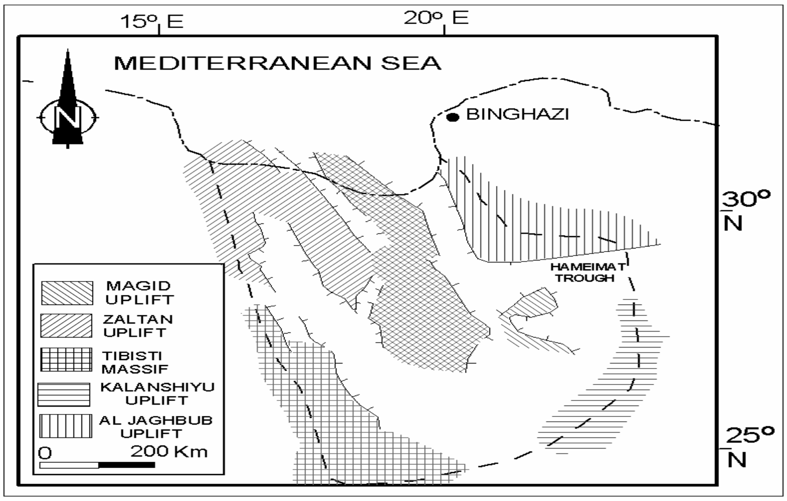

Figure 4: Uplifts distribution within Sirte basin and around studied Hameimat Trough (Modified after Van Houten, 1980).

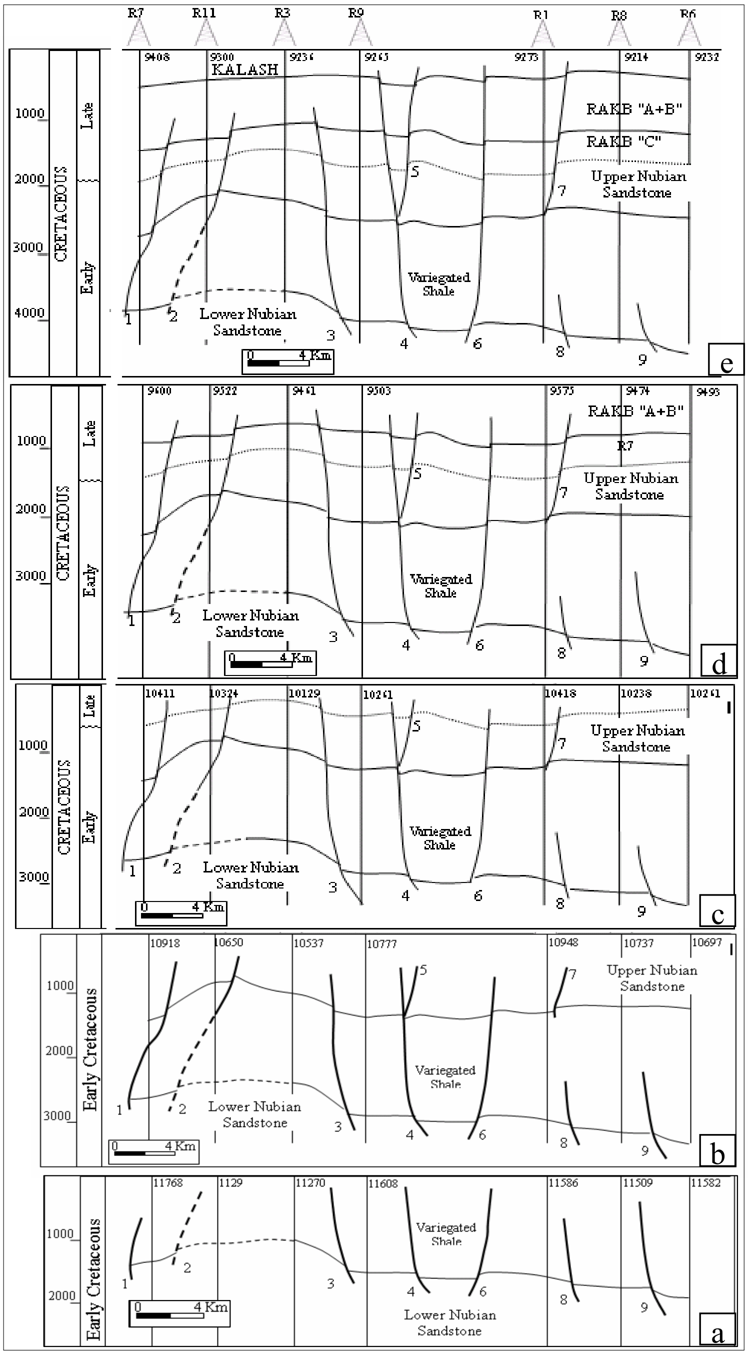

Figure 5: Northeast southwest cross section through the wells R7, R11, R3, R9, R1, R8 and R6, is reflecting the structural development of lower part from Hameimat Trough sequence.

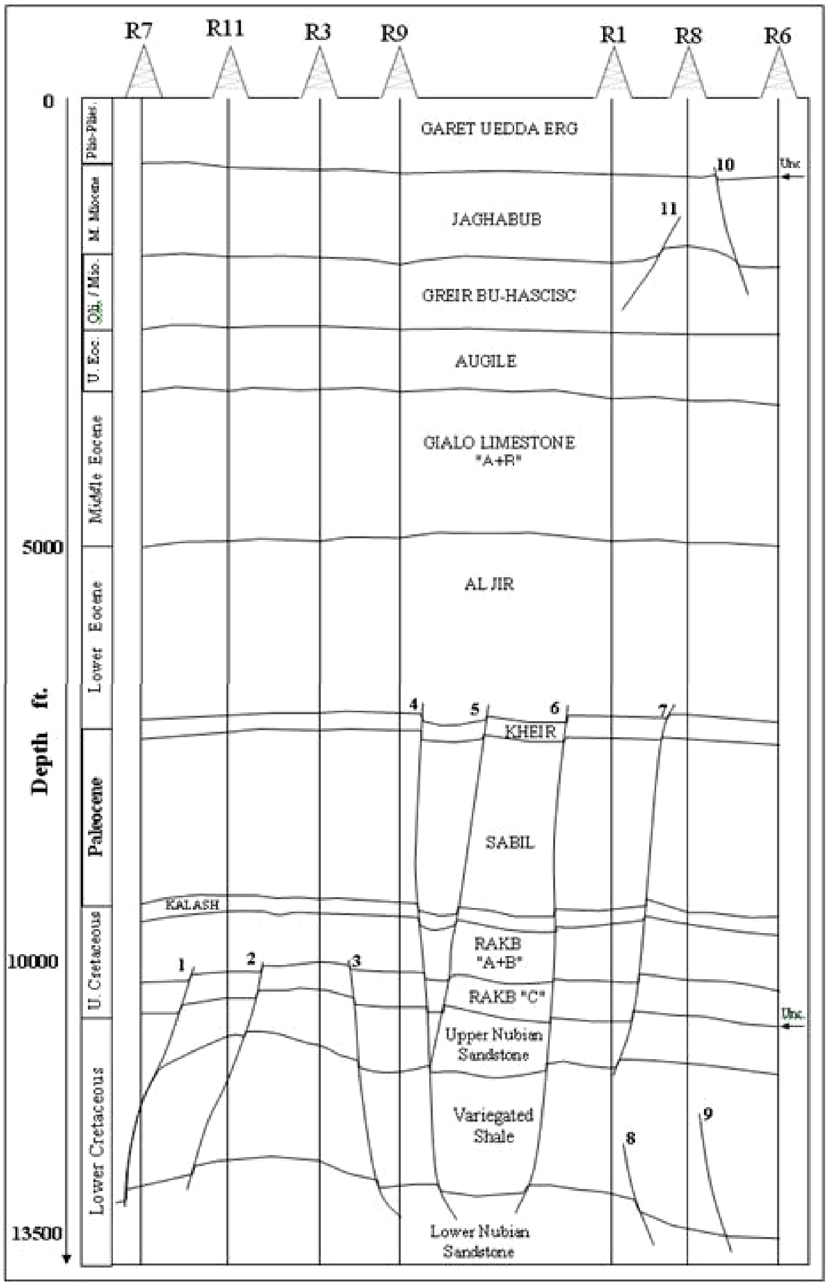

Figure 6: Northeast southwest cross section through the wells R7, R11, R3, R9, R1, R8 and R6, is reflecting the structural development of the whole sequence of Hameimat trough

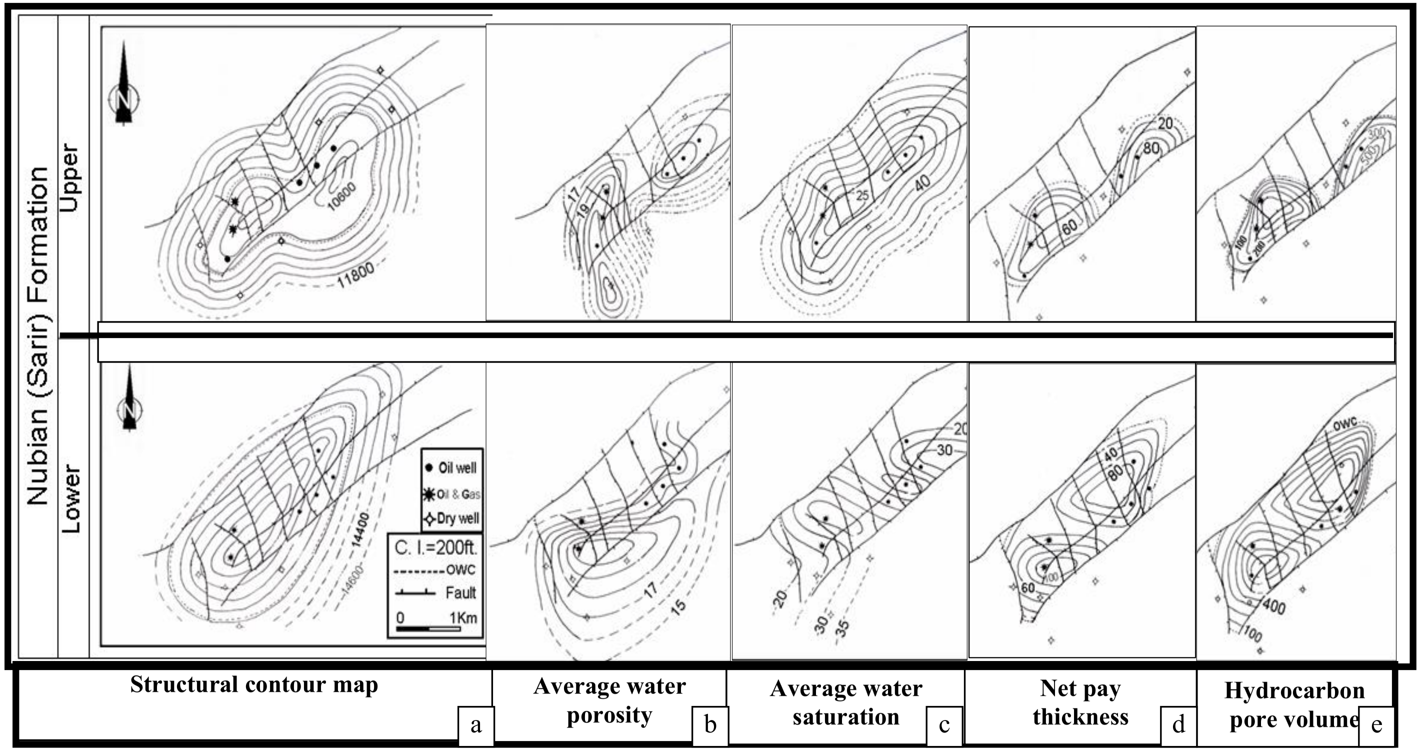

Figure 7: (a) Structural and Petrophysical contour maps of lower and upper part from Nubian (Sarir) Formation; (b) Average water porosity; (c) Average water saturation; d. Net pay thickness; (e) Hydrocarbon pore volume

Table 1: Equations and methods used in the petrophysical analysis of Nubian members units of Rimal oil field

Analysis		Equations of calculation and methods	Ref
Shale content		$IGR=(GR_{log}-GR_{min})/(GR_{max}-GR_{min})$	☼
		$V_{sh}=0.083 \times [2^{(3.7 \times IGR)}-1] \times 100$	=
porosity	Total	$Ø_D=(\rho_{ma}-\rho_b)/(\rho_{ma}-\rho_f)$	□
		$Ø_{Ncor} = Ø_N-[(Ø_{Nsh}/0.45) \times 0.3 \times V_{sh}]$	
		$Ø_{Dcor} = Ø_D-[(Ø_{Dsh}/0.45) \times 0.13 \times V_{sh}]$	
		$Ø_{NDcor} =[(Ø_{N}^{2}{}_{cor}+ Ø_{D}^{2}{}_{cor})/2]^{0.5}$	
		$Ø_{average} = \sum(Øi \times hi)/\sum(hi)$	
		$Ø_{snc} =(\Delta t_{log} - \Delta t_{ma})/(\Delta t_f - \Delta t_{ma})$	☼
	Secondary	$SPI =Ø_{ND}cor.-Øsnc$	□
Water Resistivity		Pickett cross plot on RILD against ØND	
		$TF=(T_{TD}-T_S) \times (D_F/T_D)+T_S$	
		$Rw_a=(Ø_{ND})^m \times Rt/a$	
Water Saturation		$Sw_a=[(a Rw)/(Ø_{ND}{}^{m} x Rt)]^{1/n}$ [Archie method or less 20% Vsh]	☼
		$Sw =(-V_{sh}/R_{sh}+((V_{sh}/R_{sh})^2+(Ø_{ND}{}^2/(0.2*Rw_a*(1-V_{sh})*Rt))^{0.5}) /(Ø_{ND}{}^2/ (0.4*Rw *(1-V_{sh})))$ [For intervals of higher volume shale]	
		$\sum(Ø_i \times Sw_i \times h_i)/\sum(Ø_i \times hi) =Sw_{average}$	□
Reserve estimate	Net pay thickness	Determined according to the cut off values of porosity and water saturation (for every two feet) as shown in Table (2).	
	Oil-water Contact O.W.C	According to relationship between depth versus water saturation For wells B-1, B-2, and B-5	
	Initial oil reserves	$HPV=h \times Ø \times (1- Sw)$	Volum. method•
		$OOIP=A \times HPVx Fs \times 7758$	
		Initial oil in place= OOIP/β_o; (β_o=1.65RB/STB, RF=35%)⁺	

IGR=gamma ray index(API);**GR_{log}**=gamma ray reading (API);**GR_{min}**=minimum reading clean sandstone or limestone (API);**GR_{max}**=maximum reading shale**;** V_{sh}=shale volume for tertiary rock%; ρ_{ma}=matrix index;ρ_b=bulk denity(gm/cc(log)); ρ_f=fluid density (1gm/cc); **$Ø_{Ncor}$**=corrected neutron porosity; **$Ø_N$**=neutron porosity(log); **$Ø_{Nsh}$**= neutron porosity for shale; **$Ø_{Dcor}$**=corrected density porosity; **$Ø_D$**=density porosity; **$Ø_{Dsh}$**=density porosity for shale; **$Ø_{NDcor}$**=corrected total porosity; **$Ø_i$**=total porosity; **hi**=thickness(ft); SPI=secondary porosity index; **$Ø_{snc}$**.=sonic porosity; **Δt_{log}**=formation transit time(μ/ft); **Δt_f**=formation transit time(189μ/ft(log)); **Δt_{ma}**=matrix transit time(μ/ft); **TF**= formation temp.(^{O}F); **T_{TD}**=temp of total depth(^{O}F);**T_S**=surface temp(80^{O}F);**D_F**=formation depth(ft); **T_D**=total depth(ft); **Rt**=induction resistivity (Ω.m, from the log every10 feet; **m**=cementation factor(2); **a**=tortousity factor(0.81); **Rxo**=shallow resistivity (Ω.m(log)); **Rmf**= resistivity of mud filtrate at formation temp.(0.819 Ω.m); **;Rw**=formation water resistivity (0.018 Ω.m) **Sw**=water saturation for intervals of higher volume of shale; **Sw_{cor}**.= corrected water saturation of the un-invaded zone; **Sw_r**= water saturation of the un-invaded one(Ratio method); **$Sw_{average}$**=average water saturation; **A**=area in acres; **β_o**=formation volume factor; **RF**=recovery factor;**7758**=number of barrels per acre-feet, Fs=Shape factor as a decimal.

Ref.=References; ☼Asquith and Gibson [2] ; □Khaiwka [3] ; ⁺ Per. Comm. (2004) Agip Oil Comp.; •Lovejoy and Homan [4] ; =Dresser Atlas [5] .

Table 2: Ambross (2000) divisions of Nubian sandstone Formation units.

Sarir rock units	Environment	Southeastern Sirte basin reserve
Upper Sandstone	Distal alluvial-plain, deltaic coastal-plain, tidal-flat and marsh environments	Major reservoir rock
Variegated Shale	Transition to lacustrine conditions	Significant petroleum source rock
Middle Sandstone	Fluvial system deposited by river systems flowing towards centre of Hameimat Trough	main reservoir units
Red shale	Playa-sabkha	
Lower Sandstone	Alluvial fans conglomerates, braided-plain deposits	Represents early rift deposition and is typified by its environment

Table 3: Petrophysical characteristics of Upper and Lower Nubian Sandstone Fm. in Hameimat trough of Rimal Oil field, represented by average porosity, average water saturation, average net pay thickness, and average hydrocarbon pore volume.

Well no	Nubian(Sarir) Sandstone Formation							
	L	U	L	U	L	U	L	U
	Average porosity		Average water saturation		Average net pay thickness		Average HPV	
R1-82	15.465	19.87	24.01	29.02	350	330	48.88	58.065
RR1-82	14.81	N.R	22.41	N.R	N.R	620	N.R	71.23
R2-82	N.R	N.R	N.R	N.R	N.R	N.R	N.R	N.R
R3-82	20.6	20.61	26.6	30.19	350	710	48.68	108.8
R4-8	17.	23	32.	40.0	540	170	64.5	20.0
R5-82	N.R	13	N.R	36.0	110	N.R	9.2	N.R
R6-82	14.3	18.6	26.0	30.7	310	430	60.58	17.0
R7-82	16.1	18.7	18	41.6	350	100	38.22	13.2
R8-82	15.84	19.36	12.58	24.66	270	480	39.38	39.38
R9-82	15.09	20.38	35.44	33.38	430	510	58.38	58.38
R 10-82	16.13	16.768	19.13	56.87	660	180	47.73	23.40
R11-82	N.R	21.59	N.R	28.17	250	N.R	38.77	N.R

Table 4: Calculations of Original Oil In place in Upper and Lower Nubian Sandstone Fm., using plan meter method(left half) and volumetric method(right half).Strong similarity(r) present between OOIP bbls*10^3 that calculated by planmeter and volumetric methods.

Rock unit		Planimeter Method								Volumetric Method								r
		A-HPV-C	PR	FS	Area km^2	Area Acre	HPV Ft	OOIP acre ft	OOIP bbls*10^3	A-HPV-C	Area cm^2	FS	Area km^2	Area Acre	HPV Ft	OOIP Acre ft	OOIP bbls*10^3	
Nubian (Sarir) Sandstone Formation	Upper	80	0.13	0.5	0.0956	23.621	5	118.11	919.486	80	2.7	0.5	0.169	41.758	5	104.395	812.715	0.995597
		60	0.22	1	0.0956	23.622	10	436.115	3395.155	60	3.4	1	0.169	41.758	10	680.73	5299.483	
				0.5	0.1618	39.979						0.5	0.213	52.630				
		40	0.59	1	0.2574	63.601	10	1171.95	9123.63	40	4.5	1	0.382	94.389	10	1291.05	10050.82	
				0.5	0.4338	107.188						0.5	0.281	69.432				
		20	0.66	1	0.6912	170.789	10	2307.45	17963.53	20	6.5	1	0.663	163.821	10	2139.805	16658.38	
				0.5	0.4853	119.913						0.5	0.406	100.319				
		0	0.75	1	1.1765	290.702	10	3588.37	27935.46	0	8.5	1	1.069	264.134	10	3297.734	26937.88	
				0.5	0.5515	136.270						0.5	0.5313	131.267				
		Σ	2.35		3.948	970.18			59.337*10^6	Σ	25.6		3.8833	959.514			59.76*1 0^6	
	Lower	100	0.07	0.5	0.05147	12.717	5	31.794	247.5182	100	0.18	0.5	0.0113	2.7921	5	6.9802	54.341	0.995854
		80	0.12	1	0.05147	12.717	10	227.10	1767.9774	80	2.3	1	0.0113	2.7921	10	205.826	1602.35	
				0.5	0.08088	19.984						0.5	0.144	35.5810				
		60	0.23	1	0.13235	32.702	10	526.87	4101.6868	60	2.44	1	0.1553	38.3731	10	572.755	4458.89	
				0.5	0.16176	39.969						0.5	0.153	37.8048				
		40	0.31	1	0.22941	72.67	10	1008.32	7849.8179	40	2.8	1	0.308	76.1038	10	977.242	7607.82	
				0.5	0.2279	56.321						0.5	0.175	43.2408				
		20	0.20	1	0.52205	128.99	10	1471.62	11456.56	20	4.1	1	0.483	119.3446	10	1510.092	11756.07	
				0.5	0.14706	36.337						0.5	0.2563	63.3293				
		0	0.03	1	0.66911	165.33	10	1680.56	13083.16	0	0.96	1	0.7393	182.6739	10	1900.866	14798.24	
				0.5	0.02206	5.4508						0.5	0.06	14.8254				
		Σ			2.35396	583.18			38.507*10^6	Σ	12.78		2.4965	615			40.28*10^6	