Journal of Geology and Mining Research Vol. 1(9) pp. 180-194, November, 2009
Available online http://www.academicjournals.org/jgmr
ISSN 2006 – 9766 © 2009 Academic Journals

Full Length Research Paper

Micro-zonation and characterization of the pre-miocene reservoirs in Ras Budran oil field, gulf of Suez, Egypt

Mohammad Hassaan Awad and Samy Serag El Din*

[1]Faculty of Science, Al-Azhar University, Fawzy Ismail, Egypt.
[2]Suez Oil Company (SUCO), Nazr City, Cairo, Egypt.

Accepted 7 October, 2009

The present study deals with pre-miocene reservoirs in Ras Budran oil Field as one of the most prolific Fields in Gulf of Suez. The reservoir was thought to be massive sandstone and classified initially to six macro layers. The reservoir model has been rebuilt several times at different stages of its development but still has some problems due to reservoir performance anomalies as shown from continuous reservoir monitoring by Production Logging Tools. These indicate that injected water is overriding oil bearing intervals, suggesting that the reservoir is not massive sandstone as thought but it is very stratified with high permeability streaks which lead to accelerated water breakthrough and non-uniform flood front advance. A new micro-zonation was established where thirty-two micro-zones were defined. The current micro-zonation definition has an internally consistent geological framework. This new micro-zonation definition relates production, pressure test and core-plug porosity-permeability data to the geological descriptions and identifies the main geological controls on vertical and horizontal flow.

Key words: Prolific, massive, macro layers, breakthrough, micro-zonation.

INTRODUCTION

During the life of Ras Budran Oil Field, several studies and production monitoring were carried out, some of which indicated that the injected water is overriding oil bearing intervals, suggesting that the reservoir is not massive sandstone as thought but it is very stratified with high permeability streaks which lead to accelerated water breakthrough and non-uniform flood front advance. A new micro-zonation definition was established where thirty two micro-zones were defined. They vary from 5 to 375 ft in thickness. The process of defining micro-zones is based on several criteria including sequence stratigraphy, permeability boundaries and pressure test data. Complete quantitative petrophysical analysis and reservoir quality distribution maps were performed and constructed over the micro-zones.

General outline of Ras Budran field

Ras Budran offshore oil field is located in the northern part of Gulf of Suez (Belayim offshore concession area), approximately 4 km west to Sinai coast of Gulf of Suez and 13 km northwest of Abu Rudeis at water depth of approximately 140 ft (Figure 1). The field was discovered through the drilling of the Exploratory well "EE 85-1". The well reached its total depth of 12564 ft after penetrating multiple oil-bearing reservoirs with oil water contact at 12350 fts and cumulatively produced about 12000 BOPD (Barrel Oil per Day) from five Cretaceous and Paleozoic Nubian sandstone reservoir. The commercial field production has been started on May 1983 with average production rate of about 15000 BOPD. The initial STOIIP estimated for the field was 700 MMSTB of which 220 MMBBL has been produced. Structurally, Ras Budran structure is considered as identical complex pre-miocene model as it is severely strained by faults of different throws and aligned in various directions. The faulting pattern of the field comprises two types of faults: the gravitational faults trending to the northwest - southeast direction having angles ranging from 37 to 70° with 300 – 200 ft throw, and the cross Gulf faults with northeast – southwest alignment having angle ranging from 76 to 85° with 100 – 500 ft throw (Figures 2 and 3).

The stratigraphic succession of the field is similar to the sequences presented elsewhere in the northern part of the

*Corresponding author. E-mail: seldin@adco.ae. Tel: 009712 6042792, 00971559877950.

Figure 1. Ras Budran location map.

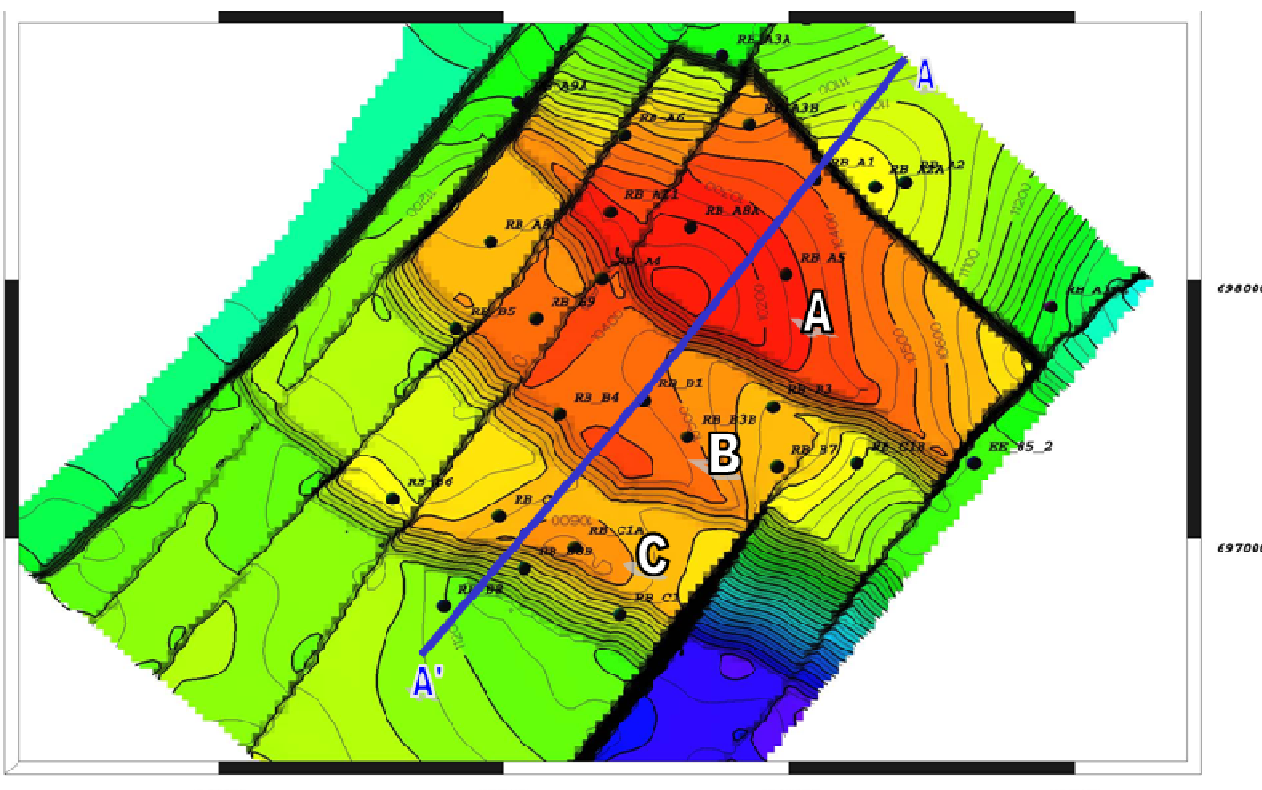

Figure 2. Structure contour map on top lower Raha Fm.

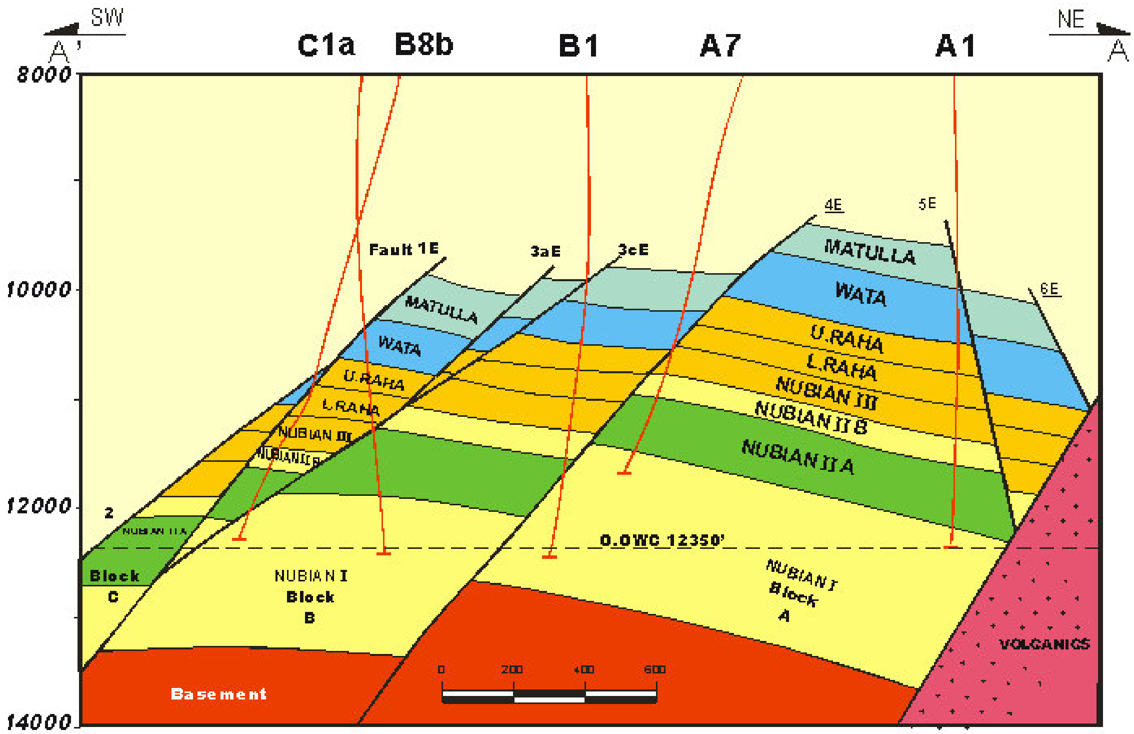

Figure 3. Ras Budran main cross section.

Gulf of Suez where a sedimentary sequence ranging in age from Paleozoic to recent with non-depositional and erosional hiatuses (Al Naggar and Helaly, 1985). Nubian Sandstone of Paleozoic to Lower Cretaceous age forms the main reservoir in the Ras Budran field. These reservoirs are divided into four units that are (from below upwards): Nubia UI, UIIA, UIIB and UIII. In addition to these, some reservoirs of secondary importance are present in sandstone of Raha and Matulla formations (Figure 4).

RESERVOIR MICRO-ZONATION

The process of defining micro-zones is based on several criteria including sequence stratigraphy, permeability boundaries based on core (Koldewjin, 1984) and log data, pressure test that indicates apparent pressure barriers and lithology variations.

Sequence stratigraphy

According to Kendall (2003), Figure 5 shows how well logs can be used to interpret shallow water clastic sequence stratigraphy. At the start of an interpretation of sequence stratigraphy using well logs one must first identify the predominant of sequence stratigraphic surfaces. The most important of these surfaces are maximum flooding surfaces (MFS) and transgressive surfaces (TS). These surfaces are picked using Gamma Ray log which correlate with radioactive shale that are interpreted as deposited across relatively flat surfaces.

Unit I low stand systems tract

Unit I consists of massive sandy sections alternating with thin shale breaks as seen in the wire line logs (Figure 6). The sand sometimes grade upwards into shale (impermeable) and has erosional bases. The repetition of such units in which sands with erosional bases grade upward into shale is typical of meandering river deposits. Unit IIA transgressive systems tract: The overlying Cenomanian Unit IIA is marked by a fining upward sand immediately above Unit I or by fining upward silty shales of variable thickness (tens of feet).

Paleontological data for this interval contain littoral and sub-littoral environments for deposition of this interval. This is consistent with tidal reworking and deposition of transgressive sand above Unit I. The upward decrease in sand content suggests marine deepening. It is interpreted as a continuation of the transgression, with shales of variable thickness deposited during an initial marine transgressive event.

Unit IIA maximum flood surface

Overlying that first transgressive sandy and silty section in the lower most portion of Unit IIA is a shaley unit. It is generally tens of feet thick. On the wire line logs it

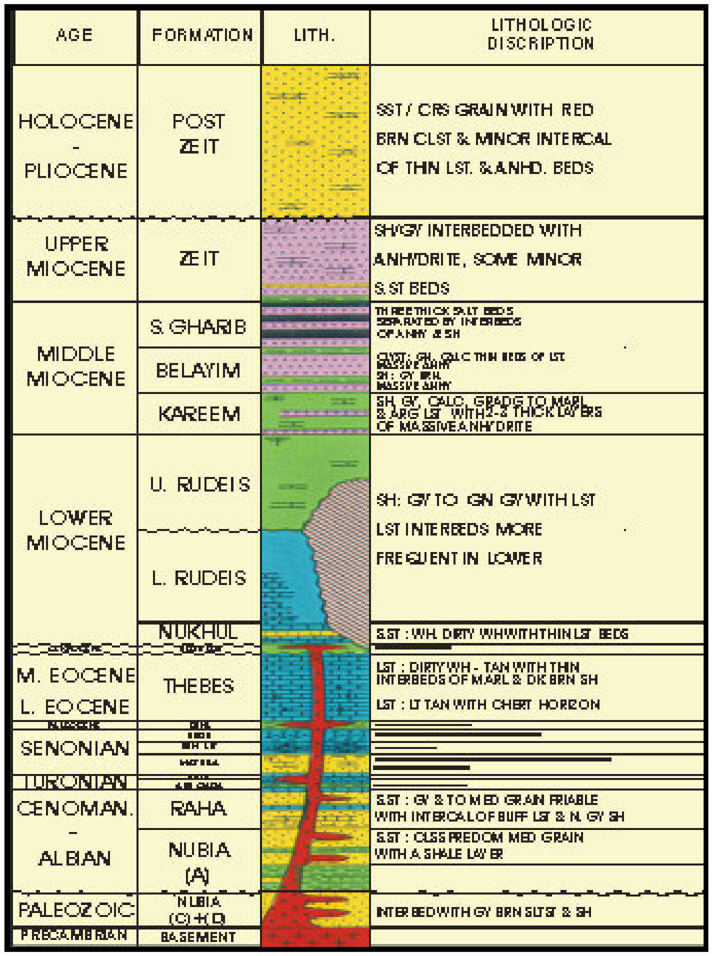

Figure 4. General stratigrahic column of Ras Budran Field.

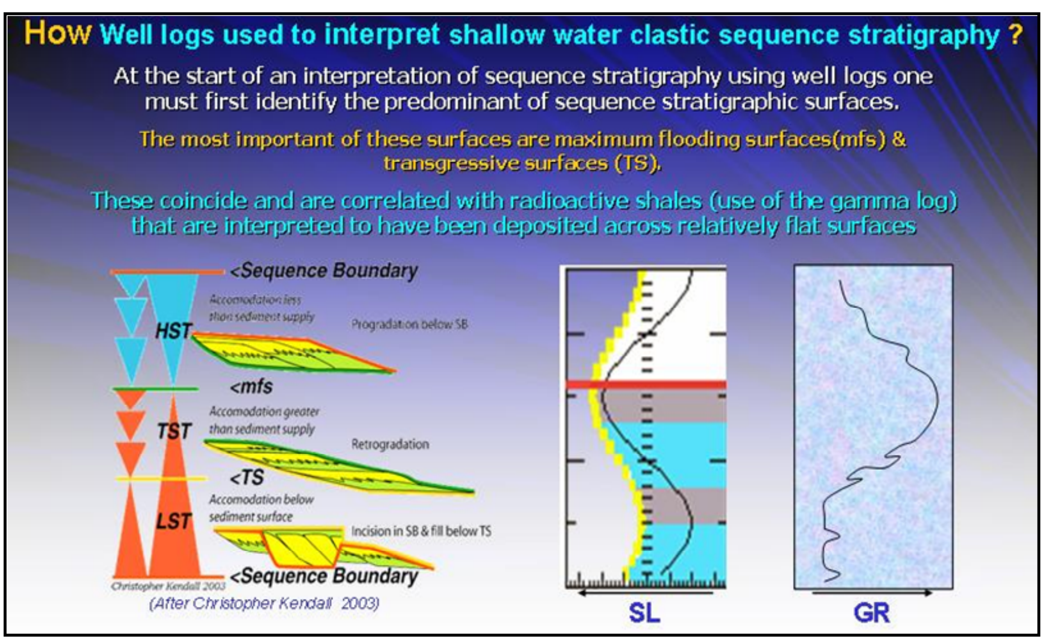

Figure 5. Sequence stratigraphy interpretation by using well logs.

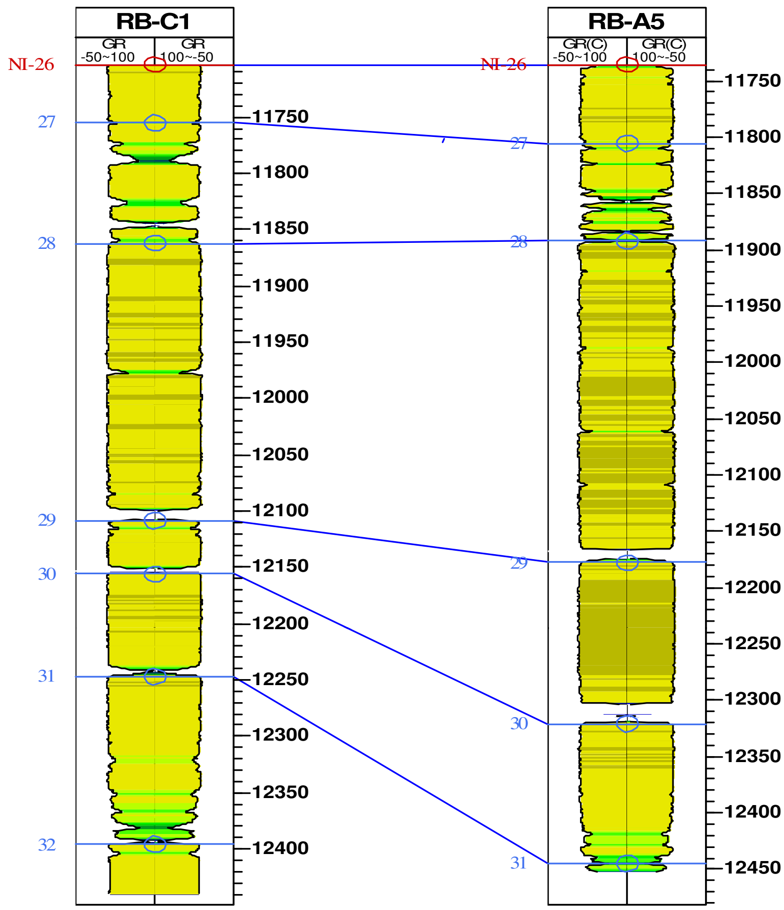

Figure 6. Massive sands of Unit I are punctuated by low permeable shale intervals. The shales appear correlatable and help to define 6 observed micro-zones.

consistently contains a peak of relatively high or hot gamma ray (often off the log scale), and correspondingly high density. This is interpreted to represent a condensed section of sedimentation. It would have been deposited during a period of maximum marine flooding.

Unit IIA highstand systems tract

The overlying section consists of blocky sands in the lower part of Unit IIA. They grade into relatively thinner sand units higher up in the section. The blocky sands are poor to well bedded, of mixed grain size, with climbing ripple marks. They are interpreted as delta-front channel mouth bar and beach barrier bar deposits. They would have prograded over the maximum flood shales during highstand. The blocky sand section is capped by impermeable shale unit that constitutes a micro-layer boundary. The sand bodies are separated by red and gray shale, tens of feet thick. Such episodic coarsening upward and capping sands of variable thickness are typical of fluvial deltaic channel bars in tidally dominated environments. In the uppermost part of Macro-Layer Unit IIA is a shaley unit (tens of feet thick) with thin sand interbeds. It consistently displays a high neutron signature on logs. This suggests a high degree of bound water, possibly due to silt.

Unit IIB and Unit III lower systems tract

They are mostly poorly sorted, often containing gravel beds, sands and shale clastics. The horizontal to cross-bedded thin layers of different grain size grade upward into weathered reddish shale which suggest fluctuating levels expected in a stacked fluvial environment. Thus they are interpreted as lowstand, braided stream and stacked fluvial to strand plain sand.

Lower Raha trangressive systems tract

The overlying Lower Raha coincides approximately with the start of the worldwide mid-cretaceous marine transgression.

As in the case of Unit IIA, the lower Raha wireline logs display coarsening upward sands. They are intercalated with thin shales. The sand appear to be correlatable field wide. This suggests that shoreface and distributary channel sands deposited during marine transgression. Low gamma spikes at the top of the sandy intervals on the logs suggest capping by clean sands, which may have been reworked at tidal wave base.

Lower Raha maximum flood surface

A low permeable limestone unit interbedded with shale, constitutes the lithostratigraphic marker for top Lower Raha. This sedimentary unit actually is relatively thin (tens of feet thick). It is the stratigraphically oldest limestone in the field. The overall Lower Raha transgression would have culminated in back stepping of the shoreline, thus allowing this offshore shaley limestone deposition.

Oldest upper Raha lowstand systems tract

The stratigraphically youngest reservoir in the field is the upper Raha. This unit is represented by the presence of porous, thin, moderately sorted and medium to coarse grained sands intercalated with shales. These indicate that clastics had once again prograded into the field area as near shore barrier bar sands.

Upper Raha transgressive systems tract

Directly overlying the Lowstand sands there is the transgressive system of the mid-Upper Raha section, represented by thin silt, pyritic shale, and shaley limestone beds, with wire-line logs displaying a trend towards cleaning upwards into tight limestones. This indicates an overall transgression, with deepening of the sea. This ultimately resulted in impeding silt and clay influx, thus resulting in offshore limestone deposition.

Upper Raha maximum flood surface

Non-porous limestone of very low permeability bounded by pyretic shale found in the upper part of the middle Upper Raha are correlatable field wide, (Figure 7), and they represent the apex of the marine transgression.

Youngest upper Raha lowstand systems tract

The upper most part of the Upper Raha is the stratigraphically youngest producing reservoir in the field. Where not faulted out, it consists of a series of thin sands interspersed with shale. Composite logs note medium to coarse grained, white friable sand. The wire-line log character of the sand bodies, especially at the base, suggests the recurrence of tidally dominated channels. Thus this reservoir is considered to represent a lowstand, with the return of deltaic and shoreline sands prograding seaward.

Wata-Abu Qada transgressive system tract: These beds constitute the stratigraphically youngest Macro Layer. The bulk of the beds are tight argillaceous limestone and they represent a continuation of the overall Cenomanian- Turanian marine transgression. Where not faulted out, a relatively thick (tens of feet), dark shaley limestone section exists in the lower half of the Wata. It is correlatable field wide.

Lithology variations

For Units Nubia IIB and Nubia III, a further subdivision of the geologically-based micro-zones, by separating correlatable non-reservoir shales have been made (?). Also, thick shales in the lower part of Upper Raha and in the uppermost and lowermost part of Nubia Unit IIA were separated as micro-zones.

This subdivision has been done because shale in the simulation model can be treated as separate sub-zones or combined with sand and treated as a reduced net to gross ratio. The first method gives a more accurate geometrical model of the reservoir, therefore the major shale sections were separated out as sub-zones. Nine major sub-zones were so designated as non-reservoir micro-zones and twenty three micro-zones were designated as reservoir micro-zones (Table 1).

Not all of the picked micro-zones are present in all of the studied wells. This is due either to erosion at the top of the Unit I unconformity, or to faulting out of section. The micro-zones in the table 1are discussed as follows:

i) Macro-zone Nubia UI can include at least 6 micro-zones. However, no individual well contain all interpreted micro-zones.
ii) Punctuating unit I are thin (tens of feet) shale breaks. Permeability logs calibrated to core indicate that the shales can have permeability less than 1 md. Therefore these shale breaks are used to define the borders of the micro-zones within Unit I. there is relatively little pressure data from this unit. Some of the available pressure data have indication that the shales may offer vertical pressure barrier.
iii) Ten-twenty feet sand body considered part of the Unit IIA transgressive system tract directly overlies Unit I in some some wells. No barriers are apparent to impede migration of hydrocarbons from unit I into this sand.
iv) Unit I micro-zones are generally capped by the thick (tens of feet) condensed shale deposited as part of the maximum flood surface. Pressure data suggest that this shale acts as communication barriers.
v) Macro-zone Nubia Unit IIA contains 3 micro-zones; The middle micro-zone contains blocky medium to coars

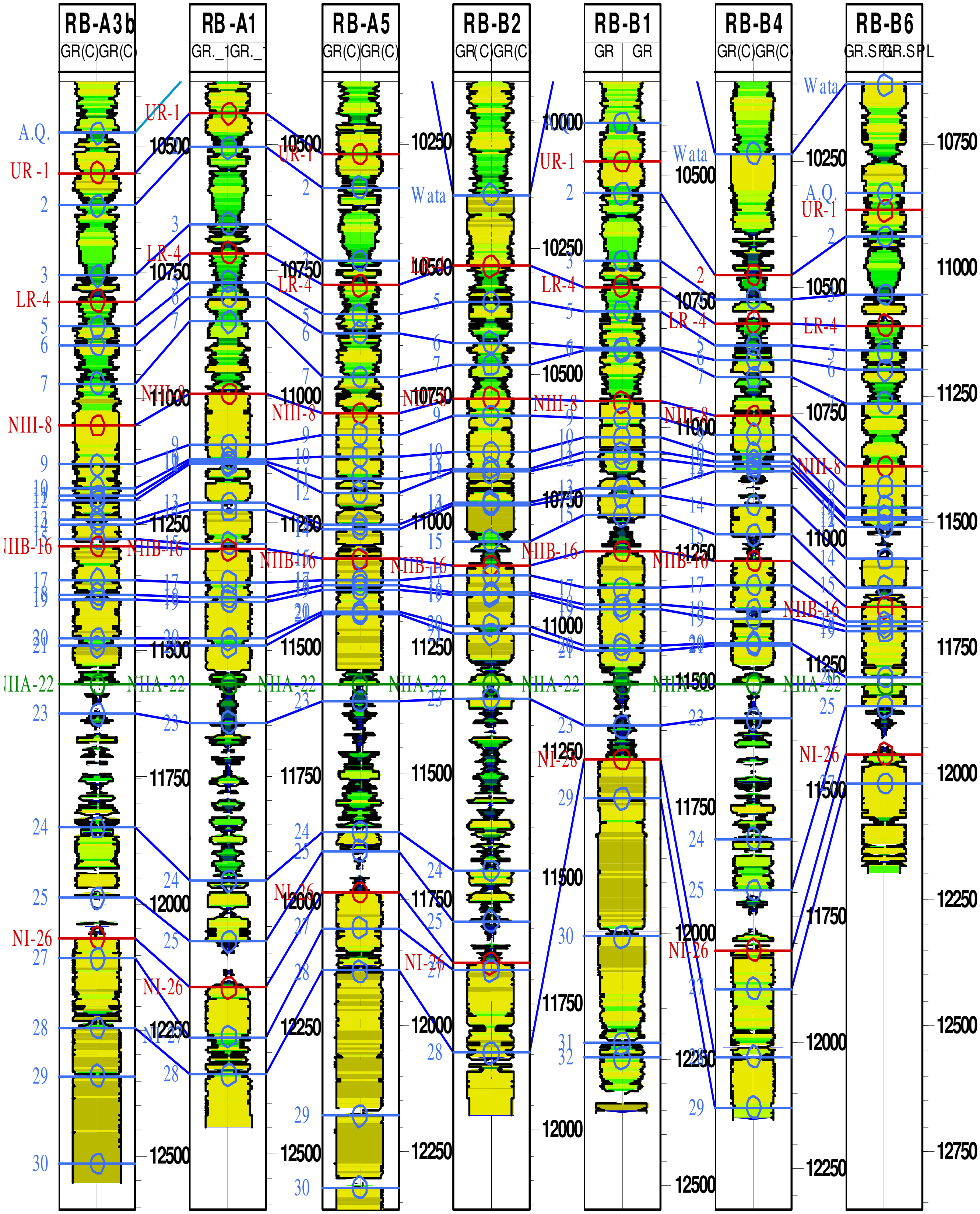

Figure 7. Log correlation of micro-zones in representative North-South cross section showing the differential erosion of Nubia Unit I micro-zones. Datu is Top Nubia Unit IIA which is the base of the overlying lowstand flivial sediments. This is a major sequence boundary throughput the field.

Table 1. Ras Budran Layering Chart (Relationship between core permeability and log porosity by creating a regression function through the data points. The regression provided a set of equations used then to compute permeability field wide).

RAS BUDRAN LAYRING CHART

AGE	MBR	MACRO-ZONE	MICRO-ZONE	LITH.	PERMEABILITY MODEL
CENOMANIAN	MELLAHA	UR	1	SST	Log(k) = 22.452*por + (-1.58252)
	ABU HAD		2	SH, LST	limestone/shale
			3	SST	Log(k) = 22.452*por + (-1.58252)
		LR	4	LST	limestone
			5	SST	Log(k) = 14.456*por + (-1.27402)
			6	SST	Log(k) = 14.456*por + (-1.27402)
			7	SST	Log(k) = 24.311*por + (-1.19752)
	NUBIA "A"	III	8	SST	Log(k) = 12.875*por + (0.33308)
			9	SST	Log(k) = 12.875*por + (0.33308)
			10	SST	Log(k) = 12.875*por + (0.33308)
			11	SH	shale
			12	SST	Log(k) = 14.911*por + (0.00678)
			13	SH	shale
			14	SST	Log(k) = 14.911*por + (0.00678)
			15	SH	shale
ALBIAN		IIB	16	SST	Log(k) = 21.880*por + (-0.96162)
			17	SST	Log(k) = 21.880*por + (-0.96162)
			18	SH	shale
			19	SST	Log(k) = 19.032*por + (-0.49832)
			20	SH	shale
			21	SST	Log(k) = 19.032*por + (-0.49832)
		IIA	22	SH	shale
			23	SH, SST	Log(k) = 19.922*por + (-1.37042)
			24	SST	Log(k) = 19.922*por + (-1.37042)
			25	SH	shale
DEVONIAN TO L.CARB.	NUBIA "C & D"	I	26	SST	Log(k) = 27.662*por + (-1.24022)
			27	SST	Log(k) = 27.662*por + (-1.24022)
			28	SST	Log(k) = 27.662*por + (-1.24022)
			29	SST	Log(k) = 27.662*por + (-1.24022)
			30	SST	Log(k) = 15.424*por + (0.21298)
			31	SST	Log(k) = 15.424*por + (0.21298)
			32	SST	Log(k) = 15.424*por + (0.21298)

grained sands within the lower section of Nubia Unit IIA that have previously been interpreted as highstand system tract deposits. The sands are underlain by a condensed shale section deposits as part of the maximum flooding surfaces. Permeability logs indicate that the shale can have less than 1 md permeability and can acts as a pressure barrier. The upper micro-zone consists of overlying terrestrial and marine shales interspersed with thin discontinuous channel sands also have relatively low permeability. The shales in this micro-zone are so numerous that they cannot be correlated and individually distinguished.

vi) Macro-zone Nubia Unit IIB contains thick massive sand bodies segmented into 3 micro-zones. The sands are interpreted as fluvial-braided stream lowstand system tract deposits. The massive sand sections are punctuated by 3 thin (less than 20 ft) generally field-wide correlatable shales. Although thin, the shales can have less than 1 md permeability as indicated on permeability logs calibrated to core.

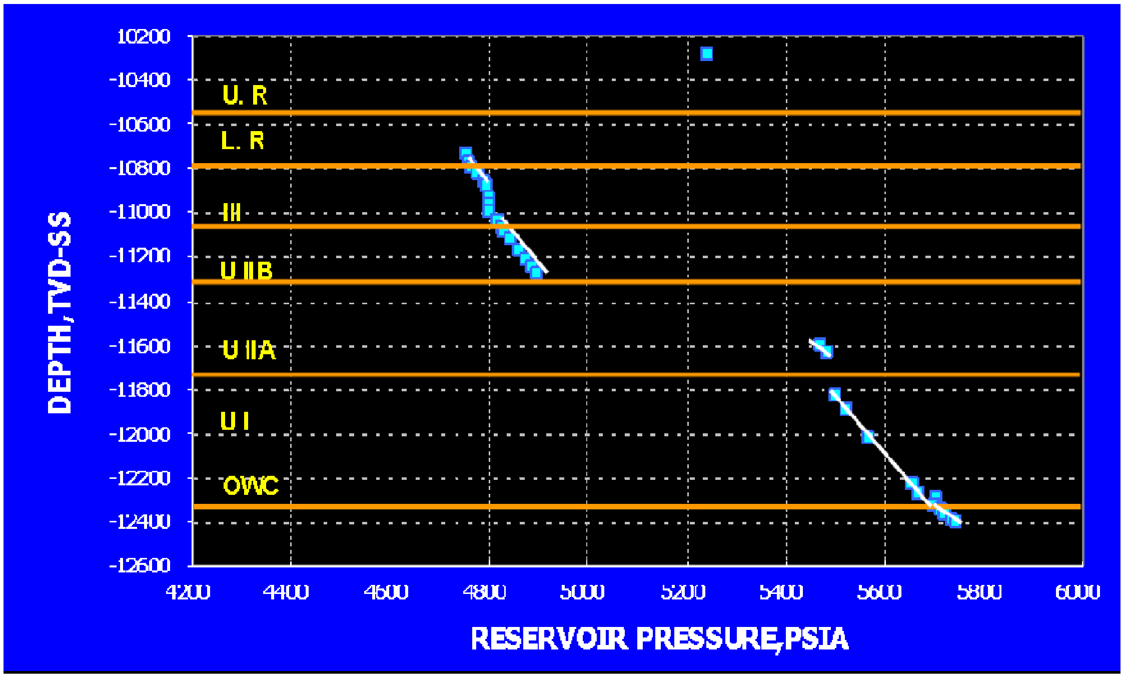

Figure 8. RFT (repeat formation tester) of RB-A5 well at zero years of production.

vii) Macro-zone Nubia Unit III also contains thick massive sand bodies which have been segmented into 3 sandy micro-zones. They are considered to represent a continuation of the lowstand system tract deposits of Nubia unit IIB. The massive sand bodies appear to have correlatable log signatures and to contain three obvious, correlatable shale breaks. The shale breaks are vary in thickness, but generally are thicker (tens of feet) than those found in Nubia unit IIB. Permeability logs suggest that these shales can have less than 1 md. There is an indication from pressure data that the shales may offer vertical pressure barriers.

viii) The lower Raha represents the next major marine incursion. It appears to contain shoreface and distributary channel mouth sands. They are interpreted as part of the transgressive system tract. The wireline log signatures of these sands indicate three distinct sandy intervals punctuated by thin shale breaks. The sands appear to be correlatable fieldwide. However the shale is so numerous that it cannot be correlated and individually distinguished, so this shale is part of the sands in these micro-zones. The lower micro-zone appears to contain fining upward channel sands capped by a thin low permeability shale (about 10-40 ft). The middle micro-zone contains more blocky sands overlain by another thin permeability shale. The upper micro-zone consists of thin blocky sand units capped by low gamma peaks; this micro-zone overlain by a dark shaley limestone whose base constitutes the top of the Lower Raha micro-zones.

ix) The Upper Raha consists of 3 micro-zones that contain 2 reservoir sands. They are considered to represent lowstand system tract deposits. The Sandy beds at the base of the Upper Raha belong to the lower micro-zone in Upper Raha Macro-zone. They overlie the tight shale and limestone lithostratigraphic marker that constitute the top of Upper Raha Macro-zone. The second micro-zone consists of tight shales and limestone. This micro-zone is considered to have been deposited during transgressive and maximum flood events. The shales and limestone, together up to 100-120 ft thick, can contain very low permeability often lower than 1 md.

x) The upper micro-zone sand (about 30-70 ft thick) constitutes the lithostratigraphic marker for the Top Upper Raha. Its upper border is provided by the known regional seal of the tight Abu Qada-Wata shaley limestons.

Validation of micro-zonation

In this section we will discuss some reservoir related measurements which highly support idea of reservoir micro-zonation. These measurements include pressure data, production data and reservoir water flood performance.

Pressure data

The pressure data highly support and validate the reservoir micro-zonation. Figure 8 shows the pressure data of RB-A5 well at zero-years of production. The figure

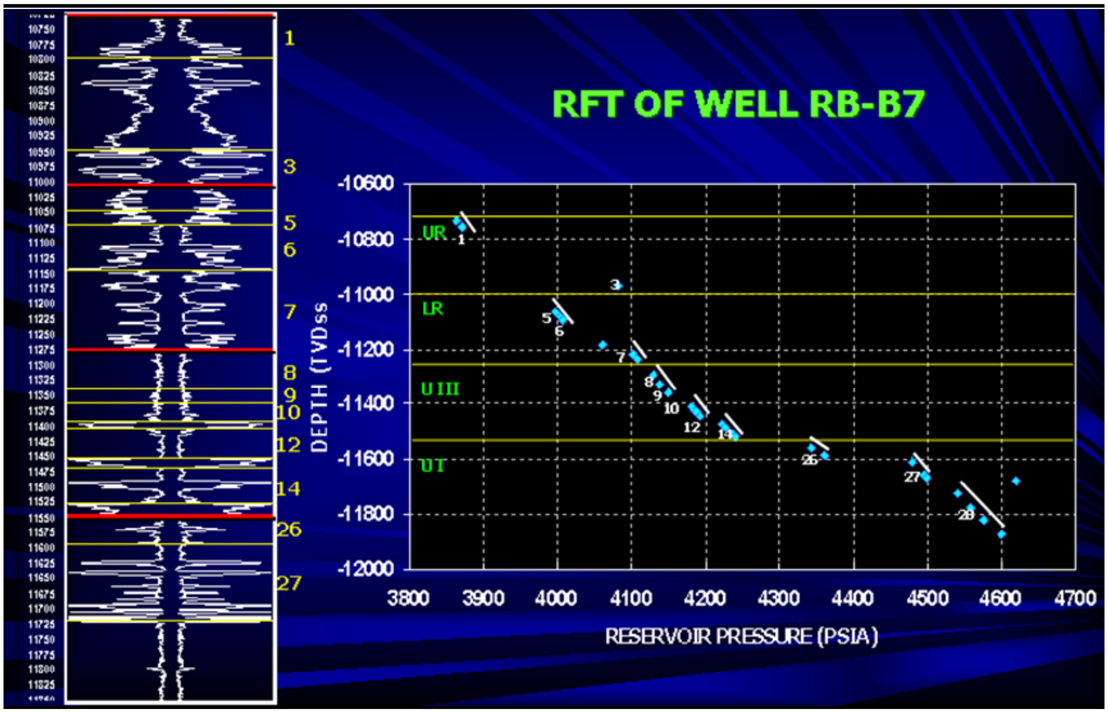

Figure 9. RFT data for RB-B7 well, after years of production.

shows that every macro-zone (UI, UIIA, UIIB and UIII) have single trend of pressure data, but after some years of production this single trend divided to many trends with different pressure values (Figure 9). It was confirmed that each pressure trend represents a different micro-zones and these micro-zones are not in communication.

Production data

The Production data also supports reservoir micro-zonation. Figure 1, representing the production data of macro-zone Nubia UIII, shows that the performance anomalies are within the same macro-zone, in which some intervals produce high water whereas adjacent intervals produce high oil. After reservoir micro-zonation, it was proved that these two adjacent intervals are not within the same unit but they are representing two different reservoir units, micro-zones 12 and 13 (Figure 10).

Water flood performance

The production from Ras Budran reservoir started in 1983. After reservoir pressure started to decline, the decision was taken to support the reservoir pressure by water injection (Figure 11). Due to the nature of Ras Budran reservoir and its dipping structure, a peripheral water injection pattern (Figure 12) was proposed and implemented in the original field development plans in October 1985 through two wells: RB-A2a (Unit IIB+III+R), and RB-A3b (Unit I). In January 1990, the system was upgraded with another injector RB-A1 (Units IIB+III) to replace the poor injector RB-A2a and finally, the last injector RB-A9a (Units IIB+III+R) was brought on line in April 1992. The reservoir water salinity is 150000 mg/l and the injection water (sea water) is highly fresher than reservoir water. This fresher water highly affects reservoir water resistivity measurements by resistivity tools. In our example the array induction tool (AIT) was used to measure reservoir resistivity to evaluate water saturation in RB-C1b well (Figure 4). The AIT (Array Induction Tool) have 5 depths of investigations where it measures AIT10, AIT20, AIT 30, AIT60 and AIT90 to measure at depths 10", 20", 30", 60" and 90" respectively. RB-C1B well was drilled with oil base mud. In case of oil bearing formation, all curves will overlay each other with high resistivity reading. In case of water bearing formation and if the water is the highly saline formation water, the tool will read low resistivity with little reverse separation (AIT190 <AIT60 <AIT30 <AIT20 <AIT10). But in case of fresher injected, the AIT will read higher resistivity and higher reverse separation between the resistivity curves (AIT190 <<AIT60 <<AIT30 <<AIT20 <<AIT10). Figure 13 shows how this phenomenon validates and supports reservoir micro-zonation. Micro-zones 16, 17, 19 and 21 are belonged to Macro-zone Nubia unit IIB. Micro-zones 16 and 19 are higher in permeability than 17 and 21 micro-zones. As shown from resistivity log, the higher permeability zones are highly flooded by water and the

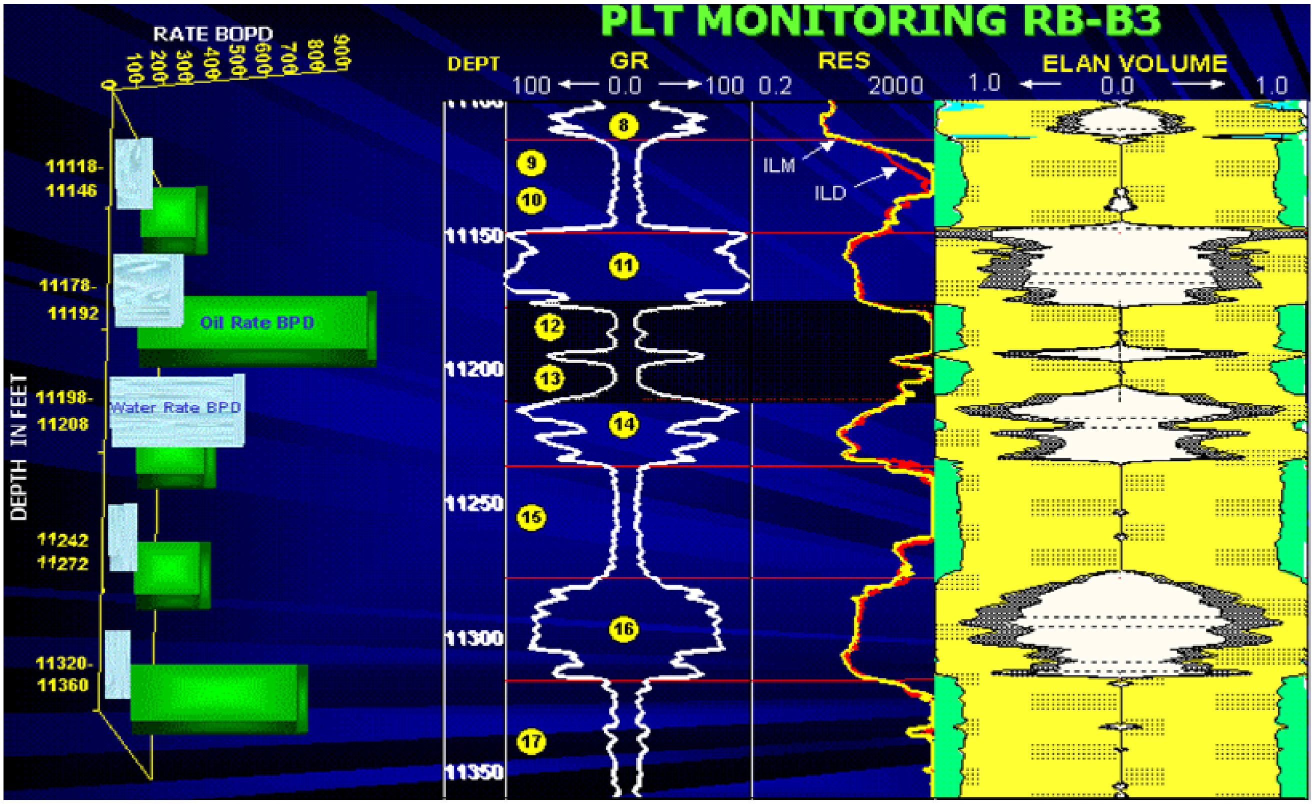

Figure 10. PLT data for RB-B3 well.

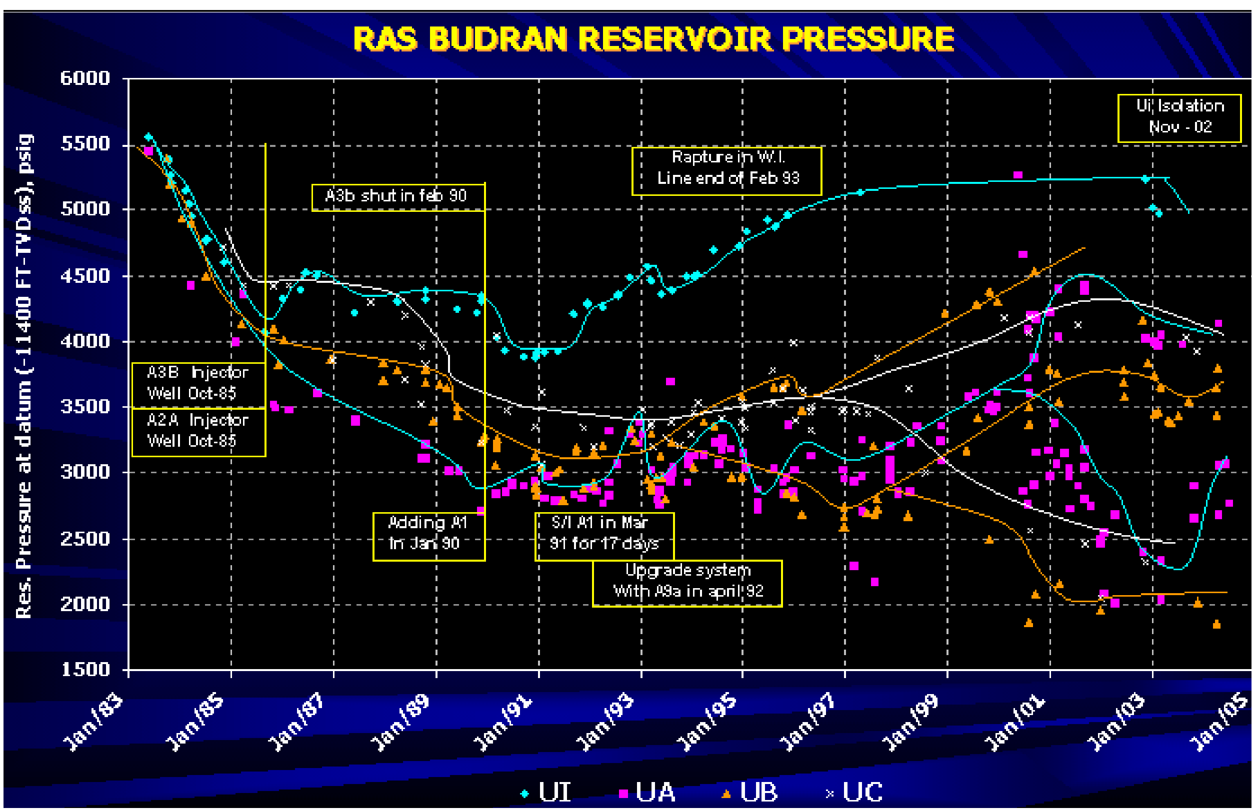

Figure 11. Ras Budran reservoir pressure data with time.

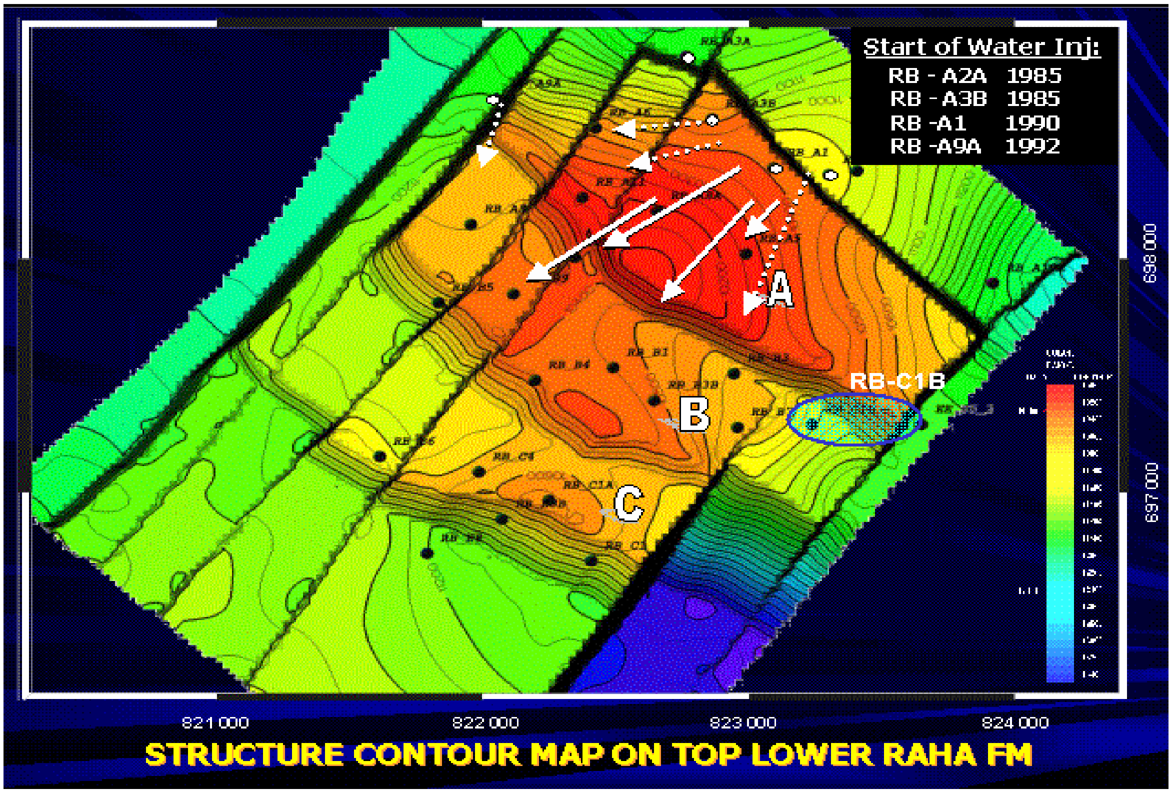

Figure 12. Ras Budran peripheral water injection.

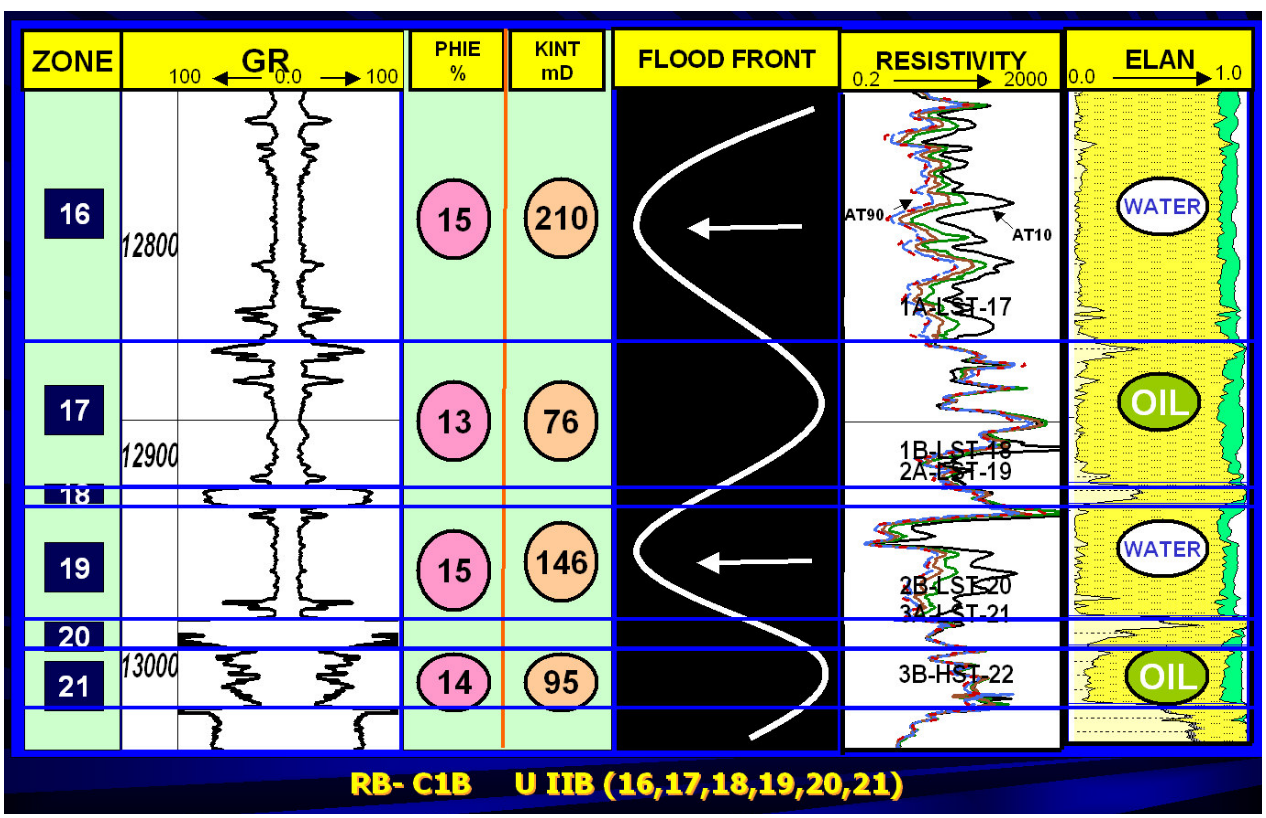

Figure 13. Effect of water flood on resistivity log.

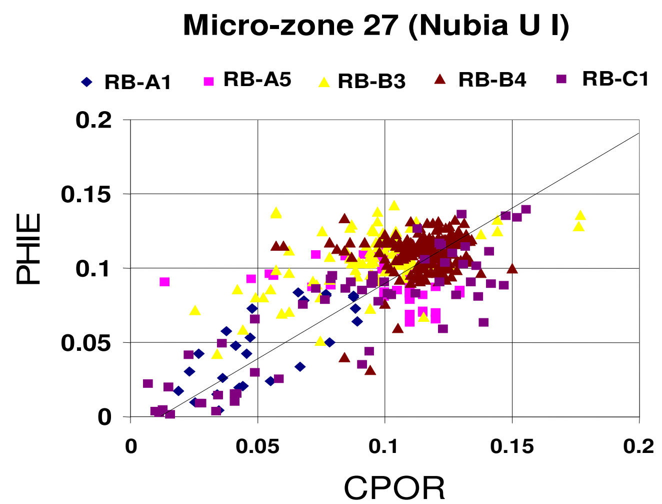

Figure 14. Cross-plot between core porosity (p.u) and log porosity (p.u) for micro-zone 27

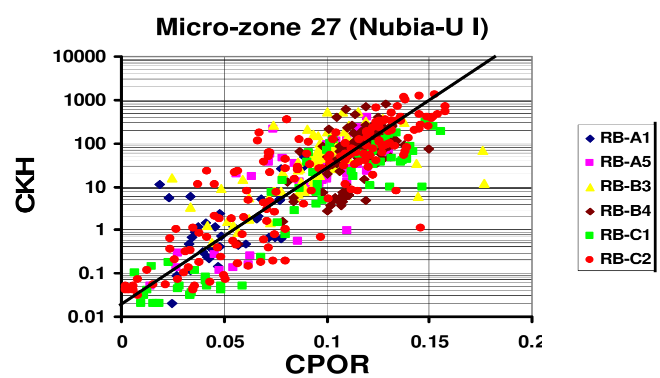

Figure 15. Cross-plot between core porosity (p.u) and core horizontal permeability (md) for micro-zone 27.

low permeability still oil bearing. This suggests that the reservoir is not massive sandstone as thought but it is a very stratified reservoir and there are some permeability streaks which accelerated the water breakthrough and resulted in a non-uniform flood front.

PERMEABILITY COMPUTATION

This was done through core calibration and correlation to the existing log porosity. Several steps were required to achieve this computation process:

Depth match

There are nine wells for which conventional core data and core descriptions are available. The core data parameters (Kh, Kv, Porosity, SW and So) were utilized for the depth match, then plotted and overlain with log data curves for verification and comparison of values.

Calibration of log curves

Log porosity were calibrated to the depth matched core data to compute field wide perm-eability curves. This was done by constructing several cross-plots for core porosity to core permeability and log porosity, (Figures 14 and 15), as well as, core horizontal permeability to core vertical permeability (Figure 16). A relationship was established between the core permeability and log porosity by creating a regression function through the data points. The regression provided a set of equations used then to compute permeability field wide. This process provides a well supported and coherent means of computing the necessary permeability that is directly integrated with the detailed micro zonation of the field and produces a finer definition for the subsequent history matching simulations (Table 1). Zone averaging of petro-

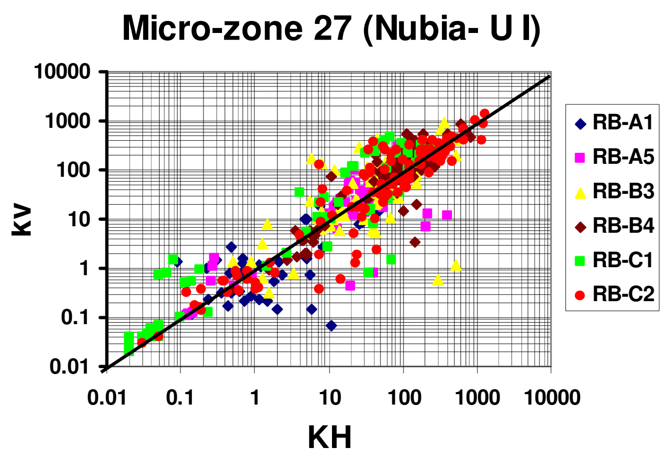

Figure 16. Cross-plot between core horizontal permeability (md) and core vertical permeability (md) for micro-zone 27.

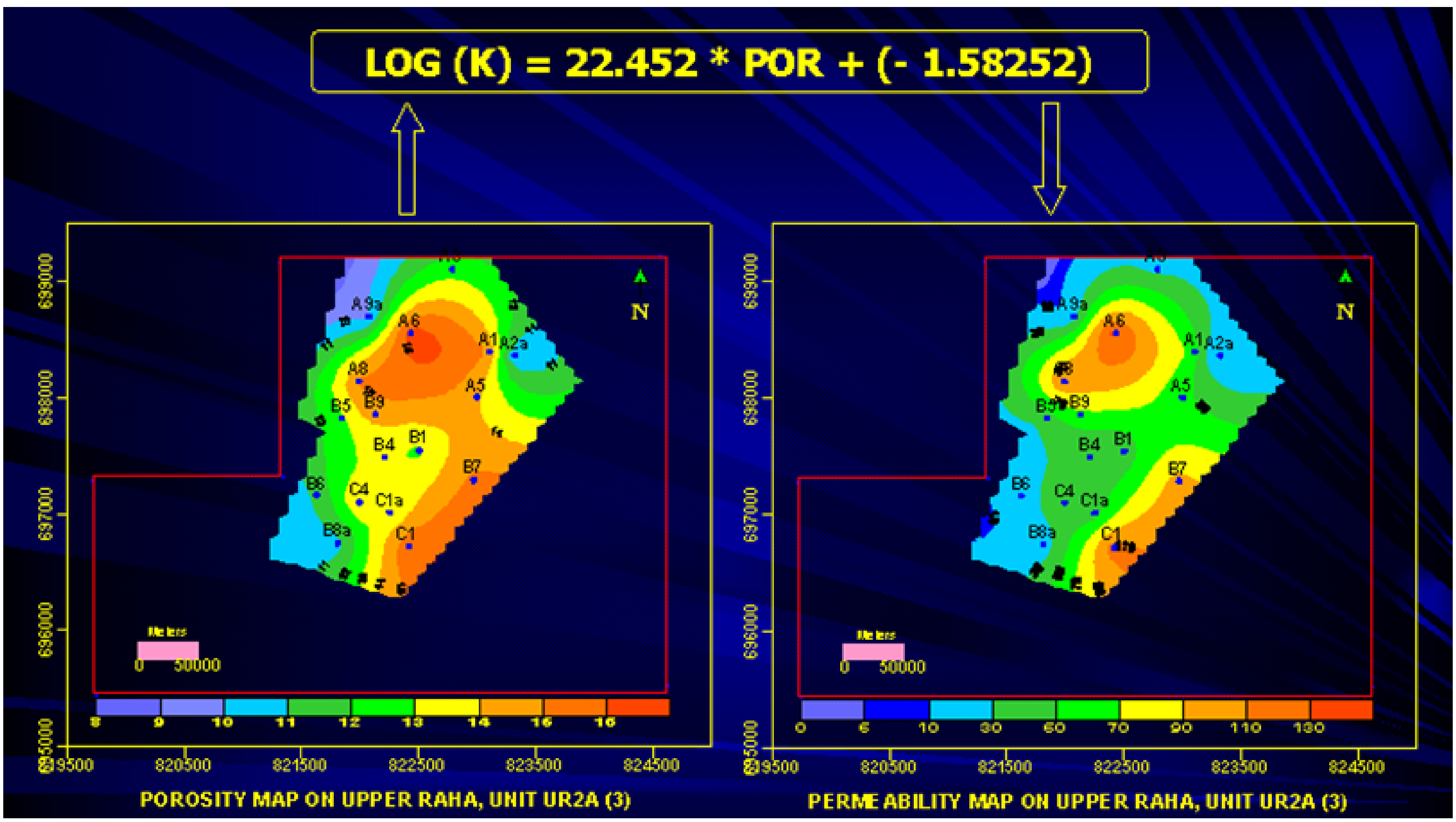

Figure 17. Porosity and permeability maps for micro-zone 3.

physical properties: In preparation for simulation, the well petrophysical parameters including Porosity, Computed Permeability, Water saturation and net-to-gross sand ratio, were correlated to the micro zones, (Figure 17). The data was averaged based on a depth range defined by the micro zones. The computation was constrained by several production related parameters where porosity cut-off is 5%, permeability cut-off is 1 md, and water saturation is 50% (Moller, 2001). Each half foot sample had to meet all three conditions to be accepted as pay. This resulted in a single zoned averaged value for each micro zones at each well location.

Summary and Conclusions

Thirty two micro-zones have been defined. They can vary from 5' – 375' in thickness. The current micro-zonation has an internally consistent geological framework. It includes relating pressure test data and core-plug porosity-permeability data to the geological descriptions and identifying the main geological controls on vertical flow. An initial sequence stratigraphic framework has been established to provide geologic parameters to help in defining the micro-zones. Permeability Computation have been done for every micro-zone. This was done through core calibration and correlation to the existing log porosity. Zone averaging of petrophysical properties have been used in preparation for simulation, the well petrophysical parameters including porosity, computed permeability, water saturation and net-to-gross sand ratio, were correlated to the micro zones. Reservoir micro-zonation helps to address many performance anomalies encountered in the field.

REFERENCES

Al Naggar A, Helaly H (1985). Geological aspects and reservoir units, Ras Budran Field, eighth production seminar, E.G.P.C., Cairo-Egypt.

Kendall CG (2003). Use of Well Logs for Sequence Stratigraphic Interpretation for Shallow Water Clastics in the Subsurface, USC Sequence Stratigraphy Website.

Koldewjin A (1984). Sedimentological investigation of Nubian sandstone cores - Ras Budran Field, SUCO internal report.

Moller A (2001). Ras Budran Petrophysical and petrographical characterization of core samples, SUCO internal report.