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PORE PRESSURE EVALUATION USING WELL LOGGING AND DRILLING EXPONENT FOR A/R "C" MEMBER, A/R FORMATION, BED-15 FIELD, WESTERN DESERT, EGYPT

BY

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ABSTRACT

Pore pressure evaluation is an integral part of the well planning and formation evaluation process. In order to drill well safely, it's necessary to detect the pore pressure and fracture pressure so that the mud density can be optimized to provide sufficient overbalance, while being low enough so that formation integrity is not compromised.

In the areas where exploration and production histories are established, offset wells' data can be used to provide detailed profiles of the expected pressures for those wells which about to be drilled. Other measurements, such as real time PP measurements, well influx, kick, mud logging outcomes (total gas, trip gas, and connection gas), MWD, and borehole instability different events (e.g., abnormal torque and dragging, tight holes, caving, hole enlargement or breakout, hole filling, and packing-off) can also be used.

In the present study, we will focus on pore pressure evaluation from both drilling and well logging data using Interactive Petrophysics (IP) software.

It was found that there is a good coincidence between the pore pressure values from Drilling Exponent (Dxc) and those values which obtained from well logging where it ranges between 9.3 to 10.0 ppg. By using modern methods and industry accepted concepts, relationships between petroleum geology and drilling engineering can be interpreted to give accurate estimations of formation pressures at any point during the well drilling.

Key Words: Pore pressure; Well logging; Drilling exponent; Evaluation; Reservoir characterization.

INTRODUCTION

BED-15 Field is a part of Badr El-Din concession in the Egyptian Western Desert, 300 km^2 west of Cairo and almost 100 km west of the BED-1 producing field. The study area is in the northwestern part of Abu Gharadig basin located between Lat 29° 45' and 30° 05' N, and Long 27° 30' and 28° 10' E. (Fig. 1).

Abu Roash (A/R) Formation is divided into seven members designated from bottom to top G, F, E, D, C, B, and A. It was deposited on a wide shallow marine shelf during several sedimentary cycles. Transgressive phases are marked by limestone and shale sequences, while regressive phases are clastic dominated. A/R "G" Member is principally limestone and Upper Cenomanian in age. It is considered the master seal for major fields in the Western Desert. A/R "G" Member is a potential source rock with high organic content. A/R units from "B' to "F" are Turonian in age, although unit "A" may be Coniacian. Units "A," "C," "E," and "G" are shales deposited in a marine-lagoonal environment, and units "B," "D," and "F" are mainly shallow marine limestone. Unit "F" with a high organic content is also considered a source rock on a regional scale for the Western Desert (Fig. 2).

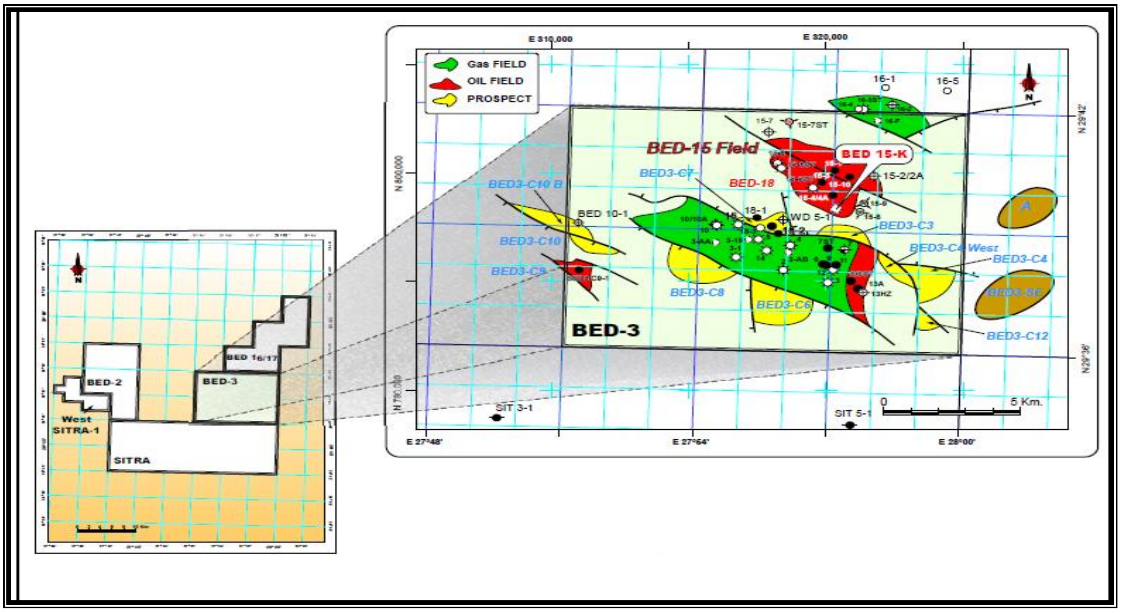


Fig. (1): Location map showing the studied wells, (After Bapetco 2013).

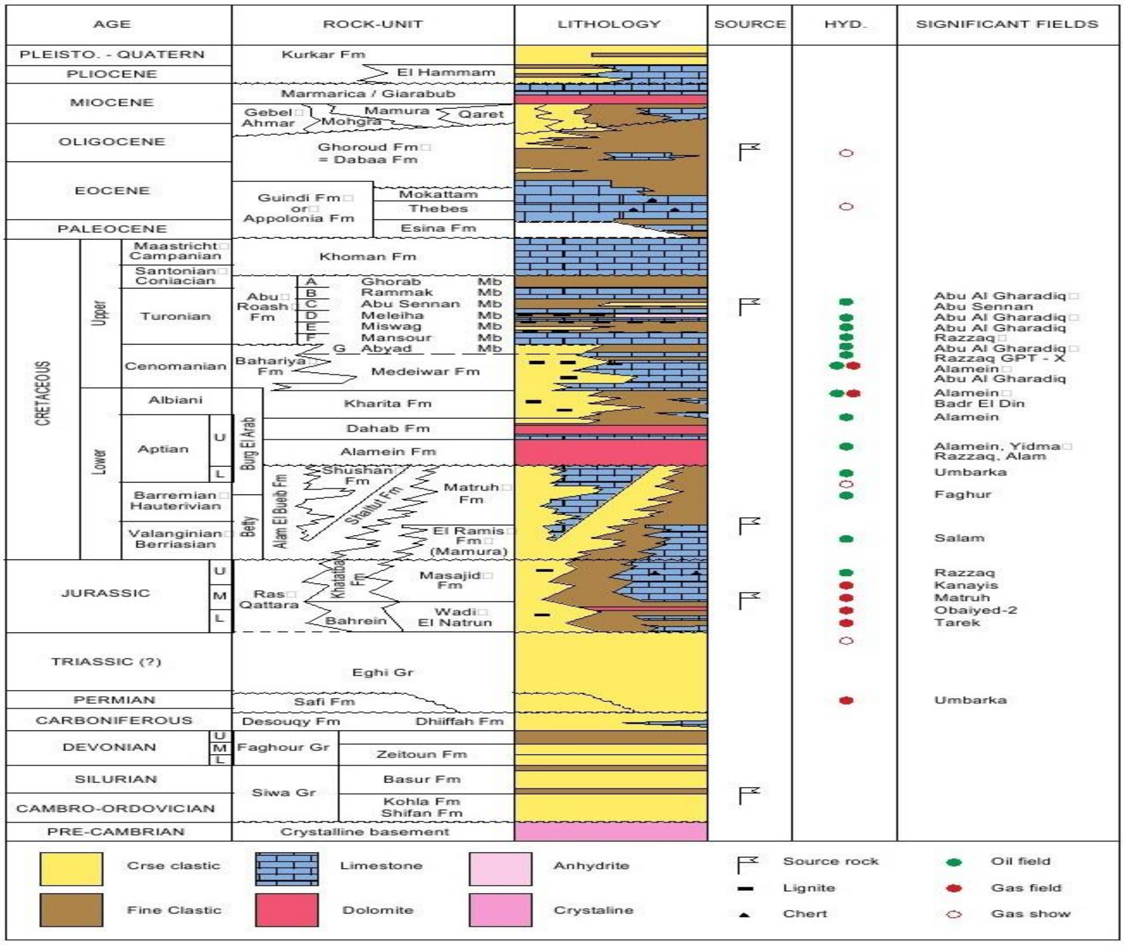


Fig. (2): Simplified stratigraphic section of the Western Desert, Egypt (modified after Schlumberger, 1984, 1995).

METHODS

Formation pore pressure evaluation for A/C “C” Member (Turonian) in the selected wells was calculated based on the corrected drilling exponent Dxc calculation and existing well log analysis to create pressure profiles for the selected wells. Pore pressure profiles were created using “IP - Interactive Petrophysics software” for the A/R “C” Member in the following 4 wells: (BED 15-07 ST1, BED 15-09, BED 15-10 and BED 15-11).

Rate of penetration (ROP), weight on bit (WOB), rotary speed (N), bit diameter, and mud density are used to calculate d-exponent to estimate the pore pressure. The d-exponent normalizes the penetration rate (ROP) to extract the formation drillability or hardness. Jorden and Shirley (1966) and Bourgoyne et al. (1986) proposed the d-exponent method for analyzing formation pore pressure**,** to attempt to normalize the rate of penetration (ROP) from the Bingham drilling model to the parameters of weight on bit (WOB), rotary speed (N) and bit diameter (db.). The purpose was to investigate the proposed relationship between the penetration rate and the differential pressure existing between the formation pore pressure and the hydrostatic pressure column in the wellbore (Jorden and Shirley, 1966). This relationship makes it possible to predict changes in the pore pressure with respect to drilling data. The d-exponent calculation is shown below (Bourgoyne et al., 1986) using the Bingham drilling model. Empirical models commonly used today include the following 1) Bingham model, 2) Jorden and Shirley model, and 3) Rehm and McClendon. Bingham (1965) proposed that the relationship between penetration rate, weight on bit, rotary speed, and bit diameter may be expressed in the following general form:

$$(R/N) = a\,(W/B)^{d}$$

Where:
d = drilling exponent (dimensionless)
N = rotary speed (rpm)
B = bit diameter (inches)
R = rate of penetration (ft. /hr.)
W = weight on bit (lbs.)
a = matrix strength constant (dimensionless)

Jorden and Shirley (1966) solved the previous equation for “d”, inserted constants to allow common oilfield units to be used, and plotted the output on semi-log paper which produced values of d-exponent in a convenient workable range. Importantly they let “a” be unity, removing the need to derive empirical matrix strength constants, but made the d-exponent lithology specific:

$$D = \mathrm{Log}\,(R / 60N) / \mathrm{Log}\,(12W / 10^{6}B)$$

Where:
D = drilling exponent (dimensionless)
R = rate of penetration (ft. /hr.)
N = rotary speed (rpm)
W = weight on bit (lbs.)
B = bit diameter (inches)

Rehm and McClendon, (1973) proposed this correction:

$$Dxc = (D \times N.\,FBG) / (ECD)$$

Where:
Dxc = corrected d-exponent
N. FBG = normal formation balance gradient-EQMD (lb. /gal)
ECD = effective circulation density (lb. /gal)

Wireline logs (Resistivity and sonic) are used to calculate the pore pressure with depth. Resistivity is a measure of the ability of a formation to conduct an electric current and is one of the earliest methods of wireline detection. The solid matrix is generally non-conductive, while the pore space may be filled either with non-conductive hydrocarbons or with conductive saline water. Therefore, resistivity values are related to the amount and nature of the pore fluid and, ultimately, porosity. All things being equal, homogeneous clay and constant fluid properties, a unit decrease in resistivity corresponds to a unit increase in porosity and overpressure.

Hottman & Johnson (1965) proposed that the expression below can represent the relationship linking normal to abnormal pressure in clays:

$$Ro / Rn$$

Where:
Ro = measured or observed resistivity
Rn = resistivity expected in normally pressured rock at depth under investigation After modifying the exponent to 1.5, **Eaton (1975)** put this into the pore pressure equation above, producing:

$$Po = S – (Ro / Rn)\ 1.5\ (S - Pn)$$

Where:
Po = Formation Pore Pressure gradient (Psi/ft.)
Pn = Normal Pore pressure gradient (Psi/ft.)

Further analysis **Eaton (1975)** suggested that the exponent value should change from 1.5 to 1.2. Eaton's equation thus became Po = S – (Ro/Rn) 1.2 (S-Pn).
Sonic transit time (Δt) is also a function of lithology and porosity. The sonic response is a function of porosity variation. If sonic transit times of normally compacted shales are plotted on a logarithmic scale against depth on a linear scale, a linear trend results, and transit time decreases with depth. **Eaton's (1975)** equation can be applied to other porosity logs in much the same way as resistivity. Commonly used logs include sonic transit time (Δt).

$$Po = S – (\Delta tn / \Delta to)\ 3\ (S - Pn)$$

Where:
S = Overburden Stress Gradient (Psi/ft.)
Po = Formation Pore Pressure gradient (Psi/ft.)
Pn = Normal Pore pressure gradient (Psi/ft.)
ΔT = Transit time (usec/ft.)

RESULTS

1. Pore pressure evaluation after drilling using well logging analysis

1.1 Resistivity logs

Normal resistivity is obtained by plotting resistivity against depth, and plotting a normal compaction trend (NCT) onto the log. Rn is, therefore, the value on the NCT at the depth where pore pressure is calculated. The difference between Ro and Rn then indicates the degree of difference between the true porosity and normal porosity at that depth**. (Fig. 3)** Shows pore pressure evaluation using available resistivity logs for the wells in the study area.

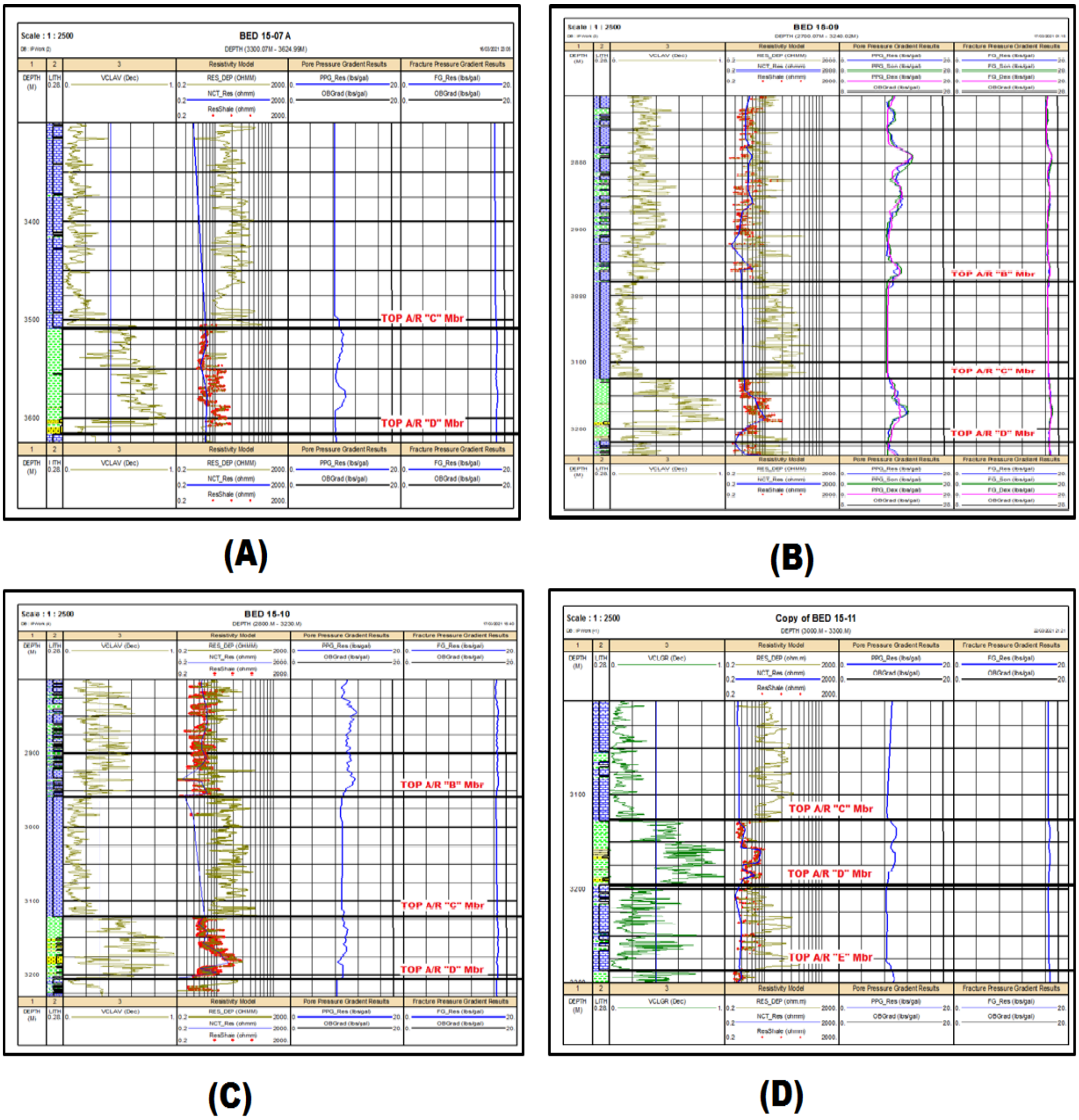


Fig. (3): Pore Pressure Evaluation from Resistivity Logs for wells: (A) BED 15-07 ST1, (B) BED 15-09, (C) BED 15-10, and (D) BED 15-11

1.2 Sonic log

A sonic log in a geo-pressured clay interval shows increasing transit time, (Δt), (increasing porosity) with an increasing pore pressure gradient. In the transition zone (if it exists), the DT curve, on the log, moves steadily to the left (higher values) with depth. **(Fig. 4)** Shows pore pressure evaluation using the available sonic logs in the study area.

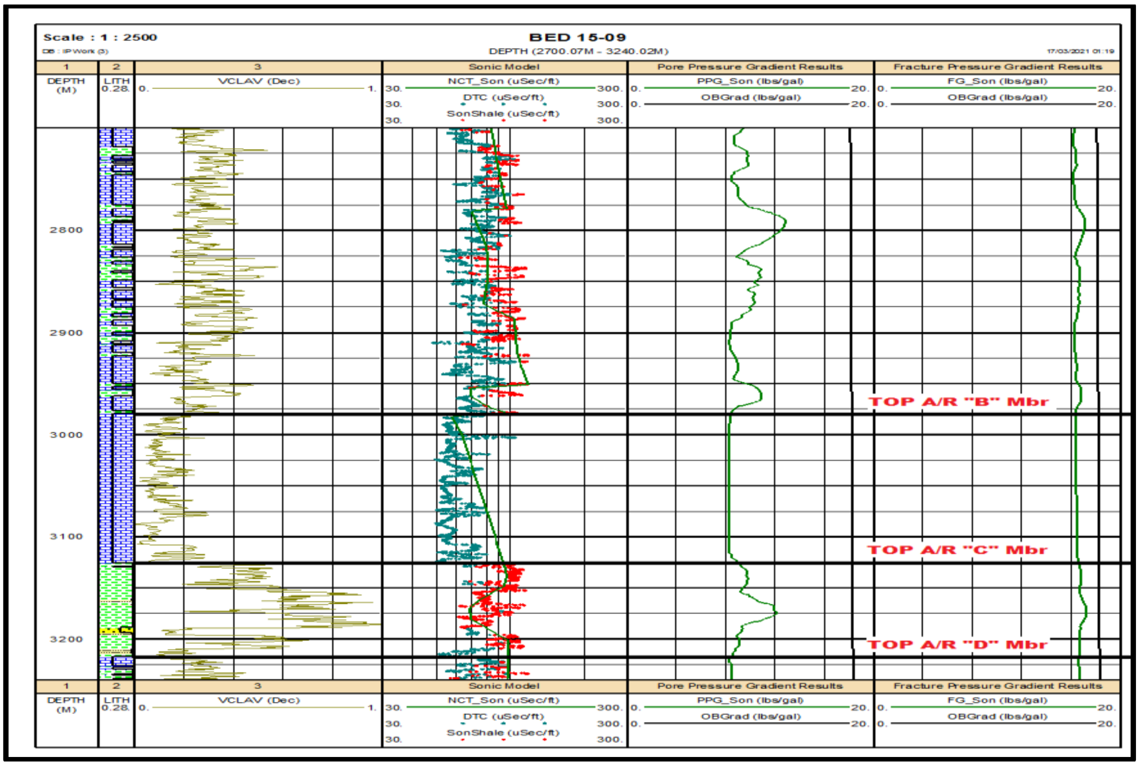


Fig. (4): Pore Pressure Evaluation from sonic Log for BED 15-09 well

1.3 Pore pressure estimation while drilling using D-Exponent

Dxc is sensitive to differential pressure, hence allows the driller to adjust the mud weight as drilling progresses. Dxc increases with depth if lithology is constant and pore pressure is hydrostatic, but decreases in overpressure zones**. Figure 5** shows pore pressure evaluation using d-exponent for the wells in the study area.

The objective is to present the results of pore pressure determination using drilling and d-exponent and from well log data (**Table (1).**

A/R “C” Member in the studied area is composed of shales and sandstones, and the average of calculated formation pore pressure ranges from 9.3 ppg to 10.1 ppg (**Figs. 6 & 7).**

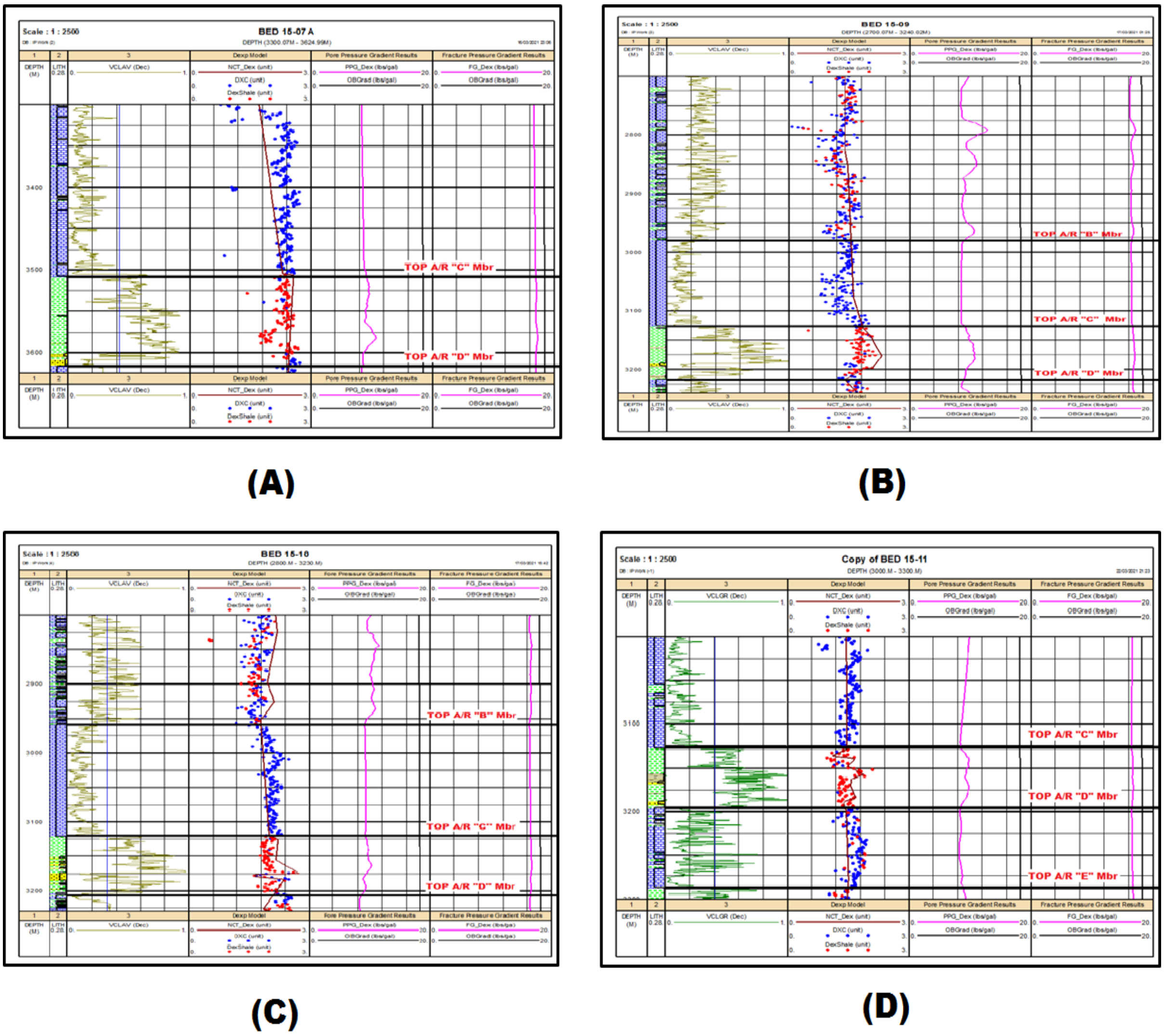


Fig. (5): Pore Pressure Evaluation from Modified D-exponent for wells: (A) BED 15-07 ST1, (B) BED 15-09, (C) BED 15-10, and (D) BED 15-11

Table (1) the results of Pore Pressure Evaluation from the two methods

Well name	Member	Pore Pressure from well logs (PPG)	Pore Pressure from Modified D-exponent (PPG)	Mud Density (PPG)
BED 15-07 ST1	**A/R “B”**	8.44-8.49	8.43-8.60	8.80-10.1
	A/R “C”	8.80-10.1	8.91-10.1	
	A/R “D”	8.60-8.90	8.39-9.10	
BED 15-09	**A/R “B”**	8.80-8.90	8.91-8.98	9.50-10.2
	A/R “C”	9.20-10.1	9.40-10.1	
	A/R “D”	9.50-9.62	9.40-9.60	
BED 15-10	**A/R “B”**	8.90-9.24	9.25-9.30	9.40-10.2
	A/R “C”	9.32-10.0	9.50-10.1	
	A/R “D”	8.44-9.34	8.44-8.80	
BED 15-11	**A/R “B”**	8.91-9.60	9.00-9.60	9.60-10.2
	A/R “C”	9.61-10.03	9.60-9.90	
	A/R “D”	8.31-8.66	8.63-8.89	

DISCUSSION

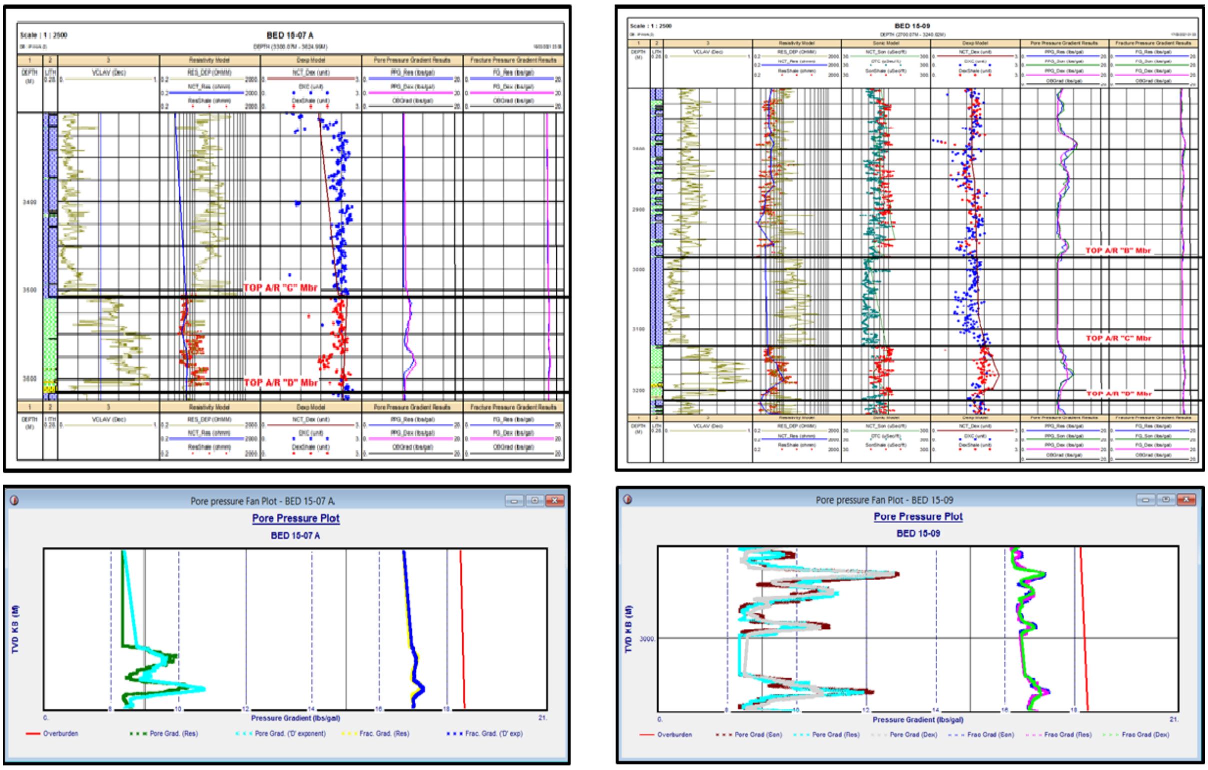
Pore pressure evaluation from d-exponent and well logs shows good matching over the three members. These calculations were plotted as shown in **Fig. (8)** and compared with established normal shale compaction trends to obtain pore pressure values at the depth of interest.

Some points to bear in mind when using Dxc for pressure detection include the following:

(1) Use only trends in shale.
(2) Trends will typically change with bit and hole size changes.
(3) Don't use in sections with controlled drilling or sliding.
(4) Trend more reliable when drilling with roller cone bits.
(5) Use in conjunction with other indicators.
(6) Deviation from normal trend is indicative of transition zone.

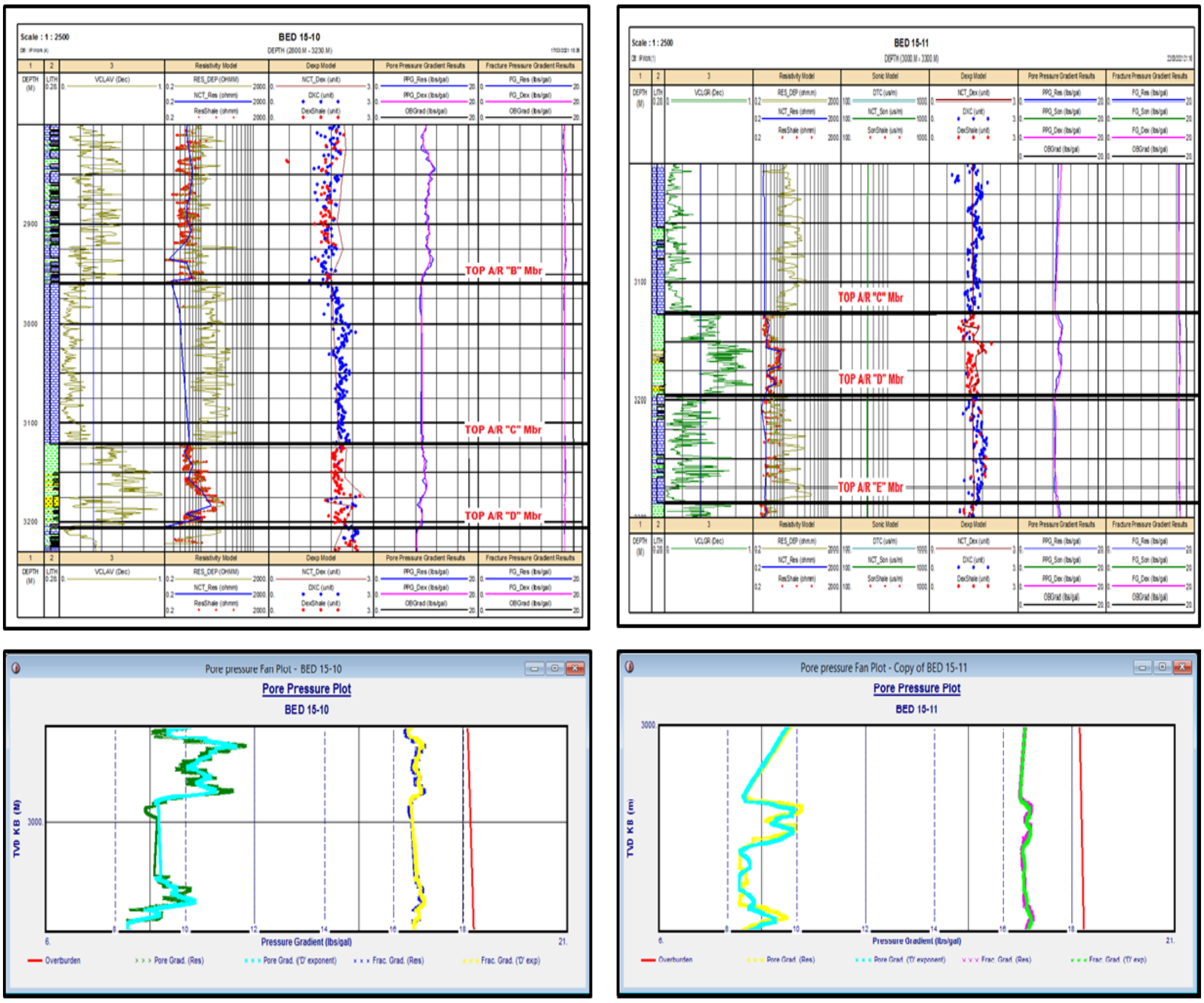
Most of these wells were drilled after field start-up, some pressure depletion was recorded and encountered in many areas while drilling for oil and gas where pressure depletion may also occur artificially by reducing oil, gas and water from permeable subsurface formations. Production of large amounts of reservoir fluids can drastically reduce formation pressure. Basically, fluid withdrawal, such as production, causes a decline in pore pressure.

Figures 6 & 7 represent the cumulative pore pressure evaluation for the selected wells compared with their pore pressure plot which show that there is a good coincidence between the pore pressure values from Drilling Exponent (Dxc) and those values which obtained from well logging.



(A) **(B)**

Fig. (6): Shows the cumulative Pore Pressure Evaluation for wells: (A) BED 15-07 ST1 and (B) BED 15-09 compared with their Pore Pressure plot extracted from IP software



(C) (D)

Fig. (7): Shows the cumulative Pore Pressure Evaluation for wells: (C) BED 15-10 and (D) BED 15-11 compared with their Pore Pressure plot extracted from IP software

SUMMARY AND CONCLUSION

The studied Formation can be divided into three zones of pore pressure designated as normal pressure zone, transitional zone (Limestones of A/R "B" Member), and abnormal pressure zone which started by (Shales and sandstones of A/R "C" Member) (Fig. 8).

A/R "C" Member can be considered a fixed volume within a closed system. In this closed system, reversal pressure could have developed, resulting from increasing pressure caused by sediment subsidence.

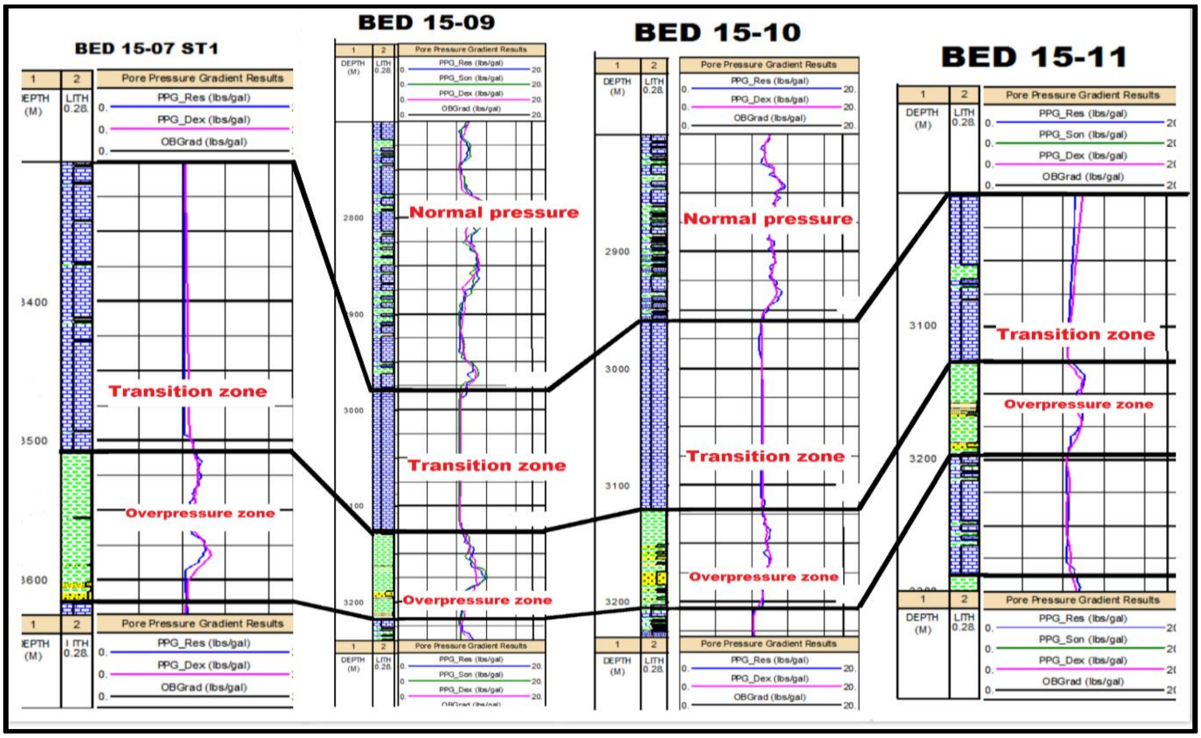


Fig. (8): Formation pressure evaluation correlation chart through the selected wells: BED 15-07 ST1, BED 15-09, BED 15-10 and BED 15-11.

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