

Pore Pressure Evaluation from Well logging and Drilling Exponent at Amal Field, Gulf of Suez area, Egypt

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Abstract: The evaluation of formation pressures is an integral part of the well planning and formation evaluation process. For example, in order to drill a well safely and economically, it is necessary to know 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 order to drill a well safely, economically, and according to the tracks set, it is obligatory to know the pore pressure and fracture pressure so that we can optimize mud density to provide sufficient overbalance, while being low enough by not exceeding the fracture pressure for the formation. According to the previous statements the evaluation of formation pressure is an important part of the well planning and formation evaluation process. In areas where exploration and production histories are established, offset(balance) data sets can be used to provide detailed profiles of expected pressures for those wells about to be drilled. Seismic data, log information (wireline, MWD, FEL and various pressure logs) and direct pressure measurements (DST, RFT and production testing) can all be used. In the present study I will focus on pore pressure evaluation from both drilling and well logging data using I.P 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 9.0ppg to 9.5 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 course of a well. In addition, mathematical models and algorithms can be used to predict formation fracture pressure following the first pressure integrity (Leak-Off) test in a competent (reliable) formation. This “real-time” information can then be used to update the initial well scenario.

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1.Introduction

Amal area is about 27 square kilometers in the offshore, southern part of the Gulf of Suez basin

(Figure.1). It is located some 55 kilometers from “Ras Gharib City” about 15 kilometers south west from Morgan oil field and 15 kilometers offshore.

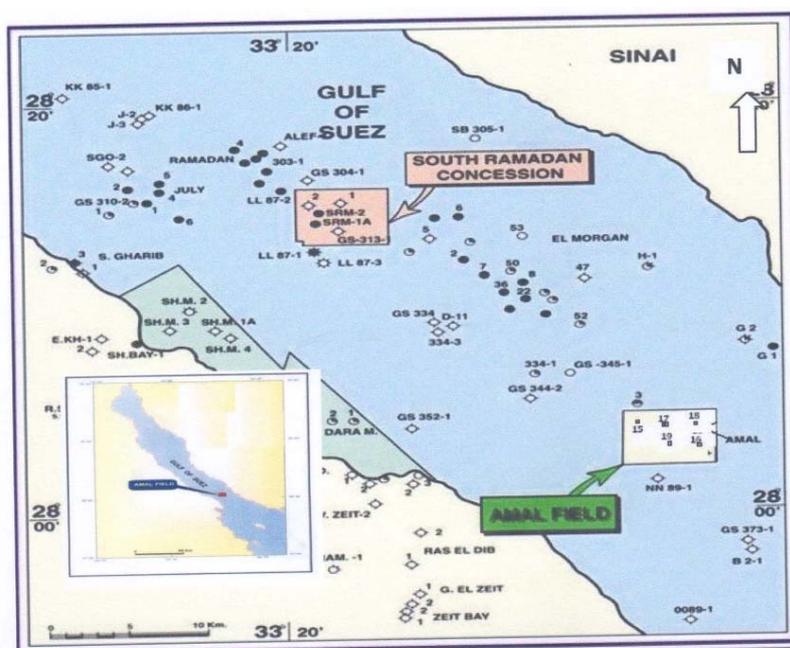


Figure. 1 Location Map of the study area.

Figure.2 shows the generalized stratigraphic column of Amal area, Gulf of Suez for which three deposition phases are generally assumed. That comprises the deposition of formations ranging in age from a postulated Devonian to Eocene. These formations which include the Nubia sands, are important as reservoir rocks, and to a lesser extent as

source rocks. In turn, it is represented by the lower Miocene and is characterized by its overall excellent qualities as source, reservoir and seal rocks. Also, the Upper Middle Miocene to Upper Miocene and Pliocene age in essence, closes the depositional history of Suez graben area.

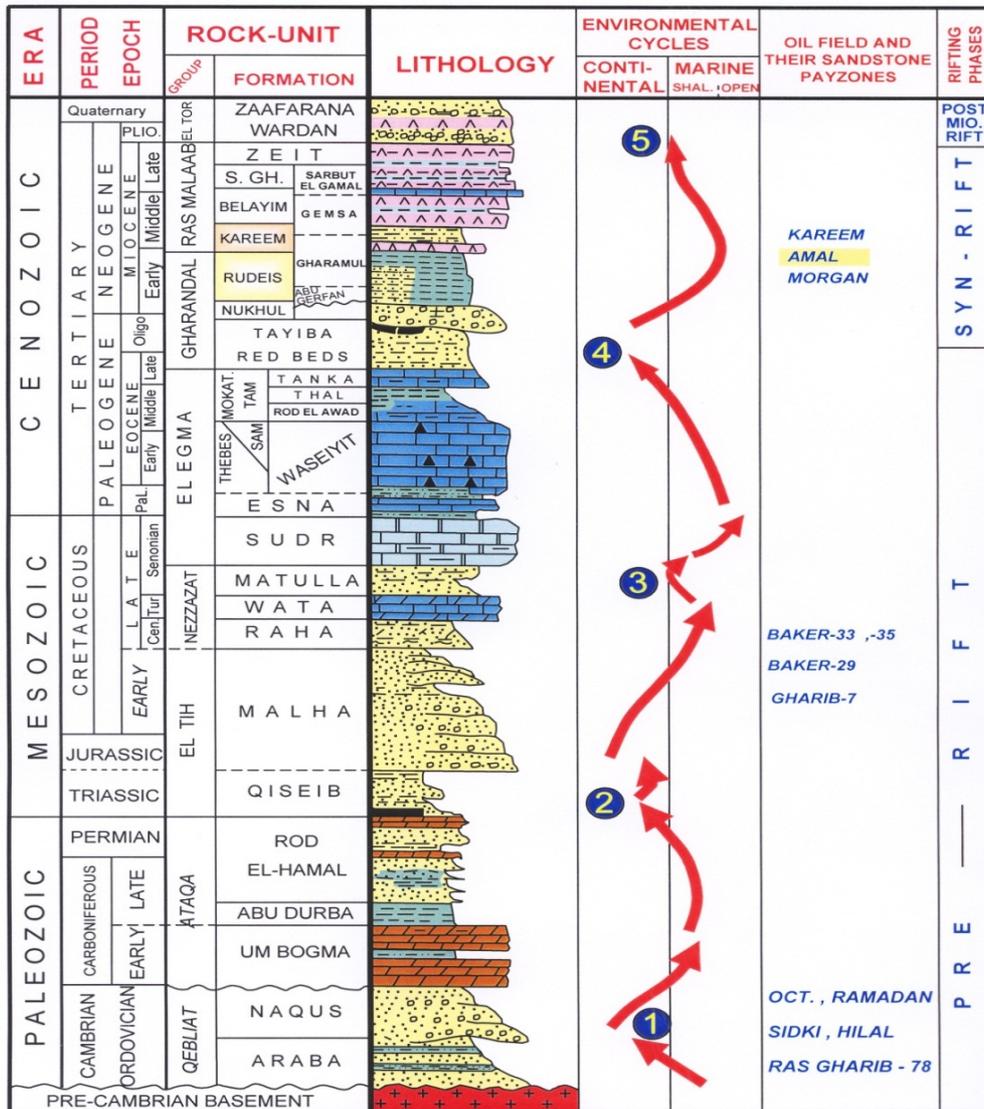


Figure.2 A generalized Litho- stratigraphic column of Amal Area, Gulf of Suez, Egypt (After Darwish& El-Araby, 1993 with modifications).

2. Methods and Techniques

Kareem Formation(Middle Miocene) in the selected wells was subjected to formation pore pressure evaluation based on corrected drilling exponent Dxc calculation, as well as flow well logging analysis. These data are based mainly on the drilling parameters and well logging data which have been used to make several pressure profiles for the

selected wells and establish the distribution of pore pressure. In areas where exploration and production histories are established, offset data sets can be used to provide detailed profiles of expected pressures for those wells to be drilled. Seismic data, log information (Wireline, Measuring While Drilling (MWD) and various pressure logs) and direct pressure measurements (Drill Stem Test (DST)

Repeat Formation Tester (RFT) and production testing) can all be used. The main target horizon was the Middle Miocene Kareem Formation, composed of frequent intervals of sandstones and shales

In this study, the author depends on offset well data that was used while drilling these wells. It is a highly effective tool that can be used to provide pressure evaluation personnel with the means to make accurate decisions and quantitative estimations of formation pressures, and to eliminate the need to make lengthy, laborious repetitive calculations.

The qualitative overpressure detection techniques includes: Temperature, Gas, resistivity & conductivity, cuttings shape and size, hole behavior and shale density.

While the quantitative overpressure detection techniques includes the corrected drilling Exponent, Dxc and Sigmalog.

Drilling Exponents

The rate at which a formation can be drilled is determined by a number of factors, some of which are: force applied rotary speed, tooth efficiency, differential pressure, drilling hydraulics, matrix strength and matrix strength.

Thus with same drilling conditions in a uniform lithology, it can be seen that the rate of penetration can be controlled by differential pressure alone. Rate of penetration would decrease uniformly with depth as compaction increases. Upon entering a geo-pressure transition zone, decreasing compaction and increase differential pressure across bottom would lead to an increase in penetration rate.

A number of "drillability" or normalized drill rate formulations have been proposed to remove the effects of many drilling variables. For the best application of these formulations, direct data monitoring and computation equipment are necessary. However, field application has shown that, when such equipment is not available, the easiest and most reliable method is the "d-exponent." This formulation allows control of the major drilling variables, and has proved so successful that most of the more complex "drillability" formulations are extensions and refinements of the basic "d-exponent".

D-exponent Evaluation

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:

$$\frac{R}{N} = a \left(\frac{W}{B} \right)^d$$

Where:

- d = drilling exponent (dimensionless)
- R = rate of penetration (ft/hr)
- N = rotary speed (rpm)
- W = weight on bit (lbs)
- B = bit diameter (inches)
- 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 semilog paper which produced values of d-exponent in a convenient workable range. Most important, however, they let "a" be unity, removing the need to derive empirical matrix strength constants, but made the d-exponent lithology specific:

$$D = \frac{\text{Log} \left(\frac{R}{60N} \right)}{\text{Log} \left(\frac{12W}{10^6 B} \right)}$$

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 (1971 & 1973) proposed this correction:

$$D_{xc} = dx \cdot N \cdot \frac{FBG}{ECD}$$

Where:

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

In a certain lithology, the d-exponent should increase as the depth, compaction and differential pressure across bottom increase (Figure.3). Upon penetration of a geo-pressured zone, compaction and differential pressure will decrease and will be reflected by a decrease in the d-exponent (Bowers, 1994).

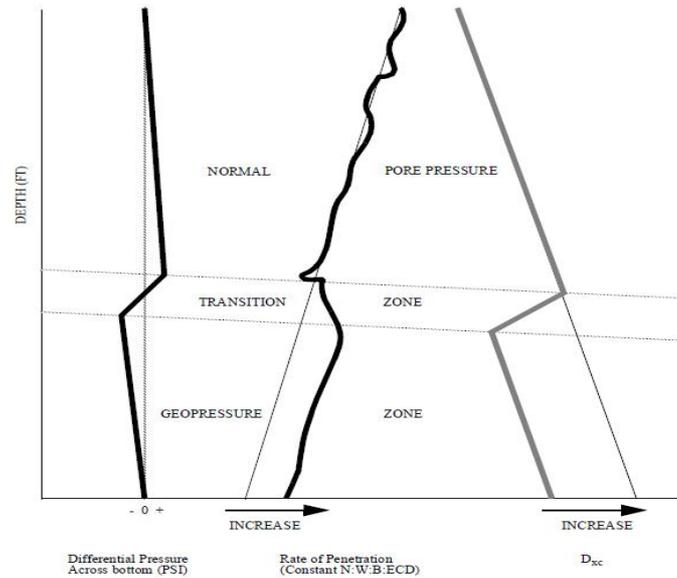


Figure.3 Depth Differential Pressure Relation.

Figure. 4 Shows a correlation chart for pore pressure and Dxc values through Amal-15 ST, Amal-17 ST and Amal-18 wells. From this chart, it appears that the studied wells can be divided into 3 zones of pore pressure designated as normal pressure zone, transitional zone (Salt and anhydrite of Belayim Formation) and abnormal pressure zone which started by Kareem Formation.

Formation Pore Pressure Evaluation: Measuring and Logging while drilling and wire line logging data:

MWD/LWD tools supply many types of bottom drilling and electric log parameters which are useful in the detection of abnormal pore pressure.

All the upcoming parameters which will be discussed, it can be measured either by traditional wireline methods or by using LWD methods, but with the exception of WOB and torque. Depending on the type of MWD/LWD tool selected for the measurement; one or more of the following parameters would be measured.

Sonic Logs

In general, the acoustic logs are considered to provide the most reliable quantitative estimations of pore pressure. The main benefits of acoustic logs are that they are relatively unaffected by borehole size, formation temperature and pore water salinity. The parameters that do affect the acoustic log are formation type and compaction related effects such as porosity/density and are therefore directly applicable to pore pressure evaluation.

Resistivity Logs

Shale resistivity values were obtained originally from the amplified short normal log. However, in recent years the use of deep induction logs is preferred as these enable the use of data in all types of drilling fluid and affording a greater depth of investigation. Shale resistivity increases with depth. The resistivity (the reciprocal of conductivity) of shales depends upon the following factors:

- porosity
- salinity of the pore water
- temperature.

The salinity of the pore water does not normally vary greatly with depth and hence its effect is often discounted. In addition, temperature normally increases uniformly with depth and hence resistivity values can be corrected for the temperature increase. Porosity is thus the major factor affecting resistivity values.

Drilling Exponent Dxc and well logging data

Formation pore pressure evaluation on the selected wells were mainly based on corrected drilling exponent 'Dxc' calculations, as well as well logging data (figures 5-8). Results of these calculations were plotted and compared with established normal shale compaction trends to obtain values of pore pressure at the depth of interest. The formation pressures and pressure overburden gradients were considered on the basis of hole section size, rather than lithological formation tops to accommodate trend variations associated with major engineering parameter changes. Furthermore such distinction prevents any confusion, which may potentially arise from reappraisal of formation top

depths. Using the DXC trend as an indicator of increasing pore pressure requires careful qualification. It is generally useable in thick homogeneous shale sections (Hottman et al, 1965). Where lithological change frequently over small depth intervals, background gas, including both that liberated whilst drilling and circulating off bottom, the nature of cuttings and caving (where present), general hole condition and lagged mud temperature were all used to identify any pressure anomalies. The assumption was made that pore pressure gradients

were as per prognosis, based on available offset data, unless any evidence was seen to the contrary.

Using Interactive Petrophysics (I.P) Schlumberger software to estimate and plot pore pressure values from both well logging data and Dxc it was found that there is good coincidence in the pore pressure values from the Dxc and Sonic well logging data where the value of pore pressure obtained from well logging and Dxc was ranging between 9.0ppg to 9.5 ppg (figures 5-8).

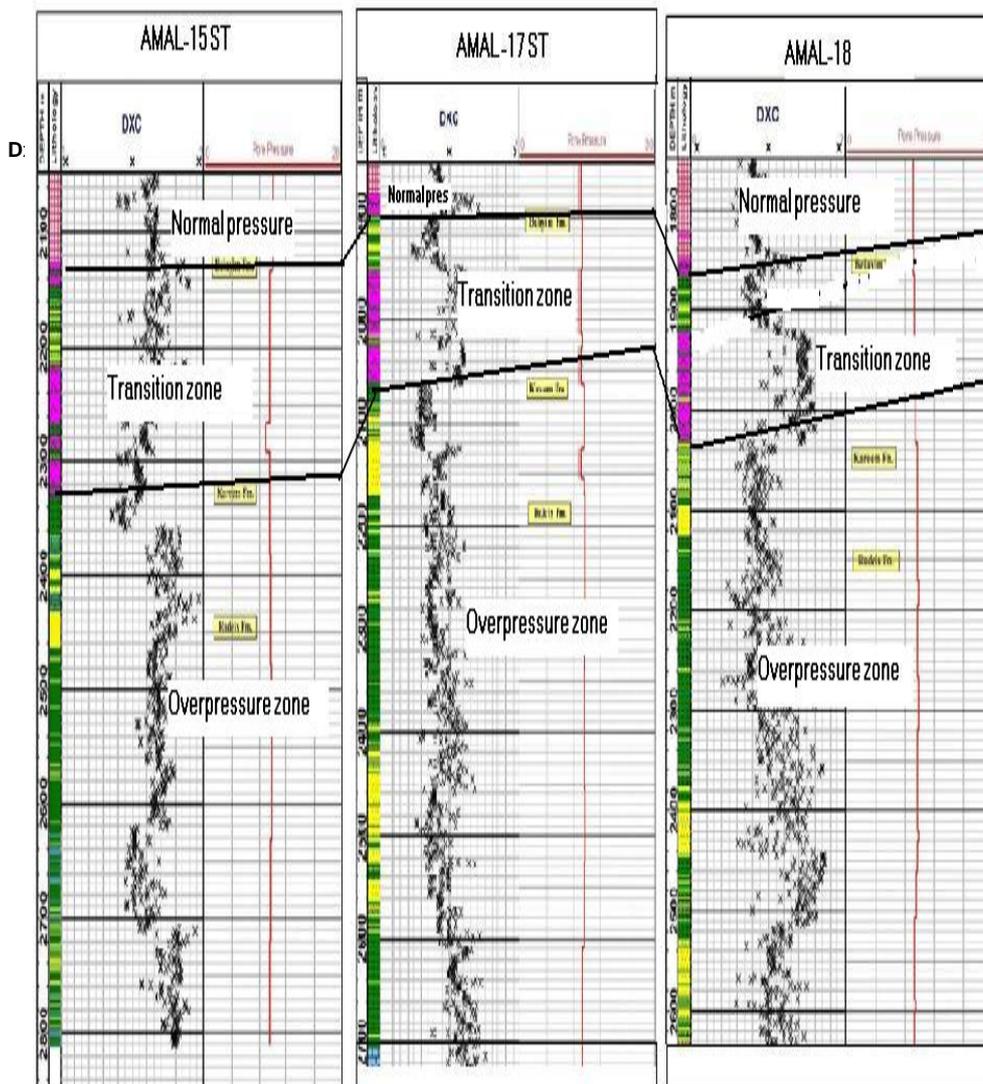


Figure.4 Pore Pressure – Dxc Correlation Chart through Amal 15 ST, Amal-17 ST and Amal-18 wells, Amal Field, Gulf of Suez, Egypt.

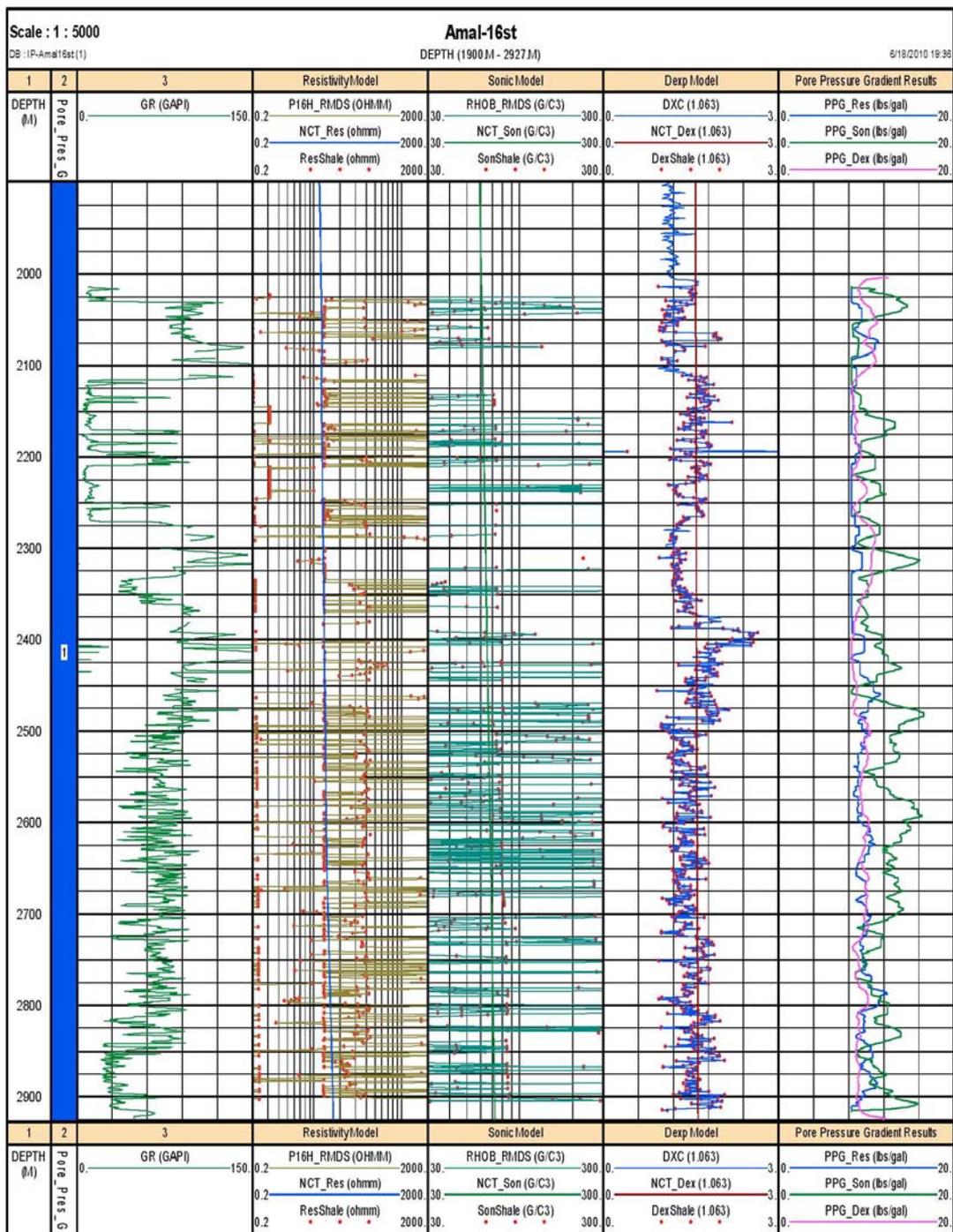


Figure.5 Correlation between pore pressure data from both Dxc and well logging data of Amal 16 well.

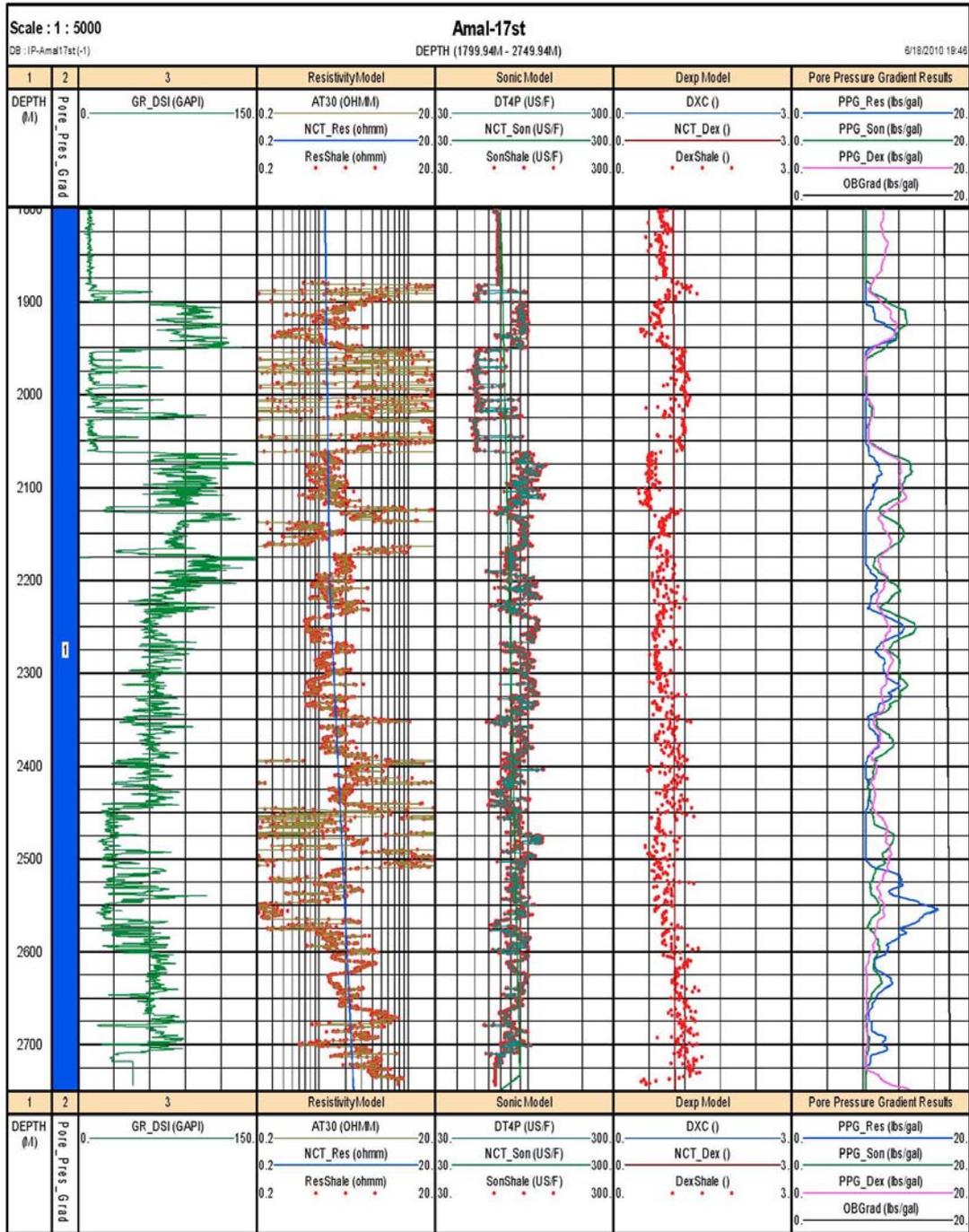


Figure.6 Correlation between pore pressure data from both Dxc and well logging data of Amal 17 well.

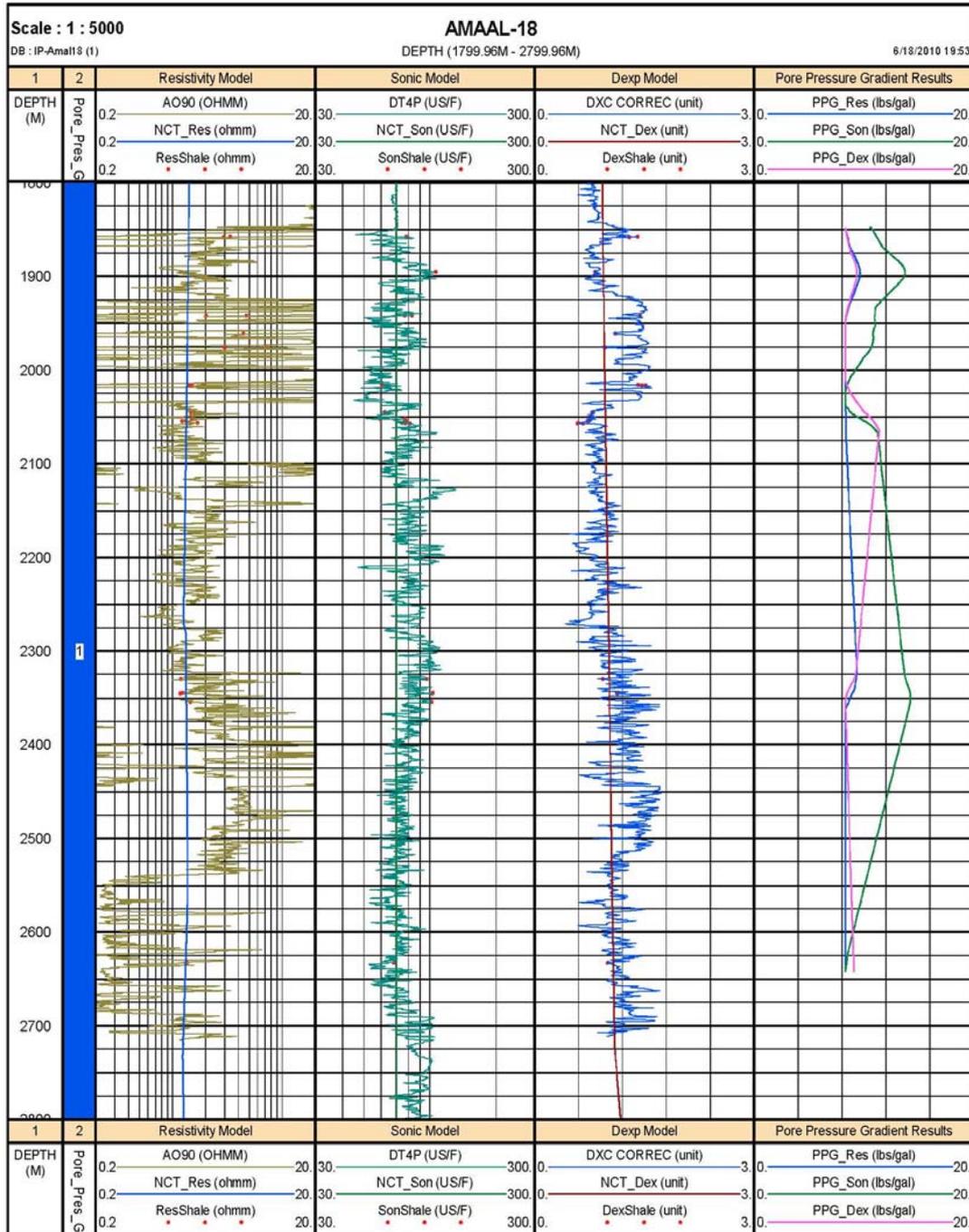


Figure.7 Correlation between pore pressure data from both Dxc and well logging data of Amal 18 well.

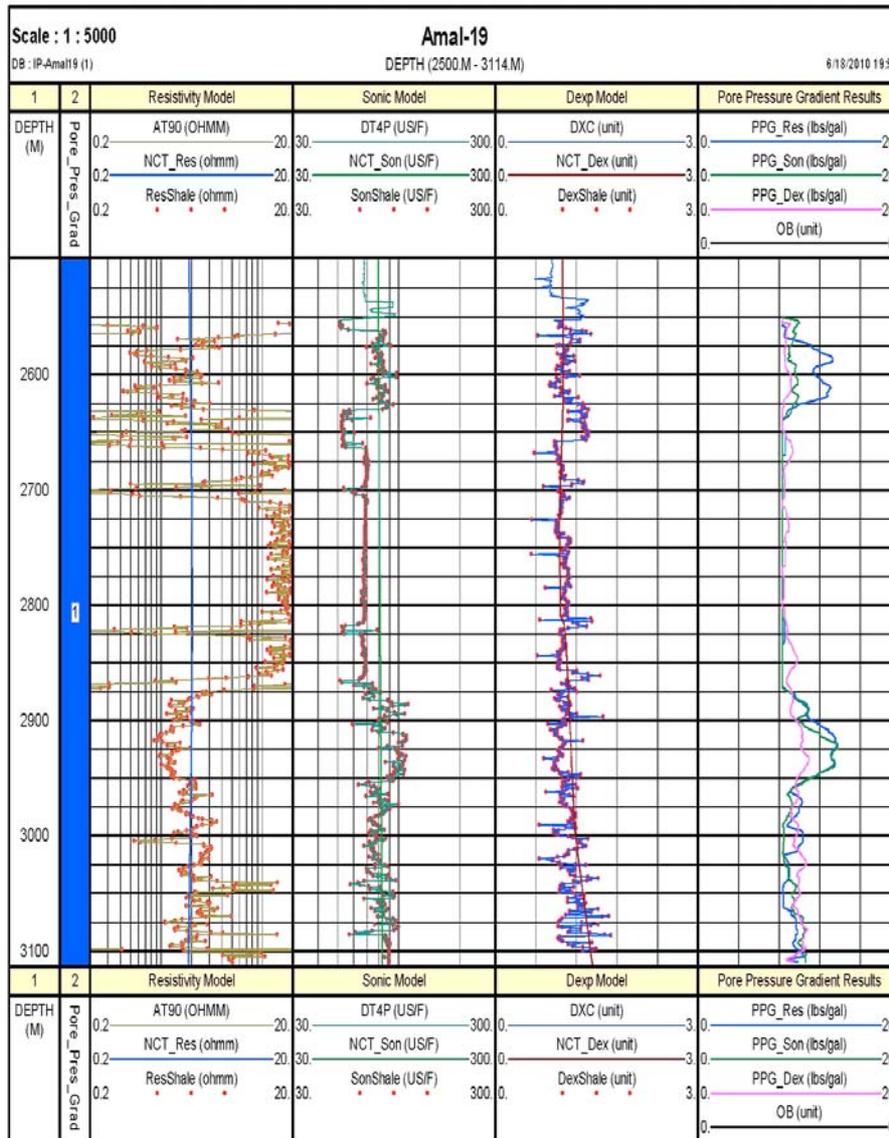


Figure.8 Correlation between pore pressure data from both Dxc and well logging data of Amal 18 well.

Pore pressure at Amal Field

Formation pore pressure evaluation services on the well AMAL-15 ST commenced below 847 M. The formation pore pressure interpretation was mainly based on corrected drilling exponent 'Dxc' calculations, as well as flow line temperature data, background gas, mud density and hole condition relationships, also based on the magnitude of pipe drag in the hole. Results of these calculations were plotted and compared with established normal shale compaction trends to obtain values of pore pressure at the depth of interest. The formation pressures and pressure overburden gradients were considered on the basis of hole section size, rather than lithological

formation tops to accommodate trend variations associated with major engineering parameter changes. Furthermore such distinction prevents any confusion, which may potentially arise from reappraisal of formation top depths.

Using the DXC trend as an indicator of increasing pore pressure requires careful qualification. It is generally useable in thick homogeneous shale sections. Where lithological change frequently over small depth intervals, background gas, including both that liberated whilst drilling and circulating off bottom, the nature of cuttings and caving (where present), general hole condition and lagged mud temperature were all used

to identify any pressure anomalies. The assumption was made that pore pressure gradients were as per prognosis, based on available offset data, unless any evidence was seen to the contrary. When ever other valid data were obtained such as formation tests or electric logs, these were used to modify the pore pressure interpretations.

12.25 HOLE " SECTION (847 m – 2356 m)

The 12.25" hole section was consisting of SALT, ANHYDRITE and Shale , this section was drilled using 9.9 – 11.2 ppg mud weight.

The formation pore pressure was estimated to be 9.0 ppg EQMW at top section, Then increased to 10 ppg @ 1614' according to negative shift in Dxc trend. Then decreased to 9.5 ppg @ 2133' according to positive shift in Dxc trend. Then decreased to 9.0 ppg @ 2266' according to positive shift in Dxc trend, Then increased to 9.5 ppg @ 2292' according to negative shift in Dxc trend and increase in back ground gas.

Pore pressure estimation was mainly based on Dxc against shale bodies, background gas & well logging data

8.5" HOLE SECTION (2356 m – 2650 m)

The 8.5" hole section was consisting of Sandstone, Shale, Limestone and Anhydrite. This section was drilled using 9.9 ppg mud weight.

The formation pore pressure was estimated to be 9.0 ppg EQMW at top section, Then increased to 10 ppg @ 1614' according to negative shift in Dxc trend. Then decreased to 9.5 ppg @ 2133' according to positive shift in Dxc trend. Then decreased to 9.0 ppg @ 2266' according to positive shift in Dxc trend, Then increased to 9.5 ppg @ 2292' according to negative shift in Dxc trend and increase in back ground gas.

Pore pressure estimation was mainly based on Dxc against shale bodies, background gas & well logging data.

Summary and Conclusion

The evaluation of formation pressures is an integral part of the well planning. So, to drill a well safely and economically, it is necessary to know the pore pressure and fracture pressure so that the mud density can be optimized to provide sufficient overbalance. Pore pressure evaluation for Kareem Formation of the five selected wells were mainly based on corrected drilling exponent 'Dxc' calculations, in addition to flow line temperature data, background gas, mud density and hole condition relationships.

Quantitative and qualitative formation pressure evaluation indicates that the pore pressure ranges

from 9.0 ppg to 9.7 ppg and the background gas value ranges from 0.005 % to 3.95 %.

Also, we can easy see the coincidence in the pore pressure values from the Dxc and Sonic well logging data where the value of pore pressure obtained from well logging and Dxc was ranging between 9.0ppg to 9.5 ppg.

In the study area, with a same lithology, the d-exponent increases as the depth, compaction and differential pressure across bottom increase. Also, it was clearly that with increasing mud density the value of the background gas was decreasing.

Kareem Formation of Middle Miocene age in the study area is composed of sandstones and shales, The characteristics of such reservoir show that, the thickness of this formation ranges between 71 m (Amal-19 well) to 139 m (Amal-16 well) with an average porosity values ranges 0.17-0.27 %.

It appears that the studied wells can be divided into 3 zones of pore pressure designated as: normal pressure zone, transitional zone (salt and anhydrite of Belayim Formation) and abnormal pressure zone which started by Kareem Formation.

An overpressure zone of Kareem Formation will be under compacted resulting in a relative increase in the rate of penetration (ROP) in the study area.

Therefore, Kareem Formation can be considered as fixed volume with closed system with abnormal pressure zone due to the efficient permeability barrier (seals) which are the evaporate (salt) of Belayiem Formation which is lying above Kareem Formation.

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