PS Pressure Regime Evaluation, Role, and Contribution in Well Planning and Formation Evaluation Process, Zeit Bay Fields - Gulf of Suez, Egypt*

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Search and Discovery Article #40600 (2010)
Posted September 30, 2010

*Adapted from extended abstract / poster presentation at AAPG Annual Convention and Exhibition, New Orleans, Louisiana, April 11-14, 2010

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Abstract

An adequate calculation and prediction of the formation pore pressure and better understanding for the pressure regime model of an oil field are very important prior drilling any well. The pressure regime modeling is an important integral part of the well planning and formation evaluation process and can play an important role in:

1) Deciding where the proposed wells can be drilled, especially in Gulf of Suez oil fields which are considered as multiple reservoirs.
2) Enable the well planner to anticipate the location and potential magnitude of possible abnormal pressure and consequently avoid lost valuable rig time and equipment problems.
3) Minimizing the drilling cost as the pressure regime model can be used as a guide to estimate the formation pore pressure and fracture pressure, so that the mud density can be optimized.
4) Enable the well planner to seat the casing seats in the proper depth.
5) Avoid environmental pollution, loss of reserves, and loss of human life or injuries resulting from abnormal pressure problems.

Offset data sets of the drilled wells can be used to provide detailed profiles of expected formation pore pressures for well proposals. These data include formation tops, composite well logs, survey data, wireline logs, logging while drilling, seismic data, various pressure evaluation logs, production tests and direct pressure measurements. Also, the geological setting of the area, the environmental deposition, and the problems encountered while drilling the wells should be taken into consideration during evaluation. These valuable information items can be subjected to regional variations during the course of a new well. It is very important to recognize, detect, and evaluate any changes in the formation pore pressure data. This "real - time" information can be used to implement new well proposal. Also, relationships between Petroleum Geology and Drilling Engineering allow accurate estimations of formation pore pressures at any point during the course of a well and lead to drilling the well safely.

Introduction

The study aims to construct a simple and effective pressure regime model for Zeit Bay Field which can assist the well planner to predict the pore pressure for the upcoming wells to be drill in the field. It aims also to find out the relationship between the constructed pressure regime model and the geological setting of the field.

An adequate prediction of the pore pressure and better understanding for the Pressure Regime Model of any area are very important prior to drilling any well. They can play a vital role at several stages of Exploration and Development Process**.**

♦ In Exploration Phase, they help in:-

- Providing calibration to Basin Modeling.
- Mapping Hydrocarbon Migration Pathways.
- Assessing the “Seal” effectiveness.
- Analyzing the “Trap” configuration and geometry for a Prospective Basin.

♦ In Development Phase, they help in:-

- Anticipating the location and potential magnitude of possible formation pressure problems.
- Providing suitable casing and mud program designs leading to Minimize Drilling Cost.
- Avoiding Environmental Pollution, Loss of Reserve, Loss of Human Life …etc).

However, it is worth mentioning that, it is very important to recognize and evaluate any changes in the Estimated Pore Pressure data during the drilling of a new well. The updated information can be used to implement the new well proposal.

General Outline about Zeit Bay Field

Zeit Bay field is an oil field located in the southwestern offshore part of the Gulf of Suez, some 65 km north of Hurghada and 85 km south of Ras Gharib. The field extends to the onshore and is combined with General Petroleum Company's Bahar North –East field (Figure 1).

The field was discovered in June 1981 through the drilling of the Exploratory well "QQ 89-1" which was drilled in the crestal part of the structure and considered as gas producer well. In October, 1981 another well "QQ 89-2" was drilled 2 km south and down dip from well QQ 89-1. This well recorded the underlying oil-leg with an oil water contact at 4850 feet sub-sea.

The commercial field production has been started in December 1983 with average daily rate 20000 BOPD.

Structurally, Zeit Bay field is interpreted as a NW–SE basement relief like anticline feature (Figure 2). This anticlinal feature, however, is dissected into several fault-block panels by two main fault systems. A set of NW–SE-trending faults affects the western and eastern flanks. Another set of W-NW/E-SE-trending fault system affects the northeast flank. Some of these faults die out at/ or near top Belayim, except for the extreme bounding faults. In addition to the northeast and southwest blocks, there are parallel, narrow, elongated rectangular high blocks down-stepping away from the above-noted triangular horst blocks (Figure 2).

The stratigraphic succession of the field is similar to the sequences presented elsewhere in the southern part of Gulf of Suez basin. The field is characterized by the presence of two different types of Miocene facies. These Miocene sediments are unconformably underlain by Paleozoic to Mesozoic Sandstone of Nubia facies which lie unconformably on the Precambrian basement rocks (Figure 3).

Oil-in-place is mainly localized over the western flank of the field comprising several reservoir units in complete hydraulic communication, making it one of the unique reservoirs. Hydrocarbons are produced from all the porous and permeable intervals from Belayim Formation down to Precambrian fractured basement (Figure 4).

Figure 1. Location map.

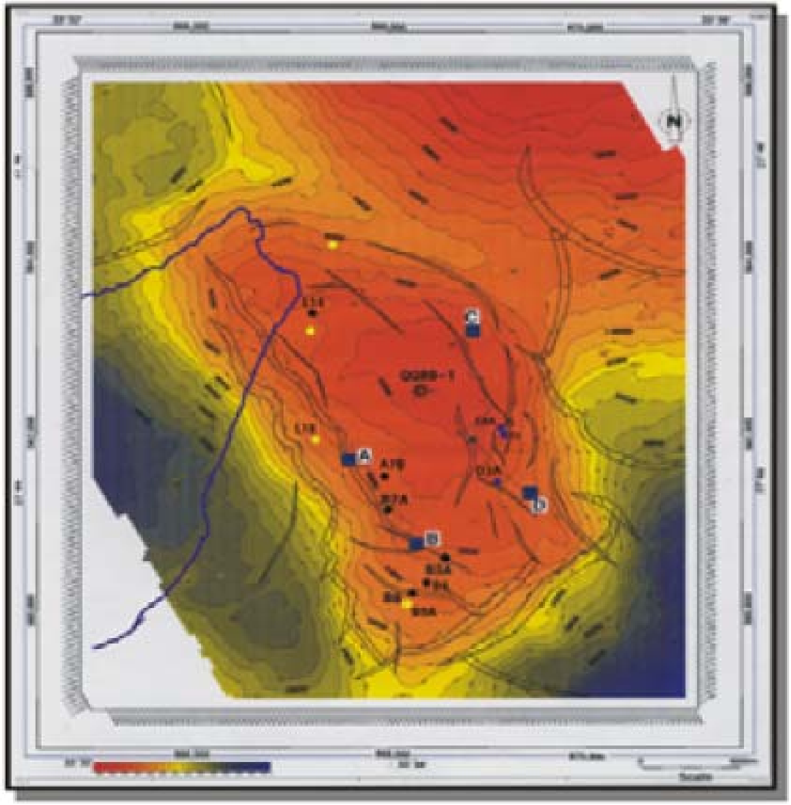


Figure 2. Structure contour map on top Hammam Faraun Member.

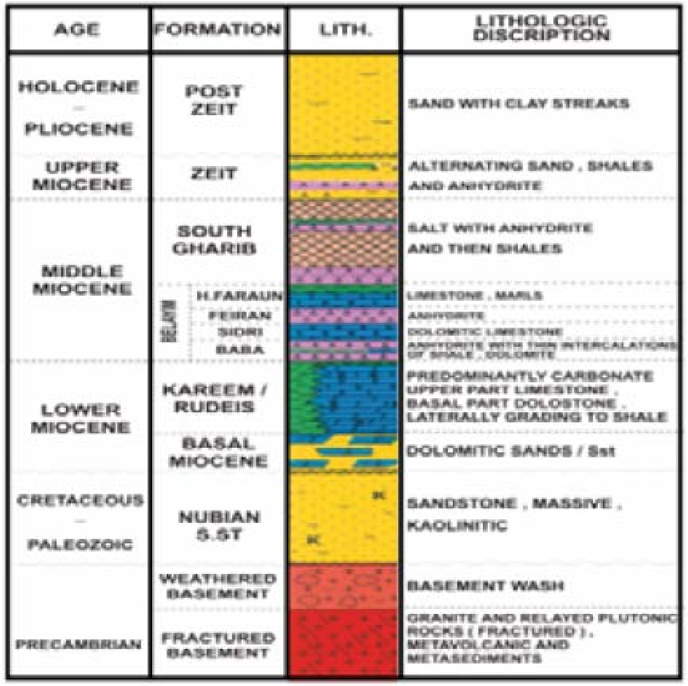


Figure 3. Generalized stratigraphic column, Zeit Bay field

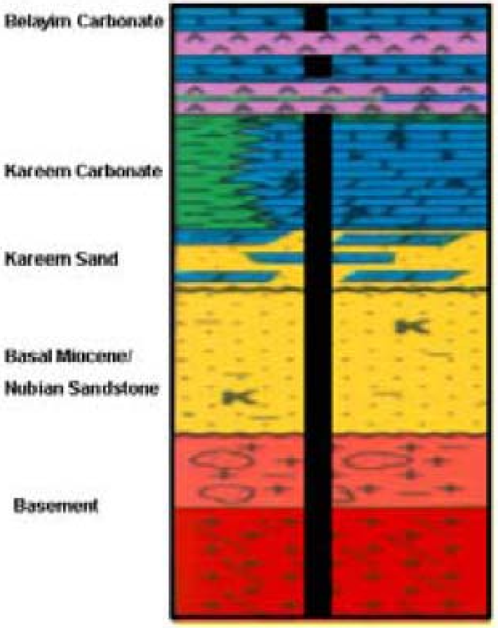


Figure 4. Hydrocarbon zones, Zeit Bay field.

Theory and Methodology

The authors follow this sequence to calculate the Estimated Pore Pressure and, consequently, the Pressure Regime Model of Zeit Bay field (Figure 5).

First, all available data of about fifty five wells were collected. These data included formation tops, composite well logs, survey data, mud log sheets, wireline logs, logging while drilling, various pressure evaluation logs, production tests and direct pressure measurements. The geological setting of field and the different problems encountered while drilling these wells were taken into consideration during evaluation.

Second, because the geopressure zones mainly originated in clay intervals as a result of dehydration process (montomorillonite (smectite) to illite, water between layers is desorbed, liberated and transferred as free water, and overburden pressure can then flush water from the sediment along with hydrocarbons); so, the clay sections had to be adequately identified.

This identification was done by the assistance of CGR (Gamma Ray corrected for uranium content). A Shale baseline (which is more-or-less vertical lines) was defined and a Normal Compaction Trend Line (NCTL) established (Figures 6 and 7).
Relative porosities for each lithology was calculated, as the porosity varies with any change of lithology and pore pressure, which was noticed to be abnormally high and deviated from the Normal Trend Values in the hydrated clay intervals. The porosity log values opposite clay intervals (especially from the density logs) was taken and Normal Compaction Trend was established to calculate the Estimated Pore Pressure (Figure 8).

Density and neutron logs were used as porosity logs and Geopressure indicators. Decreasing observed density log values from the Normal Trend Values were interpreted as an indication to the presence of abnormal pressure. However, the neutron logs showed the changes in the hydrogen index reflecting the clay type where, montomorillonite (smectite) showed high hydrogen index values while illite showed low hydrogen index values.

Sonic logs were used as a reasonable Geopressure indicator as Interval Transit Time (Dt) is usually increases with depth where, in constant clay intervals, there is an increase in the porosity and corresponding increase in pressure (Pore Pressure Gradient), observed to be steadily moving to the highest values with depth in the transition zone. Increase in the observed sonic log values from the normal trend values has been taken as an indication to the presence of abnormal pressure. Borehole rugosity was taken into consideration, as it is an indicator to clay hydration where "cycle-skipping" was observed opposite Geopressure zones.

Resistivity logs was used as another reasonable Geopressure indicator, where decreasing observed resistivty log values from the Normal Trend Values was taken as an indication to the presence of abnormal pressure.

Third, the authors used two methods applying different software to calculate the Estimated Pore Pressure and consequently the Field Pressure Regime Model. These
methods are summarized as follows: -

1) **Cross-plot Method**: -
The difference between the observed sonic log values and the Normal Trend Values had been computed to calculate the Estimated Pore Pressure in the Geopressure zones. Also, the observed resistivity log values were divided by the normal one. The values obtained from the comparison of the NCTL to the actual one were used in an empirical cross-plot relationship to determine the Estimated Pore Pressure. The cross-plot was entered from the X-axis and the pressure gradient value was determined from the pressure model.

2) **Equation Method**:-
Equation method has been formulated and applied by Eaton (1975, 1976) to determine the Estimated Pore Pressure in Geopressure zones. The equation has been formulated by dividing the Observed Resistivity and Sonic Log Values by the Normal Trend Value.
The general form of equation for predicting Pore Pressure from resistivity is:

$$\mathbf{P = S - [S - P_o]\,[R_o / R_n]^n}$$

Where
P : is the Estimated Pore Pressure.
S : is the Overburden Gradient
P_o : is the Observed Pressure Gradient.
P_n : is the Normal Pressure Gradient.
R_o : is the Observed Log Resistivity Value.
R_n : is the Normal Compaction Trend.
and **n** is an empirically derived exponent.

The general form of equation for predicting Pore Pressure from sonic is:

$$P = S - [S - P_o]\,[Dt_o / Dt_n]^n$$

Where
Dt_n : is the Normal Compaction Trend
Dt_o : is the Observed Transit Time

Fourth and Finally, the obtained data were integrated and correlated with that which was obtained either while drilling or from pressure measurement techniques. The integrated data was mapped on top of the interested zones and the Pressure Regime Model for the studied area was constructed.

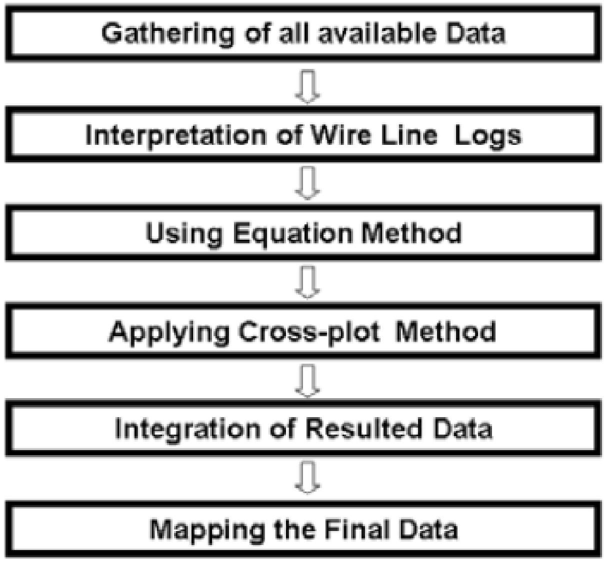


Figure 5. Sequence of applied technique.

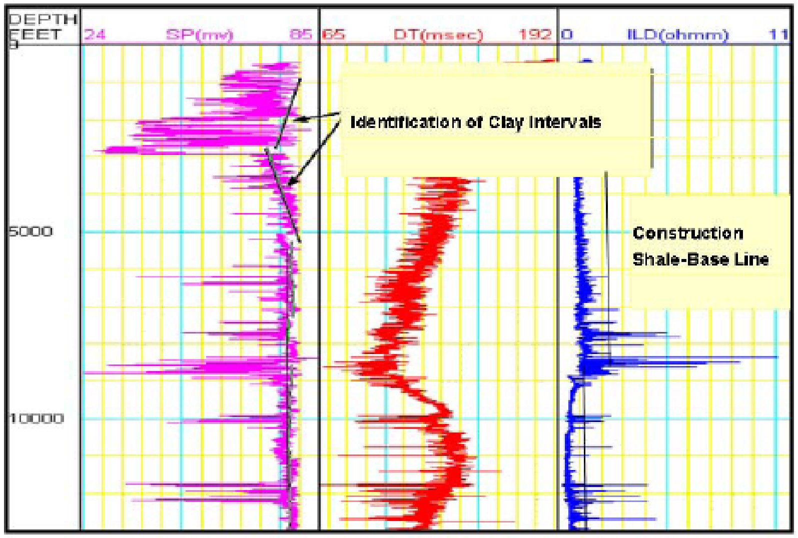


Figure 6. Identification of clay intervals and construction of shale baseline.

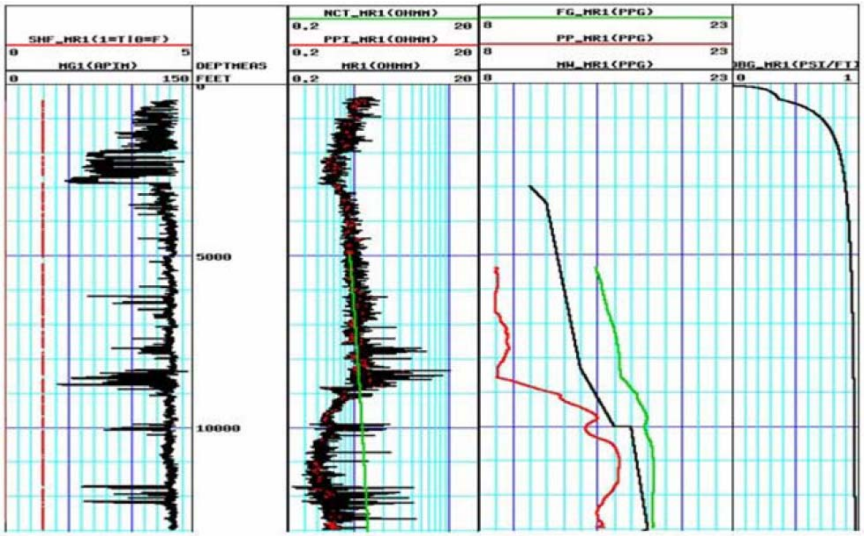
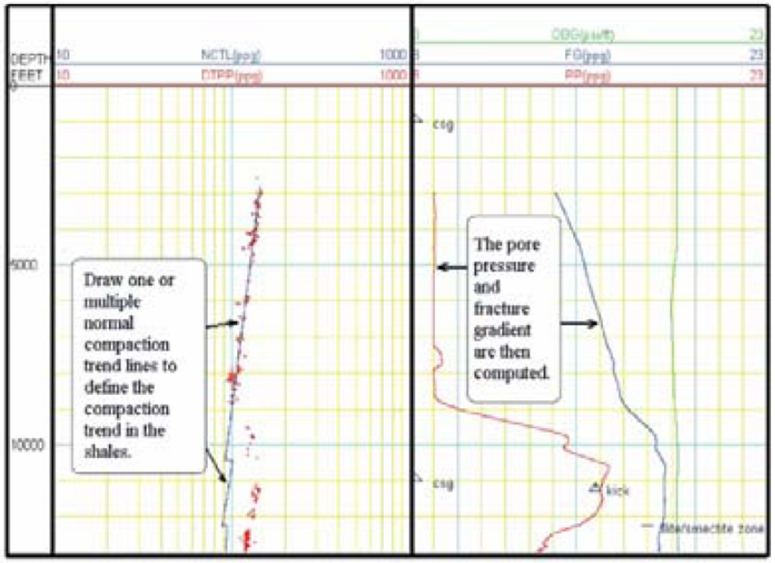


Figure 7. Construction of normal compaction trend line (NCTL).



Draw one or multiple normal compaction trend lines to define the compaction trend in the shales.

The pore pressure and fracture gradient are then computed.

Figure 8. Calculation of estimated pore pressure.

Applications and Results

As the applied technique to calculate the Estimated Pore Pressure depends on the presence of clay intervals, the clay sections was identified adequately.

In Zeit Bay field those clay sections are well represented in Hammam Faraun Member of Belayim Formation and Kareem/Rudeis Formation. Hence, data of thirty wells were selected and analyzed. The authors focused on those two interested zones in this study.

CGR logs (Gamma Ray corrected for uranium content) was used to detect the clay interval (Figure 9) and to determine the Hammam Faraun Member and Kareem/Rudeis Formation.

The resistivity log values opposite Hammam Faraun Member and Kareem/Rudeis Formation were taken and the Estimated Pore Pressure was calculated (Figures 10 and 11). The Normal Trend values was determined by using the following equation:

$$\mathbf{R_n = R_o\ ((S - P_o)/\ (S - P_n))^{-0.833}}$$

The Estimated Pore Pressure had been calculated by using the following equation:

$$\mathbf{P_o = S - (S - Pn)\ (R_o / R_n)^{1.2}}$$

The sonic log values opposite Hammam Faraun member and Kareem/Rudeis Formation were taken and the Estimated Pore Pressure was calculated (Figures 12 and 13). The Normal Trend values was determined by using the following equation:

$$\mathbf{Dt_n = Dt_o\ ((S - P_o) / (S - P_n)^{0.333}}$$

The Estimated Pore Pressure was calculated by using the following equation: -

$$\mathbf{P_o = S - (S - P_n)\ (Dt_o / Dt_n)^{3.0}}$$

Eaton Equation and Cross-plot method were used applying different software to calculate the Estimated Pore Pressure values from resistivity and sonic logs for the selected wells in the studied area (Figures 14 and 15).

The resulting Estimated Pore Pressure values were integrated and Cross-plots for these integrated values were conducted (Figure 16).

This cross-plot revealed the following points:-

♦ The Estimated Pore Pressure values vary from well to well, but the general trend behaves the same.
♦ An increase in the values of the Estimated Pore Pressure is observed at top of Hammam Faraun Shale then dropped back again.
♦ The same phenomenon is repeated in Kareem/Rudies Shale where another increase in the values is observed at the top section and then dropped back again.
♦ The Estimated Pore Pressure of Hammam Faraun Shale is lower in values than those of Kareem/Rudies Shale.

The Estimated Pore Pressure values were averaged, correlated with each other, and mapped on top of Hammam Faraun Member and Kareem/Rudeis Formation (Figure 17).

The distribution of the Estimated Pore Pressure values on these maps exhibits considerable changes from the crestal part of the field structure downdip towards the flanks. The minimum Estimated Pore Pressure values are observed at the crest and increased towards the flank. Hence, two Pressure Regime values are distinguished (one high at the flanks and one low at the crest).

To support evidence and back-up for the resulted Estimated Pore Pressure maps, potassium/thorium cross-plots was established and correlated with those maps (Figure 18).

This geoscience's application explained the exhibition of considerable changes from the crestal part of the structure downdip position towards flanks. The shale of flanks is mainly montomorillonite (smectite) while the mixed shale is localized at the crestal part of the field.

To find out the relationship between the Constructed Estimated Pore Pressure maps and the geological setting of the field, facies (change) maps were constructed for the interested zones (Figures 19 and 20).

The comparison between the maps revealed that the Estimated Pore Pressure values are matched with the field fault pattern and the lithologic facies change of Hammam Faraun Member and Kareem/Rudeis Formation. Also, the Miocene rocks are differentiated from stratigraphic point of view into two types. The first is represented in the crestal part of the field and named "coastal facies". It was deposited mainly as carbonates with thin shale layers. The second is represented by a deeper water facies and distributed on the margins of the field surrounding the coastal facies. This type is named "open shallow-marine facies" and mainly deposited as shale beds. This differentiation explains the presence of Two Pressure Regime values.

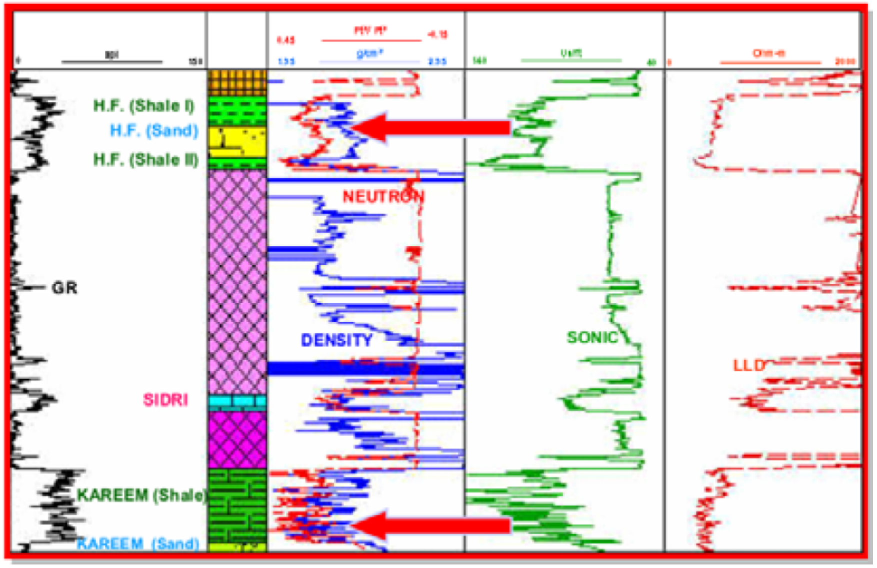


Figure 9. Log responses of corresponding shale section.

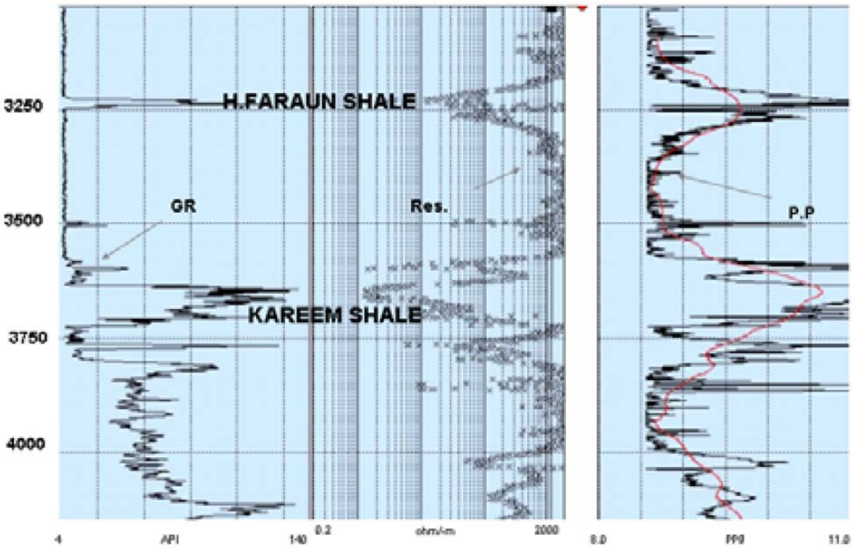


Figure 10. Estimated pore pressure from resistivity logs (Well #1).

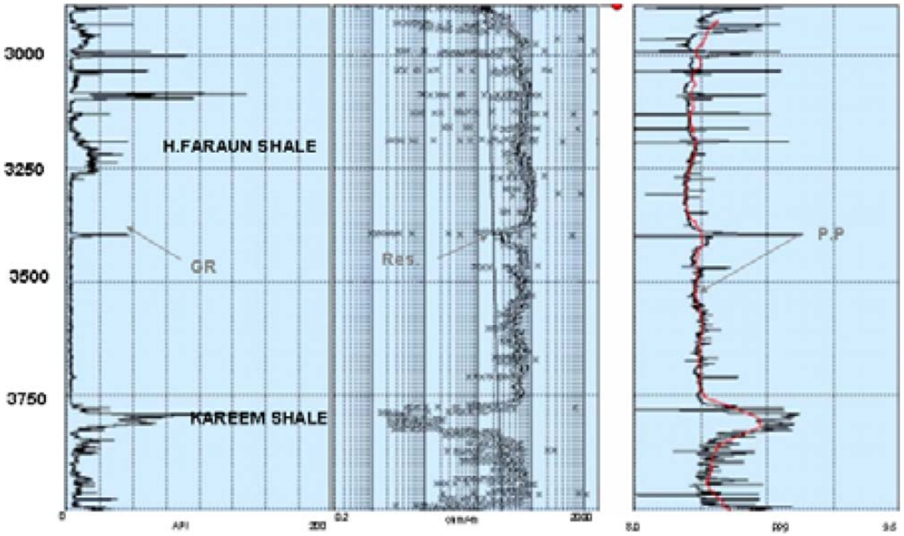


Figure 11. Estimated pore pressure from resistivity logs (Well #2).

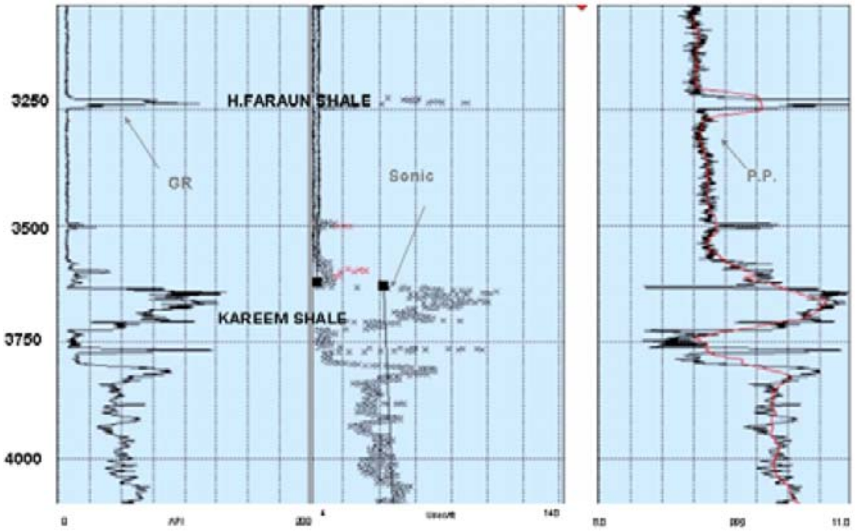


Figure 12. Estimated pore pressure from sonic logs (Well #1).

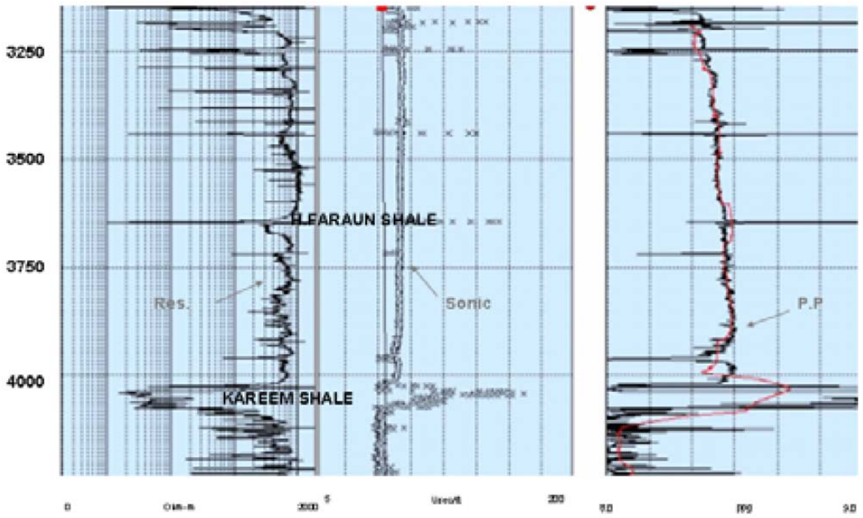


Figure 13. Estimated pore pressure from sonic logs (Well #2).

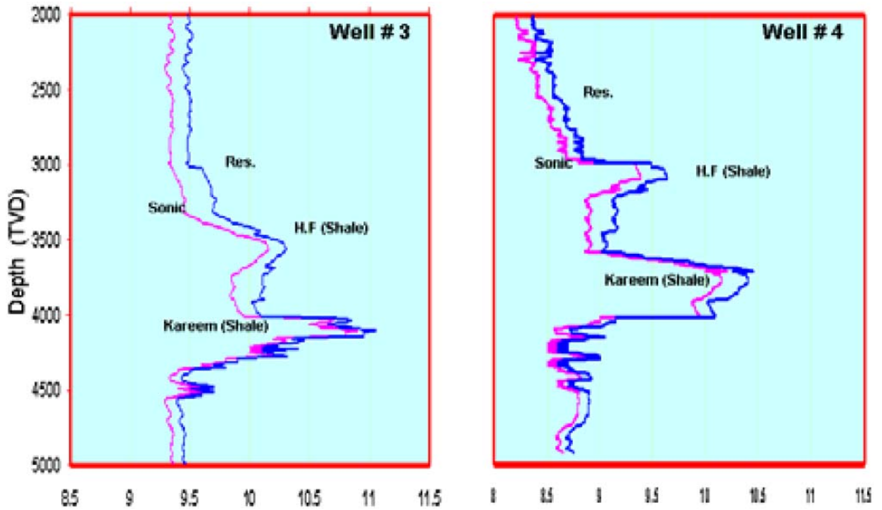


Figure 14. Estimated pore pressure from resistivity/sonic logs (using Eaton Method).

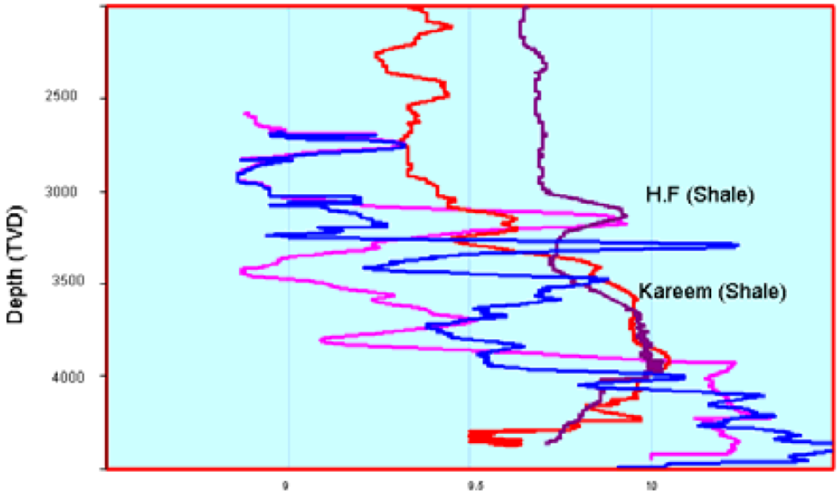


Figure 15. Estimated pore pressure from resistivity logs (using Cross-plot Method).

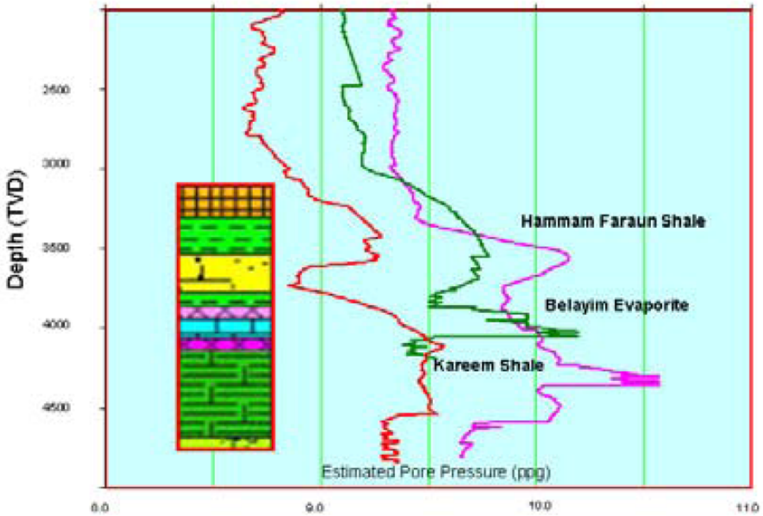


Figure 16. Simple sketch for estimated pore pressure, Zeit Bay field.

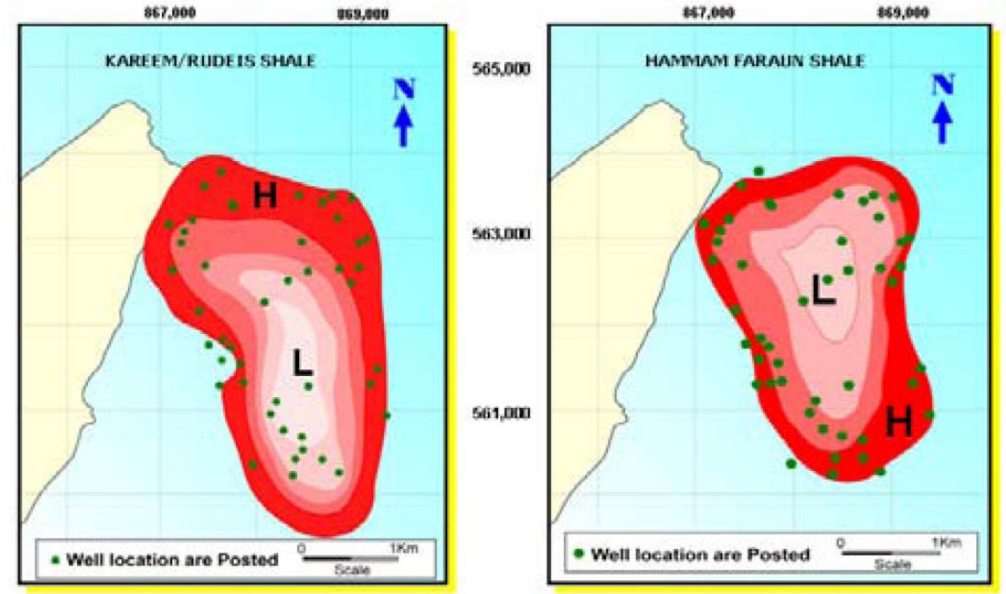


Figure 17. Estimated pore pressure maps for interested zones.

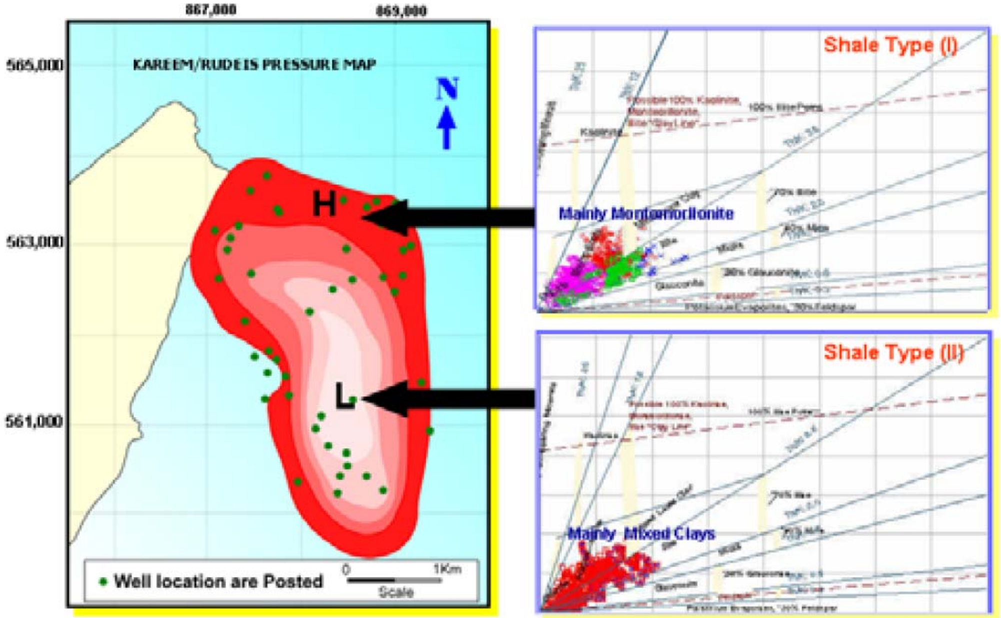


Figure 18. Shale types from potassium/thorium cross plot.

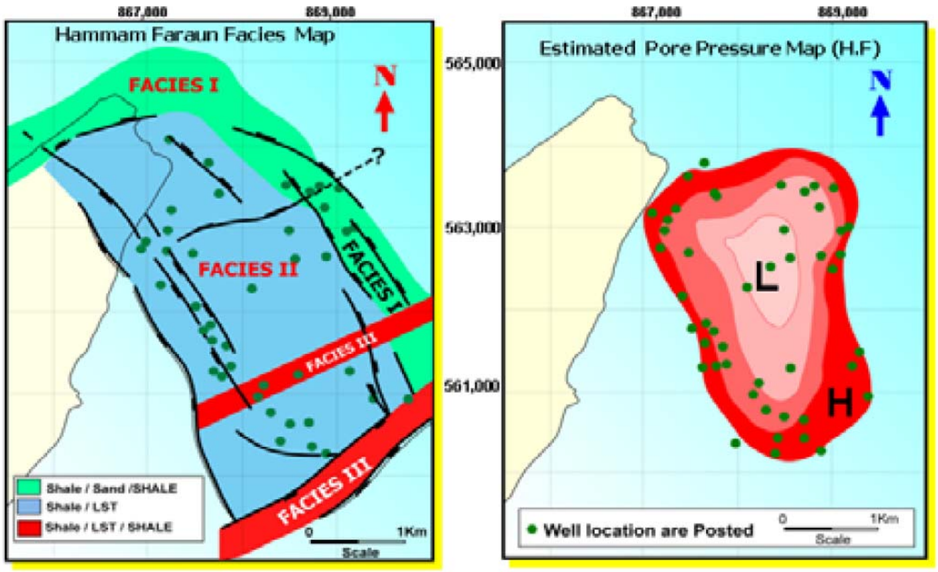


Figure 19. Relationship between estimated pore pressure and facies change on top Hammam Faraun Member.

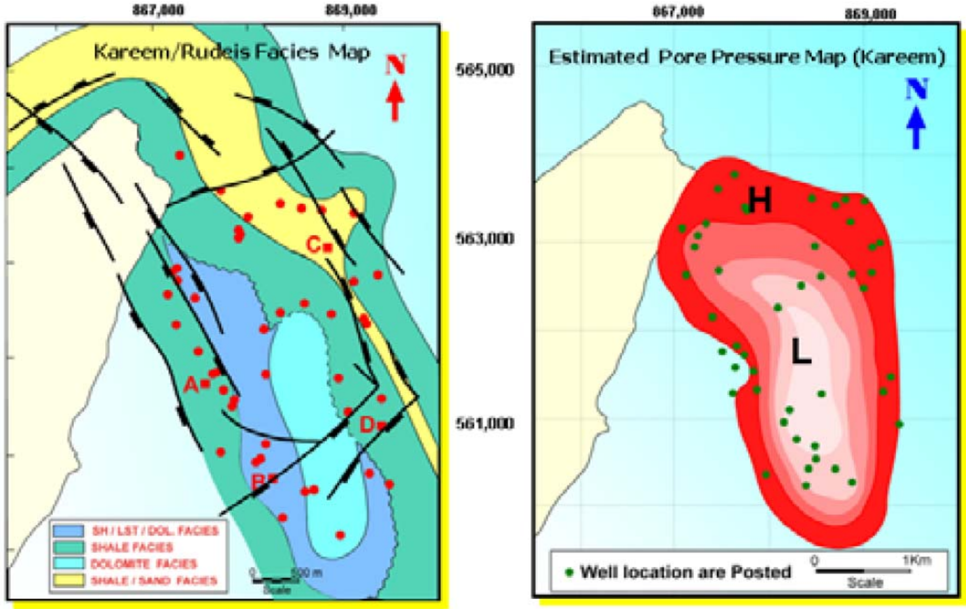


Figure 20. Relationship between estimated pore pressure at top of Kareem/Rudeis and its facies change.

Conclusions and Recommendations

1) The Pressure Regime Modeling for any area is an integral part of well planning and Formation Evaluation Process.

2) Better understanding for the Pressure Regime play a vital role prior drilling any well in:-

- Enabling the well planner to anticipate the location and potential magnitude of possible abnormal pressure problems for future drilling.
- Minimizing the drilling cost as it can be used as a guide to calculate the Estimated Pore Pressure and Fracture Pressure, so that the mud density can be optimized to provide sufficient overbalance and assure the suitable casing depth.
- Avoiding environmental pollution, loss of reserves and loss of life resulting from abnormal pressure problems.

3) The Constructed Pressure Regime Model of Zeit Bay Field revealed the following points:-

- The Estimated Pore Pressure values vary from well to another, but the general trend behaves the same.
- An increase in values of the Estimated Pore Pressure is observed at top of Hammam Faraun Shale then dropped back again.
- The same phenomenon is repeated in Kareem/Rudeis Shale where another increase in values is observed at the top section and then dropped back again.
- The Estimated Pore Pressure of Hammam Faraun Shale is lower in values rather than of Kareem Shale.
- The distribution of Estimated Pore Pressure values exhibits considerable changes from the crestal part of the structure and down dip position towards flanks.
- The minimum Estimated Pore Pressure values are observed at the crestal and increases towards the flank.
- The Estimated Pore Pressure values are matched with the field fault pattern and the lithological facies change of Hammam Faraun and Kareem formation.
- The geoscience's application explained the exhibition of considerable changes from the crestal part of the structure and down dip position towards flanks. The shale of flanks is mainly montomorillonite (smectite) while the mixed shale is localized at the crestal part of the field.

4) The Pressure Regime of Zeit Bay field needs consultation and co-operation between Geologists, Drilling Engineers, Petroleum Engineers and Well Planners are vital to:-

- Modify the well profile prior drilling to help in reducing downhole problems.
- Select the Suitable Mud and Casing Programs to drill wells safely and economically.

Acknowledgment

The authors sincerely thank the management of Suez Oil Company (SUCO), the management of Egyptian General Petroleum Corporation (GPC), and the partner GEOGE for their support to prepare and publish this work.

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