

**ROLE and CONTRIBUTION of PRESSURE REGIME EVALUATION  
in WELL PLANNING and FORMATION EVALUATION PROCESS,  
ZEIT BAY FIELD - GULF of SUEZ, EGYPT**

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**Summary:**

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.

**Introduction:**

An adequate prediction of the Pore Pressure and better understanding for the Pressure Regime Model of any area are very important prior drilling any well. They can play a vital role at Exploration and Development Processes.

- ◆ In Exploration Phase, they help in:-
  - Providing calibration to Basin Modeling.
  - Mapping Hydrocarbon Migration Pathways.
  - Assessing the “Seal” effectiveness.
- ◆ 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).

But 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. (fig.1)



Fig.1 Location Map

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

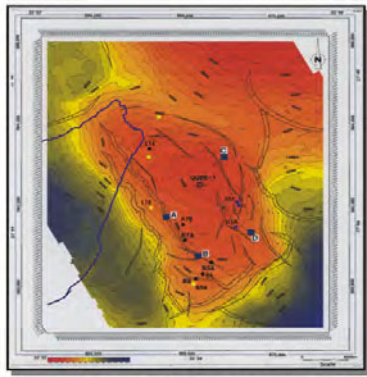


Fig.2 Structure Contour Map On Top Hammam Farau

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 cover unconformably the Pre-Cambrian basement rocks. (fig.3)

AGE	FORMATION	LITH.	LITHOLOGIC DESCRIPTION
HOLOCENE	POST ZEIT		SAND WITH CLAY STREAKS
PLIOCENE			
UPPER MIOCENE	ZEIT		ALTERNATING SAND, SHALES AND ANHYDRITE
	SOUTH CHAIRS		SALT WITH ANHYDRITE AND THEN SHALES
MIDDLE MIOCENE	H. FARAUH		LIMESTONE, MARLS
	FARAUH		ANHYDRITE
	SIDIH		SEDIMENTARY LITHOLOGICAL DIFFERENTIATION OF SANDS & CLAYSTONE
	BABA		
LOWER MIOCENE	KAREEM / RUDEIS		PREDOMINANTLY CARBONATE UPPER PART LIMESTONE, BASAL PART DOLOSTONE, LATERALLY GRADING TO SHALE
	BASAL MIOCENE		DOLOMITIC SANDS / SM
CRETACEOUS	NUBIAN S.D.T		SANDSTONE, MASSIVE, KAOLINIC
PALEOZOIC			
	WEATHERED BASEMENT		BASEMENT WASH
PRECAMBRIAN	FRACTURED BASEMENT		GRANITE AND RELATED PLUTONIC ROCKS / FRACTURED / METAVOLCANIC AND METASEDIMENTS

Fig. 3 Generalized Stratigraphic Column (Zeit Bay Field)

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 Pre-Cambrian fractured basement. (fig.4)

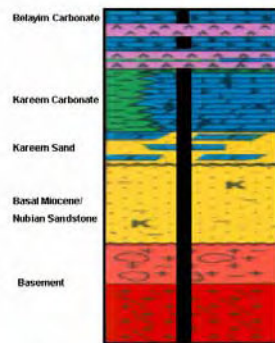


Fig. 4 Hydrocarbon Zones (Zeit Bay Field)

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

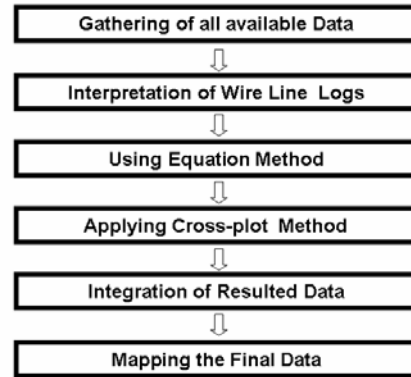


Fig. 5 Sequence of Applied Technique

**First**, all available data of about fifty five wells had been 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 while evaluation.

**Second**, since the Geopressure zones are mainly originated in Clay intervals as a result of dehydration process (Montmorillonite alters 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 been adequately identified.

This identification had been done by the assistance of CGR (Gamma Ray corrected for uranium content). A Shale baseline (which is more-or-less vertical lines) had been defined and a Normal Compaction Trend Line (NCTL) had been established. (fig. 6 & 7)

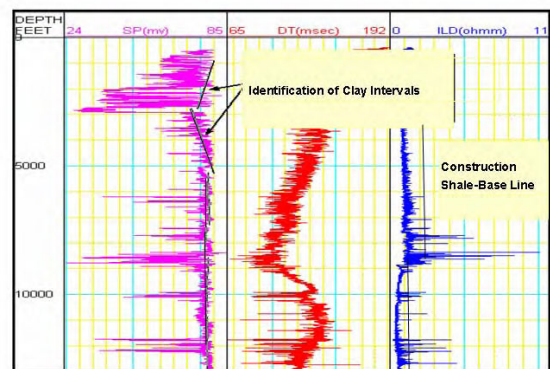


Fig. 6 Identification of Clay Intervals and Construction of Shale-base Line

**Theory and Methodology:**

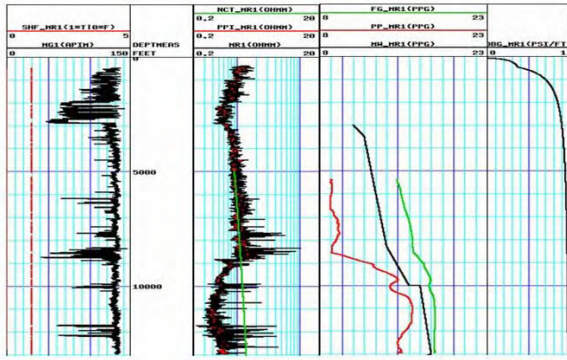


Fig. 7 Construction of Normal Compaction Trend Line

Relative porosities for each lithology had been calculated as the porosity varies with any change of lithology and pore pressure, which were 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) had been taken and Normal Compaction Trend had been established to calculate the Estimated Pore Pressure. (fig. 8)

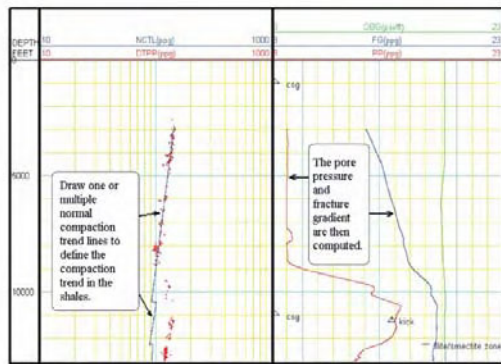


Fig. 8 Calculation of Estimated Pore Pressure

Density and neutron logs had been used as porosity logs and Geopressure indicators. Decreasing in the 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, Montmorillonite showed high hydrogen index values while Illite showed low hydrogen index values.

Sonic logs had been used as a reasonable Geopressure indicator as Interval Transit Time (Dt) is usually increased with depth in constant Clay intervals due to the increase in the porosity (Pore Pressure Gradient) and observed to be steadily moved to the highest values with depth in the transition zone. Increasing in the observed sonic log values from the normal trend values had 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 had been used as another reasonable Geopressure indicator, where decreasing in the observed Resistivity log values from the Normal Trend Values had been 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:

$$P = S - [S - P_o] [R_o / R_n]^n$$

Where

- P** : is the Estimated Pore Pressure.
- S** : is the Overburden Gradient
- P<sub>o</sub>** : is the Observed Pressure Gradient.
- P<sub>n</sub>** : is the Normal Pressure Gradient.
- R<sub>o</sub>** : is the Observed Log Resistivity Value.
- R<sub>n</sub>** : 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<sub>n</sub>** : is the Normal Compaction Trend
- Dt<sub>o</sub>** : is the Observed Transit Time

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

**Applications and Results:**

As the applied technique to calculate the Estimated Pore Pressure depends on the presence of Clay intervals so; the Clay sections had been 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 had been selected and analyzed. The authors emphasized on those two interested zones in this study.

CGR logs (Gamma Ray corrected for uranium content) had been used to detect the Clay interval (fig.9) and to determine the Hammam Faraun member and Kareem/Rudeis formation.

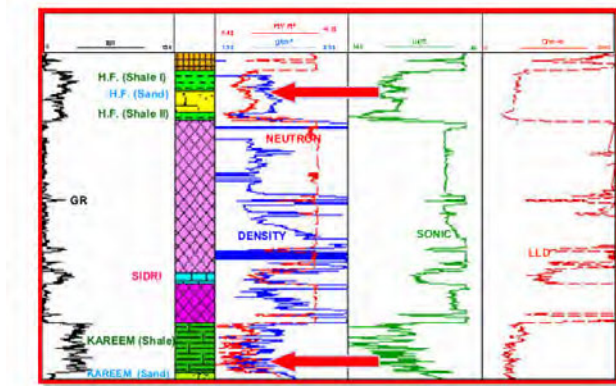


Fig. 9 Log Responses Corresponding Shale section.

The resistivity log values opposite Hammam Faraun member and Kareem/Rudeis formation had been taken and the Estimated Pore Pressure had been calculated. (fig.10 & 11) The Normal Trend values had been determined by using this equation:

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

The Estimated Pore Pressure had been calculated by using this equation:

$$P_o = S - (S - P_n) (R_o / R_n)^{1.2}$$

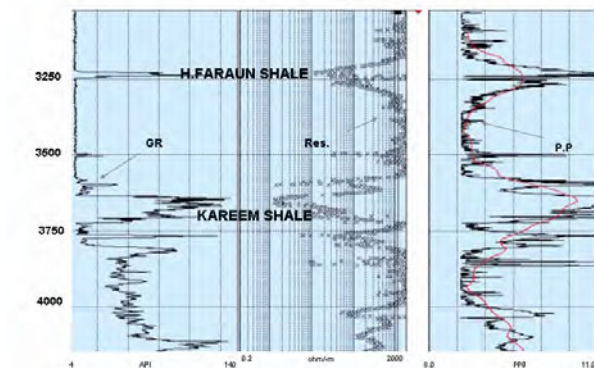


Fig.10 Estimated Pore Pressure From Resistivity Logs (WELL #1)

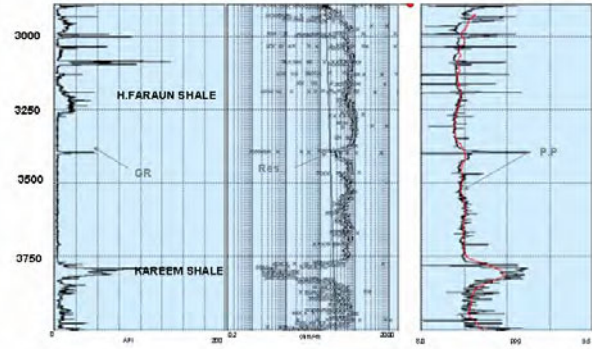


Fig.11 Estimated Pore Pressure From Resistivity Logs (WELL #2)

The sonic log values opposite Hammam Faraun member and Kareem/Rudeis formation had been taken and the Estimated Pore Pressure had been calculated. (fig.12 & 13) The Normal Trend values had been determined by using this equation:

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

The Estimated Pore Pressure had been calculated by using this equation: -

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

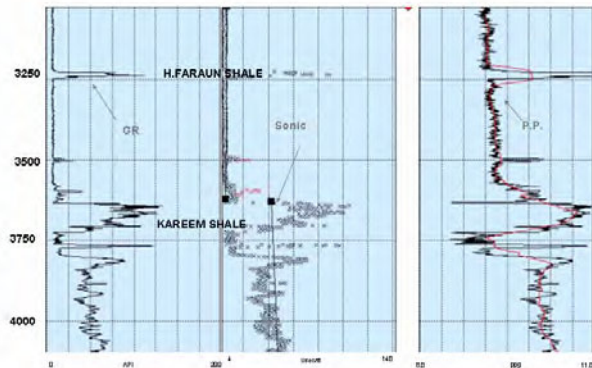


Fig. 12 Estimated Pore Pressure From Sonic Logs (WELL #1)

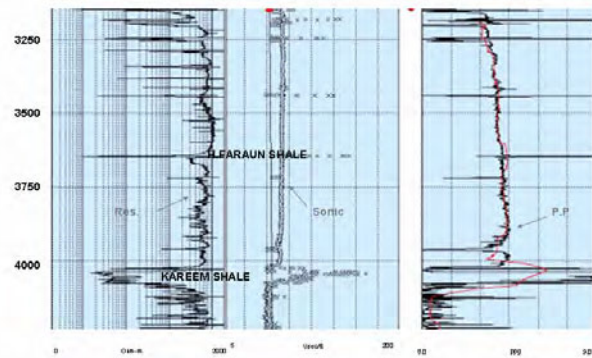


Fig.13 Estimated Pore Pressure From Sonic Logs (WELL #2)

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

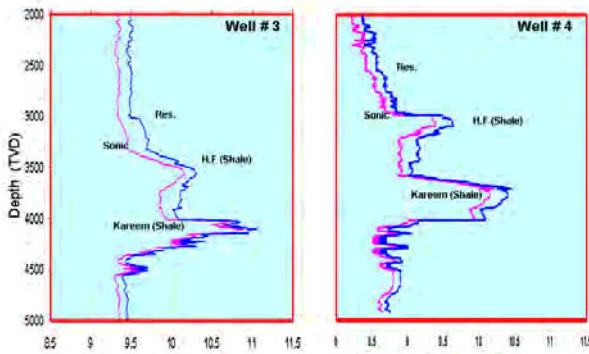


Fig. 14 Estimated Pore Pressure From Resistivity/Sonic Logs (using Eaton Method)

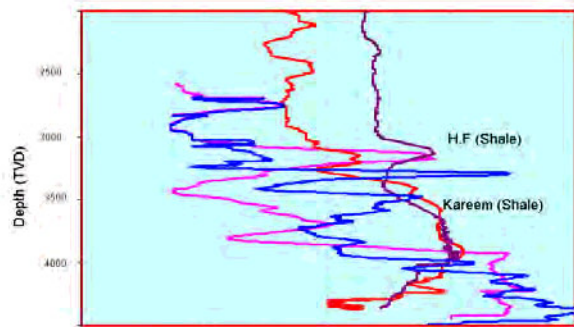


Fig. 15 Estimated Pore Pressure From Resistivity Logs (using Cross-plot Method)

The resulted Estimated Pore Pressure values were integrated and Cross-plots for these integrated values had been conducted (fig.16)

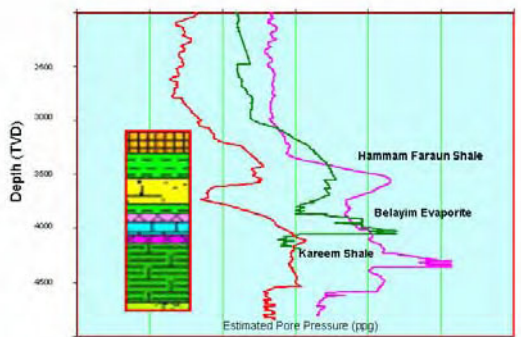


Fig. 16 Simple Sketch for Estimated Pore Pressure (Zeit Bay Field)

This cross-plot revealed the following points:-

- ◆ The Estimated Pore Pressure values vary from well to another, 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 rather than of Kareem/Rudies Shale.

The Estimated Pore Pressure values were averaged, correlated with each others and mapped on top of Hammam Faraun member and Kareem/Rudies formation (fig.17).

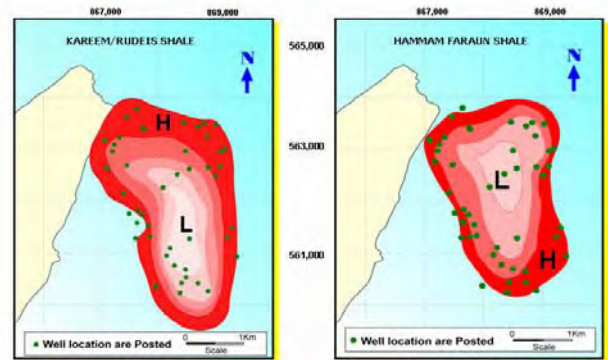


Fig. 17 Estimated Pore Pressure Maps For Interested Zones

The distribution of the Estimated Pore Pressure values on these maps exhibits considerable changes from the crestal part of the field structure and down dip position 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 had been established and correlated with those maps (fig.18).

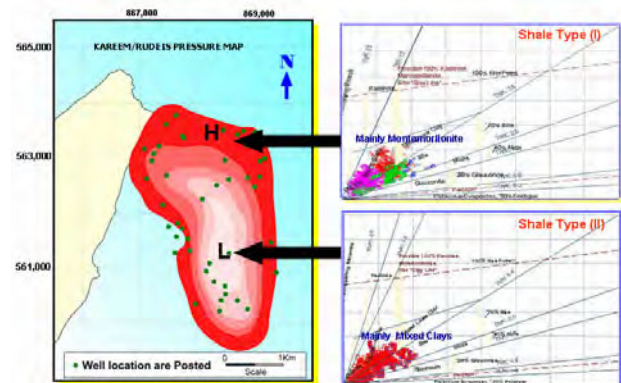


Fig 18 Shale Types from Potassium/Thorium Cross Plot

This 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 Montmorillonite 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 had been constructed for the interested zones. (fig.19 & 20)

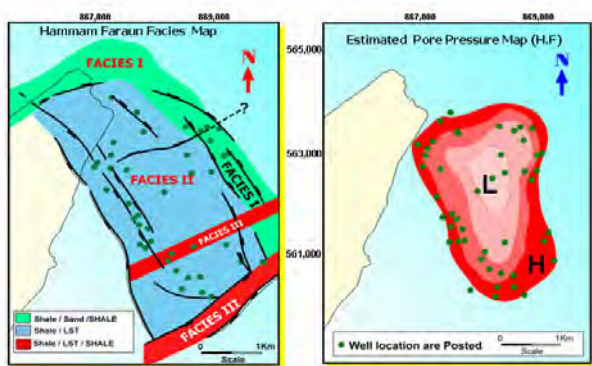


Fig .19 Relationship Between Estimated Pore Pressure and Facies Change on Top Hammam Faraun

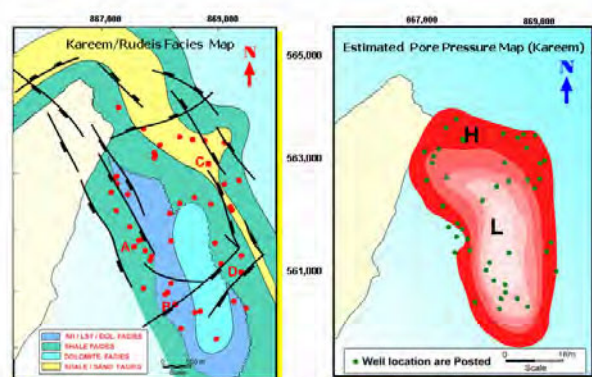


Fig .20 Relationship Between Estimated Pore Pressure and Facies Change on Top Kareem/Rudeis

The comparison between the maps revealed that the Estimated Pore Pressure values are matched with the field fault pattern and the lithological 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 one is represented in the crestal part of the field and named as "costal facies". It is mainly deposited as Carbonates with thin Shale layers. The second one is represented by a deeper facies and distributed on the marginal of the field surrounding the costal facies in all sides. This type is named as "open shallow marine facies" and mainly deposited as Shale beds. This differentiation explains the presence of Two Pressure Regime values.

### 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 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 down hole problems.
    - Select the Suitable Mud and Casing Programs to drill wells safely and economically.

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### References:

- Bradley, J.S.: Abnormal Formation Pressure, *AAPG*, 1975, vol. 59/6,  
 Bradley-Colten, Virginia A.: Role of Pressure in Smectite Dehydration-Effects on Geopressure and Smectite-to-Illite Transformation; *AAPG*, 1987, vol. 71/11,  
 Fertl, W.H.: Abnormal Formation Pressures, *Elsevier Press*, 1973