American Journal of Geophysics, Geochemistry and Geosystems
Vol. 7, No. 2, 2021, pp. 68-84
http://www.aiscience.org/journal/aj3g
ISSN: 2381-7143 (Print); ISSN: 2381-7151 (Online)

Application of Pore Pressure Evaluation for Safe Drilling and Well Design in Kareem Formation, Belayim Land Field, Gulf of Suez, Egypt

Mazen El Bay*

P. Services Gmbh Middle East, Cairo, Egypt

Abstract

Selecting new locations for drilling in oil and gas fields characterized by risks and high costs which is required more accurate study to select locations to start operations and development plans with safe drilling where we should maintain wellbore pressure in a balanced state between pore pressure of the formation and fracture pressure to avoid overpressure which represents a major danger for drillers which leads to sudden kick and formation damage and there is a further possibility that a blow out could occur. It is therefore important to the oil industry to save more costs by selecting the more accurate location and appropriate mud weight which will be used during drilling operations based on pore pressure evaluations to be safer for drilling and development for the field. In this paper, we will provide an overview on pore pressure evaluation to available wells scattered in belayim land field for a better understanding pore pressure regime and its distribution in the study area based on corrected drilling exponent (Dxc) and wireline logs (Resistivity and Sonic logs) with representation the pore pressure values for Kareem Formation in the map to observe the horizontal pore pressure distributions through the study area which can control in determining better locations for next wells and development plans.

Keywords

Pore Pressure, Eaton's Equation, Drilling Exponent, Well Logs, Well Design

Received: January 14, 2021 / Accepted: March 26, 2021 / Published online: May 15, 2021

1. Introduction

Knowledge of pore pressure represents the correct way for safe drilling and cost reduction for many problems that may be present during drilling and development plans for the study area. So first we will know the common terminologies which will be used in this paper.

- Hydrostatic Pressure is the pressure exerted by the static column of fluid (water or brine) at a reference depth. It is dependent on the height of the fluid column and the fluid density.

- Lithostatic Pressure is the pressure exerted at a particular depth by the weight of overlying sediments with including fluid.

- Pore Pressure is the pressure formed by the fluids in the pore spaces of the formation which may be normal when hydrostatic pressure equal to pore pressure, or it may be abnormal when pore pressure is higher than hydrostatic pressure which is defined as over-pressure or it may be subnormal when pore pressure is lower than hydrostatic pressure which is defined as Under-pressure. (Figure 1) Show that pressure–depth plot with the illustration of these terminologies.

2. Aim of the Study

The purpose of this study to evaluate the pore pressure for development plans and minimize the cost of drilling in the study area which presents in Belayim Land Field in the

* Corresponding author
E-mail address: Mazenahmad14@yahoo.com

eastern coast of the Gulf of Suez between longitudes 33˚12̀ and 33˚15́ east and latitudes 28˚35́ and 28˚40̀ north and it considers one of the oldest oil fields in the Gulf of Suez. It was discovered in 1954 and occupies an area of about 113 km^2 (Figure 2).

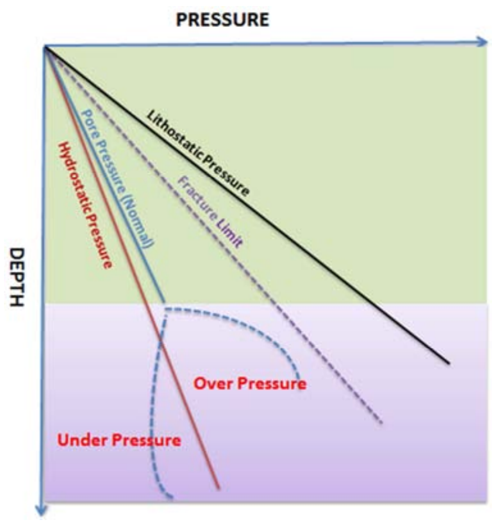

Figure 1. Show that pressure–depth plot with the illustration of pore pressure terminologies.

In the present study, we selected available wells (112-124, 112-100, 112-132, 113-A-21, 113-155, 113-95, 113-60, BLSW-1 ST) for pore pressure evaluation and discuss the experiences from drilling these wells with constructing pore pressure distribution map for Kareem Formation, which led to better development and understanding the pore pressure in the reservoir in the study area (Figure 3).

Figure 2. Location Map of Belayim Land Field.

3. Geology of Study Area

The Gulf of Suez is located in Egypt at the junction of the African and Arabian plates where it separates the northeast African continent from the Sinai Peninsula. The Gulf of Suez is among the most important hydrocarbon provinces in Egypt. The petroleum exploration around the Gulf of Suez began more than 100 years ago at Ras Gemsa.

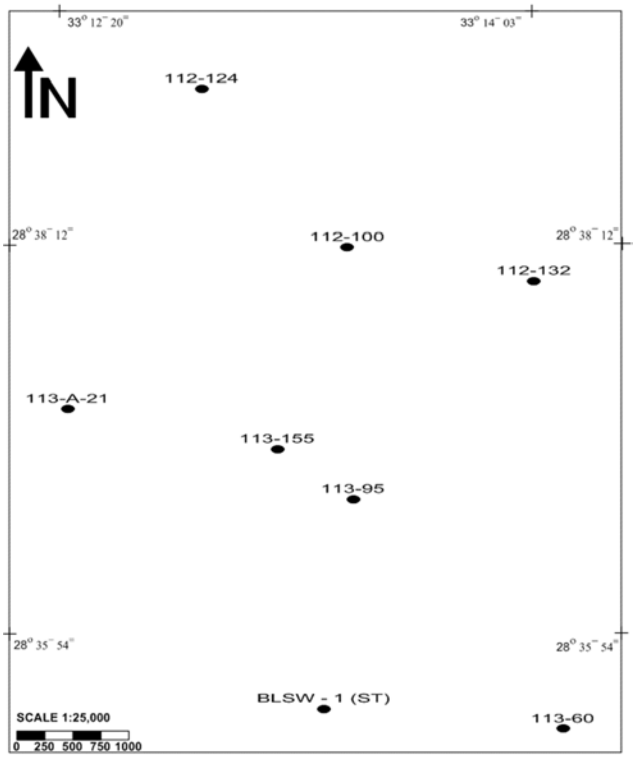

Figure 3. Base Map of Belayim Land Field Showing Available Wells.

Gulf of Suez Structural is characterized by a complex pattern of normal faults characterized by the presence in the rift basin with the presence of NE trending strike-slip faults which formed a complex structure pattern of horsts and grabens. According to El Diasty and Peters [11].

Gulf of Suez is subdivided into three provinces according to structure and dip direction. The study area is located in the central part which occupies the central province which is characterized by the pre-Miocene shallow structures underlying the Miocene sediments. These highs were subjected to severe erosion.

The general structure of the study area is consists of a north-south trending anticline. This anticline is cut by two main faulting systems, one parallel to the coast represents a normal step faulting connected with Suez graben, The second is represented by a series of transcurrent faults subdivide the structure into different blocks (Figure 4).

Stratigraphically, The sedimentary stratigraphic of Belayim Land Field represented by sediments deposited from Precambrian to Quaternary (Figure 5).

This study will concentrate on Kareem Formation which presents in the middle parts of Miocene which represent more hydrocarbon-bearing.

Figure 6 shows that facies modeling distribution in Kareem

Formation where it composed of sandstone and shale which are dominant with intercalations of hard anhydrite.

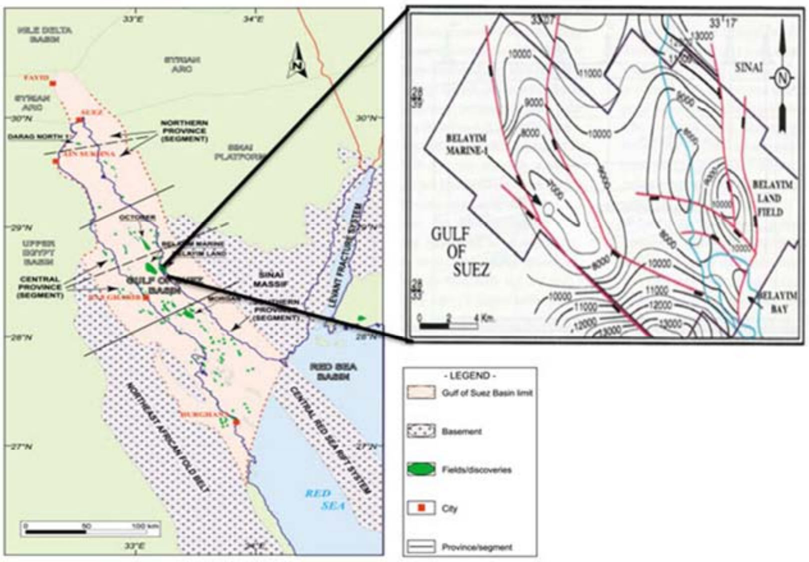

Figure 4. Map Shows Structure Provinces and Structural framework of the study area. [After EGPC].

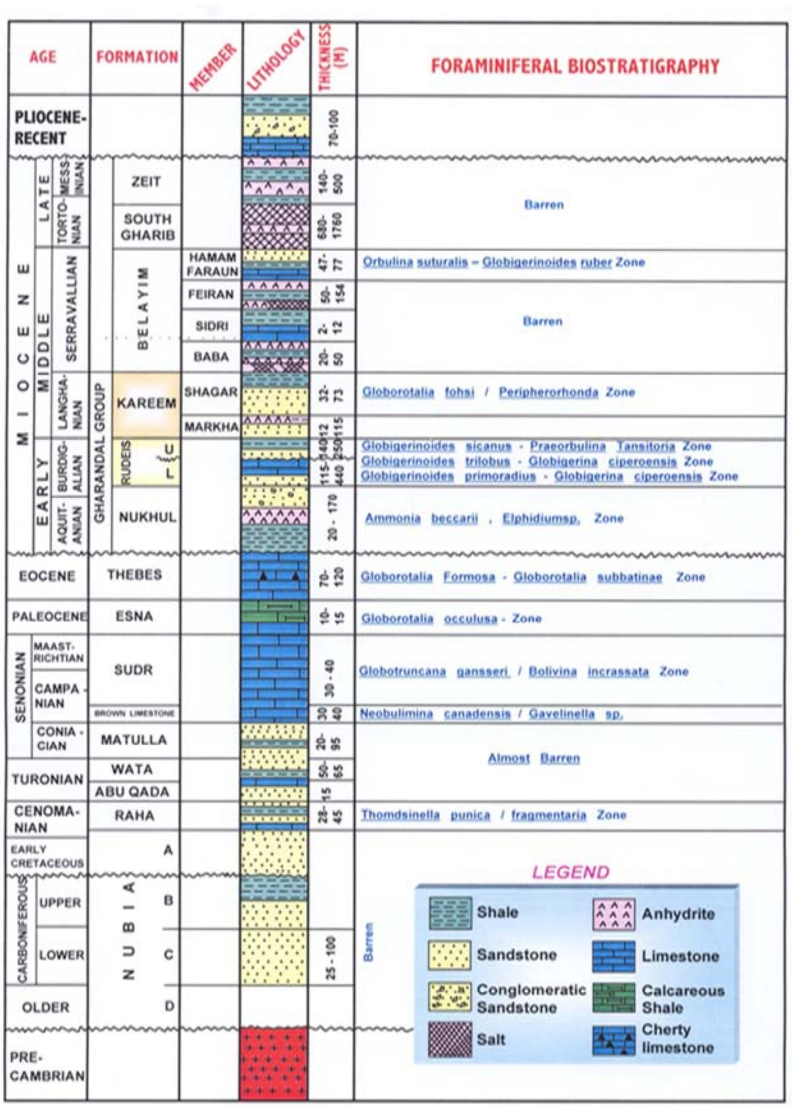

Figure 5. Generalized Subsurface Stratigraphic Section of the Gulf of Suez.

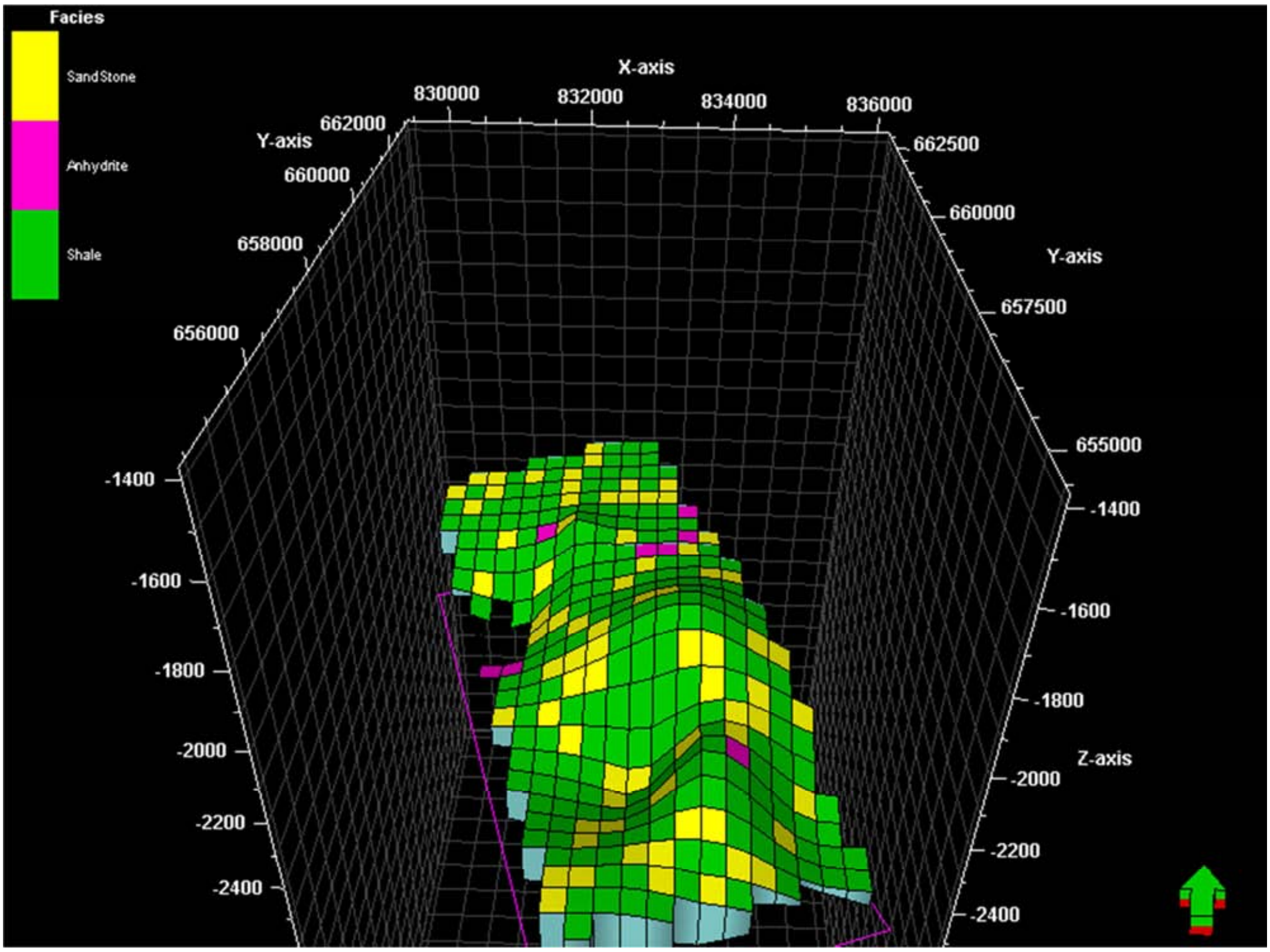

Figure 6. Facies Model for Kareem Formation in the Study Area.

4. Methodology of Formation Pressures Evaluation

In this paper, we will use corrected drilling exponent (Dxc) and wireline logs which will be started by studying the quality control of the available data, and from the available data, Pore Pressure calculated as described in the flow chart (Figure 7).

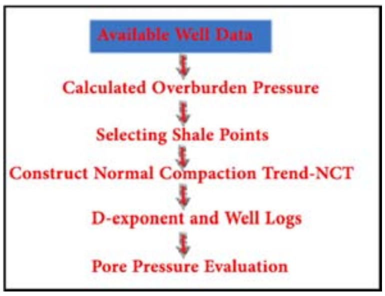

Figure 7. Flow Chart Showing Pore Pressure Calculation.

4.1. Pore Pressure Estimation Using Drilling Exponents

The d and dc exponents (Dx and Dxc) is a method of correcting or normalizing the rate of penetration (ROP) to extract the formation hardness or drillability. The d-exponent method for analyzing formation pore pressure was proposed by Jorden and Shirley [17] and Bourgoyne et. al. [7]. This was an attempt to normalize the rate of penetration (ROP) from the Bingham drilling model, with respect to the parameters weight on bit (WOB), rotary speed (N), and bit diameter (db). The main goal was to investigate the proposed relationship between the rate of penetration, and the differential pressure existing between the formation pore pressure and the hydrostatic pressure column in the wellbore Jorden and Shirley [17]. The study of this relationship it will make possible to predict changes in the pore pressure with respect to the obtained drilling data. Starting with the Bingham drilling model, this resulted in the calculation of a d-exponent, as shown below Bourgoyne et. al. [7].

The empirical models that are commonly being used today include the following:

1. Bingham model

2. Jorden and Shirley model, and

3. Rehm and McClendon

Bingham [6] put the relationship between penetration rate, weight on bit, rotary speed, and bit diameter may be expressed in the following general form:

$$\left[\frac{R}{N}\right] =^{a} \left[\frac{W}{B}\right]^{d}$$

Where:

d = Drilling Exponent (dimensionless)

R = Rate of Penetration (ft/hr)

N = Rotation Speed (rpm) W = Weight On Bit (lbs) B = bit diameter (inches) a = Matrix Strength Constant (dimensionless)

Jorden and Shirley [17] put a solution in the mid-’60s for overpressure detection to the previous equation for “d”, inserted constants to allow common oilfield units to be used, and plotted the results on semilog paper to produce values of d-exponent in a convenient workable. So, they let “a” be unity and without need to derive empirical matrix strength constants but made the d-exponent lithology specific:

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

Where:

D =drilling exponent(dimensionless)

R = rate of penetration (m/hr)

N = rotary speed (rpm)

W = weight on bit (lbs)

B = bit diameter (inches)

Rehm and McClendon [3] proposed this correction:

Dxc = dx *[N. FBG/ECD]

Where:

Dxc = Corrected d-exponent

N. FBG = Represent the normal formation balance gradient EQMD (lb. /gal).

ECD = Equavelent circulation density (lb. /gal).

Dxc is dimensionless and sensitive to differential pressure, hence can be used to adjust the mud weight as drilling progresses. In general, Dxc is expected to increase with depth if lithology is constant and pore pressure is hydrostatic, but the decrease in overpressured zones (Figure 8).

Some points that are important when using Dxc for pressure evaluation are the following:

(1) Use only trends in shale.

(2) Trends can change with change bit and hole size.

(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 the normal trend is indicative of transition zone.

The application of d-exponent (Figure 9) to (Figure 12) Shows that pore pressure evaluation to available wells in the study area.

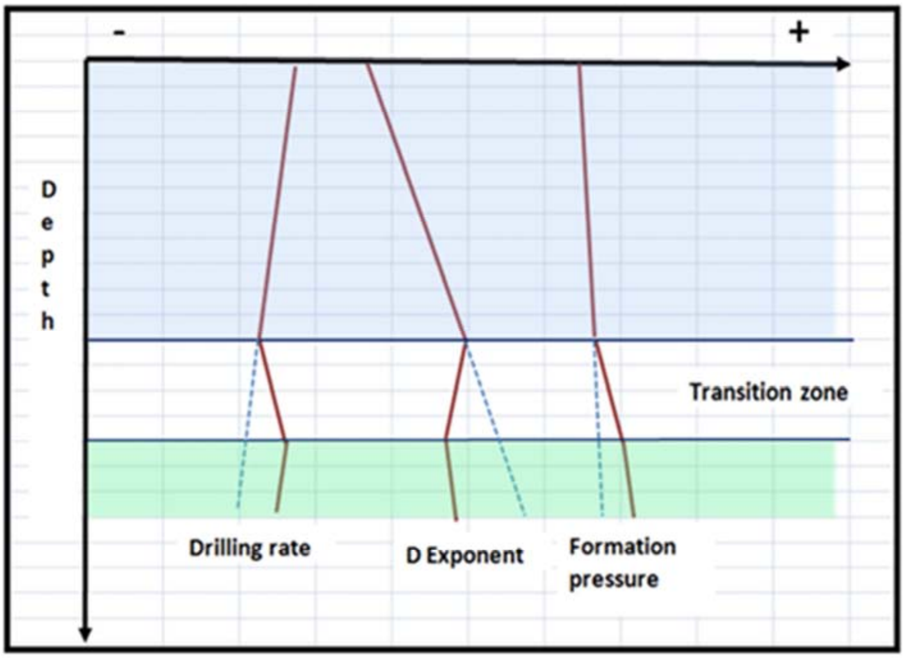

Figure 8. Idealized Responses of Drilling Rate, Dxc and Formation Pressure with Depth.

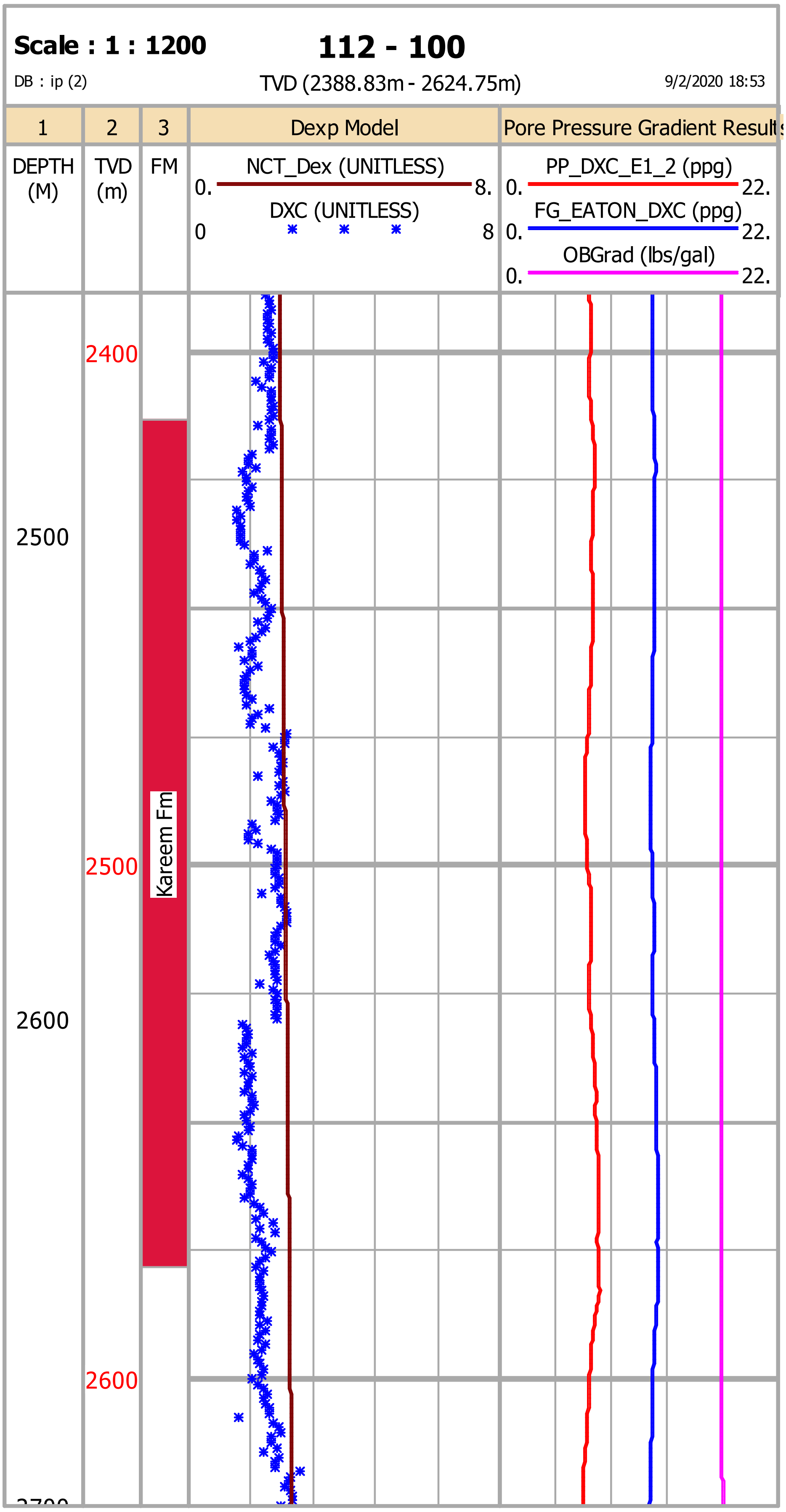

Figure 9. Pore Pressure Evaluation From Modified D-exponent for 112-100 Well.

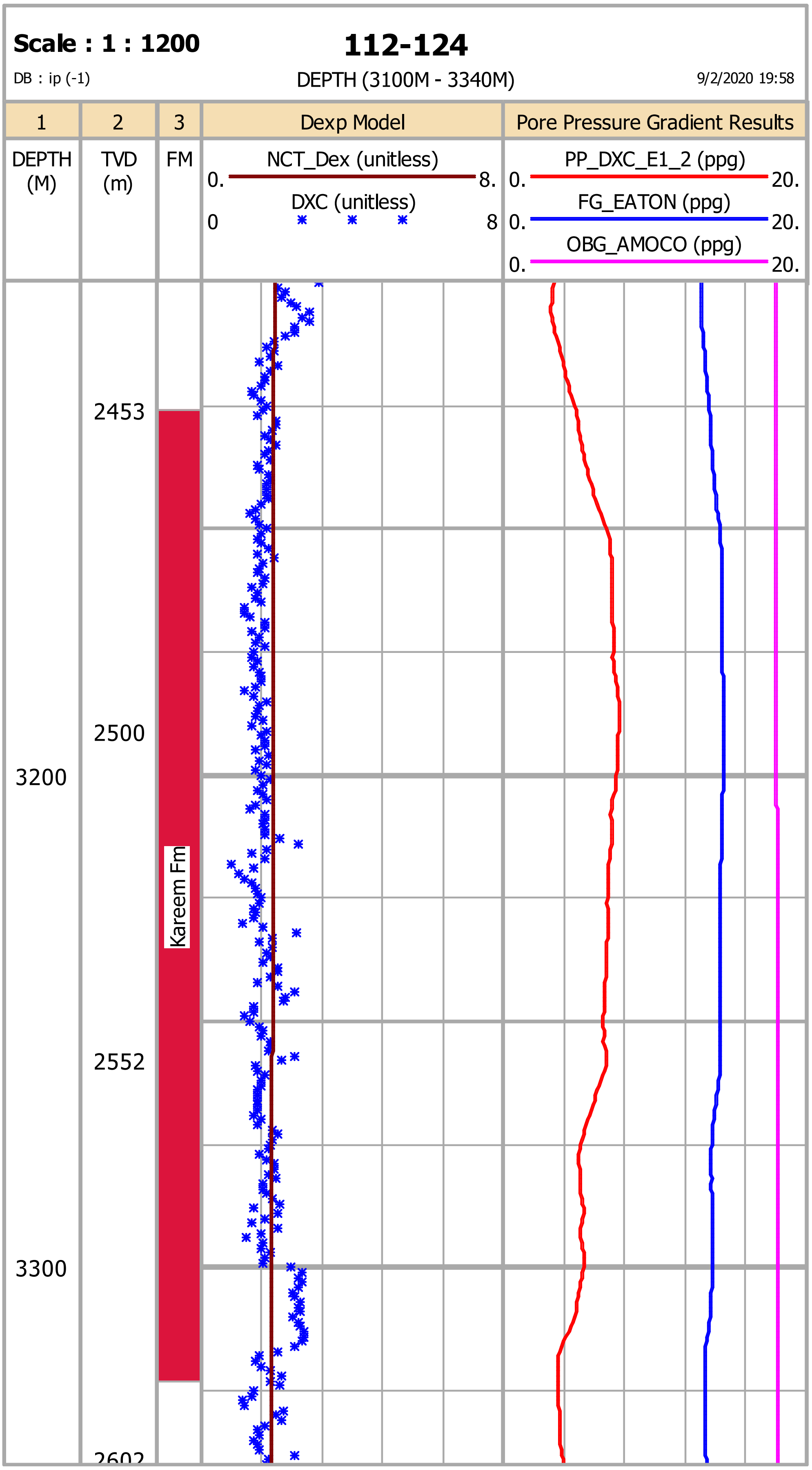

Figure 10. Pore Pressure Evaluation From Modified D-exponent for 112-124 Well.

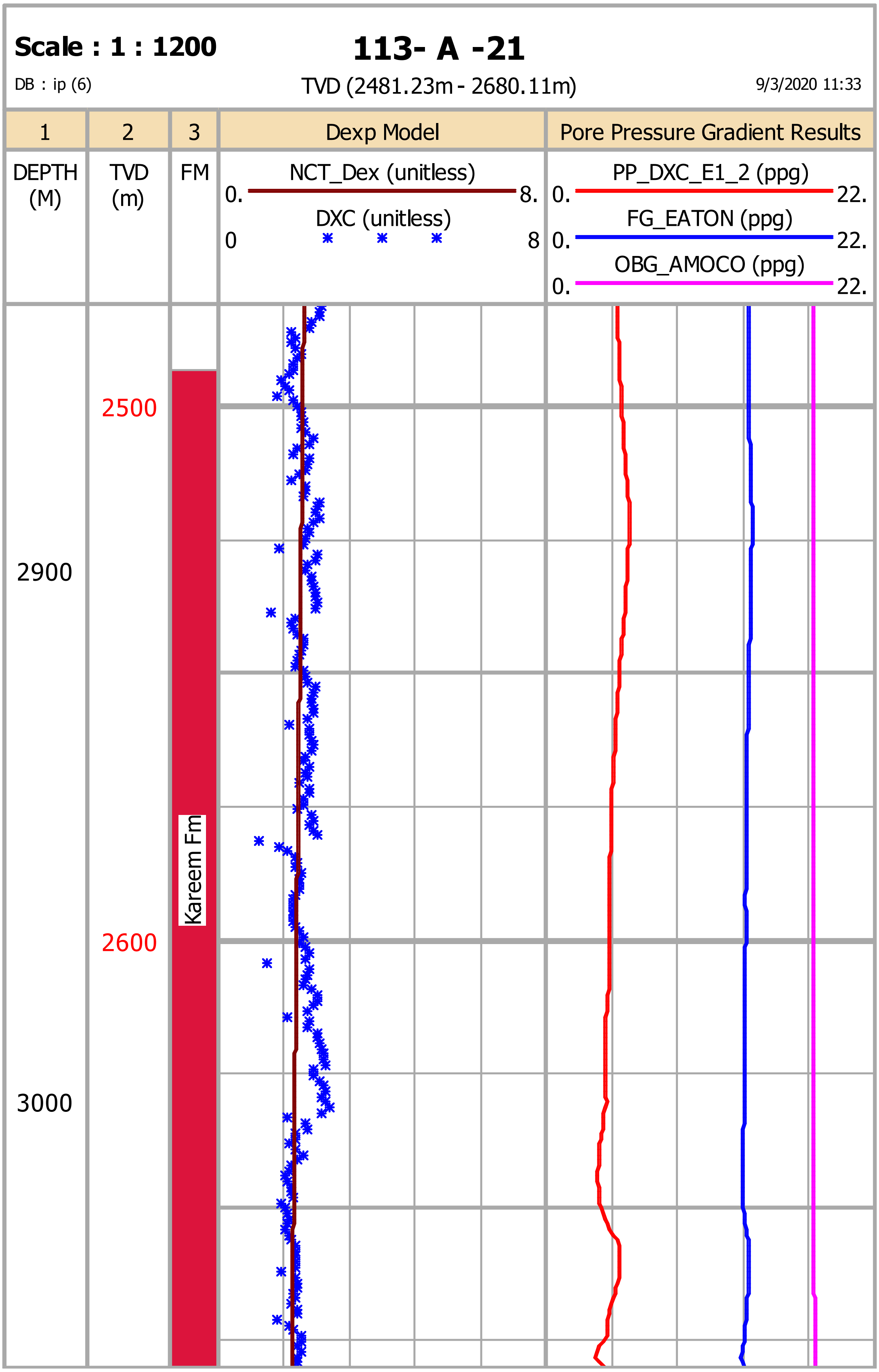

Figure 11. Pore Pressure Evaluation From Modified D-exponent for 113-A-21 Well.

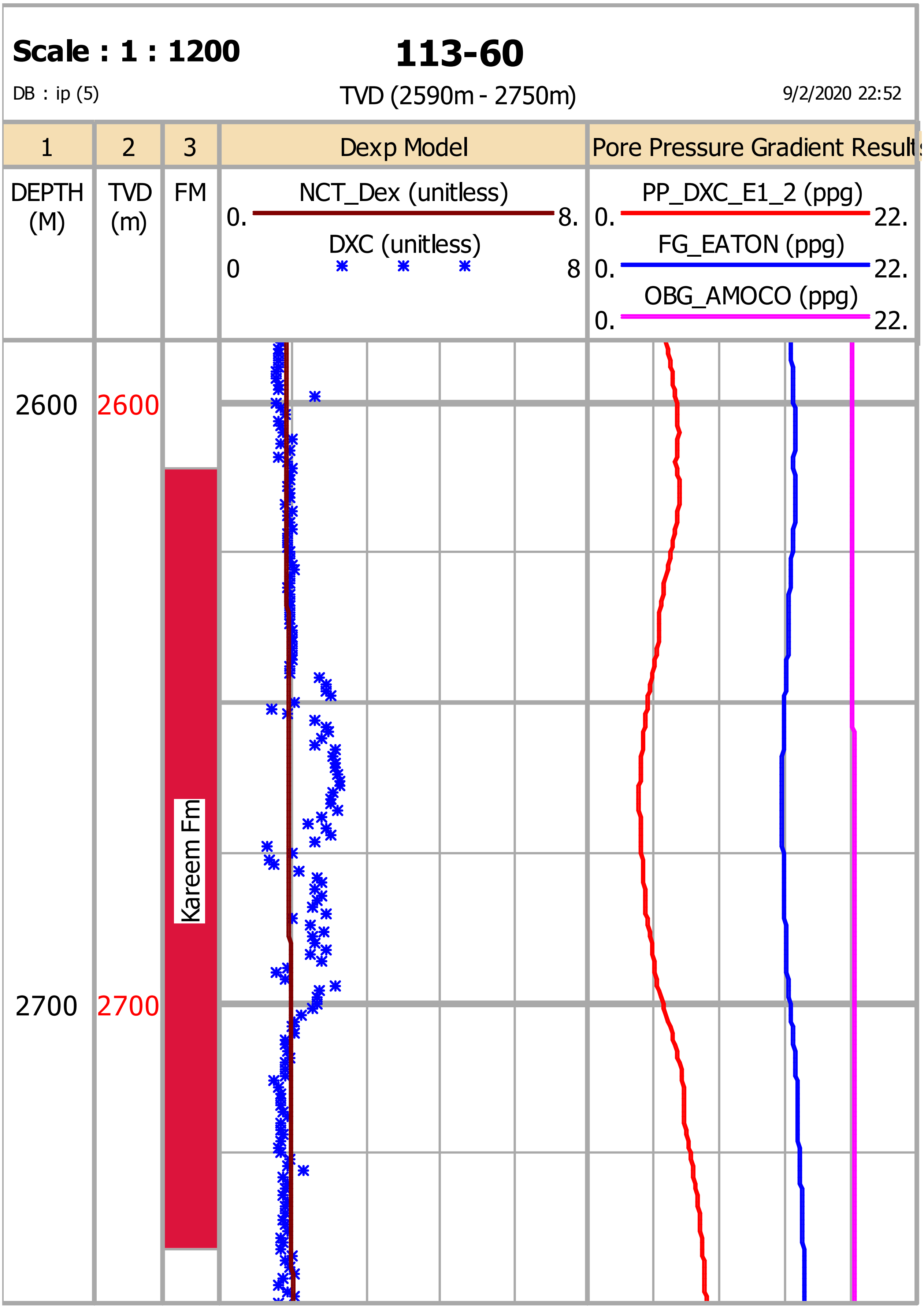

Figure 12. Pore Pressure Evaluation From Modified D-exponent for 113-60 Well.

4.2. Pore Pressure Estimation Using Wireline Log Parameters

4.2.1. Resistivity Log

Resistivity is the ability of the formation to conduct electric current and consider one of the oldest methods of wireline tools. The rock matrix either has zero conductivity where pore spaces may be filled with oil and gas or high conductivity only if the pore structure of the formation contains dissolved salts. Resistivity values reflect the amount of pore fluid with a degree of porosity. Where all things are equal (homogeneous shaly formation and fluid properties), a unit decrease in the resistivity log will correspond to a unit increase in the porosity and hence overpressure. Hottman & Johnson [8] proposed that the relationship linking normal to abnormal pressure in clays could be represented by the simple expression.

$$R_o/R_n$$

Where

R_o = measured or observed resistivity

R_n = resistivity in normally pressured rock at the depth of investigation.

After modifying the exponent to 1.5, Eaton [10] put this into the pore pressure equation above, producing:

$$Po=S-(R_o/R_n)^{1.5}(S-P_n)$$

Where

P_o = Formation Pore Pressure gradient (Psi/ft)

P_n = Normal Pore pressure gradient (Psi/ft)

Further analysis Eaton [10] suggested that the exponent value should be altered from 1.5 to 1.2. Eaton's equation thus became

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

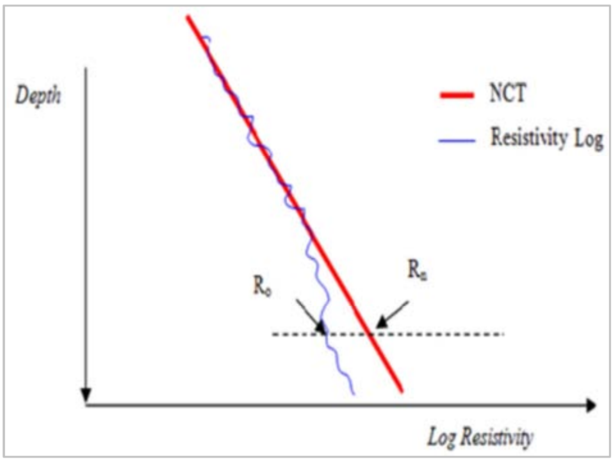

Figure 13. Resistivity Log Showing Over-Pressuring Zone (After Baker, 1996).

The construction of normal resistivity trend by plotting resistivity logs for homogenous clay section against depth, and positioning the normal compaction trend (NCT) onto the log. R_n is the value of the normal compaction trend (NCT) at the depth where pore pressure is to be calculated. The difference between R_o and R_n then indicates the degree of difference between the true porosity and normal porosity at that depth (Figure 13).

4.2.2. Sonic Log

Sonic logging is the recording of the interval transit time required for a sound wave to traverse a definite length of formation where the speed of sound in subsurface formation depends upon the elastic properties of rock matrix, the porosity of the formation, and their fluid content, and pressure. Interval transit time decreases with decreases in porosity. If sonic transit times of normally compacted shale are plotted against depth on a linear scale it will decrease with depth. The equation can be applied to other porosity logs in much the same way as for resistivity.

$$P_o=S-(\Delta t_n/\Delta t_o)^3(S-P_n)$$

Where

S = Overburden Stress Gradient (Psi/ft)

P_o = Formation Pore Pressure gradient (Psi/ft)

P_n = Normal Pore pressure gradient (Psi/ft)

Δt = Transit time (usec/ft)

In a geopressured shale interval the transit time, (Δt), will be increasing as a result of increasing porosity with an increasing pore pressure gradient. In the transition zone (if it exists), the Δt curve, on the log, will be seen to steadily move to the left (higher values) with depth (Figure 14).

Figure 15 to Figure 18 shows that pore pressure evaluation using available wireline logs to wells in the study area.

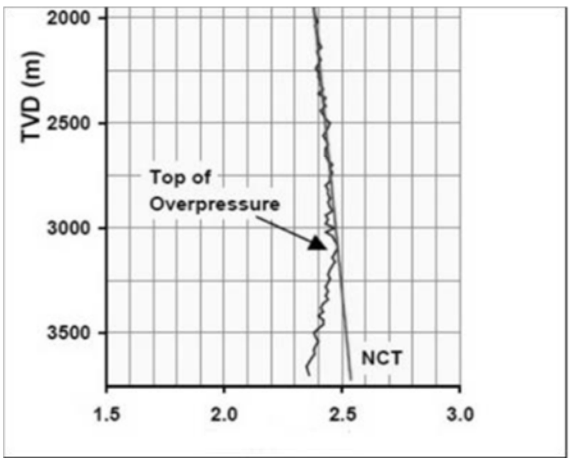

Figure 14. Sonic Log Showing Over-Pressuring Zone (After Baker 1996).

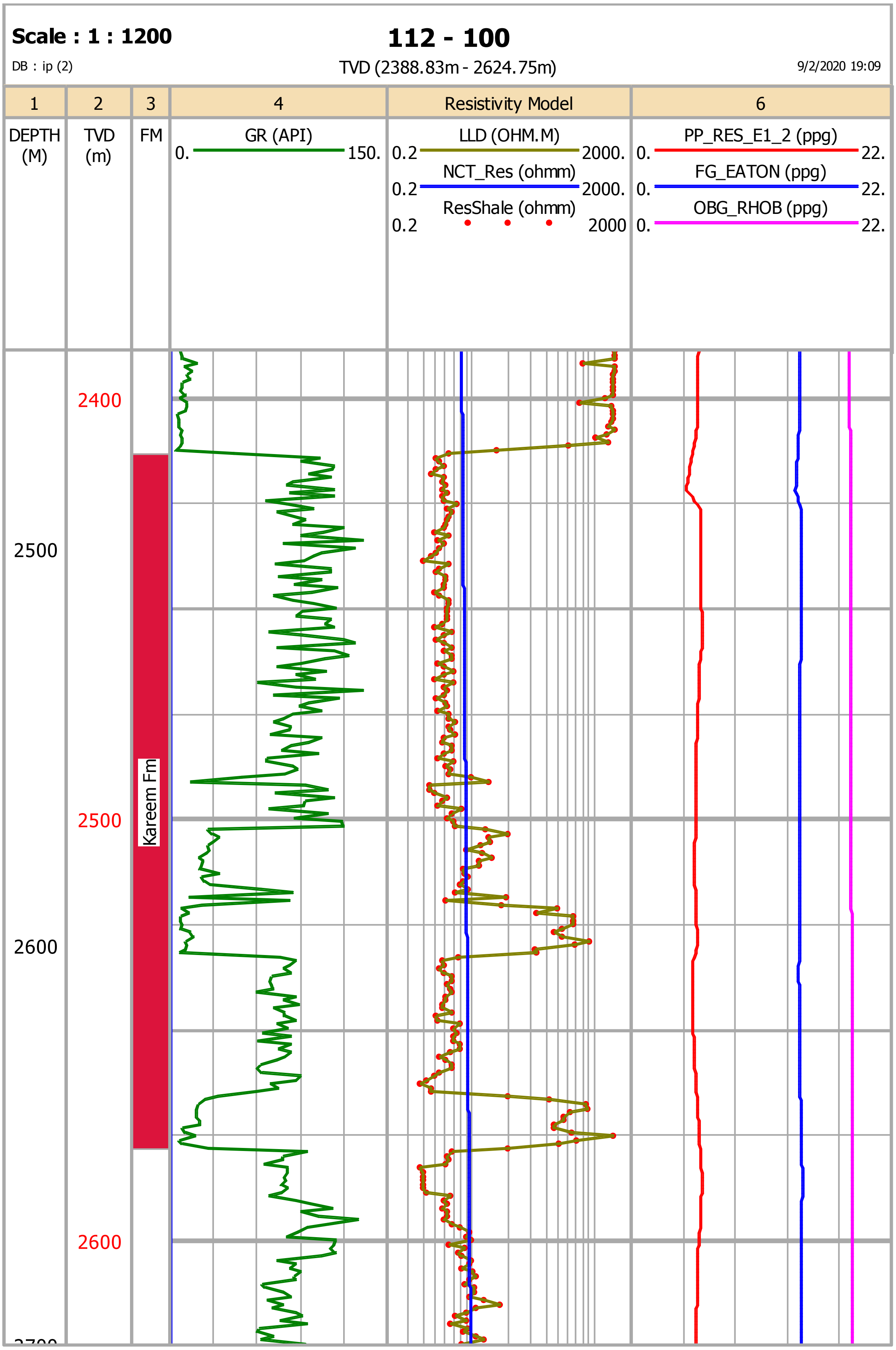

Figure 15. Pore Pressure Evaluation From Wireline Logs for 112-100 Well.

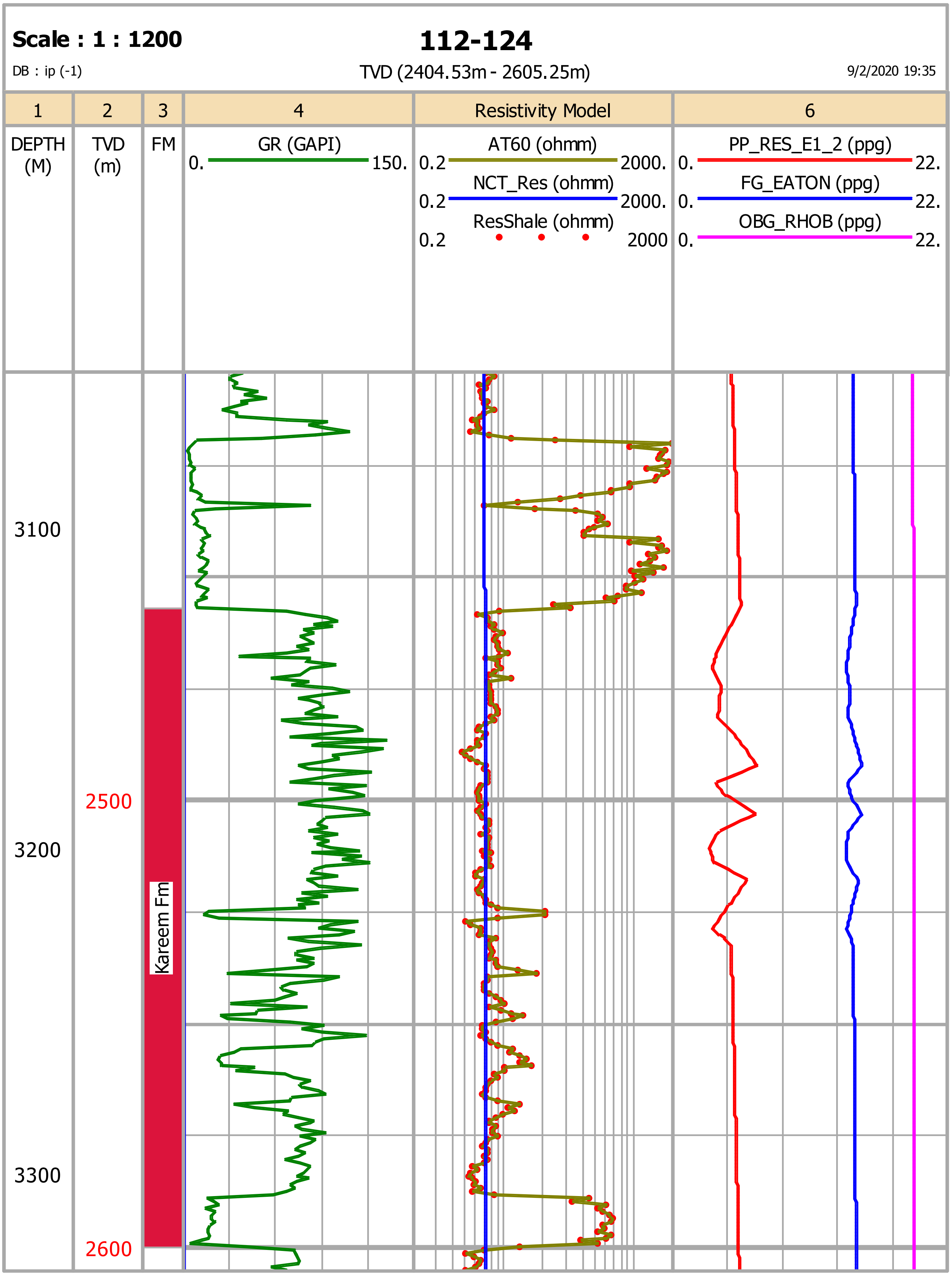

Figure 16. Pore Pressure Evaluation From Wireline Logs for 112-124 Well.

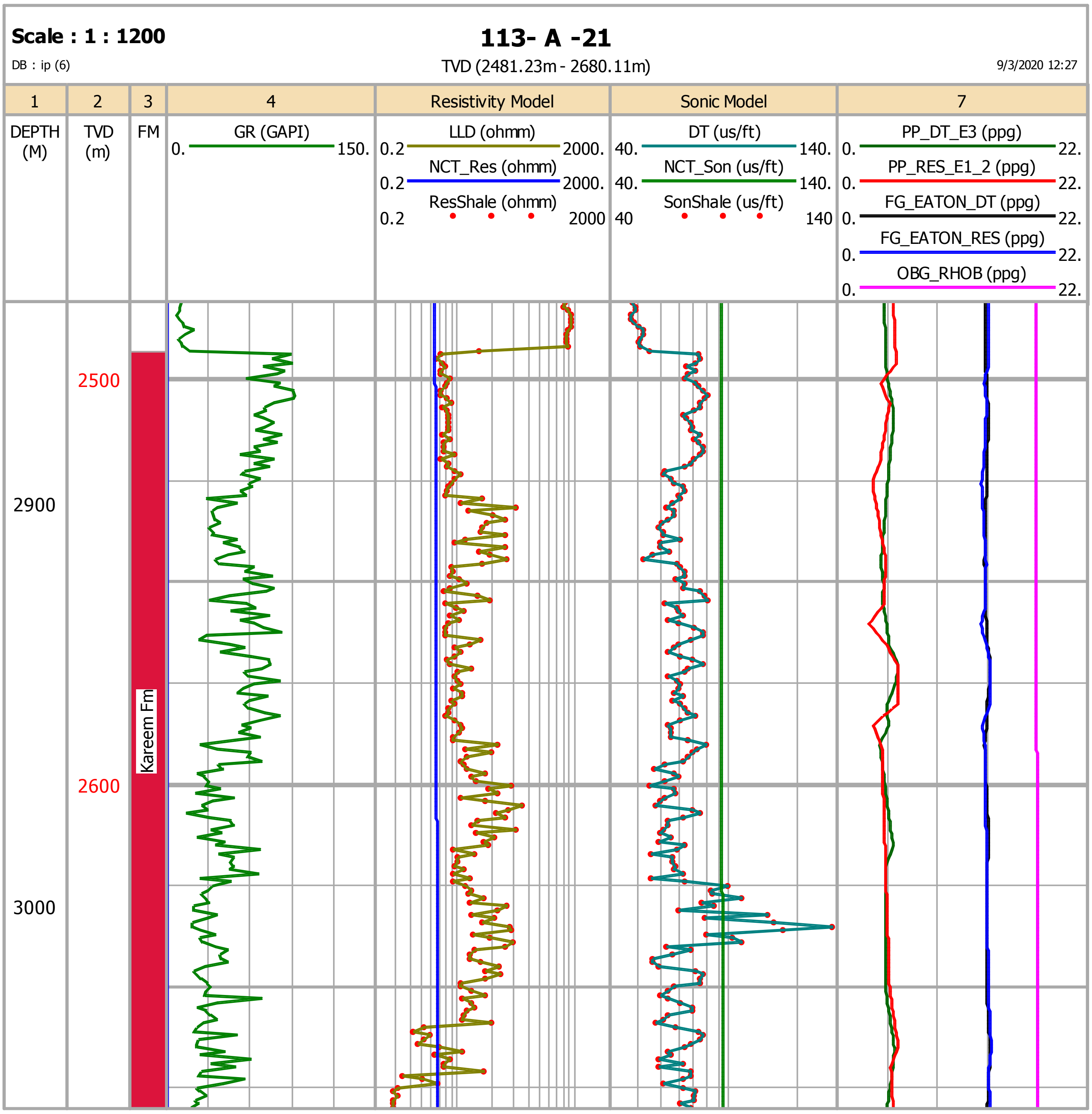

Figure 17. Pore Pressure Evaluation From Wireline Logs for 113-A-21 Well.

5. Results and Discussion

This study carried out on Kareem Formation with available wells located in Belayim Land Field (112-124, 112-100, 112-132, 113-A-21, 113-155, 113-95, 113-60, BLSW-1(ST) where the aims of this part to present the results of pore pressure and report any indication of anomaly present and study the pore pressure distribution through the study area to discuss the experiences from drilling for these wells to avoid drilling problems and determine better locations for development plans.

In the present work, First, overburden pressure is generated, also Normal compaction trends are identified for each well by using corrected drilling exponent responses (Dxc) and wireline logs responses (Resistivity and Sonic logs) Then by application Eaton's equation method we can calculate the pore pressure and then calculate the fracture pressure to available wells which presented by using corrected drilling exponent trends in Figure 9 to Figure 12 and with wireline logs trends in Figure 15 to Figure 18.

Pore pressure evaluation for 112-100 well in Kareem Formation shows that the maximum pore pressure is 8.1 ppg and the average pore pressure is 7.6 ppg which indicates

Kareem Formation affected by depletion. So, it is recommended to drill with a low mud weight under 8.34 ppg to the safe drilling operation.

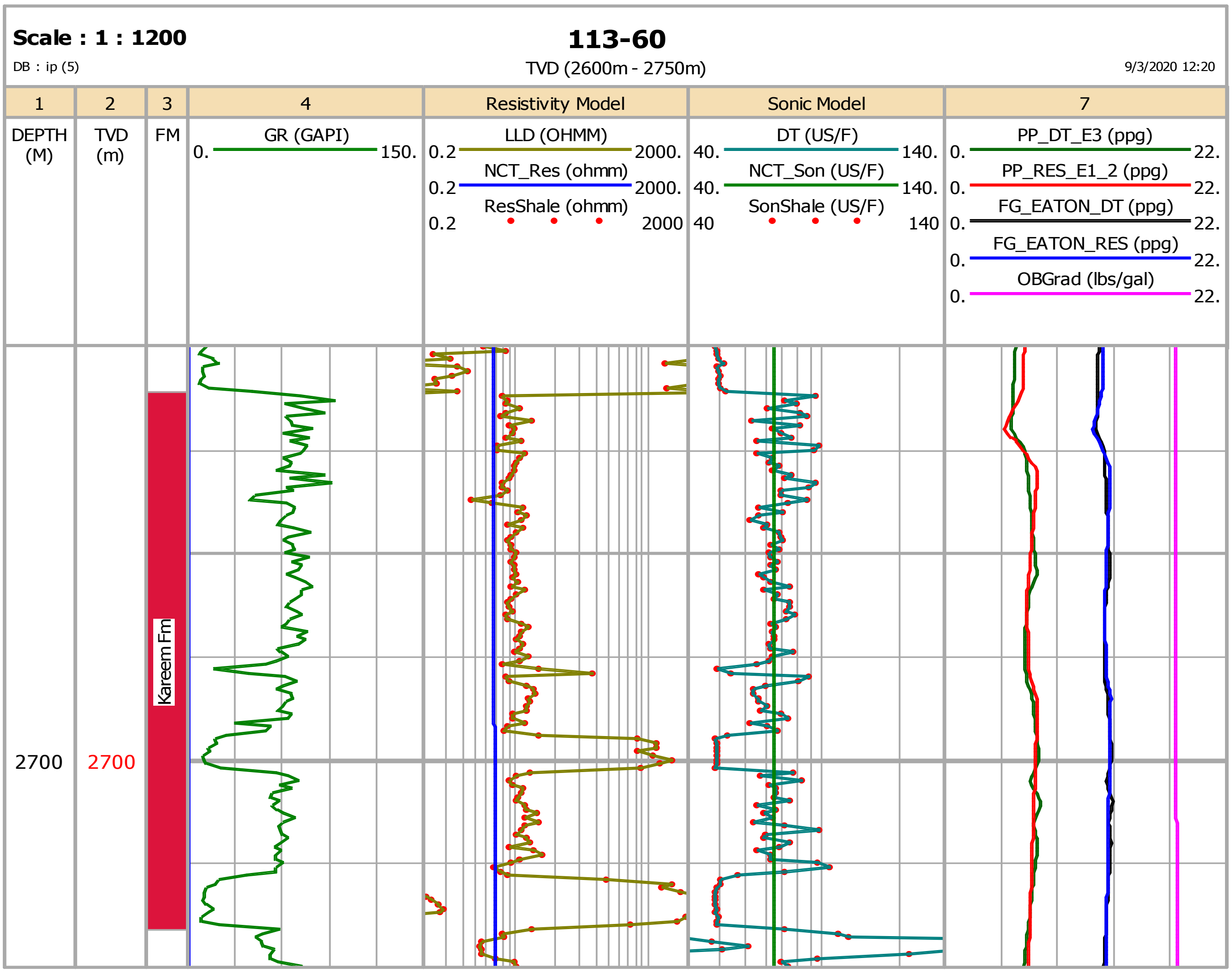

Figure 18. Pore Pressure Evaluation From Wireline Logs for 113-60 Well.

Pore pressure evaluation for 112-124 well in Kareem Formation shows that the maximum pore pressure 7.9 ppg and average pore pressure 7.2 ppg which reflect that Kareem Formation is influenced by depletion which required drilling with mud weight under 8.34 ppg to avoid the formation damaged.

Pore pressure evaluation for 112-132 well in Kareem Formation appeared that the maximum pore pressure 8.34 ppg and the average pore pressure is 7.7 ppg which is recommended to drill with mud weight more than 8.34 ppg to optimum state drilling.

Also, Pore pressure for 112-155 well was evaluated which appeared that the maximum pore pressure 7.9 ppg and the average pore pressure was 7.5 ppg which reflect depletion in Kareem Formation in this well and it required to use mud weight more than 7.9 ppg for safe drilling.

Pore pressure evaluation for 113-A-21 well in Kareem Formation shows that the maximum pore pressure was 6.5 ppg and average pore pressure was 5.4 ppg which also indicated to decreased pressure regime that affected with sharp depletion. So, it is required to drill with a mud weight more than 6.5 ppg to achieve safe drilling.

From pore pressure evaluation for 113-95 well in Kareem Formation shows that the influence of depletion where the maximum pore pressure was 6.2 ppg and average pore pressure was 5.7 ppg. So, it is recommended to drill with mud weight more than 6.2 ppg to avoid hole problems.

Pore pressure evaluation for 113-60 well in Kareem Formation, shows that the maximum pore pressure is 7.8 ppg and the average pore pressure is 6.9 ppg which required drilling with mud weight more than 7.8 ppg to avoid kick and formation damage.

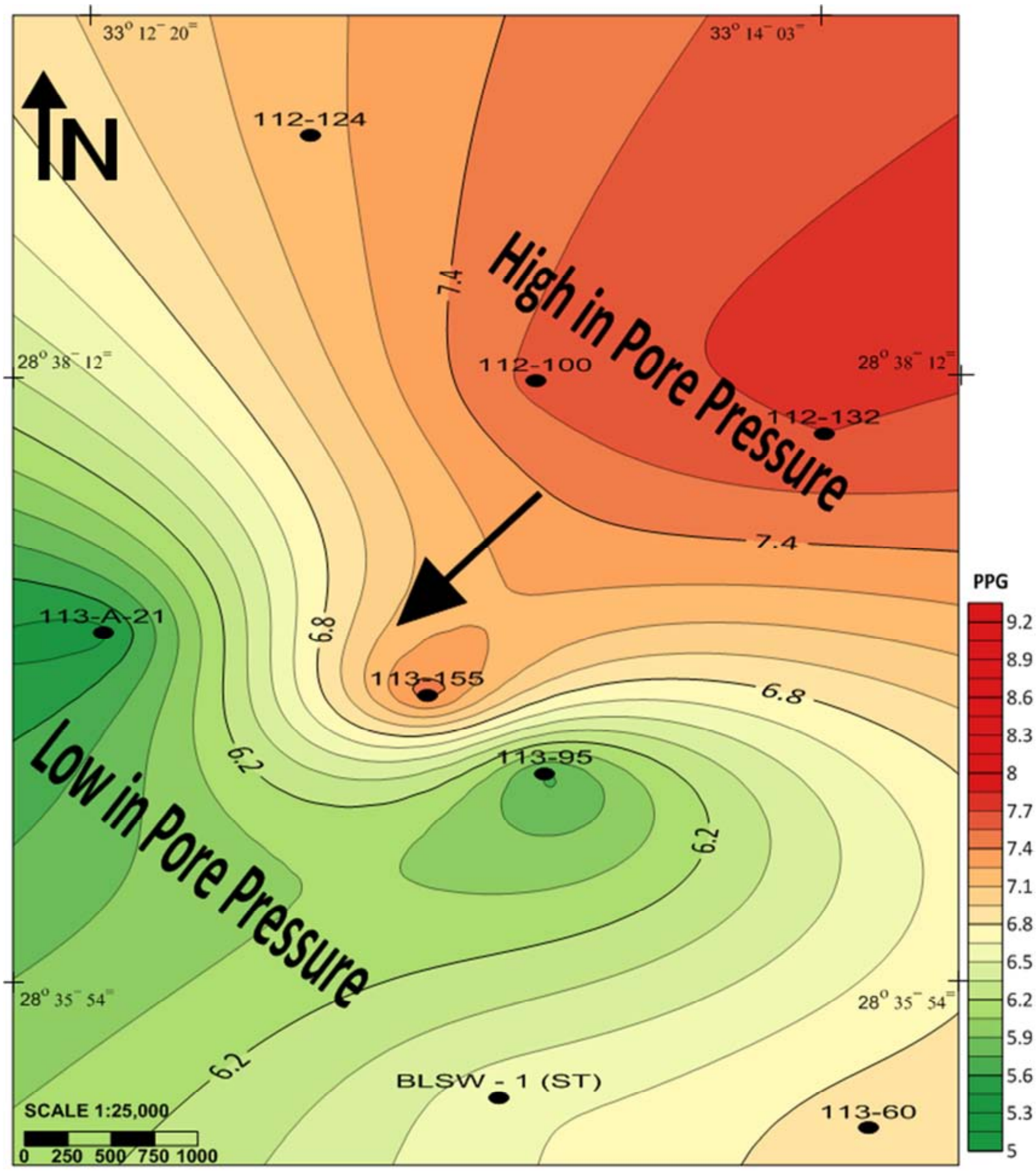

Figure 19. Pore Pressure Distribution Map to Kareem Formation.

Also from pore pressure evaluation for BLSW-1(ST) well in Kareem Formation reveal that the maximum pore pressure is 7.6 ppg and the average pore pressure is 6.6 ppg so, it is required drilling with mud weight more than 7.6 ppg for safe drilling.

Pore pressure evaluation by application (Eaton's) method to available wells in Kareem Formation reveals that decreases in pore pressure regime from the effect of depleted zones which appears as a deviation of pore pressure from the normal trend as result most of these wells were drilled after the field start-up which it may be occur artificially by reducing hydrocarbon and water from permeable formations. So, most of these wells in Kareem Formation required drilling with low mud weight for safe drilling and to avoid kick and formation damage.

Also, in this study pore pressure evaluation values in Kareem Formation represented in the map to show pore pressure distribution in the study area which used to define locations characterized with high pore pressure and low pore pressure where the lower pore pressure zones which represents a good location for development plans.

The pore pressure distribution map for Kareem Formation (Figure 19) Exhibits high pore pressure zones and low pore pressure zones in the study area where pore pressure increases in the northeast direction and decreases gradually to the southwest directions which also reflect hydrocarbon migration paths from higher zones to lower zones with consideration of fault pattern which represents conduits for fluid flow as appearing in structure map for the study area. So, from this study, we can say that the location of low pore pressure is a good location for development plans and design future wells.

6. Conclusions

This study carried out on available wells in Kareem Formation which spread in Belayim Land and it lies between longitudes 33˚12̀ and 33˚15̀ east and latitudes 28˚35̀ and 28˚40̀ north. This study started by calculating overburden Pressure, then normal compaction trends are identified for each well by using corrected drilling exponent responses (Dxc) and wireline logs responses (Resistivity and Sonic logs) Then by application of Eaton's equation method we can calculate the pore pressure to every well in Kareem Formation which shows that decreases in pore pressure regime as a common phenomenon of depleted pore pressure which found most frequently in the reservoir from which oil and gas have been produced and most of these wells were drilled after the field start-up. So it is recommended to drill with low mud weight for safe drilling and avoid kick and formation damage.

A pore pressure distribution map for Kareem Formation was constructed which shows that pore pressure increases in the northeast direction and decreases gradually to the southwest directions which reflect hydrocarbon migration paths from higher zones to lower zones with consideration of fault pattern which represents conduits for fluid flow. So, the location of low pore pressure is a good location for development plans and design future wells.

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