Available online at http://ijcpe.uobaghdad.edu.iq and www.iasj.net
Iraqi Journal of Chemical and Petroleum Engineering
Vol.19 No.4 (December 2018) 29 – 38
EISSN: 2618-0707, PISSN: 1997-4884

Estimating of Pore Pressure Gradient in Lower Fars Formation

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Abstract

In petroleum industry, the early knowledge of "pore pressure gradient" is the basis in well design and the extraction of these information is more direct when the pore pressure gradient is equal to normal gradient; however, this matter will be more complex if it deviate from that limit which is called "abnormal pore pressure", if this variable does not put in consideration, then many drilling problems will occur might lead to entire hole loss. To estimate the pore pressure gradient there are several methods, in this study; Eaton method's is selected to extract the underground pressure program using drilling data (normalized rate of penetration) and logs data (sonic and density log). The results shows that an abnormal high pressure is observed in Lower Fars formation started from Mb5 member as a transition zone and increase gradually until reach the Mb4 member and continuous to Mb3 and Mb2 then begin to decrease from Mb1 which is consider a transition zone between high pore pressure zone and sub-pressure zone represented by Jeribe-Euphrate and Upper Kirkuk formations and back to normal pore pressure at Middle-Lower Kirkuk formation. The dc-exponent method has been selected in estimating pore pressure gradient and considers the best one compared with logs data methods.

Keywords: pore pressure, pore pressure gradient, abnormal formation pressure, Lower Fars formation

Received on 07/10/2018, Accepted on 13/11/2018, published on 30/12/2018

https://doi.org/10.31699/IJCPE.2018.4.4

1- Introduction

The general meaning of pore pressure (or so-called formation pressure) is the pressure acting on the fluids contained in the pores of rocks. It is in theory equal to hydrostatic of fluids and it referred as normal pore pressure and practically it is may be equal, below or above that scale depending on different circumstances.

When pore pressure above the normal pressure it is called overpressure or geopressure, and when below the normal limit it is called sub pressure, both of them considered as abnormal which is the most difficult and important stage in well planning, since it causes common drilling problems such as stuck pipe, kicks of wells, loss of circulation, blowout, lost hole and any single or combination of these problems increase the non-productive time and therefore the total cost of drilling if not dealt professionally[**1**].

In worldwide oil fields, the problem of abnormal pore pressure is common in different formations, and its causes are attributed to combination of geological, geothermal and geochemical matter[**2**].

While drilling, there are three types of pressures will be faced, these pressures must be predefined and there is a plan to handle it to ensure a successful drilling process, the subsurface pressures are: overburden pressure, pore pressure, and fracture pressure.

This research is covered three fields from Missan oil fields (Abu Ghirab, Fauqi, and Halfaya) located near the southern- east borders of Iraq.

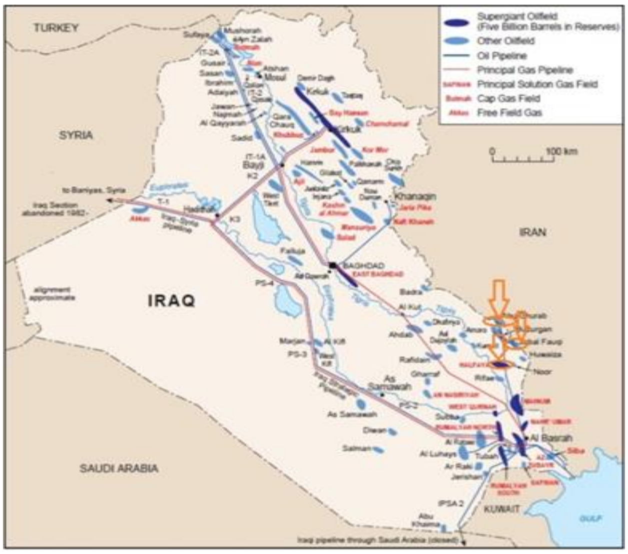

Fig. 1. Iraqi oil fields map and location of Abu Ghirab, Fauqi and Halfaya oilfields

2- Causes and Origin of Abnormal Pressure

2.1. Depositional Effect

a. Undercompaction of Shale

As deposits become buried deeper in earth's crust and rock layers formed, overburden pressure acting on these rock layers is increased, as a result, the layers compacted and its porosity decreased.

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Therefore; the fluid within the pore spaces escaped from the compacted formation with slow sedimentation results a normal compacted formation. In many cases, with rapid sedimentation, in another meaning, there is no balance between the rate of compaction of layers and the rate of escaping of fluids, the fluid could not escape out of the pores, in addition of the possibility of cap rocks existence with zero permeability, the fluid applied extra pressure and resulted overpressure zone.

b. Deposition of Evaporates

The presence of evaporites (such as salt) resulting an overpressure formation due to several causes; the first one, the uplifting of salt resulting from its low density (in comparison with surrounding rock layers) creates additional tectonic stress which leads to fold, fault, and break out the nearby layers, also the flow of salt upward may shut the broken rocks above formations (usually limestone and dolomite) and that leads to capture the pressure within these formations thus, pressure increases from its normal limit and is defined as overpressure formation **[3].**

c. Diagenetic Processes

Diagenetic are any physical or chemical alteration in sediments as a result of high pressure and temperature, it may be due to volume changes and water generation, recrystallization and lithification of the rocks, and the formation of new minerals which lead to abnormal pressure formation.

d. Tectonic Effects

Folding, faulting, and uplifting of underground layers is a results of tectonic effects. Folding is caused by compression of rocks and applied an additional horizontal stress which compact the clay laterally; in case of water cannot escape, abnormal pressure will result.

2.2. Structural Causes

a. Hydrocarbon Column

In dipping reservoir, the distribution of fluids (water, oil, gas) is according of their densities. Therefore; the pressure gradient of water will appear as abnormal in hydrocarbon column as compared with oil and gas.

b. Water Table and Artesian Effect

Water table is the level of which ground water will rise in a well. The existence of aquifer with higher elevation than the well site causes an abnormality in the reservoir pressure due to the difference of topographic nature (outcrop of aquifer is higher than the drilling site).

2.3. Thermodynamic Processes

a. Organic matter transformation (thermal cracking)

If thermal cracking of kerogen to form a simpler hydrocarbon compound at 90 degrees centigrade occurs in sealed environment, the result is high pore pressure.

b. Aquathermal Effects

The expansion of fluid within the rocks due to the increase of temperature with depth (geothermal gradient) will increase the pore pressure if the environment is totally sealed.

c. Permafrost

In freezing areas, the pressure around the well bore developed as a result of thawing and re-freezing of permafrost causing collapse in surface casing **[3]**.

3- Methods of Prediction Pore Pressure and Detection Abnormal Pressure Zones

3.1. Drilling Parameter Method

a. Rate of Penetration (ROP)

The basic concept of using ROP in detecting abnormal pressure formation summarized in two points:

- The compaction of any formation increases with depth due to the effect of overburden pressure, thus, ROP is decreasing with depth (assuming the other parameters are constant).
- The rocks are less compacted (more porous) in transition zone as compare with normal case, therefore; ROP will increase with depth and gives an indication of overpressure zone presence.

The rate of penetration increase because of the decreasing of the differential pressure (the difference between the drilling fluid pressure and formation pressure)[**4**].

b. d-exponent

Rate of penetration concept in detection of abnormal pressure zone is difficult to apply in practice since; the other drilling parameter (weight on bit, rotary speed, and bit size) cannot assume constant. A normalized ROP produced from an empirical equation used to detect abnormal pressure formations instead of ROP technique.

Bingham (1964) **[5]**, suggest the following generalized drilling rate equation:

$$R = aN^e\left(\frac{W}{D_h}\right)^d \tag{1}$$

Jordan and Shirley arranged equation (1) to be expressed in (d). The assumption of this equation based on the simplification of the drilled rocks value that doesn't change and its value (a equal to one) and the rotary speed exponent (e equal to one). This number concluded by experiments to be so close to one. The lithology and rotary speed variable dependencies were removed from this equation; according to above, the application of this formula only to a single type of lithology at the assumed single rotary speed. When the value approximately equal one based on the assumed values with the limitations of the equation, then it's not very restricted **[6].**

The following equation was produced based on these assumptions and accepting these limitations:

$$d = \frac{log\left(\frac{R}{60N}\right)}{log\left(\frac{12W}{10^6 D_h}\right)} \quad (2)$$

$$d = \frac{1.26 - log\left(\frac{R}{N}\right)}{1.58 - log\left(\frac{W}{D_h}\right)} \quad (3)$$

Equation (2) is for imperial units and (3) for metric units and they are known as the "d-exponent" equation. The values of penetration rate, rotary speed, weigh on bit, and bit size is can be measured at surface or it's known. The d-exponent value determination by the depth of entire well plotted against it.

Observed that, the d-exponent value varies oppositely by the drilling rate (R), when the bit penetrate an overpressure zone, there will be a decrease in differential pressure leads to increase in the rate of penetration and obviously, d-exponent will be decreased. Therefore; the plotting of d-exponent versus depth gives an indication of overpressure zone presence

c. Modified d-exponent (dc-exponent)

Rehm and McClendon **[7]** corrected d-exponent for the effect of drilling mud weight (dc-exponent); it can be calculated by applying equation (4).

$$dc = d\frac{\rho_n}{\rho_a} \quad (4)$$

3.2. Logs Methods

a. Sonic Log (Δt)

In normal shale compacted, the travel time decreases (velocity increases) with increasing burial depth as a result of decreasing shale porosity with continuity of matrix compression and that represented by fixed slop trend line varies from one region to another; the pressure of fluids within pores in this case called normal pore pressure. When an abnormal pore pressure formation penetrated, the data set of transit time will diverge toward abnormally high transit times for a given burial depth in case of high pressure formation, since the porosity is higher, or abnormally low transit time in subpressure formations.

The amount of divergence of a given point from the established "normal compaction trend" is related to the observed pressure in adjacent shale formation **[1]**.

b. Resistivity Log (R)

Hottman & Johnson (1965) **[8]** developed a relationship between shale resistivity and abnormal pressure formations. They improved that less compacted shale rocks (high porosity) is less resistive than compacted shale due to high water content in the first type.

They concluded that the normally compacted sediments have resistivity normal trend line increase with depth in shale section and any deviation from this trend gives indicate of abnormally pressure shale formation.

c. Density Log(ρ_b)

Using density log in estimating pore pressure gradient depends on the degree of shale compaction. Normally compacted sediment is denser than less compacted case, so that, the normal compaction trend line for density log increase with depth; when penetrated an overpressure formation, the data set of bulk density deviate toward less than the normal trend due to high porosity and fluid content there.

B. A. Eaton (1975) **[9]** developed four equations used to predict overpressure formation from drilling parameter (d-exponent) data and well logs data (sonic, resistivity, and conductivity). The assumption of Eaton's method, as shown in Terzaghi's equation (eq. (5)), is the overburden pressure is the combination of pore pressure and vertical effective stress (σ_z) :

$$S = P + \sigma_z \quad (5)$$

Eaton proved the accuracy of his equations depending on the quality of the input data and the proficiency of users. The following are Eaton's equations for pore pressure estimation.

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$$\frac{P}{D} = \frac{S}{D} - \left[\frac{S}{D} - \left(\frac{P}{D}\right)_n\right]\left(\frac{dco}{dcn}\right)^{1.2} \quad (6)$$

$$\frac{P}{D} = \frac{S}{D} - \left[\frac{S}{D} - \left(\frac{P}{D}\right)_n\right]\left(\frac{\Delta t_n}{\Delta t_o}\right)^{3} \quad (7)$$

$$\frac{P}{D} = \frac{S}{D} - \left[\frac{S}{D} - \left(\frac{P}{D}\right)_n\right]\left(\frac{R_o}{R_n}\right)^{1.5} \quad (8)$$

$$\frac{P}{D} = \frac{S}{D} - \left[\frac{S}{D} - \left(\frac{P}{D}\right)_n\right]\left(\frac{\rho_o}{\rho_n}\right)^{9} \quad (9)$$

Where, eq. (6) is for dc-exponent method, eq. (7) for sonic log method, Eq. (8) for resistivity log method, and eq. (9) for density log method.

4- Estimating of Pore Pressure by Eaton's Method using Geolog Software[10]

4.1. Hydrostatic Pressure Gradient

The first step in prediction pore pressure gradient is calculating hydrostatic pressure, the following equation used to calculate hydrostatic pressure.

$$\mathrm{PRESS_{HYD}} = \mathrm{Air\ press} + \mathrm{Water\ pres} + (\mathrm{PRGRD_{WATER}} * \mathrm{DEPTH_{BML}}) \quad (10)$$

Air pressure could be calculated by equation (11) for onshore case, and water pressure calculated for offshore case only.

$$Air\ press = (ELEV_{MEAS_{REF}}) - (SURFACE_{ELEV}) * 0.001 * 0.4334 \quad (11)$$

The above equation assumed that the porosity is interconnected and extends back to the surface through the overlying sediments; water pressure gradient is 0.465 psi/ft as default. The hydrostatic pressure gradient could be calculated by dividing the hydrostatic pressure by the depth of the interested point.

4.2. Normal Compaction Trend Line (NCT)

After calculating hydrostatic pressure, the next step is determining the normal compaction trend lines (NCT) for input electrical logs (sonic transit time, velocity, density, and resistivity) or drilling data (d-exponent, sigmalog); this line could be determined by empirical methods (Hottman, Eaton, Miller, Bowers, and Zhang) or manually according to the trend of data set in normal compacted shale formation.

4.3. Overburden pressure gradient

It is the pressure exerted, on a specific point, by the total weight of both the rock's grains and fluids within the pores. The density of the combination is called the bulk density (ρb). The overburden pressure gradient varies with depth because of the variations of formation density; this is a result of the variations in the types of rocks, the densities of fluids, and the compaction degree of rocks**[3]**.

In geolog software, the overburden pressure module computes overburden pressure from integrating bulk density log values over depth by the following equation:

$$PRESS_{OB} = air\ press + water\ press + 0.4334 * \int_0^D \rho_b(D)\, dD \quad (12)$$

Where the water pressure is used for only offshore situation, and the 0.4334 factor is used for converting density (g/cc) to pressure, air pressure is calculated in onshore situation using equation (11).

If density log information is not available for all intervals, it is often estimated from sonic transit time (P-wave velocity); in IP software there are three methodologies those of Gardner[**11**], Bellotti et al**[12]** and Lindseth**[13]** and the following equations represented these methods respectively:

$$\rho_b = a{v_p}^b \quad (13)$$

Where a and b are constants (a=0.23, b=0.25)

$$\rho_b = 3.28 - \Delta t/89 \quad (14)$$

$$\rho_b = 2.75 - 2.11(\Delta t - 47)/(\Delta t + 200) \quad (15)$$

Where, eq. (14) is for consolidated formations and eq. (15) for unconsolidated formations.

$$\rho_b = (v_p - 3400)/(0.308 * v_p) \quad (16)$$

Overburden gradient could be calculated for any point by dividing the overburden pressure of this point by its depth.

4.4. Pore Pressure Gradient

The last step is to estimate pore pressure by Eaton's methods using equations from 6 to 9 which applied on dc-exponent, sonic, resistivity, and density data respectively.

5- Cases Under Study

The data of three fields (Abu Ghirab oilfield, Fauqi oilfield, Halfaya oilfield) represent in three wells are selected for this research which are: AGCS-44, FQCS-32, , and HF013-M013. Data sets available for each well are drilling parameter data (ROP, RPM, WOB, D_h) and logs data (ρ_b, Δt, GR, CAL, Bit size).

6- Calculations

6.1. Overburden Pressure Gradient

The overburden pressure is calculated using equation (12). The water pressure is neglected because they are onshore wells and the air pressure is calculated using equation (11), the surface elevation and elevation of measurement reference is defined for each well in well header. In these cases, ρ_b data is not available for whole depth so, it is estimated using sonic log data by applying Gardner method using equation (13) which gives minimum average percentage error equal 3.6% as comparison with measured ρ_b data of a specific interval.

6.2. Normal Compaction Trend Line (NCT) Determination

a. dc-exponent method

By applying equation (2) on drilling parameters data (ROP, RPM, WOB, Bit size) the d-exponent is calculated; then, it is corrected for the effect of mud weight using equation (4) and the value of normal mud weight (ρ_n) used is 1.08 gm/cc as referred in final well reports, dc-exponent results is obtained and plotted versus depth on semi-log paper; the interval of normal compacted shale is determined from final geological reports.

In normal formation pressure zone the dc-exponent increase with depth as a result of decreasing ROP; so that, the equation of NCT is estimated from the trend of dc-exponent in normal compaction shale interval as a function of depth with positive slop and the equation of it is constant for each field as follow:

Table 1. NCT equations of dc-exponent

Field	NCT equation	Units
Abu Ghirab oilfield	$dc_n = 0.75e^{0.000143D}$	-
Fauqi oilfield	$dc_n = 0.8e^{0.0001D}$	-
Halfaya oilfield	$dc_n = 0.9e^{0.0001D}$	-

b. Sonic Log (Δt) Method

The data set of Δt decreasing with depth when plotting on semi-log paper; so that, the trend of NCT for sonic log in normal compacted shale interval is with negative slop and constant as a function of depth for each field as follows:

Table 2. NCT equations of Δt

Field	NCT equation	Units
Abu Ghirab oilfield	$dt_n = 123.6e^{-0.0002328D}$	us/ft
Fauqi oilfield	$dt_n = 125e^{-0.00023D}$	us/ft
Halfaya oilfield	$dt_n = 114e^{-0.0001878D}$	us/ft

c. Density Log (ρ_b) Method

The data set of ρ_b.has a positive slop trend line; since, in normal compacted interval the density of rocks increase with depth due to the increasing of compaction and reducing of porosity. The NCT of rock density as a function of depth for each field is as follow:

Table 3. NCT equations of $\boldsymbol{\rho_b}$.

Field	NCT equation	Units
Abu Ghirab oilfield	$\rho_n = 2.2 + 0.000132D$	gm/cc
Fauqi oilfield	$\rho_n = 2.183 + 0.00014D$	gm/cc
Halfaya oilfield	$\rho_n = 2.223 + 0.000108D$	gm/cc

6.3. Pore Pressure Gradient Estimation

Pore pressure value will be estimated using Eaton equations and depending on the normal compaction trend line for each field using three methods (dc-exponent, Δt, and ρ_b) the overburden pressure gradient results obtained as referred in (6.1.) for each well,), the normal pore pressure gradient is calculated using equation (10). The results are obtained by geolog 8.0 software.

a. dc-exponent method

Pore pressure gradient by dc-exponent method is calculated using equation (6), the observed dc-exponent is calculated using equations (3) and (4) as mentioned above and the normal dc-exponent represented by normal compaction trend line and it is a function of depth, its equations for each field inserted in Table **1**.

b. Sonic Log Method

Pore pressure gradient by sonic method is calculated using equation (7), the normal transit time represented by normal compaction trend line and it is a function of depth, its equations for each field inserted in **Table 2**.

c. Density Log Method

Pore pressure gradient by ρ_b method is calculated using equation (9), the normal bulk density represented by normal compaction trend line and it is a function of depth, its equations for each field inserted in **Table 3**.

7- Results

The results of hydrostatic, overburden, and pore pressures and their gradients are inserted as figures below:

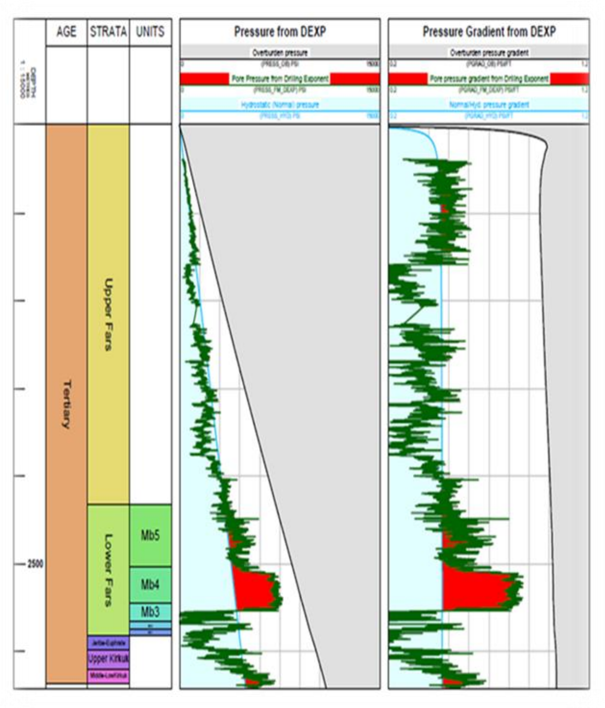

Fig. 2. Pore pressure, overburden pressure, normal hydrostatic pressure and their gradients for AGCS-44 by d-exp. Method

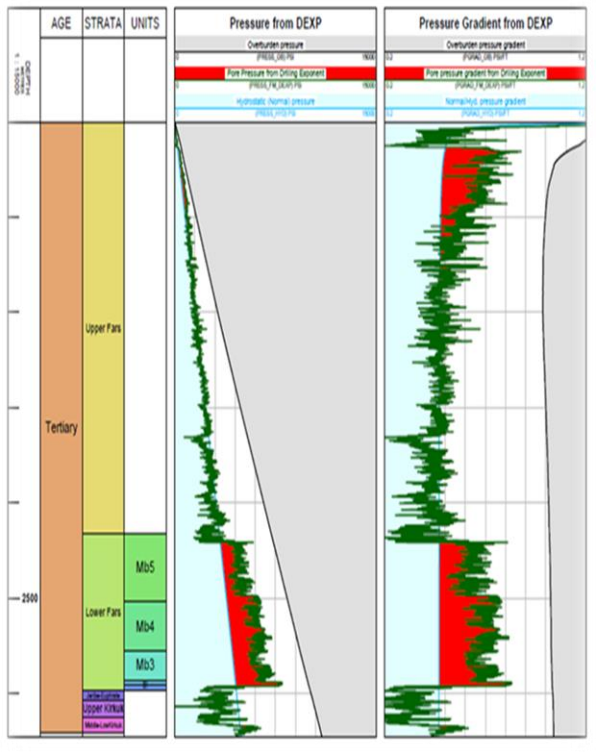

Fig. 3. Pore pressure, overburden pressure, normal hydrostatic pressure and their gradients for FQCS-32 by d-exp. method

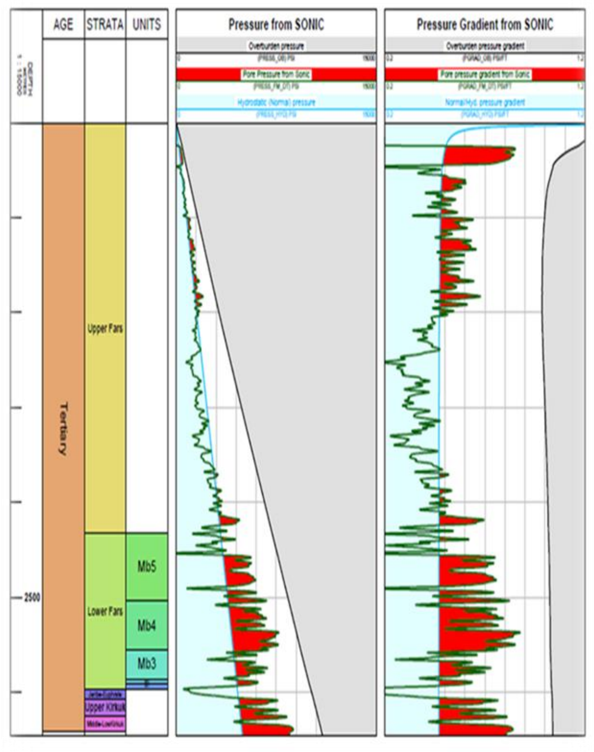

Fig. 5. Pore pressure, overburden pressure, normal hydrostatic pressure and their gradients for AGCS-44 by sonic method

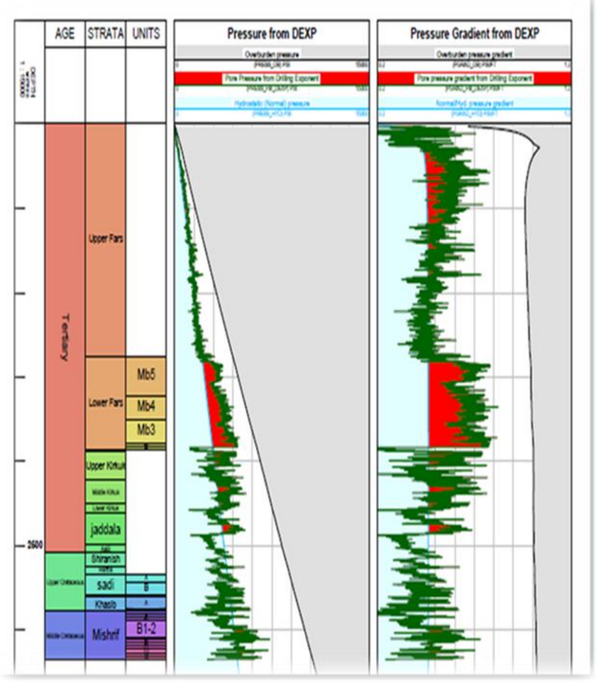

Fig. 4. Pore pressure, overburden pressure, normal hydrostatic pressure and their gradients for HF013-M013 by d-exp. method

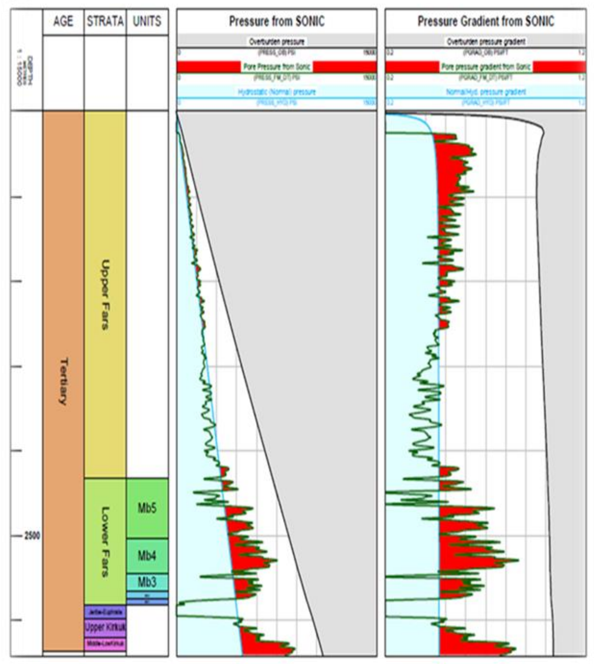

Fig. 6. Pore pressure, overburden pressure, normal hydrostatic pressure and their gradients for FQCS-32 by sonic method

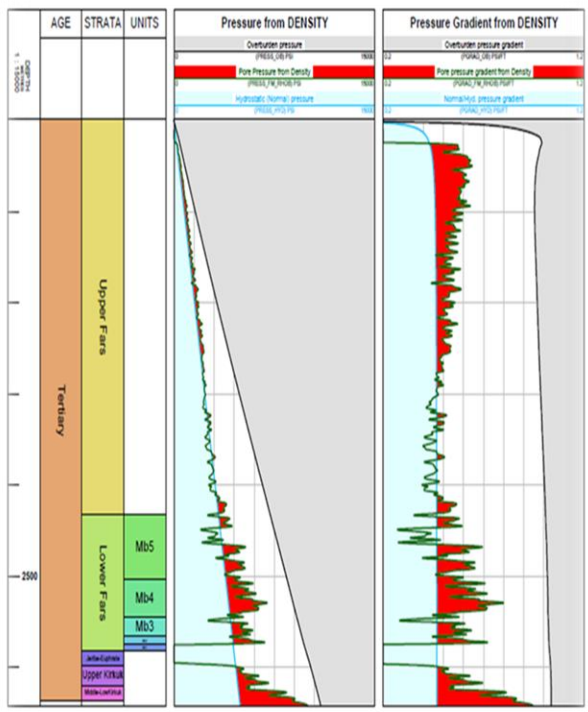

Fig. 7. Pore pressure, overburden pressure, normal hydrostatic pressure and their gradients for AGCS-44 by $\rho_b$method

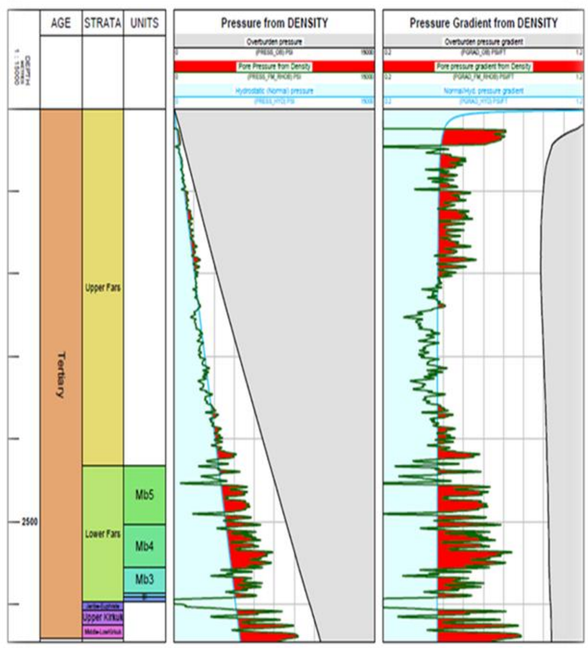

Fig. 8. Pore pressure, overburden pressure, normal hydrostatic pressure and their gradients for FQCS-32 by ρ_b method

8- Discussion

The estimating of pore pressure using the three methods (dc-exponent, Δt, and ρ_b) give approximated results as will be shown in Figure (A-1) ; but, the results of dc-exponent method will be taken into account for the following reasons:

- It considers a real time record data and it inevitable presence in every well.
- The data of sonic log dose not presence in the whole interval in some well also the data of density log presence for only reservoirs intervals to achieve the total cost optimization.
- Logs data records are for every (0.1 m); thus, these huge data cannot be handled issue only after pruning it and this cannot always be true. But it can be used as confirmation methods.

By observing figures from Fig. **1** to Fig. **8** can be inferred that:

1- In Abu Ghirab oilfield, the deviation of pore pressure from the normal limit start from Mb5 member in Lower Fars formation and increase gradually until it reach the pick point in Mb4 about (0.85 psi/ft) in (AGCS-44) and continue in the same limit until it reach Mb1 which consider a pressure transition zone between overpressure zone and sub-pressure zone represented by Jeribe-Euphrate and Upper Kirkuk when the whereas the lost circulation is a common problem there and back to normal limit equal approximately (0.468 psi/ft) at Middle-Lower Kirkuk formation.

2- In Fauqi oilfield, the same behavior of underground pore pressure as Abu Ghirab oilfield; however, the pick point is concentrated in well FQCS-32 and reaches (0.71 psi/ft) at Mb4 member in Lower Fars formation.

3- In Halfaya oilfield, the Lower Fars formation is shallower than Abu Ghirab and Fauqi oilfields; the pore pressure gradient is the lowest there and reaches (0.68 psi/ft) as pick point at Mb4 in HF013-M013.

The previous results showed that the peak point of Mb4 pore pressure gradient concentrated in AGCS-44 well in Abu Ghirab oilfield at X= 726439 m; Y= 3584470 m coordinates, FQCS-32 well in Fauqi oilfield at X=741865 m; Y=3555520 m coordinates , and HF013M-M013 at X=737332.; Y=3506843.84 m coordinates. If these wells are dotted according to their location on the same paper, the locations of well according each other will be as the following figure:

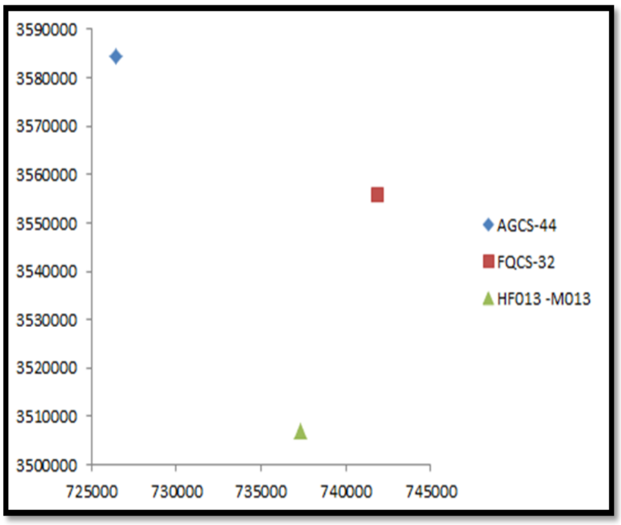

Fig. 9. Location of AGCS-44, FQCS-32, and HF013-M013

The main reason of pore pressure increasing after the nature of precipitation in this area comes from the north, the Taurus and Zacros Mountains are the result of the movement of Arabian plate and its collision with the Eurasian plate; this reaction began to fade gradually in the southern direction forming anticlines and domes turned into oil traps with the impact of lateral high pressure on their layers. That impact is represented in the 3D direction and the z direction will represent the pore pressure gradient for Mb4 member in Lower Fars formation as follow:

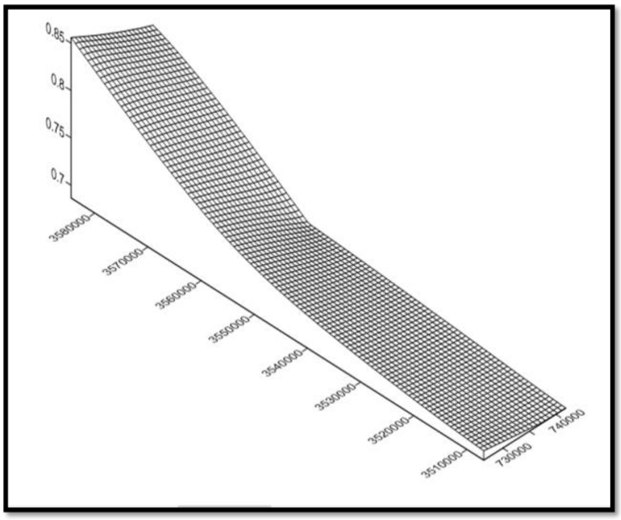

Fig. 10. Pore pressure gradient with distance in Mb4 member in Lower Fars

And when compared with the map of Iraqi fields at Fig. **1**, this direction represent the point of convergence with the aforementioned collision zone.

9- Conclusion

1- The main high pressure formation in this area is Lower Fars formation and its pore pressure gradient value varies from one location to another.
2- The causes of abnormally increasing in pore pressure at Lower Fars formation are the nature of precipitation layers in this formation and the external pressures applied from the vertical and lateral directions causes.
3- The lateral stresses are the results of a reaction resulting from movement of Arabian plate and shocked with the Eurasian plate.
4- The overburden pressure gradient is not constant in this region and increase with depth.
5- The drilling parameter method is better than logs methods in estimating pore pressure gradient.

Nomenclature

Symbols	**Description**	**unit**
Air PRESS:	air pressure	psi
CAL:	Caliper log	in
D:	depth	m
D_h:	Hole diameter (bit size)	in
D:	Drilling exponent	-
Dc:	Correct drilling exponent	-
Dcn:	Normal dc	-
Dco:	Observed dc	-
$DEPTH_{BML}$:	Mean sea level depth	m
$ELEV_{MEAS_{REF}}$:	Elevation of measurement reference	m
GR:	Gamma ray	GAPI
M_{w1}:	Normal mud weight	Gm/cc
M_{w1}:	Actual mud weight	Gm/cc
N:	Revolutions per minute	RPM
P:	Pore pressure	psi
p_w:	Fracture pressure	psi
$PRESS_{HYD}$:	Hydrostatic pressure	psi
$PRGRD_{water}$:	Water pressure gradient	Psi/ft
R:	Rate of penetration	m/hr
R_O:	Observed resistivity data	Ohm.m
R_n:	Normal resistivity data	Ohm.m
s:	Overburden pressure	psi
$SURFACE_{ELEV}$:	Elevation of drilling surface	M
V_p:	Compressional velocity	Ft/us
W:	Weight on bit	tons
Water press:	Water pressure	psi

Greek Symbols	**Description**	**unit**
Δt:	Sonic compressional transit time	us/ft
Δt_n:	Normal transit time	us/ft
Δt_o:	Observed transit time	us/ft
Δt_s:	Shear transit time	us/ft
ρ_b:	Bulk density of rock	gm/cc
ρ_n:	Normal bulk density	gm/cc
ρ_o:	Observed bulk density	gm/cc

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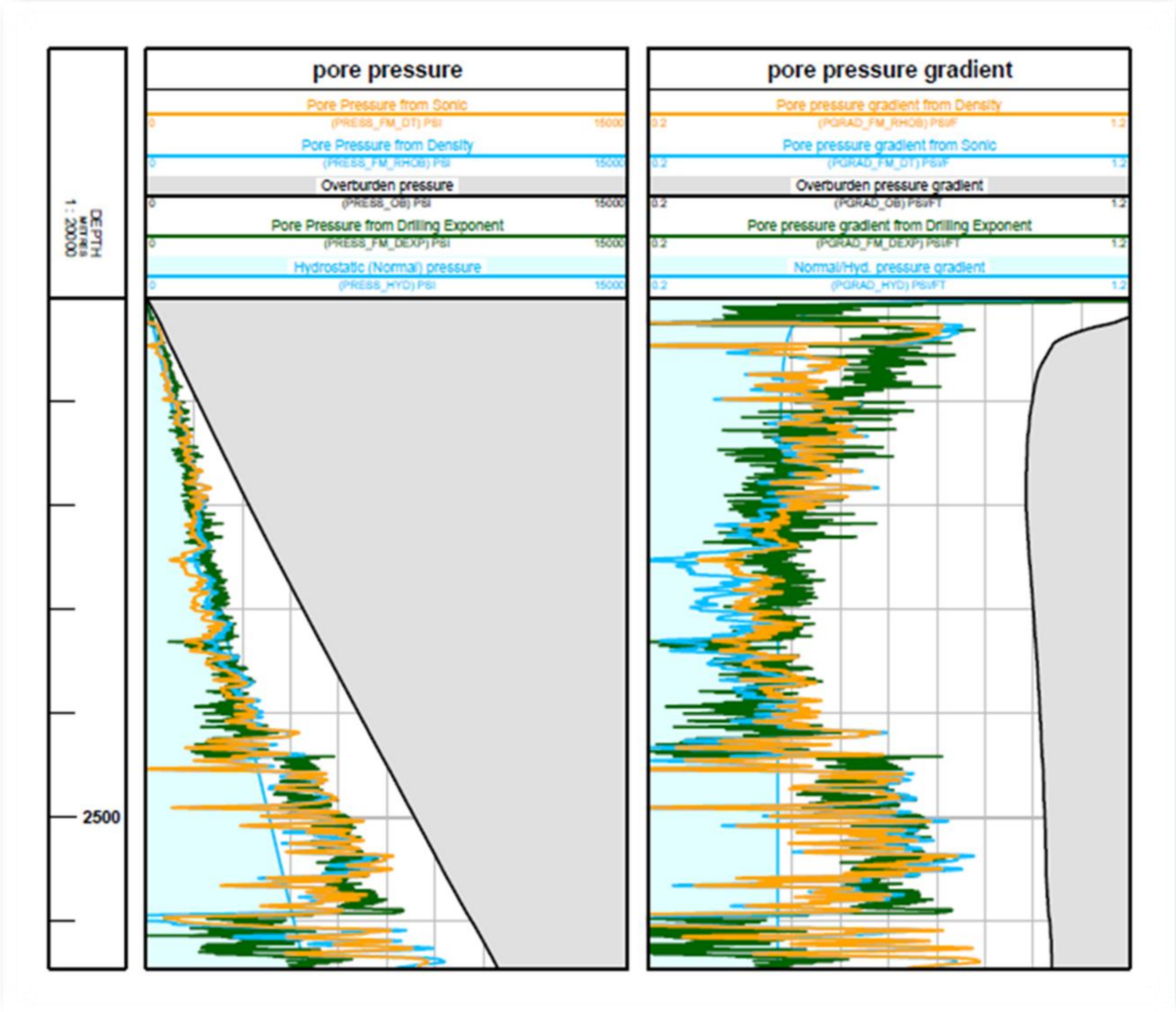
Appendix A

Comparison between dc-exponent, ρ_b, and Δt methods in estimating pore pressure gradient for FQCS-



تقدير تدرج الضغط المسامي في تكوين الفارس الاسفل

الخلاصه

في الصناعة البترولية ، تشكل المعرفة المبكرة عن "تدرج ضغط المسام" الأساس في تصميم البئر; يكون استخلاص هذه المعلومات في أكثر مباشرة عندما يكون تدرج الضغط المسامي مساويا للتدرج الطبيعي.

ومع ذلك ، ستكون هذه المسألة أكثر تعقيدًا إذا كانت تنحرف عن ذلك الحد وهذا يسمى "ضغط المسام غير الطبيعي" ، إذا لم يضع هذا المتغير في الاعتبار ، عندها سيحدث العديد من مشاكل الحفر قد يؤدي إلى فقدان كامل للبئر. لتقدير التدرج ضغط المسام هناك عدة طرق ، في هذه الدراسة ؛ يتم اختيار طريقة إيتون لاستخراج برنامج الضغط تحت الأرض باستخدام بيانات الحفر (مؤشر الحفر dc–exponent) وبيانات السجلات (سجل الصوت والكثافة). تظهر النتائج أنه لوحظ ارتفاع في تدرج الضغط المسامي يبدأ من تكوين الفارس الاسفل (Lower Fars) يبدأ من المنطقه Mb5 كمنطقه انتقاليه وتتزايد تدريجيا حتى يصل الى Mb4التي تعتبر منطقة الضغط العالي في ذلك التكوين وتستمر الى Mb3 و Mb2 ثم يبدأ الضغط بالتناقص من منطقة Mb1 التي تعتبر منطقة انتقاليه بين منطقة الضغط العالي ومنطقة الضغط المنخفض المتمثله بتكوين –Jeribe (Euphrate) و (Upper Kirkuk) ومن ثم تعود الى منطقة الضغط الطبيعي في تكوين (–Middle Lower Kirkuk).

ان طريقة مؤشر الحفر (dc–exponent) تم اختيارها في تخمين تدرج الضغط المسامي وتم اعتبارها أفضل طريقه بالمقارنه مع الطرق الاخرى المتمثله ببيانات المجسات.