Sudan University of Science and Technology

College of Petroleum Engineering and Mining

Petroleum Exploration Department

Prediction of Pore pressures gradient profile using wire line-logging data

Prepared by:

- *Abu-Bakr Abdulla khaier abdelfatah*
- *Alaaeldein Nasereldein Ali Fadoul*
- *Mohammed Abdalrouf Mohammed Hamid*
- *Mo**ham**med khaled* Ahmed Idreis

Supervisor:

DR.Abdalhakm Eltayeb Mohamed

External Supervisor:

Eng.Ateeg Abdelrazig

November 2020

الآيــة

قال تعالى :

﴿قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ﴾

سورة البقرة

الآية (32)

Dedication

To candles always lighten my life, loved parents…

To my family and other loved ones ….

To anyone who has showed me friendship and kindness
during my education travel…

Humbly, accept this work.

Acknowledgement

It is our pleasure to extend our deep thanks and gratitude to

DR.Abdalhakm Eltayeb Mohamed

for his extended supports and directions to gain the most from this research.

We extend our great thanks to

External Supervisor:
External Ateeg Abdelrazig Mohammed

Power Station, and we name Eng. Salah for his assistance.

We appreciate the great support and help from friends in Exemplar Training Center.

Abstract:

Pore pressure prediction prior drilling a well is most essential for selection of casing, setting depth, and optimum mud weight .

If the pore pressures are not accurately predicted prior to drilling, catastrophic incidents, such as well blowouts, may take place and endanger the life of personnel beside we might lose the well completely

The well will be drilled in normal formation using mud weight gradient as higher slightly than normal pore pressure gradient (0.465psi/ft.). On the other hand, when we encounter abnormal formation (> 0.465psi/ft.) the mud weight should be increased higher than when we are in normal situation as stated before.

It has been observed that sonic and resistivity reading can qualify or indicate the occurrence of the abnormal pressure (qualitative tools). To quantify pore pressure as a figure, EATON used empirical equation from his observation from the qualitative behavior of both resistivity and sonic (quantitative tools)

In this research the pore pressure gradient, over pressure gradient and fracture pressure gradient are predicted and plotted vs. Depth by using Eaton empirical equations (resistivity &sonic well log data) using IP software program (Interactive Petro physics) in order to facilitate the calculation of pore pressure (formation pressure).

The values of pore pressure at specified depth that obtained from curve are correlated to the values obtained from same depth through direct calculation using equations related to pore pressure prediction; the values of pore pressure show approximately the same results.

التجريد

التنبؤ بضغط التكوينات الصخرية قبل البدء بعمليات الحفر ضروري لاختيار عمق تثبيت بطانة الحفر بالاضافه لاختيار كثافة سائل الحفر المناسبة. اذا لم نتنبأ بضغط التكوينات قبل الحفرفإن احداث خطيرة قد تحدث مثل اندلاع الابار و التي قد تعرض حياة العمال للخطر و في احيان كثيرة قد تفقد البئر مجملا.

الابار التي تحفر في تكوينات طبيعية لا تحتاج الي سائل حفر ذو كثافة عاليه جدا اما التكوينات غير الاعتياديه تحتاج الي سائل حفر ذو كثافة اعلى .

قد لوحظ من قراءة المقاومة الكهربائية و الموجات الصوتية انها تشير بصورة نوعية الي وجود الضغوط العاليه و غير الاعتياديه و منها استفاد العالم ايتون في استنتاج قيم كمية بإستخدام معادلات مبتكرة .

في هذا البحث استفدنا من فكرة ايتون في حساب ضغط التكوين الصخري مستخدمين برنامج IP لتسهيل عملية الحساب و إختصار الوقت و الجهد .

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Chapter One

Introduction

1. **Introduction:**

1.1 general Introduction

Pore pressure (the fluid pressure in the pore spaces of the subsurface formation) and fracture gradient are two important aspects to be (safety, cost effectiveness and the efficiency of the overall drilling program (Jayasinghe et al., 2014). Hydrostatic pressure (the gradient is equal to 0.465 psi/ft.) (normal pore pressure) exerted by static column of fluid varies according to the density of the fluid (Osborne and Swarbrick,1997).

The situation of the normal pore pressure happens where the water escape from pore, and then accordingly the grains will so close to each other as the depth of burial increases (normal compaction). The trend of porosity plotting versus depth will show an exponential reduction in porosity. On the other hand where the water cannot escape from pores, the will prevent the formation to be compacted as more as the normal situation, also could be called as compaction disequilibrium (under compaction). The porosity at concerned depth will deviate from normal trend. The pore pressure gradient at the aforementioned situation will be higher than the hydrostatic pressure, and then the abnormal pressure will occur.

Abnormally high pore pressure may result in a drilling hazard if the precautionary measures are not taken into consideration care. Prediction of pore pressure is essential in well planning, selection of casing point (Low and spencer , 1998;Ruth et al ,2002).

Pore Pressure Gradient and Fracture Gradient considerations impact the technical merits as well as the financial aspect of the well plan (Chennakrishnan,2008) In areas where elevated Pore Pressure Gradients are known to cause difficulty for drillers, having an accurate pressure prediction at the proposed location is critical to a successful drilling operation. Pre-drill estimation of Pore Pressure Gradient is the standard practice for major oil companies (Mukherjee et al.,2009).

Abnormal pore pressures, particularly overpressures, can greatly increase drilling non-productive time and cause serious drilling incidents (e.g., well blowouts, pressure kicks, and fluid influx) if the abnormal pressures are not accurately predicted before drilling and while drilling. Study on 2,520 shelf gas wellbores drilled in the Gulf of Mexico shows that more than 24% non-productive time was associated with incidents of kicks, shallow water flow, gas flow and lost circulation (Dodson, 2004).

Pore Pressure Gradient and Fracture Gradient information guide the development of the mud schedule, the casing program, rig selection and wellhead ratings. Each of these aspects of well planning is capital intensive and benefit from having a good pre-drill estimate of Pore Pressure Gradient (Mukherjee et al.,2009).

Fracture gradient is calculated by dividing the fracture pressure by true vertical depth (Zhang, 2011).Fracture pressure can be obtained directly from leak-off test (LOT). Knowledge of fracture gradient is essential in mud designing, cementing, matrix and fracture acidizing, hydraulic fracturing, and fluid injection in secondary recovery (Eaton, 1969).

1.2 Problem statement: -

The Pore pressure in deepest sedimentary formations are not hydrostatic; instead they are over pressured and elevated even to more than double of the hydrostatic pressure If the abnormal pressures are not accurately predicted prior to drilling, catastrophic incidents, such as :

- kick
- Blow out.
- Lost well.
- Stuck pipe

1.3 Objective

Main project objective:

1. Prediction of pore pressure gradient from well logging data through IP software program
2. To prepare pore pressure – depth curve from pore pressure values
3. Calculate pore pressure values at specified depth using , analytical method
4. Compare the values obtained from IP software to the values calculate through analytical method

Chapter Two

Background & literature review

2.1 Sonic or acoustic log: -

The sonic or acoustic log measures the travel time of an elastic wave through the formation. This information can also be used to derive the velocity of elastic waves through the formation.

Its main use is to provide information to support and calibrate seismic data and to derive the porosity of a formation.

The main uses are:

1. Determination of porosity (together with the FDC and CNL tools).
2. Strata graphic correlation.
3. Identification of lithology.
4. Fracture identification.
5. Identification of compaction.
6. Identification of over-pressures.

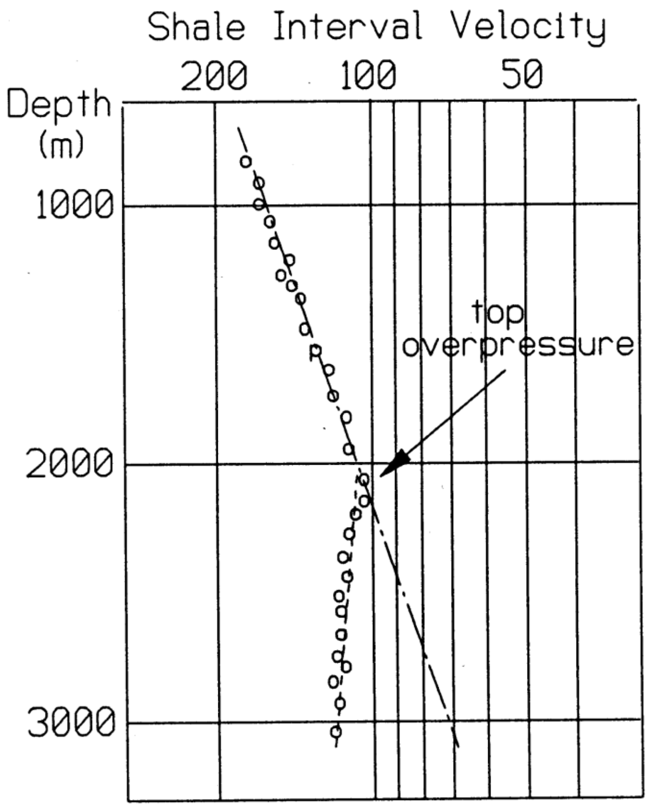


Figure 2.1 the interval velocity

2.1.1. Overpressure: -

The sonic log can be used to detect over pressured zones in a well. An increase in pore pressures is shown on the sonic log by a drop in sonic velocity or an increase in sonic travel time .

Plot interval transit time on a log scale against depth on a linear scale . In any given lithology compaction trend will be seen. If there is a break in the compaction trend with depth to higher transit times with no change in lithology, it is likely that this indicates the top of an overpressure zone.

Table (1) bulk density

Compound	**Composition**	**Actual Bulk Density**
Quartz	SiO_2	2.654
Calcite	$CaCO_3$	2.710
Dolomite	$CaCO_3.MgCO_3$	2.870
Anhydrite	$CaSO_4$	2.960
Sylvite	KCL	1.984
Halite	NaCl	2.165
Gypsum	$CaSO_4.2H_2O$	2.320
Anthracite (low)		1.400
Anthracite (high)		1.800
Coal (Bituminous)		1.200
Coal		1.500

2.2 Formation density log:

The formation density log measures the bulk density of the formation. Its main use is to derive a value for the total porosity of the formation. It's also useful in the detection of gas-bearing formations and in the recognition of evaporates.

The formation density tools are induced radiation tools. They bombard the formation with radiation and measure how much radiation returns to a sensor

Comparison of apparent density measured by the formation density tool with the actual bulk density for common mineralogist and fluids:

2.3 Total gamma ray log: -

The gamma ray log measures the total natural gamma radiation emanating from a formation. This gamma radiation originates from potassium-40 and the isotopes of the Uranium-Radium and Thorium series. The gamma ray log is commonly given the symbol *GR*.

Once the gamma rays are emitted from an isotope in the formation, they progressively reduce in energy as the result of collisions with other atoms in the rock (*Compton scattering*). Compton scattering occurs until the gamma ray is of such a low energy that it is completely absorbed by the formation.

2.3.1 Uses of the Total Gamma Ray Log: -

- Determination of Lithology
- Determination of Shale Content
- Depth Matching
- Cased Hole Correlations
- Recognition of Radioactive Mineral Deposits
- Recognition of Non-Radioactive Mineral Deposits

2.3.2 Determination of Lithology:

The gamma ray log is an extremely useful tool for discrimination of different lithology's. While it cannot uniquely define any lithology, the information it provides is invaluable when combined with information from other logs.

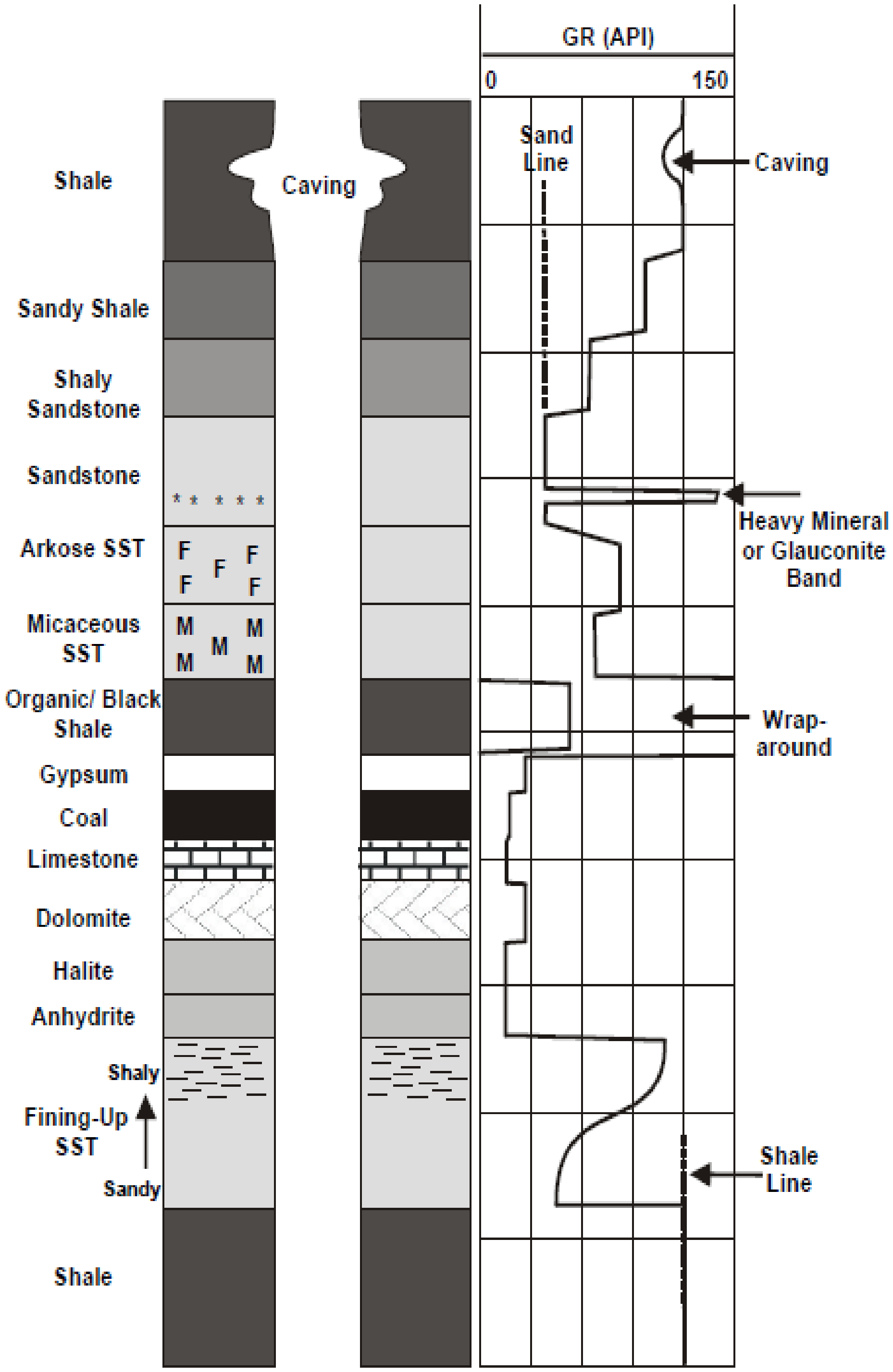


Figure 2.2 Gama ray log

2.4 Resistivity Theory:

Relate the resistivity of a formation to the resistivity of the fluids saturating a formation, the porosity of the formation and the fractional degree of saturation of each fluid present. As always, the story begins with Ohm's Law.

Law states that the current flowing from point A to point B in a conductor *I* is proportional to the difference in electrical potential □*E* between point A and point B. The constant of proportionality is called the electrical conductance *c*. Current is measured in amperes (A), potential difference in volts (V), and conductance in Siemens (S)

$$I = c\,\Delta E$$

Thus, if we take a cylindrical rock sample with two flat faces A and B, and set a potential difference $\Delta E = EA - EB$ between its end faces, a current I will flow through the rock from face A to face B . If we measure the current and the potential difference, we can calculate the resistance of the rock sample using eq1

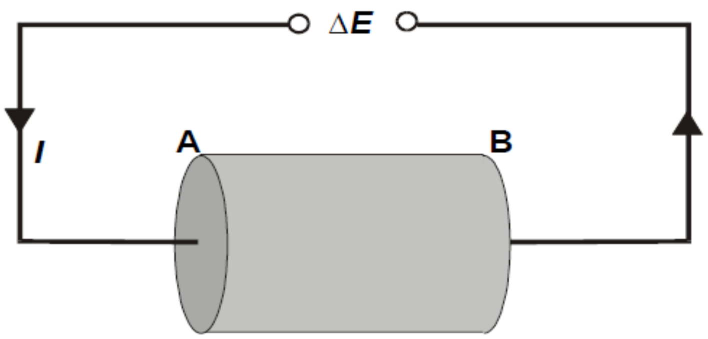


Figure 2.3 resistivity of rock in lap

2.4.1 Ohm's Law for a rock sample.

1. If the resistance is high, a given potential difference ΔE will only give a small current *I*.

2. If the resistance is low, a given potential difference ΔE will give a high current I.

The value of resistance is a property of the material which describes how much the material resists the passage of a current for a given applied potential difference.

Imagine that the size of our rock sample now changes.

So the resistance (and therefore conductance) depends upon the size of the sample.

2.4.2 Resistivity of Rocks:

Reservoir rocks contain the following constituents

Table (2) leave of resistivity

Material	Resistivity
Matrix material	High resistivity
Formation waters	Low resistivity
Oil	High resistivity
Gas	High resistivity
Water-based mud filtrate	Low resistivity
Oil-based mud filtrate	High resistivity

2.5 Literature review

The classic paper on fracture gradient prediction was presented by Hubbert and Willis (1957). They presented an equation predicting fracture extension pressure for vertical fractures based on overburden pressure gradient, pore pressure gradient, and approximate ratio of horizontal stress to vertical stress (matrix stress coefficient). A fracture gradient may also be readily derived by system computer from the pore pressure gradient using Poisson's ratio for rock, as described in Eaton

(1969). They assumed that the pressure in the fracture was equal to pore pressure plus the horizontal component of vertical stress on the rock. Matthews and Kelly (1967) and Eaton used the equation of Hubbert and Willis along with measured formation breakdown pressures to develop an empirical matrix stress coefficient that allows calculation of formation breakdown pressure, often simply called fracturing pressure. Regression techniques are used to derive a predicted pore pressure to interval transit time relationship (U.S. Pat., 1992) once the relationship of interval transit time to pore pressure is empirically determined, one may estimate pore pressures at locations away from an actual well by applying the relationship to interval transit times determined by common depth point (CDP) gathers of seismic survey data. The well planner must be cautious about calculated values that always result in the lowest fracture gradient being at the casing seat. When depths of lost circulation were found in the Gulf Coast, the losses were within 500 ft. of the casing seat only 80% of the time. Thus, where fracture gradient prediction is critical, the well planner should carefully check the accuracy of calculations against leak off tests and experience in the vicinity. A graph of fracture gradient versus depth should be provided as a basis for casing design, or as a minimum the fracture gradients at the casing seats should be shown.

Initially, all simulations were based on the black-oil fluid model, where the hydrocarbon system is represented by two pseudo-components, oil and gas, according to their status at standard conditions. In the early 1980s, compositional simulation, where the hydrocarbon system is represented by an arbitrary number of components and pseudo-components (e.g. Verma and Aziz, 1996), became more mature and ready to use. The development of compositional simulation makes it possible to simulate volatile oil reservoirs, CO_2 flooding and other EOR processes. However, compositional simulation is much more expensive than black-oil simulation, due to the larger number of unknowns per grid block and complex flash behavior.

Chapter Three

Methodology

3- Methodology:

3.1 Problem description:

The Pore pressure in deepest sedimentary formations are not hydrostatic; instead they are over pressured and elevated even to more than double of the hydrostatic pressure

If the abnormal pressures are not accurately predicted prior to drilling, catastrophic incidents, such as well blowouts may take place.

3.2 Data description:

In this research IP software program are used IP designed based on EATON formulas input data .

3.3 input data :

for IP software are depended on well logging (sonic log , gamma ray ,resistivity ,formation density log) this data were collected through log recorded from HAMRA _SE well .

3.4 Output data :

The values of pore pressure and fracture gradient are output data of IP software program .

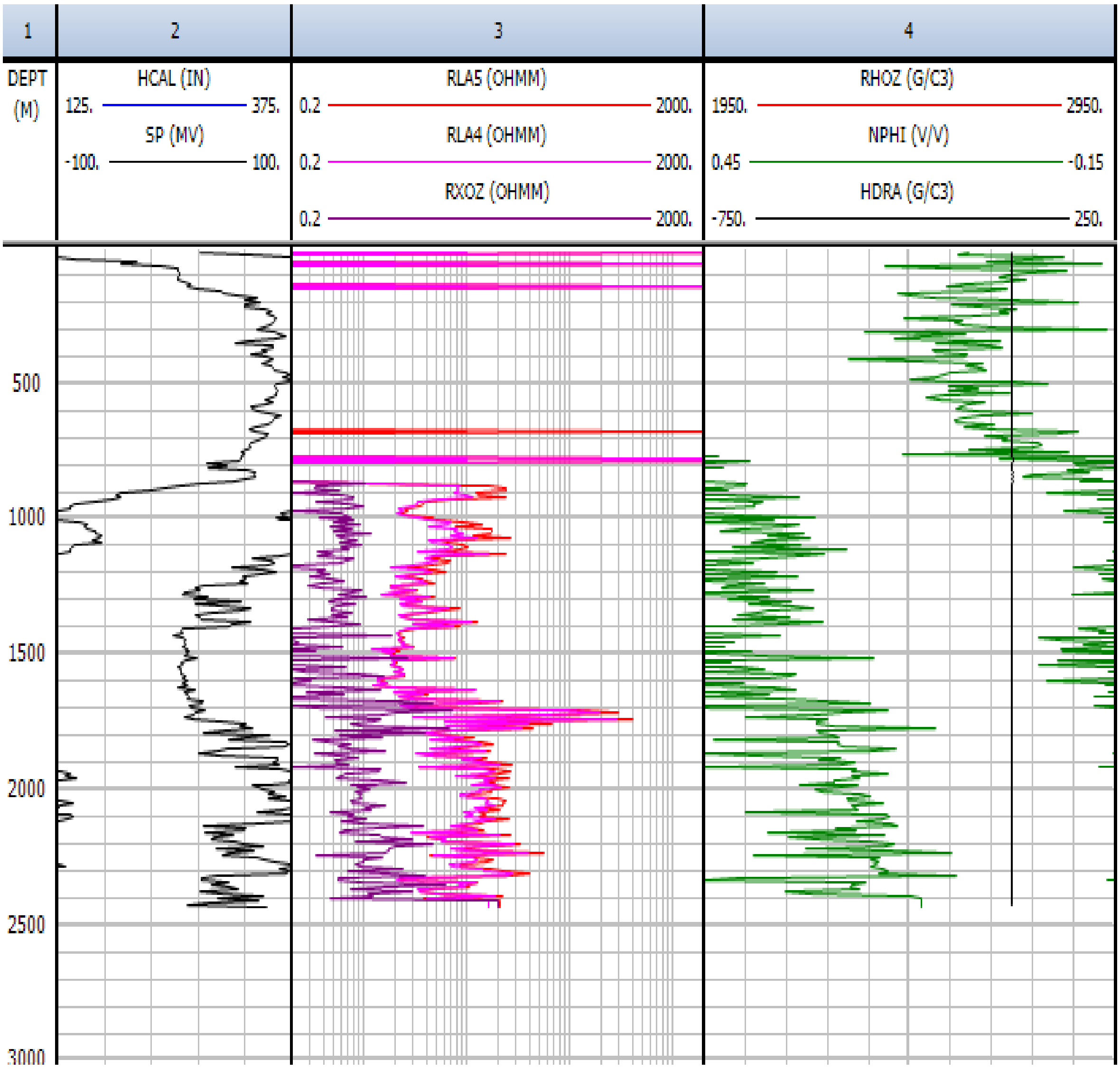


Figure 3.1 Gamma Ray(GR), Formation density log (RHOZ), resistivity log (RLA5) and sonic log (DTCO)

3.5 mud weight data.

Table (3): mud weight data

Depth		MW
from	To	
344	519	8.7
519	788	9.1
788	868	9.2
868	1048	9.5
1048	1127	9.5
1127	1298	9.5
1298	1398	9.5
1398	1560	9.7
1560	1762	9.7
1762	1906	9.8
1906	2070	10
2070	2193	10
2193	2279	10
2279	2295	10.1
2295	2305	10.2
2305	2323	10.3
2323	2425	10.4
2425	2431	10.4
2431	2540	9.8
2540	2585	9.8
2585	2700	9.9
2700	2844	9.9
2844	3000	9.9
3000	3104	10
3104	3190	10
3190	3206	10
3206	3234	10
3234	3240	10.1
3240	3291	10.1
3291	3337	10.3
3337	3363	10.3
3363	3414	10.3
3414	3421	10.3
3421	3486	10.3
3486	3538	10.3
3538	3555	10.3
3555	3596	10.3
3596	3613	10.3
3613	3629	10.3
3629	3636	10.3
3636	3656	10.3
3656	3699	10.3
3699	3739	10.3
3739		10.3

using the IP (interactive petro physics) software program and by entering of well logging data. we can obtain pore pressure gradient, overburden gradient, facture pressure and Mud window.

3.6 Calculate shale volume from gamma ray loge:

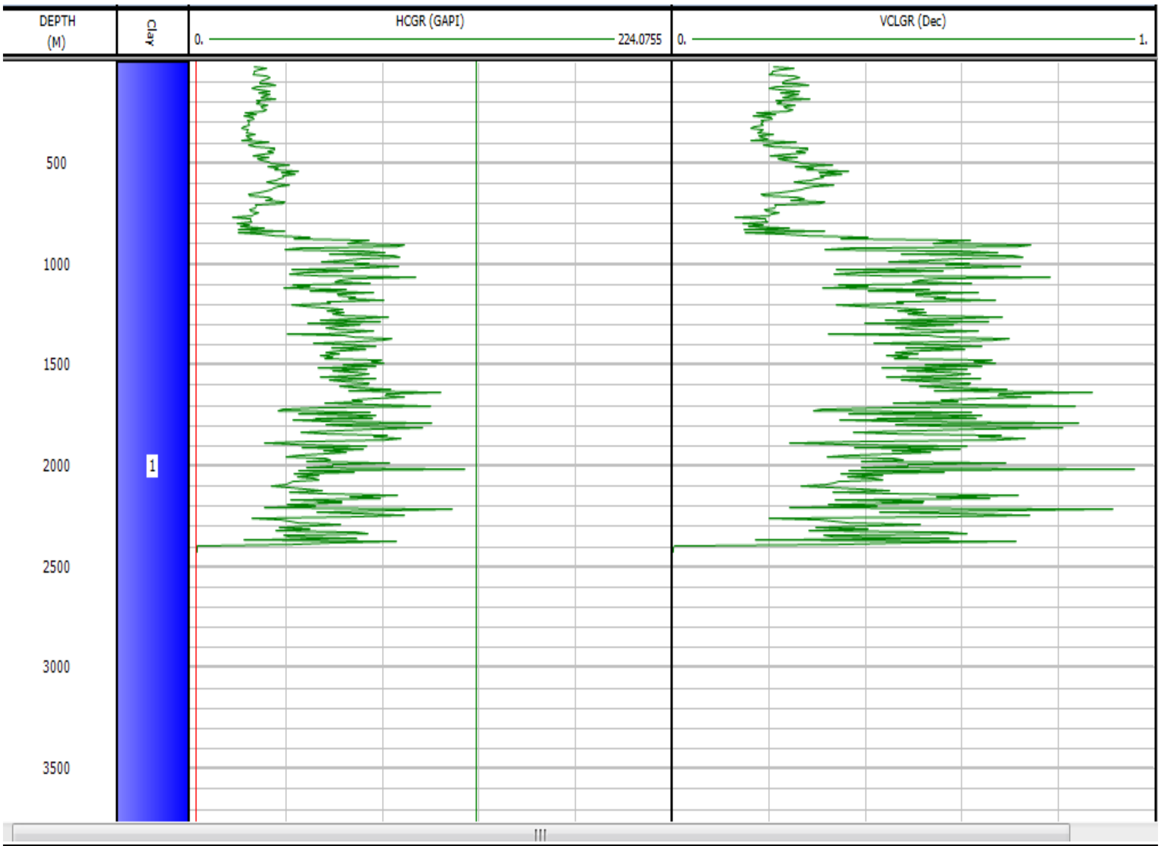


Figure 3.2 volume of shale from gamma ray log

overburden pressure *calculation:* -

$$S=P+\sigma \text{--} \quad (1)$$

P = fluid pressure

S=overburden pressure

σ =stress in the spring

$$p=0.052*\rho b * D \text{------------------------------------} \quad (2)$$

D = the vertical depth or higher of the column

ρb= bulk density (RHOZ)

3.7 calculate over burden gradient curve & over burden pressure curve by using IP program the :

3.7.1 input data: depth & bulk density curves

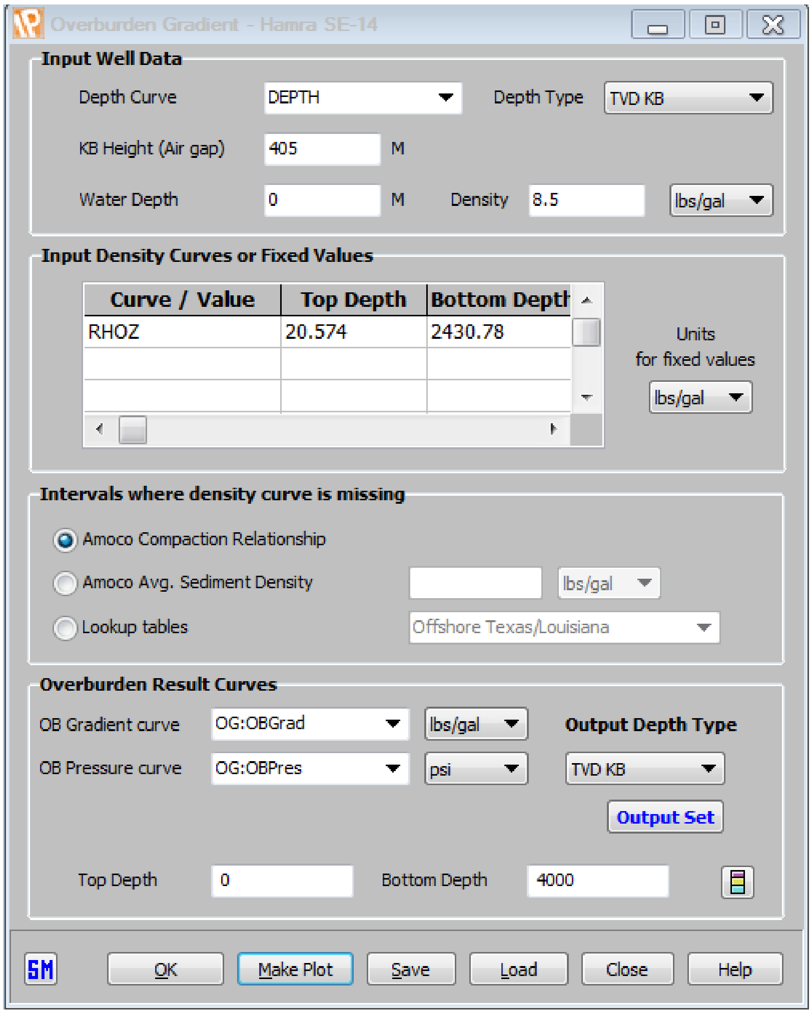


Figure 3.3 input data of depth & bulk density

3.7.2 Outpot :

- **Over burden Gradient curve**
- **Over burden pressure curve**

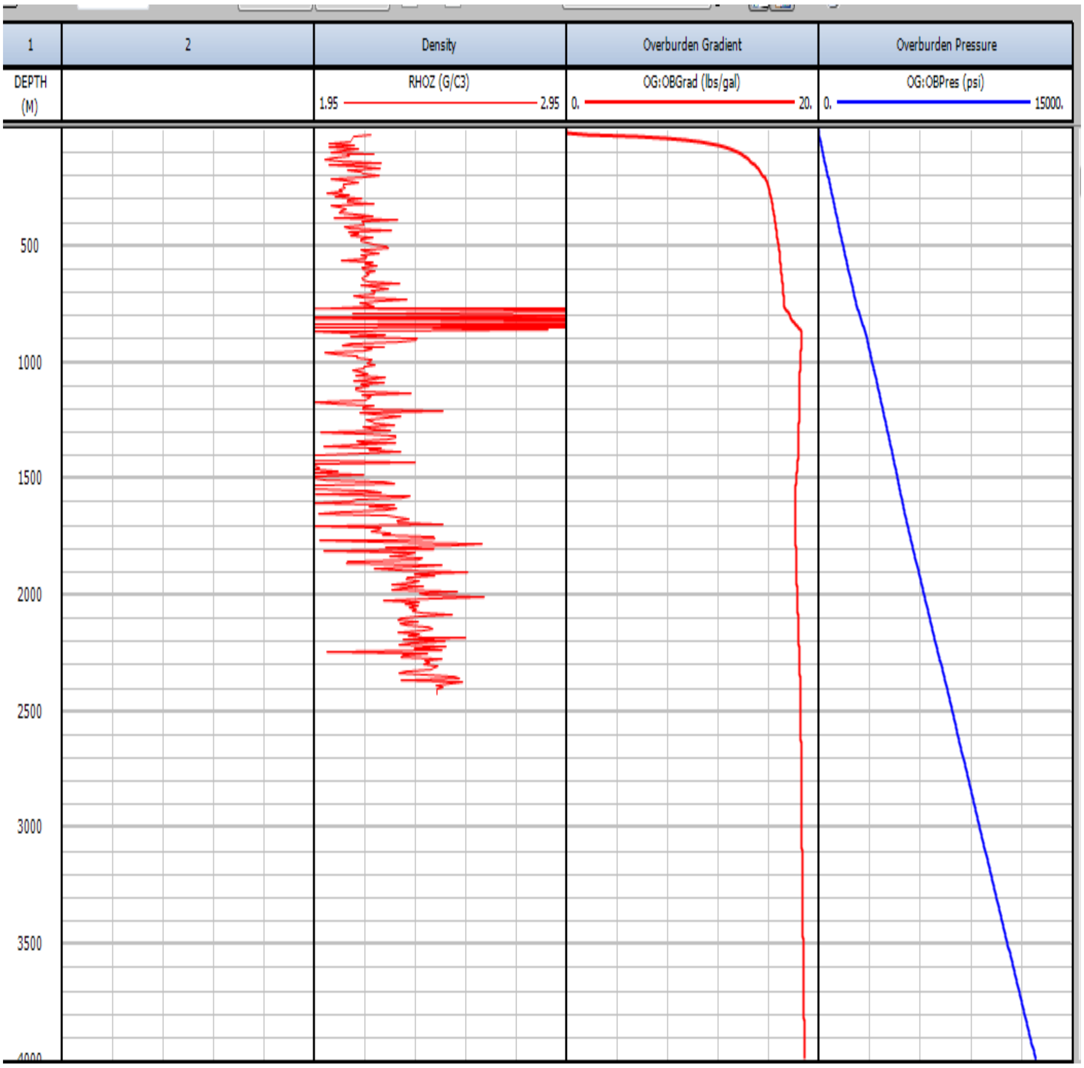


Figure 3.4 output data of over burden Gradient curve& Over burden pressure curve and bulk density

(–): over burden Gradient curve

(–): Over burden pressure curve

3.8 Porosity calculation: -

$$\Phi = {}^{(\rho m - \rho b)}\!\big/_{(\rho m - \rho f)} \text{-----------------------------------} \ (1)$$

Φ = porosity **of the rock**

ρm=matrix density

ρb=bulk density

ρf= fluid density

3.9 Average porosity calculation: -

$$\Phi = \Phi_0 e^{(-kDs)} \text{---} \quad (2)$$

Φ= average porosity

Φ_0=surface porosity

K=porosity decline constant

Ds= depth below the surface

$$K = \frac{Ln(\Phi_0/\Phi)}{Ds} \text{--} \quad (3)$$

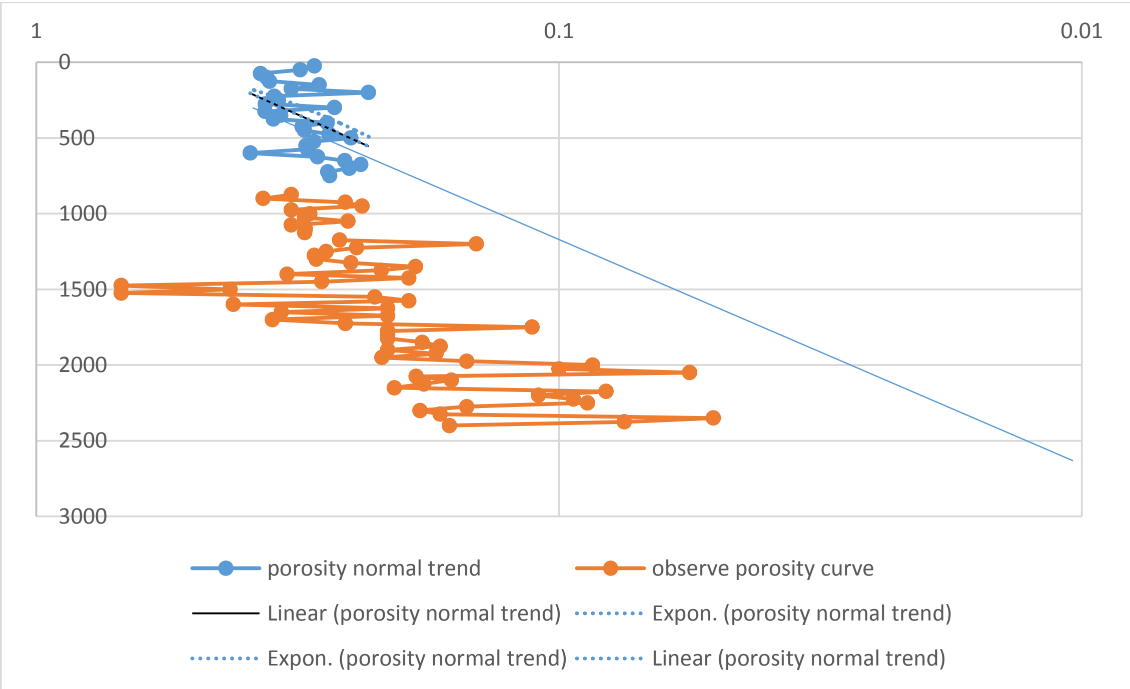


Figure 3.5 curve porosity

3.10 Pore pressure gradient prediction from resistivity log :-

Gp=Go-$|Go - Gn| * \left(\frac{Ro}{Rn}\right)^{1.2}$ -------------------------------(9)

Gp=pore pressure gradient $psi/_{ft}$

Go=overburden gradient$psi/_{ft} \simeq 1$

Gn=normal pore pressure gradient $\simeq$ 0.465

R0=reading observed from resistivity log

Rn=reading from normal resistivity trend

3.11 Pore pressure gradient prediction from sonic log:

$$\mathbf{Gp=Go\text{-}|Go - Gn| * \left(\frac{\Delta Tn}{\Delta To}\right)^3} \text{------------------------------ (9)(5)}$$

ΔTn=normal reading

ΔTo= observe reading

Gp=pore pressure gradient $^{psi}/_{ft}$

Go=overburden gradient$^{psi}/_{ft}\simeq 1$

Gn=normal pore pressure gradient $\simeq 0.465$

plotted pore pressure gradient/pressure by(IP) software using well logging data(sonic-resistivity-GR) - mud weight information –overburden gradient-

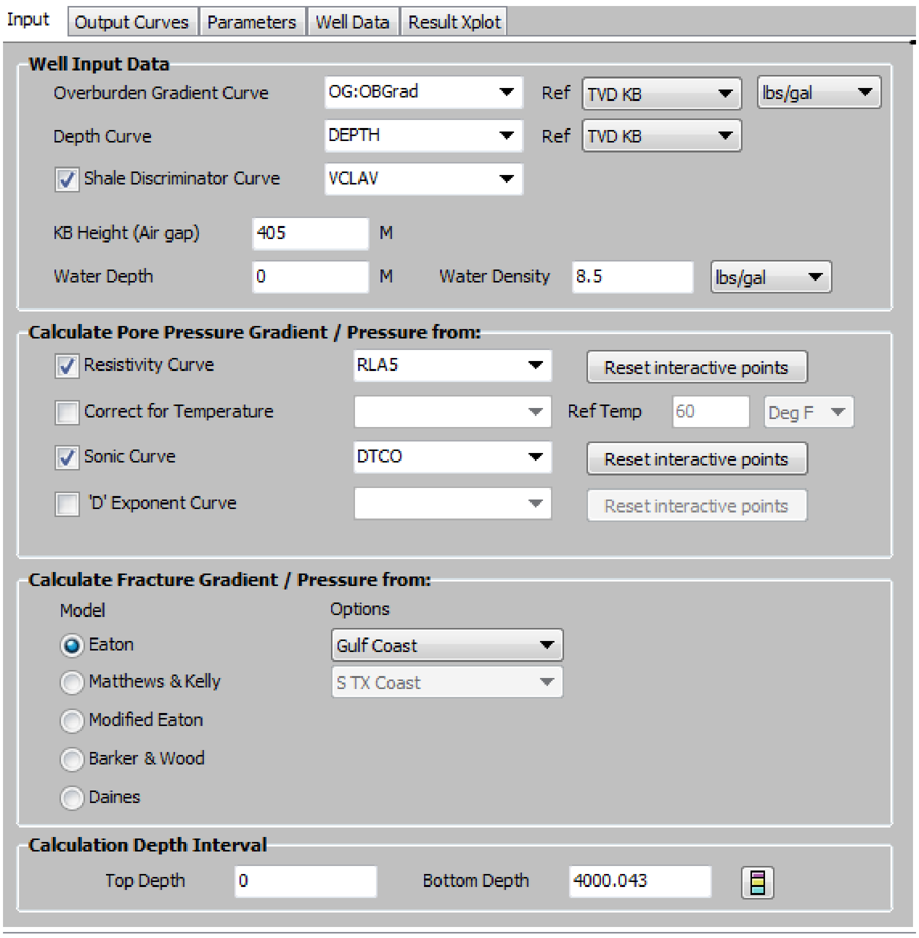


Figure 3.6 input data of resistivity and sonic curve by using EATON equation

3.12 Input data :

We input mud weight information from well data to creat curve of hydrostatic pressure of mud weight in well .

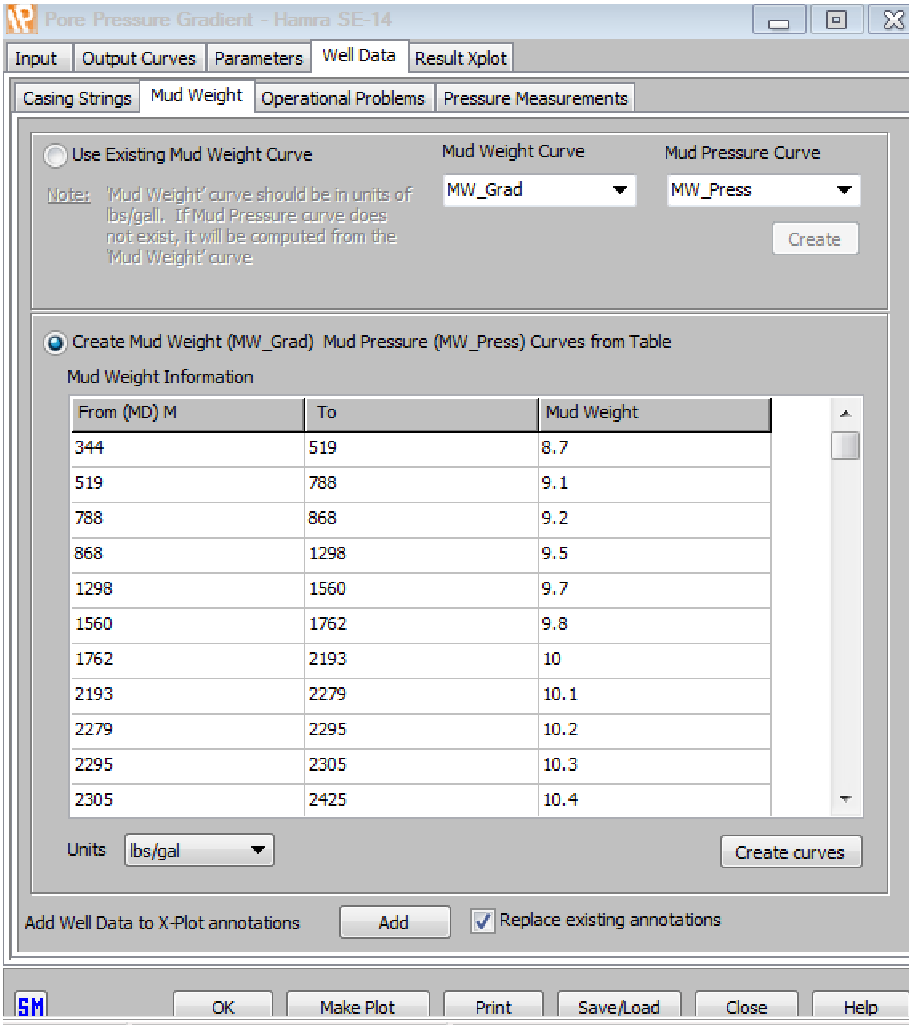
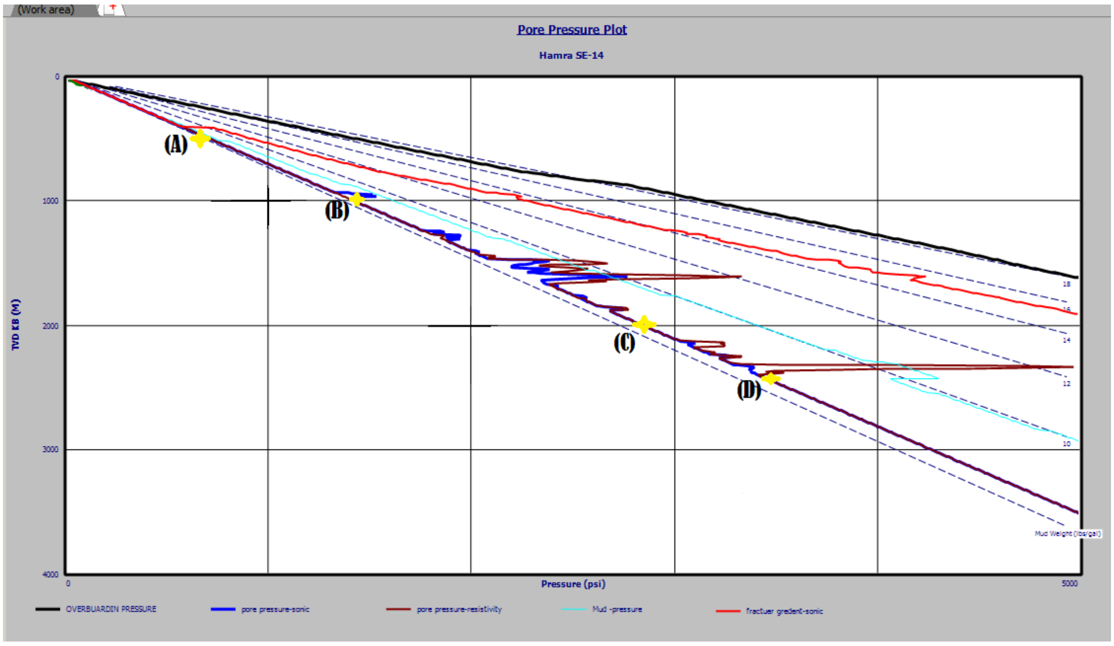


Figure 3.7 input of depth and mud weight

3.13 Output data :



(Figure 3.8 final result of input data)

(——) overburden graden

(——) pore pressure sonic

(——) pore pressure resistivity

(——) mud pressure

(——) fracture gradient sonic

Since the two curves of pore pressure (sonic& resistivity) are relatively identical, this increases the certainty that the predictions are correct.

Result

In depth from (0-800 m), normal pore pressure is observed, and the mud weight higher slightly than the pore pressure.

At depth from (1500—1700 m), (2200—2400 m) observed the (sonic-electrical resistivity) pore pressure curve are deviated from normal trend of pore pressure curve (increase in pore pressure) , In this case the drilling mud pressure should be increased to equilibrium the formation pore pressure increased

We are correlation by theory equation

$$\sigma_{ob} = \rho_{sw} g D_w + \rho_g g D_s - \frac{(\rho_g - \rho_{fl}) g \phi_o}{K} (1 - e^{-KD_s}).$$

$$K = \frac{\mathbf{Ln}(\Phi_0/\Phi)}{\mathbf{Ds}}$$

Φ_0=0.293%

Φd=0.16%

Ds=7872 ft

$$K = \frac{\mathbf{Ln}(0.293/0.16)}{7872} = 0{,}000076$$

$$=0+0.052*2.6*8.33*1-\left(\frac{0.052*(2.6-1)*(8.33)*(0.293)}{0.000076}\right)*(1-e^{-0.000076*1}) = 0.92\text{psi/ft}$$

P=0.052*ρf

ρf =pore fluid de density

p= 0.052*8.33=0.433 psii/ft

Table (4): correlated Pore pressure from IP vs. Pore pressure from equation

Points	Depth (m)	Depth (ft.)	Pore pressure from IP(psi)	Pore pressure from equation psi)
A	500	1640	716	710
B	1000	3280	1433	1420
C	2000	6560	2867	2840
D	2400	7872	3424	3408

Theoretical calculation was made for specified depths points and the results were correlated against the same depth point.

The results drawn show slight deviation between these values, and this indicate the results approximately the same as shown on the table above.

Chapter Four

Conclusion & Recommendations

4-1 Conclusion:

Using wire-line logging readings (resistivity and sonic) as quantitative tool in calculating pore pressure utilizing Eaton empirical equations for both resistivity and sonic via IP software is a powerful tool in predicting pore pressure especially in disequilibrium compaction (under -compaction). In order to crosschecking the results, the two methodologies of calculating have been compare each one to the other which mean that the figures of each methods should be close to each other.

4-2 Recommendations:

For further accuracy of the calculated figures which are captured from Eaton empirical equations, the methodologies should be applied widely in the entire the field or area from the beginning of the exploration stage, besides conducting calibration with actual data like RFT, MDT and DST

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