بِسْمِ اللَّـهِ الرَّحْمَـٰنِ الرَّحِيمِ

Sudan University of Science and Technology

College of Petroleum Engineering and Mining

Department of Petroleum Exploration Engineering

Pore Pressure Prediction Using D-exponent Method for Hamra E-8 well - Hamra oil field, block 2A - Heglig

توقع الضغط المسامي باستخدام طريقة مؤشر الحفر d لبئر حمرة E- 8

حقل حمرة - مربع A ٢ منطقة هجليج

Prepared By Students:

- Abdalhkam Ahmed Abdalla Sdeig .
- Abdelbagi Alameen Abdellah Alameen .
- Elyagout Nasraldayn Mohammed Abdalla .
- Musadag Omer Mohammed Elhassan .
- Mutwakil Suliman Abdallah Dafallah .

Supervisor :

Dr. Adil Abdelmagid Saad .

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هذا المشروع مقدم إلى كلية هندسة النفط و التعدين - جامعة السودان للعلوم والتكنولوجيا - كإنجاز جزئي لأحد المتطلبات الأساسية لنيل درجة البكالوريوس مرتبة الشرف في هندسة إستكشاف النفط .

- **إعداد الطلاب** :
  - ❖ الياقوت نصرالدين محمد عبدالله .
  - ❖ عبدالباقي الأمين عبدالله الأمين .
  - ❖ عبدالحكم أحمد عبدالله صديق .
  - ❖ متوكل سليمان عبدالله دفع الله .
  - ❖ مصدق عمر محمد الحسن .

- **مشرف المشروع :**

د. عادل عبد الماجد سعد التوقيع ....

- **رئيس قسم هندسة إستكشاف النفط :**

د. أميمة حسن تركمان التوقيع ....

- **عميد كلية هندسة النفط والتعدين :**

د. إلهام محمد محمد الخير التوقيع ....

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الاستـهلال

قال تعالى:

(هُوَ الَّذي جَعَلَ الشَّمسَ ضِياءً وَالقَمَرَ نورًا وَقَدَّرَهُ مَنازِلَ لِتَعلَموا عَدَدَ السِّنينَ وَالحِسابَ ما خَلَقَ اللَّهُ ذلِكَ إِلّا بِالحَقِّ يُفَصِّلُ الآياتِ لِقَومٍ يَعلَمونَ)

صدق الله العظيم

Dedication

This project is dedicated to our fathers , mothers, and families who have encouraged us all the way and have made sure that we give it all to finish what we have started. Special thanks to our teachers and college. Also, we dedicate this project to all staff and students in College of petroleum Engineering and mining department of petroleum Exploration Engineering .

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First and foremost, we thank **ALLAH** for endowing us with health, patience, and knowledge to complete this project .

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Abstract

Reduction of drilling problems particularly those associated with drilling costs can be achieved, to a certain degree, by an early determination of pore pressures , The prediction of these pressures and fractures degree can be used to chose optimum mud weight and define the limit of casing of the drilling boreholes for petroleum purposes.

In the present study , one borehole have been selected from Hamra field , south Sudan , to prediction pore pressure by using d-exponent method , this method is depending on drilling data , therefore , it is an accurate method to calculate pore pressure .

In this research the pore pressure gradient, overburden pressure gradient and fracture pressure gradient are predicted and plotted vs. Depth by (drilling data) using IP software program (Interactive Petro physics). and we benefited from the idea of Eaton in calculating the pore pressure of the formation, using the IP program to facilitate the calculation process and shorten the time and effort And we calculated the pore pressure of formations using special equations in specific depth ,We compared the results for the same depths with the results obtained from the IP program, and found convergence in the values.

التجريد

إن تقليل مشاكل الحفر و بالأخص كلفة الحفر إلى حد كبير يمكن الوصول إليه بالتحديد المبكر للضغوط المسامية ، وإن التنبؤ بهذه الضغوط و بتدرجات التشقق يساعد في اختيار كثافة سائل الحفر المناسب و تعيين حدود إستعمال البطانات الواقية وحماية عملية حفر الآبار النفطية .

تم في هذه الدراسة اختيار أحد ابار حقل حمرة الواقعة جنوب السودان لتحديد ضغط المسام باستخدام طريقة موشر الحفر d و هي من الطرق المعتمدة على بيانات الحفر لذلك هي من الطرق الدقيقة في حساب ضغط المسام.

في هذا البحث ، تم توقع تدرج ضغط المسام ، وتدرج ضغط التكوين الصخري وتدرج ضغط الكسر ورسمت مقابل العمق باستخدام برنامج IP و استفدنا من فكرة ايتون في حساب ضغط المسام مستخدمين برنامج IP لتسهيل عملية الحساب و إختصار الوقت و الجهد و قمنا بحساب ضغط التكوينات باستخدام معادلات خاصه لأعماق محدده وقد قمنا بمقارنه النتائج لنفس الاعماق مع النتائج المتحصل عليها بواسطه برنامج IP وقد وجدنا تقارب في القيم .

Nomenclature

ROP	Rate of penetration .
WOB	Weight on bit .
WHO	Weight on hock .
N	Rotary speed in rpm .
D	Bit size in inch .
TVD	True vertical depth .
PP	Pore pressure .
OBG	Overburden gradient .
Psi	Pound square inch .
MW	Mud weight .
NCT	Normal Compaction trend .

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Chapter one

Introduction

Chapter one

1.1. General introduction :

1.1.1. Pressure Concepts :

Before starting to drill any well in any location in the world the driller must know and understand the different pressure within the subsurface that will come into contact with during the drilling operations.

The various formation pressures in a region is a major role in the exploration and use of future hydrocarbon reservoirs and their reserve The different types of reservoir pressure that normally occur while drilling operations are commonly classified into three type :

- Hydrostatic
- Overburden
- Pore (formation)

1.1.2. Type of pressure :

1.1.2.1. Hydrostatic pressure :

5. Hydrostatic pressure is defined as the pressure exerted by a column of fluid. The pressure is a function of the average fluid density and the vertical height or depth of the fluid column. (Rabia, 2002)

For the purposes of interpretation, all wellbore pressures, such as formation pressure, fracture pressure, fluid density and overburden pressure, are measured in terms of hydrostatic pressure. (Rabia, 2002)

1.1.2.2. Overburden Pressure :

The overburden pressure is defined as the pressure exerted by the total weight of overlying formations above the point of interest. The total weight is the combined weight of both the formation solids (rock matrix) and formation fluids in the pore space. The density of the combined weight is referred to as the bulk density (ρb). The overburden pressure can therefore be expressed as the hydrostatic pressure exerted by all materials overlying the depth of interest. (Rabia, 2002)

1.1.2.3. Pore (formation) Pressure :

Pore pressure is defined as the pressure acting on the fluids in the pore spaces of the rock. This is the scientific meaning of what is generally referred to as formation (pore) pressure. Depending on the magnitude of pore pressure, it can be described as being normal, abnormal or subnormal. (Rabia, 2002)

1.1.2.3.1. Normal Pore Pressure :

Normal pore pressure is equal to the hydrostatic pressure of a column of formation fluid extending from the surface to the subsurface formation being considered. In other words, if the formation was opened up and allowed to fill a column whose length is equal to the depth of the formation then the pressure at the bottom of the column will be equal to the formation pressure and the pressure at surface is equal to zero. Normal pore pressure is not a constant. The magnitude of normal pore pressure varies with the concentration of dissolved salts, type of fluid, gases present and temperature gradient. For example, as the concentration of dissolved salts increases the magnitude of normal pore pressure increase. (Rabia, 2002)

1.1.2.3.2. Subnormal Pore Pressure :

Subnormal pore pressure is defined as any formation pressure that is less than the corresponding fluid hydrostatic pressure at a given depth Subnormal pore pressures are encountered less frequently than abnormal pore pressures and are often developed long after the formation is deposited. Subnormal pressures may have natural causes related to the stratigraphic, tectonic and geochemical history of an area, or may have been caused artificially by the production of reservoir fluids. (Rabia, 2002)

1.1.2.3.3. Abnormal Pore Pressure :

Abnormal pore pressure is defined as any pore pressure that is greater than the hydrostatic pressure of the formation water occupying the pore space. Abnormal pressure can be thought of as being made up of a normal hydrostatic component plus an extra amount of pressure. Abnormal pore pressure can occur at any depth ranging from only a few hundred feet to depths exceeding 25,000 ft. The cause of abnormal pore pressure is attributed to a combination of various geological, geochemical, geothermal and mechanical changes. (Rabia, 2002)

❖ Origins for the Generation of Abnormal Pressure :

◇ Piezometric fluid level

◇ Repressuring of reservoir rock

◇ Faults

◇ Salt diapirism

◇ Diagenesis phenomena

◇ Thermodynamic and biochemical. (Adams, 1985)

1.2. Problem statement :

Abnormal pressures affect the well plan in many areas, Including the following:

•casing and tubing design.

•mud weight and type selection.

•casing setting depth selection.

•cement planning In addition, the following problems must be considered as a result of high formation pressures:

•kicks and blowouts

•differential pressure pipe sticking

•lost circulation resulting from high mud weights

• heaving shale Well costs increase significantly with Geo pressure.

because of the difficulties associated with high-pressure exploratory well planning, most design criteria, publications , and studies have been devoted to this area; the amount of effort expended is justified. (Adams, 1985)

1.3. The main objectives of the Study :

1. Prediction of formation pore pressure .
2. Detection abnormal zones from d-exponent curve .
3. Calculate pore pressure values at specific depths .

1.4. Methodology :

1.Collecting data from daily drilling report and final well report2

2. Using Eaton's equation to calculate formation pore pressure

3. Using IP software to calculate formation pore pressure

1.5. Study area :

1.5.1. introduction:

The Muglad Basin is the largest graben structure straddling Sudan and Southern Sudan Republics.The total area of the basin is approximately 120,000 km2 extending 800 km in a NW-SE direction with a maximum width of 200 km . The maximum sediment thickness in the Muglad Basin, which was determined seismically, reaches about 15 km. The basin comprises nine sub- basins oriented in a NW-SE to NNW-SSE direction; with extensional and strike-slip structural histories. (Zayed, 2015)

1.5.2. Geologic and tectonic setting:

The Muglad Basin area is a flat plain of low relief surrounded by hilly crystalline rocks exposed to the northeast in the Nuba Mountains, isolated basement and Mesozoic sedimentary outerops in the north and basement rocks in the southwest . (Zayed, 2015)

1.5.3. Stratigraphic and sedimentological:

characteristics Based on sedimentological evidence, seismic and log interpretations, Schull (1988) subdivided the Muglad succession into twelve formations: Sharaf, Abu Gabra, Bentiu, Darfur Group (Ara-deiba, Zarqa, Gahzal and Baraka) and Kordofan Group (Amal, Nayil, Tendi, Adok and Zeraf). Due to the non-marine nature of the sediments filling the basin, age determination of the vari- ous units was solely based on terrestrially-derived palynomorphs (e.g. Kaska, 1989; Stead and Awad, 2005; Eisawi et al. 2012 (Zayed, 2015)

FORMATION		LITHOLOGY AND ENVIRONMENTS	AGE	
KORDOFAN GROUP	Zeraf Fm.	predominantly iron - stained sands and silts with minor claystones interbeds. braided streams / alluvial fans.	Recent - Middle Miocene	TERTIARY
	Adok Fm.		Oligocene - Late Ecocene	
	Tendi Fm.	predominantly claystone / shale interbedded with sandstones. fluvial / floodplain & lacustrine.		
	Nayil Fm.			
	Amal Fm.	predominantly massive medium to coarse sandstones sequences. braided streams / alluvial fans.	Paleocene	
DARFUR GROUP	Baraka Fm.	predominantly sandstones with minor shales and claystones interbeds. fluvial / alluvial fans.	Late Senonian Turonian	CRETACEOUS
	Ghazal Fm.			
	Zarga Fm.	predominantly sandstones, shales with interbeds of siltstones and sandstones. floodplain / lacustrine with fluvial / deltaic channel sands.		
	Aradeiba Fm.			
Bentiu Fm.		predominantly thick sandstones sequences. braided / meandering streams.	Cenomanian Late Albian	
Abu Gabra Fm.		predominantly claystones and shales with fine sandstones and siltstones. lacustrine / deltaic.	Albian - Aption	
Sharaf Fm.		claystones, shales with interbeds of fine sandstones and siltstones. lacustrine / fluvial - floodplain.	Barremian - Neocomian	

Source rocks   Reservoir rocks

Figure (1) Stratigraphic units of the Muglad rift basin, SW Sudan, their lithology and depositional environment (adapted from Schull 1988)

1.5.4. Geological Objective :

Hamra East–8 is proposed as a development well to test the oil potentiality of Aradeiba and Bentiu. The primary objective is Aradeiba and Top Bentiu Sandstone. It was spudded in at 16:30 on February 16, 2013 by Rig PPS #103 and reached final total depth 1900m at 20:00 on March 14, 2013.

1.5.5. Litho Profile :

Pre Nayil, Nayil Shale, Amal Sand, Braka Shale, Ghazal Shale, Zarqa, Aradeiba Upper Shale, Aradeiba Main Sand, Aradeiba lower Shale, Aradeiba E Sand, Aradeiba F Sand, Bentiu1, Bentiu2 and Bentiu3 Sand formations were encountered while drilling the well. Samples indicated the lithology in this area is mainly sandstone interbedded with claystone.

1.5.6. Formation Tops :

FORMATIONS		DEPTH (m)					
Age	Member	PROGNOSED		SAMPLE		E-log depth (m,KB)	
		MD	Thickness	MD	Thickness	MD	Thickness
Eocence	Nayil	464	116	436	122	436	174
Paleocene	Amal	580	165	558	349	610	298
Maastrichtian	Baraka Shale	745	395	907	245	908	245
Campanian	Ghazal Shale	1140	140	1152	56	1153	58
	Zarqa	1280	48	1208	171	1211	170
	Aradeiba Upper Shale	1328	142	1379	169	1381	166
	Aradeiba Main Sand	1470	60	1548	86	1547	76
Santonian	Aradeiba lower Shale	1530	125	1634	32	1623	42
	Aradeiba E	1655	10	1666	44	1665	45
	Aradeiba F	1665	80	1710	23	1710	23
Albian –Aptian	Bentiu 1*	1745	17	1733	39	1733	39
	Bentiu 2*	1762	88	1772	128	1772	129
	Total depth	1900	1900	1900		1901	

Table(1) formation tops

1.6. Well under Study : Hamra East-8 well :

The type of the well is a development well to test the oil potentiality of Aradeiba and Bentiu. The well is located in the south of main Heglig field in the Muglad Basin[ ] , The coordinates are Latitude 9° 54' 16.10"N , Longitude 29° 26' 15.23"E[ ] .

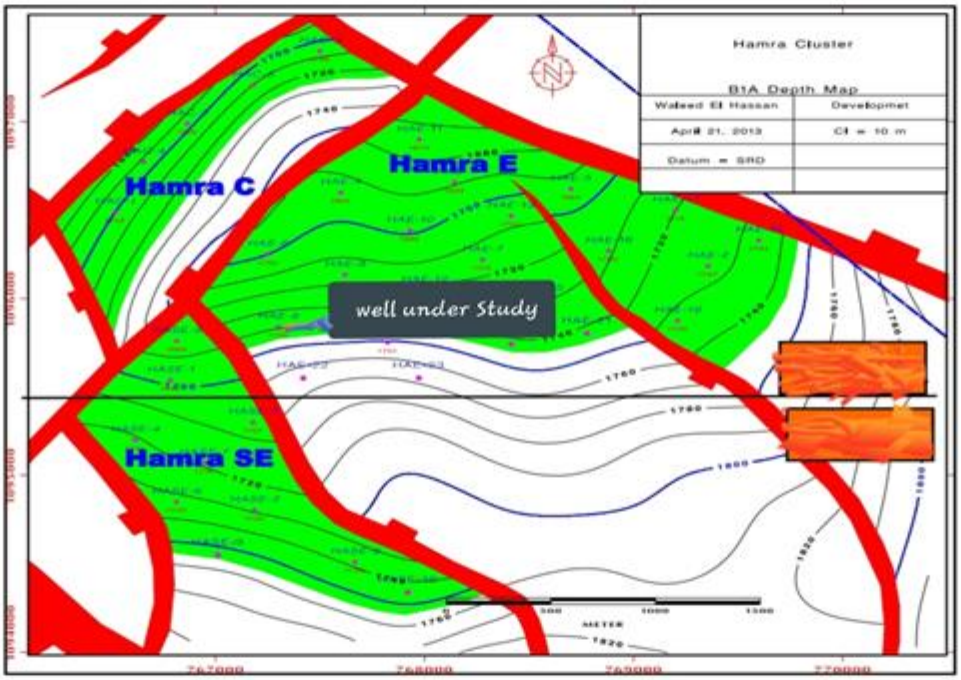

Figure (2) Hamra East-8 well location

1.7. Project lay out :

- Chapter One:

In this chapter present background of the research, statement of the problem Objectives of the project and methodology.

- Chapter Two:

This chapter present literature review and theoretical background.

- Chapter Three:

In this chapter present methodology of the prediction of pore pressure.

- Chapter Four:

In this chapter, present the result and discussion for prediction of pore pressure.

- Chapter Five:

This chapter present conclusions and recommendation.

Chapter two

Theoretical Background

& Literature Review

Chapter two

2.1. Theoretical Background :

In drilling engineering, methods used to estimate formation pressure can be divided into two categories: prediction methods and detection methods (Moutchet & Mitchell, 1989). Pressure predictive methods are based on seismic velocities (transit times), offset well logs, and well history (Moutchet & Mitchell, 1989; Bourgoyne et al., 1991). Pore pressure detection methods normally use drilling parameters and well logs (MWD/LWD) obtained during drilling (Moutchet & Mitchell, 1989; Bourgoyne et al., 1991) .((Adams, 1985)

2.1.1. Seismic Analysis :

Geophysical methods such as seismic can be used to detect the presence and top of abnormally pressured formations and to evaluate the magnitude of the Seismic data analysis methods are based on the elementary reflection analysis summarized by Pennebaker.e pressures. A normal environment exhibits decreasing porosity as compaction occurs. Therefore, the travel times should decrease. An abnormal pressure zone has greater-than-normal porosities for the specific depth and causes higher travel times. (Adams, 1985)

2.1.2. Drilling parameters (D exponent) :

The D exponent methodology was developed with the goal of normalizing the penetration rate from drilling parameters. The method was proposed by Jorden and Shirley (1966) based on the Bingham (1969) equation, which was developed to consider the differential pressure effect in normalizing penetration rate. Rehm and Mcledon (1971) modified Jorden & Shirley's equation to include mud weight, as shown in Equation . This expression is known as the D exponent equation, calculated from :

$$\boldsymbol{D = \frac{log\left(\frac{ROP}{60 * RPM}\right)}{log\left(\frac{12 * WOB}{1000 * B}\right)}} \qquad (\mathbf{2.1})$$

Where :

D = drilling d exponent

ROP = penetration rate (ft/h)

RPM = rotary speed (rpm)

WOB = weight on bit (lbs.)

B = diameter of the bit (in)

Calculate the Pore Pressure, using **Eaton Method** or **Ratio Method** . (Rabia, 2002)

2.1.2.1. Eaton Method :

Record the value of the normal trendline dc (dcn) and observe dc (dco) at the depth of interest.

a. NOTE: use only dco values from shale. Do not use any other lithology dc value.

b. Record the overburden gradient from the overburden plot at the depth of interest .

c. Use the following formula to calculate pore pressure.

$$\boldsymbol{PP = \sigma_{ov} - (\sigma_{ov} - p_n) * \left(\frac{d_{co}}{d_{cn}}\right)^{1.2}} \qquad (\mathbf{2.2})$$

Where :

PP = Pore pressure (psi)

σ_{ov} = Overburden pressure (psi)

p_n = Normal pore pressure gradient (psi)

d_{co} = Observed value of dc at depth of interest

d_{cn} = Normal trend line value of dc at depth of interest. (Rabia, 2002)

2.1.2.2. Ratio Method :

The ratio method is much simpler and does not require values of overburden. To calculate pore pressure, use the following formula:

$$PP = p_n \left(\frac{d_{co}}{d_{cn}}\right) \qquad (2.3)$$

Where:

PP= Pore pressure (psi)

Pn= Normal pore pressure (psi)

dcn= Normal trend line value of d exponent . (Rabia, 2002)

2.1.3. Log Analysis:

2.1.3.1. resistivity log :

Hottman and Johnson developed a technique based on empirical relationships Where by an estimate of formation pressures could be made by noting the ratio between the observed and normal rock resistivities the following steps are necessary to estimate the formation pressure.

1 The normal trend is established by plotting the logarithm of shale resistivity vs depth.

2 The top of the pressured interval is found by noting the depth at which the plotted points diverge from the trend.

3. The pressure gradient at any depth is found as follows:

a. The ratio of the extrapolated normal shale resistivity to the observed shale resistivity is determined.

The formation pressure corresponding to the calculated ratio is found from Fig 3. (Adams, 1985)

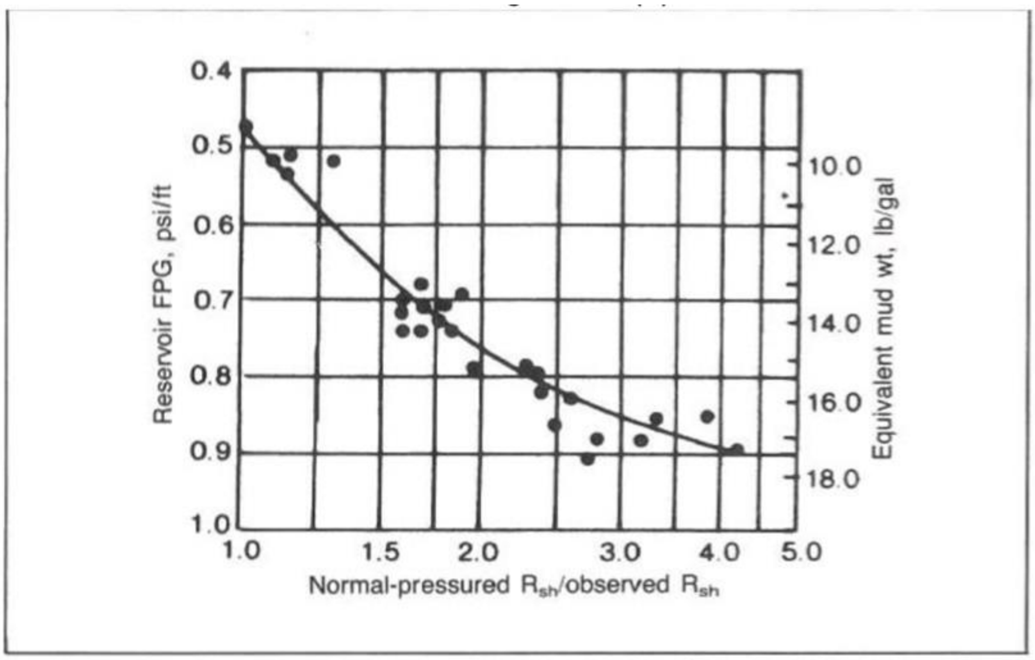

Figure (3) Empirical correlation of formation pressure gradients vs a ratio of normal to observed shale resistivities (After Hottman and Johnson) .

2.1.3.2. Sonic Log :

. The sonic log has been used successfully as a pressure evaluation tool. The technique utilizes the difference in travel times between high porosity overpressure zones and low-porosity, normal pressure zones Observed transit times are plotted, and the normal trend line is established and extrapolated throughout the pressure region. At the depth of interest, the difference between the observed and normal travel times is established.

This difference is used to estimate the formation pressure Pore pressure can then be calculated at the point of interest using the following Eaton equation . (Adams, 1985)

$$\boldsymbol{PP_g = OBG - (OBG - p_n) * \left(\frac{\Delta T_n}{\Delta T}\right)^3} \qquad (\mathbf{2.4})$$

Where :

ΔT_n = the sonic transit time or slowness in shale at the normal pressure

ΔT = the sonic transit time in shale obtained from well logging, and it can also be derived from seismic interval velocity.

This method is applicable in some petroleum basins, but it does not consider unloading effects. This limits its application in geologically complicated area, such as formations with uplifts. To apply this method, one needs to determine the normal transit time (Δtn). (Adams, 1985)

2.1.4. FORMATION DENSITY LOGS :

plot of shale bulk density versus depth will show a straight line normal compaction trend line. The shale bulk density will increase with depth due to the increased compaction. This results in reduced porosity and pore water expulsion. In an abnormally pressured shale, compaction is often retarded, resulting in increased porosity and thus lower density than a normally pressured shale at an equivalent depth. As such a decrease in shale bulk density values from the normal compaction trend line is observed when entering a zone of abnormal pore pressure. (Rabia, 2002)

2.1.5. REPEAT FORMATION TESTER (RFT) DATA :

The RFT is a wire line run tool designed to measure formation pressures and to obtain fluid samples from permeable formations. The RFT is only useful after the hole section is drilled and can only work across porous and permeable zones. The formation pore pressure measured by RFT is used to verify the estimates made while drilling the well and to construct a reservoir pressure profile. This will yield information on the pressure gradients and nature of the reservoir fluids.

The RFT tool provides 3 distinct pieces of pressure data:

- The drilling fluid hydrostatic pressure (two readings).
- The formation pore pressure.

- The pressure transient induced by the withdrawal of 2 small samples. The tool has 2 pre-test chambers of 10cc volume which can be used to sample the formation at 2 differing rates. (Rabia, 2002)

2.1.6. DRILL STEM TEST (DST) DATA :

DST is a method of testing formations for pressure and fluid. A Drill stem with a packer is run and set just above the zone to be tested. The packer is set and a DST valve is opened to allow the reservoir to communicate with the inside of the drill stem which is run either empty or with a small calculated cushion.

The drill stem is run with several pressure gauges. The purpose of the pressure gauges is to record the down hole pressure during the sequence of flow and shut in periods that comprise the DST. The pressures recorded during the test are used to calculate reservoir characteristics such as formation pressure, permeability, skin damage and productivity index.

Analysis of the pressure build up from shut in periods leads to accurate determination of the formation pore pressure. The second shut-in period is used for determining the final shut-in reservoir pressure. The actual static reservoir pressure is determined from Horner analysis of DST pressure data. (Rabia, 2002)

2.2. Literature review :

Pore pressure can be estimated from elastic wave velocities using a velocity to pore-pressure transform. Early examples include the work of Hottman and Johnson (1965) using sonic velocities and that of Pennebaker (1968) using interval velocities obtainedfrom stacking velocities. (P.Salano, 2006)

Given seismic velocities with sufficient spatial resolution, a seismic velocity-to-pore pressure transform is required in order to predict pore pressure. Existing approaches include the empirical methods of Eaton (1975) and Bowers (1995), which are widely used in the industry. (Sayers, 2002)

Although the use of elastic wave velocities for porepressure prediction is well known(Hottman and Johnson, 1965; Pennebaker, 1968), conventional seismic-velocity analysis assumes that the velocity varies slowly both laterally and in depth. The resulting resolution is usually too low for accurate pore-pressure prediction. Reflection tomography (Stork, 1992; Wang et al., 1995; Woodward et al., 1998) replaces the low-resolution layered medium and hyperbolic moveout assumptions of conventional methods with a more accurate raytrace modeling–based approach. Completely general moveout curves are calculated by ray tracing through background models of arbitrary complexity. Lee et al. (1998) give an example of the use of tomographic velocity inversion for pore-pressure prediction in the south Caspian Sea. (Sayers, 2002)

Hottmann and Johnson (1965) were probably the first ones to make pore pressure prediction from shale properties derived from well log data (acoustic travel time/velocity and resistivity). They indicated that porosity decreases as a function of depth from analyzing acoustic travel time in Miocene and Oligocene shales in Upper Texas and Southern Louisiana Gulf Coast. This trend represents the “normal compaction trend” as a function of burial depth, and fluid pressure exhibited within this normal trend is the hydrostatic. If intervals of abnormal compaction are penetrated, the resulting data points diverge from the normal compaction trend. They contended that porosity or transit time in shale is abnormally high relative to its depth if the fluid pressure is abnormally high. (Zhang, 2011)

Bowers (1995) calculated the effective stresses from measured pore pressure data of the shale and overburden stresses and analyzed the corresponded sonic interval velocities from well logging data in the Gulf of Mexico slope to predict pore pressure by following equation. (Zhang, 2011)

The Miller sonic method describes a relationship between velocity and effective stress that can be used to relate sonic/seismic transit time to formation pore pressure . In Miller’s sonic method an input parameter "maximum velocity depth", $d_{\max}$, controls whether unloading has occurred or not. If $d_{\max}$ is less than the depth (Z), unloading has not occurred, the pore pressure can be obtained from the following equation(Zhang et al., 2008) . (Zhang, 2011)

Slotnick (1936) recognized that the compressional velocity is a function of depth, i.e., velocity increases with depth in the subsurface formations .Sayers et al. (2002) used this relationship as the normally pressured velocity for pore pressure prediction.. porosity is an indicator (a function) of effective stress and pore pressure particularly for the overpressures generated from under-compaction and hydrocarbon cracking . Efforts have been Holbrook et al. (2005) presented porosity-dependent effective stress for pore pressure prediction. Heppard et al. (1998) used an empirical porosity equation similar to Eaton's sonic method to predict pore pressure using shale porosity data. Flemings et al. (2002) and Schneider et al. (2009) also applied porosity-stress relationships to predict overpressures in mudstones. (Zhang, 2011)

Chapter three

Methodology

Chapter three

Methodology

3.1. Description of problem and data :

3.1.1. Problem description :

Formation pressure can be the major factor affecting drilling operations .If pressure is not properly evaluated , it can lead to drilling problems such as lost circulation , blowouts , stuck pipe , hole in stability , and excessive costs Unfor-tunately , formation pressures can be very difficult to quantify precisely where unusual , or abnormal , pressures exist .The complete well planning process, with few exceptions , is predicated on a knowledge of formation pressures.

3.1.2. Data description :

In this research designed IP software program based on Eaton formulas to input data.

3.1.3. Input data :

In IP software are dependent on drilling data & well logging data this data collected from Hamra E_8 well.

3.1.4. Output data :

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

3.2. Calculate shale volume from gamma ray log :

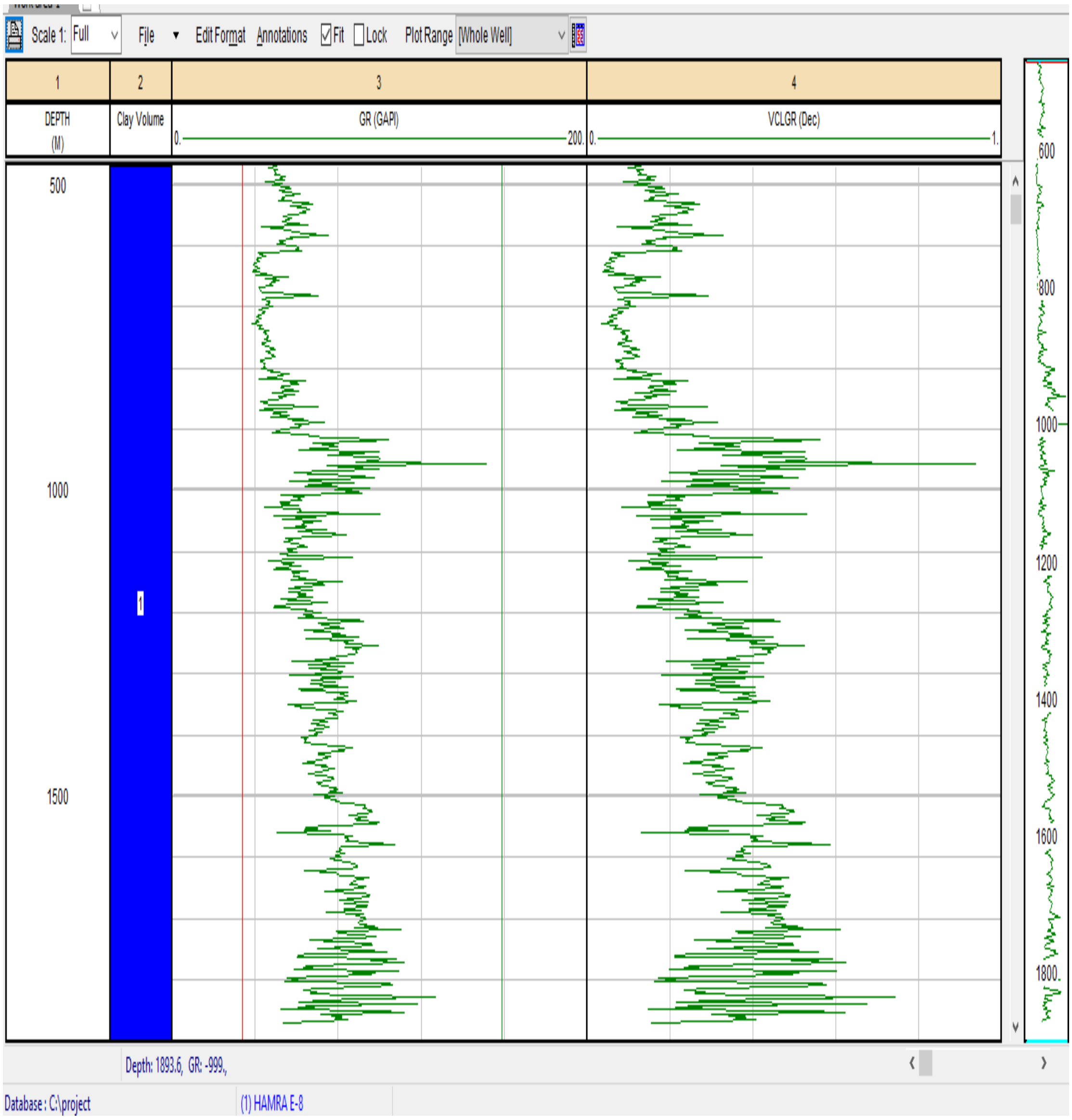

Figure (4) : shale volume from gamma ray log .

3.3. Estimate density curve :

3.3.1. Input data:

- ❖ Sonic curve .

3.3.2. Output data :

- ❖ Density curve .

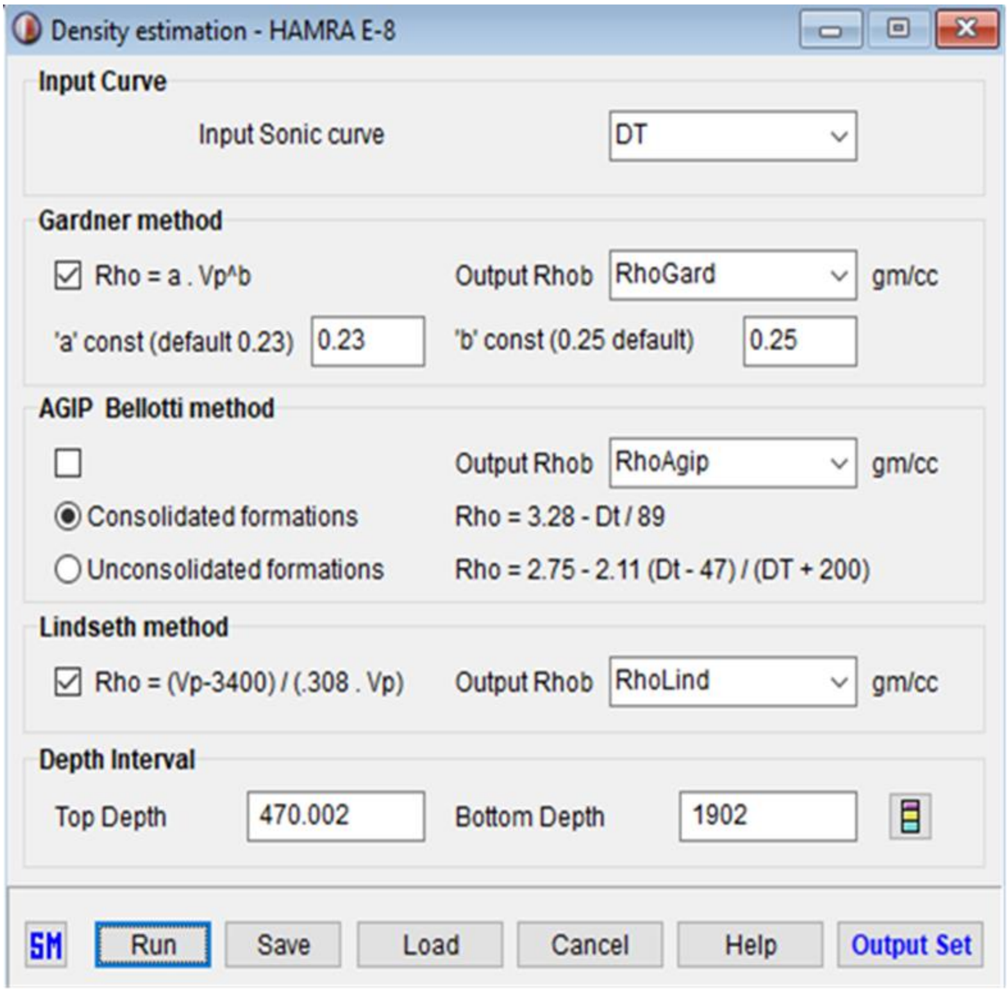

Figure (5) : input of sonic curve.

3.4. Calculate Overburden pressure curve and Overburden gradient curve:

3.4.1. Input data:

- ❖ Density curve.

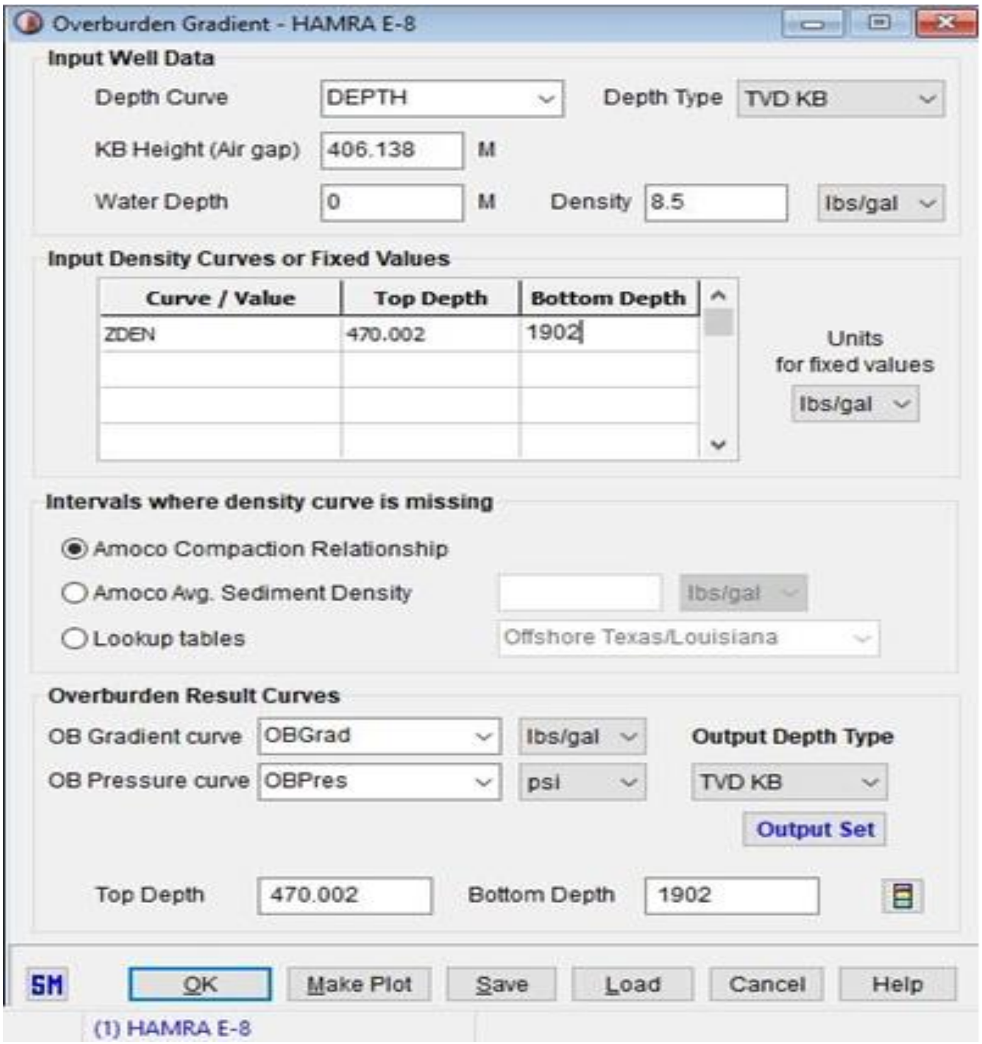

Figure (6)) : input of density curve.

3.4.2. **Output data :**

- ❖ Overburden pressure curve
- ❖ Overburden gradient curve

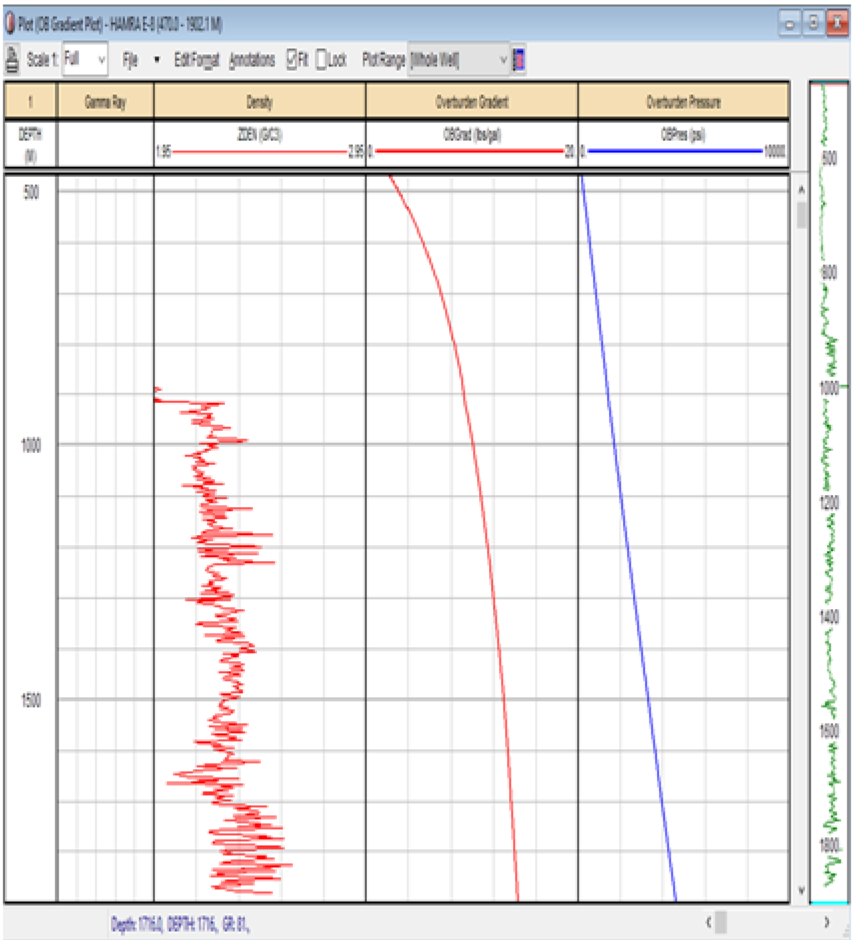

Figure (7) : Overburden pressure curve & overburden gradient curve .

(–) overburden gradient curve .

(–) overburden pressure curve .

3.5. Calculate d-exponent from drilling data and correct it using excel sheet :

$$\boldsymbol{D = \frac{log\left(\frac{ROP}{60 * RPM}\right)}{log\left(\frac{12 * WOB}{1000 * B}\right)}} \qquad (\mathbf{3.1})$$

Where :

D = drilling d exponent

ROP = penetration rate (ft/h)

RPM = rotary speed (rpm)

WOB = weight on bit (lbs.)

B = diameter of the bit (in)

$$\boldsymbol{D_c = D * \left(\frac{MW_n}{MW_a}\right)} \qquad (\mathbf{3.2})$$

Where :

D_c = Corrected d-exponent .

MW_n = Normal Mud Weight .

MW_a = Actual Mud Weight .

Hamra E-8_Drilling Data Ascii_Final_30-1900m_130314 (Recovered)1234 [Compatibility Mode] - Excel

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Q445 | f_x 470

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1																
2																
3																
4	ROP	WOB	WOH	RPM	TRQ_avg	SPP	Fpump	MWI	SPM	MWN	DEX1	DEX2	BIT	D ex	DC	DEPTH
5	m/hr	tonnes	tonnes	RPM	kft-lb	psi	gal/min	ppg	SPM	MWN	DEX2	DEX3	BIT	D ex	DC	DEPTH
445	5.94	6.91	49.89	102	3.54	1668	779	9.2	150	8.7	1.004235	1.020233	17.5	0.98432	0.930824	470
446	5.56	5.73	51.07	102	3.25	1663	779	9.2	150	8.7	0.975524	1.030385	17.5	0.946756	0.895302	471
447	6.86	6.62	50.18	102	3.48	1668	779	9.2	150	8.7	1.066773	1.02275	17.5	1.043044	0.986357	472
448	6.92	5.63	51.17	102	3.39	1672	779	9.2	150	8.7	1.070555	1.031235	17.5	1.038129	0.981709	473
449	8.04	6.34	50.46	102	3.57	1667	779	9.2	150	8.7	1.135705	1.025167	17.5	1.107825	1.047617	474
450	8.05	6.29	50.51	102	3.75	1668	779	9.2	150	8.7	1.136245	1.025597	17.5	1.107887	1.047675	475
451	8.22	4.67	52.99	102	2.96	1667	775	9.2	149	8.7	1.145321	1.046413	17.5	1.094521	1.035036	476
452	37.71	1.21	57.79	103	1.56	1669	772	9.2	149	8.7	1.811143	1.084072	17.5	1.670685	1.579887	477
453	6.94	7.77	51.51	103	3.39	1667	775	9.2	149	8.7	1.076045	1.034111	17.5	1.040551	0.984	478
454	8.57	8.67	50.61	103	3.79	1665	775	9.2	149	8.7	1.167667	1.026456	17.5	1.137572	1.075747	479
455	6.86	8.33	50.95	103	3.52	1666	775	9.2	149	8.7	1.07101	1.029363	17.5	1.040459	0.983912	480
456	5.71	8.73	50.55	103	3.57	1665	775	9.2	149	8.7	0.991322	1.02594	17.5	0.966257	0.913743	481
457	5.72	8.41	50.87	103	3.47	1665	775	9.2	149	8.7	0.992082	1.028681	17.5	0.964421	0.912007	482
458	6.92	8.67	50.61	103	3.61	1665	775	9.2	149	8.7	1.074792	1.026456	17.5	1.047091	0.990184	483
459	7.91	8.76	50.52	103	3.54	1661	774	9.2	149	8.7	1.132862	1.025683	17.5	1.104496	1.044469	484
460	9.28	7.66	51.62	103	3.38	1661	774	9.2	149	8.7	1.202234	1.035037	17.5	1.161537	1.09841	485
461	9.03	7.26	52.02	103	3.33	1663	774	9.2	149	8.7	1.190374	1.03839	17.5	1.146365	1.084063	486
462	13.09	7.49	51.79	103	3.42	1663	775	9.2	149	8.7	1.351626	1.036465	17.5	1.304072	1.233199	487
463	7.31	6.4	52.88	103	3.15	1664	775	9.2	149	8.7	1.098603	1.045511	17.5	1.050782	0.993674	488
464	9.35	7.99	51.29	103	3.63	1664	775	9.2	149	8.7	1.205498	1.032252	17.5	1.167833	1.104363	489
465	9.12	8.24	51.04	103	3.75	1664	775	9.2	149	8.7	1.194681	1.03013	17.5	1.159738	1.096709	490
466	7.59	8.67	50.61	103	4.1	1660	773	9.2	149	8.7	1.114928	1.026456	17.5	1.086192	1.02716	491
467	8.31	8.88	50.4	103	4.03	1658	771	9.2	148	8.7	1.154287	1.02465	17.5	1.126519	1.065295	492
468	8.20	8.19	51.09	103	3.94	1657	771	9.2	148	8.7	1.1485	1.030555	17.5	1.114448	1.05388	493
469	8.93	7.25	52.03	103	3.47	1658	771	9.2	148	8.7	1.185537	1.038473	17.5	1.141616	1.079572	494
470	11.76	8.07	51.21	103	3.72	1658	771	9.2	148	8.7	1.305093	1.031574	17.5	1.265147	1.196389	495
471	9.84	8.48	50.8	103	3.75	1658	771	9.2	148	8.7	1.227681	1.028083	17.5	1.194146	1.129247	496

Figure (8) : d-exponent calculation and correction it .

3.6. load corrected d-exponent and its depths on IP software to create new curve in the name of d-exp .

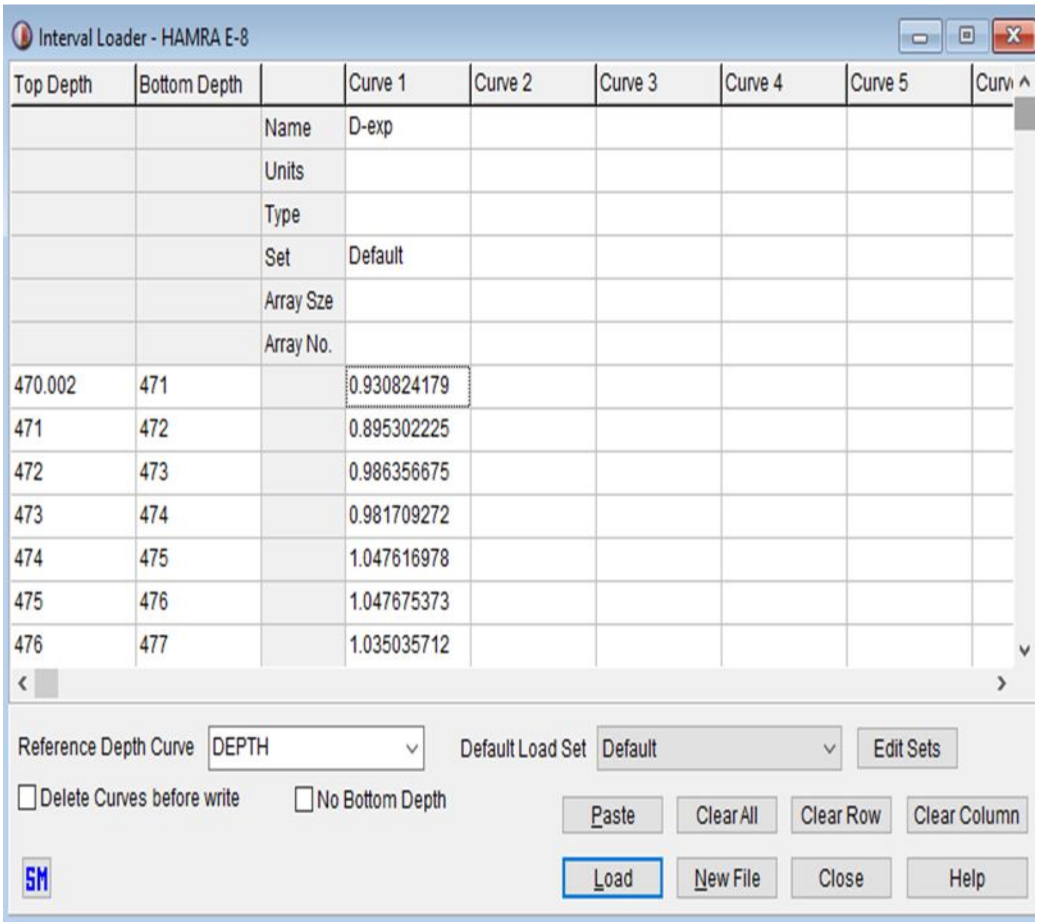


Figure (9): load corrected d-exponent data .

3.7. Calculate pore pressure , fracture pressure , mud pressure :

3.7.1. Input data :

3.7.1.1. d- exponent curve & Temperature curve :

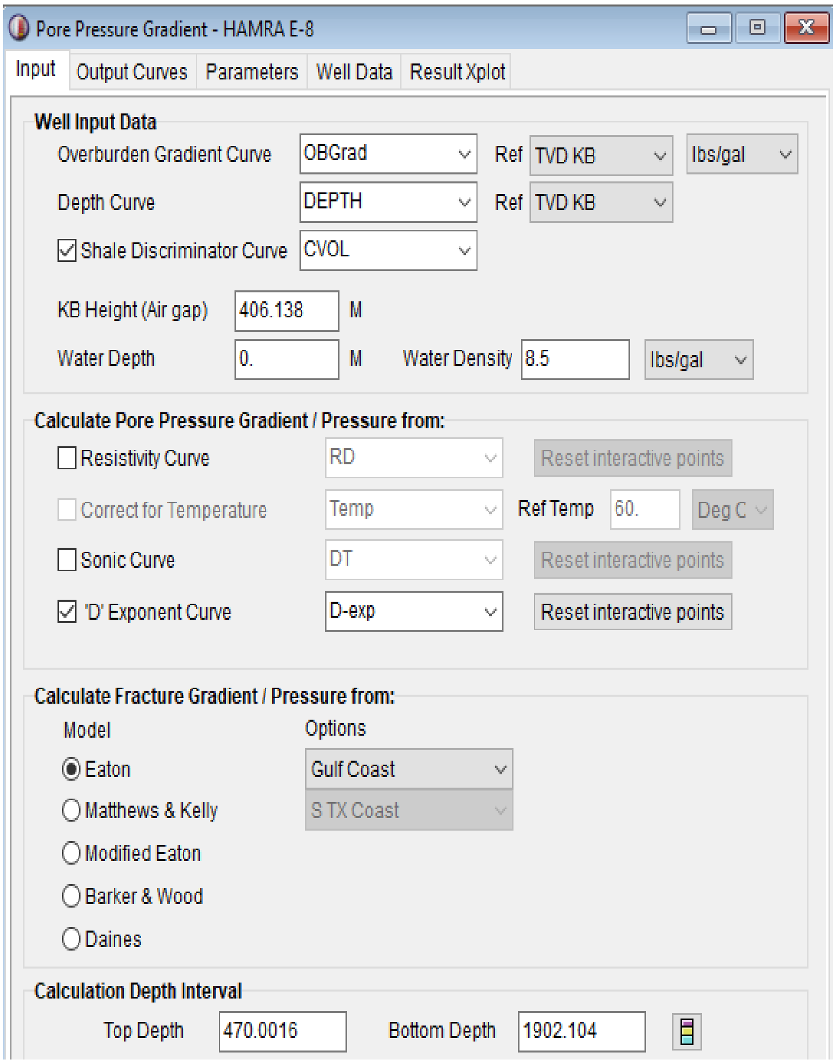
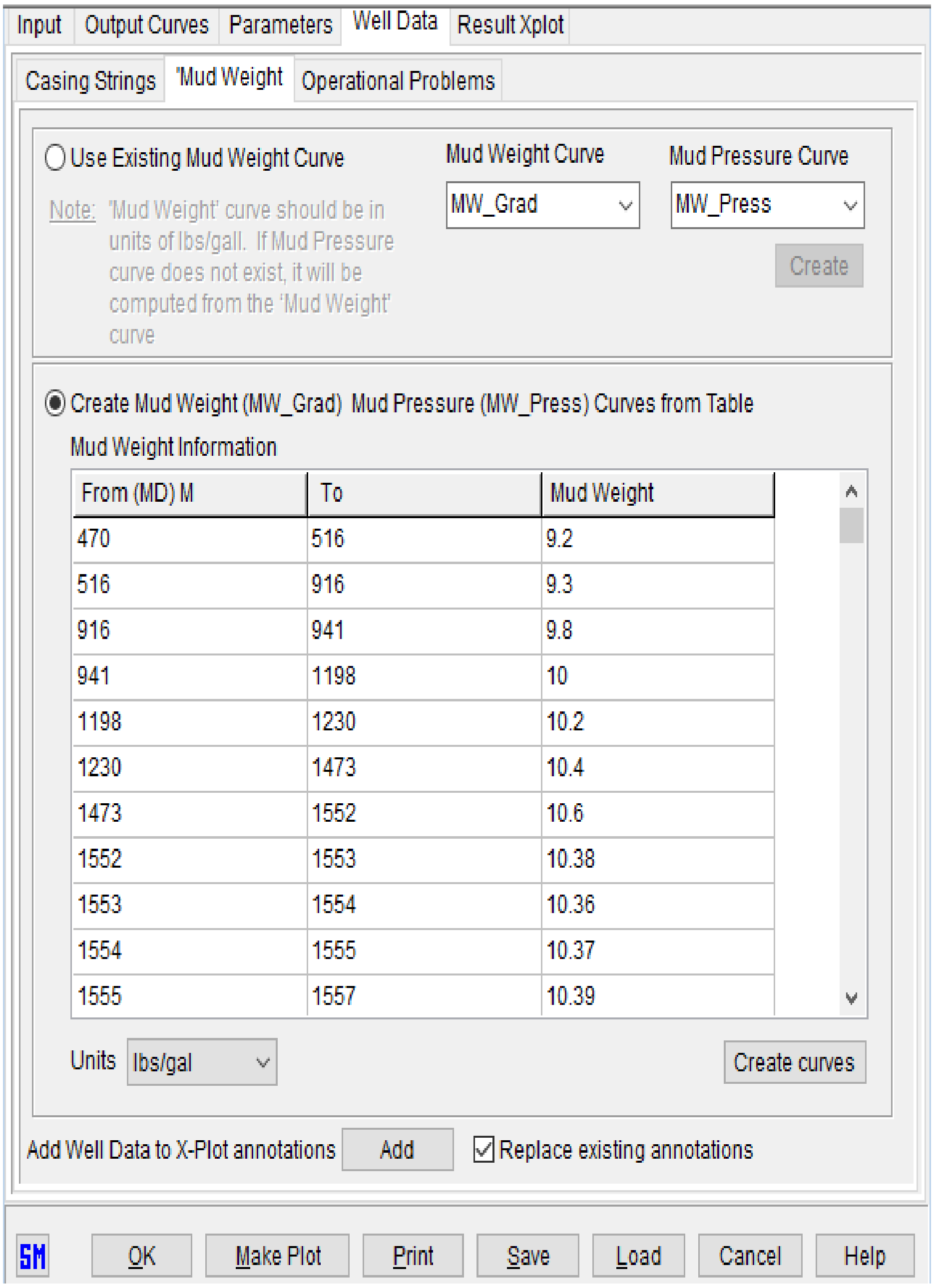


Figure (10): input of d- exponent curve & Temperature curve .

3.7.1.2. Mud weight data :

Depth (m)		Mud weight
From	To	
470	516	9.2
516	916	9.3
916	941	9.8
941	1198	10.00
1198	1230	10.20
1230	1473	10.40
1473	1552	10.60
1552	1553	10.38
1553	1554	10.36
1554	1555	10.37
1555	1557	10.39
1557	1558	10.40
1558	1559	10.39
1559	1560	10.41
1560	1561	10.42
1561	1562	10.43
1562	1563	10.41
1563	1669	10.70
1669	1688	10.80
1688	1689	10.08
1689	1691	10.04
1691	1692	10.02
1692	1693	9.840
1693	1694	9.790
1694	1713	10.80
1713	1724	10.01
1724	1900	10.80

Table 2) : mud weight data



From (MD) M	To	Mud Weight
470	516	9.2
516	916	9.3
916	941	9.8
941	1198	10
1198	1230	10.2
1230	1473	10.4
1473	1552	10.6
1552	1553	10.38
1553	1554	10.36
1554	1555	10.37
1555	1557	10.39

Figure (11) : input of mud weight data .

3.7.2.1. Out put data : pore pressure gradient , fracture gradient , hydrostatic pressure gradient :

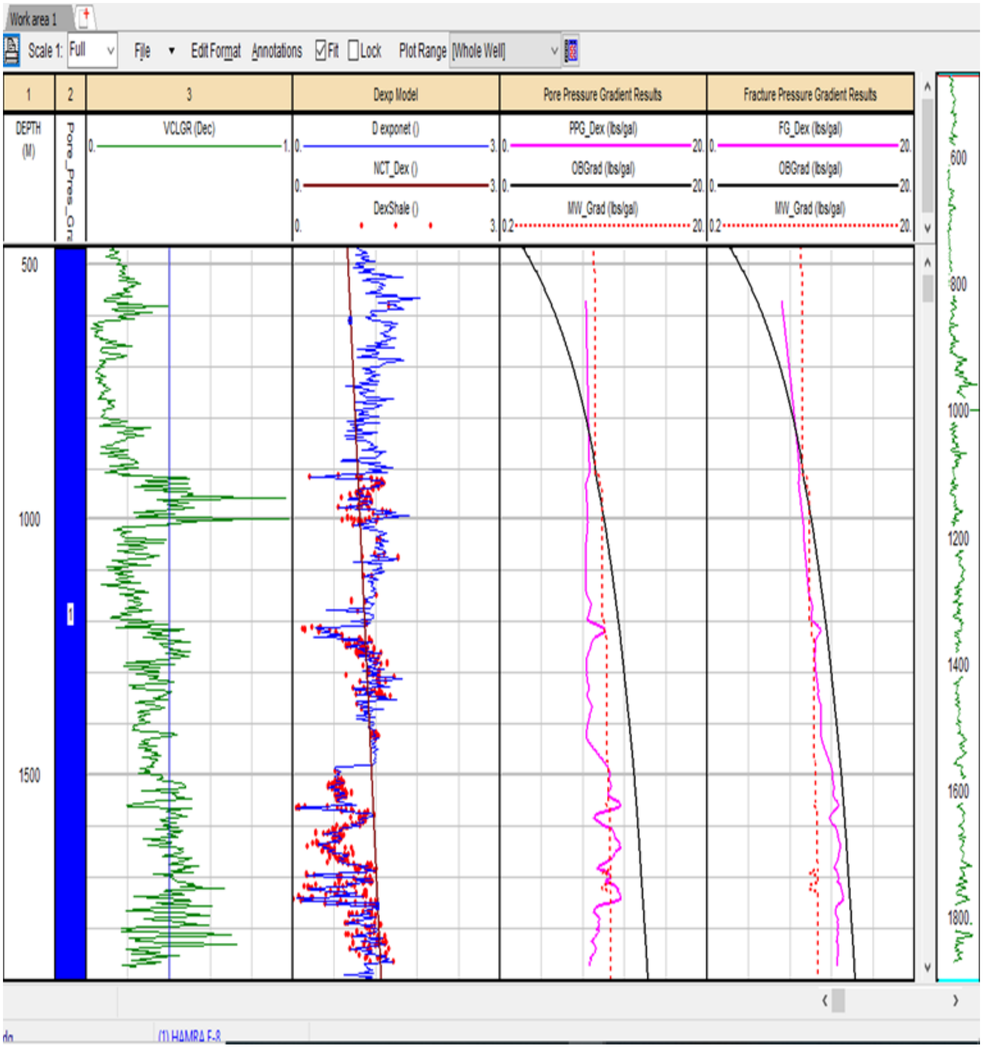


Figure (12) : pore pressure gradient curve , fracture pressure gradient curve & hydrostatic pressure gradient curve .

3.7.2.2. Output data :

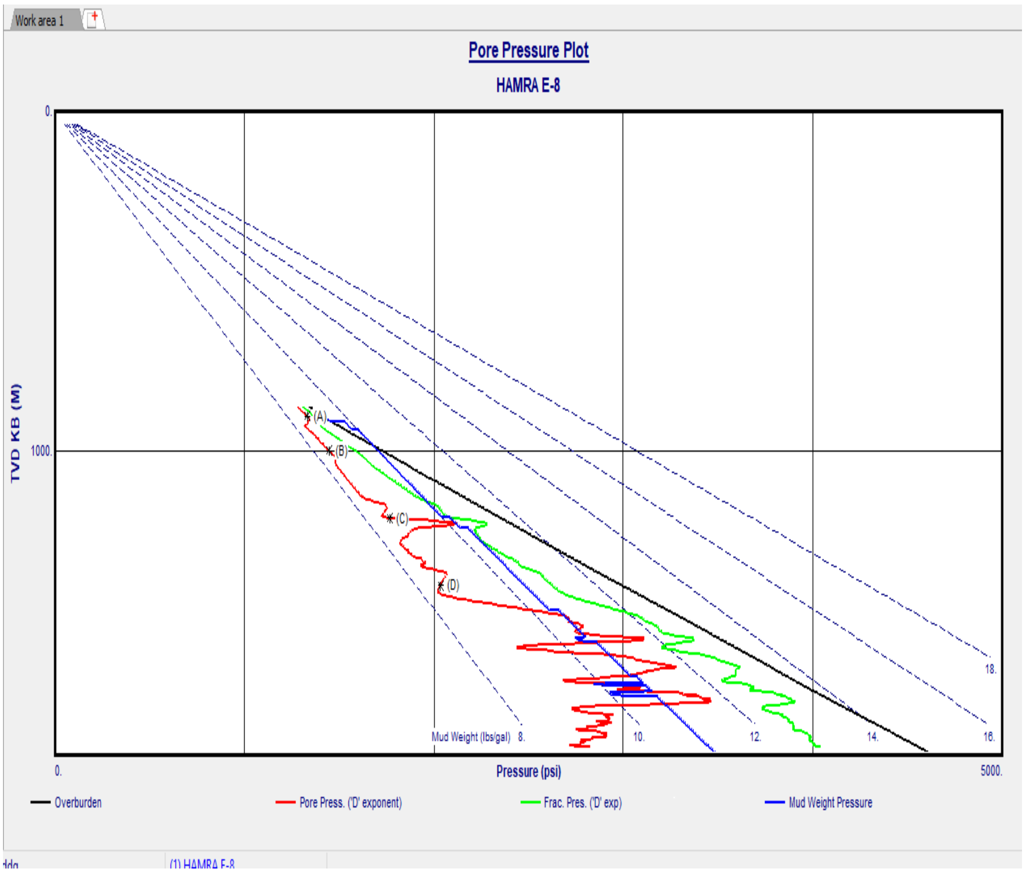


Figure (13) : final result of input data

(–) Pore pressure curve .

(–) Fracture pressure curve.

(–) Mud weight pressure curve.

(–) Overburden pressure curve.

Chapter four

Results & Discussion

Chapter four

Results & Discussion :

We calculated pore pressure from Eaton's equation at the specific depth :

$$\boldsymbol{PP = \sigma_{ov} - (\sigma_{ov} - p_n) * \left(\frac{d_{co}}{d_{cn}}\right)^{1.2}} \qquad (4.1)$$

Where :

PP = Pore pressure (psi) .

σ_{ov} = Overburden pressure (psi) .

p_n = Normal pore pressure gradient (psi)

d_{co} = Observed value of dc at depth of interest

d_{cn} = Normal trend line value of dc at depth of interest

Overburden pressure depend on the variation in density with depth .

$$\boldsymbol{\sigma_{ov} = \rho b(g/cc) * TVD(ft) * 0.433} \qquad (4.2)$$

Where :

σ_{ov} = Overburden .

ρb = Bulk density .

TVD = Total vertical depth .

$$\boldsymbol{\rho b} = \Phi * \boldsymbol{\rho f} + (\mathbf{1} - \Phi) * \boldsymbol{\rho m} \qquad (\mathbf{4.3})$$

ρb = Bulk density

ρf = fluid density

Φ = porosity

ρm =matrix density

Table below showing the densities of formation at specific depths :

Depth(m)	Lithology	Formation interval	Matrix density (gm/cc)
900	Sandstone	Amal Massive Sand	2.65
1000	CLAYSTONE	Baraka Shale	~ 2.7 - 2.8
1200	CLAYSTONE	Zarqa Shale	~ 2.7 - 2.8
1400	CLAYSTONE	Aradeiba upper shale	~ 2.7 - 2.8

Table 3 : Typical densities of formation lithology .

Table below showing the correlation values of pore pressure that obtained from IP software and Eaton's equation :

Points	Depth		Pore pressure (psi)	
	meter(m)	feet(ft)	from IP software	from equation
A	900	2952	1329	1304
B	1000	3280	1446	1504
C	1200	3936	1764	1729
D	1400	4592	2032	2028

Table (4) : the values of pore pressure at specific depths.

- Results obtained from our approach are summarized in Figure (12) .
- In the depth (470 - 1600) the pore pressure is observed , and the mud weight higher slightly than pore pressure .
- In the depth (1600 - 1700) slightly increase in pore pressure curve than hydrostatic pressure curve , In this case mud weight must be increase to maintain pore pressure.
- Figure(12) shows the slightly deflection in the d–exponent curve from normal compaction trend (NCT) .

- In most geographical areas the pore pressure gradient approximately 0.465 psi/ft (assumes 80,000 ppm Salt content) this pressure gradient has been defined as the maximum normal pore pressure gradient . Where the minimum normal pore pressure is 0.433 psi/ft (fresh water) . Any formation pressure above or below the points defined by this gradient are called abnormal pressure. By comparing the results in table (4.3) with normal pore pressure range , this values within the range of normal pore pressure.

Chapter five

Conclusion & Recommendation

Chapter five

5.1. Conclusion :

- In this study we calculated formation pore pressure using drilling data and log data collected from Hamra E-8 well – using IP software .

- By observing the d-exponent curve and pore pressure curve vs hydrostatic pressure curve we concluded that there are no abnormal pressure in Hamra E-8 well .

5.2. Recommendation :

1. We recommend to use this method due to the big advantage of this method is that the parameters needed for calculation are obtained or measured from the drill bit (the BHA). Therefore, reduction of cost and time and the pore pressure obtained from the corrected d-exponent method reflects the pore pressure near the bottom of the hole.

2. We recommend to use this method in the case where there is no LWD data .

3. Due to some limitation in this method such as It can only be used to calculate pore pressures in clean shale or clean argillaceous limestone , Large increases in mud weight cause lower values of dc, and dc exponent values are affected by lithology, poor hydraulics, type of bit, bit wear, motor or turbine runs and unconformities in the formation. Therefore we recommend using other method (e.g well logging) to confirm the results .

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