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Prediction of abnormal pore pressure in southern Iraqi oil field

A graduation project submitted to the Department of Petroleum Engineering, in partial fulfillment for the requirements for the award of the degree of Bachelor of Petroleum Engineering.

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بِسْمِ اللَّـهِ الرَّحْمَـٰنِ الرَّحِيم

(يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ)

الإهداء

من قال انا لها "نالها"
وانا لها إن أبت رغما عنها أتيتُ بها
لم تكن الرحلة قصيرة ولا ينبغي لها أن تكون لم يكن الحلم
قريبا ولا الطريق كان محفوفا بالتسهيلات لكنني فعلتها ونلتها
إلى الذي زين أسمي بأجمل الألقاب، من دعمني بلا حدود
وأعطاني بلا مقابل إلى من علمني أن الدنيا كفاح وسلاحها
العلم والمعرفة الى من غرس في روحي مكارم الأخلاق
داعمي الأول في مسيرتي وسندي وقوتي وملاذي بعد الله...
إلى فخري واعتزازي (والدي)
إلى من جعل الله الجنة تحت أقدامها واحتضنني قلبها قبل يدها
وسهلت لي الشدائد بدعائها إلى القلب الحنون والشمعة التي
كانت لي في الليالي المظلمات
سر قوتي ونجاحي ومصباح دربي الى وهج حياتي (والدتي)
إلى ضلعي الثابت وأمان ايامي الى ملهمي نجاحي إلى من
شددت عضدي بهم فكانوا لي ينابيع أرتوي منها الى خيرة
أيامي وصفوتها الى قرة عيني (أخواني أخواتي (لكل من كان
عونًا وسندا في هذا الطريق.. الرفقاء السنين وأصحاب
الشدائد والأزمات أهديكم هذا الإنجاز وثمرة نجاحي الذي
لطالما تمنيته ها أنا اليوم أتممت أول ثمراته راجية من الله
تعالى أن ينفعني بما علمني وان يعلمني ما أجهل ويجعله حجة
لي لا علي

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ABSTRACT

Anticipating pore pressures are essential for the operation of drilling success for oil and gas wells in particular that may anticipate encounter abnormal pressure, i.e. higher than normal pressure. Drilling problems such as blow out or kick due to not considering the abnormal pressure where the formation pressure become greater than hydrostatic pressure, and vice versa in the case of differential pipe sticking because of sub normal pressure. Thus, drilling cost can be significantly reduced by early recognition the abnormal high pore pressures. The normal range for pressures attain to 0.433 and 0.50 psi/ft. The usual muds density is about 9 ppg. (pounds per gallon) which exerts a bottom hole pressure of about 0.47 psi/ft. Meanwhile, a well is in the process of being drilled, there are several parameters that indicate the presence of abnormal pressure, such as a sudden increase in penetration rate(ROP), a sudden increase in the temperature of the drilling mud, and a decrease in the density of the shale fragment There are many methods for predicting the abnormal pore pressures. The current study focuses the ratio (d- exponent) method This study is conducted in X oil field is one of the most important oil fields in Maysan Governorate the ratio (d- exponent) method was used to find intervals of abnormal pressure for Lower Fars formation Consists of five units (Lower Fars MB5 /Lower Fars MB4/ Lower Fars MB3/ Lower Fars MB2 /Lower Fars MB1) The results show that the ratio (d-exponent) method is considered as the best method for indication of the abnormal pressure intervals. The abnormal pressure intervals in(BM 4_BM3)this study can mitigate so many problems while drilling new wells formations Within the 'X' field.

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NOMENCLATURE

API American Petroleum Institute

BHP Bottom Hole Pressure

BHT Bottom Hole Temperature

DC Drill Collar

DP Drill Pipe

FDR Final Drilling Report

LWD Logging While Drilling

ROP Rate of Penetration

RPM Rotations Per Minute

THP Tubing Head Pressure

TVD True Vertical Depth

WHP Well Head Pressure

WOH Weight On Hook

WOB Weight On Bit

Chapter One

Introduction

1.1 Introduction :

Formation pressure is important information for well planning and operation because it impacts on several things as well control, casing design, drilling fluid program, pore pressure prediction, etc .

During an era of sedimentation and erosion, little grains of sediment are constantly building above each other, usually in an environment of full irrigation. As the sediment thickness of the base layer increases, the sediment grains are packed strongly near to each other, and some water is excluded from the small pore spaces. Though, if the pore spaces through the deposit sediments are connected to the top pressure surface, the fluid at any depth in the sediment will be same as that which would be found in a simple column of fluid.

Knowing pore pressure, which is the pressure of fluid in the pore spaces of a porous formation , It varies from hydrostatic pressure (normal pore pressure) to severe overpressure, which can be more than twice the hydrostatic pressure in the subsurface formation. Knowing the expected pore pressure is the basis for efficient well drilling using the correct mud weights and engineering casing programs, and for proper completion which must be effective, safe and allow the well to be killed without excessive damage to the formation .

In addition to predicting pore pressure in subsurface formations, the stress below the rock breaking point must be estimated. Therefore, in a subsurface formation, knowing the pressure that will be exposed Its rock formation and its predictability is an important fundamental consideration. The pressure at which the open-pit formation collapses is called the "fracture pressure." These fractures may result in the loss of massive amounts of mud or drilling fluid and these fluids may move all the way to ground level in a shallow formation environment that may tend to cause an explosion.

By predicting the pressure of the pores (fluid pore pressure) and the pressure of the fracture, We are able to manage and operate the well or wells in order not to have instability that is by making the pressure of the drilling (mud pressure) neither exceed the fracture pressure nor goes below the formation pore pressure.

1.2 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 different types of reservoir pressure that normally occur while drilling operations are commonly classified into three types:

▪ Hydrostatic

▪ Pore (formation)

▪ Overburden

1.2.1 Hydrostatic

The pressure at any point in a column of fluid caused by the weight of fluid above that point. Controlling the hydrostatic pressure of a mud column is a critical part of mud engineering. Mud weight must be monitored and adjusted to always stay within the limits imposed by the drilling situation. Sufficient hydrostatic pressure (mud weight) is necessary to prevent an influx of fluids from downhole, but excessive pressure must also be avoided to prevent creation of hydraulic fractures in the formation, which would cause lost circulation. Hydrostatic pressure is calculated from mud weight and true vertical depth as follows

Hydrostatic pressure, psi = 0.052 x Mud Weight, lbm/gal x True Vertical Depth, ft.

The Vertical Depth below the ground level until the point of interest is called the True Vertical Depth (TVD) it is shown in Figure 1.1 the difference between the TVD & MD, Measured Depth or (MD) is the total length of the well starting from ground level until the point of interest including the angels along the well (curves)

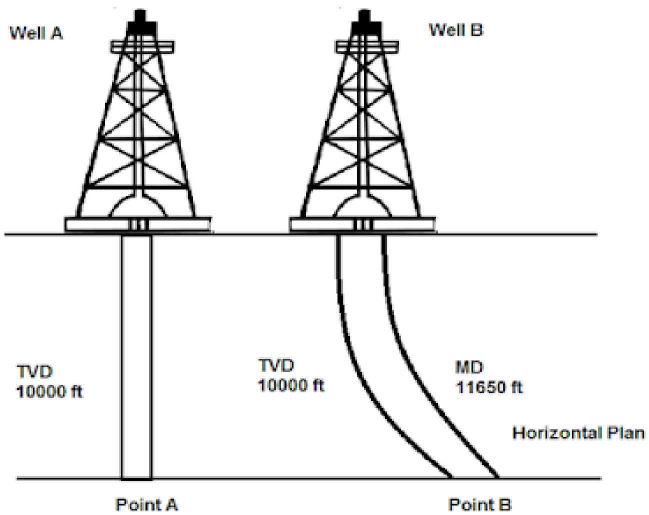


Figure 1.1 the difference between TVD and MD

In figure 1.1 can notice that both wells A and B have reached the same point if we pass a horizontal plan through the both points A and B at the depth of the 10000 ft, but in fact the drilling bit has not passed the same passage for the well A and B. the bit at the well A has drilled 10000 ft but in the well bit has drilled 11650 ft. we say the well B has a true vertical depth of 10000 ft and a measured depth of 11650 ft. for the well A the true vertical depth and measured depth are the same.

In order to calculate the bottom hole pressure in any well we tend to use the TVD because the gravity works vertically down the well.

1.2.2 Overburden Pressure:

Overburden pressure is the vertical stress imposed by the overlying formation at a reference point below the surface. In other words it is the hydrostatic pressure exerted by all the material above a reference point. The overlying layers can include rock columns and bodies of water. The importance of calculating Overburden Pressure lies in determining the fracture pressure of rocks. The figure below shows a visual representation of what overburden stress is:

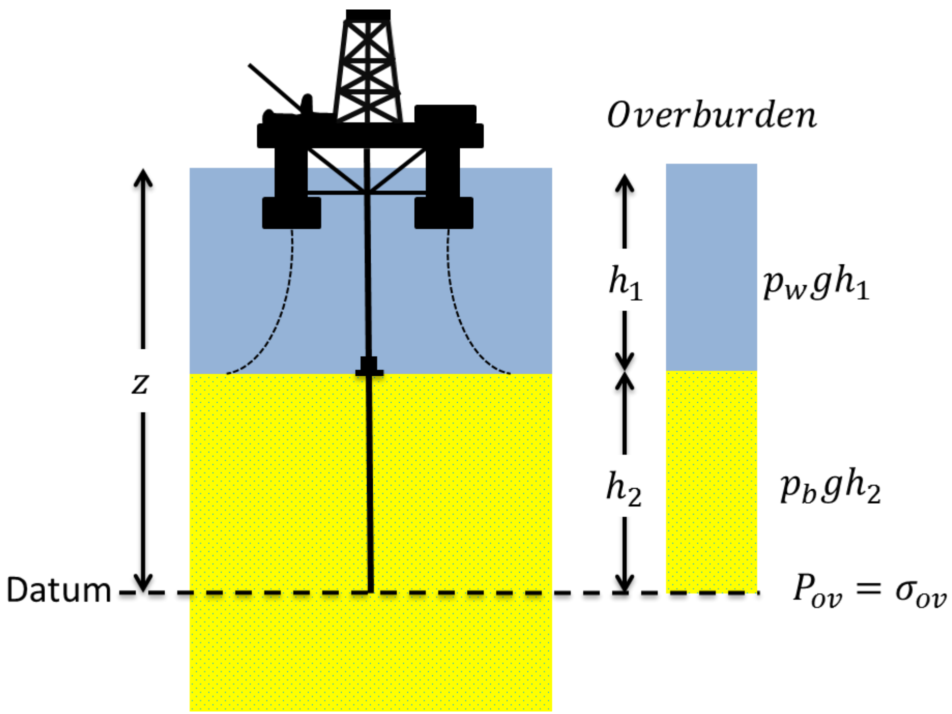


Figure 1.2 (The Overburden pressure factors)

From the figure above, it is clear that the overburden stress at a depth z, the datum point, is the sum of the pressure caused by the fluid column and the pressure caused by the rock (fluid-grain mixture) .to be more accurate when describing the overburden pressure it can be said that at any point in the earth, the overburden pressure is a summation of the stresses of the rock mass and the fluid above a certain point of interest.

$\sigma ov = 0.052 \times \rho bulk \times TVD$

Where: ρbulk = bulk density (ppg) TVD = Total Vertical Depth (ft) σov = overburden pressure (psi)

It cannot be used ethine the rock or the fluid density but the Bulk density must be used the equation of the bulk density is shown below

$$pb = pf * \Phi + pm * (1 - \Phi)$$

Where: $pb = bulk\ density\ of\ porous\ rocks\ pm = density\ of\ rock\ matrix\ pf = density\ of\ pores\ media\ fluid\ \Phi = Porosity$

1.2.3 Pore (formation)

Pore pressure and pore pressure gradient

The hydrostatic pressure and formation pore pressure in a typical oil and gas well are plotted in Fig. 1.3. At relatively shallow depths (less than 2000 m), pore pressure is hydrostatic, indicating that a continuous, interconnected column of pore fluid extends from the surface to that depth. At a depth of more than 2000 m the overpressure starts, and pore pressure increases with depth rapidly, implying that the deeper formations are hydraulically isolated from the shallower ones. By 3800 m, pore pressure reaches a value close to the overburden stress, a condition referred to as hard overpressure.

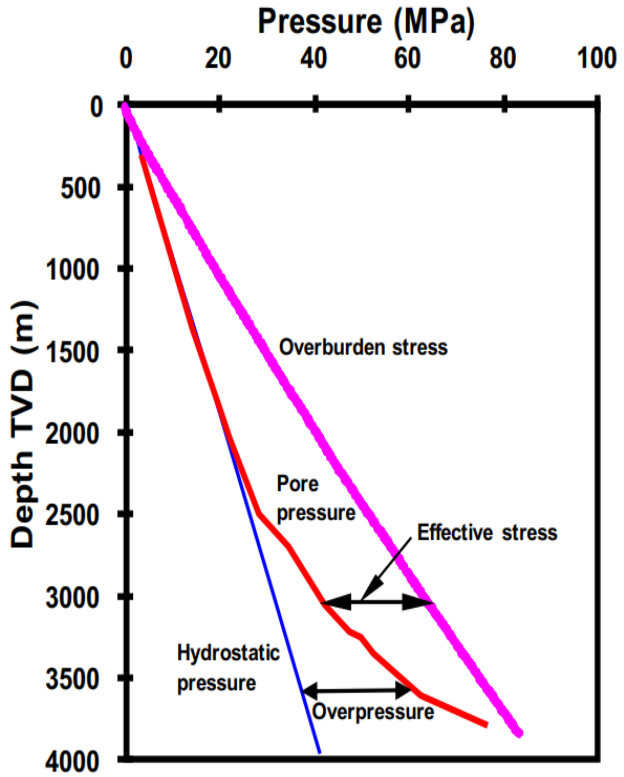


Figure.1.3(Hydrostatic pressure, pore pressure, overburden stress, and effective stress in a borehole).

The effective stress in pore pressure prediction community is conventionally defined to be the subtraction of pore pressure from overburden stress, as shown in Fig. 1.3. The increase of overpressure causes reduction in the effective stress.

Pore pressure gradient is more practically used in drilling engineering because it is more convenient to be used for determining mud weight (mud density). Pore pressure gradient at a given depth is the pore pressure divided by the true vertical depth. The mud weight should be appropriately selected based on pore pressure gradient, wellbore stability, and fracture gradient before setting and cementing a casing. The drilling fluid (mud) is applied in the form of mud pressure to support the wellbore walls for preventing influx and wellbore collapse during drilling. To avoid fluid influx and wellbore instability in an open hole section, a heavier mud pressure than the pore pressure is needed. However, when mud weight is higher than the fracture gradient of the drilling section, it may break the formation, causing mud losses or even lost circulation. To prevent a wellbore from unintentional hydraulic fracturing by the high mud weight, as needed where there is overpressure, a casing needs to be set to protect the overlying formations from fracturing, as illustrated . Pressure gradients and mud weight are expressed in the metric unit, SG or g/cm3 (i.e., specific gravity) . However, pressure gradients and mud weight are often reported in the English or the US unit system in the oil and gas industry.. the pressure gradient in the subsurface formation is normally converted to an equivalent mud weight (EMW) at surface for display and interpretation. In the US unit system, the unit of the pressure gradient is lbs/gallon, or ppg, which is a commonly used unit for pressure gradients and mud weight in the drilling industry in some countries, such as the United States.

Converting a pressure into the EMW at a given depth can use the following equation:

$$EMW(ppg) = \frac{pressure \quad (psi)}{0.051948 \times \ TVD \quad (ft)}$$

where TVD is the true vertical depth in ft.

Formations are classified based on the magnitude of their pore pressure gradients.

There are 3 categories of the formation pressure which are normal pressure, abnormal pressure and subnormal pressure.

1. Normal Pressure:

Normal pressure is the hydrostatic of water column from the surface to the subsurface formation. It can be simply stated that normal pressure is equal to hydrostatic pressure gradient of water in pore spaces of formations on each area. The concentration of salt in water affects the normal pressure. Higher salt concentration in water, higher specific gravity of water will be. Therefore, the normal pressure can vary from slightly salt 0.433 psi/ft (8.33 PPG) to highly concentrated salt 0.478 psi/ft (9.2 PPG) based on salt concentration in water.

Formation Water	Example Area	Pressure Psi/ft	Gradient (SG)
Fresh Water	Rocky Mountains & Mid-continent, USA	0.433	1.00
Salt Water	Most sedimentary basins worldwide	0.442	1.02
Salt Water	North Sea, South China Sea	0.452	1.04
Salt Water	Gulf of Mexico, USA	0.465	1.07
Salt Water	Some areas of Gulf of Mexico	0.478	1.10

Table 1 demonstrates the average normal pressure gradient based on several areas

2. Subnormal Pressure:

The subnormal pressure is the pressure that is less than normal pressure and it possibly causes lost circulation problems.

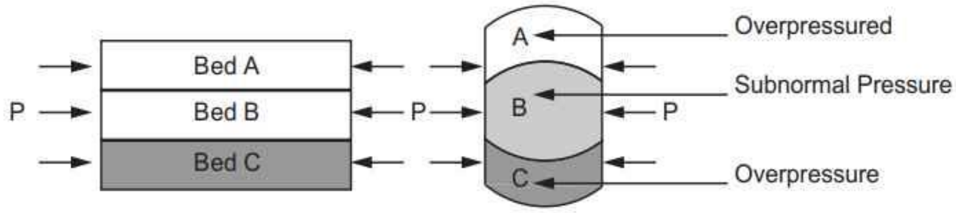
Origin of Subnormal Formation Pressures The major mechanisms by which subnormal (less than hydrostatic) pressures occur may be summarised as follows:

(a) Thermal Expansion

As sediments and pore fluids are buried the temperature rises. If the fluid is allowed to expand the density will decrease, and the pressure will reduce.

(b) Formation Foreshortening

During a compression process there is some bending of strata (Figure 1.4). The upper beds can bend upwards, while the lower beds can bend downwards. The intermediate beds must expand to fill the void and so create a subnormally pressured zone. This is thought to apply to some subnormal zones in Indonesia and the US. Notice that this may also cause overpressures in the top and bottom beds.



Foreshortening of intermediate beds. shortening of bed B due to the warping of beds A and C causes unique pressure problems (Figure 1.4).

(c) Depletion

When hydrocarbons or water are produced from a competent formation in which no subsidence occurs a subnormally pressured zone may result. This will be important when drilling development wells through a reservoir which has already been producing for some time. Some pressure gradients in Texas aquifers have been as low as 0.36 psi/ft.

(d) Precipitation

In arid areas (e.g. Middle East) the water table may be located hundreds of feet below surface, thereby reducing the hydrostatic pressures.

(e) Potentiometric Surface

This mechanism refers to the structural relief of a formation and can result in both subnormal and overpressured zones. The potentiometric surface is defined by the height to which confined water will rise in wells drilled into the same aquifer. The potentiometric surface can therefore be thousands of feet above or below ground level Figuer 1.5

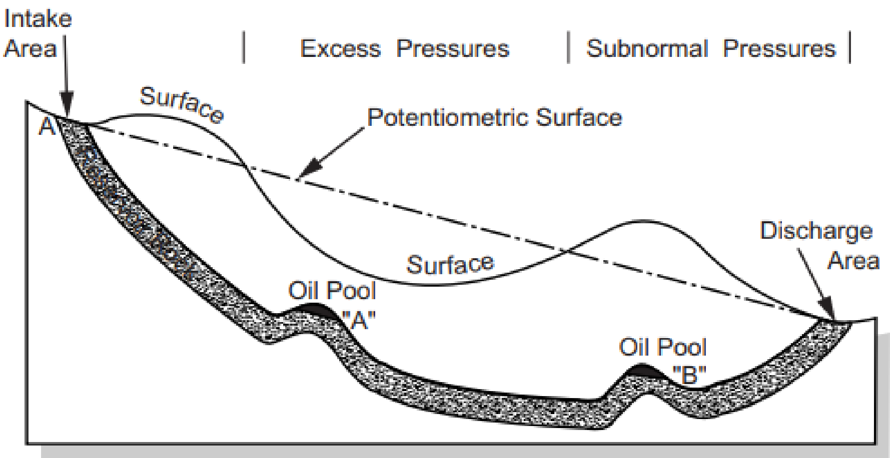


Figure 1.5 The effect of the potentiometric surface in relationship to the ground surface causing overpressures and Subnormal Pressure

(f) Epeirogenic Movements

A change in elevation can cause abnormal pressures in formations open to the surface laterally, but otherwise sealed. If the outcrop is raised this will cause overpressures, if lowered it will cause subnormal pressures (Figure 1.6).

Pressure changes are seldom caused by changes in elevation alone since associated erosion and deposition are also significant. Loss or gain of water saturated sediments is also important.

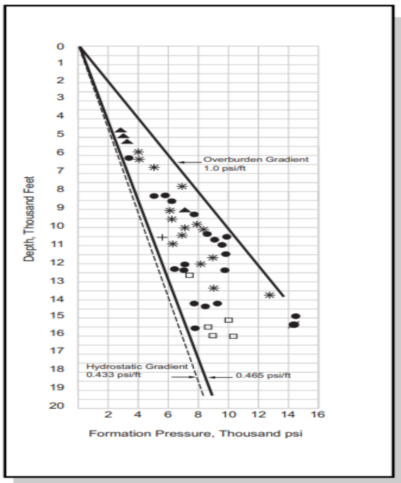


Figure 1.6 Section through a sedimentary basin showing two potentiometric surfaces

The level of underpressuring is usually so slight it is not of any practical concern. By far the largest number of abnormal pressures reported have been overpressures, and not subnormal pressuer.

3. Abnormal Pressure：

The abnormal pressure is the pressure greater than the pressure column of water (normal pressure).A normal, hydrostatic pressured geologic environment can be visualized as a hydraulically “open” system; i.e. permeable, fluid communicating formations allow establishment and/or reestablishment of hydrostatic conditions. Conversely, abnormally high formation pressure systems are essentially “closed”, preventing, or at least greatly restricting, fluid communication. Here, overburden pressure, in part, is supported by formation fluids in the pore space.

Abnormally high pore fluid pressures are encountered worldwide in formations ranging in age from the Cenozoic era (Pleistocene age) to as old as the Paleozoic era (Cambrian age).

With the tremendous pace of technological advancements, the subsurface velocity information and various geophysical attributes obtained from seismic reflection data are routinely integrated with the high-resolution petrophysical and drilling data along with the knowledge of geological processes for the purpose of carrying out accurate pore pressure prediction.

The aim of this study is prediction of abnormal pore pressure in southern Iraqi oil field. through different formation with a different lithology of each formation using drilling parameters such as; rate of penetration (ROP), d,This calculation depend upon data collected with figures explain the relation of the parameters with depth.

Chapter Two

Origin of Over-pressured Formations

2.1 Introduction

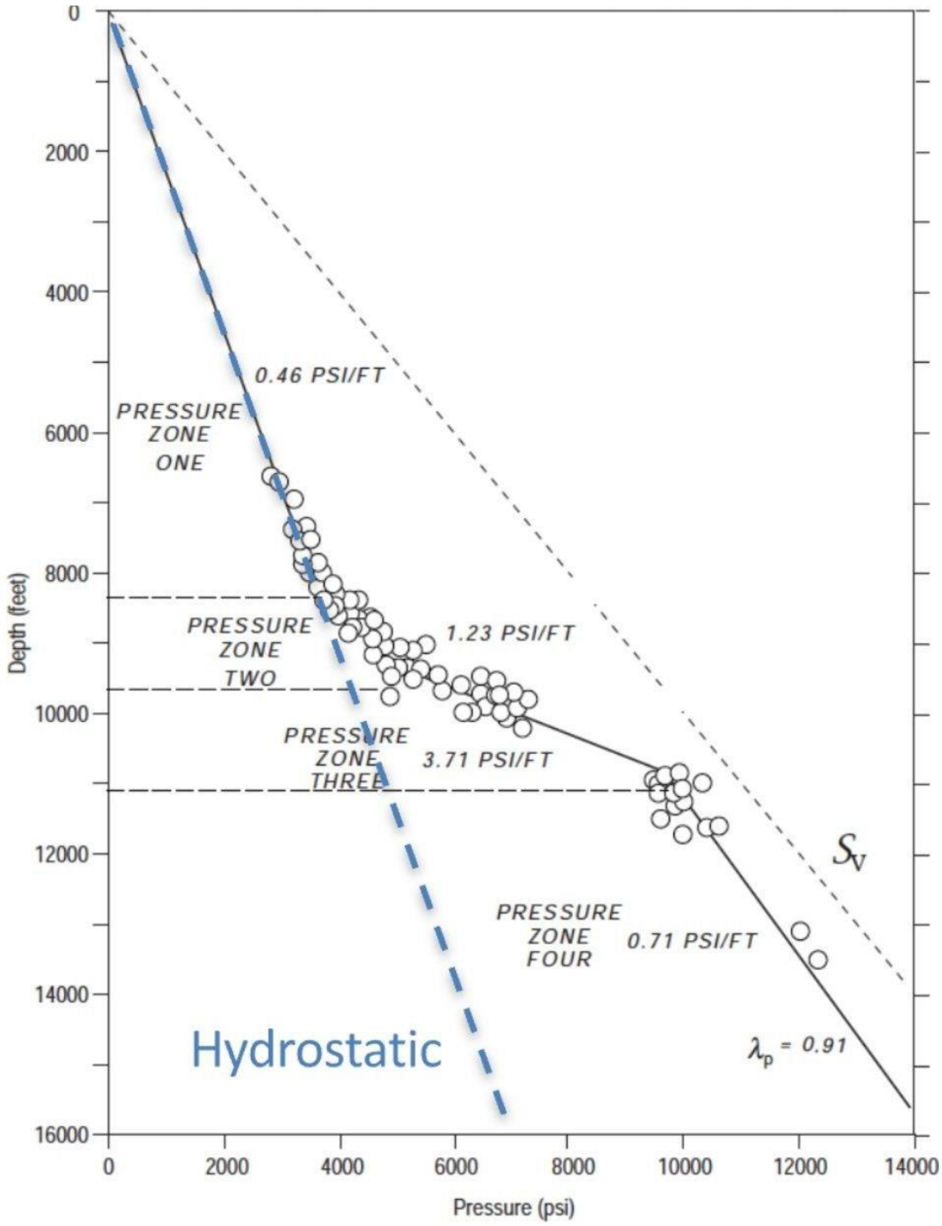
Many factors can cause abnormal formation pressures, that is, pressures other than hydrostatic. In some areas, a combination of these factors prevails. To place causes of abnormal formation pressures in proper perspectivepore pressure (or simply formation pressure), is an important consideration in many aspects of well planning and operations.

In some cases, the size of the geological formation may change over time, not necessarily in equilibrium with the fluid within it. These changes in size can occur due to various geological processes, such as tectonic activity or compaction. When the compartment size changes, it can impact the pressure distribution within the formation. On the other hand, there are situations where the compartment size remains fixed, but other factors, such as fluid migration or hydrocarbon generation, can lead to abnormal pressure. In these cases, the pressure anomalies develop within a fixed-size compartment. By understanding these mechanisms and considering the geological environment, well planners can anticipate troublesome zones where abnormal pressures may be encountered. This knowledge helps them take appropriate measures to mitigate drilling and production challenges associated with abnormal pressure zones.

2.2 The principal causes of abnormal pressures

1. Under-compaction

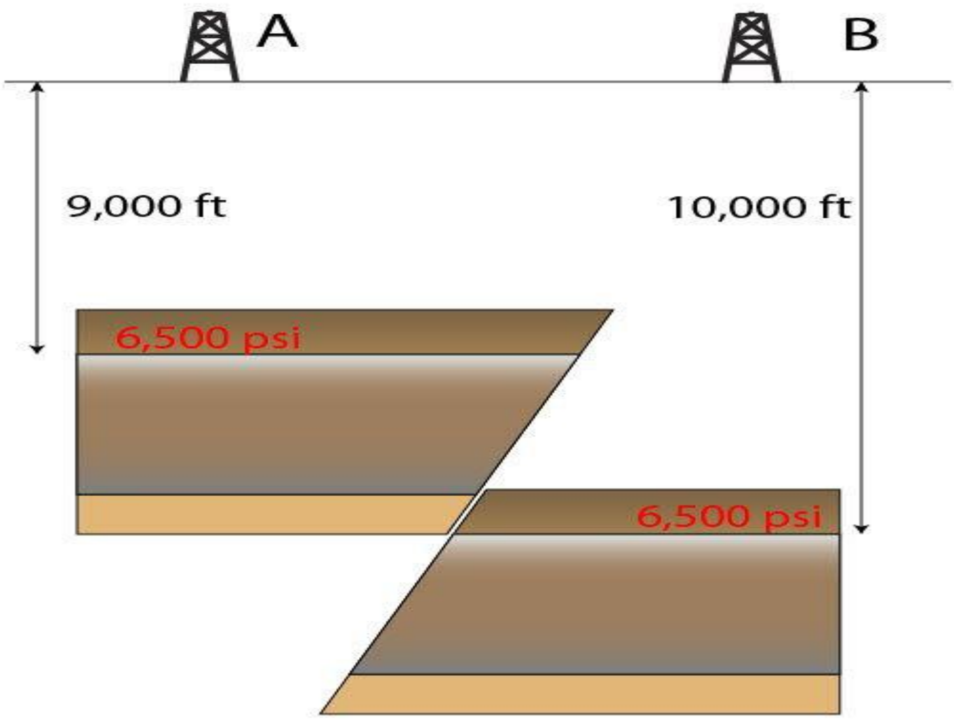
Disequilibrium compaction (which is often called undercompaction) is perhaps the most easily understood physical mechanism leading to overpressure. At a given depth, ongoing sedi- mentation increases the overburden stress which, in turn, will tend to cause compaction and porosity loss. In a hydraulically open system, that is, in sufficiently permeable for- mations to be hydrologically connected to earth's surface, the compaction and porosity loss associated with burial can be accommodated by fluid flow without excess pressure build up. This is apparently the case with the formations at depths less than 8000 ft in Figure 1. However, in a low permeability formation (such as a shale), in confined sands isolated from other sands (such as with the formations deeper than 9000 ft in Figure1), or in regions of such rapid sedimentation and compaction fluid expulsion cannot keep pace with the porosity loss. In this case, the increasing overburden stress driving compaction will cause increases in pore pressure as the overburden stress is carried by the pore fluid pressure. This state, in which externally applied stresses are supported by pore fluid pressure, is related to the concept of effective stress. Fiegur1



Figure(2.1) Overpressure example in the Monte Cristo field.

2.Tectonic

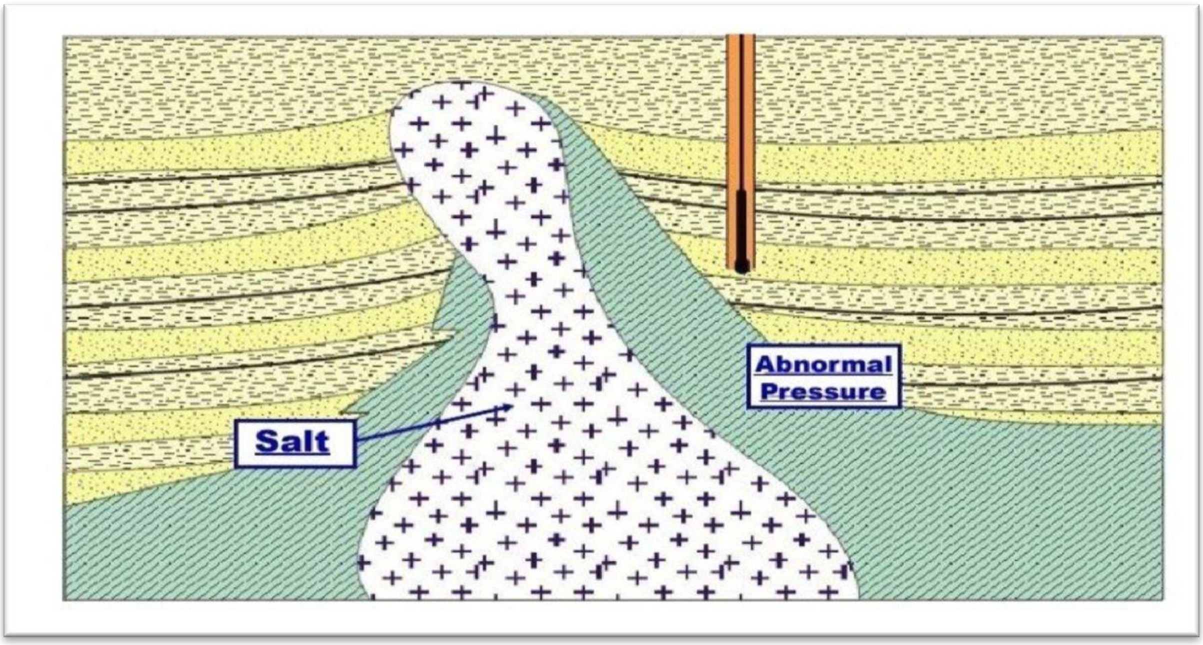
Various authors have suggested uplift as a cause of abnormal pressures. A pressure regime that is normal for one depth would, if elevated and preserved, be abnormal for shallower depths. There may be areas in which this has occurred, but the unambiguous evidence of the major regressive sequences with abnormal pressures, such as the US. Gulf Coast, the Niger delta and several sedimentary basins of South-east Asia, is that the abnormal pressures were generated during subsidence and the accumulation of the regressive sequence, and that these areas are still subsiding . Likewise, tectonic compression cannot be a general cause because the Niger delta and the U.S. Gulf Coast are tectonically passive, and there is unambiguous evidence from growth faults that the stress field is and was one with a component of horizontal tension. Nevertheless, tectonic compression could cause abnormal pressures in mudstones, and Berry (1973) has described a zone in California 650-800 km long and 40-130 km wide (400-500 X 25-80 miles) associated with the San Andreas fault. There is little doubt that on a local scale, abnormal pressures may be associated with faulting, the pressures being due to mechanical deformation of the mudstone and the consequent tendency to reduce porosity.



Figure(2.2)Uplift fault

3. A salt diapirism

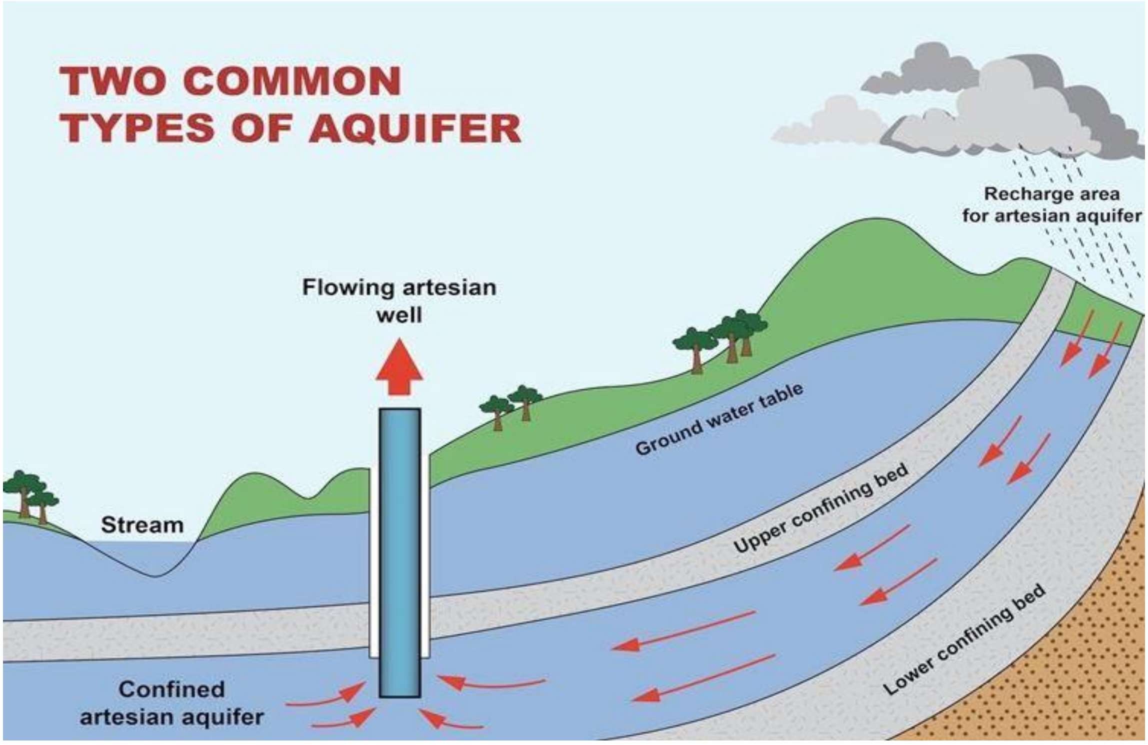
is an upward intrusion of salt to form a salt dome. This up thrust disturbs the normal layering of sediments and over pressures can occur due to the folding and faulting of the intruded formations. Figure(2.3).



Figure(2.3) A salt doms

4. Artesian Hydrostatic Pressure (Hydraulic Head)

Hydraulic head and buoyancy force are two phenomena that can impose extra pressure onto pore fluid in confined conditions. Hydraulic head is also known as piezometric head, which is a specific measurement of water level and equivalent pressure above a datum .The main controlling parameters in the artesian head are the piezometric level or water table elevation and sealing . In unconfined aquifers, pressure would easily dissipate through the pore spaces and the hydraulic head would be equivalent to the sea level or elevated free water table altered by the soil capillary. This mechanism is liekly to take place in shallow aquifers where they are in a hydrodynamic connection to the free water.



Figure(2.4)Aquifer Vocabulary Flashcards

5.Petroleum generation

Petroleum generation could affect mudstone pore pressures in two ways: the generation of petroleum itself could involve an increase in net volume, and the products could reduce the relative permeabilities to water and to petroleum. We shall take the latter first. Chapman (1972) noted that upward flow of water through the transition zone is towards lower pressures, and concluded that any petroleum exsolution during this migration would reduce the effective permeability of the mudstone to water and so reduce the rate of expulsion of pore fluids. Such a process cannot eliminate permeability, but if relative permeability diagrams determined for sandstone reservoirs are generally applicable to mudstones, the permeability to both fluids together (i.e., the sum of their relative permeabilities) may be reduced to about l/lOth of its value for a single fluid. Visser and Hermes (1962) described the drilling of the Gesa anticline in the Mamberamo delta, Irian Jaya, and the problems encountered with abnormal pressures. Methane and some carbon dioxide were found in the mudstones only, and so could have contributed to these pressures by reducing the permeability to the fluids. Gas is sometimes (but not always) detected in the mud while drilling the transition zone. Illing (1938) stated that the generation of oil from organic matter involved an increase in volume, and that this could give rise to considerable pressures in compacted rocks. Hedberg (1974,1980) suggested that the generation of methane and other hydrocarbons of low molecular weight is an important source of energy for primary migration, abnormal pressures, mudstone diapirs, and mudvolcanoes. Such pressures are enhanced and retained by the effects on effective permeabilities. In the Lower Mississippian Bakken Shale of the Williston

basin in North America, Meissner (1978) found abnormal pressures in certain areas over certain intervals. The prevailing pressure regime in the sequence is even a little below normal hydrostatic, and Meissner argued that the abnormality is directly due to oil generation in a relatively well-compacted source rock. Similarly, the Kimmeridge Clay (Jurassic) of the northern North Sea is overpressured and considered by many to be the source rock of much of the North Sea oil. This example is confused, but not irrelevantly to our purpose,by the fact that it is unusually radioactive, and also hot. Hbritier et al. (1981) reported that the Frigg discovery well penetrated 77 m of oil shale of Kimmeridgian age that registered 250 API units of gamma radiation at. about 4200 m (but they do not regard it as the source rock for the Frigg petroleum because the vitrinite reflectance is only 1%). From these examples, it is clear that attention must be paid to the geophysical properties of the fine-grained rocks that might be petroleum source rocks. Source rocks generating petroleum may also generate local abnormality of pressure, resistivity, sonic velocity, and their temperatures may well provide more direct evidence of the requirements for oil and gas generation..

6. Clay-mineral diagenesis

The diagenesis of smectite (montmorillonite) to illite involves the release of inter-layer water. Powers (1967) suggested that this release of water could aid primary migration, and the hypothesis that this process could lead to abnormal pressures grew from this suggestion. If the density of inter-layer water is greater than that of free water, there is expansion on liberation that would result in a net decrease of bulk density of the mudstone, and abnormal pressures, unless the water can escape. There is ample evidence that this diagenesis is real, but little that it contributes significantly to abnormal pressures. Powers regarded 1800 m (6000 ft) as the ceiling of this diagenesis. Burst (1969) concluded that it did not operate between depths of 800 and 2500 m in the U.S. Gulf Coast. Comparable depths were found by Perry and Hower (1970), and rather greater depths were found by Weaver and Beck (1971). Magara (1978) has shown that the observed degree of undercompaction cannot be accounted for by smectite diagenesis because it cannot account for the bulk density decrease observed within the transition zone. This diagenesis cannot contribute, it seems, to those abnormal pressures that lie above its ceiling, so it cannot be a general cause. If it can be established that inter-layer water has significantly greater density than free water, it is possible that release of this water to the pore spaces will contribute to abnormal pressures, and primary migration, at depths below two or three kilometers. As with thermal processes, the rate at which the diagenesis takes place is important: it must generate a volume of water greater than that that can be dissipated, so that the rate of generation exceeds the rate of dissipation.

7. Osmosis

When a semi-permeable membrane separates two liquids of different salinities, the less saline liquid moves through the membrane into the more saline liquid. This tendency to equalize chemical potentials across the membrane can lead to pressure differences. As a process that could generate abnormal pressures in thick mudstones of regressive sequences, it is unconvincing. Magara has argued that the osmotic gradient in a mudstone opposes the generation of abnormally high pore pressures in mudstones by assisting the expulsion of pore water. There is laboratory evidence that water expelled early from a mudstone is more saline than that expelled later. And there is field evidence that the salinity of mudstone pore water is less than that of the adjacent sandstones when the latter are normally pressured. When abnormally pressured, the salinity of sandstone pore water tends to be less than that of normally pressured sandstones, and more comparable to that of the abnormally pressured mudstone. Hill et al. (1961) suggested that osmosis might be the cause of abnormally low pore pressures in the Mesaverde sandstone in central U.S.A. and the Viking Sandstone in Canada, both of which not only have pressures below normal hydrostatic but have waters that are fresh. The same conditions are found in the Molasse basin of southern Germany. Some pore pressure anomalies appear to be related to osmosis , but there is no evidence that the generality of abnormal pressures is so caused, and some that it is not so caused.

Chapter three

Prediction and detection of Abnormal Pressure

3.Methods and techniques for prediction abnormal pore pressure

It is well known that the predictive techniques for prediction and detection of abnormal pressure rely basically on surface measurements, for instance; geophysical measurement, or through performing analysis of data extracted from drilled wells in adjacent locations (offset wells). It is normal to use geophysical to determine geological conditions that may suggest overpressure potential, like salt domes, associated with over-pressured areas. Generally, engineers use seismic data to detect transition zones and gas presence as a fluid content function. The history of offset wells can provide details on the utilized mud weights, stuck pipe issues, any circulation losses or kicks. During the process of predicting over-pressurized zones, any relevant wireline logs or information extracted from mud logging is of great value.

Time	Source of data	Pressure indicator
Before drilling	Surface geophysical detection	Seismic velocity
		Gravity
While drilling	Drilling parameters (A)	Penetration rate
		Measurement while drilling
	Drilling parameters (B)	Mud-gas cutting
		Pressure kicks
		Flowline temperature
		Pit-level and total pit volume
		Hole fill-up
		Mud flow rate
	Shale cutting parameters	Bulk density
		Shale formation factor volume, shape, size, sand/shale ratio
	Correlation between new and existing wells	Drilling data
After drilling	Subsurface geophysical detection	VSP
	Well logging	Sonic, resistivity, density, neutron, downhole gravity
When well is tested or completed	Monitoring pore pressure variations in short zones	Repeat formation tester
		Drill stem test
		Pressure bombs

- **Predictive Techniques**

These techniques include different geophysical techniques used during the early exploration phase. They will predict and forecast the presence of conditions of any possible abnormal pressure.

- **Detection techniques**

  These techniques are the ones that can be monitored while the drilling operations are going on and with these techniques , the drilling team (crew) will be alert if they have drill across an over-pressurized zone or transition zone. This refers to factors and characteristics that can be tracked during the process of drilling. These parameters play a significant and crucial role in giving an alarm to the drilling crew that a transition/over-pressurized zone has been encountered.

In order to detect the presence of abnormal pressure zones, three different categories of data sources must be mentioned as follows :

I. Drilling Parameters These parameters are related to drilling parameters monitoring, and utilizing the drilling rate empirical equation which takes into consideration the pore pressure as a dependent term.
II. Drilling Fluid (Mud) In this section, the effect of the abnormal pressure zone on the drilling fluid is studied. This effect includes for instance influx of quantities of hydrocarbons and an increase in the temperature.
III. Drilling Cuttings In this category, the study of the drilling cuttings from the sealing zone is carried out.

- **Confirmation techniques**

These techniques are related to techniques used to confirm and detect any abnormal pore pressures of the encountered formations. These techniques are applicable after the completion of the well drilling successfully.

3.1 Detection of Abnormal Pressures System from Seismic Data

Detection and evaluation of high abnormal pressures and prediction of fracture pressure gradient has become a topic of vital importance in the planning of drilling oil wells, especially if we talk about exploratory wells.

In exploratory wells, since we don’t have any direct information obtained from wells, we must use different techniques rather than those used on developed fields. An example of those techniques ,is the use of the information obtained from a study of seismic superficial reflection.

Pore pressure estimation using seismic survey

Pore pressure could be estimated by seismic data. The basis of this method is based on the premise that any physical change in formation effects on seismic wave properties. Seismic survey is usually done before the main drilling phase of the field, so this method is the only way whose results can be used in drilling phase (Badri et al. 2000). Porosity and rock compaction are two parameters that control the subsurface seismic responses. These parameters are influenced by the effective stress. Increasing the effective stress decreases the porosity. Decreasing the effective stress increases the pore pressure and porosity, so grain contact decreases and the result is decreasing the velocity wave passing through the rock. The differences between seismic and sonic waves are their frequency and pathway through the rock

3.2 Pore Pressure from Well-Logging Methods

Hottman and Johnson (1965) laid the foundation of detecting and quantifying pore pressure from log-derived shale values – resistivity and velocity or transit time. Since then many other geophysical tools are used for pore pressure measurements. Invariably, most logging devices used to detect and measure pore pressure are essentially shale porosity measuring devices, and indicate overpressure because of abnormally high or low values of any of the following characteristics of over pressured shales: density, porosity, transit time, conductivity, resistivity, drilling rate, water salinity, and temperature gradient, as shown schematically in Figure 3.1. It shows a conceptual display of responses from various geophysical well logs in normal and abnormally high-pressure environment. Porosity is the common variable in the indicators of all of these tools.

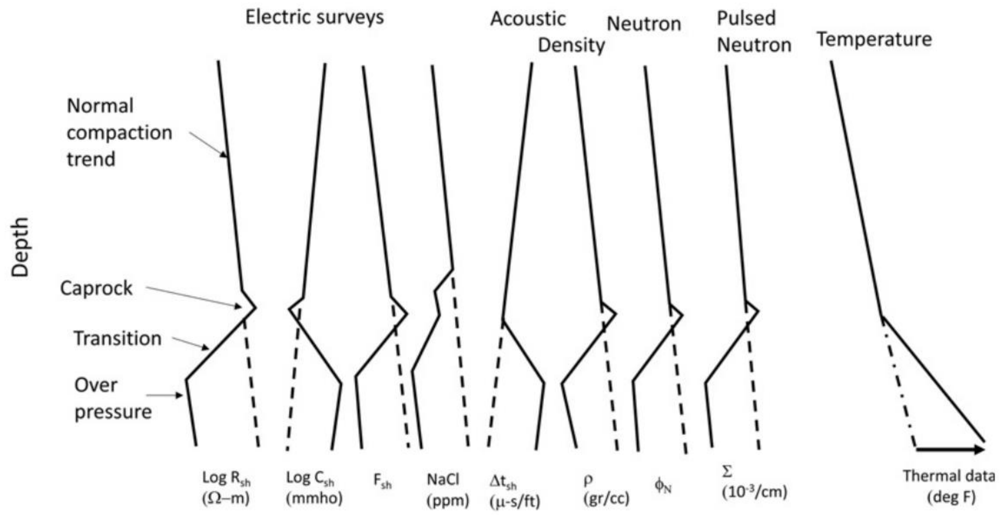


Figure 3.1 Conceptual response of various geophysical well logs for normally pressured and geopressured rocks. Modified after Fertl and Timko (1971).

Overpressure detection by well logs

Pore pressure variation changes the physical properties of rock such as compaction, porosity and electrical properties. These changes observed as anomalies in the overpressure zone rather than their normal state. Almost overpressure detection by well logs is a qualitative method.

Pressure effect on sonic log

The sonic log is sensitive to pressure changes since there is a relation between porosity, compaction, acoustic parameters and pore pressure (Chopra and Huffman 2006; Li et al. 2000). An increase in burial depth leads to an increase in compaction and a decrease in porosity (Zhu et al. 1992; Keary et al. 2002). Hence, shear and bulk modulus increases with depth leading to a decrease in rock compressibility and an increase in velocity. In overpressure zone, the compaction rate is decreased, and sometimes it even ceases. The acoustic velocity decreases in the overpressure zone because of the decrease in compaction. Hence, the sonic log is a powerful tool to detect overpressure zones. The sonic log follows the same physics' principles as a seismic survey, but the difference is a range of frequency. To predict pore pressure using the sonic log, a number of relations are developed. The most basic and reliance relations are Eaton (1969, 1972) and Bowers (1995). These are used for both sonic and seismic data to convert velocity to pore pressure, especially for sandstone formations. Both relations have several constants that are determined by well test.

Pressure effects on density log

An increase in compaction leads to an increase in bulk density since pore volume decreases with respect to bulk volume (Dutta and Khazanedari 2006; Kelly et al. 2005). The increase in bulk density with depth is steady. Several theories are represented for increasing density by depth. In the overpressure zone by considering naught decreasing porosity and naught increasing rock compaction, density increasing trend with depth would be slow down or stop. But in overpressure zone rock density is smaller normal state due to a decrease in compaction. The density log by companionship with seismic is used to predict pore pressure quantitatively.

Pressure effect on resistivity log

Increasing pore pressure causes decreasing grain contacts and not decreasing in pore space, so electrical conductivity in rock is depended on fluid. Resistivity changes are extremely dependent on fluid type and lithology, so resistivity log should be used cautiously as a detecting index for the overpressure zone.

Estimation of formation pressures

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. Analyzing the data presented by Hottmann and Johnson (1965), Gardner et al. (1974) proposed an equation that can be written in the following form to predict pore pressure:

$$p_f = \sigma_V - \frac{(\alpha_V - \beta)(A_1 - B_1 \ \ln \Delta t)^3}{Z^2}$$

where pf is the formation fluid pressure (psi); σV is expressed in psi; αV is the normal overburden stress gradient (psi/ft); β is the normal fluid pressure gradient (psi/ft);

Z is the depth (ft); Δt is the sonic transit time (μs/ft); A and B are the constants, A1=82,776 and B1=15,695. Later on, many empirical equations for pore pressure prediction were presented based on resistivity, sonic transit time (interval velocity) and other well logging data. The following sections only introduce some commonly used methods of pore pressure prediction based on the shale properties.

Pore pressure prediction from resistivity In young sedimentary basins where under-compaction is the major cause of overpressure, e.g., the Gulf of Mexico, North Sea, the well-log-based resistivity method can fairly predict pore pressure. Eaton (1972, 1975) presented the following equation to predict pore pressure gradient in shales using resistivity log:

$$P_{pg} = OBG - \left(OBG - P_{ng}\right)\left(\frac{R}{R_n}\right)^n$$

where Ppg is the formation pore pressure gradient;

OBG is the overburden stress gradient;

Png is the hydrostatic pore pressure gradient (normally 0.45 psi/ft or 1.03 MPa/km, dependent on water salinity);

R is the shale resistivity obtained from well logging;

Rn is the shale resistivity at the normal (hydrostatic) pressure;

n is the exponent varied from 0.6 to 1.5, and normally

n= 1.2. Eaton's resistivity method is applicable in pore pressure prediction, particularly for young sedimentary basins, if the normal shale resistivity is properly determined .

One approach is to assume that the normal shale resistivity is a constant. The other approach includes to accurately determine the normal compaction trendline.

3.3.1.Pore pressure prediction from interval velocity and transit time

- Eaton's method

Eaton (1975) presented the following empirical equation for pore pressure gradient prediction from sonic compressional transit time

$$P_{pg} = OBG - \left(OBG - P_{ng}\right)\left(\frac{\Delta t_n}{\Delta t}\right)^3$$

where Δtn is the sonic transit time or slowness in shales at the normal pressure; Δt is the sonic transit time in shales 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).

1. Adapted Eaton's methods with depth-dependent normal compaction trendlines

1. Eaton's resistivity method with depth-dependent normal compaction trendline

In Eaton's original equation, it is difficult to determine the normal shale resistivity or the shale resistivity in the condition of hydrostatic pore pressure. One approach is to assume that the normal shale resistivity is a constant. However, the normal resistivity (Rn) is not a constant in most cases, but a function of the burial depth, as shown in Fig.3.6. Thus normal compaction trendline needs to be determined for pore pressure prediction. Based on the relationship of measured resistivity and burial depth in the formations with normal pressures, the following equation of the normal compaction trend of resistivity can be used (refer to Fig.3.6):

$$\ln R_n = \ln R_0 + bZ$$

where Rn is the shale resistivity in the normal compaction condition; R0 is the shale resistivity in the mudline; b is the constant; and Z is the depth below the mudline Substituting

$$R_n = R_0 e^{bZ}$$

$$P_{pg} = OBG - \left(OBG - P_{ng}\right)\left(\frac{R}{R_n}\right)^n$$

$$P_{pg} = OBG - \left(OBG - P_{ng}\right)\left(\frac{R}{R_0 e^{bZ}}\right)^n$$

where: R is the measured shale resistivity at depth of Z; R0 is the normal compaction shale resistivity in the mudline; b is the slope of logarithmic resistivity normal compaction trendline. A case study is examined to verify the adapted Eaton's resistivity method with depth dependence. The studied basin is located in a deepwater field in Green Canyon of the Gulf of Mexico, U.S.A. The water depth is 5000 ft, and the Tertiary formations are mainly shales (mudstones) with some sandstones. The target reservoir is located in the Miocene sandstones. Several offset wells are analyzed to examine pore pressures in this field. Fig. shows the pore pressure calculation in an oil well from the modified Eaton's resistivity method in this basin. Prior to the pore pressure calculation, the normal resistivity compaction trend is firstly analyzed based on Eq.

$$R_n = R_0 e^{bZ}$$

as shown in Fig3.6.a. With calibration of the measured pore pressure data, the normal compaction trendline is obtained with the following parameters in this basin: R0= 1.28 ohmm, b= 0.000034. Pore pressure calculated from the adapted Eaton's method with n= 1.2, Png= 8.7 ppg) is compared to the measured pore pressure from the repeat formation tests (RFT) and mud weight. Fig3.7. indicates that the formation is in normal compaction when depth is less than 4900 ft below the sea floor. Deeper than this depth (from 4900 to 7600 ft), the formation is slightly under-compacted with a lower resistivity than the normal compaction trend (Fig3.2.a), implying that the pore pressure increases, as shown in Fig.3.7.b. From 7600 to 13,000 ft, the formation is further under-compacted and more elevated pore pressures exist. Fig.3.6 demonstrates that the adapted Eaton's resistivity method gives a fairly good result in pore pressure calculation. It should be noted that the pore pressure in the formation near the wellbore is affected by drilling-induced stresses .Therefore, in order to obtain the formation pore pressure the deep resistivity is needed for the pore pressure calculation.

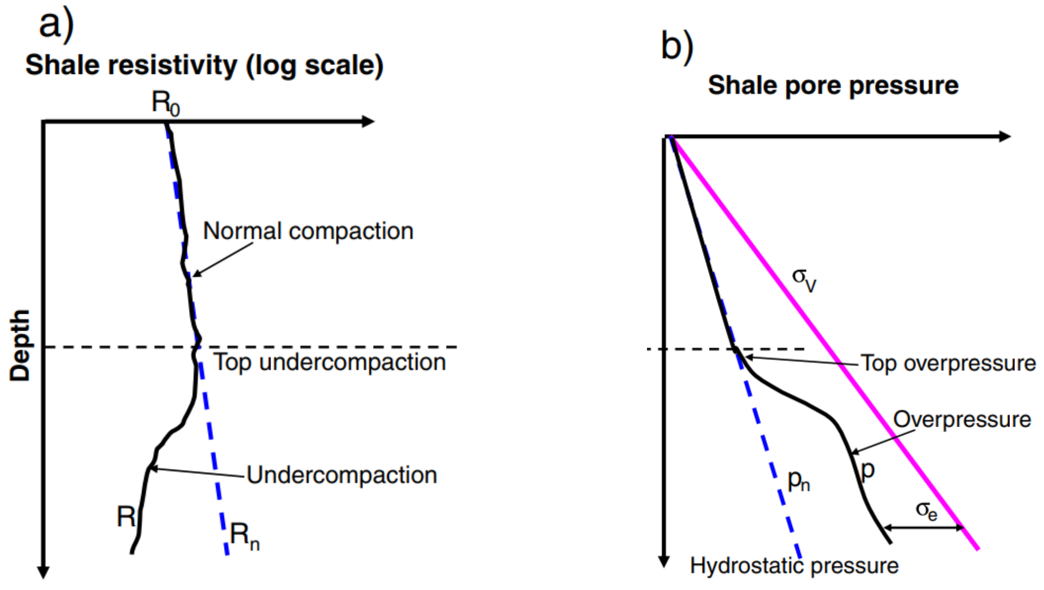


Fig.3.2. Schematic resistivity (a) and pore pressure (b) in an undercompacted basin. The inclined line in (a) represents the resistivity in normally compacted formation (normal resistivity, Rn). In the under-compacted section the resistivity (R) reversal occurs, corresponding an overpressured formation in (b). In the under-compacted /overpressured section, resistivity is lower than that in the normal compaction trendline (Rn). In the figure,

σV=lithostatic or overburden stress; σe= the effective vertical stress; pn=normal pore pressure; p= pore pressure.

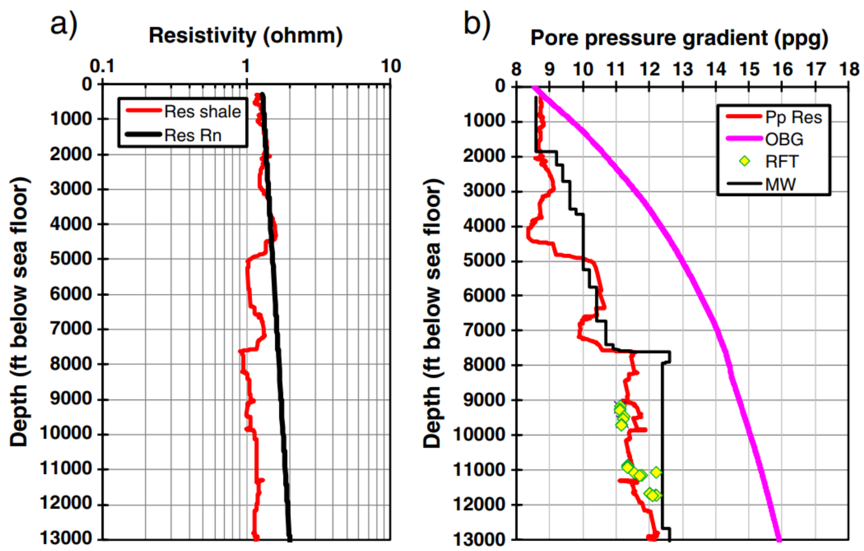


Fig.3.3 Pore pressure calculated by adapted Eaton's resistivity method with depth-dependent compaction trendline in a deepwater post-well analysis in the Gulf of Mexico.

The left figure (a) plots the resistivity in shale and the normal resistivity , and the resistivity is plotted in logarithmic scale. The right figure (b) shows the overburden stress gradient (OBG), mud weight used while drilling (MW), measured pore pressure gradient (RFT) and pore pressure gradient (Pp Res) .

3.3.2.Sonic with Depth method- Normal Compaction Trend Line Dependent

Based on the data on the calculated Normal pore-pressure sonic transit time of the formations, the following general relation is proposed the compaction pattern of the transit time:

$$\Delta t_n = \Delta t_m + (\Delta t_{ml} - \Delta t_m)e^{-cZ}$$

Where:

DTm = the transit time of compression through the shale matrix (no porosity)

DTml = the time of transit of the mud line

c = the constant of compaction

Z = the distance below the mud line

The pore pressure can be determined when this DTn is replaced by the Eaton velocity/transit time equation

$$P_{pg} = OBG - \left(OBG - P_{ng}\right)\left(\frac{\Delta t_n}{\Delta t}\right)^3$$

$$P_{pg} = OBG - \left(OBG - P_{ng}\right)\left(\frac{\Delta t_m + (\Delta t_{ml} - \Delta t_m)e^{-cZ}}{\Delta t}\right)^3.$$

Of all the drilling parameters used to indicate pore pressure, the d-exponent method as developed by Jordan and Shirley (1966) is the most popular method. It is dependent of the rate-of-penetration parameter, R (expressed by drillers in foot per hour) and is widely used as an indicator of high pore pressure. This parameter indicates how fast each foot of a well is drilled. It is the first parameter received as the well is drilled. We noted earlier that it is affected by pore pressure as well as lithology changes. Thus deciphering the effect of pore pressure from this parameter requires a good knowledge of the lithology being drilled such as the difference between carbonates and clastics. Jordan and Shirley (1966) discussed a method, still widely used, to normalize rate-ofpenetration data and change in rotary speed, bit weight, and bit diameter in order to detect overpressure. Jordan and Shirley (1966) and Bourgoyne et al. (1986) suggested the following equations for the d-exponent

$$R = K(RPM)^E\left(\frac{W}{D_B}\right)^d$$

Where

R = rate of penetration in feet per hour

K = drillability constant

RPM = rotary speed in revolutions per minute

E = rotary speed exponent

W = weight on bit in 1000 pounds

DB= bit diameter in inches

d = bit weight exponent or d-exponent

Jordan and Shirley (1966) assumed K = 1 and E = 1 and rearranged the above to express the d-exponent in the following form:

$$d = \frac{\log(R/60RPM)}{\log(12W/10^6 D_B)}$$

The ratio (R/60RPM) is always less than 1.0. The absolute value of log(R/60RPM) varies inversely with R. Therefore, the d-exponent varies inversely with the rate of penetration. Basically, plots of d-exponent versus depth show a decreasing trend with depth. In transition zones and overpressure environments, the calculated d-exponent values diverge from the normal trend to lower than the normal values. When lithology is constant, the d-exponent gives a good indication of the state of compaction (i.e., porosity) and pressure. Quantitative pressure evaluation can be made with the (1) Eaton method (Eaton, 1972), (2) Zamora method (Zamora, 1972). The pertinent equations are

$$P = S - (S - P_n)\left(\frac{d}{d_n}\right)^{\alpha} \qquad \text{(Eaton method)}$$

$$P = P_n\left(\frac{d_n}{d}\right) \qquad \text{(Zamora method)}$$

where P is the pore pressure, Pn is the normal pressure, S is the overburden stress and the exponent, α, is the Eaton exponent (typically varying between 1.2 to 1.5), d is the d-exponent, and dn is the normal trend of the d-exponent. Any decrease in the d-exponent when drilling an argillaceous sequence is a function of the degree of undercompaction and of the value of the associated overpressure.

Since the d-exponent is influenced by mud weight variations, a modification was introduced by Harper (1969) and Rehm and Mcledon (1971) to include the effect of mud weight on the d-exponent in order to normalize the d-exponent for the effective mud weight:

$$d_c = d\left(\frac{M_n}{M}\right)$$

where dc is the modified or corrected d-exponent, Mn is the mud weight under normally pressured condition, and M is the actual mud weight used. An example is given in

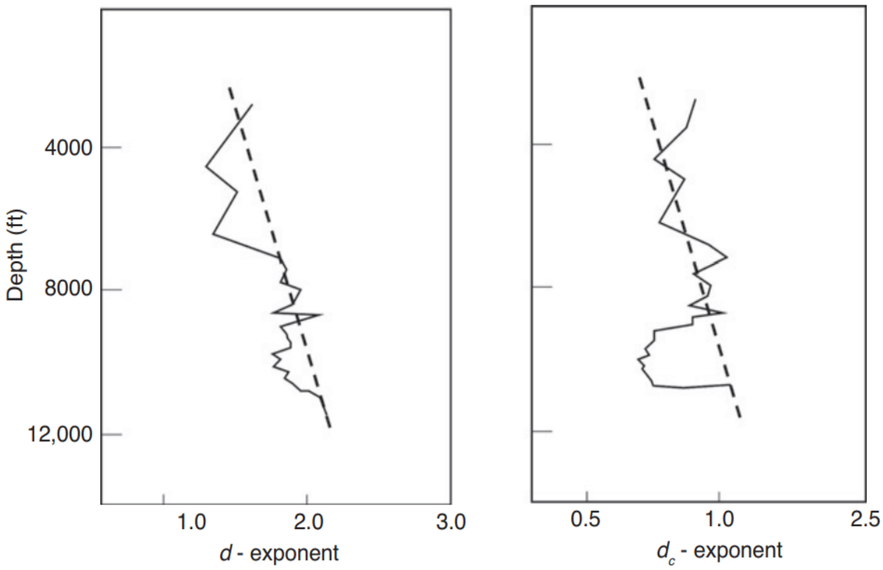


Figure 3.4 Comparison of d-exponent and dc exponent versus depth in the same well. Note that dc exponent defines overpressure zone more clearly

where we show a comparison of the d-exponent and the dc-exponent in the same well. The protective casing in the well was set at 8700 ft (2652 m). We note that the dc-exponent defines overpressure more clearly than the d-exponent. The procedure to calculate pore pressure from the dc-exponent is given below:

1. Calculate dc over 10- to 50-ft intervals.

2. Plot dc versus depth (use only data from clean shale sections).

3. Determine the normal line for the dc versus depth plot.

4. Establish where dc deviates from the normal line to determine abnormal pressure zone.

5. Calculate pore pressure using one of the three methods suggested above (Eaton, Zamora, or equivalent depth).

The d-exponent methodology provides several operating advantages (Moutchet and Mitchell, 1989): it is a low cost methodology and thus has a minor financial impact on exploration; the method can be performed in real time during drilling; implementation and application is simple, and it does not require highly skilled personnel on the rig to acquire data. However, quality control of the data and the results require some expertise who are familiar with common drilling practices in the area under investigation and its imprint on the data.

3.4.1 Case study of West Qurna Oil Field (WQ - 15)

West Qurna Oil Field (WQ - 15)

It is existed about 70 km Northwest of Basra city in southern Iraq. West Qurna is one of the biggest oil fields in Iraq. This deep well was the fifteenth wells drilled by the Iraqi National Oil Company in West Qurna field of Southern Iraq. West Qurna 15 was the first well that has been drilled near the crest of West Qurna structure. It is extend from Upper Fars formation at surface to final depth at Najmah formation at 4400 m. This field contains a certain reserves predestined at 18 billion barrels and reserves potential is estimated at 40 billion barrels. Now, the production of the field is about 120,000 bbl/day, but it can reach to 1 million bbl /day. It is one of the oils light desired globally, the bottom hole pressure is around 7200 psi and the number of oil wells is 247 wells, while the number of water injection wells is 64 wells

Lithology of (WQ - 15)

The formation of this field and its composition which are covered in this study according to availability of data are explain through the table below: Table-2: Formation, depth range and lithology of (WQ- 15).

Formation name	Depth rang m	Lithology
Tanuma	2170	Black fissile shale, macro crystalline, argillaceous, detritus limestone
Khasib	2218	Chalky, oligsteginal limestones
Mishrif	2270	Organic detritus limestones, beds of algal, coral-reef limestone and limonitic fresh water limestone
Rumaila	2432	Oligsteginal limestones, beds of dolomite, dolomitic limestones
Ahmadi	2513	Gray shale, Limestone
Mauddud	2648	Dolomitize organic, detritus limestone
Nahr Umr	2803	Black shales, grained sandstones, amber, pyrite
Shuaiba	2991	Shaly limestone
Zubair	3081	Sandstone, siltstone, alternating shale
Ratawi	3406	Slightly pyritic, shales, beds of buff, pseudo oolitic, detritus limestones
Yamama	3529	Argillaceous limestones, oolitic shoal limestones
Sulaiy	2857	Marly limestone, oolitic limestone
Gotnia	4120	Calcareous shales and salt
Najmah	4400	Shale with streaks of limestone

Table 3: Formation, depth range and lithology of (WQ-15).

Pressures Distribution in (WQ-15) Formation

The formation with an abnormal pressure in (WQ-15), are explain below: - Shuaiba Formation (Subnormal Pressure): Consider as one of a critical formations with big problems like of the loss of drilling fluid circulation (total loss), as well as stuck pipe and hole failed problems.- Yamama Formation (Abnormal Pressure): contain oil and gas in two carbonate units each one with basal reservoir oolitic limestones overlain by lime mudstone seals. - Sulaiy Formation (Abnormal Pressure): The problem of this formation is the appearance of gas with high pressure that causes the abnormal high pressure with flow of gas inside the well. - Gotnia Formation (Abnormal Pressure): Numerous states of flowing saltwater and gas kicks have been occurred. - Najmah Formation (Abnormal Pressure): the flow of gas or salt bed (Abnormality high pressure) problem.

Calculation and Results with Discussion

Rate of Penetration According to availability of data, raw penetration had been drawn versus depth to give allusion of the occurrence of overpressure zone as shown in figure (1) and table (2), which show that the rate of penetration increased slightly in Yamama and Sulaiy formation. While at nearly (4200 m) depth, we note a high rate of penetration, due to the effect of Gotnia salt formation which it is denser than compared with other rocks. Penetration rate in other formation is lower due to two reasons:

1. The bit show dulling tendencies with depth which naturally decreases penetration rate throughout the bit life.

2. With an increase in depth, a constant mud density will result an increase differential pressure across the borehole, if the pore pr

essure remains normal.

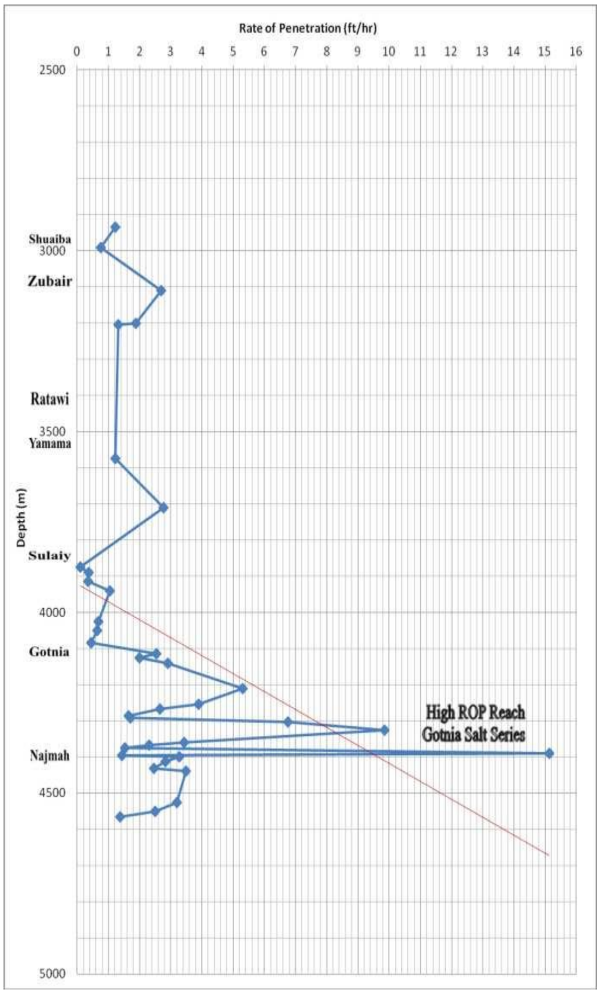


Fig-3.5:Rate of penetration versus depth relationship.

Depth	ROP (ft/hr)	WOB (1000 Ib)	N (RPM)	Dh (in)	Mw (gm/cc)	d-Exponent	Mwn (gm/cc)	dc-Exponent
2935	1.213	20	90	12.25	1.31	2.1362374	1.13	1.8427086
2992	0.7553	19.5	90	12.25	1.31	2.2422648	1.13	1.9341673
3110	2.7	18	88	12.25	1.31	1.8767767	1.13	1.618899
3201	1.875	18	88	12.25	1.32	1.9670795	1.13	1.6839393
3205	1.31	18	70	12.25	1.32	1.9992093	1.13	1.7114443
3575	1.23	9	85	12.1875	1.52	1.762573	1.13	1.3103339
3710	2.779	9	74	8.4375	1.52	1.6924722	1.13	1.2582194
3874	0.1	21.8	120	12.25	1.96	2.9077146	1.13	1.6763865
3890	0.376	14.5	50	8.375	2.05	2.3192171	1.13	1.2783977
3915	0.35	14.5	50	8.375	2.09	2.337714	1.13	1.2639315
3940	1.05	16	50	8.375	2.09	2.1076822	1.13	1.1395602
4025	0.677	18	70	8.375	2.09	2.3875269	1.13	1.2908638
4050	0.633	18	70	8.375	2.09	2.4058992	1.13	1.3007972
4085	0.45	19	80	8.375	2.09	2.5737381	1.13	1.3915426
4115	2.532	19	60	8.375	2.09	2.0145292	1.13	1.0891952
4125	2.004	19.5	60	8.375	2.09	2.094523	1.13	1.1324454
4140	2.9123	15	60	8.375	2.172	1.8540766	1.13	0.9645979
4211	5.3	13	62	8.375	2.364	1.645374	1.13	0.7864944
4255	3.89	13	62	8.375	2.36	1.7230255	1.13	0.825008
4268	2.65	15.6	61	8.375	2.36	1.90239	1.13	0.9108901
4286	1.65	18	65	8.375	2.36	2.1237109	1.13	1.0168616
4291	1.7	19	70	8.375	2.36	2.1678543	1.13	1.0379981
4304	6.76	16.5	100	8.375	2.36	1.8128076	1.13	0.8679969
4325	9.843	12	60	8.375	2.36	1.4525346	1.13	0.6954933
4360	3.4187	15	75	8.375	2.36	1.8704374	1.13	0.8955908
4368	2.312	8	75	8.375	2.312	1.6948532	1.13	0.8283668
4375	1.5354	8.6	55	5.625	2.312	1.9190338	1.13	0.937936
4390	15.132	7.5	55	5.625	2.312	1.3022126	1.13	0.636462
4395	1.43	7.5	85	5.625	2.312	1.9779908	1.13	0.9667516
4400	3.281	5.7	85	5.625	2.312	1.6665552	1.13	0.8145361
4413	2.836	7	80	5.625	2.312	1.7682433	1.13	0.8642365
4431	2.454	6	80	5.625	2.2944	1.7388969	1.13	0.8564128
4439	3.476	6	80	5.625	2.2944	1.6590121	1.13	0.8170692
4526	3.198	6	100	5.59375	2.2944	1.7315509	1.13	0.8527948
4550	2.497	6	100	5.59375	2.2944	1.7883968	1.13	0.8807917
4565	1.565	6	115	5.84375	2.2944	1.9086691	1.13	0.9400262

Table-4: Calculated values of d and dc-exponent atselected depth.

Normalized Penetration Rate (dc-exponent): Since d-exponent method is influenced by mud weight variations, dc-exponent method will normalize d-exponent values for the variations of mud weight by using equation.

For example, at depth, D = 4025 (m),

d-exponent = 2.3875269, Mwn = 1.13 (gm/cc), Mw = 2.09 (gm/cc)

$$\cdot\ dc = 2.3875269 * \frac{1.13}{2.09}$$

$$\cdot\ dc = 1.2908638$$

The resulted values are tabulated in table (2), and plotted versus depth in figure (3). This plot shows an increase in dc- exponent values in normal pressure zones, while at overpressure zones, dc-exponent values will decrease due to the increase of the rate of penetration.

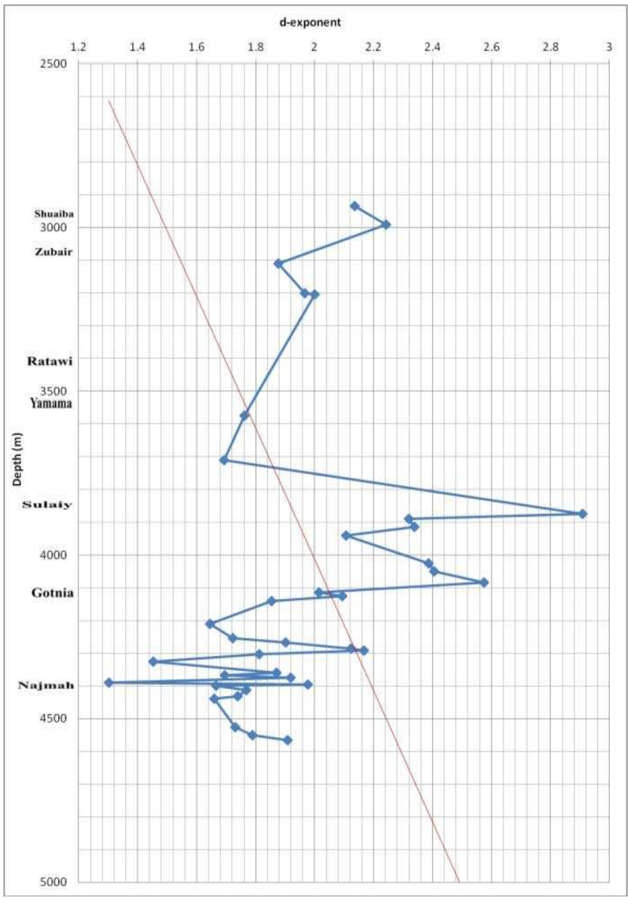


Fig-3.6 d-exponent versus depth relationship.

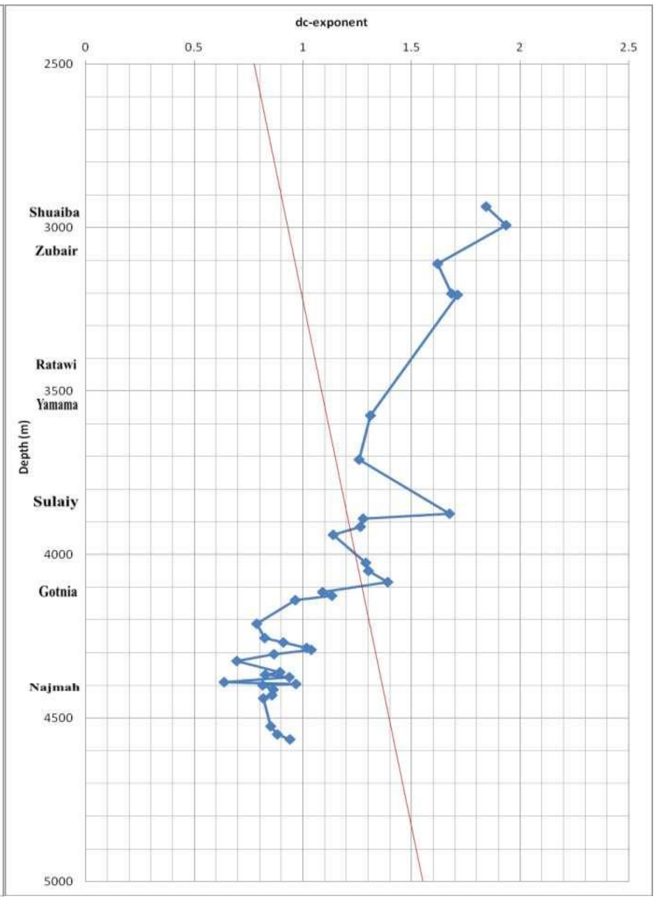


Fig-3.7 dc-exponent versus depth relationship.

3.4.2 Case study to Predict the Abnormal Pore Pressures in Abu Amoud Oil Field, Southern Iraq

3.4.3 Area of the Study

Abu Amoud oil field covers about 208 km2 and has a structural orientation of northwest to southeast. The area is between longitudes 45.30 to 46.30 degrees, at latitude 31 degrees . Tables (1 and 2) represent the geology and lithological composition of the studied area. Five wells information has been studied and analyzed in this work. Abu Amoud field represents an important part of the oil region of Abu Amoud basin in southern Iraq, which is characterized by its potential high hydrocarbons . The study area is located in the southeastern part of Iraq, which represents the north and northeastern part of the Arabian plate, and the two continental blocks adjoining it from the north the Turkish block (Bitlis block) and from the east of central Iranian block. The Zubair Formation is one of the main deposits of Abu Amoud oil field, which is bounded from the top by the formation of the Shuaiba and from below is the formation of Al-Ratawi. The geological composition for Zubair unit in Abu-Amoud oil field is a shaly sand. The range of granular limestone rocks (carbonate sand), which forms an important part of the Yamama Formation, is an exploratory target (Sadooni, 1993). Within the deposits of the early Cretaceous period, the presence of oil was proven in this range in the fields of southern Iraq. As for the Mishrif Formation, it is rich in hydrocarbons, as the thickness of the Mishrif Formation increases towards the east, which means that it increases from the Abu Amoud field in Nasiriyah towards the east of the Abu Amoud field in Maysan Governorate. It is also noted that the pattern of the distribution of the faults in Abu Amoud field is of the type of faults that are associated with the convex structures formed as a result of vertical forces. The source of these vertical forces is the combination of the bedrock and the rise of salts. The fault systems affecting Mishrif Formation are of the transverse type as shown in Figure (2). When the fault happened in the subsurface make sediments to be cross over each other, and making barriers for the fluid to move because the permeable zones will be conflicting the impermeable zones. That will prevent the fluids in the pours to be expelled out, that will lead to a rise in the value of porosity and the pressure to be abnormal .

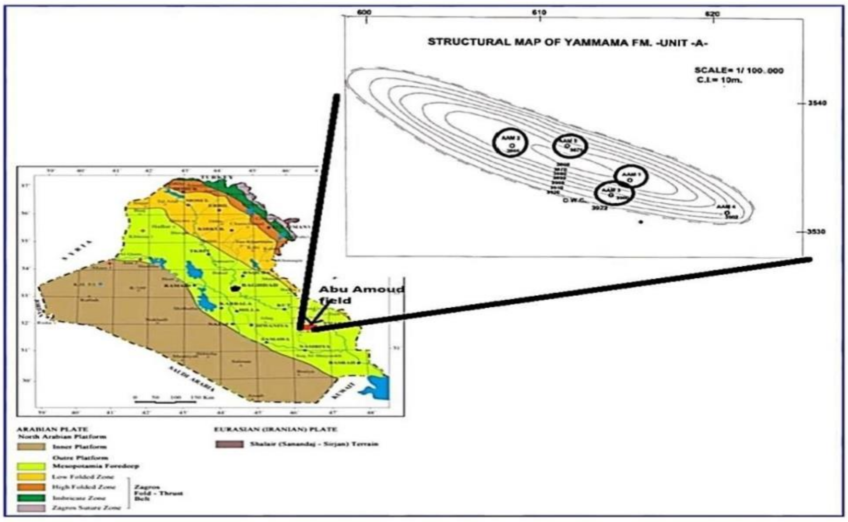


Fig.3.8 The location of the studied area (Al-Baldawi1, 20210)

Table 5: Lithology including formations depths, ages, thickness, and log depths.

AGE	Formations	logging depth(m)	Subsea depth(m)	Thickness(m)
Early-middle Miocene	Lower Fars	850	830.1	**339**
	Ghar	1189	1169.1	**6**
Middle Oligocene	Bejawan	1195	1175.1	**24**
	Baba	1219	1199.1	**54**
	Tarjil	1273	1253.1	**31**
Early Oligocene	Palani	1304	1284.1	**32**
Late-middle Eocene	Dammam	1336	1316.1	**131**
Paleocene- Early Eocene	Rus/Umm.er-radhuma	1467	1447.1	**161**
Middle cretaceous	A'aliji	1628	1608.1	**348**
	Shiranish	1976	1956.1	**57**
Late cretaceous	Hartha	2033	2013.1	**139**
	Sadi	2172	2152.1	**149**
	Tanuma	2321	2301.1	**52**
	Khasib	2373	2353.1	**585**
	Mishrif	2431.5	2411.6	**293.5**
	Rumaila	2725	2705.1	**56**
	Ahmadi	2781	2761.1	**18**
	Mauddud	2799	2779.1	**246**
	Nahr umr	3045	3025.1	**137.5**
Early cretaceous	Shuaiba	3182.5	3162.6	**111.5**
	Zubair	3294	3274.1	**409**
	Ratawi	3703	3683.1	**132**

	Yamamma	3835	3815.1	**283**
Late Jurassic	Sulaiy	4118	4098.1	**257**
	Gotnia	4375	4355.1	**261**
	Najma	4636	4616.1	**261**

Table 2: The lithology of Abo Amoud oil field (Assi, 2022)

Formation name	Top of vertical depth(m)	Formation Lithology
Dammam	1335	Dolomite: buff - light. grey at top, buff-beige, porous, vuggy; fractured Limestone
Rus	1460	Anhydrite; white, massive, interbedded with Dolomite buff, porous vuggy
Umm Er Radhuma	1470	Dolomite and dolomitic Limestone interbedded with thin Anhydrite
A'aliji	1600	Bituminous thin Shale layer at the top, Dolomite; grey buff and vuggy. Anhydrite locally
Shiranish	1900	Marl and Limestone; ash grey plastic
Hartha	2030	Dolomite; buff-brown, porous, locally vuggy. Limestone (chalky); grey
Sadi	2170	Limestone; chalky, porous
Tunumma	2320	shale
Khasib	2370	Limestone
Mishrif	2430	Limestone
Rumaila	2720	Limestone
Ahmadi	2760	Shale and limestone
Mawdud	2800	Limestone porous
Nahur Omar	3040	Shale and sandstone
Shaiba	3180	Limestone shaley
Zubair	3290	Shale and sandstone
Ratawi	3700	Limestone porous
Yamamma	3833	Carbonate sand
Sulaiy	4110	Carbonate sand
Gotnia	4370	Shaly limestone
Najma	4630	Shaly sandstone

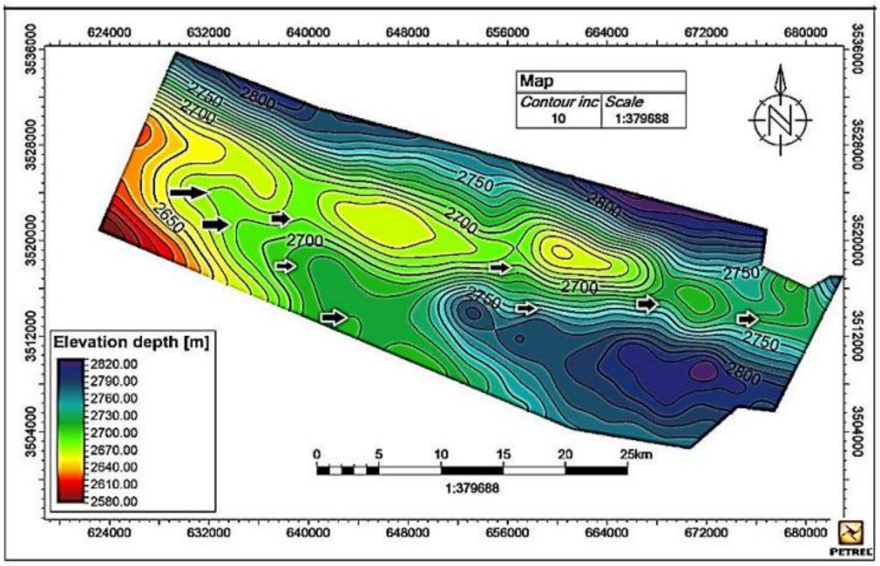


Fig. 2. Faults at the top of Mishrif Formation for the depth domain (Mohammed and Hussein, 2021).

Materials and Methods

The abnormal pressure is defined as any pressure that deviates from this normal pressure gradient (Figure 3). The normal hydrostatic value is 0.433 psi/ft for the fresh water while it is about 0.465 psi/ft for the salty water.

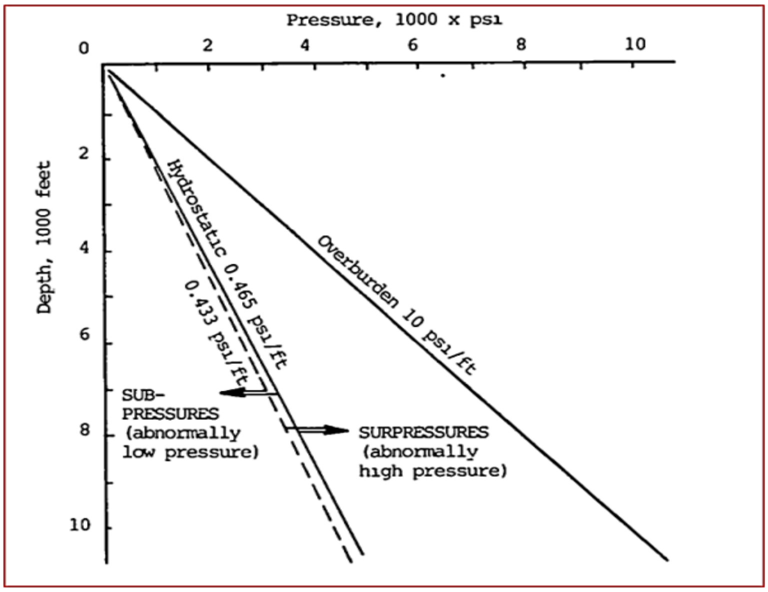


Fig3.10 abnormal pressure concept (Jordin and Shirlay, 1966)

Equivalent depth methods:

One instance of analysis by the trend line is the equivalent depth method as shown in Figure (4). This technique first assumes that there is a depth segment over which the pore pressure is hydrostatic, and the sediments are generally compressed since the systematic rise in active stress with depth. As soon as the log of the measured values is strategized by means of a function of depth, the Normal Compaction Trends (NCTs) are displayed as straight lines formfitting to the information over the typically compressed interval. Since the measured physical property value is a unique function of the effective stress, the pore pressure at any depth at which the measured value is not NCT can be calculated from Equation (1). The normal pressure trend (NCT) is a straight line in a linear logarithmic space that is fitted to slow down as a function of depth at which sediments are normally compressed. The effective pressure at depth (Z) is equal to the effective pressure at depth (A); therefore, the pore pressure at depth (Z) is simply (Al-Baldawi1, 2021) calculated:

$$Pz = Pa + (Sz - Sa) \qquad (1)$$

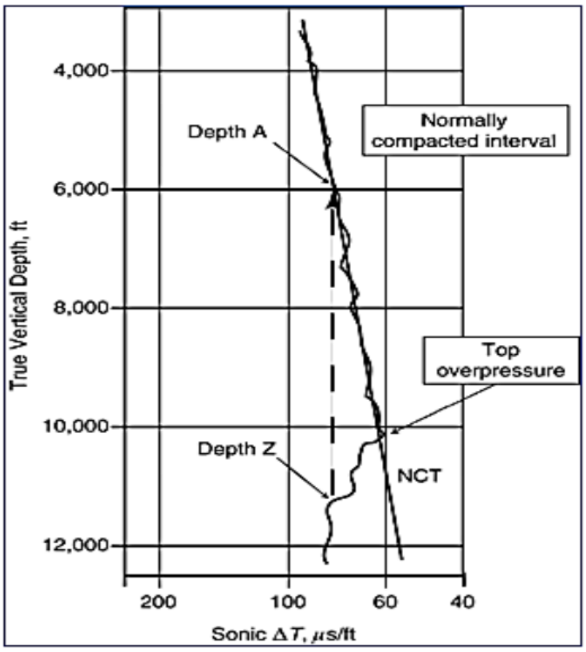
where:

Pa: effective pore pressure at a, psi.

Pz: pore pressure at z, psi.

Sa: the stress at a, psi.

Sz: the stress at z, psi.



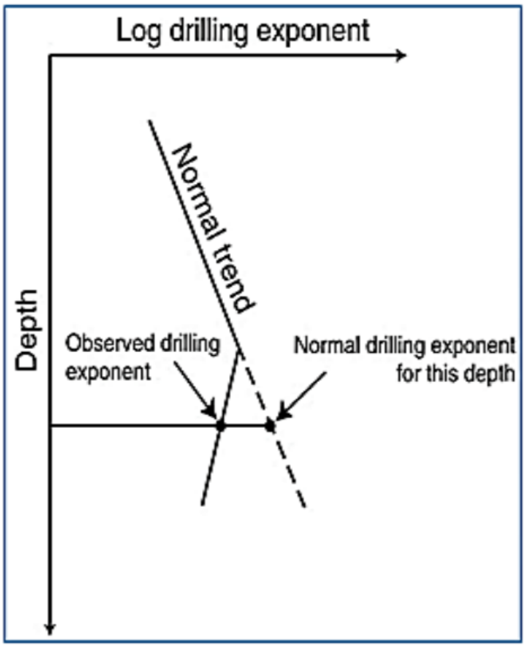


Fig 3.11 Equivalent depth method and b: ratio method (Swarbrick, 2002)

The ratio method (Moos et Al., 2001):

It is also called the exponential (d) method or the standard rate of penetration method, and it is considered one of the most common used methods. This method depends on the effect of the weight on bit (WOB), hole size (Dh), rate of penetration (ROP), and revolution per minute (RPM) as in Equation (2). The ratio method is also useful for analyzing pore pressure from exponential drilling as in Figure (3b).

$$\boldsymbol{ROP = a\left(\frac{W}{Dh}\right)^{d} N^{e}} \ldots\ldots\ldots\ldots(2)$$

Where:

ROP: Rate of penetration, ft./hr.

N: Revolution per minute, RPM

W=Weight on bit

Dh=Bit or hole size, inch

d: (d-exponent)

e: exponent rotation speed, e=1

a: formation drillab

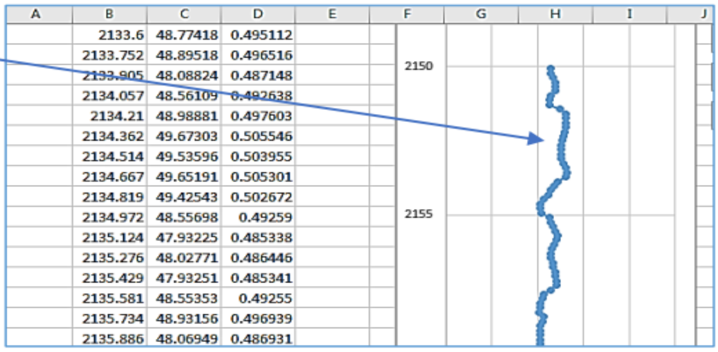
Shale density method

The normal trajectory of compacted shale density increases with increasing depth. When the actual values of shale density deviate from the normal path, i.e. deviation to the left, this means that the increase in porous pressure in the shale layers has prevented their compaction or reduced their density, which caused their deviation towards lower values. This method is considered very good in theory, but from a practical point of view, the value of density remains unclear because of the difficulty in making accurate measurements and the difficulty in choosing shale that represents rock crumbs. Therefore, in this research, the shale size was compensated for instead of its density, and this relationship is reflected, due to the possibility of calculating the shale size. The following is the necessary calculations for this method:

VSh Calculation:

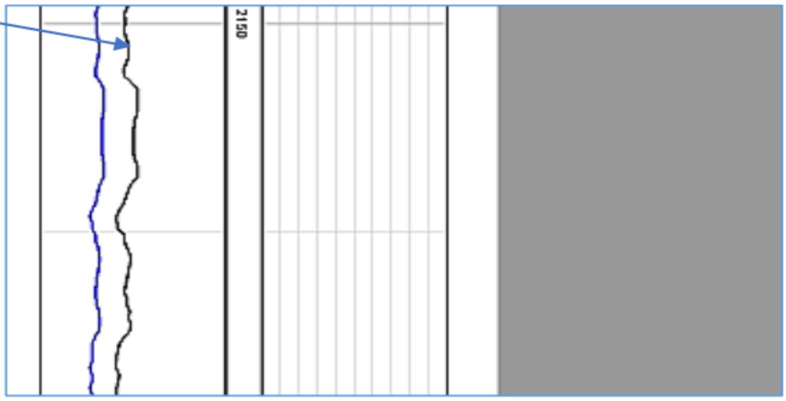
The calculation of VSh which can be done in many different ways including:

1-Using Microsoft Office Excel Sheet; by Open LAS, find min., and max. values of GR then insert V_{sh} eq. to calculate V_{sh} to the entire depth and then draw V_{sh} curve.



A	B	C	D	E
	2133.6	48.77418	0.495112	
	2133.752	48.89518	0.496516	
	2133.905	48.08824	0.487148	
	2134.057	48.56109	0.492638	
	2134.21	48.98881	0.497603	
	2134.362	49.67303	0.505546	
	2134.514	49.53596	0.503955	
	2134.667	49.65191	0.505301	
	2134.819	49.42543	0.502672	
	2134.972	48.55698	0.49259	
	2135.124	47.93225	0.485338	
	2135.276	48.02771	0.486446	
	2135.429	47.93251	0.485341	
	2135.581	48.55353	0.49255	
	2135.734	48.93156	0.496939	
	2135.886	48.06949	0.486931	

2-Calculating V_{Sh} using Neuralog; Open LAS, Calc. new curves from existing curve formula. The result is a new curve designed by the user. Recognize the variation you have get it in this figure. In what depth and in what kind of lithology and what about the other figure on the right.



The Volume of shale (VSh) can be calculated by another softwares such as Geolog and IPetrophisics…etc. It should be noted that the result of calculating VSh using Excel, Neuralog, or any other software shows the same results always because of the mentioned and unmentioned software above use the same digital data from the same LAS file that exported by the software to be used initially in this study is Neuralog. Therefore, the quality or the correct calculation and results of VSh depend on the digitizing process at the first place. Figure (5) shows logs used in this study.

The second column of Figure (5) represents the light blue color readings of the porosity sensor, while the dark blue color is of the density sensor; as in the normal case, the density increases with depth, but in the areas of abnormal pressures, the opposite is observed, i.e. a decrease in density with depth. Also, the presence of slate can lead to a decrease in the recorded porosity value from the density sensor recording. The third column represents the recording of the spontaneous effort, where in front of the layers containing the shale, a fixed line is recorded, but in front of the sandy formations, it deviates towards the positive line. The fifth column represents the specific resistance, as this recording is useful in determining the type of liquid present in the formation. Where if the resistance is high, this means the presence of hydrocarbons, and vice versa. In the case of salt water, where it is approximately

0.1 ohms. meter. The fourth and sixth columns represent gamma ray sensors to predict the presence of radioactive materials to detect shale layers, where the reading of the gamma ray sensor is recorded as large as possible in front of the layers containing the shale. The first column represents the cement bond log, i.e. the sonic log. It is used to identify areas of abnormal pressure because the sound transmission time is faster because it is less compact and contains salty water.

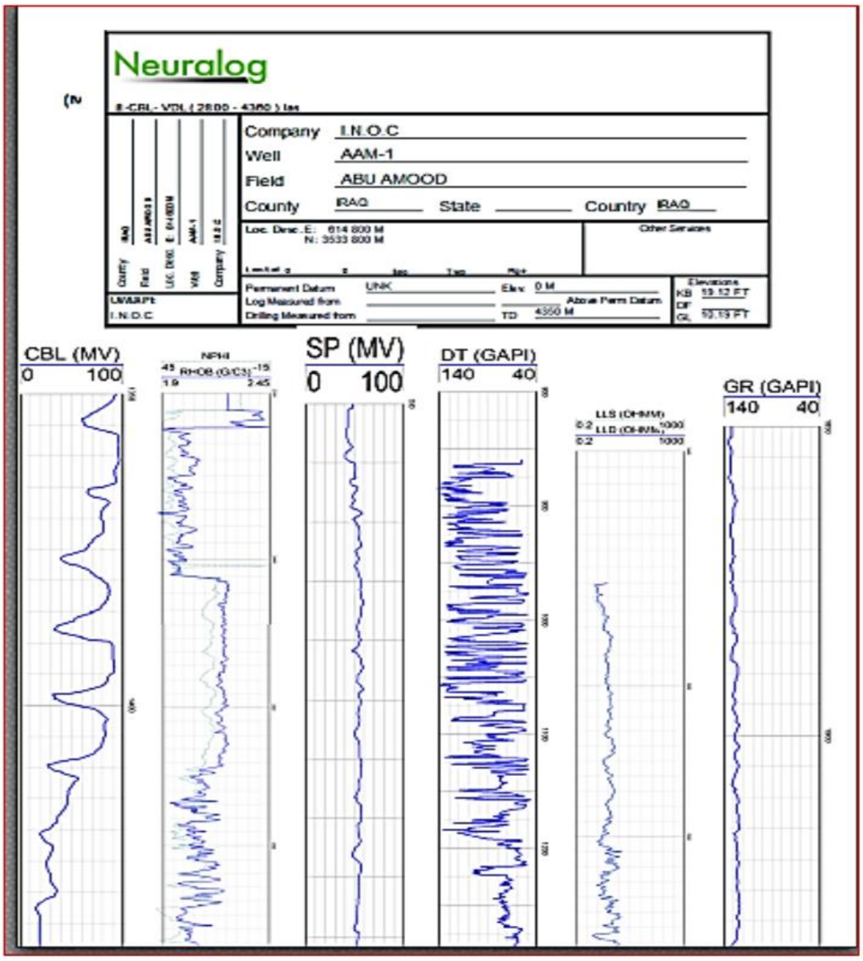


Fig.3.12. The different logs for Abo Amoud Field

The tectonic activity considered one of the main reasons for the occurrence of abnormal pressures, and this is due to the fact that this phenomenon may cause a total blockage of the reservoir rocks by hard, high-density, impermeable rocks, and thus the unusual pressures occur. Mohammed and Hussein (2021) showed the two main directions of the transverse fault systems of the Abu Amoud field. The eastern trend, which is most dominant in east and northeastern parts of Iraq, while the northeastern trend, dominates the east and north parts of Iraq

Results and Discussion

It is clear from the figures the exponent (d) in terms of depth and rate of penetration that there is a decreasing path with depth, that is, a decrease in penetration rate with depth. In transitional regions or high-pressure regions, it is noted that the calculated d values deviate from the normal path towards lower values, i.e. to the left. This deviation from the normal path indicates the presence of an area of high pressure (or unusual pressure) as shown in figures (6 and 7). Continuous drilling indicates the formation compaction will rise. That leads to low (ROP) if all other factors are held constant. The rock features within the abnormal zones, that are with less compressed rock in comparison with the normal zones. In this case, subsequently, ROP will rise. Also, this will reduce the difference between the hydrostatic pressure and the pore pressure, which will lead to an increase in the rate of penetration.

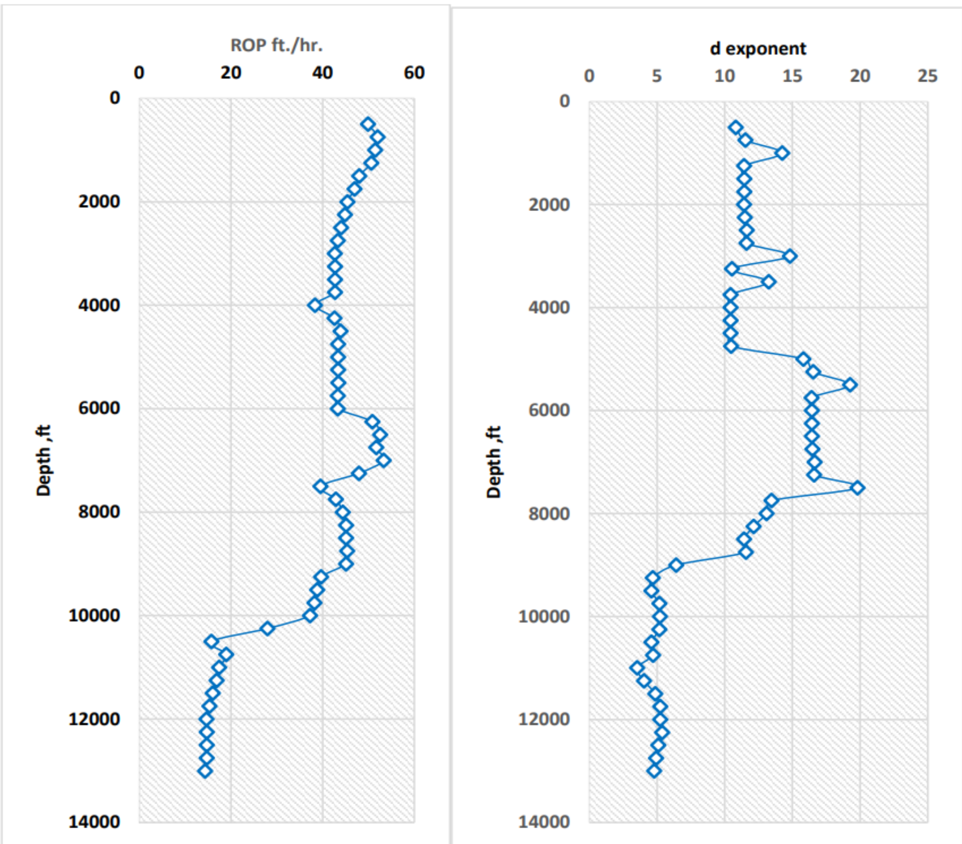


Fig.3.13 The relation between rate of penetration (ROP), d- exponent and depth

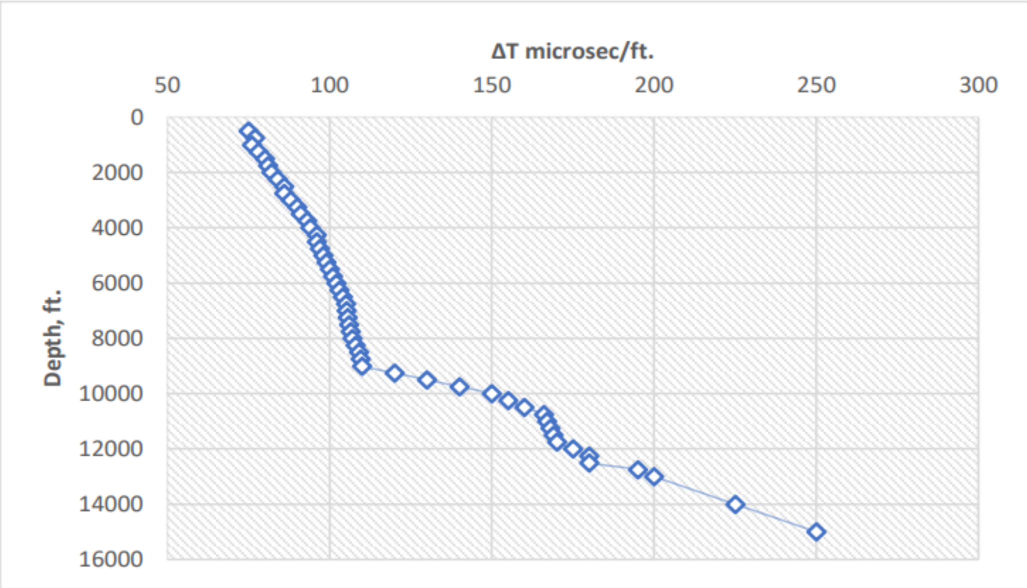


Fig.3.14 The relation between sonic wave time and depth

Figure (8) shows the relationship between porosity and the permeability to porosity, where some depths recorded a low permeability to porosity ratio compared to a somewhat high porosity, especially in shale layers, which is an indication of the presence of abnormal pressure zones at intervals (2330, 2460, and 2500) meters. The high increase in pressure comes from the phenomenon of layer compaction as a result of (the presence of a low permeability layer and a rapid sedimentation rate), meaning that the possibility of forming rock layers with unusual pressures increases with the increase in the sedimentation rate and the increase in the total thickness of the deposited layers.

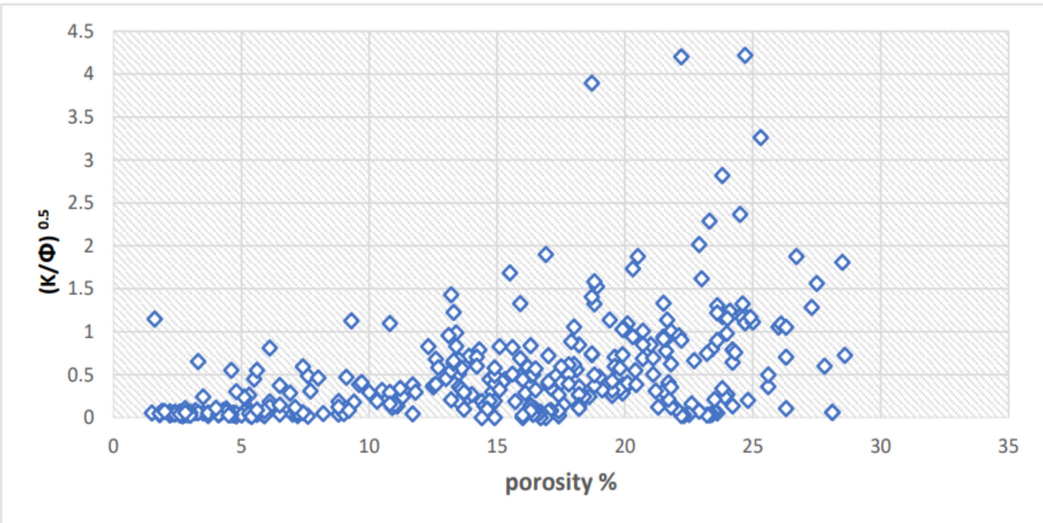
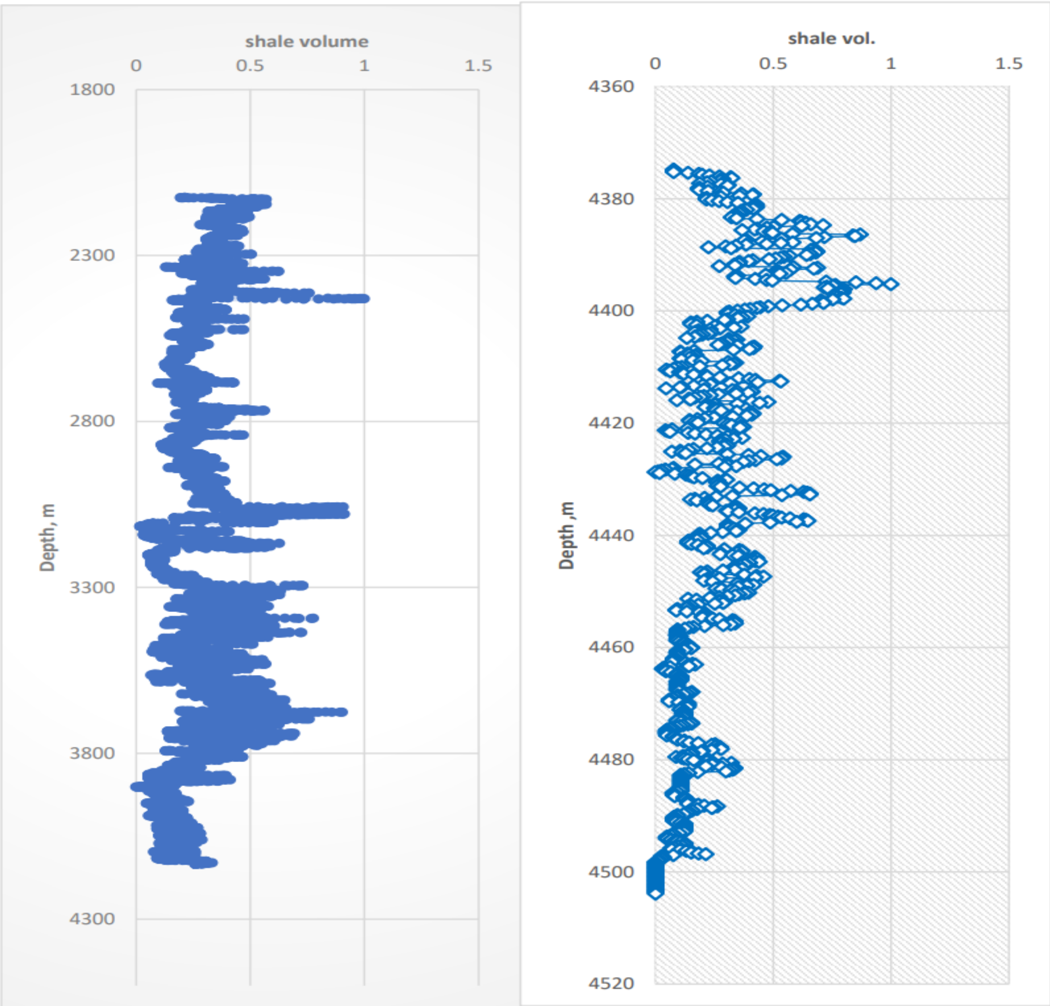


Fig.3.15 The relation between porosity and the root of permeability to porosity.

The relationship of shale density with depth is proportional, which means that volume decreases. If the actual values of the density or volume of oil shale deviate from the normal values, this means that the pore pressure in the layers of oil shale has increased and its volume has increased. The pressure was prevented (reduced its intensity, causing it to deviate from lower values) as in figure (9). Table (3) shows formations with pore and fracture pressure, where the presence of abnormal pressure was concentrated in the upper and lower regions of the five studied wells. Since it has been proven that the normal pore pressure may be equal to (9 $lb./gal$) 0.47 psi /ft. (Swarbrick, 2002), where some formations gave less than the normal level, and vice versa in other formations as documented in Table (3). The Lower Fares Formation is exposed to an abnormally high pressure of about 2.28 g/cc especially at a depth of (850-930) meters, due to its geological composition of Anhydraite and the probability of salty water flowing is expected. Dammam Formation gave subnormal pressure about 0.454 psi/ft. Umm-ERadhuma Formation principally has high abnormal pressure because of its sulfur water content. The Saadi Formation also gave an abnormal pressure because it contains salty water, where the pressure gradient is about 0.5781 psi/ft. As for the rest of the formations in Table (3) (Ghar, Haritha and Tanumma), they gave pressures slightly greater than the normal pressure, but they are included in the previous table for the sake of accuracy.



Formation and Lithology	Top MD m	Bottom MD m	Frac. Top ED SG	Pore Top ED SG	Remarks
Lower fars Anhydraite,limestone	850	1120	2.34	2.28	Abnormal high-pressure comparison with upper and lower layers. (18.99 > 9) ppg
Ghar loose sandstone	1050.0	1088.0	1.58	1.16	Abnormal pressure comparison with upper and lower layers. (9.66 > 9) ppg.
Dammam dolomite	1330.0	1690.0	1.72	1.04	sub normal pressure (8.66< 9) ppg.
Shiranish plastic	1840.0	2034.0	1.71	1.08	sub normal pressure 8.99<9
Hartha dolomite	2034.0	2182.0	1.72	1.11	Abnormal pressure (9.25 > 9) ppg.
Saadi limestone	2182.0	2227.0	1.70	1.23	Abnormal high pressure (10.245 > 9) ppg. (Salt water)
Tanumma shale	2327.0	2560.0	1.80	1.12	Abnormal pressure (9.33 > 9) ppg.

Fig. 3.16 The relationship between shale volume and depth (1800-4500) m.
Table 7: Formations with pore and fracture pressures

Conclusions

The prediction and control of abnormal pore pressure are useful to avoid many serious drilling risks. Abnormally high pore pressures can cause breakouts during drilling and also reflect the range of limits that must be set in relation to the total pressure in the annular space during the drilling process. Correct prediction of pore pressure secures and increases wellbore stability as well as reduces drilling risks, then gives a better representation of the mud program, and more accuracy in selecting the casing seat. The results of this research are obtained from the average data of five oil wells in Abu Amoud oil field in southern Iraq. Through the results of the shale volume method, it's found that the depths (450-750), (2300- 2500) m have abnormal pressure. As for the two other methods of exponential-d and the method of the acoustic probe, their consequences are that the depths (2875-4022) meters have unusual pore pressures, and they failed to predict the unusual pressures in the surface layers. This is indicated by the relationship between the rate of penetration and the depth, and it is found that the depths (1400- 1600) m have subnormal pressures. The aforementioned three methods have proven the existence of areas of abnormal pressure in Abu Amoud oil field at different depths. The reason for the occurrence and formation of anomalous pressure zones is due to two main factors: the tightness factor as the availability of layers with little permeability represented by shale layers, and the tectonic factor due to fault in the field in the Mishrif Formation that lead to the transfer of the fluid from one depth to another. As predicting the pore pressure gradient is a very important factor in the design of oil wells, and it has a very effective effect on that.

Chapter Four

Calculation and results of Case Study

4.1 Introduction

In this study, the main objective is to obtain prediction and detection of formation pore pressure in the "X" field of the Lower Fars Formation.

From the data of the drilled well, the pore pressure will be detected based on the D-Exponent.

By knowing the areas of excess pressure, it is possible to know the weight range of mud that will be used in the drilling process in the same area, which will save a lot of time and money that will be lost if the forecast is not done.

4.2 Data Gathering

The firstly to do is to get certain parameters that are needed in the equations that will be used to get to the goal.

The parameters that are needed will be taken get it from the FDR(final drilling report) which consists of well name, field name, rig name, operation description…ect and what we are aiming to get from the FDR is :

ROP(rate of penetration)

Lithology,

Operation description

Bit diameter

Drilled depth

RPM(round per minute)

WOB(weight on bit)

Cost(daily cost for the operation)

4.3 Study Formation

Lower Fars Formation

The Lower Fars Formation was deposited during the middle Miocene era and consists of a series of different rocks (shale, anhydrite, salt) with sometimes limestone rocks. On this basis, the formation was divided into five units, and the formation has a variable thickness in the Maysan fields and increases towards the east and northeast until it reaches the limits of 1050 m in the Fakka field.

The formation is characterized by its high pressure (abnormal pressure), and it is believed that the reason for this pressure is due to the presence of formation fluids within the impermeable rocks of the Shale, which are confined between the hard and also impermeable anhydrite rocks, which does not allow these fluids to move.

The Lower Fars Fm formation gains importance for two reasons. The first is that the formation has an unusual and variable pressure within the section of the formation until it becomes a normal pressure in front of the second member (MB2), and the second is that the lower part of the formation (MB1) consists of thick anhydrite rocks, which form... Cap Rock of the Asmari Reservoir in the area, and the pressure in this member is characterized by normal pressure, and if it is not precisely determined and penetrated during drilling with heavy clay (SSM), which causes a complete loss of clay circulation due to the presence of thin beds.) It is permeable among the anhydrite rocks, and the Lower Fars Formation covers most of Iraq and its rocks are visible on the surface in the northern region and some parts of the western desert region, and the thickness is not homogeneous. While the thickness does not exceed some tens of meters in some areas, it becomes more than a meter in advance. Other areas (Fakka field, for example). There are several reasons for this variation in thickness, including the processes of advance and retreat of the sea and the depth and shape of the sedimentation basin.

4.4 Stratigraphy

The Lower Fars Formation represents a complete depositional cycle that began with the advance and then retreat of the sea during the Middle Miocene.

The Lower Faris Formation in the Maysan fields sits above the Jaribi Formation (lower Miocene).

In the fields of Basra, it sits in a consistent manner above the Al-Ghar Formation (lower Miocene), and the formation that lies above the Lower Faris Formation in Maysan fields is the Upper Faris Formation, Upper Miocene. In Basra, it is above the Al-Dabdiyya Formation, upper Miocene. The Lower Faris Formation in Iraq is similar to the (Mishan / Jaran) Formation in Iran (James and Wand (1965). It is similar to the Al-Dam Formation in Saudi Arabia and the Al-Faris Al-Safali Formation in Kuwait.

The thickness of the Lower Fares Formation in the Maysan fields varies from one field to another, and the thickness also changes

In one field from one place to another. In general, the thickness increases eastward towards the Iraqi-Iranian border.

There are several divisions to form the Lower Knight in Iraq. In the northern region, the formation was divided into four units based on the repetition of limestone layers, anhydrite, salt layers, and shale. In the Kirkuk field, the four units are:

From the top, the red layers, the exudation layers, the layers with salt content, and the transitional layers at the bottom. In the Maysan fields, the formation was divided into five members, which mainly consist of:

Mb5 Anhydrite, Shale

Mb4 Salt, Anhydrite, Shale

Mb3 Anhydrite, Shale, Salt

Mb2 salt

Mb1 Thick Anhydrite ,Shale

4.5 GEOLOGICAL SUMMARY

Lower Fars formation MB5 Sample: 2048.00～2385.00m thickness 337.00m. Mainly consists of thin and massive Shale interbedded with Anhydrite. SHALE: Greenish gray to medium gray, moderately brown, firm, occasionally moderately hard, subblocky to blocky, occasionally subflaky, occasionally subfissile to fissile, slightly to moderately calcareous. ANHYDRITE: White, off white, trace milky white, firm to hard, subblocky to blocky, amorphous in part, plastic in part, crystalline. Lower Fars formation MB4 Sample: 2385.00～2737.00m thickness 352.00m. Mainly consists of Shale and Anhydrite, interbedded with Salt. SHALE: Medium bluish gray, minor greenish gray, occasionally dark yellowish brown, soft to firm, amorphous, subblocky, sticky in parts, pasty, slightly calcareous. ANHYDRITE: Off white, minor white, firm, occasionally hard, subblocky to blocky, plastic in part, crystalline, glass luster in part. SALT: Colorless, transparent, occasionally translucent, white, light brown, smoky, blocky, occasionally flaky, trace splintery, friable, glass luster. Lower Fars formation MB3 Sample: 2737.00～2871.00m thickness 134.00m. Mainly consists of thin to thick and massive Anhydrite, interbedded with Shale and Salt. - 20 - ANHYDRITE: Off white, minor white, firm, occasionally hard, subblocky to blocky, plastic in part, crystalline, glass luster in part. SHALE: Medium bluish gray, minor greenish gray, occasionally dark yellowish brown, soft to firm, amorphous, subblocky, sticky in parts, pasty, slightly calcareous. SALT: Colorless, transparent, occasionally translucent, white, light brown, smoky, blocky, occasionally flaky, trace splintery, friable, glass luster. Lower Fars formation MB2 Sample: 2871.00～2908.14m thickness 37.14m. The lithology consists of massive Salt. SALT: Colorless, transparent, occasionally translucent, white, smoky, blocky, occasionally flaky, trace splintery, friable, glass luster. Lower Fars formation MB1 Sample: 2908.14～2930.00m thickness 21.86m. Mainly consists of thick Anhydrite interbedded with Shale. ANHYDRITE: White, minor off white to grayish white, firm to hard, blocky to subblocky, crystalline, glassy luster in part. SHALE: Medium bluish gray, soft to firm, amorphous, subblocky, sticky in parts, pasty, slightly calcareous.The drilling rate was used for several years to differentiate between sand and shale. The obvious relation between the penetration rate and fluctuations in pore fluids pressure was therefore recognized. The drilling rate is basically dependent on Weight On Bit WOB, size of bit and type, hydraulic characteristics, rotary speed Drilling-mud and characteristics of the formation. There is a decrease of ROP (rate of penetration) with depth (because of the compaction) (as long as all parameters above are constant)

STRATIC LITHOLOGY DESCRIPTION

Formation	Interval (m)		Lithology	Description
Lower Fars MB5	2048	2385	Shale interbeded with Anhydrite	SHALE (60)%: Greenish gray to medium gray,moderately brown, firm, occasionally moderately hard, sub blocky to blocky, occasionally sub flaky, occasionally sub fissile to fissile, slightly to moderately calcareous. ANHYDRITE (40)%: White, off white, trace milky white, firm to hard, sub blocky to blocky, amorphous in part, plastic in part, crystalline.
Lower Fars MB4	2385	2737	Salt interbeded with Anhydrite and Shale	SALT (40)%: Colorless, transparent, occasionally translucent, white, light brown, smoky, blocky, occasionally flaky, trace splintery, friable, glass luster. ANHYDRITE (35)%: Off white, minor white, firm, occasionally hard, subblocky to blocky, plastic in part, crystalline, glass luster in part. SHALE (25)%: Medium bluish gray, minor greenish gray, occasionally dark yellowish brown, soft to firm, amorphous, subblocky, sticky in parts, pasty, slightly calcareous.
Lower Fars MB3	2737	2871	Anhydrite interbeded with Salt and Shale	ANHYDRITE (70)%: Off white, minor white, firm, occasionally hard, subblocky to blocky, plastic in part, crystalline, glass luster in part. SALT (15)%: Colorless, transparent, occasionally translucent, white, light brown, smoky, blocky, occasionally flaky, trace splintery, friable, glass luster. SHALE (15)%: Medium bluish gray, minor greenish gray, occasionally dark yellowish brown, soft to firm, amorphous, subblocky, sticky in parts, pasty, slightly calcareous.
Lower Fars MB2	2871	2908.14	Salt	SALT (100)%: Colorless, transparent, occasionally translucent, white, smoky, blocky, occasionally flaky, trace splintery, friable, glass luster.
Lower Fars MB1	2908.14	2930	Anhydrite interbeded with Shale	ANHYDRITE (70)%: White, minor off white to grayish white, firm to hard, blocky to subblocky, crystalline, glassy luster in part. SHALE (30)%: Medium bluish gray, soft to firm, amorphous, subblocky, sticky in parts, pasty, slightly calcareous.

4.6 Results and discussion

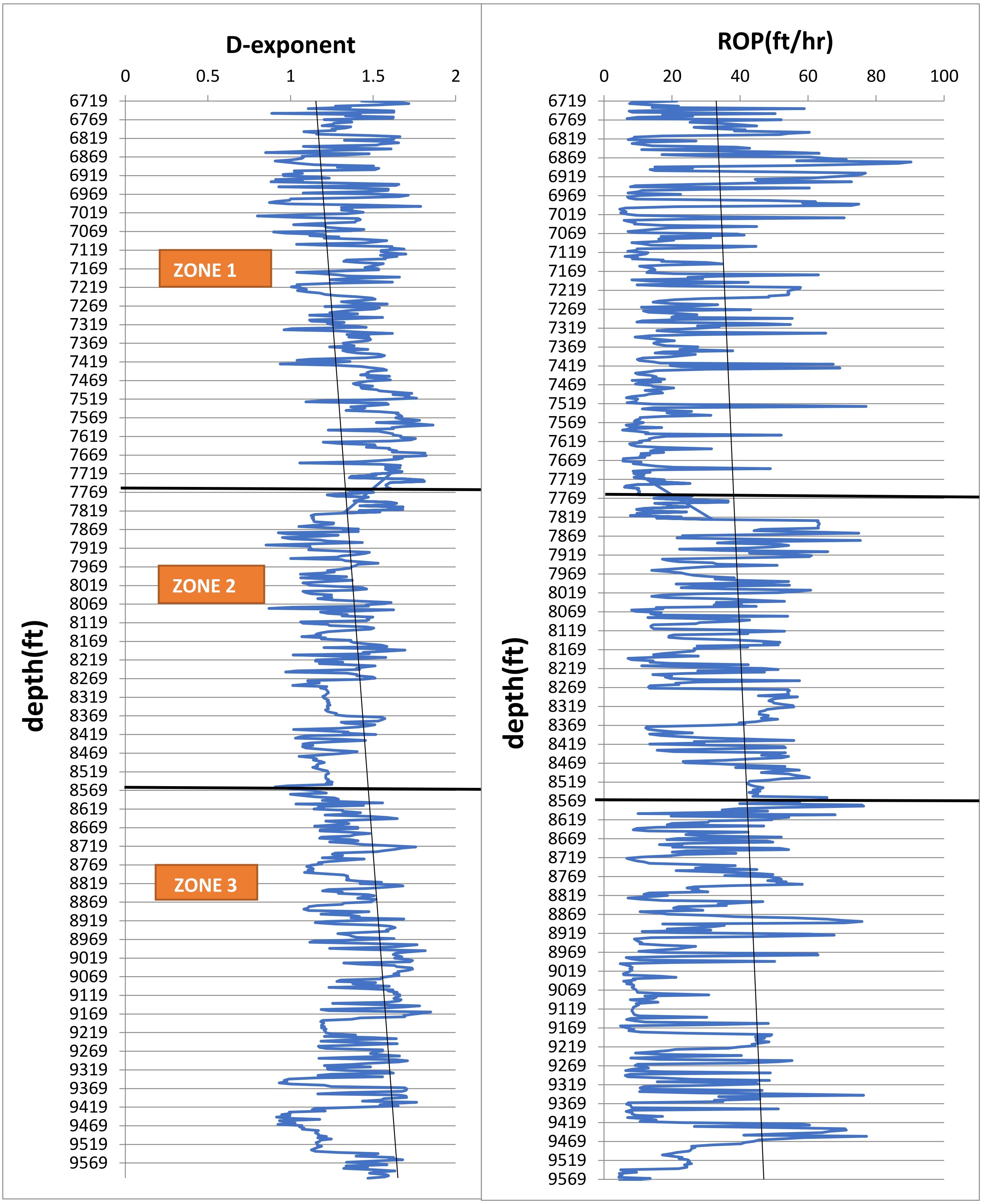


Fig.4.1 The relation between d- exponent and ROP with depth.

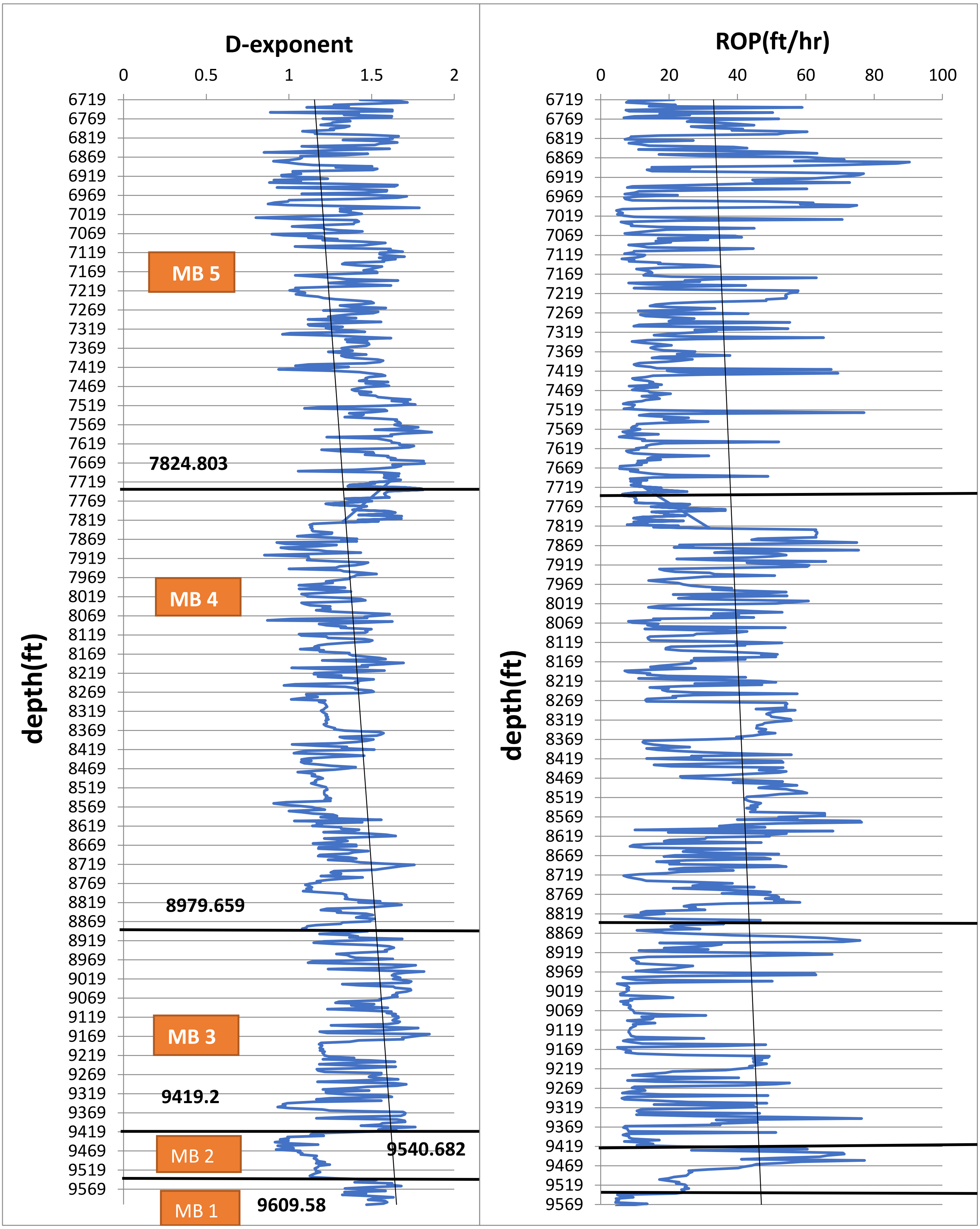


Fig.4.2 The relation between d- exponent and ROP with depth.

From the **figure 4.1** we notice the following:

Zone 1: shows a gradual increase in the d-exponent curve with increasing depth.

Zone 2: We notice a higher deviation in the d-exponent curve , which indicates a sudden transition from an area of normal pressure to an area of abnormal pressure.

Zone 3: The deviation begins to decrease gradually, indicating a transition zone and a return to normal. Near the end of the graph there is a sudden rise in the exponential D curve. The reason for this rise is that the formation is very fragile because it contains 100% salt, so drilling speeds are high in such a formation, which reflects a rise in the D-exponent.

According to the term ROP

The basic concept of using ROP is to detect abnormal pressure formation at two points:

- The pressure of any formation increases with depth due to the effect of overpressure, and therefore the ROP decreases with depth (assuming other parameters constant).
- The rocks are less compact (more porous) in the transition zone compared to the natural state, therefore; The ROP will increase with depth and give an indication of the presence of an area of overpressure.

The penetration rate increases due to the decrease in differential pressure (the difference between the drilling fluid pressure and formation pressure).

In **Figure 4.1** The relationship between penetration rate and depth is clear, as we notice that there is an increase in penetration rates for areas with abnormal pressure, and this is due to the rocks being less compressible, as there is not enough applied hydrostatic pressure to increase the formation's compressive forces and thus the pressure difference decreases according to the relationship ($\Delta P=Pm-Pf$) and the penetration rate increases.

Procedures for sudden increase in drilling rate:

A. Stop the rotation on the drill string.

B. Pick up the drill string to correct the position of the tool connection above the drill table.

C. Stop slurry pumps.

D. Perform flow check. If there is no leak, continue drilling. When the well flows, the appearance of pressure is announced, and the well is closed. Next, the standing pipe pressure (SIDPP) and SICP (casing pressure) values are subtracted.

Through the figure 4.2, it is clear that the high-pressure areas of the Lower fars Formation change with the change in depth. From the fig.4.2, the pressure behavior in the members of the Lower fars Formation is as follows:

Lower Fars MB5: The pressure gradually increases downwards until it reaches unity Lower Fars MB4.
Lower Fars MB4: the completely unusual situation in this unit Lower Fars MB4 has the highest pressure in the formation.
Lower Fars MB3: The pressure is lower than in the fourth member and gradually decreases until it reaches the transformed state Lower Fars MB2
Lower Fars MB2: The pressure in this member changes from a variable or abnormal state to a normal pressure.
Lower Fars MB1: This organ is distinguished by its normal pressure.

We conclude that the mb4 unit is distinguished from the rest of the units of the fars formation is of high pressure (unusual pressure), the d-exponent values deviate from the normal path towards lower values, i.e. to the left. This results from the fact that this mb4 unit contains layers of shale It contains formational water, as these rocks are characterized by their high porosity and zero permeability. There are also layers of salt and layers of anhydrite that form cover rocks. The reasons for the continued presence of formational water within the pores of shale rocks are:

- The nature and environment of sedimentation: the presence of dry bedrock layers that prevent water leakage.
- The presence of layers or shale rocks with high porosity and zero permeability.

4.7 Conclusions

1. In transitional regions or high-pressure regions, it is noted that the calculated d values deviate from the normal path towards lower values, i.e. to the left. This deviation from the normal path indicates the presence of an area of high pressure (or unusual pressure) as shown in figures (4.1 and 4.2).
2. The pressure is highest in the MB 4 layer compared to other layers.
3. The causes of high pore pressure have very close relationship with the character of formation. Fars formation contains salt, anhydrite and shale. The low permeability of salt and anhydrite rock is good for pressure reserve and they are good cap rock for high pressure.
4. The Lower fars Formation represents a complete depositional cycle of advancing and receding sea.
5. The formation rocks consist of shale and anhydrite salt, forming repeated layers.
6. The first member, or what is called the cap rock (MB1), has normal pressure.
7. Salt rocks are found in the Fourth Third Second Members. These rocks are always sitting on layers of anhydrite.

4.8 Recommendations

▪ It is recommended to use well logging (Porosity Logs) to estimate the pore pressure and fracture pressure in order to make sure the results that have been obtained are valid.

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