Pore Pressure Estimation in HPHT Wells

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Geoscience & Petroleum Engineering Programme
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BACHELOR OF ENGINEERING (Hons)
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Approved by,

....

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertake or done by unspecified sources or persons.

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ABDUL HAKIM BIN ALIAS

Abstract

The title of the project is "pore pressure estimation in high heat flow reservoir". This project is about how to estimate pore pressure in High Pressure High Temperature (HPHT) environment. As the industry today troubled with depletion of existing fields, scarcity of easier targets, HPHT wells are now increasing in many parts of the world. However, HPHT wells pose a greater challenge that allow small margin of error and requires great expertise. A pre-drill estimate of formation pore pressure is a key requirement for safe and economic drilling of deepwater wells, and enables optimal casing and mud design. In this project, sets of data from HPHT wells will be interpreted using various available pore pressure estimation techniques that already developed and see what is the most accurate to be used in HPHT wells. A new correlation also developed to predict pore pressure using formation data and temperature data.

ACKNOWLEDGEMENT

This dissertation would not have been completed without the guidance and help of several individuals who contributed and gave their assistance in the preparation and completion of this study.

First and foremost, I offer my sincerest gratitude to my supervisor, AP Wan Ismail Wan Yusoff whose sincerity and encouragement I will never forget. His guidance and support have enabled me to complete this project and thesis within the time. One simply could not wish for a better or friendlier supervisor.

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Chapter 1

Introduction

1.1 Background of study

It is a common knowledge that pre-drill pore pressure prediction is crucial element in any exploration. It is more important when we are dealing with high heat flow reservoir or HPHT reservoir.

The conventional method of pore pressure prediction works well in young and low temperature sediments such as Nile Delta is based on principles that govern compaction of compressible sediments. During burial, porosity is reduced in sediments as results from compaction, driven by stress. When sediments are not sufficiently dewatered within the time frame that a stress is imposed, stress is distributed partially on the grain while others on the fluids. This will leads to overpressure mechanism, known as compaction disequilibrium. Compaction disequilibrium occurred when the magnitude of overpressure is controlled by the weight of the added load, as well as the rock properties. Typically, pore pressure profiles evolve with depth to be overburden-parallel.

Conventional method of pore pressure prediction is accurate in this type of formation, where the compaction disequilibrium is the main source of overpressure. Obviously, this method cannot be implemented in high heat flow reservoir and still be accurate. In higher temperature conditions, additional pore pressure can also be generated by fluid expansion mechanism and framework weakening/load transfer. This two factor can causes the pore pressure to increase at faster rate than overburden stress.

1.2 Problem statement

Pore pressure knowledge is very important in drilling at deeper and complex well. This knowledge will help in planning the well development in overpressured formations. Particularly in high heat flow formations, data for pore pressure are needed for design of drilling fluids, cement, tubular, logging and testing for safe and economical operations.

Current pore pressure estimation capability is well optimized for formation where compaction disequilibrium is the primary source of overpressure. But, as industry venture into deeper and more complex well where temperature can exceed 100°C, this conventional prediction method can be inaccurate.

The project is highly significant for exploration in HPHT environment. Optimized pore pressure estimation methods are required to optimally predict pore pressure in HPHT environment so that design of well can be done accurately to save time and cost.

1.3 Objectives

The objectives of study are as follows:

i. To compare the effectiveness between several existing pore pressures estimation methods in HPHT wells.
ii. To create a relationship between pressure and temperature to predict pore pressure in HPHT wells.

1.4 Scope of study

Different pore pressure estimation techniques will be identified and analyzed from SPE journals and papers. One that has been identified is from (Bowers, Pore Pressure Estimation From Velocity Data: Accounting for Overpressure mechanism besides undercompaction, 1995).

A set of data from different HPHT wells will be obtained from Project supervisor. This data then will be interpreted to estimate the pore pressure in each well. A correlation between temperature and pore pressure will be created so that it can be used to estimate pore pressure in another well in the same field or for deeper depth in the same well.

1.5 Relevancy of the Project

Pore pressure estimation is proven to be essential in field development. During the drilling phase, a pre-drill pore pressure estimate allows the appropriate mud weight to be selected and the casing program to be optimized, thus enabling safe and economic drilling. Too low of a mud weight will make formation fluids to enter the wellbore, and too high will make the rate of penetration too low or worse, fracturing the formation.

As the industry venture more into exploration of deeper wells, pore pressure method need to be adjusted to cater the HPHT environment. This project is relevance as we discussed and research on how accurately the estimation of pore pressure in HPHT wells using existing methods.

1.6 Feasibility of the Project

The project is based on testing the accuracy of pore pressure prediction methods in HPHT environment. The project is expected to be completed within 8 months of research period as no experiments needed to be done. A 4 month of research on suitable topics in FYP 1, and the remaining to execute the project in FYP 2. Positive and implemented outputs are expected to be produced from the project.

Chapter 2
Literature review

2.1 Terminology

2.1.1 Hydrostatic pressure

Hydrostatic pressure is defined as the normal, predicted pressure for a given depth, or the pressure exerted per unit area by a column of freshwater from sea level to a given depth. There can be abnormally low pressure caused by drainage of a reservoir, or abnormally high pressure caused by rapid burial of fluid-filled sediments by impermeable sediments that caused the fluid cannot escape.

It can mathematically expressed by:

$$HP = g \times \rho f \times D$$

HP = hydrostatic pressure
g = gravitational acceleration
ρf = average fluid density
D = true vertical depth or height of the column

All wellbore pressures, such as formation pressure, fracture pressure, fluid density and overburden pressure, are measured in terms of hydrostatic pressure to help with interpretation. Hydrostatic pressure also commonly referred in term of pressure gradient and can be converted to equivalent mud weight and pressure gradient by:

$$HG = HP / D$$

2.1.2 Overburden pressure

Overburden pressure can be defined as the pressure exerted by total weight of overlying formations above the point of interest. The total weight of overlying formation is the combined weight of formation solids and formation fluids in pore space. The density of the combined weight is expressed as bulk density (ρb). Overburden pressure can be represented by:

$$\sigma_{ov} = 0.052 \times \rho b \times D$$

σ_{ov} = overburden pressure (psi)
ρb = formation bulk density (ppg)
D = true vertical depth (ft)

Overburden pressure is varied at different depth due to variations in formation density (caused by variations in lithology and pore fluid densities).

2.1.3 Effective stress

Effective stress can be generally defined as the difference between overburden pressure and pore pressure (Terzaghi, 1923)

$$\sigma = \sigma_{ov} - p$$

2.1.4 Matrix stress

Matrix stress is defined as the stress under which the rock material is confined in a particular position in the earth's crust. The matrix stress acts in all directions. The vertical component of the matrix stress is that portion which acts in the same plane as the overburden load. The overburden load is supported at any depth by the vertical component of the rock matrix stress and the pore pressure. This relationship is expressed as:

$$\sigma_{ov} = Pf + \sigma_{mat}$$

The equation above can be used to quantify the magnitudes of pore pressures using data from drilling.

2.2 Theory

2.2.1 Pore pressure

Pore pressure is defined as the pressure acting upon the fluids in the pore space of the formation. Pore pressure can be equal to hydrostatic pressure, higher (overpressure) or lower (under-pressure).

Pore pressures are generated from various mechanisms (Jeremy Greenwood, 2009). It can be summarized in table 1. The generation mechanisms are used to determine the appropriate prediction method and information source required for estimation techniques. Methods available in predicting pore pressure can be subdivide into estimation techniques in argillaceous formation and estimation techniques in permeable formation.

To estimate pore pressure in argillaceous formation, we require the use of measurement that respond to changes in porosity or the effective stress state of the rock. Permeable formation in the other hand, need the direct measurement for formation pressure and knowledge on fluid type.

Pore pressure can be estimated based on several methods, mainly involving velocity, density, D exponent, porosity and resistivity to the pressure signal in the formation.

TABLE 1–SUMMARY OF PORE PRESSURE GENERATION MECHANISMS		
Formation Type	**Category**	**Mechanism**
Agillaceous	Mechanical Stresses	Disequilibrium compaction through vertical strain
	Mechanical Stresses	Disequilibrium compaction through lateral strain
	Mechanical Stresses	Normal and reverse faulting
	Mechanical Stresses	Listric faulting
	Mechanical Stresses	Salt diapirism/mud volcanoes
	Thermal Stresses	Unloading due to thermal stresses
	Chemical Stresses	Clay diagenesis
	Chemical Stresses	Differential precipitation
	Chemical Stresses	Hydrocarbon cracking
	Buoyancy/Hydrostatic	Uplift/downthrow of formations
Permeable	Mechanical Stresses	Open conduits such faults and fractures
	Chemical Stresses	Hydrocarbon cracking
	Buoyancy/Hydrostatic	Artesian effects
	Buoyancy/Hydrostatic	Hydrocarbon buoyancy
	Buoyancy/Hydrostatic	Production
	Buoyancy/Hydrostatic	Centroid effect

Table 1-Summary of pore pressure generation mechanisms (Jeremy Greenwood, 2009)

2.2.2 Normal Pore pressure

Normal pore pressure is equal to the hydrostatic pressure of a column of formation fluid extending from the surface to the subsurface formation being considered. The magnitude of normal pore pressure varies with the concentration of dissolved salts, type of fluid, gases present and temperature gradient thus making normal pore pressure as not constant. For example, as the concentration of dissolved salts increases the magnitude of normal pore pressure increases.

2.2.3 Abnormal Pore pressure

Abnormal pore pressure can happens at any depth and is defined as any pore pressure that is greater than the hydrostatic pressure of the formation water occupying the pore space. It also referred to as overpressure or geopressure.

2.2.4 Subnormal Pore pressure

Subnormal pore pressure or underpressure is defined as any formation pressure that is less than the corresponding fluid hydrostatic pressure at a given depth. It is encountered less frequently than the abnormal pressure and can be generated by stratigraphic, tectonic and geochemical history of an area, or may have been caused artificially by the production of reservoir fluids. The Rough field in the Southern North Sea is an example of a depleted reservoir with a subnormal pressure.

2.2.5 Detection of overpressure

There are many ways to detect overpressure zones. The most used one is d-exponent method. Generally, with depth, d-exponent will increase except when in overpressure zone, the d-exponent will decrease.

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

Where;

R = drilling rate, ft/hr

K = drillability constant

N = rotary speed, RPM

E = rotary speed expon.

W = bit weight, lbs

D_B = bit diameter, in

D = bit wt. Exponent or D – exponent

2.2.6 Cause of Overpressure

Abnormal pore pressure is developed as a result of a combination of geological, geochemical, geophysical and mechanical process. The overpressure mechanism can be divided into three major groups, those on the loading limb and those on the unloading limb of a stress-strain relationship, and those with no volume change. Most method of prediction uses loading limb relationship and only taken into account the effect of disequilibrium compaction. This will results in underestimate pore pressure in areas where other overpressure mechanisms occurs.

loading limb	Disequilibrium compaction
unloading limb	Fluid expansion • Aquathermal • Hydrocarbon generation • Hydrocarbon cracking • Clay mineral digenesis • Osmosis Uplift
no volume change	Tectonic stress Fluid density contrasts

Table 2-Overpressure mechanisms

- **Fluid expansion**

Fast burial in high temperature zones can generate expansion of fluids contained in the rock pores. A relative increase in fluid volumes in relation to the rock volume caused by thermal coefficient of expansion of the fluids is higher than the matrix rock. If the overlying sediment is composed of low permeability rock, the fluid will be restrained in pores causing the increase in pore pressure and resulting to overpressure zone.

- **Undercompaction**

When fluids contained in the rock pores cannot escapes during burial phase and compaction process, it confined in the porous rock supporting part of the sediment weight adding to the pore fluid pressure. This will increase the pore pressure and also called disequilibrium compaction. The disequilibrium of compacting occurs when a fast deposition of thick layers of rocks with low permeability such as clays takes place. This overpressure mechanism can be identified by analysis of electrical logs, mainly density, resistivity and sonic.

- **Clay Diagenesis (Conversion of Smectite to Illite)**

Clay diagenesis is the most important abnormal mechanism in marine environment. On initial burial, marine clays are composed of predominantly smectite clays of which montmorillonite are by far the most common. The montmorillonite minerals are composed of hydrous aluminum silicates in the form of extremely small particles. They take up water between their layers, causing swelling, and change the interlayer spacing according to the mineral variety. This environment is usually alkaline in nature and is rich in calcium and magnesium ions but poor in potassium ions. When further burial occur, free pore water is expelled by compaction and will reduce the water content to 30%. With further burial, there will be increases in both the overburden load and temperature and these two effects cause all but the last layer of structural water to be expelled to the pore space. This causes the clay lattice to collapse and in the presence of potassium ions, montmorillonite diagenesis to illite occurs.

If the water released in this process cannot escape during compaction, then the pore fluid will support an increased portion of the overburden and will thus be abnormally pressured. The transition from montmorillonite to illite is dependent on depth, temperature and ionic activity. In areas of high geothermal gradient, the alteration occurs at shallow depths than those with low geothermal gradient.

- **Uplift**

It occurs when a normally pressured formation is uplifted to a shallower depth then the formation and will appear to have an abnormal pressure due to the fact that the formation pressure has more hydrostatic pressure than a corresponding normally pressured zone at the same depth. The increase in pressure due to uplift is not permanent if the formation is not totally sealed due to cooling effects caused by moving from greater depth to a shallower depth.

- **Faulting**

Faulting in sedimentary rocks is caused by tectonic activities. Sedimentary beds are broken up, moved up and down or twisted. There are a variety of reasons why abnormal pressure develops due to faulting:

1. The fault plane act as a seal against a permeable formation thereby preventing further pore fluid expulsion with compaction. The permeable zone will become overpressure.
2. If the fault is non sealing, it may transmit fluids from a deeper permeable formation to a shallower zone, causing abnormal pressures in the shallow zone.
3. A zone may move down the fault plane causing the zone to be subjected to a higher overburden pressure and higher geothermal temperature. If the zone further compacts and the pore fluids cannot escape, abnormal pressure will result.
4. Rate of sedimentation usually increases on the downthrown block and this rapid sedimentation can lead to undercompaction and development of overpressure.

2.2.7 Pore pressure estimation

2.2.7.1 Well logs

An important data that we needed in pore pressure estimation is log analysis from offset wells that will provide information on the petrophysical properties of the formation to be drilled. Sonic log are the most relevant, because the deviations of measured sonic transit-time from normally compacted formation are a function of the effective stresses in the formation, therefore influenced by the pore pressure. Sonic log also has a resolution of 2 to 5 ft, helping with the interpretation of the seismic cross section. Sonic logs usually represented by reciprocal-velocity units, dTP and dTS for the compressional and shear travel-times, respectively. (R.Wydrinski, 1998)

2.2.7.2 Pore pressure estimation by using seismic velocity

To estimate and predict pore pressure using velocity, several techniques are available including Hottman and Johnson, Pennebaker, Eaton, Bowers, Dutta and Wilhelm et al. As is illustrated in Fig. 1, pore pressure can be estimated from seismic velocities using a suitable velocity to pore pressure transform.

A starting point for pressure prediction from seismic velocity is to build an empirical relationship between the velocity and effective pressure. Effective pressure, σ, is the difference between the overburden pressure, S, and the pore pressure, p.

Velocity analysis has been used for many years to predict pore pressure. A standard approach for pressure prediction is to use conventional stacking-velocity analysis and convert the stacking velocities to Dix equation-corrected interval velocities. There are more complicated and accurate ways including horizon-keyed velocity analysis, refraction and reflection tomography, and prestack inversion. These methods are more accurate than the conventional method, but require additional analysis and processing.

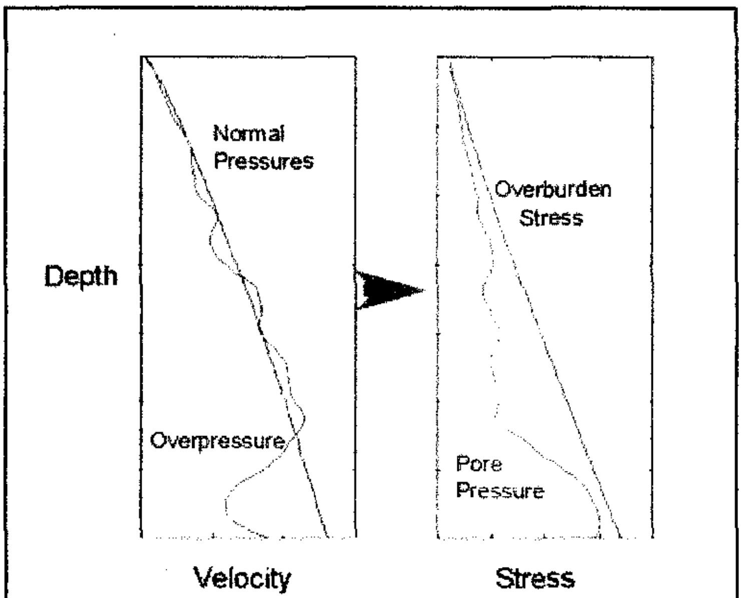


Fig. 1. Seismic velocity to pore pressure transform.

Figure 1: Seismic velocity to pore pressure transforms (Jeremy Greenwood, 2009)

- ***Eaton's method***

A widely used method, Eaton's, estimates the vertical component of the effective stress from the seismic velocity using the relation:

$\sigma = \sigma_{Normal} \ (v / v_{Normal})^{n}$

σ_{Normal} and v_{Normal} refers to vertical effective stress and seismic velocity that would occur if the sediment is normally pressured, and n is the sensitivity of velocity to effective stress (normally set to 3 in gulf of Mexico). The exponent n can also be adjusted using offset well data. The pore pressure then can be calculated using:

$\sigma = \sigma_{ov} - p.$

Where σ_{ov} can be calculated from equation:

$\sigma_{ov} = g \int^{z}_{0} \rho\ (z)\ dz$

Where ρ (z) is the density at depth z below the sea surface and g is the acceleration due to gravity. If there is no density log available, z can be estimated using empirical correlations such as the Amoco equation:

$\rho = 16.3 + (h/3125)^{0.6}$

- ***Bowers method***

Normal conventional pore pressure predicting method usually only take into account one overpressure mechanism, and that is undercompaction (Bowers, Pore Pressure Estimation From Velocity Data: Accounting for Overpressure mechanism besides undercompaction, 1995).

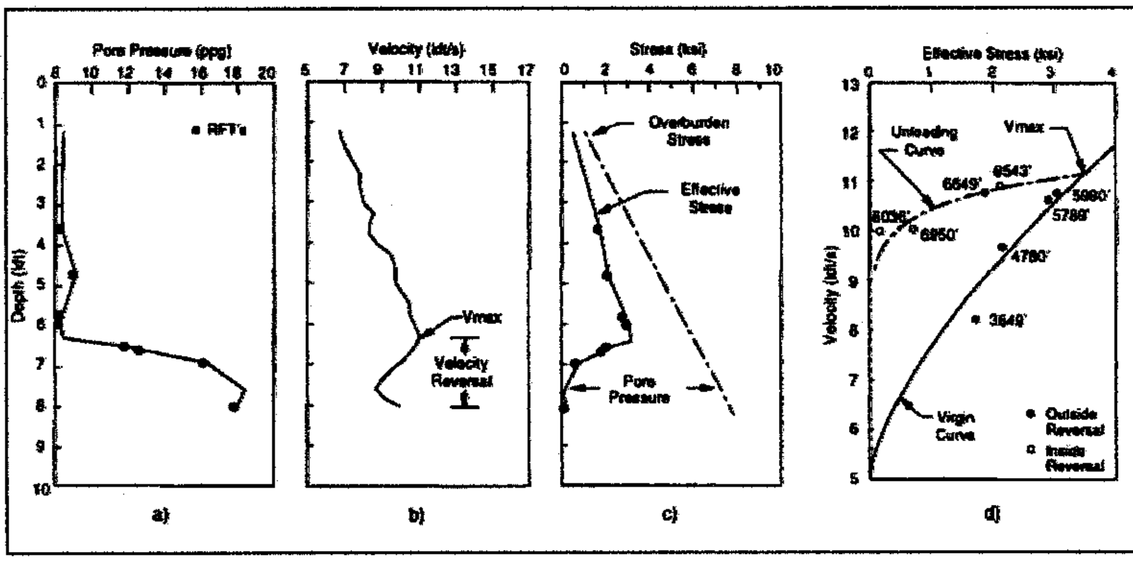


Figure 2- Fluid expansion overpressure in offshore Indonesia (Bowers, 1995)

Fluid expansion will generate velocity reversal as seen in figure (b). This velocity reversal is results of decreasing of effective stress with depth due to rapid increase in pore pressure due to fluid expansion compared to overburden pressure. This velocity reversal will leads to overestimation in effective pressure. Because effective pressure is the difference of overburden pressure and pore pressure, this mean, we will underestimate pore pressure. This underestimation will become disastrous in HPHT environment.

Bowers had made an adjustment to the pore pressure predicting method to include both fluid expansion and undercompaction mechanism for a more accurate prediction. He employs two curve, virgin curve and unloading curve. Basically, virgin curve is used to estimate the area which lies in outside velocity reversal zone and unloading curve used to estimate pressure inside velocity reversal zone. Below are the formula used for both curves.

- Virgin Curve
  - $V = 5000 + A\,\sigma^B$
    - V=velocity
    - A and B= parameters calibrated with offset velocity vs effective stress data

        - σ= effective stress
- Unloading curve
    - $V=5000 + A\,[\sigma_{max}\,(\sigma/\sigma_{max})^{1/U}]^{B}$
        - U= measurement of how plastic the formation is, u=1 meaning no permanent deformation. Usually valued around 3-8
        - $\sigma_{max} = [(V\ max-5000)/A]^{1/B}$
        - Vmax= V at start of velocity reversal

- ***Miller method***

Its first debut is in Drillworks predict software, Miller method uses sonic velocity and can be use to determine pore pressure caused by compaction or other cause of overpressure mechanism. When compaction equilibrium are the main cause of overpressure, only one empirical parameter is required that can be determine from compaction trend analysis or offset wells data. Below is the proposed equation for Miller:

$$p_f = \sigma_v - \ln((V_{ma} - V_{ml}) / (V_{ma} - V)) / \lambda$$

V=speed of sound in the compacting medium (shale)
Vma= speed of sound in the matrix
Vml=mud-line velocity, essentially the speed of sound in the liquid
λ=a fitting parameter, adjusted based on calibration data
σ=effective stress
σ v=vertical stress due to the weight of the overburden
p f =pore fluid pressure

2.2.7.3 Pore pressure estimation by using porosity

Porosity can be used for reserve estimation, reservoir simulation, and pore pressure prediction. Porosity based pore pressure prediction is based on mechanical compaction of fine grained sediments with known compressibility behavior.

Porosity is used as a rock property implicitly reflecting the degree of compaction (both mechanical and chemical) of sediment. Porosity is related to pore pressure through its relationship with effective stress. The porosity may be measured, derived from wireline response, or a porosity attribute may be used, for example velocity data derived from seismic.

Different lithologies compact at different rate. Compaction is a function of mean effective stress, although vertical effective stress is used as an alternative for mean effective stress in pore pressure estimation. Athy-type algorithm which a starting porosity and compaction coefficient are related to depth or effective stress is usually described compaction behavior in pore pressure estimation.

Porosity based pore pressure prediction works best in low temperature and young sediments where lithology remains similar and normal compaction curve can be reliably developed. Two most used methods in pore pressure prediction using porosity is Eaton Ration Method and Equivalent Depth Method.

Chapter 3
Methodology

3.1 Research methodology

This project will be divided into two phase, for FYP 1 and FYP 2. The first phase, the research phase are done in FYP 1. Here, all literature consists of papers and journals regarding pore pressure prediction will be explored. Methods of pore pressure will be researched and each one will be identified with its advantages and disadvantages. Well data also will be obtained in phase 1 for the use in FYP 2. Software to interpret the data will be chosen and familiarization with the software will be conducted during the duration of Final Year Project 1.

For second phase of the project, analyses of data are planned. Data of wells acquired from project supervisors will be analyzed. First, pore pressure will be calculated using methods identified in the first phase. Second, the correlation between temperature and pore pressure will be investigated.

The expected result from this project is a correlation that can be used to predict pore pressure in HPHT wells using temperature data as an input. Error of each method will be recorded to find out the most accurate methods in HPHT wells.

3.2 Project activities

- **Pore pressure prediction**

Set of well data will be obtained from supervisor. Three methods will be employed simultaneously to predict pore pressure, and then the most accurate method will be picked based on the data set and suitability to employ in HPHT environment.

- **Relationship Identification**

The next process is to come out with an equation that will predict pore pressure using temperature data. Pressure will be plotted against temperature, and relationship between the two parameters will be observed.

3.3 Tools and Software

- **Microsoft Office**

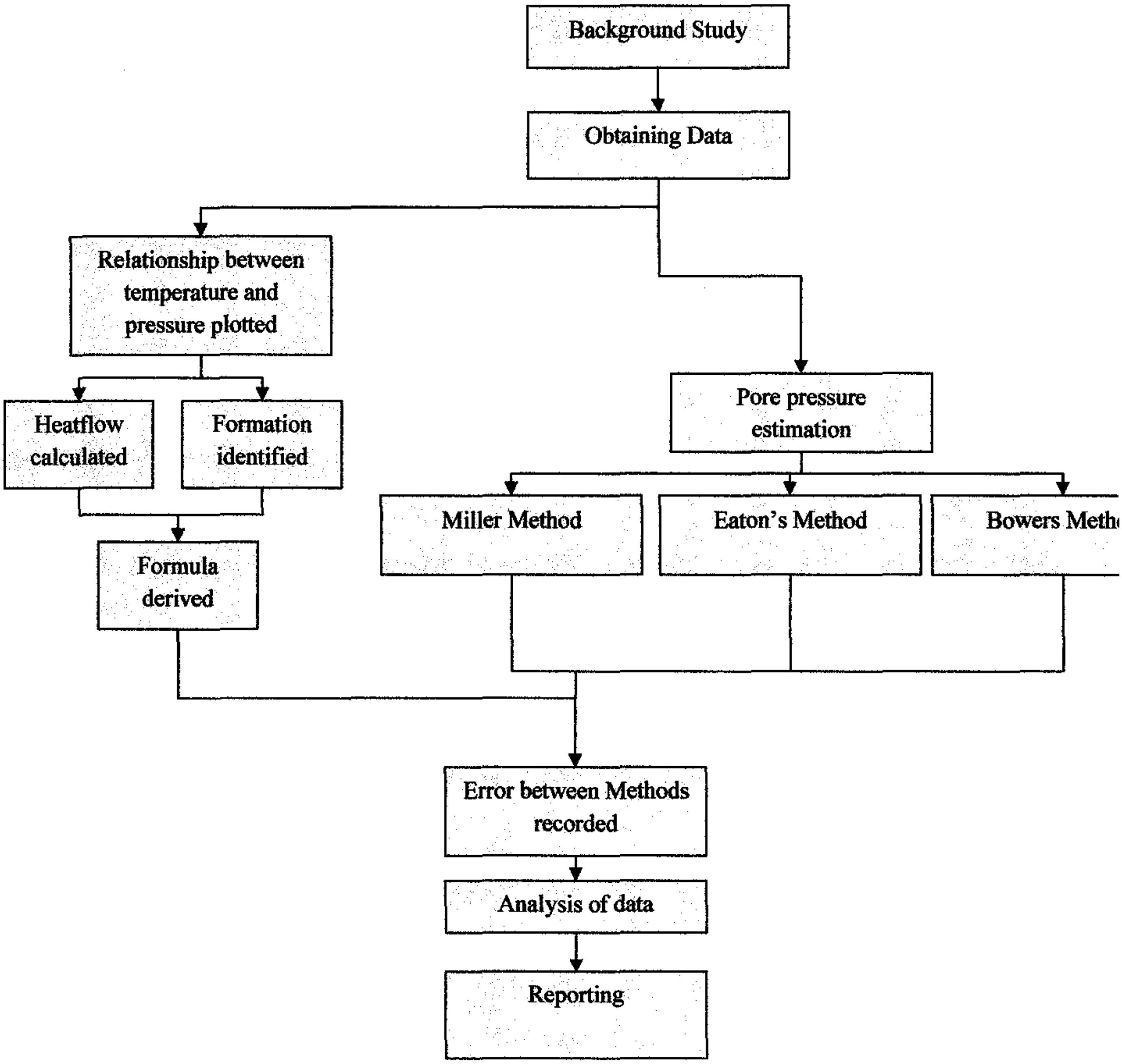
For this project, the software that has been identified to assist in this project is Microsoft Office. Word will be used to prepare reports and Excel to help in plotting data to find the relationship and to help in documenting results.

- **Drillworks Predict**

Drillworks predict is software that specially designed to predict pore pressure from log data (gamma ray, sonic log, density log, and resistivity data). User just has to feed the data into the software, and choose from several available methods to predict pore pressure. Drillworks predict also used to display log files in .las format.

Below is the flow chart of the project:

- Flow chart.



3.4 KEY MILESTONE AND GANTTCHART

No.	Activities /Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues															
2	Progress Report Submission															
3	Project Work Continues															
4	Pre- EDX															
5	Draft Report Submission															
6	Dissertation Submission (soft copy)															
7	Submission of Technical Paper															
8	Oral Presentation															
9	Project Dissertation Submission (Hardbound)															

Chapter 4

Results and discussions

4.1 Data gathering and analysis

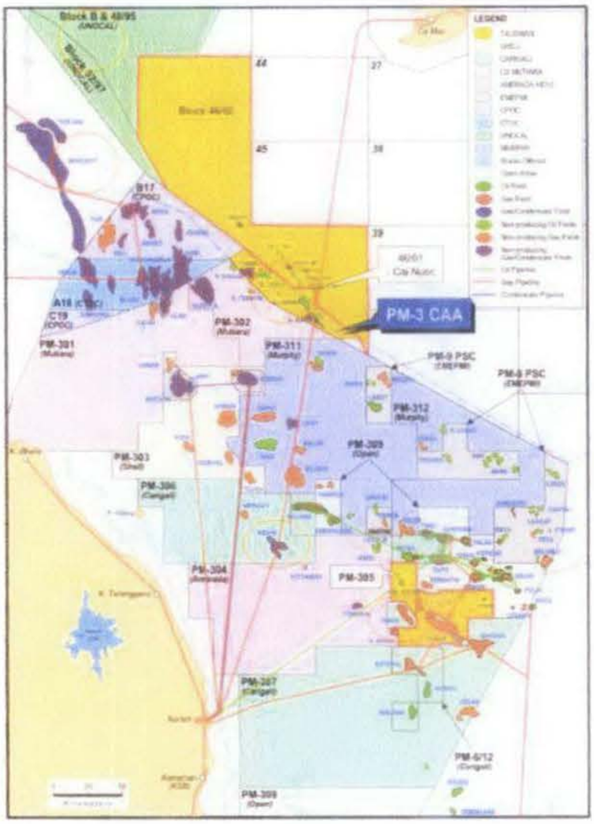


Figure 3-Malay Basin

For this project, the data needed are categorized into two, log data (acoustic, temperature, resisitivity, density, and gamma ray), and also depth (TVD, MD, azimuth, and inclination of the wells). Both of this data are important in determining the pore pressure. A well will be used in finding the relationship between pressure and temperature. The well is a gas well and was taken from Malay Basin area.

4.1.1 Pore pressure prediction

Several methods will be employed to predict pore pressure in HPHT wells. The wells used are from Gulf of Mexico basin as limited data from Malay basin obtained. By using the data gathered, Bowers and Eaton method are selected in Pore pressure estimation. The pore pressure predicted will be compared to the real measured pressure. The error of each method will be recorded, and the method that yields the least error will be claimed as the most accurate to be used in HPHT wells. Below are the results of each method:

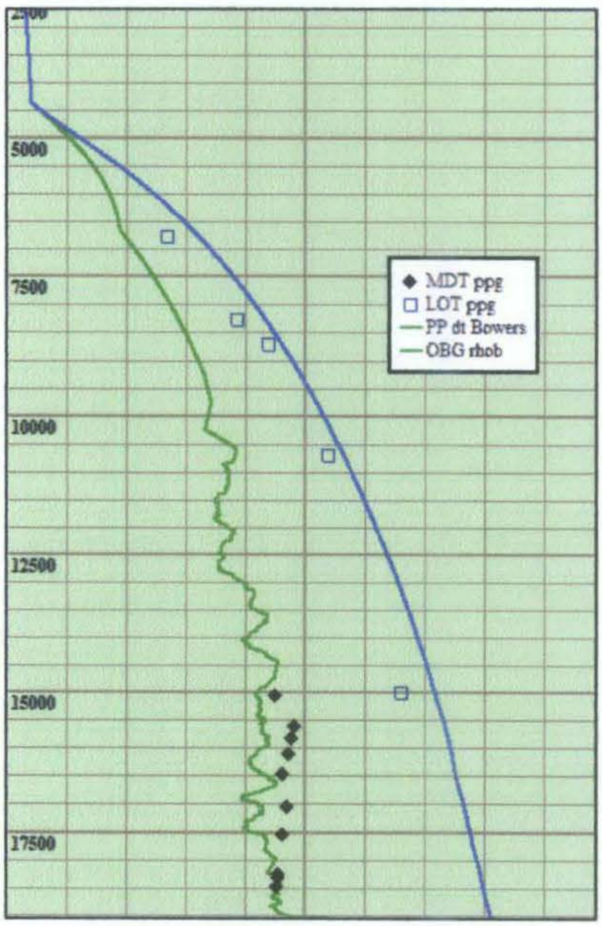


Figure 4-Pore pressure calculated using Bowers Sonic method

Depth	Measured Pressure(ppg)	Calculated Pressure(ppg)	% error
15060	12.51	12.21067	2.392726
15610	12.84	12.28682	4.308255
15818	12.79	12.39444	3.092729
16104	12.73	12.20159	4.150903
16460	12.64	12.28593	2.801187
17042	12.71	12.2636	3.512195
17527	12.64	12.21904	3.33038
18257	12.56	12.43442	0.999841
18311	12.56	12.52724	0.260828
18491	12.53	12.53642	0.051237
19235	13.35	12.85714	3.691835
19280	13.34	12.85171	3.660345
19532	13.3	13.38216	0.617744

Table 3- Calculated percentage error when using Bowers sonic method.

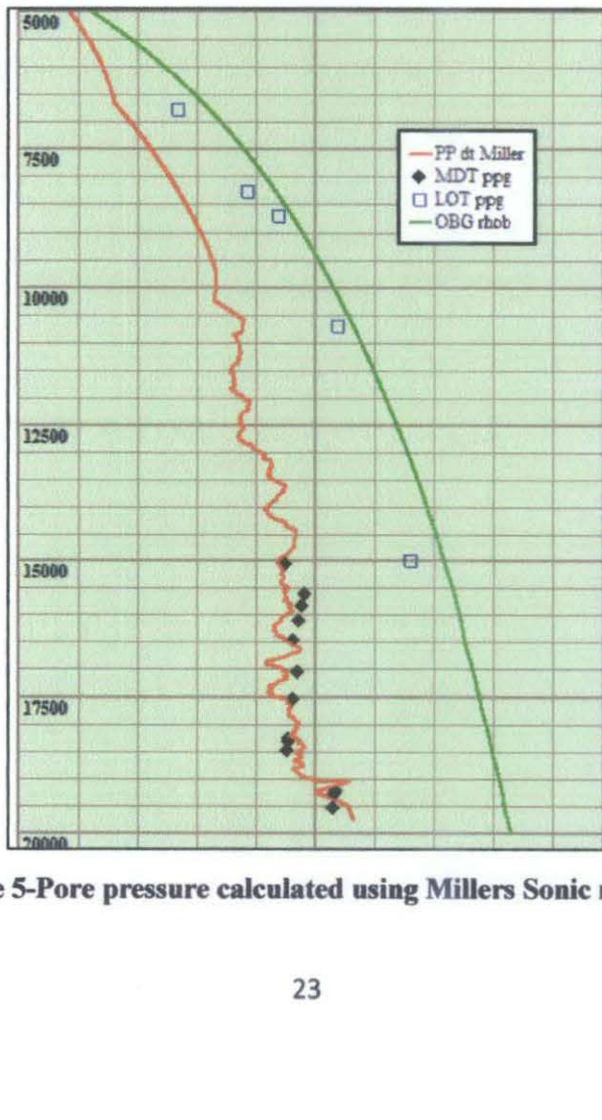


Figure 5-Pore pressure calculated using Millers Sonic method

Depth	Measured Pressure(ppg)	Calculated Pressure(ppg)	% error
15060	12.51	12.41272	0.777618
15610	12.84	12.49917	2.654439
15818	12.79	12.49917	2.273886
16104	12.73	12.42842	2.369049
16460	12.64	12.51013	1.027453
17042	12.71	12.49033	1.728324
17527	12.64	12.41742	1.760918
18257	12.56	12.64356	0.665287
18311	12.56	12.73784	1.415924
18491	12.53	12.74325	1.701915
19235	13.35	13.05645	2.198876
19280	13.34	13.04999	2.173988
19532	13.3	13.57538	2.070526

Table 4-Calculated percentage error when using Millers sonic method.

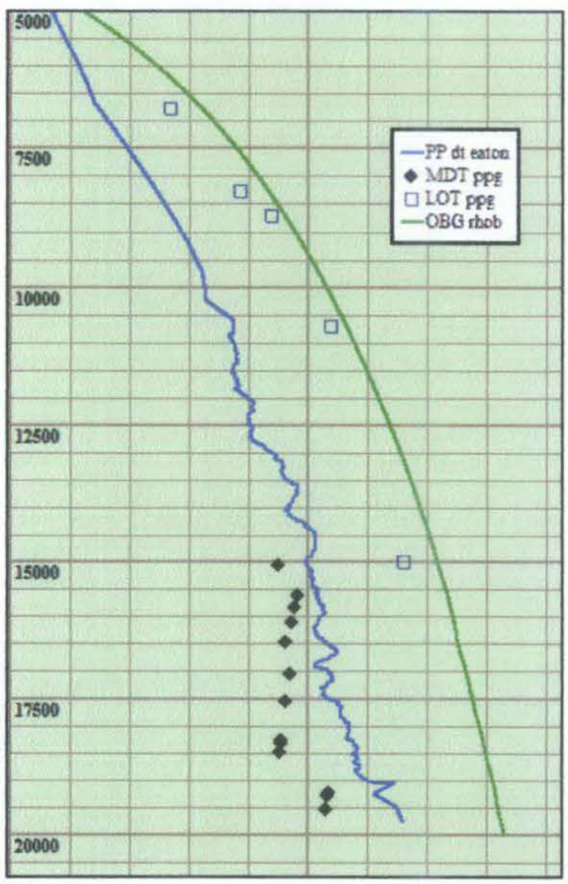


Figure 6-Pore pressure calculated using Eaton Sonic method

Depth	Measured Pressure(ppg)	Calculated Pressure(ppg)	% error
15060	12.51	13.00576	3.9629
15610	12.84	13.16424	2.52523
15818	12.79	13.2777	3.81313
16104	12.73	13.19166	3.62655
16460	12.64	13.30132	5.23196
17042	12.71	13.39338	5.37671
17527	12.64	13.42294	6.19414
18257	12.56	13.70299	9.10023
18311	12.56	13.77411	9.66648
18491	12.53	13.80481	10.1740
19235	13.35	14.14387	5.94659
19280	13.34	14.1528	6.09295
19532	13.3	14.51899	9.16533

Table 5-Calculated percentage error when using Eaton sonic method.

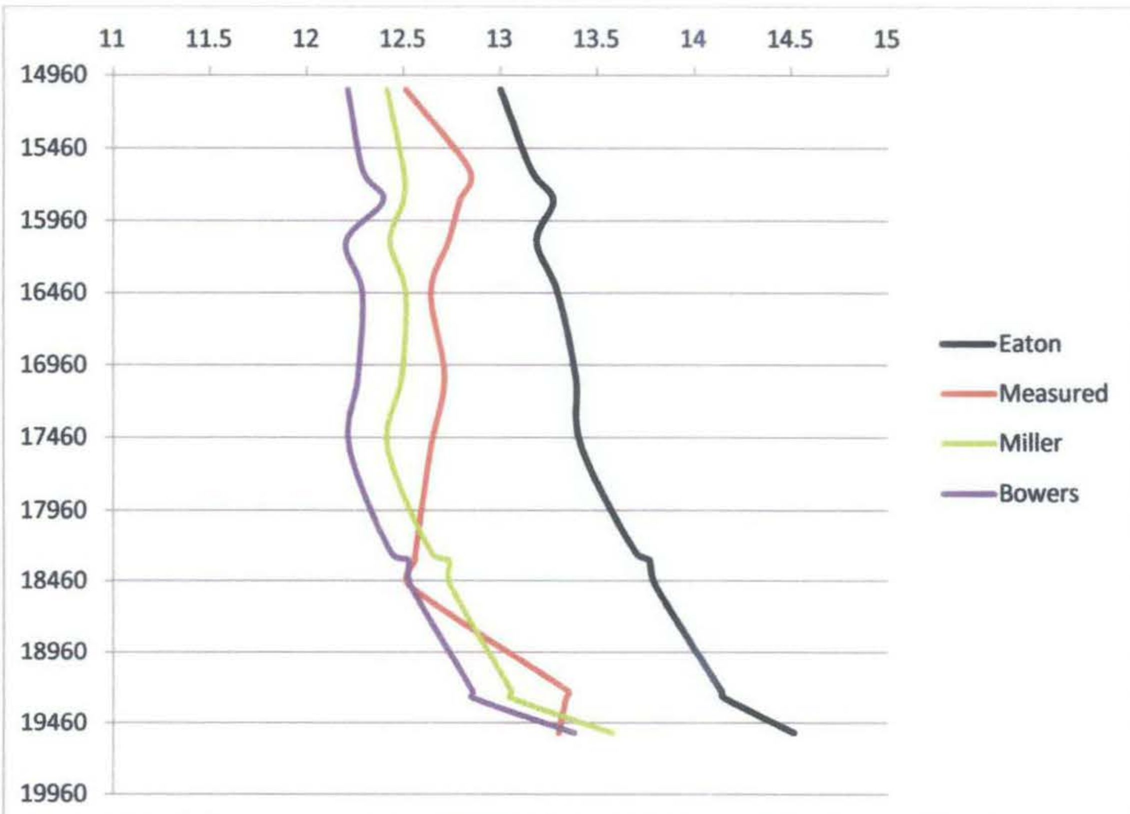


Figure 7-The accuracy of 3method to be applied in HPHT well

Methods	%error
Miller	1.755246
Bowers	2.528477
Eaton	6.221255

Table 6- average error of each method

As shown on graph above, the most accurate method is Miller. This is because the Miller methods are designed to improve Eaton methods and Bowers methods. Eaton's method, when applied in HPHT wells, assumes velocity in formation as fast as velocity in solid steel and Eaton method also only taken into account that only one overpressure mechanism. Bowers techniques also have several weaknesses. According to the equations, acoustic velocity will return to 5000 ft/m which is the acoustic velocity of sea water when the effective stress is zero (R.Wydrinski, 1998).

4.1.2 Relationship between temperature and pressure

A set of log data from a well from Malay basin will be investigated to determine the relationship between temperature and pressure. The results will show whether the relationship can be used to determine pore pressure from temperature data, and how accurate the prediction will be.

First, the pressure profile is plotted. As we can see, the overpressure is observed starting around 1700 meters. That will be the main area of investigation.

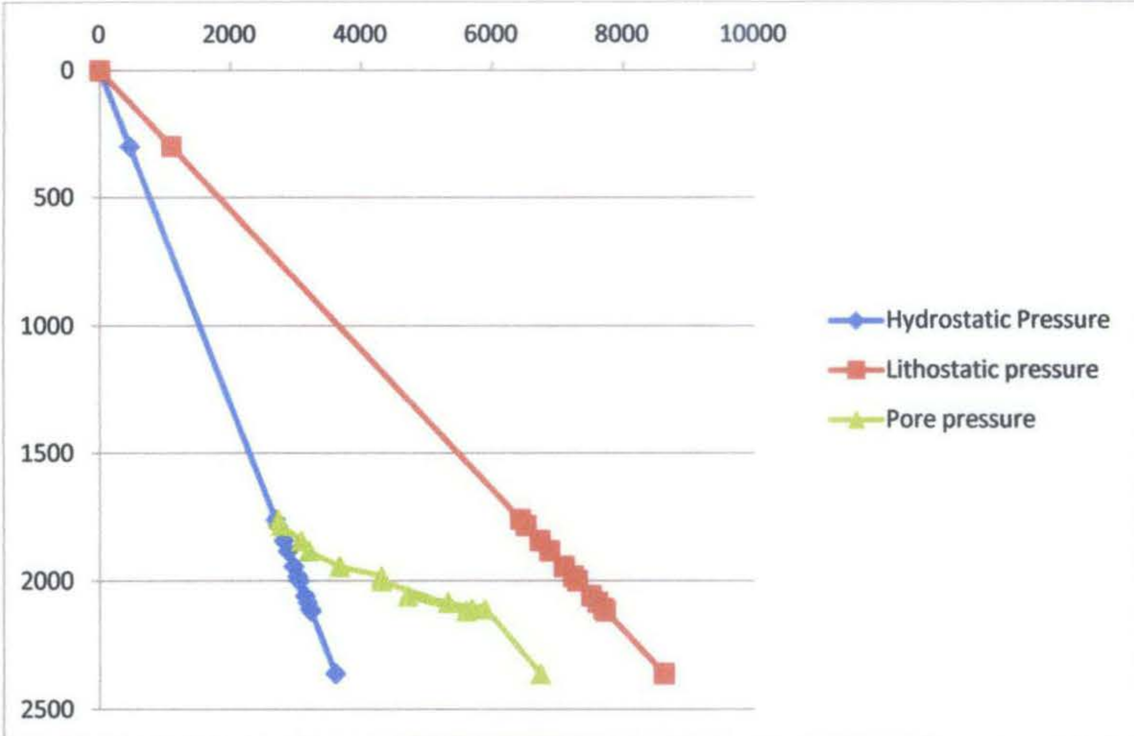


Figure 8-Pressure profile at Well A

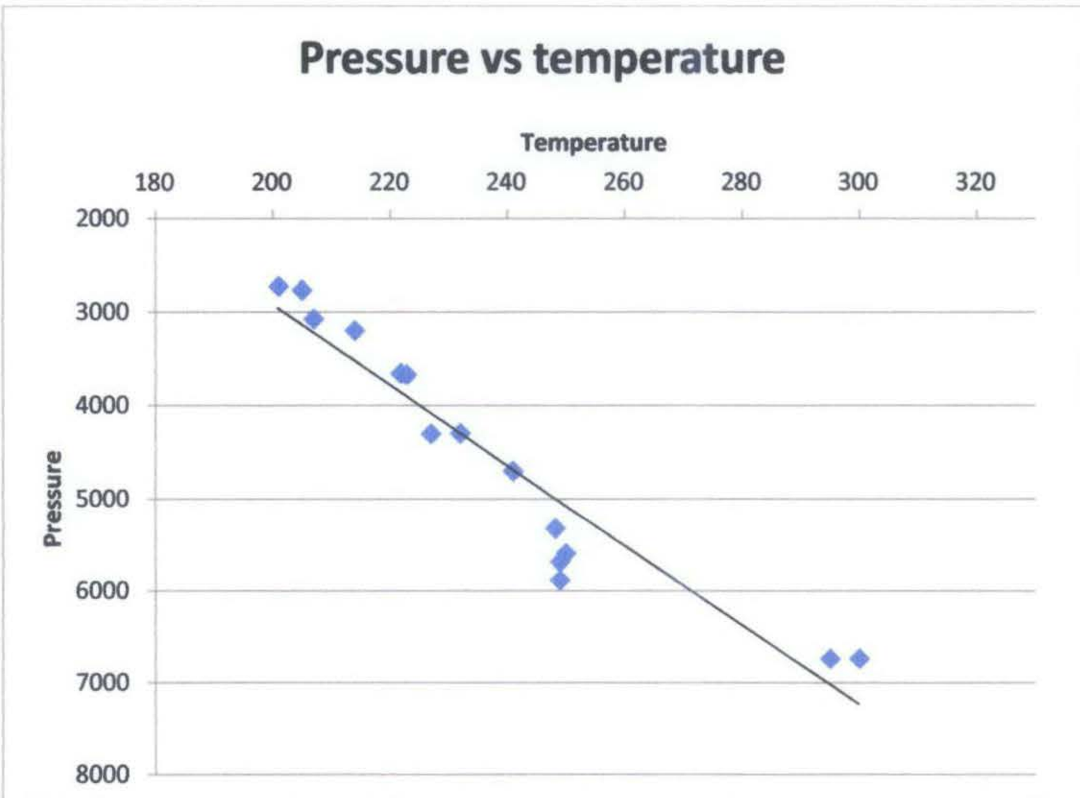


Figure 9-Pressures vs. Temperature

Plotted above is the data for pressure and temperature for the investigated. As the pressure increase, the temperature also increases resulting in positive relationship, but without a certain pattern. The next step in the project is to come out with an equation that uses temperature to predict pore pressure. In order to do this, several parameters must be investigated:

1. The type of formation.
2. The zone lies in overpressure or normal zone
3. The type of overpressure mechanism

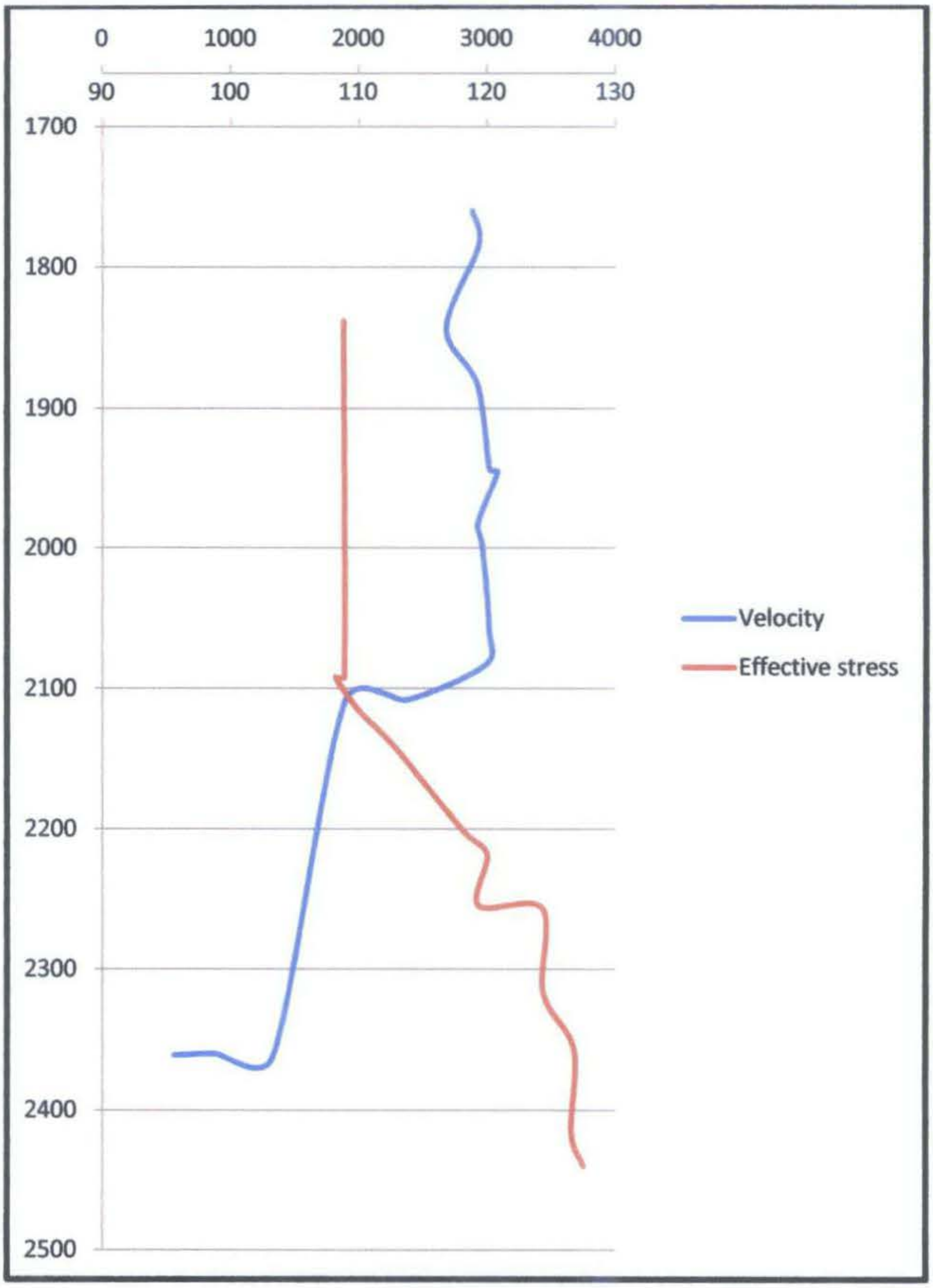


Figure 10-Depth vs. velocity, depth vs. effective stress

Plotted above in figure 11 is depth vs. velocity and depth vs. effective stress. As we can see, there is velocity reversal in the investigated depth. This proved that the overpressure mechanism in this area are not contributed by undercompaction as discussed by (Bowers, Pore Pressure Estimation From Velocity Data: Accounting for Overpressure mechanism besides undercompaction, 1995), but maybe contributed by fluid expansion.

The formation can be obtained from gamma ray log. Here we can find the type of formation, whether it is sand, silt or shales.

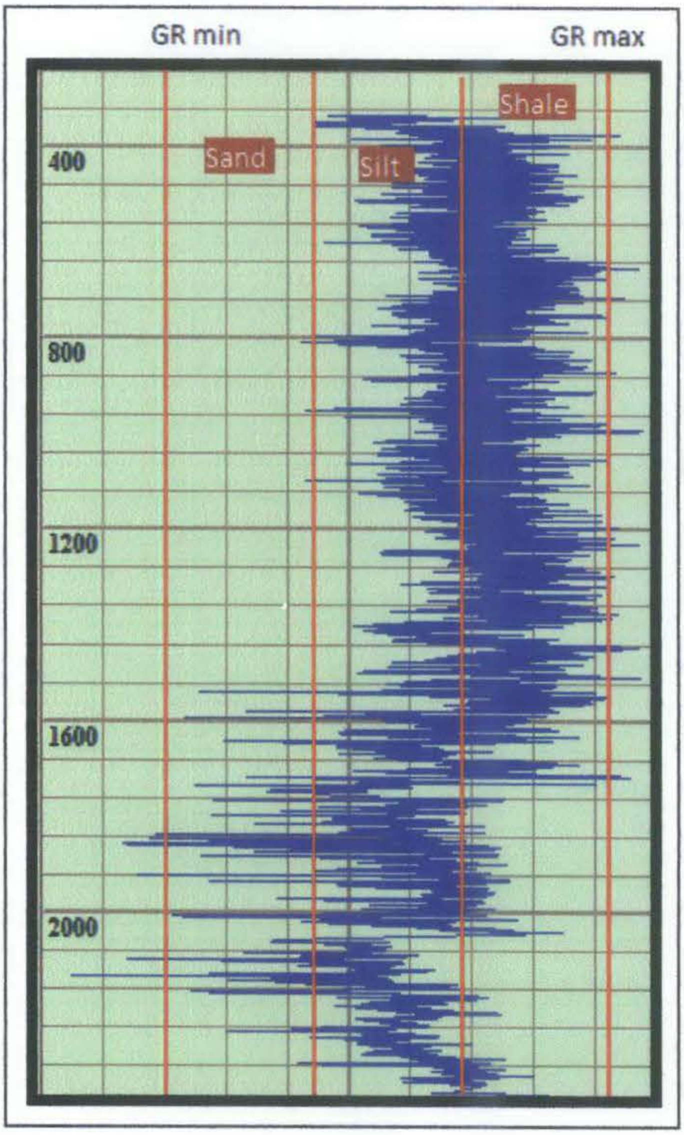


Figure 11-Gamma Ray log

Based on the gamma ray log, below are the formations that are identified at each depth:

Depth(m)	GR	Formation	Pressure(psia)	Temp (degF)
1760	83.5948	Silt	2725.45	201
1784	88.3072	Silt	2765	205
1843	95.0742	Shale	3074	207
1883	71.3518	Sand	3199	214
1943	91.6058	Shale	3656	221.86
1945	96.4981	Shale	3670	222.86
1982	92.0828	Shale	4302	227
1999	74.1723	Sand	4298	232
2083	56.8966	Sand	5319	248.2
2108	75.4924	Sand	5683	249
2109	81.238	Silt	5883	249
2116	81.0085	Silt	5591	250
2362	108.3815	Shale	6736	295

Table 7-Lithology idenfication on each depth

From the above information, Pressure vs. Temperature graph will be plotted to see the relationship between pressure and temperature at each formation type.

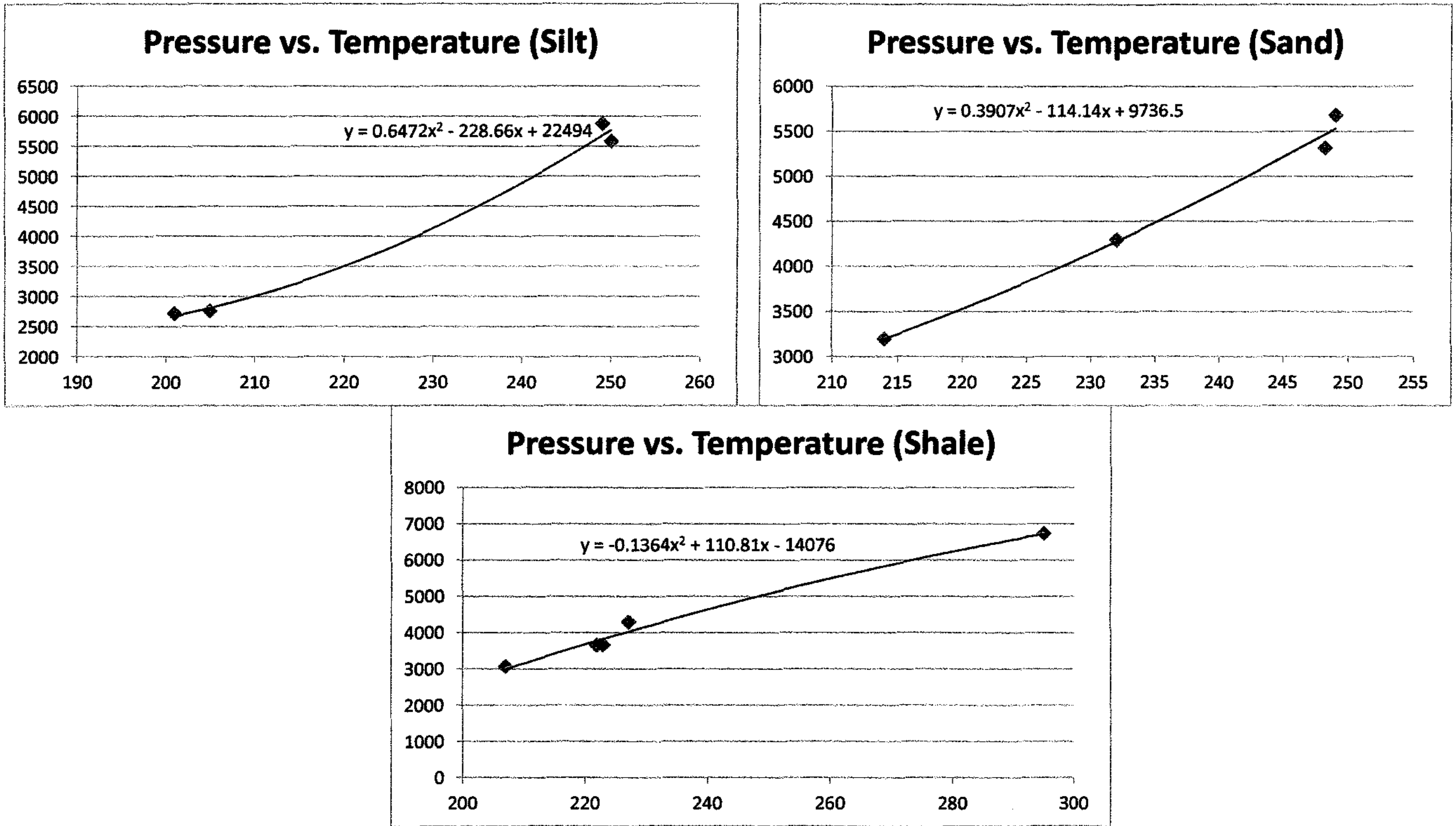


Figure 12- Pressure vs. Temperature for each lithology

With the relationship between pressure and temperature already established by the graph above, we will now use the relationship to predict the pressure using the temperature data and record the error.

Depth(m)	Pressure(psi)	Temp(degF)	Pressure(calculated)	error%
2083	5319	248.2	5475.338	2.939234217
1883	3199	214	3203.037	0.126201938
1999	4298	232	4285.057	0.301144718
2108	5683	249	5539.431	2.526294211
2116	5591	250	5779	3.36254695
2109	5883	249	5684.707	3.370606833
1760	2725.45	201	2680.867	1.635795924
1784	2765	205	2817.28	1.890777577
1943	3656	221.86	3794.445	3.786787488
1982	4302	227	4049.314	5.873677359
1843	3074	207	3017.066	1.852101496
1945	3670	222.86	3844.595	4.757360833
2362	6736	295	6742.74	0.100059382
			Average error:	2.50173761

Table 8- Calculated and measured pressure

The results yield an average error of 2.5%, the lowest of all methods.

Although the methods yields low error results, it is important for us to list the disadvantages of using this method. The disadvantages of using this method are:

- Temperature data need to be obtained in upper depth first.
- Only valid for that particular wells.

Chapter 5

Conclusions

5.1 Conclusions

The success of HPHT wells depends on accurate pore pressure estimation. There were many available methods depending on what data are available. Based on the research done on pore pressure estimation method, I will choose Bowers, Eaton, and Miller's method to predict the pore pressure in this project.

The input data are depth, gamma ray log, resistivity log, density log, and acoustic/sonic log. The data will be fed into the software that contains the formula of each method. The results will be compared to the measured pore pressure. Based on the prediction and estimation, we can see that the Miller method yields less error and more accurate out of the three methods. Eaton methods proven to be unsuitable for HPHT wells as the error are the largest.

For the method using temperature data as the input for pore pressure estimation, the method produces the lowest error percentage, but is not recommended as the temperature data need to be obtained first and only useful for that particular well.

5.2 Recommendations

- Compute the estimated pore pressure using different techniques for other HPHT reservoirs
- Analyze more temperature and rock properties data to see the empirical relationship of the computed pore pressure and the reservoir properties.

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