Pre-drill Well Gradients Estimation using Seismic Data

by

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14169

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Petroleum Engineering Programme
Universiti Teknologi PETRONAS
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(PETROLEUM)

Approved by

____

(Mr Titus Ntow Ofei)

UNIVERSITI TEKNOLOGI PETRONAS
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January 2015

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 undertaken or done by unspecified sources or persons.

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DOMINGOS JOAO JORGE

ABSTRACT

The need to have an estimation of pore gradient, fracture gradient and overburden gradient prior to drilling a new well is essentially a key requirement to well planners. When planning to drill a new well, the prediction of well gradients consisting of pore, fracture and overburden gradient can be effectively made using data from offset wells such as well logs and drilling parameters. However, when considering drilling a wildcat well in a new area with no offset wells in the surrounding, the estimation of well gradients becomes critical. Drilling in an unknown area with no knowledge of the subsurface pressure distribution poses a great risk to operators economically and operationally. Hence to reduce the risk associated with wildcat wells, this project employs seismic data (two-way time and average velocity) to estimate the pre-drill well gradients from a developed C++ computer program. Pre-drill well gradients estimated from seismic data will provide a good background concerning the formation pressures and possible overpressured zones to be encountered during drilling operations. This will prompt the drilling engineer to design a safe and sound mud weight and casing program that will effectively enable the operator to drill a wildcat well with minimum risk. Sophisticated drilling software such as Drillworks, WellCheck and Landmark are used to transform seismic data into pressure gradients; however obtaining the license for a given software suite is difficult and expensive. Therefore, in this project, C++ programming language has been used to develop a model that effectively predicts pre-drill well gradients from seismic data. The model developed enables the user to easily estimate well gradients with the availability of the input data such as two-way time and average velocity. From the results, several graphs of well gradients (pore gradient, fracture gradient and overburden gradient) are generated using different sets of seismic data, and the obtained results were validated with field post-drill data. The model prediction compared excellently with the field data. Information from this study is very essential in making better and sound decisions about mud weight design and casing program before drilling wildcat wells especially in deep offshore environment.

Key words: Well gradients, pore gradient, fracture gradient, overburden gradient, overpressure pre-drill, seismic data, two-way time, average velocity, wildcat.

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ABBREVIATIONS AND NOMENCLATURES

C++: General-Purpose Programming Language

FPG: Fracture Pressure Gradient

OBG: Overburden Gradient

NCT: Normal Compaction Trend

PPG: Pore Pressure Gradient

TWT: Two-Way Time

Vav: Average Velocity

CHAPTER 1

1. INTRODUCTION

1.1 Background

The estimation of pore pressure, fracture pressure and overburden pressure is of great importance in designing drilling programs for wildcat or exploratory wells. Since no other sources of data are available in the location, the estimation of pre-drill well gradients (pore gradient, fracture gradient and overburden gradient) will be made using seismic data which includes two-way time and average velocity. The estimation of these gradients is a pre-requisite for designing an effective mud weight and casing program, thus ensuring the drilling operations are carried out safely and economically. The knowledge about subsurface pressure enables the operator to prevent critical drilling problems such as formation fracture and losing drilling mud, as well as avoiding potential influx of formation fluids into the wellbore which may eventually lead to a blowout if uncontrolled. A further use of pre-drill well gradients helps the drilling team design cementing program, casing setting points and casing design, and they are also useful for optimization of hydraulic program, bit selection, BOPs & well head selection, drilling rig dimensioning, equipment selection, detection of potential hole problems and forecast of operation costs.

By applying an appropriate transformation model, two-way time and average velocities will be used to provide an estimation of the gradients before the well is drilled. Well gradients estimated from seismic data do not ensure the true trend of pore pressure, fracture pressure and overburden pressure that will be encountered while drilling the well; however, these gradients will serve as a pre-guide for designing the drilling program of the well. Therefore, drilling a wildcat well demands an effective contingency plan and awareness of the drilling events during the operations.

1.2 Problem Statement

The source of data for the estimation of well gradients depends on the type of well to be drilled; for appraisal and developments wells, these gradients can be easily estimated from offset or reference wells; however, for explorative or wildcat wells, the estimation of well gradients is more difficult and uncertain, since no wells have been previously drilled in the area which could be taken as a reference to provide an insight about pressure distribution in the subsurface. The lack of knowledge about the formation pressures poses high drilling risk in terms of safety and operational cost. Furthermore, software used to predict well gradients such as Drillworks and WellCheck are not easily available obtaining a license for a given software suite is very expensive.

To resolve the aforementioned problems, a computer model that uses C++ programming language will be developed to estimate pre-drill well gradients (pore, fracture and overburden gradient) from seismic data (two-way time and average velocity).

1.3 Objectives

This study aims at achieving the following objectives:

- To develop C++ computer model for estimating well gradients (pore gradient, fracture gradient and overburden gradient) using seismic data (two-way time and average velocity) for wildcat wells;

- To validate the developed model with post-drill data.

1.4 Scope of Study

The scope of this project is to carry out the estimation of pre-drill well gradients (pore gradient, fracture gradient and overburden gradient) focused on wildcat wells using seismic data. This is necessary in areas with no drilling records from surrounding wells, that is, the field is completely new with no offset wells. Therefore, to drill a wildcat well, it is necessary to predict and estimate the pore, fracture and overburden pressure of the formation so that drilling risk will be minimized. The estimation of gradients for wildcat drilling will rely on seismic data which are obtained from the field of interest.

CHAPTER 2

2. LITERATURE REVIEW

2.1 The relevance of formation pressure in well planning

Banik and Wagner (2014) have stressed that the knowledge about formation pressure is vital in well planning; because it allows the drilling engineer to design a safe mud weight which is below the fracture gradient in order not to fracture the formation and lose the drilling fluid into the formation. On the other hand, a safe mud weight should be designed above the pore pressure gradient, so that formation fluids will not flow into the wellbore (kick) which can eventually culminate in a blowout if the kick is not controlled (Narciso, 2014).

Pore pressure can be defined as the pressure due to the fluids contained in the pores within the formation, and usually expressed in terms of a gradient or density. The pore pressure can be normal (1.03 – 1.07 $Kg/cm^2/10m$ or 0.447 – 0.464 psi/ft) or abnormal. Abnormal pore pressures are pressures that fall above (overpressures) or below (underpressure) the normal pore pressure range as defined by Brahma, Sircar and Karmakar (2013). Overpressures are a major concern in drilling operations since drilling through these zones is troublesome and requires effective well control. Another important component of well gradient is the fracture pressure, which is the pressure that causes the formation to fracture which is also commonly expressed as the fracture gradient. According to Haiz and Zausa (2013), exceeding the fracture gradient leads to fracturing the formation and eventually incurs lost circulation. The pore pressure and fracture pressure establish the drilling window in which the mud weight will be effectively designed to walk above the pore pressure (avoid kick) and below the fracture pressure so that the formation will not fracture and lose drilling mud. The overburden pressure is the total vertical pressure made up of pressures due to fluid and rock matrix.

Pre-drill well gradients estimation involves estimating the pore pressure gradient, fracture pressure gradient and overburden gradient before the well is drilled in a given area. As stated by Godwin (2013), if offset wells are available in the vicinity, then offset data such as well logs can be used to predict the formation pressure in the new well to be drilled. However, if the well to be drilled is a wildcat, this entails that area is new and no wells have been drilled before in the surrounding; thus, little knowledge is known about the pressure in the subsurface. Therefore, the only method to estimate the well gradients (pore gradient, fracture gradient and overburden gradient) will rely on seismic data which involves using two-way time and average velocity (Francis, 2013 & Banik et al, 2013)

According to Suwannasri et al (2013), drilling through overpressured zones is quite problematic, thus it can lead to well control incidents such as influx of formation fluids into the well, which can potentially result in a blowout if the drilling crew fails to control the influx. The prediction of pore pressure is relatively easy for formations having normal pore pressure gradient (1.03 – 1.07 $Kg/cm^2/10m$ or 0.447 – 0.464 psi/ft). However the estimation of formation pore pressure in geopressured (overpressured) zones is critical and relevant. Furthermore, knowledge about well gradients is important for well planning as it provides the drilling engineer key information for designing the mud weight and casing program of the well. With a safe mud weight, one is able to drill through overpressured zones and zones with wellbore instability without incurring severe problems, thus allowing the well to be completed effectively (Pervukhina, et al, 2013). On the other hand, a well-designed mud weight based on accurate estimation of pore pressure and fracture pressure, can greatly reduce the chances of having well control related issues such as influx, blowouts and lost circulation, as well as avoid drilling events such stuck pipes, packoff and wellbore collapse. When fewer problems are encountered during drilling operations, this gives the operator an opportunity to achieve the target in a cost-effective manner (Kumar, Niwas & Mangaraj, 2012).

The study conducted by Chatterjee, Mondal and Patel (2012) emphasizes that the need for an accurate estimation of well gradients is substantial; hence, in order to predict pore pressure in overpressured zones, it is first necessary to have a background understanding with regard to how overpressures are generated. The understanding of formation pressure helps identify drilling hazards encountered when drilling through overpressured zones. Overpressures are more critical and cause more problems in drilling operations if not addressed properly. Yan and Han (2012) and Li, George and Purdy (2012) both studies explained that the origin of overpressure is due to rapid deposition of sediments which preclude sufficient time for pore fluids to escape. As a result, the pore fluids become trapped in the pores due to a phenomenon termed undercompaction. These trapped fluids build high pressures within the pore spaces in which they are trapped and when intercepted during drilling operations, high pressure fluids will be released, hence increasing the likelihood of having an influx if the mud weight is less than formation pore pressure (O'Connor et al, 2011)). Figure 1 below shows the process of undercompaction and how overpressures are generated due to rapid sediment deposition.

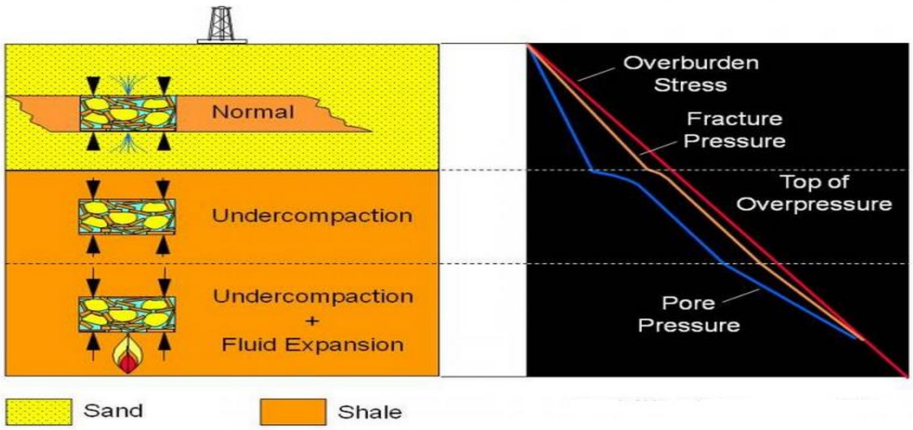


Figure 1: Overpressure generation due to undercompaction [14]

Dutta (2012) demonstrated that the understanding of the concepts behind pore pressure, overburden pressure and fracture pressure is essential for designing a safe mud weight, cementing program and casing program, while preventing wellbore instability and ensuring better well control. Figure 2 below shows pore, fracture and overburden gradient and the mud gradient used to drill the well, as well as predicting the critical drilling problems that are likely to be encountered.

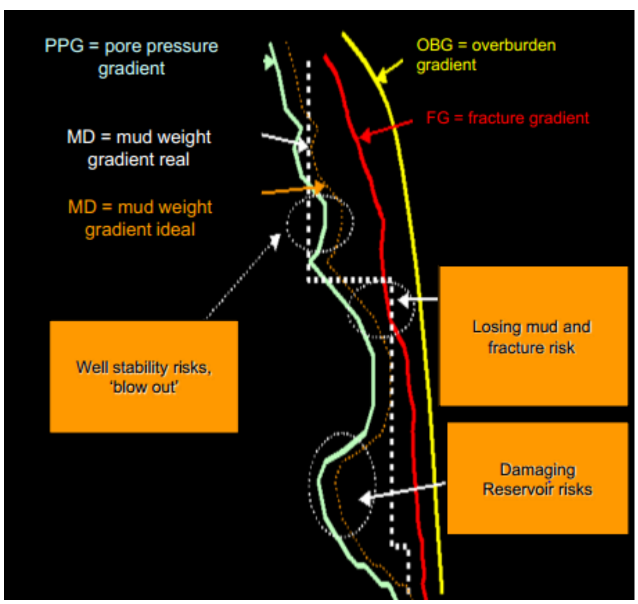


Figure 2: Use of well gradients for proper mud weight design [15]

2.2 Use of seismic data for estimating well gradients

A good prediction of well gradients will enable the operator to decrease the risk and cost associated to drilling operations. This is done by properly designing an effective mud weight and casing program, hence resulting in high drilling efficiency and performance while ensuring safe drilling. By using seismic data to estimate well gradients, it has been studied that seismic interval velocity can accurately predict pore pressure and the onset of overpressure of a given geological formation (Babu & Sircar, 2011). The relation between interval velocity and pore pressure is shown in Figure 3 below.

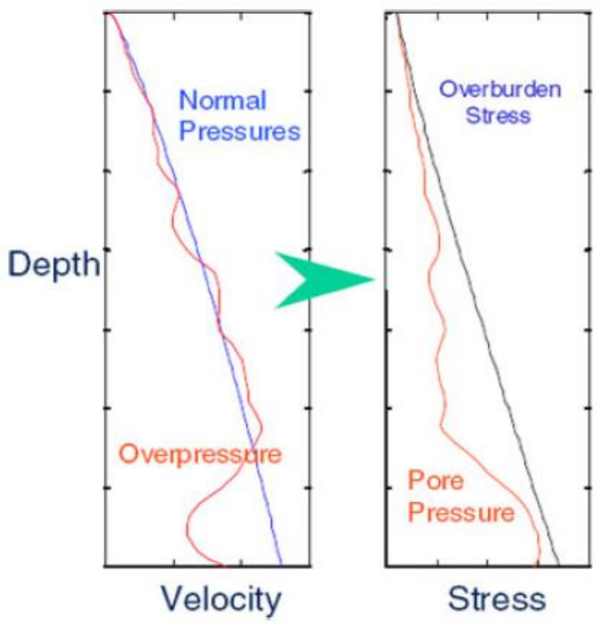


Figure 3: Relationship between interval velocity and pore pressure, and overpressured zones identification [16]

The pre-drill well gradients estimation is essential when considering the drilling of a wildcat well where no data from offset wells are available in order to assist the prediction of formation pressures. In this case, we rely on seismic data, which include two-way time and average velocity acquired during seismic survey. The two-way time and average velocity to estimate the seismic interval velocity in a mathematical relation provided Dix (Rabinovich, 2011).

$$V_N^2 = \frac{(V_{2,rms}^2 \cdot t_{N,2} - V_{1,rms}^2 \cdot t_{N,1})}{(t_{N,2} - t_{N,1})} \quad \textbf{(2.1)}$$

Where V_N is the interval velocity estimated from two-way time and average velocity.

According to Zhang (2011), the interval velocity can further be used to estimate parameters such as interval transit time, depth interval and depth reference which aid towards the process of estimating the well gradients. Although seismograms are used mainly by geophysicists and geologists for subsurface structural and lithological interpretation, since the beginning of the 1970's they have also become of great interest and help to the drilling engineers. In fact, two of the most important applications of seismic data for drilling purposes consist in detecting formations characterized by geopressures (overpressures) and provide an estimation of pore pressure gradient, overburden gradient and fracture gradient. Experience has shown that when good seismic data are available and proper interpretation is performed, it is possible in most cases to locate the overpressure tops and estimate the well gradients. Naturally, the determination of fracture gradients is strictly dependent on the quality of pore pressure gradients evaluation since better approximations are obtained in the calculation of overburden gradients (Shykhaliyev, 2010). The ultimate objective is to predict the pore pressure gradient, fracture pressure gradient and overburden gradient from seismic interval velocity through a transformation model as shown below.

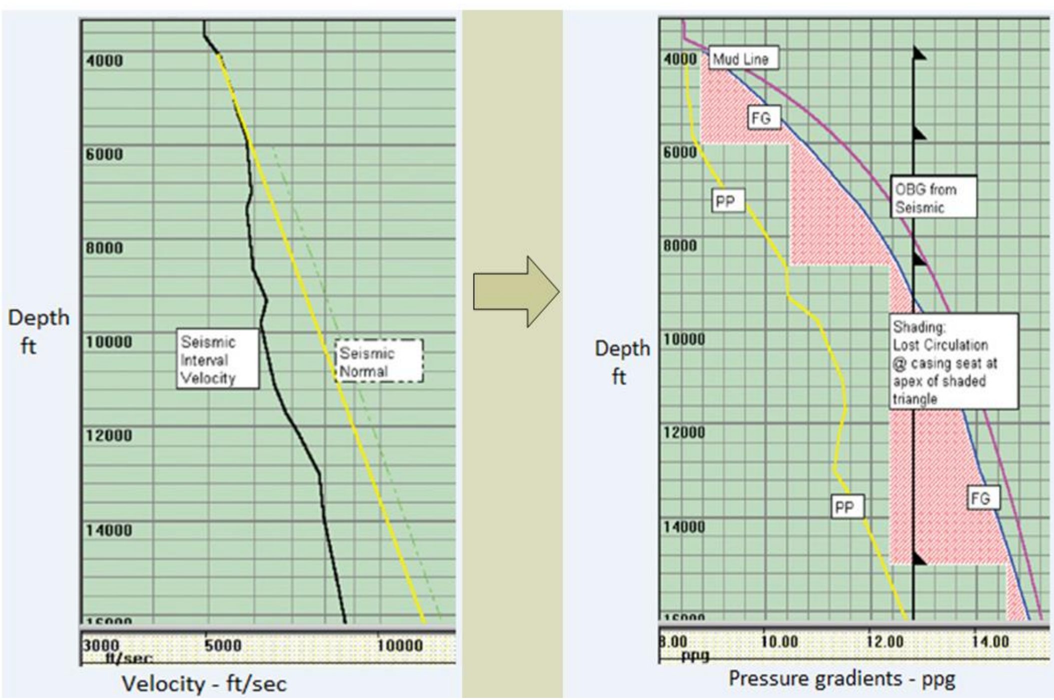


Figure 4: Transformation of seismic interval velocity to well gradients [20]

CHAPTER 3

3. METHODOLOGY

The estimation of pore gradient, fracture gradient and overburden gradient from seismic data will be achieved by using C++ programming. Three (3) sets of seismic data comprising of two-way time and average velocity will be used to estimate and plot various 6 sets well gradients using C++, and then validated with post-drill data.

A workflow for carrying out the estimation of overburden gradient, pore gradient and fracture gradients is given as follows:

3.1 Overburden gradient estimation

i. From seismic data, obtain two-way time (TWT) and average velocities (v_m) [m/s]

ii. Compute the interval velocity (v_i) [m/s]

$$v_i = \sqrt{\frac{v_{m2}^2 t_2 - v_{m1}^2 t_1}{t_2 - t_1}} \quad \textbf{(3.1)}$$

iii. Compute the transit time (Δt) [μs/ft]

$$\Delta t = \frac{304800}{v_i} \quad \textbf{(3.2)}$$

iv. Calculate the depth intervals (Δh) [m]

$$\Delta h = \left(\frac{t_2 - t_1}{2}\right) v_i \quad \textbf{(3.3)}$$

v. Compute the depth reference (Hi) [m]

$$H_i = \sum_i \Delta h \quad \textbf{(3.4)}$$

vi. Calculate the average density between two reflectors

$$\delta_{sed} = \delta_{max} - 2.11 \left(\frac{1 - {v_i}/{v_{max}}}{1 + {v_i}/{v_{min}}} \right) \quad \textbf{(3.5)}$$

From field practice, $\delta_{max} = 2.75\ g/cm^3$, $v_{max} = 7000\ m/s$, $v_{min} = 1500\ m/s$

vii. Compute the pressure applied by the overlaying sediment column for each considered depth interval [kg/cm^2]

$$p_{ovb}^{1} = \frac{\delta_{sed}^{1} \times \Delta z^{1}}{10} \quad \textbf{(3.6)}$$

viii. Sum of the pressures applied by the different intervals for integrated sediment pressure calculation [kg/cm^2]

$$p_{ovb}^{n} = \frac{\delta_{sed}^{1} \times \Delta z^{1}}{10} + \frac{\delta_{sed}^{2} \times \Delta z^{2}}{10} + \frac{\delta_{sed}^{3} \times \Delta z^{3}}{10} \ldots\ldots \frac{\delta_{sed}^{n} \times \Delta z^{n}}{10} \quad \textbf{(3.7)}$$

ix. Estimate the overburden gradient (G_{ovb}) [kg/cm^2/10m]

$$G_{ovb} = \frac{p_{ovb} \times 10}{z} \quad \textbf{(3.8)}$$

3.2 Pore pressure gradient estimation

The estimation of pore pressure gradient has the following workflow using the Equivalent Depth Method, in which the transit time is plotted against depth on semi-log graph:

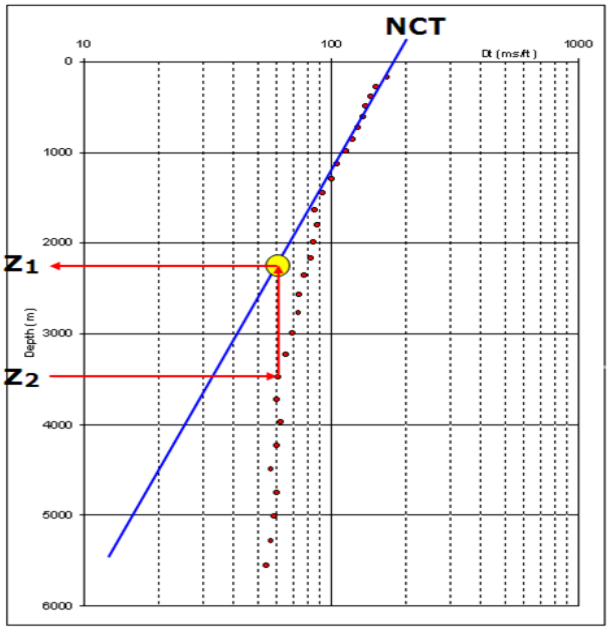


Figure 5: Equivalent depth interpretation with transit time (Δt) [21]

i. Define the Normal Compaction Trend (NCT)

ii. Choose the depth at which the pore gradient (assumed overpressured) will be calculated

iii. Draw a vertical line from the chosen depth (point 2) until Normal Compaction Trend is reached (point1). The depths at point 2 and point 1 have the same effective pressure

iv. Determine the overburden pressure gradient of the two chosen points

v. Calculate the effective pressure of point 1, given overburden and pore pressure gradients

$$p_{eff}^{1} = p_{eff}^{2} = \frac{\left(G_{ovbd} - G_{p}\right) \times z_{1}}{10} \tag{3.9}$$

vi. Calculate the overburden pressure at point 2

$$p_{ovbd}^{2} = \frac{G_{ovbd} \times z_{2}}{10} \tag{3.10}$$

vii. Calculate pore pressure at point 2 from the difference between overburden and effective pressure calculated at step 5

$$p_{p}^{2} = p_{ovbd}^{2} - p_{eff}^{2} \tag{3.11}$$

viii. Calculate the pore pressure gradient

$$G_{p}^{2} = \frac{p_{p}^{2} \times 10}{z_{2}} \tag{3.12}$$

3.3 Fracture pressure gradient estimation

The estimation of fracture pressure gradient is carried out by using Eaton's correlation as shown below.

$$G_{frac} = G_{p} + \frac{\nu}{1-\nu}\left(G_{ovbd} - G_{p}\right) \tag{3.13}$$

Where G_{frac} – Fracture gradient (kg/cm²/10m)

G_p – Pore gradient (kg/cm²/10m)

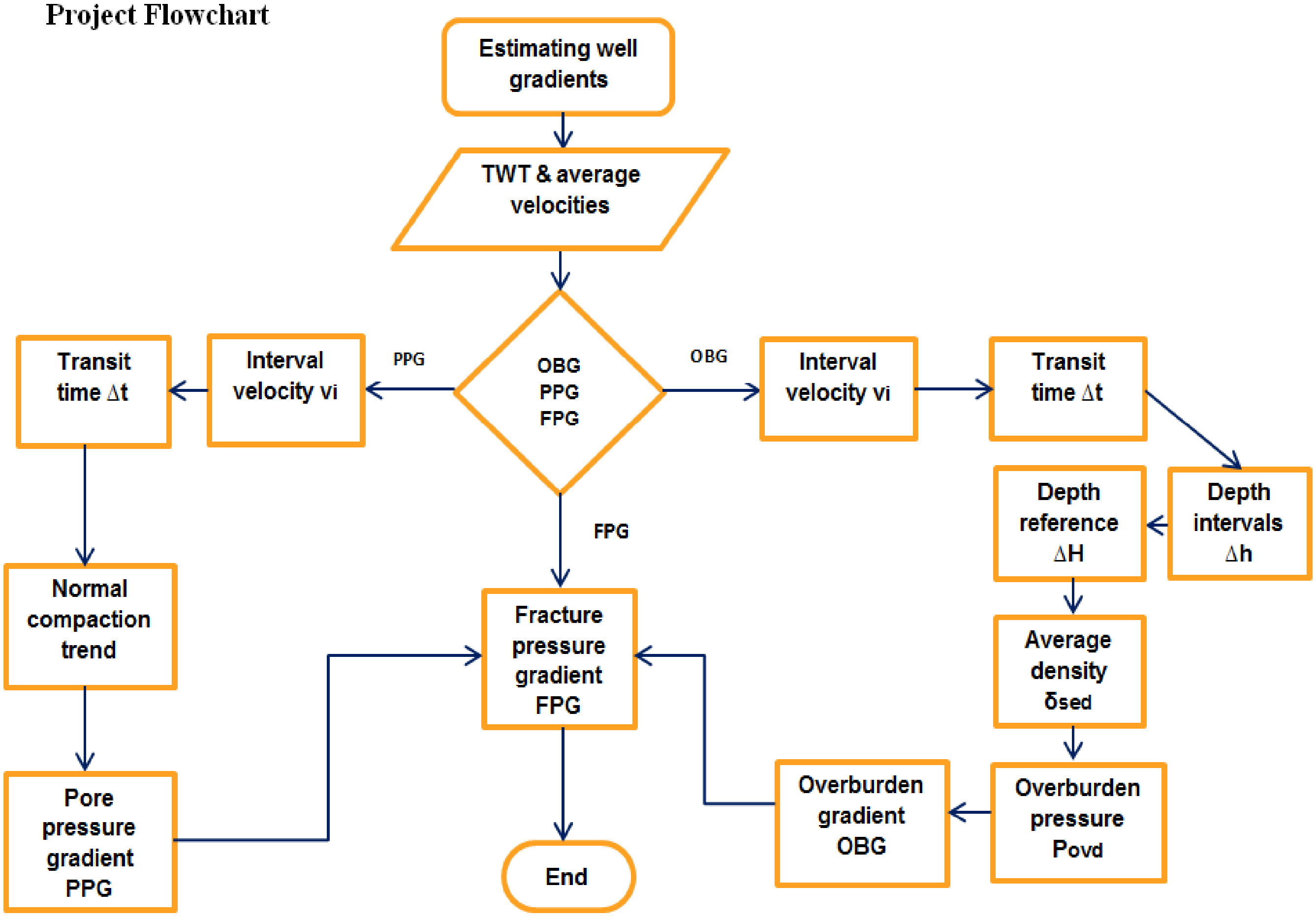
G_{ovbd} – Overburden gradient (kg/cm²/10m)

v – Poisson's Ratio

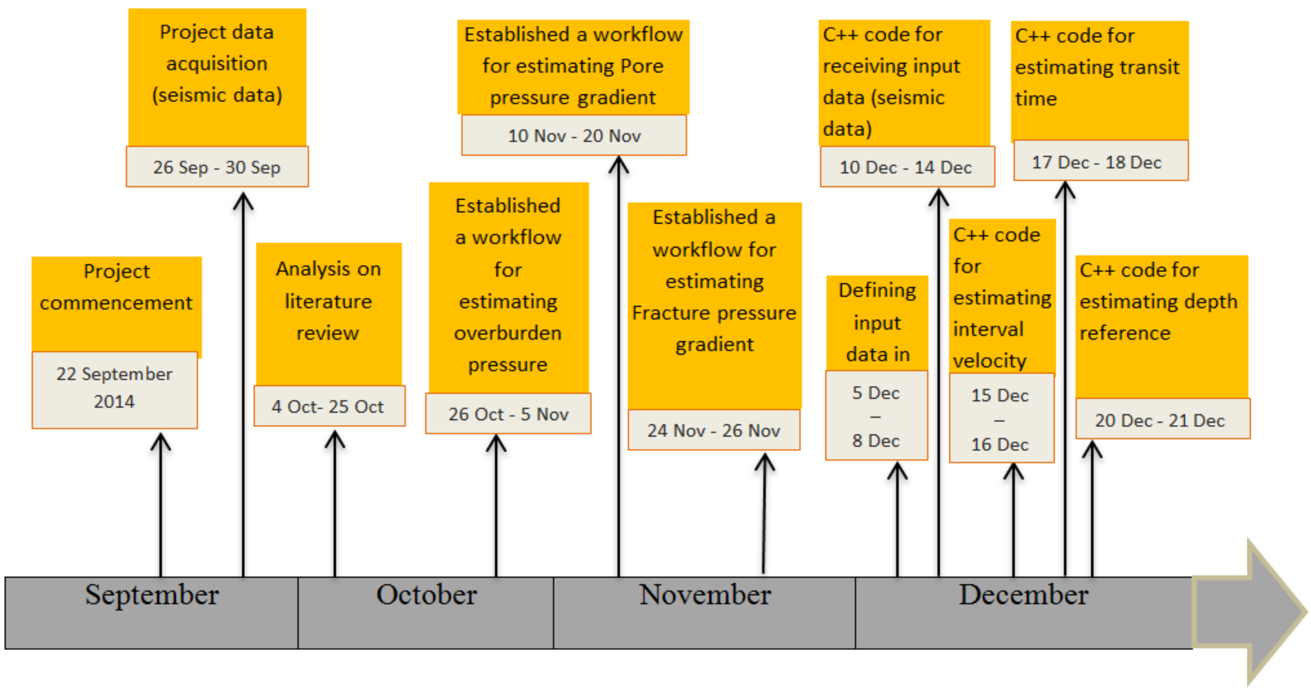
Traditionally, the Poisson's Ration value commonly used is 0.4. Therefore, the fracture gradient equation (eq. 3.13) can further be written as follows:

$$G_{frac} = \frac{2}{3}\left(G_{sed} - G_p\right) + G_p \qquad \textbf{(3.14)}$$

Project Flowchart



KEY MILESTONES



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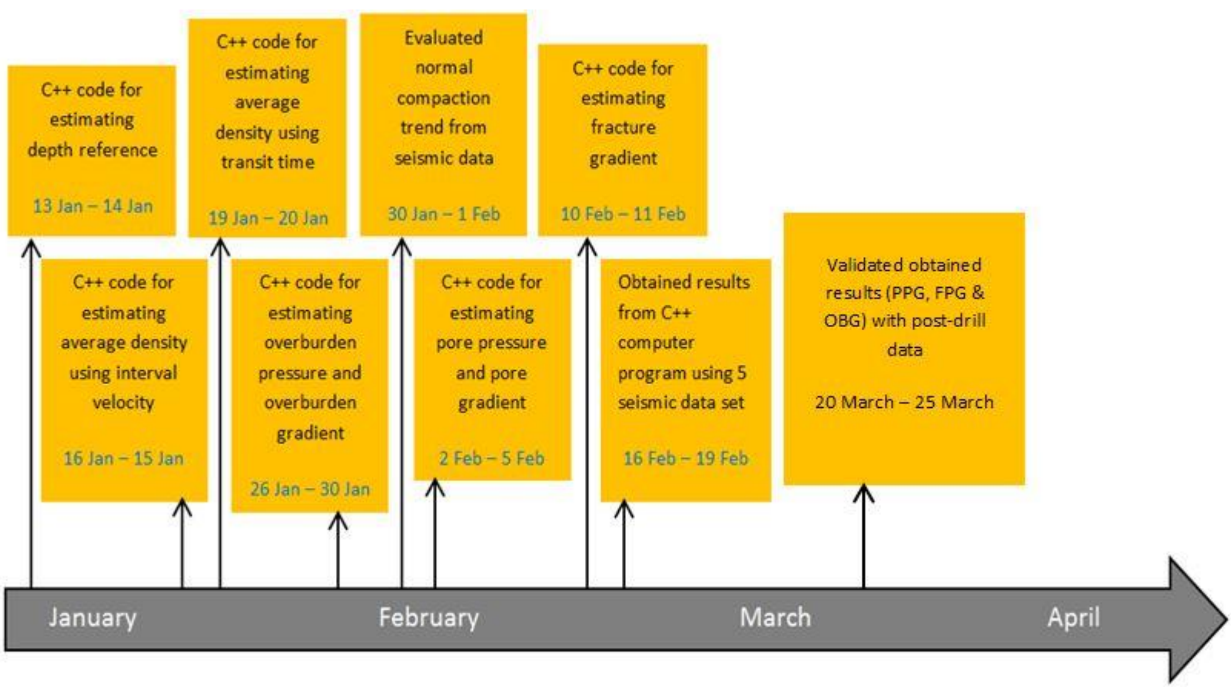

2015

Gantt chart

Activities/Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1.Selection of project topic (Pre-drill well gradients estimation using seismic data)																												
2.Research on past studies about the topic and write literature review																												
3.Data acquisition and propose project methodology																												
4.Workflow for estimating overburden gradient, pore pressure gradient and fracture gradient																												
5.Start building the model using C++ and define the input data																												
6.Write C++ code to estimate interval velocity, transit time and depth intervals																												
7. C++ code to estimate reference depth, average density, overburden pressure and gradient																												
8. Evaluate normal compaction trend from seismic data, & write C++ code to estimate pore pressure, pore gradient fracture pressure and fracture gradient																												
9. C++ code to plot pore, fracture, and overburden gradient, and run several sets of seismic data for different wells and plot well gradients																												
10. Validate well gradients from seismic data with post-drill data																												

- Completed

CHAPTER 4

4.0 RESULTS AND DISCUSSION

Seismic data (two-way time and average velocity) were used as input data for estimating well gradients (pore gradient, fracture gradient and overburden gradient). A computer code which uses C++ language is being developed to provide a model that carries out the estimation of well gradients from seismic data.

The computer program prompts the user to provide the input data (seismic data) and then estimates various parameters mathematically and the end result is to compute the well gradients and present their respective plots.

Below in Figure 6 is shown the interface of C++ program prompting the user to provide the input data (two-way time (s) and average velocity (m/s)). Input data from Data Set #1 were used to compute all the parameters that lead to the final estimation of well gradients.

```
===============================================================
Welcome to Pre-Drill Well Gradients Estimation using Seismic Data
===============================================================

Please enter the two-way time (s), 10 entries are required:

 twt1:  0.04
 twt2:  0.47
 twt3:  0.7
 twt4:  1.04
 twt5:  1.2
 twt6:  1.73
 twt7:  2.2
 twt8:  3.73
 twt9:  5
 twt10: 8


Now enter the average velocities (m/s) recorded at each two-way time:

 v1:  1700
 v2:  1860
 v3:  1890
 v4:  2090
 v5:  2190
 v6:  2540
 v7:  2940
 v8:  3740
 v9:  4000
 v10: 5300
```

Figure 6: C++ user interface prompting the user to provide input data (seismic data)

Once the user has provided the input data (two-way time and average velocity, the program carries out the estimation of the first key parameter which is interval velocity (m/s); upon the estimation of interval velocity, the next parameter to be estimated is the transit time (Δt – μs/ft) which depends on interval velocity. Futhermore, depth intervals which are mathematically related to two-way time and interval velocity are also estimated and the results are presented in Table 4.1 below

Table 4.1 Estimated interval velocity, transit time and depth interval

No of input data	Interval velocity(m/s)	Transit time (μs/ft)	Depth interval (m)
1	1700	179.3	34
2	1874.2	162.6	403
3	1949.9	156.3	224.2
4	2450.9	124.4	416.7
5	2752.8	110.7	220.2
6	3193.7	95.4	846.3
7	4088	74.6	960.7
8	4655.3	65.5	3561.3
9	4680.9	65.1	2972.4
10	6545.5	43.9	10418.3

Estimated interval velocity, transit time and depth interval from C++

In the same process, the estimation of cumulative depth, average density using interval velocity and average density using transit time is performed. The results are shown in table 4.2 below.

Table 4.2 Estimated cumulative depth and average density

No of input data	Cumulative depth (m)	Average density using interval velocity (g/cc)	Average density using transit time (g/cc)
1	34	2.0	2.01
2	437	2.06	2.08
3	661.2	2.09	2.1
4	1077.8	2.23	2.25
5	1298	2.3	2.32
6	2144.4	2.38	2.4
7	3105	2.51	2.54
8	6647.2	2.58	2.6
9	9638.8	2.58	2.61
10	20057	2.75	2.78

Estimated cumulative depth, average density using interval velocity and transit time from C++

Furthermore, the pressure applied by the overlying sediment column for each depth interval, the overburden pressure applied by cumulative depth intervals and the overburden gradient were estimated as shown in Table 4.2 below.

Table 4.3 Estimated interval pressure, overburden pressure and overburden gradient

No of input data	Interval pressure (kg/cm^2)	Overburden pressure (kg/cm^2)	Overburden gradient ($kg/cm^2/10m$)
1	6.8	6.8	2.014
2	83.7	90.6	2.074
3	47.2	137.7	2.083
4	93.6	231.3	2.146
5	51	282.3	2.175
6	203.5	485.8	2.265
7	243.8	729.6	2.35
8	922.3	1652	2.485
9	779.3	2431	2.522
10	2893	5324	2.655

Estimated interval pressure, overburden pressure and overburden gradient from C++

On a similar process, the pore pressure, the pore gradient and fracture gradient were estimated from C++ and results are presented in Table 4.4 below.

Table 4.4 Estimated pore pressure, pore gradient and fracture gradient

No of input data	Pore pressure (kg/cm^2)	Pore gradient ($kg/cm^2/10m$)	Fracture gradient ($kg/cm^2/10m$)
1	3.5	1.03	1.69
2	45	1.03	1.72
3	68.1	1.03	1.73
4	111	1.03	1.77
5	162.1	1.25	1.87
6	337.2	1.57	2.03
7	464.7	1.5	2.07
8	1242	1.87	2.28
9	1464	1.52	2.19
10	3886	1.94	2.42

Estimated pore pressure, pore gradient and fracture gradient from C++

4.1 Plot of pore gradient, fracture gradient and overburden gradient with post-drill data

Three sets of seismic input data (two-way time and average velocity) with the corresponding post-drill data were provided. The well gradients (pore, fracture and overburden gradient) were estimated by keying in each set of seismic data into the developed C++ computer program. As seen above, prior to estimation of pore, fracture and overburden gradients, various parameters were estimated, however for this section, only the plots of the gradients against depth will be emphasized using different data set and compared with post-drill data for validation

Table 4.1.1 Results for data set #1

Data set #1		**Results**			
TWT	Vav	Depth	PG	FG	OBG
s	m/s	m	sg	sg	sg
0.04	1700	34	1.03	1.69	2.01
0.47	1860	437	1.03	1.72	2.07
0.7	1890	661	1.03	1.73	2.08
1.04	2090	1078	1.03	1.77	2.15
1.2	2190	1298	1.25	1.87	2.18
1.73	2540	2144	1.57	2.03	2.27
2.2	2940	3105	1.5	2.07	2.35
3.72	3740	6647	1.87	2.28	2.49
5	4000	9639	1.52	2.19	2.52
8	5300	20057	1.94	2.42	2.65

Estimated depth, pore gradient, fracture gradient and overburden gradient for data set #1

The plot of pore gradient, fracture gradient and overburden gradient as a function of depth is shown in Figure 7 with the corresponding post-drill pressure gradients.

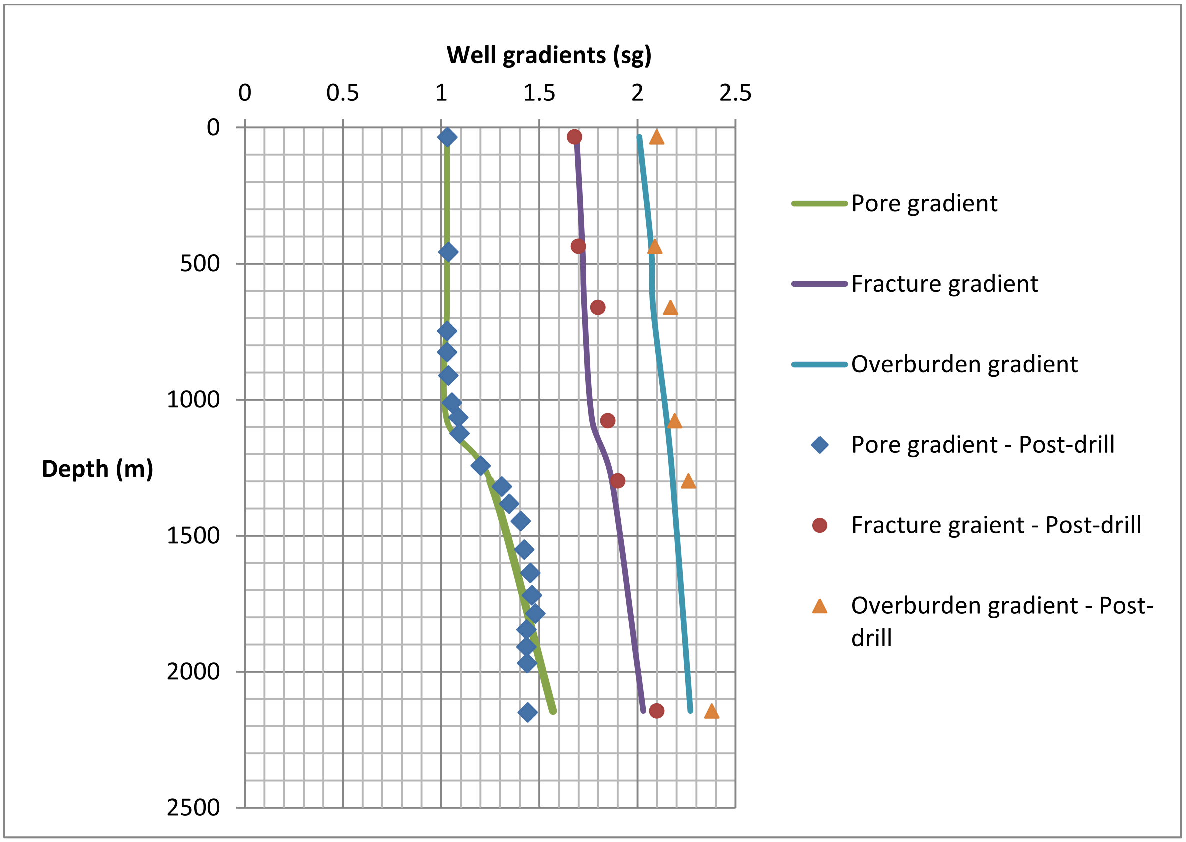

Figure 7: Comparison between pre-drill well gradients and post-drill well gradients for data set #1

In Figure 7 it is evident that the pre-drill well gradients matches closely with the post-drill gradient, this is desirable as it reduces the drilling risk when drilling wildcat wells using seismic data. This close match is attributed to the accuracy of seismic data which is a key requirement for better prediction. Furthermore, it can be observed that overpressure zones lie below 1000 m, which matches excellently between the predicted pore gradient and post-drill pore gradient. This accurate prediction is crucial for enhancing drilling efficiency and reducing well control incidents.

Table 4.1.2 Results for data set #2

Data set #2		Results			
TWT	Vav	Depth	PG	FG	OBG
s	m/s	m	sg	sg	sg
0.04	1650	33	1.03	1.67	1.99
0.51	1900	484	1.03	1.73	2.09
0.83	2000	828	1.03	1.76	2.12
1.03	2070	1062	1.03	1.77	2.14
1.25	2200	1362	1.31	1.89	2.18
2.05	3100	3014	1.86	2.21	2.38
2.4	3325	3787	1.35	2.06	2.42
3.55	3900	6597	1.71	2.24	2.51
8	4000	15671	1.9	2.32	2.52
9.5	5500	23402	1.65	2.32	2.65

Estimated depth, pore gradient, fracture gradient and overburden gradient for data set #2

Figure 8 shows the plot of well gradients with the corresponding post-drill pressure gradients.

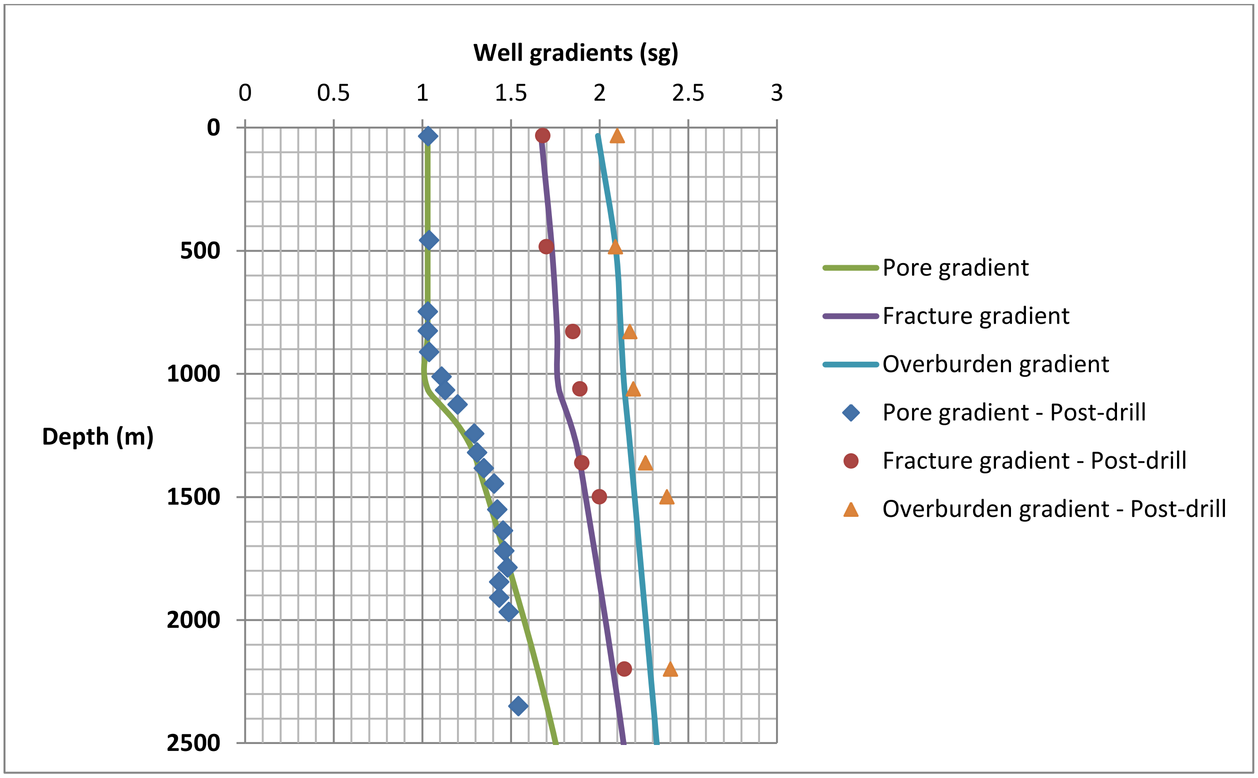

Figure 8: Comparison between pre-drill well gradients and post-drill well gradients for data set #2

The pre-drill pore pressure in Figure 8 compares closely with the post-drill pore pressure gradient, and the overpressure is accurately predicted to lie below 1000m. However, at depth of about 2350 m the pre-drill pore pressure has been overestimated, on the other hand the predicted fracture gradient is slightly lower than the post-drill fracture gradient, hence, the overestimation in pre-drill pore gradient would not cause any problem since the mud weight would still be lower than the actual fracture gradient, and no formation fracture would occur.

Table 4.1.3 presents the results of pore gradient, fracture gradient and overburden gradient obtained from pre-drill analysis using seismic data set #3

Table 4.1.3 Results for data set #3

Data Set #3		**Results**			
TWT	Vav	Depth	PG	FG	OBG
s	m/s	m	sg	sg	sg
0.04	1600	32	1.03	1.66	1.97
0.34	1750	297	1.03	1.7	2.03
0.65	1850	600	1.03	1.72	2.07
0.89	2000	883	1.03	1.76	2.12
1.45	2320	1654	1.63	2.02	2.21
1.7	2500	2074	1.31	1.94	2.26
2	2600	2540	1.28	1.95	2.28
2.3	3000	3274	1.39	2.03	2.36
3.4	3300	5393	1.61	2.15	2.42
4.3	3600	7444	1.46	2.13	2.47

Estimated depth, pore gradient, fracture gradient and overburden gradient for data set #3

Figure 9 shows the plot of well gradients with the corresponding post-drill pressure gradients.

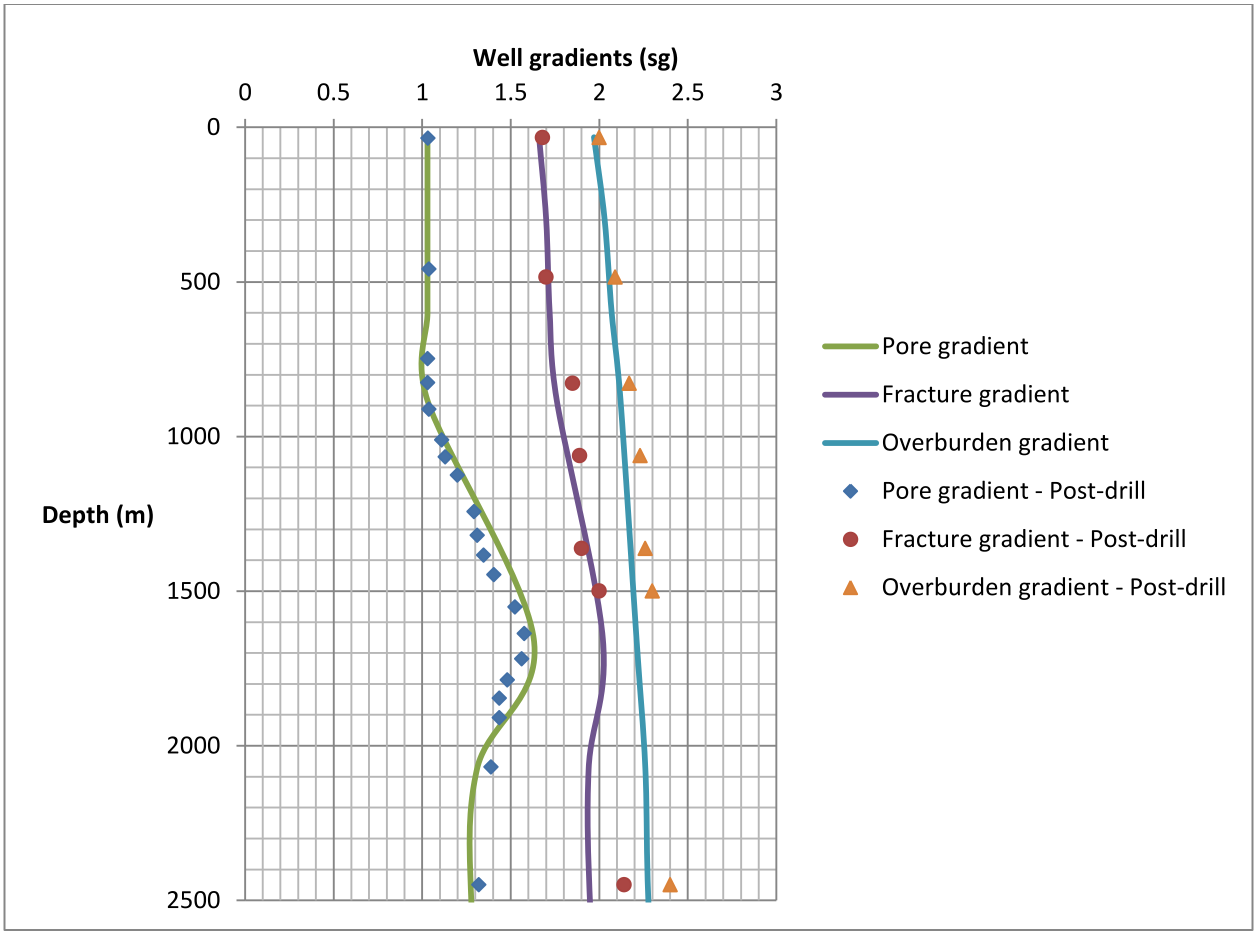

Figure 9: Comparison between pre-drill well gradients and post-drill well gradients for data set #3

For Figure 9, the pre-drill pore pressure gradient has been slightly overestimated from 1200m to 1900m. However this slight overestimation would not pose critical drill problems provided that the pre-drill fracture gradient lies below the post-drill fracture gradient and therefore no fluid loss (formation fracture) would occur.

Figure 10 shown below presents the plot between the pre-drill pore gradient and post-drill pore gradient.

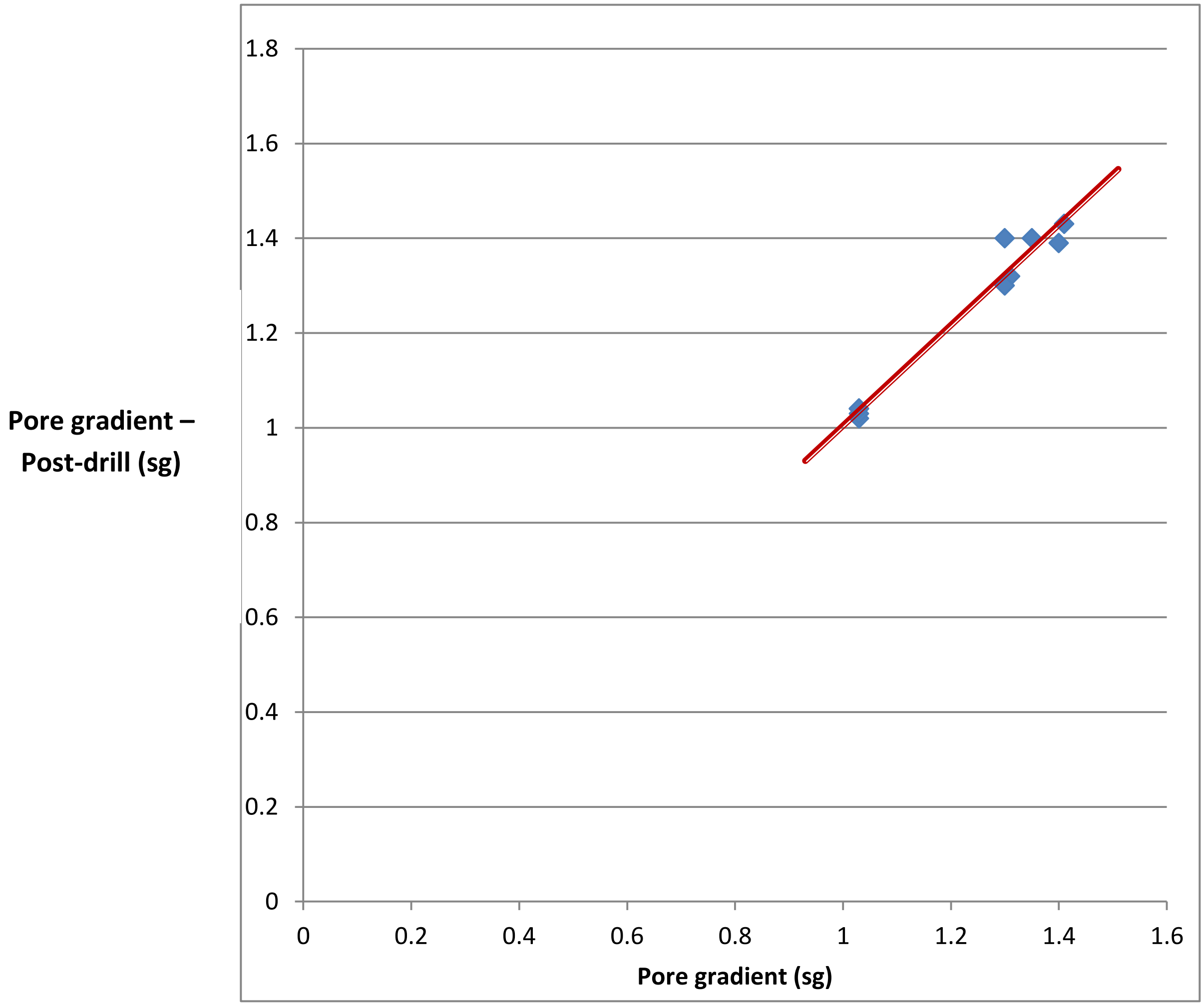

Figure 10: Cross plot between the pre-drill pore gradient and post-drill pore gradient for data set #1

From Figure 10 it is observed that the pre-drill pore gradient compares quite closely to the post-drill pore gradient, therefore the model accurately predicts the pressure gradients as shown in the previous graphs. The key factor for accurate prediction of well gradients is mostly dependent on the accuracy of seismic data employed.

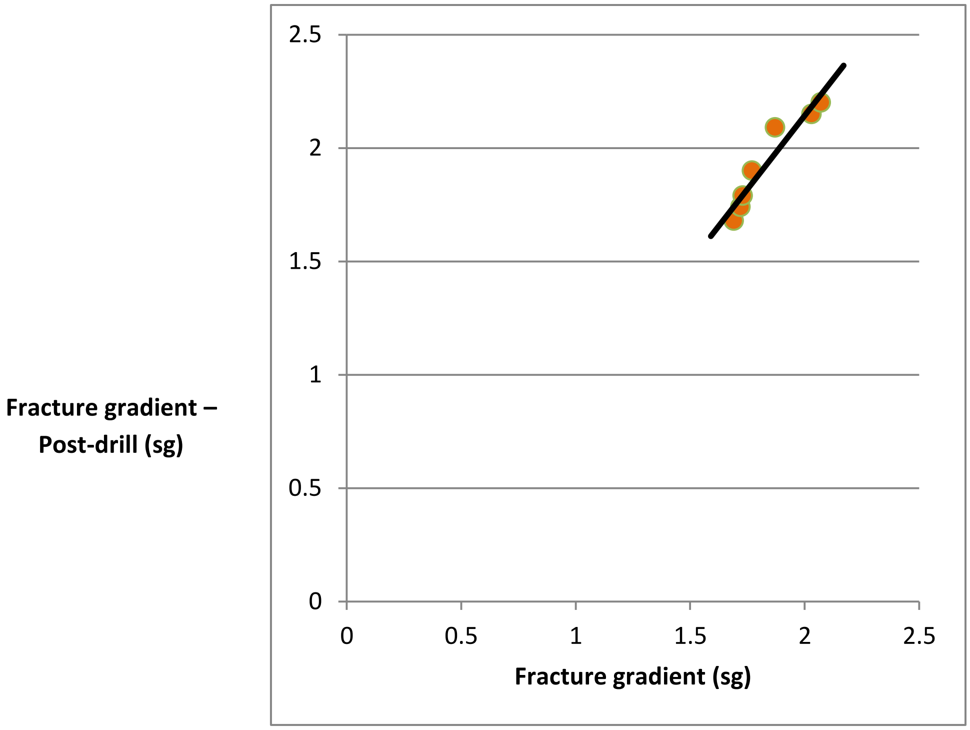

Figure 11: Cross plot between the pre-drill fracture gradient and post-drill fracture gradient for data set #1

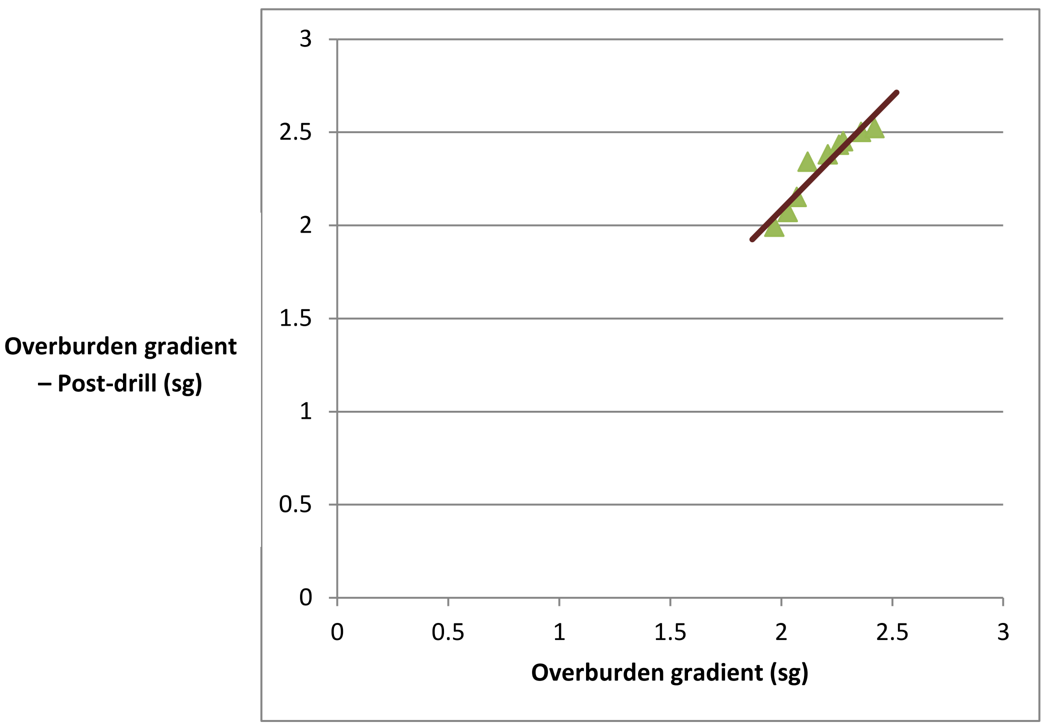

Figure 12: Cross plot between the pre-drill overburden gradient and post-drill overburden gradient for data set #1

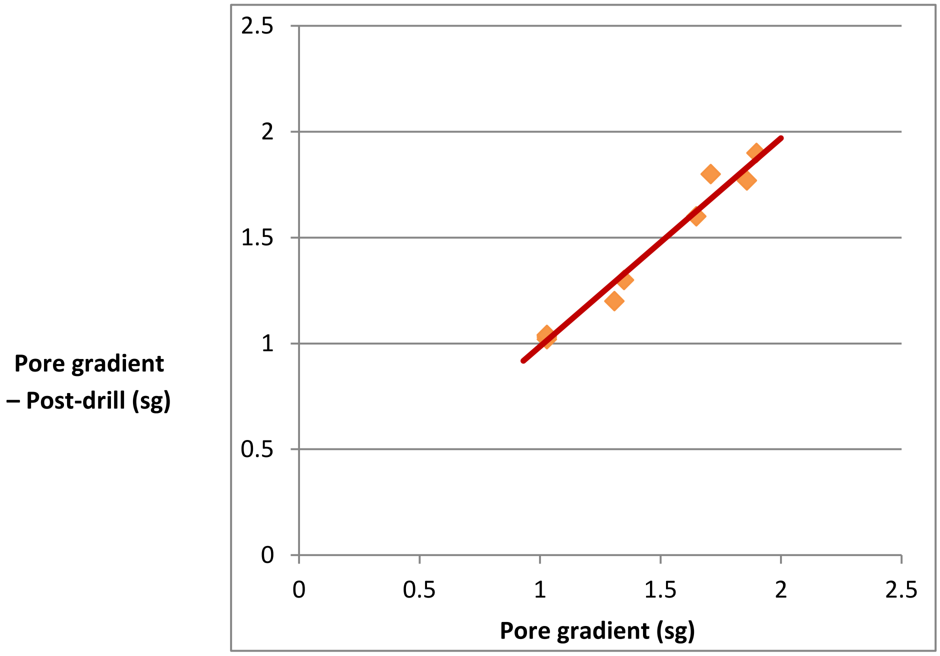

Figure 13: Cross plot between the pre-drill pore gradient and post-drill pore gradient for data set #2

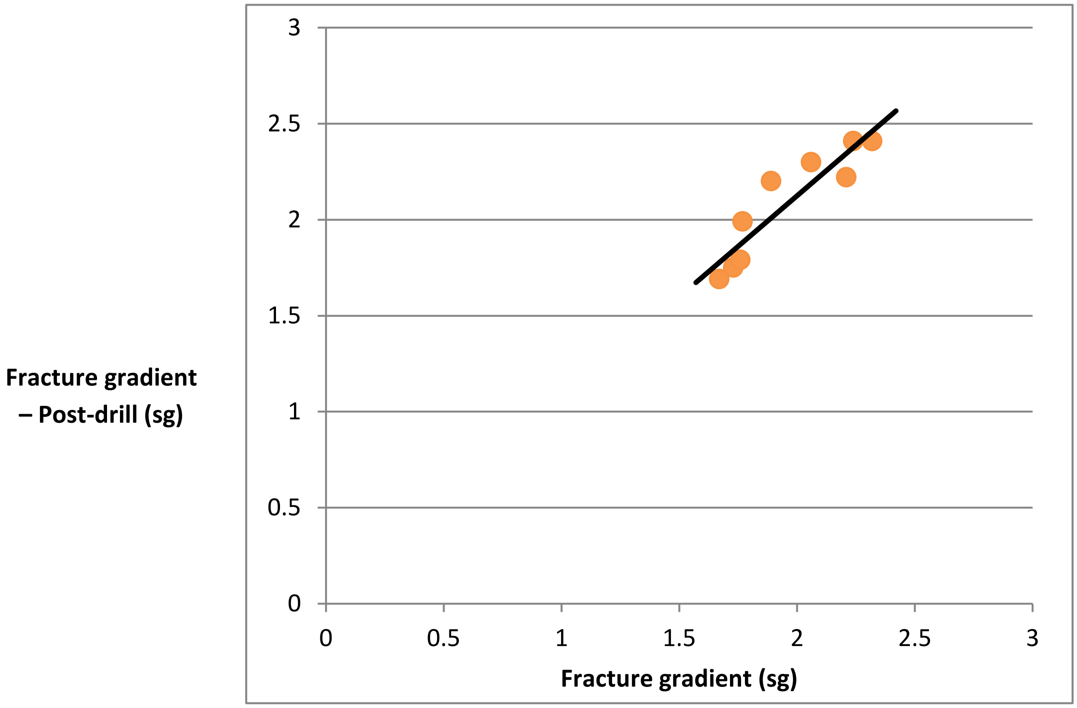

Figure 14: Cross plot between the pre-drill fracture gradient and post-drill fracture gradient for data set #2

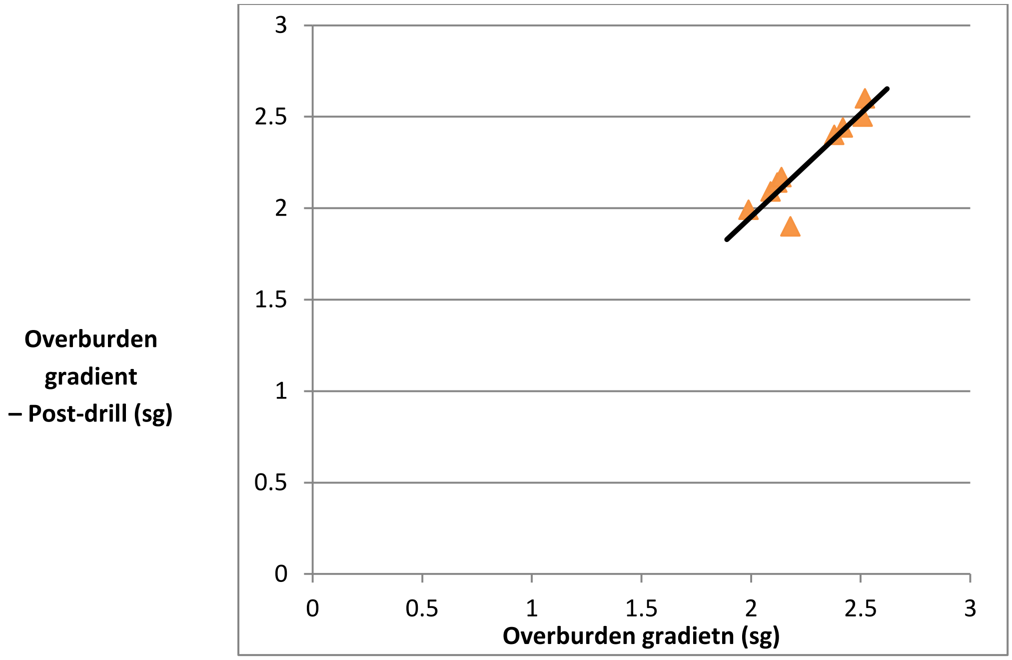

Figure 15: Cross plot between the pre-drill overburden gradient and post-drill overburden gradient for data set #2

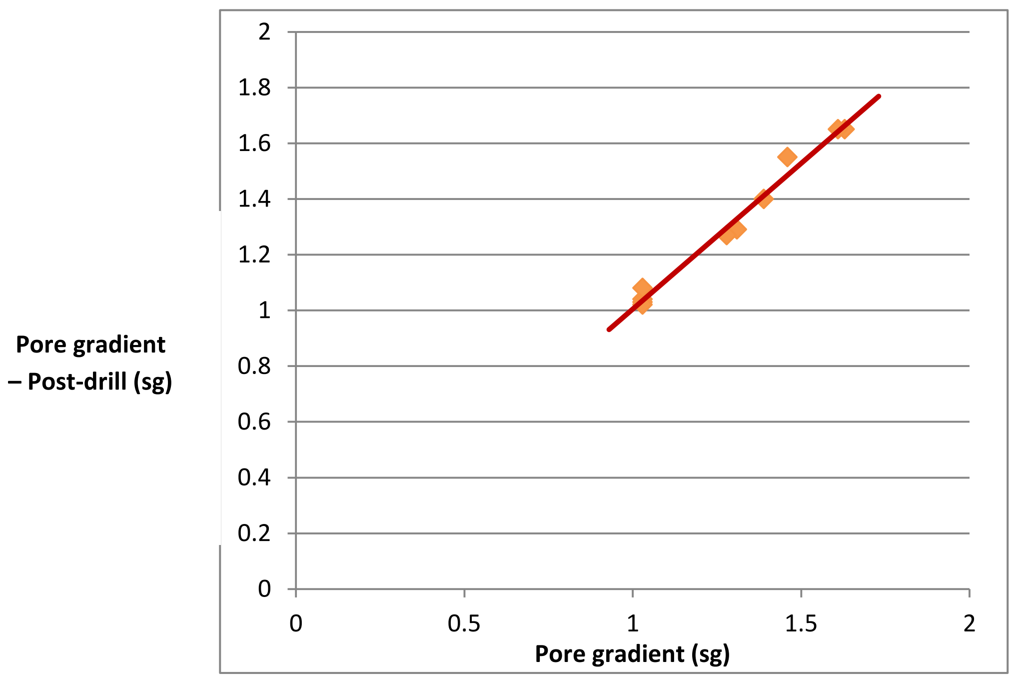

Figure 16: Cross plot between the pre-drill pore gradient and post-drill pore gradient for data set #3

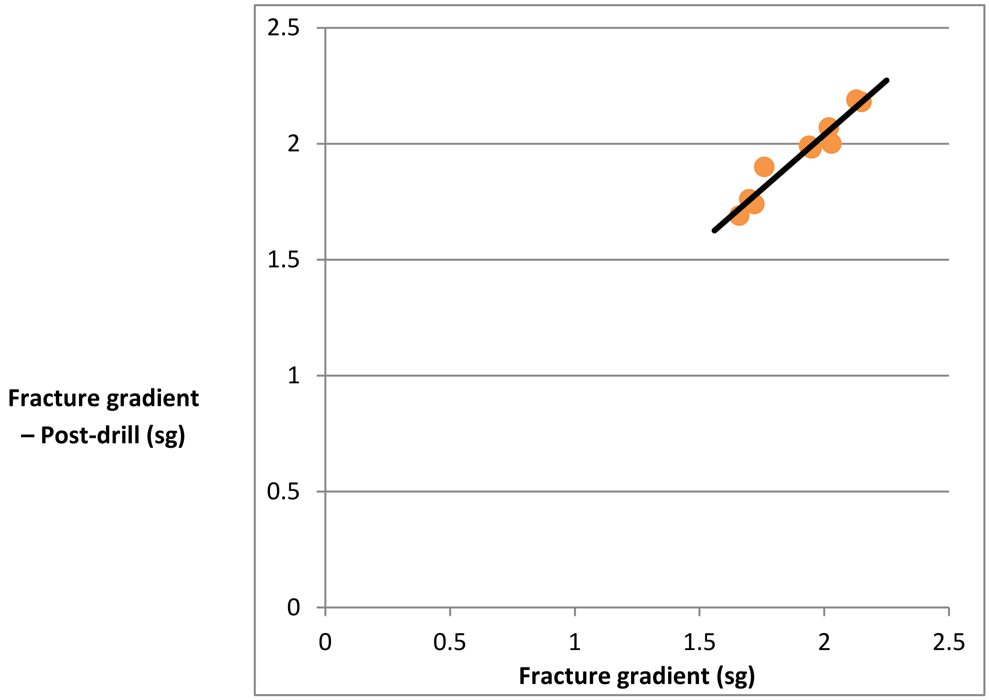

Figure 17: Cross plot between the pre-drill fracture gradient and post-drill fracture gradient for data set #3

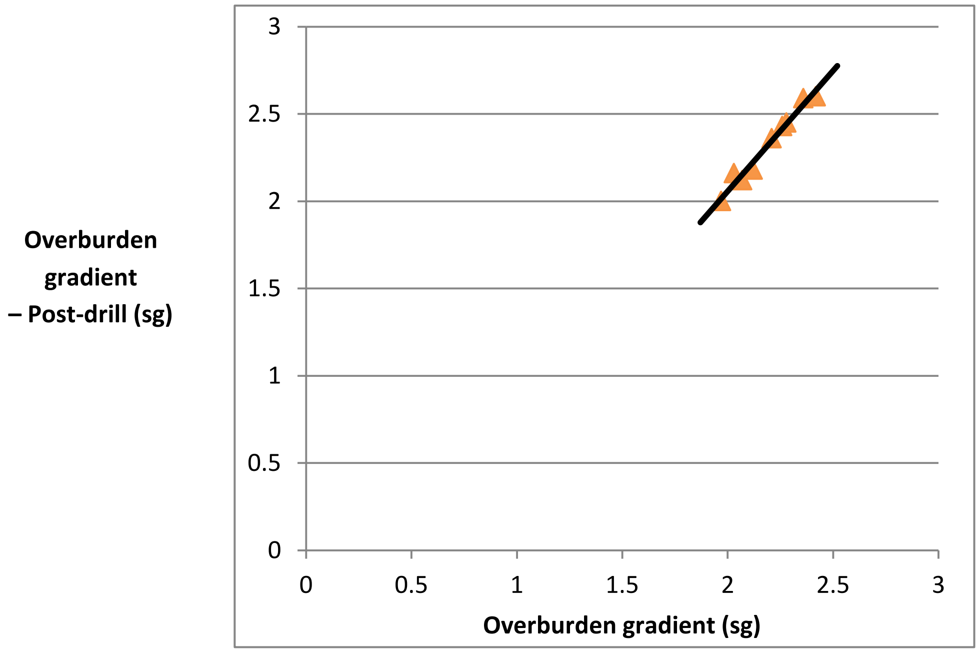

Figure 17: Cross plot between the pre-drill overburden gradient and post-drill overburden gradient for data set #3

4.2 Mean absolute percent error (MAPE)

$$M = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \qquad (4.2.1)$$

Where A_t is the actual value (post-drill gradient value) and F_t is the forecast value (pre-drill gradient value).

Data set#1

Pore gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 4.64\%$$

Fracture gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 5.78\%$$

Overburden gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 5.31\%$$

Data set#2

Pore gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 4.98\%$$

Fracture gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 5.46\%$$

Overburden gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 6.14\%$$

Data set#3

Pore gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 5.74\%$$

Fracture gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 6.23\%$$

Overburden gradient

$$M = \frac{1}{10}\sum_{t=1}^{10}\left|\frac{A_t - F_t}{A_t}\right| = 6.07\%$$

The cross plots between pre-drill well gradients and post-drill well gradients show an excellent prediction made from pre-drill analysis, and the mean absolute percent error for all cases is relatively small as calculated above. The model developed from C++ proved to be an efficient tool for an effective estimation of pre-drill gradients using seismic data (two-way time and average velocity). However, apart from the accuracy of the model, data quality greatly influences the accuracy of the prediction. Therefore, to achieve an excellent prediction of pre-drill well gradients, one should ensure that the seismic data used is as accurate as possible.

CHAPTER 5

5.0 CONCLUSION

Due to the fact that wildcat wells are drilled in new areas where no offset wells are available to provide data for predicating well gradients (pore gradient, fracture gradient and overburden gradient), therefore, the use of seismic data (two-way time and average velocity) for estimation of pre-drill well gradients is of great importance prior to drilling a wildcat well. The gradients derived from seismic data, enables the operator to design safe drilling mud and casing program required to drill a wildcat well with an awareness of the drilling window and overpressured zones. Hence, avoiding incurring critical well control events and issues related to wellbore instability, thereby reducing nonproductive time and increasing operational safety and efficiency.

For this project, a computer code which is developed using C++ programming language which provides an effective platform for carrying out the estimation of pre-drill well gradients from seismic data. The well gradients have been successfully estimated as stated in the objective, and the results obtained will be validated with post-drill data.

The pre-drill well gradients matched closely with post-drill well gradients, therefore we can conclude that the seismic data employed in the estimation of pre-drill well gradients is quite accurate.

For better accuracy of the estimated well gradients, it is recommend that input data (two-way time and average velocity) obtained from seismic be accurate. If the seismic data are not representative for the formation in which the data are measured, this will lead to poor estimation of well gradients, thus increasing operational and economical risk of drilling operations.

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