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Drilling exploration design controlled by pore pressure prediction from 2D seismic and well data: case study of South Sumatra Basin

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Abstract. To have safe and economical in drilling design, an information of formation pore pressure is required. Pore pressure can be estimated from seismic data using a velocity to pore pressure transform. The objective of this paper is proposing the drilling exploration design for the case study of South Sumatra field, which is controlled by predicted pore pressure. The pore pressure is predicted by using Eaton method that used velocity from 2D seismic and was validated with well log data. The predicted pore pressure is used to design exploration drilling including casing depth and mud weight. Eaton parameter (N =1.1), shear stress (Ko= 0.6), Gardner (A = 0.198 and B = 0.268), which is used in this works, is gained from existing well data. The velocity model is derived from RMS velocity that should be converted into interval velocity. In addition, this velocity should be validated with the sonic log from existing well. The Normal Compaction Trend (NCT) from interval velocity that was combined with generated previous parameter is used for predicting pore pressure and fracturing pressure. Our experiment shows that based on pore pressure prediction, the drilling exploration design is divided into three sections. i.e. section 17-1/2", 12-1/4" and 8-1/2" and four casing sections, i.e. Casing 20", K-55, 90 ppf at 160 ft, casing 13-3/8", K-55, 54.5 ppf at 1400 ft with mud weight 8.8 - 13.7 ppg, casing 9-5/8 ", K-55, 40 ppf at 4000 ft with mud weight 9.5 - 14.0 ppg and casing 7", L-80, 26 ppf at 5500 ft with mud weight 10.4 - 14.6 ppg.

1. Introduction

The successful in drilling design is dependent on the knowledge of subsurface pore pressure. Inaccurate prediction of the subsurface pore pressures can cause slow penetration, excessive consumption of drill bit, increase costs and risk in drilling activity [1]. Pore pressure can be predicted from seismic data using a velocity to pore pressure transform. Given seismic velocities with sufficient spatial resolution, we can predict subsurface pore pressure. Existing approaches include the empirical methods of Eaton [2] which are widely used in the industry. In this paper, we proposed pore pressure prediction to design exploration well drilling by using Eaton method that used velocity from 2D seismic and was validated with well log data of G-field of South Sumatra basin.

G Field is an exploration field in South Sumatra Basin, precisely in the Middle Palembang Sub-Basin. Exploration target in this region is Talang Akar Formation. South Sumatra Basin is a tertiary back-arc basin that has the NW-SE direction, bounded by the Bukit Barisan in the southwest and Sunda Shelf in the northeast. South Sumatra Basin separated from Sunda Basin on the east by

Tinggian Palembang and Lampung, which was filled by Tertiary sediments with a thickness up to 4000 meters.

One of exploration wells (G-1 well) has been drilled in this field, which undergone a kick in the depth of 5132 ft. This kick occurred due to lack of pore pressure information, so the drilling design is not optimal. To overcome this problem, predrill pore pressure prediction has been carried out to propose the next drilling activities in term of location and drilling design.

In this study, the pore pressure is predicted from seismic interval velocity, which is validated with Sonic from well log data. The Eaton coefficient parameter (N), Shear Stress (Ko) and Gardner coefficient were obtained from well log data. The predicted pore pressure will be used for drilling design including; setting the number of well trajectories, casing seats and mud weight.

2. Pore pressure prediction and casing design

Pore pressure estimation, which is developed by Eaton, used seismic interval velocity and pressure information from previous drilling result. Eaton method explained that the majority of the pressure in the subsurface is influenced by overburden activity the so called primary overpressure [2]. Relation between overburden pressure and pore pressure described by Eaton written on the following equation:

$$P_p = P_{ovb} - (P_{ovb} - P_h)\left[\frac{V_i}{V_n}\right]^N, \text{ for seismic data} \quad (1)$$

$$P_p = P_{ovb} - (P_{ovb} - P_h)\left[\frac{\Delta t_n}{\Delta t_i}\right]^N, \text{ for sonic data} \quad (2)$$

Where P_p is pore pressure (psi), P_{ovb} is overburden pressure (psi), P_h is hydrostatic pressure (psi), N is Eaton exponential coefficient, V_n is interval velocity from NCT (ft/s), V_i is interval velocity from seismic (ft/s), Δt_n is transit time from NCT (µsec/ft), and Δt_i is measured transit time from well log (µsec/ft). NCT is determined on a layer, which has a low permeability value, such as shale. NCT for acoustic travel time in the depth domain is an exponential trend which is plotted in semi-log, whereas NCT for seismic velocity in the depth domain is a linear relation [3].

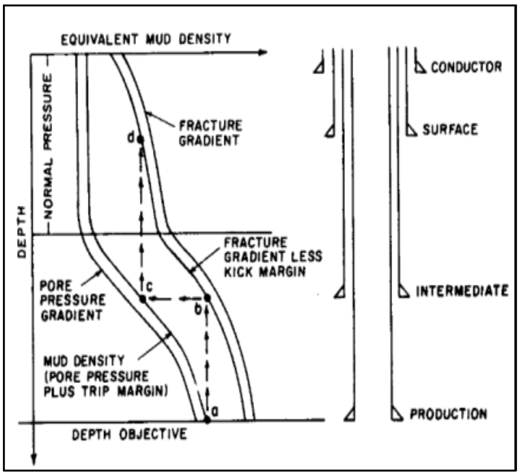


Figure 1. Illustration of casing design that was guided by pore pressure and fracturing pressure [4].

To achieve the optimal solution, the design engineer must consider casing as a part of a whole drilling system. A knowledge of formation properties such as pore pressure, fracture pressure, strength, and chemical stability/sensitive shale (mud type and exposure time) involved in the design process is required. Mud weight is applied to prevent the flow of formation water penetrate into well, which is also known as “kick.” Moreover, the casing must be fitted to the depth where the amount of mud weight is equal to the fracturing pressure to prevent formation damaged, the illustration is shown in Figure 1.

In general, pore pressure prediction process is divided into three stages; well evaluation, analysis of seismic interval velocities and application of Eaton method to predict pore pressure. The availability data in this study consist of 2D seismic data with the length of 15.68 km (Figure 2), VSP, well log data (GR, Density, and Sonic), Repeat Formation Test (RFT), Drilling Report of G-1 well and Formation Integrity Test (FIT).

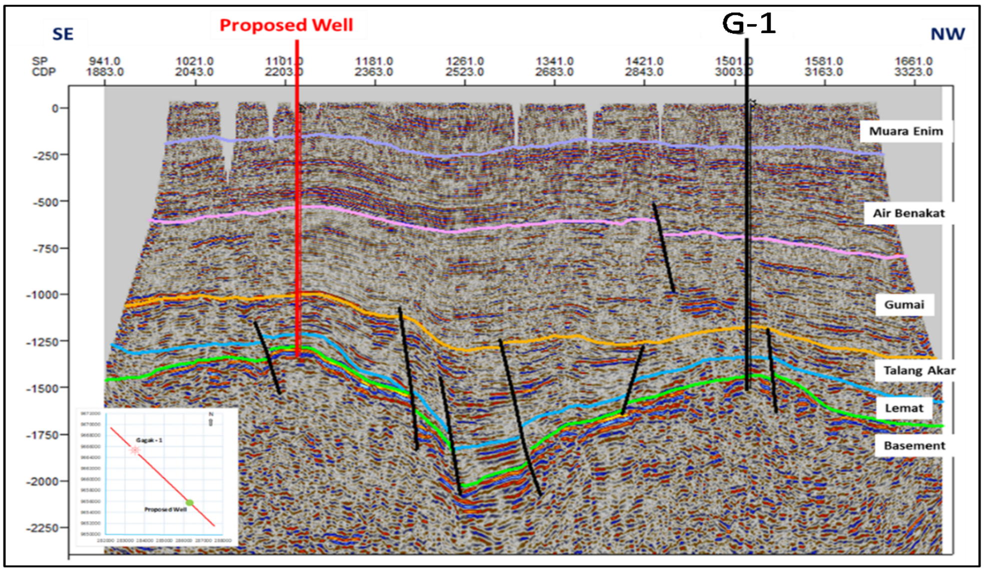


Figure 2. The seismic section in the study area, which is passing through the existing Well G-1 (black line) and proposed well (red line).

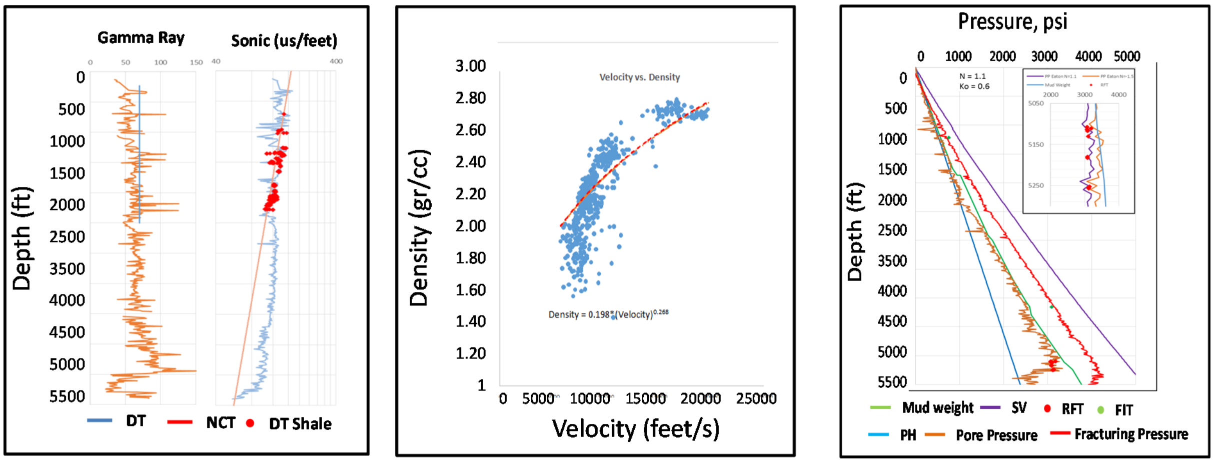
3. Result and discussion

Our evaluation is performed on G-1well to obtain several parameters such as NCT, Eaton pressure Parameter (N), shear factor (Ko) and Gardner coefficient. Calculation of NCT is carried out to G-1 well by using sonic of the shale data as shown in Figure 3(a). Gardner coefficient A and B determined using a cross-plot of density and sonic log as illustrated in Figure 3(b). From the cross-plot, Gardner coefficient was obtained as follows A=0.198 and B =0.268.

The best Eaton coefficient produces pore pressure values which have the best fit with RFT. Our exercise to various values, the best Eaton coefficient d is 1.1 as shown in Figure 3(c). Similar to Eaton coefficient, shear factor (Ko) is determined by comparing the fracturing pressure with FIT. From this process, it was obtained that shear factor is 0.6. The plot of pore pressure and fracturing pressure that has the best fit with RFT and FIT is displayed in Figure 3(c).

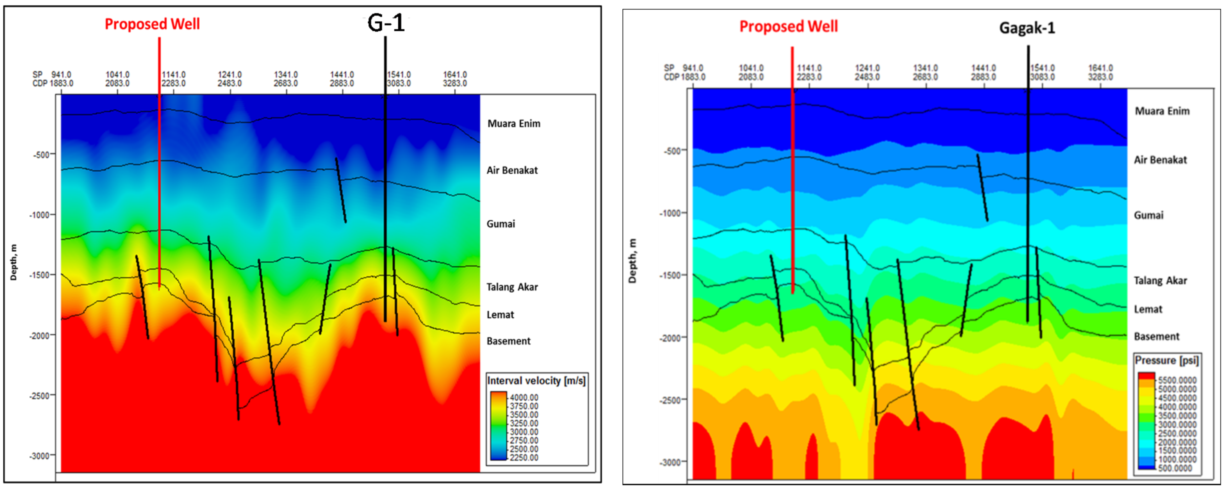
Root Mean Square (RMS) velocity model was obtained from velocity analysis in the seismic data processing. This kind of velocity must be converted to interval velocity by using Dix's equation. The interval velocity model is then converted to depth domain for adjusting the well. The result of the interval velocity in the depth domain can be seen in Figure 4(a). The predicted pore pressure, which is based on the interval velocity, is shown in Figure 4(b).

Pore pressure prediction in this study used the interval velocity and the parameters that have been obtained from the well analysis. Before the interval velocity is being used it must be corrected by the sonic log. The process was done by cross plot between the interval velocity and the sonic log as shown in Figure 5(a).



(a) (b) (c)

Figure 3. (a) The plot of Gamma Ray log (track one) and Sonic log (track two), which is overlaid with predicted normal compaction trend from the sonic of shale (red line). (b) The plot of Density versus Sonic to determine Gardner coefficient. (c) The plot of pore pressure (brown line) and fracturing pressure (red line) for determining Eaton constant (N) and shear factor (Ko) in Well G-1.



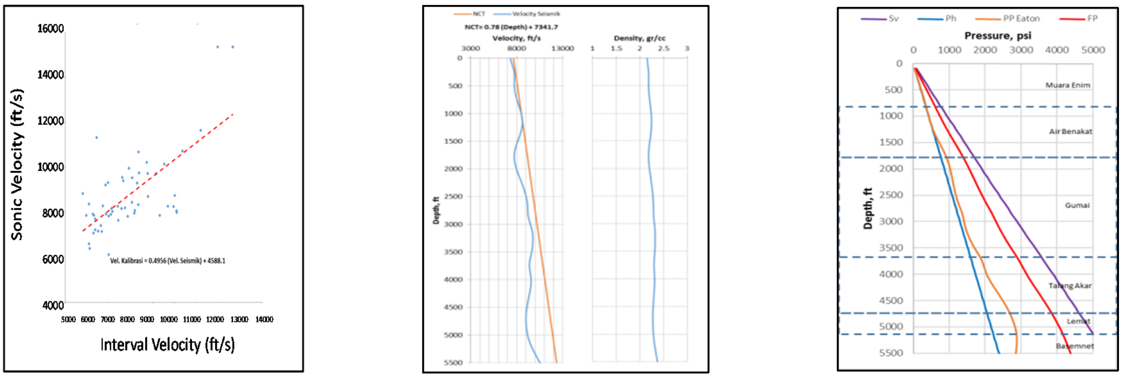
(a) (b)

Figure 4. The section of the interval velocity model (a), and the predicted pore pressure (b) in the depth domain (hot colors represent high magnitude).

NCT prediction of the proposed well is calculated using linear trend of shale velocity. Whereas the density log is determined using the Gardner equation using the coefficient, which was already obtained in the well log evaluation. These two parameters of the proposed well are shown in Figure 5(b). The last step is calculating pore pressure and fracturing pressure on the location of the proposed well using Eaton coefficient and shear factor. Detailed analysis of predicted pore pressure is shown in Figure 5(c). It can be observed that the pore pressure in the prospect area has relatively normal pore pressure. However, at depths below 4200 ft, it has increased pressure. This phenomenon is possible due to the presence of oil or gas content.

The predicted pore pressure and fracturing pressure were then used to design the casing seat and mud weight in the well drilling planning. Pore pressure and fracturing pressure are converted to equivalent mud weight. After converting the predicted pore pressure to equivalent mud weight, the trajectory well design is proposed, which is divided into three following sections:

- Section 17-1/2" has a normal pore pressure or equal to the hydrostatic pressure.
- Section 12-1/4" has pore pressure range 9.0 - 10.0 ppg or 0.67 - 1.67 ppg above hydrostatic pressure.
- Section 8-1/2" has pore pressure range 10.0 - 11.0 ppg or 1.67 - 2.67 ppg above hydrostatic pressure.



(a) (b) (c)

Figure 5. (a) Linear regression in interval velocity calibration, (b) Track one is the result of NCT (red indicates NCT and blue indicated seismic velocity), and track two is density log, (c) Predicted pore pressure (brown line) and fracturing pressure (red line).

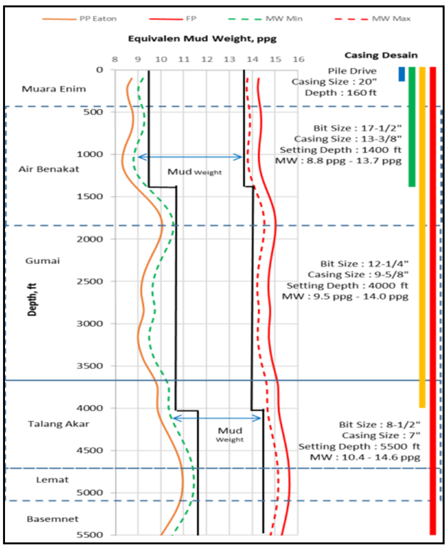


Figure 6. Drilling design on proposed well which contains drilling trajectory, casing design and mud weight.

Figure 6 shows the trajectory well design, which is constrained by pore pressure and mud weight. In general, the designed well trajectory, which is illustrated in Figure 6, can be described as follows:

- Section 1: Casing 20" with grade K-55, 84 ppf serves as surface casing, which is piled up to a depth of 160 ft or bedrock. This casing is intended to protect the aquifer of fresh water in a shallow layer, and avoiding the washout in the surface layer, which can lead to the foundation of the drilling rig and the installation of a diverter system during the drilling. In this section, the estimated pore pressure is equal to the hydrostatic pressure.

- Section 2: Casing 13-3/8" with a grade K-55, 54.5 ppf is installed up to a depth of 1400 ft which reach Muara Enim and Air Benakat formation. This casing is a conductor casing which is drilled with bits 17-1/2" and the mud weight range of 8.8 - 13.7 ppg. The function of this casing is as the holder of the Blow-out Preventer (BOP), the wellhead and the protector of the freshwater aquifer.
- Section 3: Casing 9-5/8" with a grade K-55, 40 ppf is installed up to a depth of 4000 ft which close to lower Air Benakat, Gumai, and Top Talang Akar Formation. Section 3 is drilled with bits 12-1/4" and mud weight range of 9.5 - 14.0 ppg. The purpose of section 3 is to avoid problems such as clay/shale swelling due to exposure of drilling mud which can lead to the collapse of the borehole wall that causes the pipe pinched.
- Section 4: Casing 7" with grade L-80, 26 ppf is installed up to 5500 ft (Total Depth) that close to the Talang Akar, Lemat Formation, and Basement. Section 4 drill with bits 8-1/2" and mud weight range of 10.4 - 14.6 ppg. This section is production casing that penetrates the objective zones which are estimated at a depth of 4200 ft.

4. Conclusions

The pore pressure and fracturing pressure is the most important parameter in determining the reliability and success of a casing design. Therefore, the pore pressure and fracture prediction by considering all available parameters are required. For G Field case, we have proposed the trajectory well design, which is constrained by pore pressure and mud weight, which is divided into three sections that are section 17-1/2”, 12-1/4” and 8-1/2”. In general, the designed well trajectory in G Field case is proposed into four sections casing step with respect to drilling depth. Casing 20” is piled up to a depth of 160 ft, casing 13-3/8” installed up to a depth of 1400 ft, casing 9-5/8” installed up to a depth of 4000 ft and casing 7” installed up to 5500 ft (Total Depth) that close to the Talang Akar, Lemat formation, and Basement.

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