COMBINING SONIC WHILE DRILLING AND FORMATION PRESSURE WHILE DRILLING FOR PORE PRESSURE ANALYSIS TO REDUCE DRILLING RISK: A CASE STUDY IN OFFSHORE VIETNAM

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Summary

The accurate prediction of pore pressure is important for safe drilling and can significantly reduce financial risk. The major focus during drilling in a high-temperature/high-pressure (HP/HT) environment is optimising the drilling operation to mitigate risk by utilising data such as sonic logging-while-drilling (LWD) and offset well information.

An offshore exploration well was being drilled in offshore Vietnam with drilling challenges of abnormally high formation pressure. In normally compacting sediments, water escapes through permeable sands or along fractures as overburden sediments build up, and fluid or pore pressure remains close to hydrostatic pressure. In such normally compacting sediments, under increasing effective pressure, porosity decreases and compressional velocity increases. However, if formation fluids cannot escape, for example due to the low permeability of overlying shales, then they bear part of the overburden load and hence become overpressured. These formations are called undercompacted, meaning they have a higher porosity than normally compacted shales. In overpressured shales, which contain pressured water, density is lower, porosity is higher, and compressional velocity is lower than normal.

Formation pressure can be the major factor affecting the success of drilling operations. If pressure is not properly evaluated, it can lead to drilling problems such as lost circulation, kick, stuck pipe, hole instability, and excessive costs. Therefore, knowledge of the pore pressure is of considerable value because it provides the means for improving drilling operations and designing better casing programmes to reduce those risks. Using the data gathered from well logs, it is possible to predict the probable pressure profile that will be encountered while drilling. LWD data enable monitoring pore pressure very effectively; this pore pressure prediction can be continuously updated using LWD sonic and formation pressure while drilling (FPWD) to make optimal decisions for the drilling operation. Once a suitable predrill pressure profile is established, it is monitored on the current wells with logging while drilling sonic and directly calibrated with formation pressures taken in sands.

In the offshore Vietnam well, pore pressure monitoring by LWD formation pressures and estimated pore pressure from LWD sonic data allowed drilling operations to be optimised. Employing this technique led to successful drilling without any incidences related to pore pressure. The computed pressures from LWD sonic matched the measured pressures obtained from FPWD. The real-time sonic matched the recorded-mode sonic closely. This technique could apply not only to the wells in this basin but also to the other wells in the locations with abnormal high formation pressure.

Key words: *Pore pressure prediction, sonic while drilling, formation pressure while drilling, LWD sonic, casing optimisation.*

1. Introduction

The subject well is located in Nam Con Son basin, offshore Vietnam. This basin is one of a series of Tertiary rift basins created on Vietnam's continental shelf as a consequence of the East Sea seafloor spreading. The formation pressure profiles in central Nam Con Son basin are characterised by overpressure beneath the late Pliocene-Quaternary sedimentary section. Predicted bottom hole static temperature of this high-pressure/high-temperature (HP/HT) well is about 172°C (most likely) and may vary from 165°C to 177°C.

There are many drilling challenges in the Nam Con Son basin due to the complex sedimentary environment and complex geological structures. This increases the challenges in drilling exploration wells, especially in the HP/HT environment. In addition, the safe mud weight is within a very narrow window between the pore pressure and formation breakdown, increasing the drilling risk [1].

Generally, to better reduce the drilling risk, pore pressure analysis is usually undertaken using available offset well information together with the surface seismic data prior to drilling the well. As an important input for pore pressure analysis, sonic data is acquired during or after drilling to provide an estimate for safe mud window and drilling risk evaluation for the current well. This information can be utilised for subsequent nearby wells.

In projects with high risk, real-time data provide the information required to perform instantaneous analysis and update models that can assist in both drilling and reservoir evaluation. Real-time sonic data together with real-time FPWD data can be used to tackle the issue of unknown pore pressure with a narrow mud weight window [1].

Acquiring good quality LWD sonic data and other measurements such as gamma ray, density, resistivity, and FPWD, as well as monitoring the equivalent circulating density (ECD) and downhole parameters, were the keys to success in this HP/HT well. Predrill pore pressure provided early drilling hazard prediction in the job planning and was updated in real time to reduce uncertainties due to the complexity of geological structure.

Basic data acquisition (i.e., LWD gamma ray and resistivity) were required to assist lithology interpretation. LWD sonic was required for overpressure detection in real time and for geophysical evaluation. FPWD was required for formation pressure evaluation and pore pressure validation in the sand reservoir.

2. Case study

Pore pressure is the fluid pressure in the pore space of the formation. Pore pressure values range from hydrostatic pressure to severe overpressure (48% to 95% of the overburden stress). Pore pressure analyses include three aspects: predrill pore pressure prediction (PPP), PPP while drilling, and post-drilling pore pressure analysis. Predrill pore pressure can be predicted by using surface seismic interval velocity data in the planned well location, and by using geological, well logging, and drilling data in offset wells.

The purpose of pore pressure modelling is to create a safe operating window of mud weight such that the designed mud density will be high enough to ensure wellbore stability and low enough that drilling mud losses will not occur (Figure 1).

Figure 2 relates the mud weight (MW) to wellbore failures. The safe MW window should be higher than pore pressure and lower than mud losses. MW less than shear failure can lead to wellbore breakout; MW less than the pore pressure can lead to wellbore kicks or cavings. On the other hand, MW higher than mud losses can lead to partial loss and severe lost circulation if the MW is higher than breakdown.

The FPWD is a direct pore pressure measurement in permeable formations where a draw-down can be achieved, normally sands.

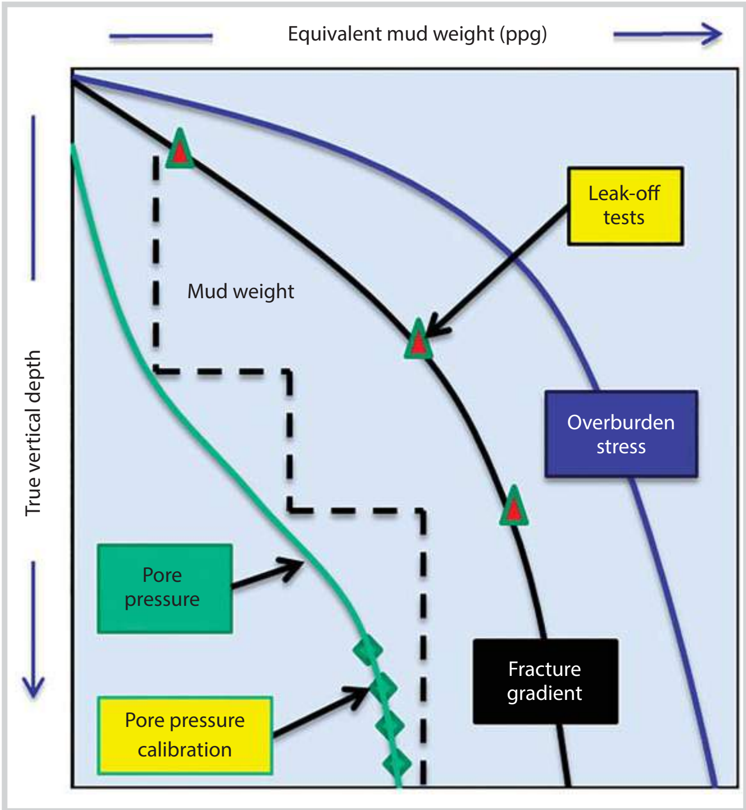


Figure 1. *Simple mud weight window*

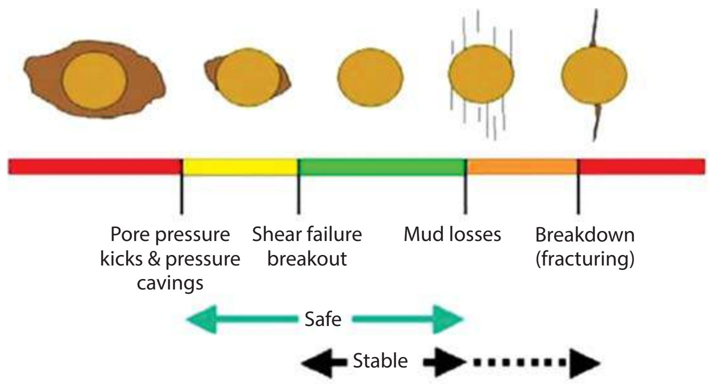


Figure 2. *Schematic relationship of mud weight and wellbore failures*

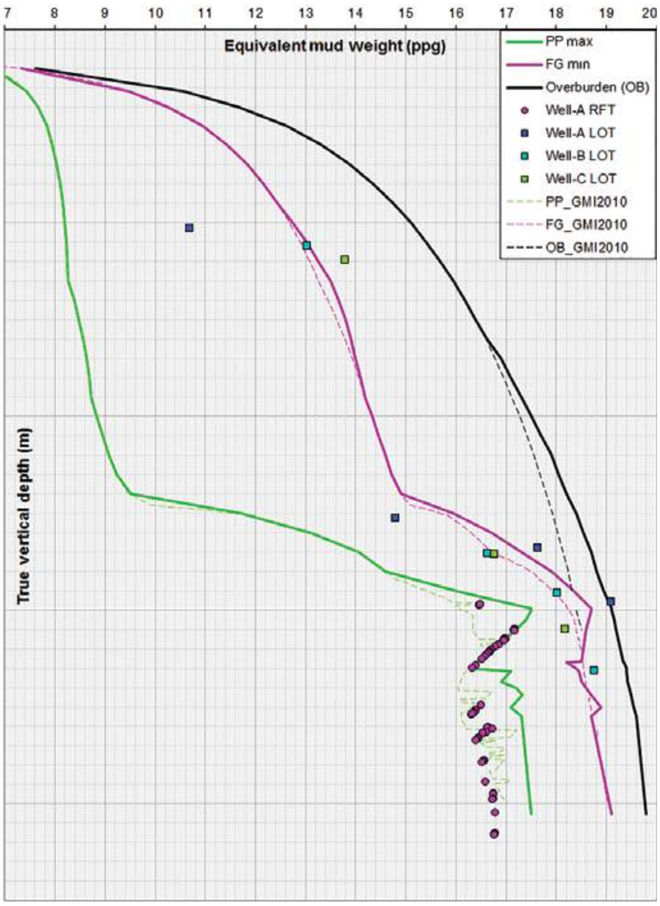


Figure 3. *Predrill pore pressure model*

2.1. Before drilling

A predrill pore pressure model must be built before drilling by using all available well-log data. In some sedimentary basins where undercompaction is the major cause of overpressure, the well-log-based resistivity method [2] can be used to predict pore pressure. Based on this relationship, pore pressure can be obtained from seismic interval velocity.

In this study, pore pressure was estimated from the sonic data using Eaton's method [2], and it compared well to pore pressure obtained from interval velocity and resistivity. This estimated pore pressure was calibrated by the direct formation pressure measurement from offset wells. The predrill pore pressure model is shown in Figure 3.

2.2. While drilling

To determine the minimum mud weight for drilling operations, the workflow described in Figure 4 was used for the pore pressure analysis and real-time monitoring.

There are always some uncertainties existing when pore pressure has been calculated and validated. The

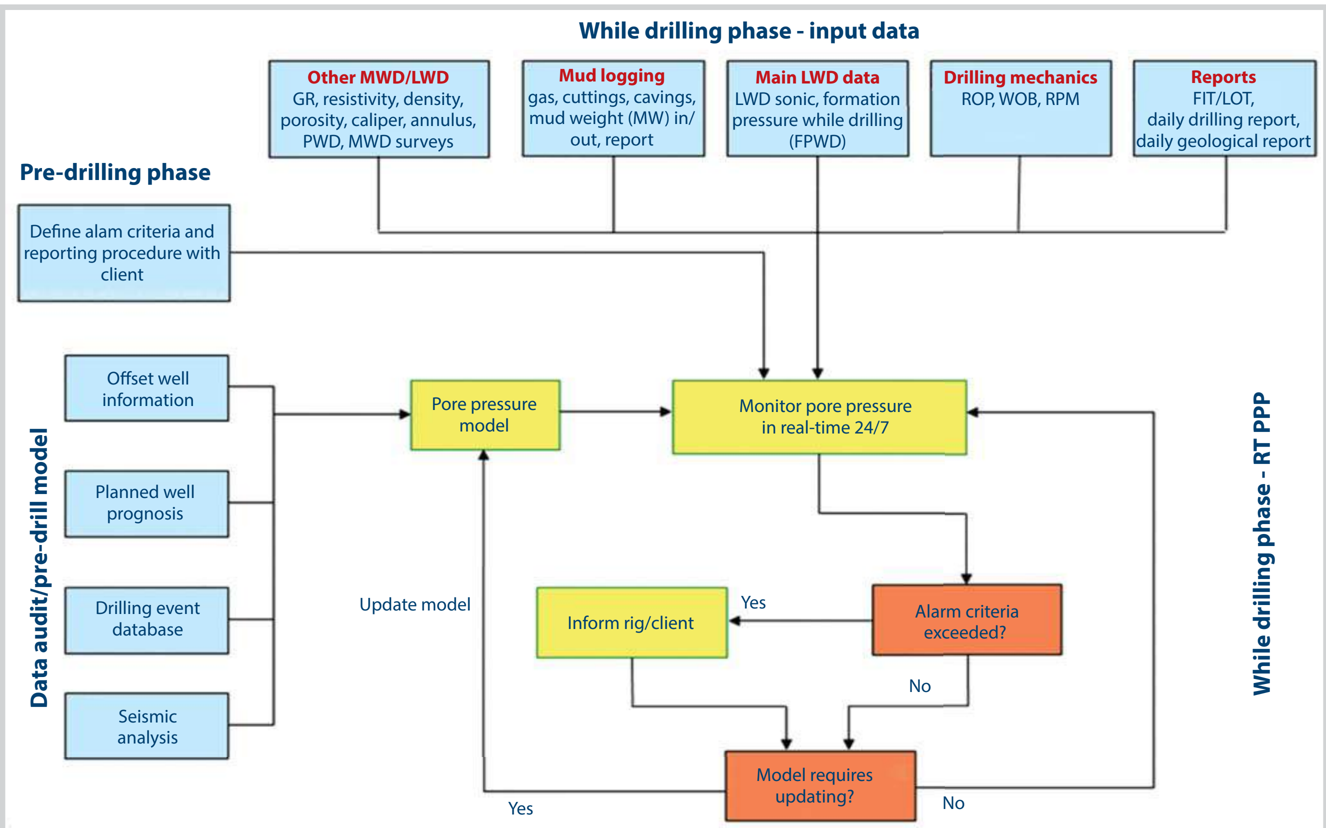


Figure 4. *Real-time pore pressure analysis and monitoring workflow [3]*

predrill pore pressure was planned based on the available offset well log data along with assuming similar lithology and little structural complexity. Thus, monitoring and updating pore pressure in real time are the keys to success when there is a high risk of wellbore instability.

In this HP/HT well, there was an extremely challenging narrow mud weight window and hence, low tolerance for MW uncertainty. Therefore, LWD logging data, LWD sonic measurement, and FPWD were acquired for three hole sections (16.5-in., 12.25-in. and 8.5-in.) for pore pressure monitoring in real time. In this case, the pore pressure was updated to total depth (TD) of the well to reduce the prediction uncertainties. The following steps were used to monitor and update the pore pressure in real time.

Monitoring and quality check (QC) of the LWD data compressional slowness (DTCO), density, and resistivity were done to make sure the acquired data were of good quality.

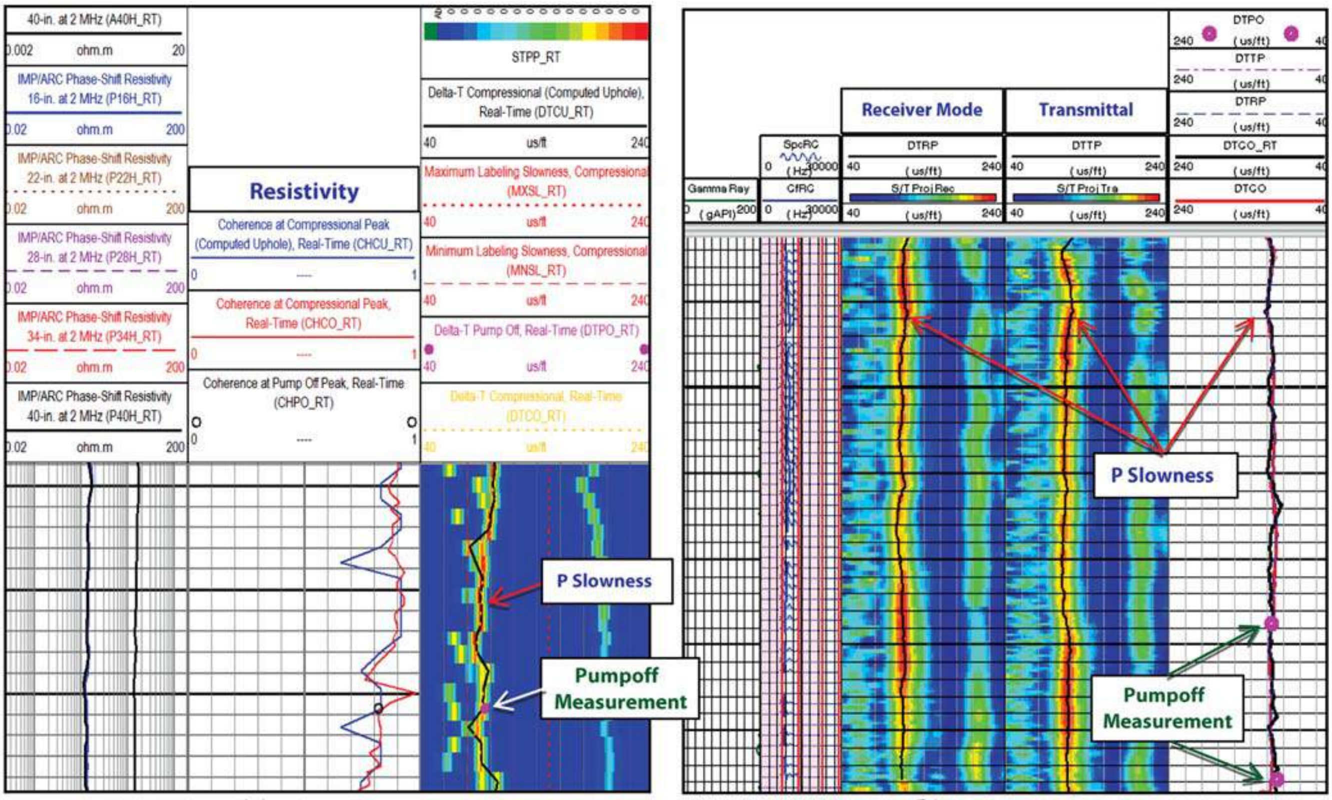
The formation lithology was correlated between the acquired LWD data and the offset well data, and the predrill PPP was adjusted immediately based on the changes of formation lithology [4].

The pore pressure was calculated in real time from LWD sonic and well calibrated by FPWD, and then used to calibrate the predrill PPP.

In general, the quality of LWD sonic data acquired in real time was good. The pore pressure was calculated from the compressional slowness (P slowness) and then calibrated by FPWD points in sand formation. The MW window was updated from the calculated pore pressure profile for safe drilling.

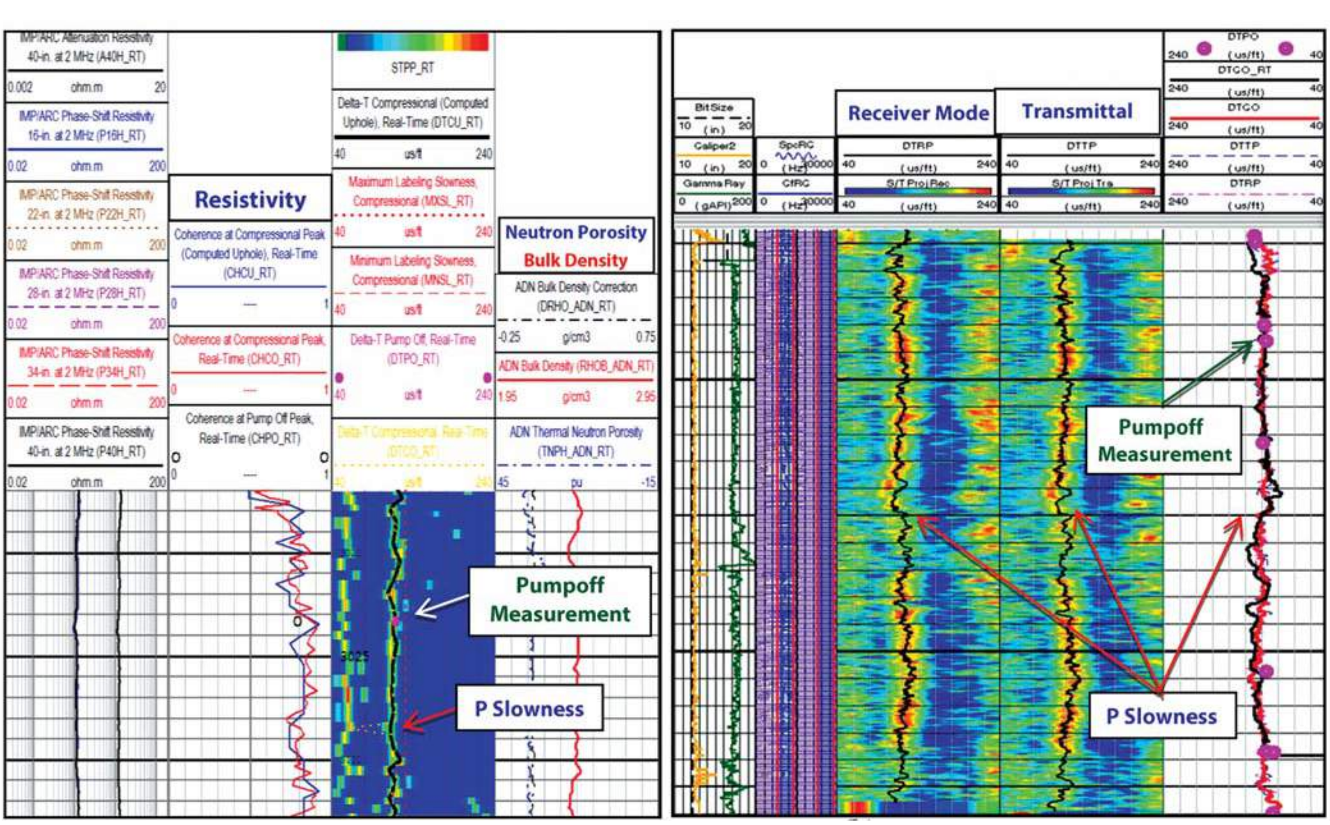
Figures 5 - 7 show the quality of real-time LWD sonic data and recorded-mode data for the 16.5-in., 12.25-in., and 8.5-in. sections. The real-time LWD sonic data was matched very well with the recorded-mode LWD sonic and pump-off measurement over the entire interval in all three sections.

Figures 8 - 10 show the pore pressure calculation in real time using LWD sonic and FPWD data. The main challenge was to manage the MW in the 16.5-in., 12.25-in., and 8.5-in. hole sections where the pressure was increased rapidly by depth. The mud weight window was updated based on the calculated pore pressure, and the predrill model was updated in real time for the 16.5-in., 12.25-in., and 8.5-in. sections.



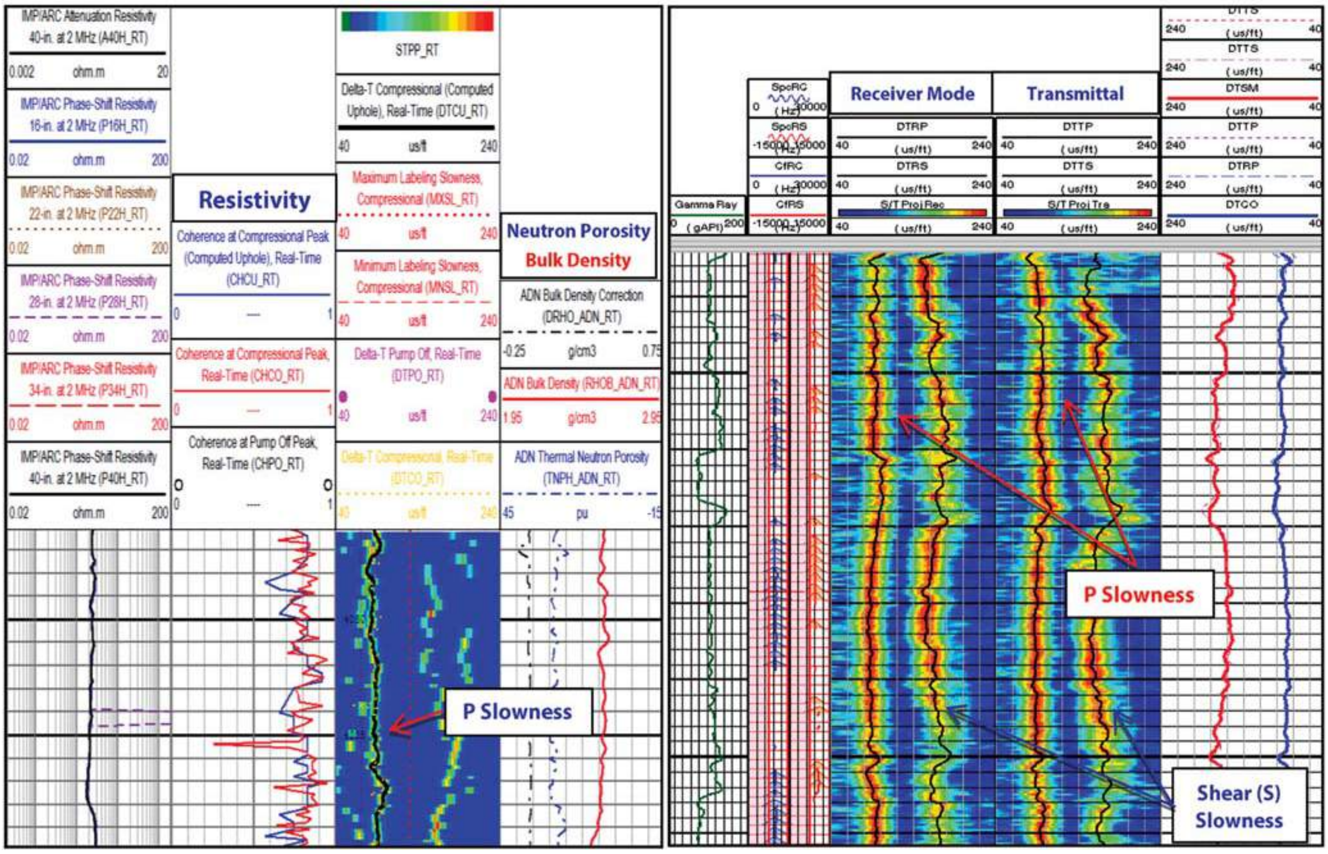
(a) (b)

***Figure 5.** LWD sonic real-time (a) and recorded-mode (b) data in 16.5-in. section*



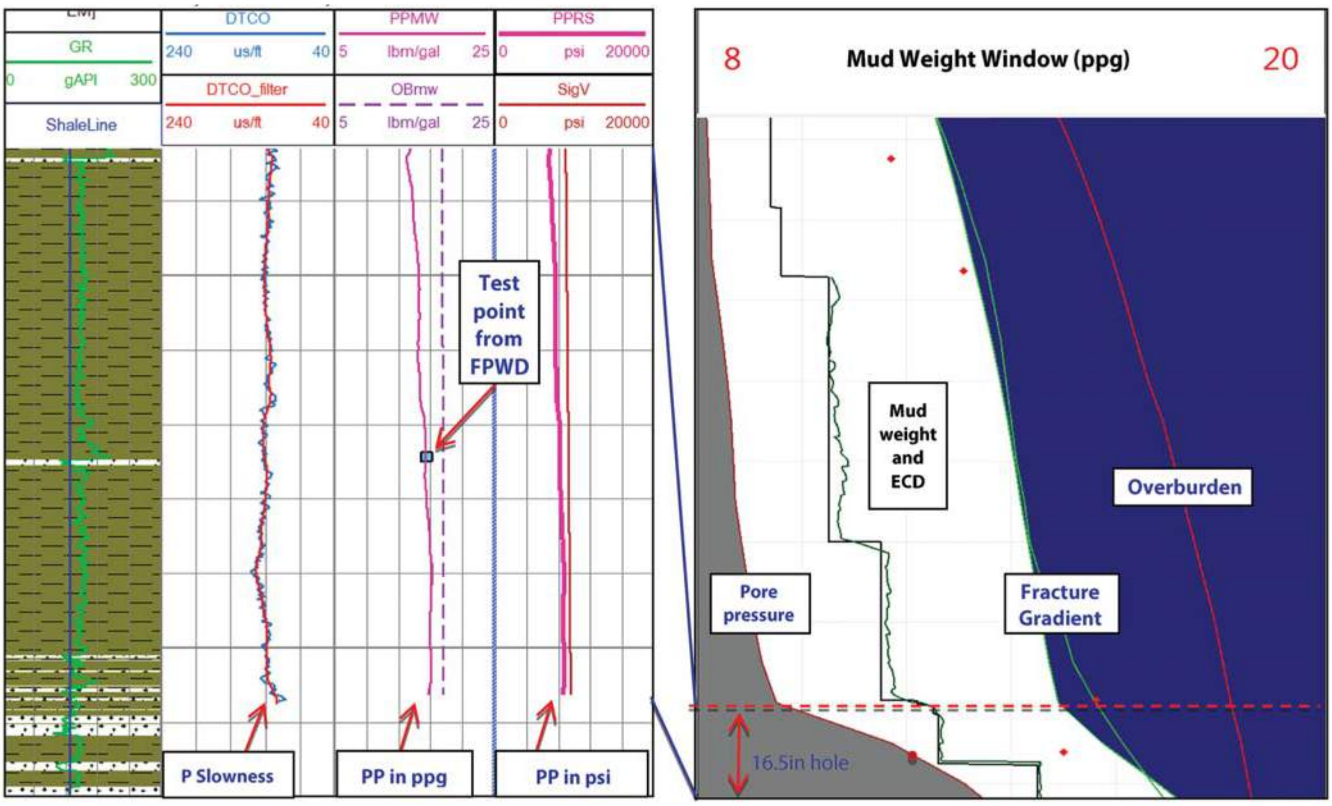
(a) (b)

Figure 6. *LWD sonic real-time (a) and recorded-mode (b) data in 12.25-in. section*



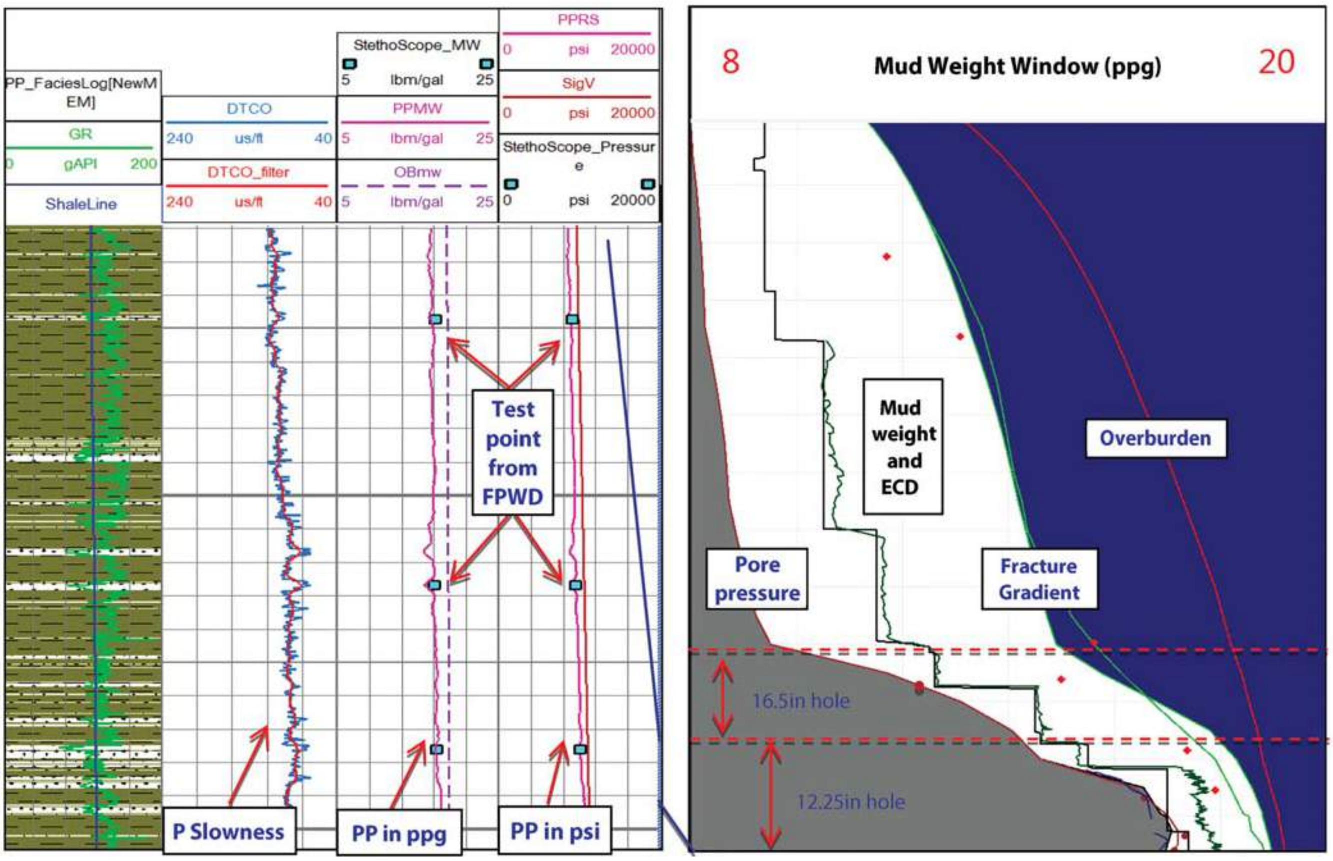
(a) (b)

Figure 7. *LWD sonic real-time (a) and recorded-mode (b) in 8.5-in. section*



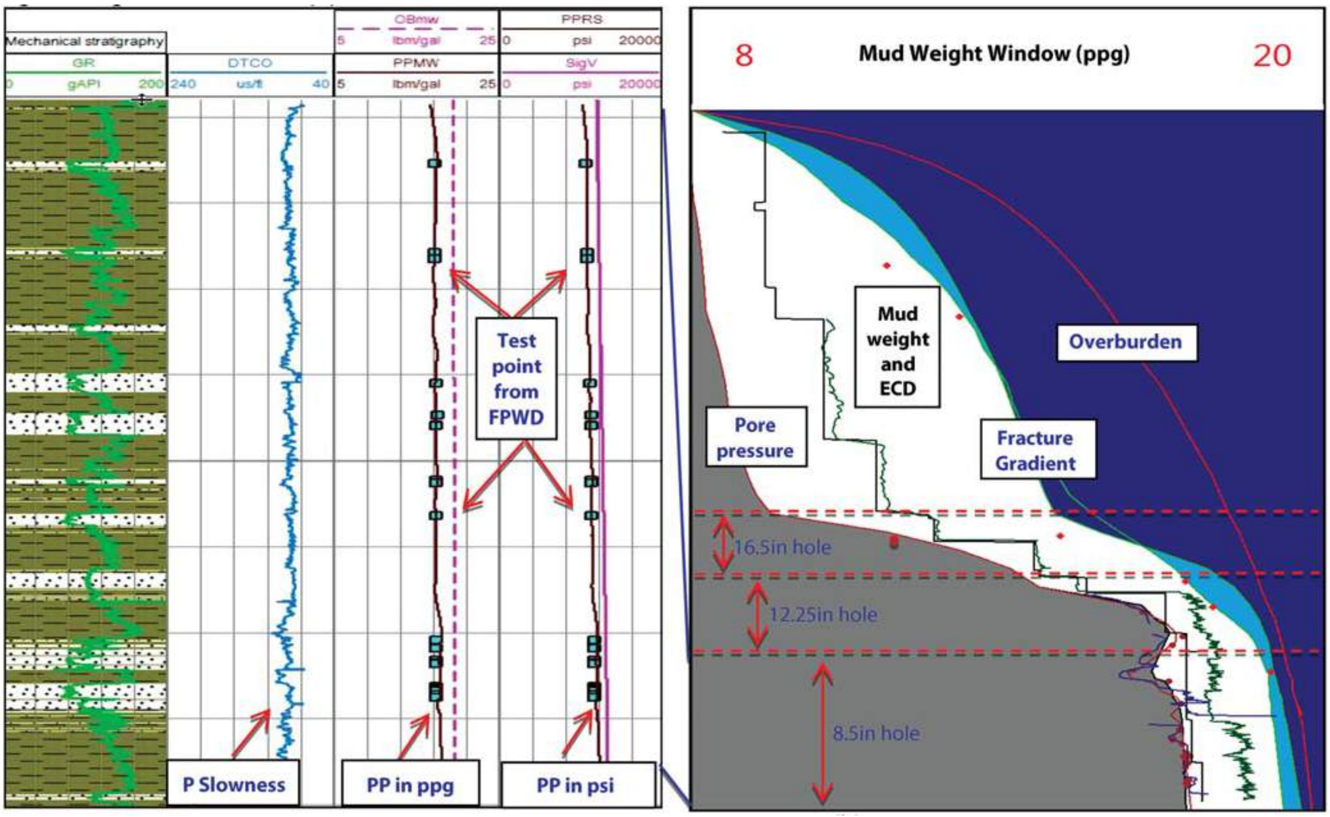
(a) (b)

Figure 8. *Real-time pore pressure calculation using LWD sonic and FPWD data (a) and the updated predrill model (b) in 16-in. hole*



(a) (b)

Figure 9. *Real-time pore pressure calculation using LWD sonic and FPWD data (a) and updated predrill model (b) in 12.25-in. hole*



(a) (b)

***Figure 10.** Real-time pore pressure calculation using LWD sonic and FPWD data (a) and updated predrill model (b) in 8.5-in. hole*

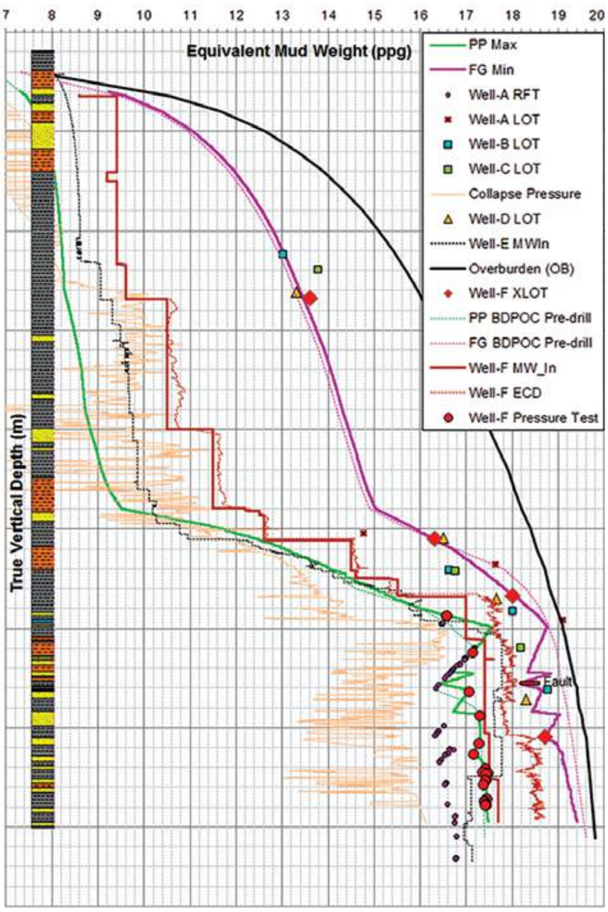


***Figure 11.** Post-drilling model*

By using this technique, this well was successfully completed; drilling to TD of the well was accomplished without any pore pressure related incident.

2.3. Post-Drilling model

The real-time LWD sonic data matched well with recorded-mode and pump-off measurements for all three sections. The calculated pore pressure and fracture gradient matched the drilling observations; this indicates a correctly calibrated model that could be used for modelling and planning future wells in the same area. The post-drilling model is displayed in Figure 11.

3. Conclusions

The acquired real-time P slowness showed good agreement with the recorded-mode P slowness in this study. The calculated pore pressure from LWD sonic was matched with FPWD points in the sand formation. The MW window defined from calculated pore pressure in real time helped to improve well planning, prevented wellbore stability problems, and reduced drilling risks.

Accurate predrill PPP is the key to improving drilling efficiency and reducing risks and costs. Seismic data, regional geology data, formation pressure measurement, and well log data from offset wells can be used for predrill PPP.

The pore pressure profile, caliper log, and drilling events in offset wells were used to obtain a valid wellbore stability solution for predrill wells. Real-time analysis was performed while drilling to update the predrill model, reduce uncertainty, avoid drilling incidents, and increase drilling efficiency.

The good integration among petrophysics, geomechanics, acoustic, and the drilling domain helped to optimise the drilling performance in this well. As the result of this integration, the well was drilled successfully without major pore pressure related issues.

4. Discussion

LWD sonic data was combined with FPWD data to give a very good monitoring of pore pressure in real time. However, this method still has its own limitations, only pore pressure and fracture gradient boundaries are available, there are no information about the shear failure and mud loss boundaries. Therefore, real-time pore pressure and wellbore stability monitoring are recommended to provide four boundaries (pore pressure, shear failure, mud losses, breakdown) to avoid wellbore failures and reduce nonproductive time in the planned well, particularly for wells with high risk and when drilling in difficult geologic conditions/formations. The wellbore stability model (Figure 12) should be conducted before planning the well to recommend the MW and casing program.

The safe MW window can be determined between the shear failure (minimum MW) and mud losses (maximum MW). Real-time prediction helps to constrain and update the predrill model while providing real-time advice for making decisions in drilling operations.

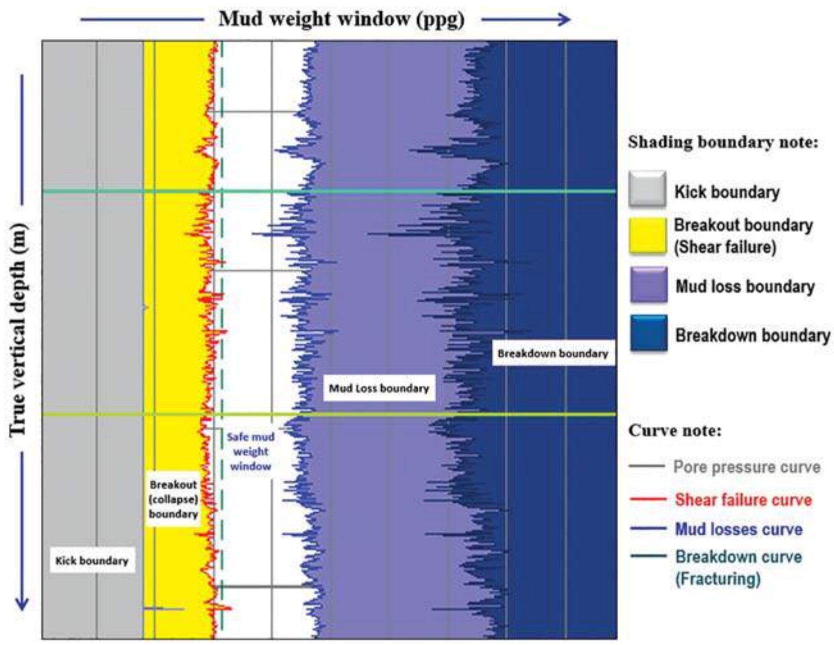


Figure 12. Wellbore stability model predicts safe mud window with four boundaries (kick, breakout, mud loss, and breakdown)

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