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[PS]Planning and Preparation of a Viable Pore Pressure Prediction in a Wild Cat High Pressure, High Temperature (HPHT) Exploration Well in Offshore Sarawak, Malaysia*

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Abstract

Efficient and efficacious well planning is the key to lowering the cost of drilling, and pore-pressure prediction is an important part of this planning process. Precise and accurate pore-pressure prediction is necessary for assessing the seal integrity through to delivering the pressure profiles to the drilling engineer. This paper focuses on different aspects of pore-pressure analysis that were considered to deliver a prediction with high precision and accuracy, leading to the successful drilling of a wild cat HPHT exploration well in Central Luconia Province, offshore Sarawak, Malaysia. Firstly, the uncertainties in prediction models arise from the quality and relevance of offset well control. In the study area, two offset wells penetrated thick carbonate sequence and one offset well encountered a thick sand-shale sequence with carbonate stringers. The variation in lithologies has to be considered while selecting the relevant offset well. Secondly, understanding the drilling challenges in offset wells related to pore pressure is key to design the planned well. All the offset wells drilled encountered significant challenges in terms of pore pressure. Similar drilling challenges were expected at the proposed location. However, the offset wells did not penetrate the deeper cycles and as such there is no calibration in deeper undrilled sections at the proposed location. The third aspect is the complexity of the geological and structural conditions around the well. The proposed well was planned to be drilled in a structure, which was formed on the footwall block for the shallow targets and crossing the fault to hanging wall block to hit the main target in deeper cycles. The fourth aspect, deals with the overpressure generation mechanism and prediction methodologies. A conventional workflow to plan a wild cat exploration well makes an accurate and precise prediction almost impossible until the overpressure generation mechanism is well understood in the study area. Such analysis was carried out in offset wells to carry a fit for purpose prediction at the proposed location. The fifth aspect considers the seismic velocities in terms of quality and calibration. Very coarse 2D seismic velocities were available with very poor quality seismic reflections along the proposed well path. The errors that are inherently present in such velocities from different sources has to be considered for determining the quality of the seismic based pore-pressure calibration. By considering all the above aspects and their associated uncertainties, a fit for purpose pore-pressure model was developed to develop high predictive accuracy with precision. The paper outlines how all the aspects were addressed to reduce uncertainty to increase precision. Three scenarios for pore pressure were proposed which helped to make decisions on well design in real-time. A postdrill analysis shows the actual pore pressure was within the uncertainty model, which validated our pore-pressure prediction approach.

Planning and Preparation of a Viable Pore Pressure Prediction in a Wild Cat High Pressure, High Temperature (HPHT) Exploration Well in Offshore Sarawak, Malaysia

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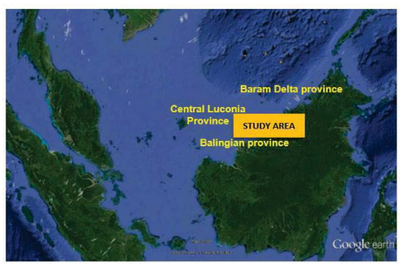
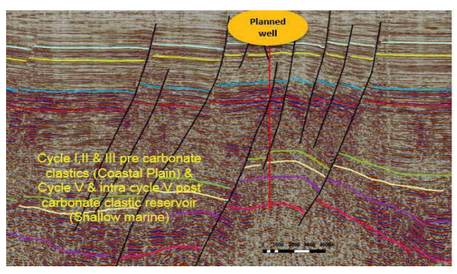
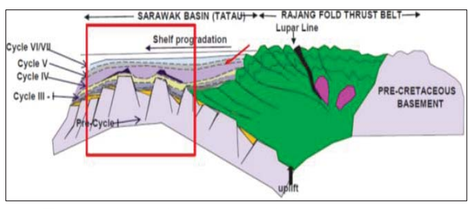
Abstract

Efficient and efficacious well planning is the key to lowering the cost of drilling, and pore-pressure prediction is an important part of this planning process. Precise and accurate pore-pressure prediction is necessary for assessing the seal integrity through to delivering the pressure profiles to the drilling engineer. This paper focuses on different aspects of pore-pressure analysis that were considered to deliver a prediction with high precision and accuracy, leading to the successful drilling of a wild cat HPHT exploration well in Central Luconia Province, offshore Sarawak, Malaysia. Firstly, the uncertainties in prediction models arise from the quality and relevance of offset well control. In the study area, two offset wells penetrated thick carbonate sequence and one offset well encountered a thick sand-shale sequence with carbonate stringers. The variation in lithologies has to be considered while selecting the relevant offset well. Secondly, understanding the drilling challenges in offset wells related to pore pressure is key to design the planned well. All the offset wells drilled encountered significant challenges in terms of pore pressure. Similar drilling challenges were expected at the proposed location. However, the offset wells didn't penetrate the deeper cycles and as such there is no calibration in deeper undrilled sections at the proposed location. The third aspect is the complexity of the geological and structural conditions around the well. The proposed well was planned to be drilled in a structure which was formed on the footwall block for the shallow targets and crossing the fault to hanging wall block to hit the main target in deeper cycles. The fourth aspect, deals with the overpressure generation mechanism and prediction methodologies. A conventional workflow to plan a wild cat exploration well makes an accurate and precise prediction almost impossible until the overpressure generation mechanism is well understood in the study area. Such analysis were carried out in offset wells to carry a fit for purpose prediction at the proposed location. The fifth aspect considers the seismic velocities in terms of quality and calibration. Very coarse 2D seismic velocities were available with very poor quality seismic reflections along the proposed well path. The errors that are inherently present in such velocities from different sources has to be considered for determining the quality of the seismic based pore-pressure calibration. By considering all the above aspects and their associated uncertainties, a fit for purpose pore-pressure model was developed to develop high predictive accuracy with precision. The paper outlines how all the aspects were addressed to reduce uncertainty to increase precision. Three scenarios for pore pressure was proposed which helped to make decisions on well design in real-time. A postdrill analysis shows the actual pore pressure was within the uncertainty model which validated our pore-pressure prediction approach.

Study Area and Offset Well Data



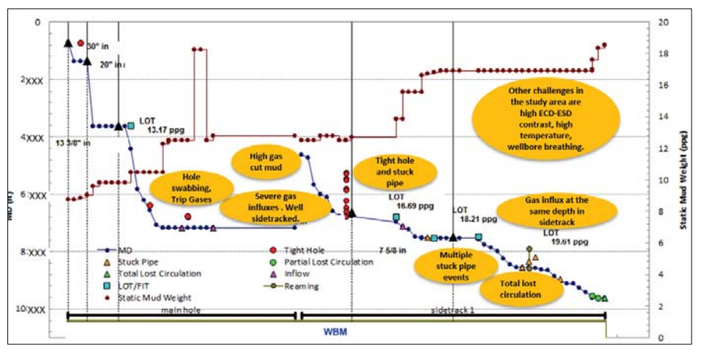




- The regional basinal setting is characterized by the deposition of a prograding deltaic sequence with each depositional cycles becoming successively younger due to the overall outbuilding nature of the shelf system.
- The stratigraphic sequences within this deltaic successions are often associated with high sedimentation rates, and exhibit increasing shaliness downwards and basinwards in the overall regressive delatics.

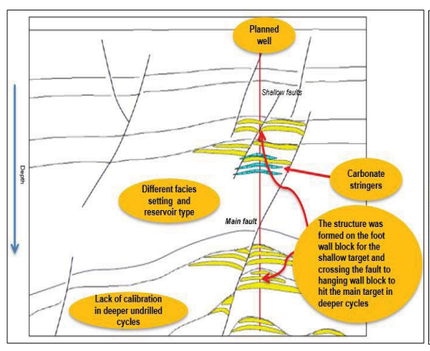
- The depths to top of overpressure are often a result of the stratigraphy of the prograding delta and the corresponding net to gross content.
- Overpressures related to undercompaction are encountered at depths where the sequences are shaly and at subsequently younger stratigraphic levels from the proximity to the distal offshore
- The two offset wells (Offset -2 & -3) penetrated thick carbonate sequence and one offset (Offset-1) well encountered thick sand shale sequence with interbedded carbonate stringers. The three offset wells penetrated similar formations but with a varied lithology. The proposed well was expected to penetrate sand shale sequences with interbedded carbonate stringers.

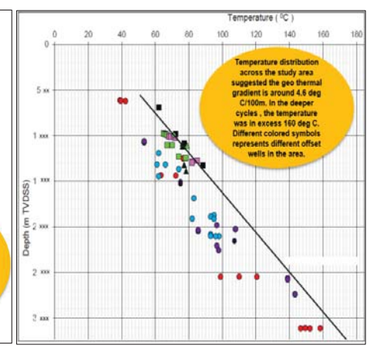
Well Data and Drilling Challenges



- All the offset wells (Offset -1,-2 & -3) had significant drilling challenges such as shallow overpressure top, high gas cut mud, gas influx, wellbore breathing, total lost circulation, tight hole and stuck pipe eventually leading to sidetrack wells.
- The offset wells were drilled in 70's with limited information to conduct a full blown postdrill analysis. All the wells were drilled with significantly lower mud weight which resulted in severe pore pressure related events like violent gas flow from bell nipple.
- There was a significant uncertainty in the depth and magnitude of overpressure top.
- The offset wells didn't penetrate the deeper cycles and as such there is no calibration in deeper undrilled sections at the planned location.

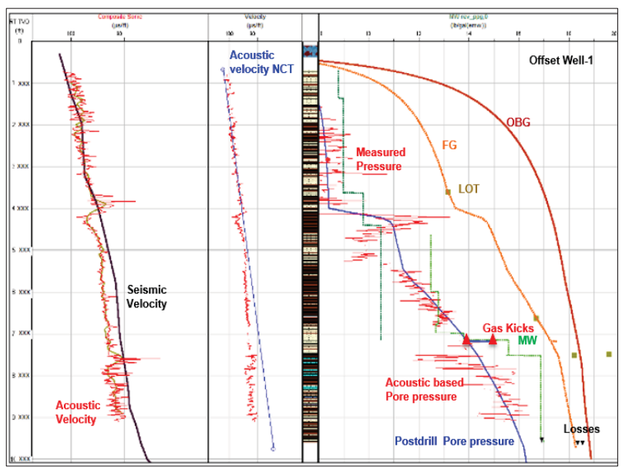
Geological Challenges

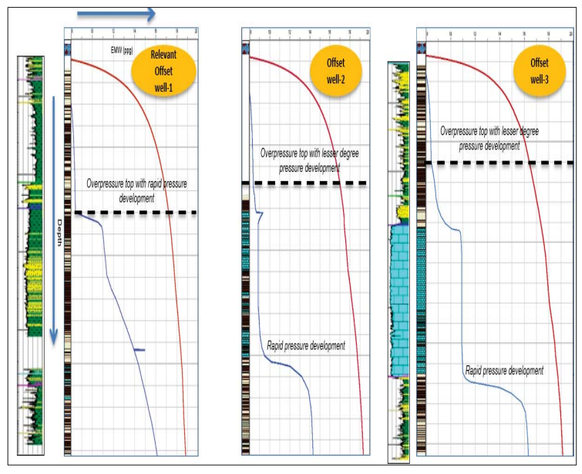




- Understanding the geological challenges (structure, temperature etc.) is the key in planning the pore pressure prediction methodology.
- In the study area, the structure was formed on the footwall block for the shallow targets Cycle V and crossing the fault to hanging wall block to hit the main target in deeper cycles III, II and I.
- The shallow and deeper cycles consists of different facies setting and reservoir type. Cycle V interval was prograding depositional event was deposited in shallow marine environment which is calm environment and fine sediment will be deposited. The result from setting is fine grain siliciclastic with shale rich. Cycle I/II/III were deposited on coastal environment with fluviomarine influence which is mixture of shallow marine and freshwater sediment derived from nearby discharge river (Interbedded shale/sand).
- The geothermal gradient is high and the expected temperature near TD is in excess of ~160 degree.
- The deep seated growth fault and an elevated temperature in the study area can have a pronounced effect on pore pressure distribution and can possibly result in pressure compartmentalization.

Pore Pressure Methodology

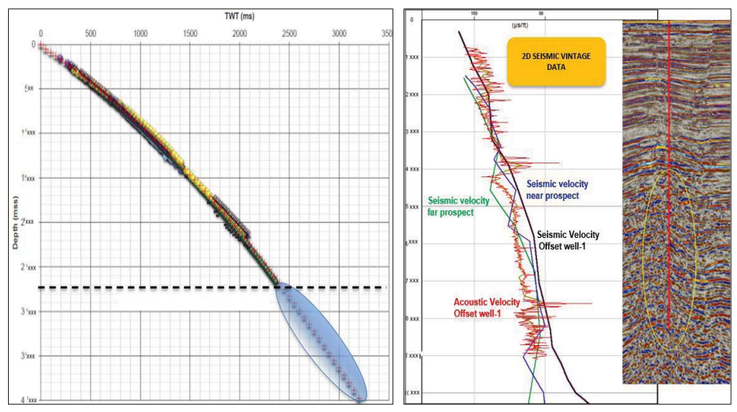




- The dominant cause of overpressure observed at the relevant offset well-1 is primarily undercompation. However the possibility of thermal generated pressure is not ruled out in the deeper undrilled cycles at the offset well.
- Pore pressure estimations were based on Eaton's method for acoustic & resistivity for the offset wells. The normal compaction trends (NCTs) applied to the existing wells keeping the slope of compaction trends similar for similar formations and depositional environment.

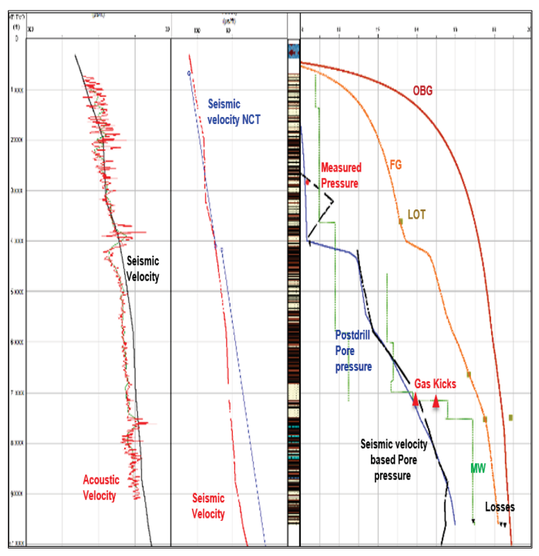
- A very shallow overpressure top with rapid pressure development was observed in the relevant offset -1 well as compared to -2 &-3 where the overpressure is deep in the pre-carbonate cycles.
- The occurrence of overpressure with rapid pressure development at shallow depth in the relevant offset well-1 may be possibly attributed to thick dominantly shale-sand sequence which is replaced by carbonate in the same cycle in the other offset wells -2 & -3 showing lesser degree of overpressure.

Seismic Challenges



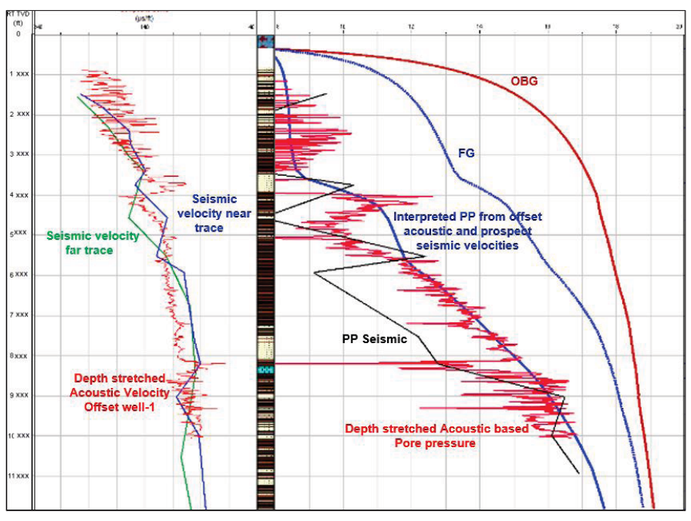
- Interpreting the seismic velocity data and having a calibrated time-depth function is one of the key underpinning assumptions of pore pressure prediction.
- A very coarse 2D seismic velocities were available for the study. The quality of seismic reflection within the prospect was good to poor with depth. The data quality was good in the shallow section where it is characterized by continuous frequency reflector. At the middle and deeper part, the data quality is challenging to interpret where it is dominated by lower frequency discontinuous events.
- The offset wells didn't penetrate the deeper cycles and hence time to depth conversion based on the offset well function carried a considerable uncertainty with depth.

Seismic Based Pore Pressure Model

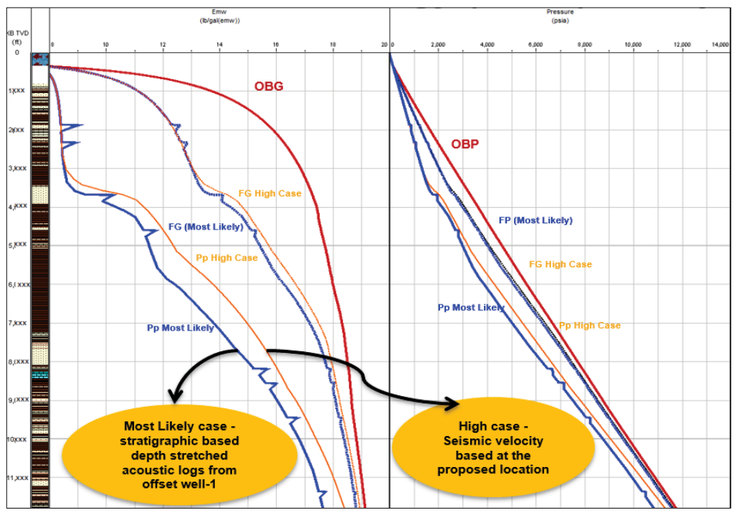


- A seismic based pore pressure prediction was carried out to test the predictive capability of the seismic velocities. Comparative analysis between acoustic and seismic showed seismic velocities are faster than the acoustic which necessitated a modified compaction trend when prediction using seismic was done. The seismic velocities are probably affected by lithology (streaks of carbonates and calcareous shales).

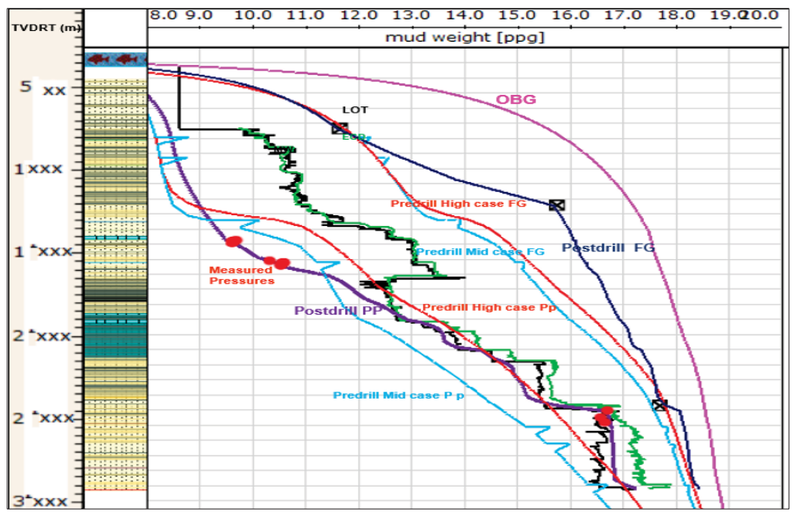
Acoustic vs. Seismic Based Pore Pressure



Predrill Pore Pressure Model



Comparative Analysis of Pre and Postdrill Pore Pressure



Summary and Conclusions

A continued real-time pore pressure monitoring from MWD data and well behavior (gas events, losses and gains) by RT PP Engineers with support from consulting and global Advisors on a regular basis provided an integrated value added service. Overall collaboration with asset team, operations team and real-time service resulted in day to day update of the models and successful monitoring of the well considering many factors like PPFG Risk overview (Low/Medium/High, based on risk matrix), RT Services recommendations and detailed geomechanics analysis. Uncertainties in pore pressure models arise from unreliable input data, uncalibrated assumptions used in the workflow, unspecified subsurface complexities as well as unknown stress conditions and rock properties. Considering all the prevalent uncertainties in the predrill stage, a PPFG risk profile (based on the regional risk matrix) was prepared for the proposed well. It was recommended to follow the most likely case pore pressure profile for well planning with contingency planning for high case. An integrated approach was adopted through a robust predrill analysis followed by realtime monitoring of the well and updating the predrill model wherever required using the new information. The shale pore pressure was within the uncertainty model which helped to make decisions on well design in realtime with reduced NPT. The predrill model predicted a manageable mud window for the middle cycles and a very narrow mud window for deeper cycles.