EXTENDED ABSTRACT

Efficient Well Delivery in Shale Plays – Examples from the Marcellus and Permian

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Summary

This presentation will discuss ways to minimize non-productive time (NPT) through geomechanics. Previously, multiple geomechanical models have been built for different areas within the Marcellus and Permian to understand previous drilling problems and optimize the design of future wells. In this talk, accumulated knowledge from multiple studies in the Marcellus and Permian has been utilized to construct a generalized geomechanical model for each play that is tailored to address the field-specific issues. These issues include weak bedding in the Marcellus and the presence of shallow underpressured zones in the Permian. We tailored our Marcellus model by increasing the typical values used for allowable breakout/failure width as well as bedding plane cohesion and friction coefficient, as we found the standard model inputs were too conservative, resulting in many drilled wells appearing to have been un-drillable. For the Permian model, we had to weigh the risk of leaving the underpressured zone exposed while drilling a lateral in the overpressured reservoir against the cost savings of skipping an intermediate casing string. In order to do this, it was necessary to look past the incorrect assumption that the shallow zones are insignificant and pay particular attention to modeling the magnitude of the shallow underpressure. In this presentation, we will illustrate how understanding previously identified geomechanics related drilling problems and tailoring our models to address them can lead to smarter well design which in turn allows for more efficient well delivery.

Introduction

Minimizing NPT is of utmost importance to controlling well costs, especially during this current period of prolonged low oil and gas prices. Certain NPT events can also have a health, safety and environment (HSE) impact, which our industry strives to minimize so as to limit the damage done to the environment and human health.

Despite a fair degree of variation in geomechanical parameters across each of the Marcellus and Permian shale plays, particularly in pore pressure (P_p) and maximum horizontal stress (S_{Hmax}), a generalized geomechanical model was constructed for each play. These are tailored for the Marcellus and Permian in order to create specific examples we will use to illustrate certain common wellbore stability problems in each area. Through a better understanding of these commonly occurring issues, we can design more efficient wells and minimize NPT in these shale plays in the future.

Method

Previously, several geomechanical models were constructed for multiple projects and wells in each play using logging data and drilling information from multiple offset wells. For each offset well, vertical stress, S_V, pore pressure, P_p, minimum and maximum horizontal stress magnitudes, S_{hmin} and S_{Hmax}, and rock properties profiles were calculated in order to construct a basic geomechanical model. Stress direction was determined primarily from observations of wellbore failure such as breakouts and drilling-induced tensile fractures interpreted from image logs. These basic geomechanical models were then fine-tuned to address problems specific to each area. In the Marcellus, these problems include weak bedding, while in the Permian shallow underpressured zones can be problematic when left exposed while drilling laterals in the Wolfcamp. Additionally, mud invasion was found to be an issue in both the Marcellus and Permian.

The resulting field-tailored geomechanical models were used to calculate a borehole collapse pressure (dependent upon the P_p, stresses, rock properties, wellbore trajectory and allowable breakout/failure width) and predict failure along each offset wellbore. Failure predicted by the tailored model was compared to the actual failure observed in the well, using drilling experience, caliper and image logs for calibration. Model parameters were re-examined and adjusted as necessary to obtain a reasonable match of predicted to observed failure before applying the model to any planned wells.

Marcellus Example

The tailored Marcellus example has slight overpressure in the reservoir and a strike-slip faulting stress regime ($S_{Hmax} > S_V > S_{hmin}$). Weak beds and two sets of vertical joints (J1 and J2) are assumed to be present. The beds are assumed to be horizontal while the J1 and J2 joints are assumed to be parallel and perpendicular to the orientation of S_{Hmax}. The lateral portion of the well is assumed to be drilled parallel to the orientation of S_{hmin}. Reservoir rocks are assumed to be moderately strong (e.g. UCS = 8,000 psi). Platy shaped cavings, often indicative of weak bedding planes (Gallant et al., 2007), were observed in some of the more problematic study wells while drilling highly deviated sections of the well. Modelling confirmed that the instability experienced in the offset wells could not be explained by isotropic failure, and weak bedding was included in the geomechanical models. Weak bedding can have a large effect on the model predictions (Aadnoy and Chenevert, 1987; Willson et al., 1999, Zoback, 2007), as was the case in our Marcellus studies.

Figure 1 shows the impact of weak bedding planes on the mud weight required to prevent excessive wellbore failure. Excessive wellbore failure (collapse) is defined as the breakout/failure width exceeding the designed parameters – here 90° wide in a vertical well and 60° in a lateral well. In Figure 1, the stereonet on the left shows the minimum mud weight required to prevent excessive wellbore failure for any well trajectory for our tailored Marcellus example in the absence of weak bedding planes. The stereonet on the right uses the same input parameters but also includes the effects of horizontal weak bedding planes with 800 psi of cohesion and a friction coefficient of 0.6. The inclusion of weak bedding has increased the mud weight recommended to drill a horizontal well parallel toward S_{hmin} by ~1.9 ppg (from~9.5 to ~11.4 ppg; Kowan and Ong, 2016; Addis et al., 2016). Note that the same color scale has been used in both plots. In this presentation, we will discuss the potential impact of using the high mud weights required to stabilize weak beds as well as other possible alternatives.

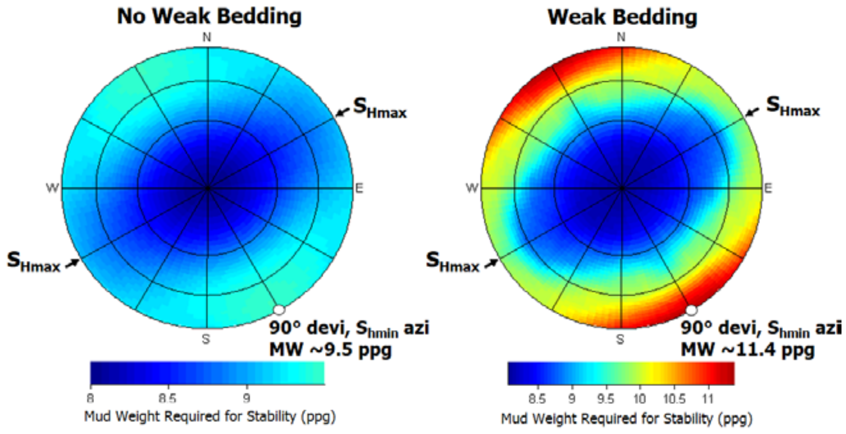

***Figure 1**, from Kowan and Ong (2016). The mud weight required to maintain stability significantly increases if weak shale beds are added to the model (compare left and right plots). Drilling parallel to S_{hmin} (white circle) requires the highest mud weight to prevent excessive wellbore failure.*

Traditionally, 30° has been used as the upper limit for breakout/failure in a horizontal well, and bedding plane cohesion and friction coefficient values have been set closer to 300 psi and 0.4, respectively, but these values were found to be too conservative in the Marcellus with many drilled wells appearing to have been un-drillable when standard model inputs were applied. We can consider these adjustments to standard input parameters to be local calibration factors that have been referenced to the drilling experience.

Permian Example

The tailored Permian example also has slight overpressure in the reservoir but is in a normal faulting stress regime ($S_V > S_{Hmax} > S_{hmin}$). Figure 2 shows the P_p and stress profile of this tailored Permian example, which will be used to illustrate the potential complications to mud and casing programs of having a shallow underpressured zone above an overpressured reservoir. In Figure 2, the plot on the left shows the Pp and stress profile with normal pressure above the reservoir (note the reservoir pressure begins to ramp up at ~9000 ft TVD). The plot on the rights shows the adjusted P_p and stress profile when there is a shallow naturally underpressured zone (dashed lines). Understanding the potential complications posed by a shallow underpressured zone is necessary to evaluate certain drilling risks. For example, is the risk of leaving the underpressured zone exposed while drilling a lateral in the overpressured reservoir worth the cost savings of skipping an intermediate casing string? The answer likely lies in the previous drilling history as well as the relative magnitude of the under- and overpressurization.

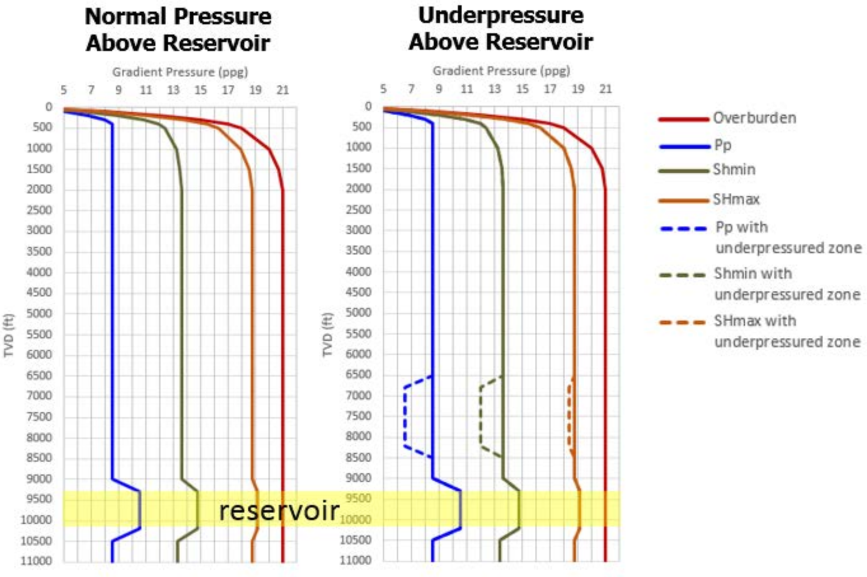

Figure 2 *shows the P_p and stress profile of our tailored Permian example. The plot on the left shows the Pp and stress profile with normal pressure above the reservoir (note the reservoir pressure begins to ramp up at ~9000 ft TVD). The plot on the rights shows the adjusted P_p and stress profile when there is a shallow underpressured zone (dashed lines).*

Conclusions

These examples of tailored geomechanical models from the Marcellus and Permian shale plays have been used to illustrate certain common wellbore stability problems in each area, such as complications posed by weak bedding planes in the Marcellus and shallow underpressured zones in the Permian. Through a better understanding of these common wellbore stability risks, we can better weigh drilling risks and thus deliver more efficient wells by minimizing NPT in these shale plays in the future.

Acknowledgements

The authors wish to thank J. Kowan Consulting, LLC and Baker Hughes, a GE company, for the opportunity to present this work.

References & Further Reading

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