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Integrated approach to address wellbore instabilities in the Fold Thrust Belt, Assam Arakan Basin

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Abstract

Integrated approach has been taken to understand the distribution of stresses in a region of intense folding and thrusting, which in turn helped to address the root cause of well bore instability. In this study, we have analyzed the drilling complications and presented a Geo-mechanical modeling to address the severe wellbore instabilities encountered in an onshore exploratory well drilled in the fold-thrust belt of Assam Arakan Basin. The studied well, drilled in the Ramphan structure had experienced severe drilling complications due to excessive wellbore failures in the Lower Bhuban and Renji Formations, leading to premature wellbore abandonment. These formations are observed to be over pressured with a high shear failure gradient of ~11.6-12.8 PPG. Based on the post-drill Geo-mechanical modeling, we interpreted the suitable down hole mud weight window to avoid such instabilities in future exploratory wells. Limitations of the workflow and necessary recommendations are discussed as well.

Introduction

Drilling exploratory wells in fold-thrust belts is challenging due to the complex stress distribution. Pore pressure analysis and Geomechanical modeling is critical to design the stable mud window and successful well completion. In this study, we analyzed an onshore exploration well drilled in the Cachar fold-thrust belt of the Assam-Arakan Basin (Figure 1a). The studied well was drilled through the Middle Miocene Upper and Middle Bhuban, Early Miocene Lower Bhuban and terminated in Late Oligocene Renji Formation in a transpressional stress regime (Figure 1b). The selected well is the first well drilled in the anticline structure, however it had to be prematurely abandoned at 3076m while the target depth was 3245m. The geological objectives could not be achieved due to severe wellbore instability issues and wireline logs could be recorded till 2836m only. The operator experienced huge nonproductive time (NPT) as the well took 294 days when compared to the planned 188 days, majority of which was contributed by the drilling issues faced in 12.25" and 8.5" sections (Figure 2a).

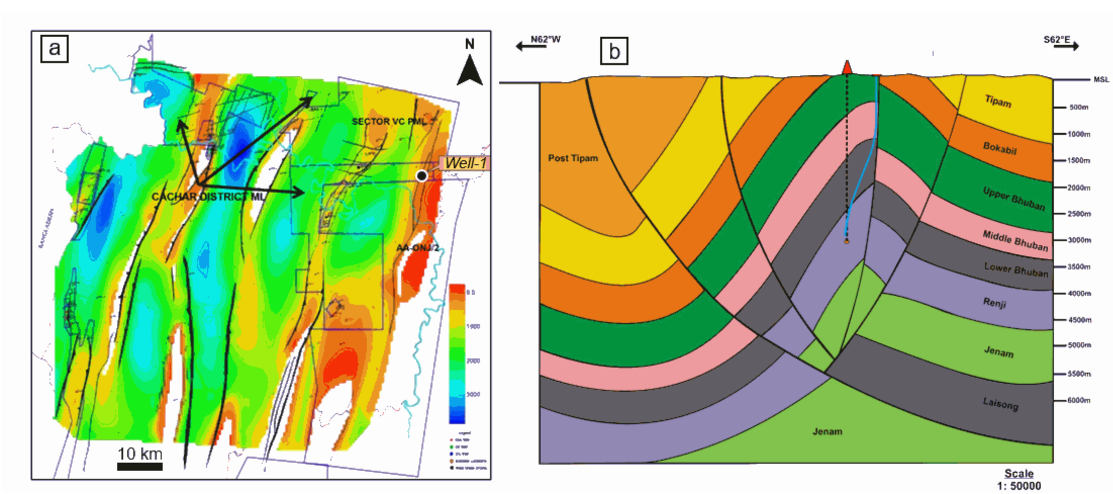

Figure 1: Location map of the studied exploratory well in the Cachar fold thrust belt, Assam Arakan Basin.

Drilling events like frequent held ups, tight pulls, severe torque and drag and string stalling were observed in the 12.25” and 8.5” sections of the wellbore. Wireline logs indicate caliper readings as high as 22” (average ~16”) against the 8.5” section. In most of the cases the caliper got saturated due to bad hole. Huge cavings were observed in this section which choked up the down hole tools (MWD, bit sub etc.) (Figure 2b-d) and contributed to the hole cleaning issues and mechanical stuck up in the process. Five cement plugs were carried out prior to side track the well and finally the well had to be abandoned due to severe failures in the Late Oligocene Renji Formation. In this work, we attempted a post-drill geomechanical analysis of the mentioned well to address the wellbore instability by integrating wireline logs, drilling data available down hole measurements and regional geological understanding. The principal objectives of this work are to estimate pore pressure, fracture gradient and decipher shear failure gradient. Being the first well in the structure and due to the limited data availability, our target was to constrain the various geomechanical parameters following a conservative approach to shed lights on the observed instability issues.

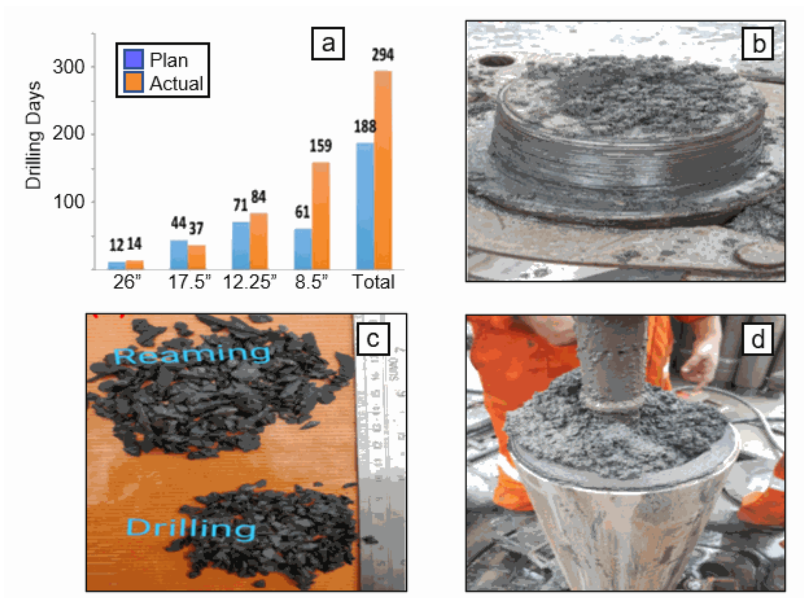

Figure 2: Drilling complications encountered in the studied well; (a) Phase wise planned vs actual drilling days, (b) Bit sub choked up with shale and silt cuttings, (c) Cavings observed during reaming and drilling, (d) MWD tool choked with very fine cuttings.

Estimation of geomechanical parameters

Here we briefly discuss the steps to estimate the various geomechanical outputs of this work: vertical stress or overburden stress gradient (OBG), pore pressure (PP), fracture gradient (FG) and shear failure gradient (SFG). Estimation of OBG was straight forward, by using bulk-density log. Since the top section was not logged (0-200m in the studied well), we generated pseudo-density profile using Amoco relationship, which was then combined with the wireline log to generate a composite density profile before using it for OBG calculation. Pore pressure (PP) was predicted against shale sections using compressional sonic slowness (DT) dataset by employing the Zhang (2011) model. The equation is as follows:

$$PP = OBG - (OBG-Phyd) * [\{\ln(DTml-DTm) - \ln(DT-DTm)\} / (c*Z)] \quad \ldots\ldots\ldots\ldots (1)$$

Where, Phyd is the hydrostatic pressure, DTml is the DT log value at mud line, DTm is the matrix slowness value, Z indicates depth. The parameter ‘c’ is the normal compaction parameter which is obtained from the following normal compaction trendline (NCT) of transit time (Zhang et al., 2020):

DTn = DTm + (DTml – DTm) $e^{(-cZ)}$ ………………. (2)

Where, DTn is the DT value along NCT. Fracture pressure gradient (FG) was determined using effective stress ratio (k1)-based approach (Matthews and Kelly 1967). The equation is as follows:

FG = k1 (OBG – PP) + PP.............(3)

Where, 'k1' is inferred from Leak-off tests recorded at casing shoes. To address the wellbore stability, shear failure gradient (SFG) was estimated using Mohr-Coulomb failure criteria (Gholami et al., 2014):

SFG = {3SHMax-Shmin-UCS+PP(Q-1)}/(Q+1)…………….(4)

Where, SHMax and Shmin are the maximum and minimum horizontal stress gradients, respectively. Due to the unavailability of the extended leak-off test, we considered FG as Shmin in the SFG calculation. UCS is the unconfined compressive strength calculated from sonic compressional slowness and Q is a function coefficient of internal friction (µ). Due to the unavailability of the image log-based breakout width information, we followed the following approach to estimate SHMax (Lang et al., 2011):

SHMax = k2 (OBG – FG) + FG ....(5)

Where, 'k2' is known as tectonic factor. Authors suggested K2<1 for normal faulting stress regime and it varies between 1-2 in strike-slip and reverse faulting stress regimes.

Results and discussions

The Amoco pseudo-density profile for the studied well established considering a surface sediment density of ~1.9 gm/cc and Amoco coefficient of 0.4. These set of parameters provided a satisfactory trend of the synthetic density when compared with the wireline bulk-density log. Density log was unavailable in the 8.5" section, so a Gardner density was calculated against the Renji Formation. The measured and calculated density profiles were compiled into a composite density profile and at the logging TD of 2831m, the estimated OBG value is observed as 20.6 ppg (Figure 3). This translates to a 1.03 PSI/ft or 23.29 MPa/km vertical stress gradient.

To estimate the shale PP, we employed a normal compaction trend line-based approach using DT log. Based on the gamma ray cut-offs, shale intervals were distinguished and a DT-NCT was established using Equation (2) where we considered a mud line slowness of ~90 µs/ft and a matrix slowness value of 54 µs/ft. With these values, a compaction parameter 'c' value of 0.0006 was observed to be best fitting, which was used for both the wells to estimate PP using Equation (1). The calculated PP is presented in Figure 3. The final PP profile was interpreted by combining the DT-based model output and drilling mud weight as proxy, which indicates a hydrostatic pore pressure of ~8.5 ppg in the Upper Bhuban and top part of Middle Bhuban Formations till 1400m. PP increases gradually from hydrostatic to 10.08 PPG in the Lower Bhuban Formation; this section was drilled with 10.4-10.75 PPG mud weight. The Renji Formation is seen to have a higher pore pressure of 11.25 PPG and it was successfully drilled with 12 PPG mud weight (Figure 3). Absence of any connection gas or formation fluid influx event indicates that the drilled mud weight was sufficiently overbalanced.

A reliable FIT of 16.6 PPG was available from the 13 3/8" shoe and we estimated FG using an effective stress ratio (k1) value of 0.72 (Figure 3). Due to the unavailability of LOT or extended LOT, we could not calibrate and establish a confident FG profile, however the presented FG can be considered as a lower bound, which is just above the recorded FIT.

SHMax was the most difficult parameter to estimate due to the unavailability of any calibration data. The study area belongs to a fold-thrust belt (SHMax > OBG) which indicates that K2>1 (Equation 5). In this study, we have considered k2~1.1, which provides a lower estimate of SHMax (Figure 3). Elastic properties and rock strength parameters were estimated using bulk-density and sonic logs. Results are presented in Figure 4. Poisson's ratio (υ) varies between 0.29-0.37; Young's modulus (E) has a range of 24-47 GPa. DT-derived UCS varies between 21-40 MPa, while the coefficient of internal friction (μ) exhibits a narrow range of 0.55-0.73 with an average value of 0.7. Fast Shear azimuth data was also available from the studied well which indicates a dominantly NE-SW orientation for the SHMax (Figure 4).

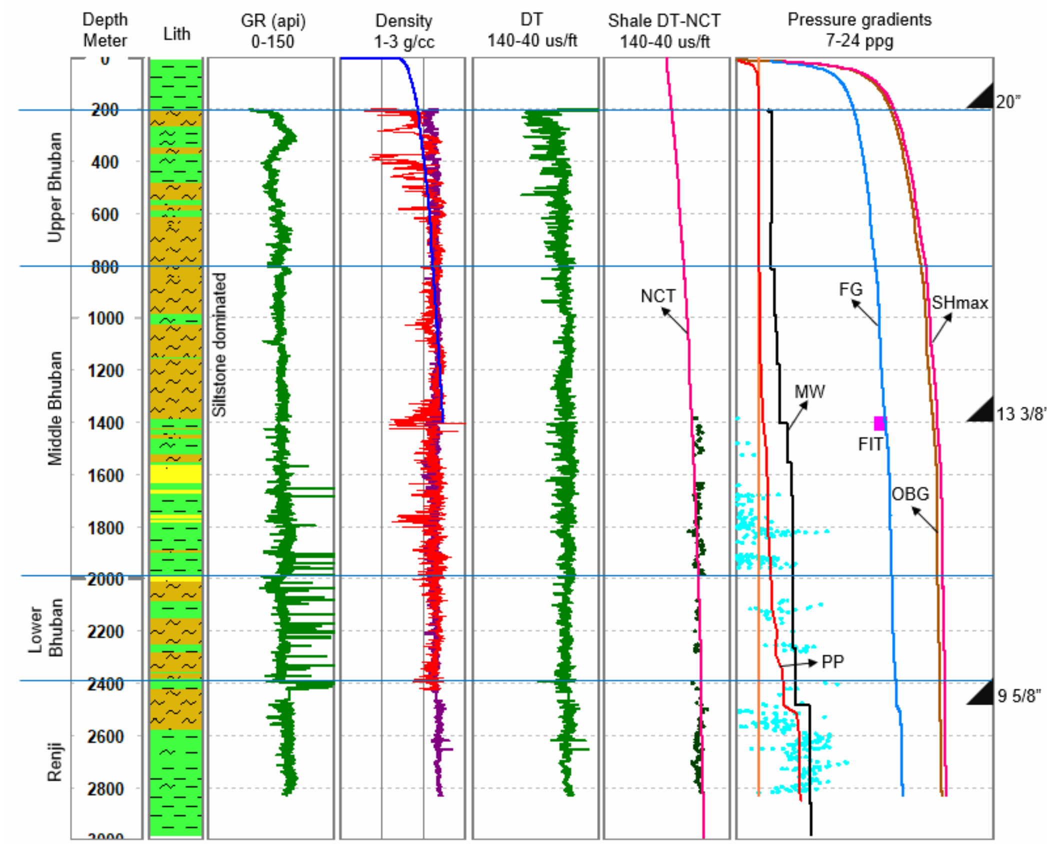

Figure 3: : Interpreted sonic compaction trendline and estimated pressure gradients in the studied well.

The studied well exhibits massive wellbore failures in the Lower Bhuban and Renji Formations. The lower part of the Lower Bhuban Formation shows 16-20" hole size in caliper log against the 12.25" hole diameter (between 2305-2430m). The Ranji Formation, drilled with 8.5" bit size is more affected by failures, as seen by consistent 16" caliper, while the maximum drilled hole diameter reaches 22" which caused a lot of drilling complications. To address the wellbore instabilities, we employed Mohr-Coulomb criteria to estimate the shear failure gradient. Based on the rock-mechanical properties, PP and in-situ stress magnitudes (as discussed previously), the estimated SFG is presented in Figure 5. When compared with the drilling mud weight data, it indicates consistently higher SFG in Lower Bhuban and Renji formations than the mud weight. The Lower Bhuban has a SFG range of 11.6-11.9 PPG, and the Renji Formation has an average SFG of 12.8 PPG, while the maximum mud weight utilized while drilling was 12 PPG. We infer that mud weight was insufficient to prevent the compressive failures. A higher mud weight (> 12.8 PPG at least) is required to decrease the circumferential hoop stress below rock compressive strength and minimize such failures. It is to be noted that the lower estimate of FG in the Renji Formation is estimated as 17.9 PPG, which should be considered as the maximum allowable down hole mud weight to avoid any fluid loss.

Conclusions

Being the first well in the structure, this work has been performed in a minimum data environment. Down hole formation pressure measurements were not taken. However mud overbalance was considered indirect indicator of formation PP trend. Only one FIT was available, which restricted us to establish a confident fracture gradient. However the actual FG might be higher, the presented FG can be considered as a lower estimate or a very conservative one. LOT and extended LOT (XLOT) from the future exploratory wells will be critical to confidently constrain the inferred FG. XLOT with multiple cycles (at least two) will be the ideal one which can provide us confident fracture closure pressures (FCP). FCP measurements could then be used to estimate Shmin, which is a critical input parameter for SHMax as well as SFG. Uncertainty is also present in SHMax, which can be much higher than our conservative estimate. A higher SHMax will result in a much higher SFG value. Considering the potential uncertainties, we conclude that the discussed SFG is a lower bound of shear failure. Image logs, if recorded in the future wells, can provide in-depth information about the formation failures and horizontal stress calibrations. Exposure time of open hole in a well, especially in thrust belts has to be reduced so that the down hole complications due to hole instability can be minimized. This can be achieved by faster drilling using specialized bits based on Drill Bit Optimization Studies (DBOS). Efforts may be made to keep the section lower where formations have high shear failure gradient (i.e. Renji Formation). Down hole complexities can be minimized by using specially designed drilling fluid system after studying compatibility with the drill cuttings. Rigs with sufficient mud pump capacities need to be deployed while drilling in this tectonically challenging areas. To drill the over pressured deeper targets, managed pressure drilling (MPD) will be more suitable compared to conventional drilling methods.

Having said that, the present work shed critical insights about the failure behaviour of the studied well. Lower Bhuban and Renji Formations are mildly overpressured and have higher shear failure gradients. We discussed the optimum drilling window to avoid such failures and potential fluid losses, which will be beneficial for planning the future exploratory wells in and around the study area.

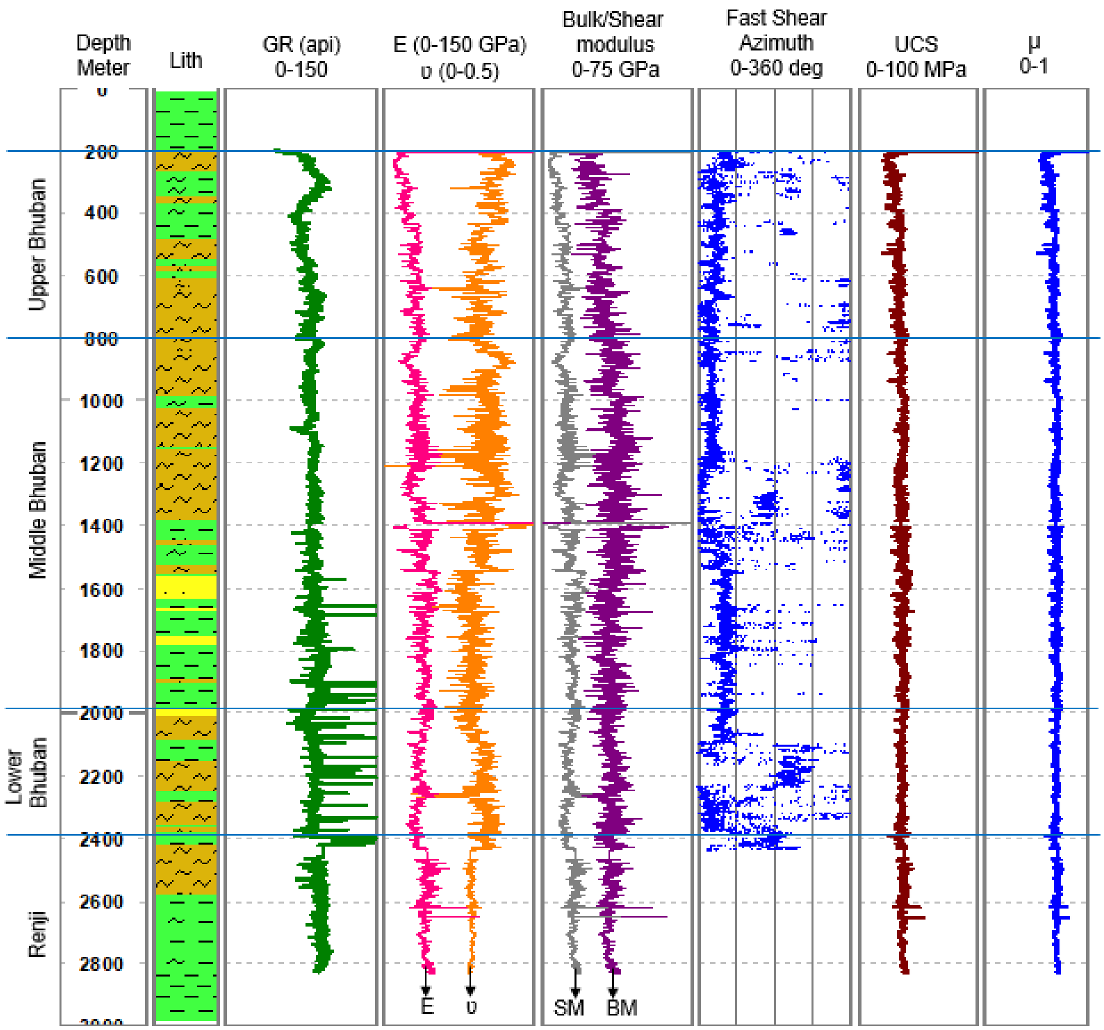

Figure 4: Estimated rock-mechanical properties and Fast Shear azimuth in the studied well. E = Young's modulus, SM = Shear modulus, BM =Shear modulus, υ = Poisson's ratio, μ = coefficient of internal friction, UCS = unconfined compressive strength.

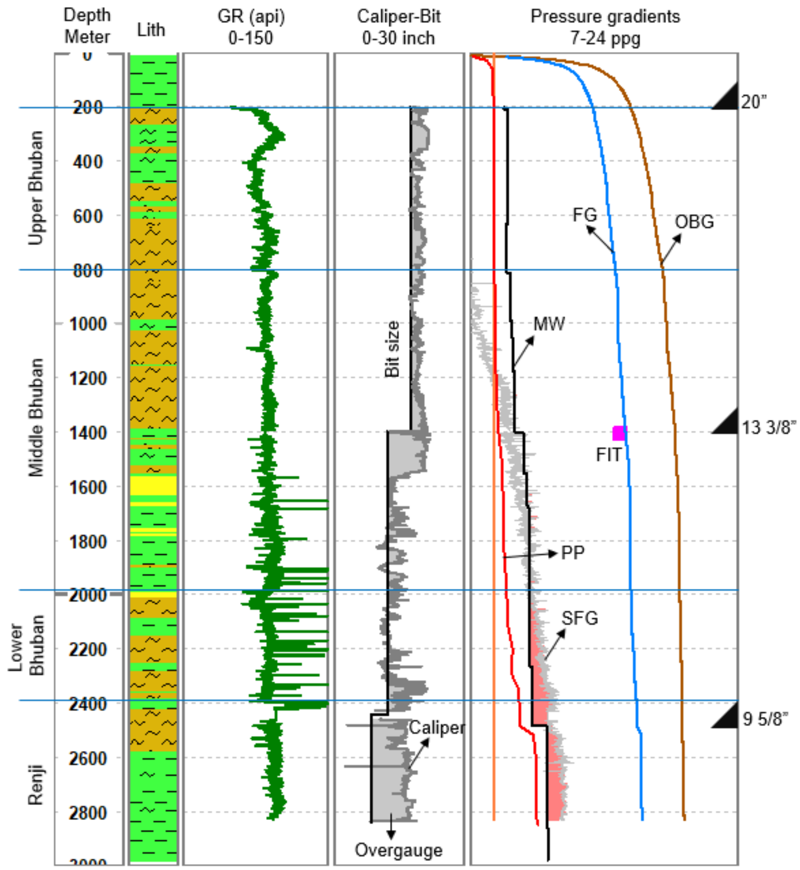

Figure 5: Wellbore failure and estimated shear failure gradient in the studied well. MW = drilling mud weight.

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References

Gholami, R., Moradzadeh, A., Rasouli, V. and Hanachi, J., 2014. Practial application of failure criteria in determining safe mud weight windows in drilling operations. Journal of Rock Mechanics and Geotechnical Engineering, 6(1), 13-25.

Lang, J., Li, S. and Zhang, J., 2011. Wellbore stability modeling and real-time surveillance for deep water drilling to weak bedding planes and depleted reservoirs. In SPE/IADC Drilling Conference and Exhibition, Amsterdam, The Netherlands, March 1-3, SPE-139708.

Matthews, W.R. and Kelly, J.,1967, How to predict formation pressure and fracture gradient, Oil Gas Journal, vol.65, pp.92-106.

Zhang, J., Zheng, H., Wang, G., Liu, Z., Qi, Y., Huang, Z. and Fan, X., 2020, In-situ stresses, abnormal pore pressures and their impacts on the Triassic Xujiahe reservoirs in tectonically active western Sichuan basin, Marine and Petroleum Geology, vol. 122, 104708.

Zhang, J., 2011, Pore pressure prediction from well logs: methods, modifications, and new approaches, Earth Science Reviews, vol.108, pp.50–63.