Pore Pressure Estimation Using Resistivity Log in the Southern Pattani Basin, Gulf of Thailand

Pongpipat Bunyanupong

Petroleum Geoscience Program, Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok 10330, Thailand

*Corresponding author email: pongpipat217@gmail.com

Abstract

The application of Eaton's resistivity log-based pore pressure prediction method is typically not a pore pressure analyst's preferred method, yet a resistivity log is run is almost every well to identify hydrocarbon occurrence. Rather, Eaton's sonic log -based approach is typically used to predict overpressure in the Gulf of Thailand and other hydrocarbon basins in SE-Asia. Significant factors affecting the utility of resistivity measurement are typically poorly constrained or quantified over the complete downhole length of a resistivity log run. Rather the log-analyst tends to focus on the interpretation of a suite of resistivity logs in particular zones of potential hydrocarbon occurrence. And so, until now, Eaton's resistivity approach has not been successfully used for reliable pressure prediction in the Pattani Basin, Gulf of Thailand. Success requires accurate downhole corrections for salinity and temperature variation, and application of appropriate resistivity filters to minimize influences of organic-rich shale and radioactive non-shale formations. The methodology and filtering approach developed in this study means resistivity logs, rather than sonic logs can reliably predict overpressure in the Gulf of Thailand. This approach can supplement or even replace the sonic-based method as a resistivity log suite is typically run in every petroleum well in Pattani Basin, and in most other hydrocarbon basins worldwide. Its application can also improve cost efficiencies in terms of wireline tool selection for pore pressure analysis in any particular well in the Gulf of Thailand. Furthermore, in order to increase drilling efficiency and minimize drilling risk, it can be used as real-time application while drilling (MWD/LWD) and so perform real-time pore pressure prediction during field operations.

Keywords: Overpressure, Eaton's Resistivity method, Eaton's Sonic method, Southern Pattani Basin, Gulf of Thailand

1. Introduction

Abnormal pressure or overpressure can cause severe drilling incidents such as fluid influxes, gas kicks or blowouts in situations where pore pressure profiles are not well defined. Such outcomes can impact also on drilling cost efficiencies. Accurate pore pressure prediction is necessary for pre-drill assessment and safer well planning, especially in the exploration phase, where it is needed for more responsive mud weight schedules and casing point determinations, as well as mitigating drilling risks and avoiding non-productive time in the operation. Usual pore pressure prediction methods utilizing wireline-based methods rely on sonic transit time logs. Eaton (1972) and Bowers (1995) published successful methods using sonic-based approaches to predict shale pore pressure under the assumption that shale pore pressure is at equilibrium level with pore pressure in the adjacent sand intervals.

In this research study, the Eaton resistivity method (1972) is tested for pore pressure prediction for the first time in this area. Outcomes are compared to measured pore pressure data and to the successful sonic-based method, which is widely used in the region (Amonpantang, 2010). Techniques and filters are developed and tested in order to improve resolution on resistivity data and so lead to more reliable and consistent outcomes, when compared to sonic-based pore pressure prediction method.

2. Methods

Testing the applicability of Eaton's resistivity method is done in the knowledge that resistivity measurements are affected by changes in temperature and salinity, and also altered by measurements in presence of organic-rich shale. Hence, temperature and salinity correction and filtering techniques for anomalous organic-rich shale are undertaken in this study of shale resistivity identification in order to improve the resolution and increasing the accuracy and reliability of resistivity data outputs.

SHALE RESISTIVITY IDENTIFICATION

Shale resistivity identification is a critical part of this study, as the studied rock generally contains a mixture of matrix material and formation fluids in pore spaces. The rock matrix and organic material, including hydrocarbons, act as electrical insulator, except for the formation water and water-based mud filtrate, both of which tend to be conductive. The resistivity of the rock, as measured by the resistivity log, therefore depends only upon the salinity and temperature of formation water or water-based mud filtrate occupying its pore space.

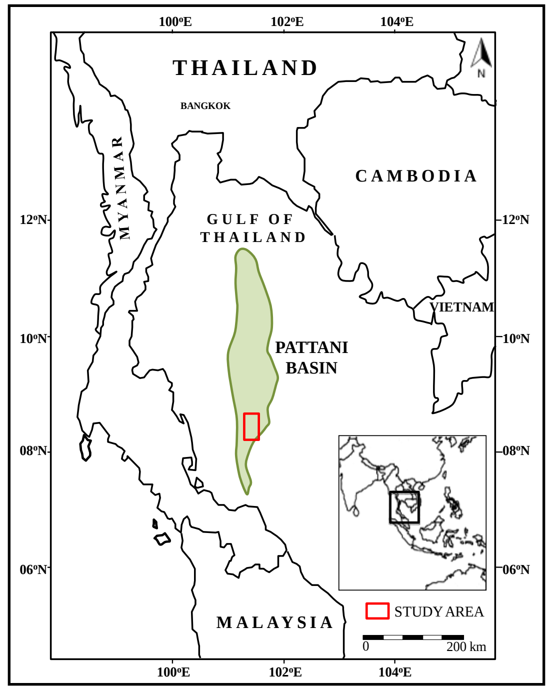

Figure 1. The area of study is located in the southern part in the Pattani Basin, Gulf of Thailand.

TEMPERATURE AND SALINITY CORRECTION

The resistivity measurement is sensitive to changes in temperature and salinity. Both temperature and salinity changes must be considered as part of this study. Thus, it is necessary to set up a reference set of downhole temperature and salinity conditions. The Arps formula (Schlumberger, 1972) is used to compensate for downhole temperature and salinity changes.

The temperature gradient is derived from a gradient quadratic regression from temperature samplings of the wireline formation test (RFT). In this study, the bottom hole temperature of all selected wells are close to 400 °F, therefore; it can be used as the reference temperature. From the sensitivity analysis**,** it can be seen that it does not really matter whichever reference temperature is applied. However, using a reference temperature at 400 °F makes much easier to capture a normal trend line (Figure 2).

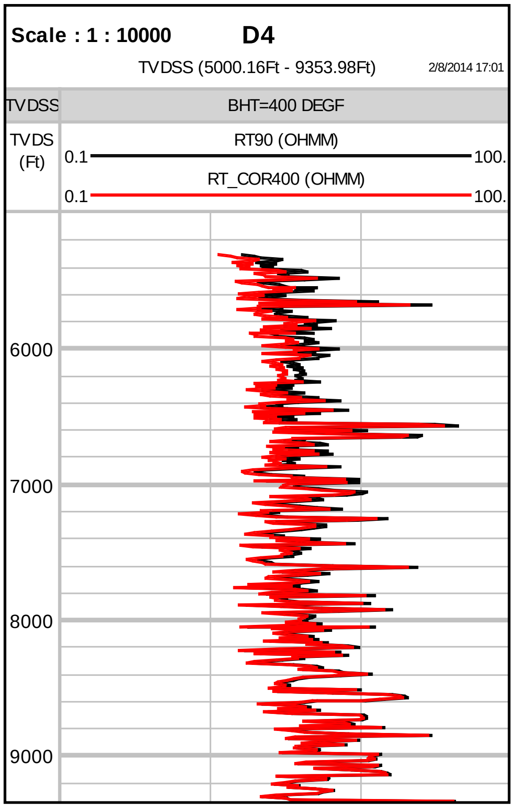

Figure 2. The corrected resistivity curve for a reference temperature (BHT=400 DEGF), compared to non-corrected resistivity.

ORGANIC-RICH SHALE DISCRIMINATION

Identifying properties of clean shale is perhaps one the most important techniques in this study that will improve the resolution and reliability of analyzed resistivity data. Using a gamma ray log alone to discriminate shale can be misleading, especially in radioactive sands (Mathews, 2004). From Kamvan (2013), it is now known that organic-rich marine shale signature can be recognized reliably on wireline log assemblages in the offshore of Thailand. These organic rich shales are generally thin, with relatively higher radioactivity values and especially elevated resistivity values compared to non-organic shale. Such intervals cause spikes in the resistivity log and so increases the noise in the resistivity data if used to indicate overpressure. Therefore, all anomalous organic-rich shale formations have to be first identified and filtered out. Next, shale volume has to be computed from neutron-density separation to minimize the influence of heavy minerals in non-shale lithology (i.e. radioactive sands). More than 85-90% shale volume is used as a Vsh cut-off for determining the clean shale points. Finally a shale resistivity curve is created by filling and smoothing the data gaps within shale points to capture the general trend of actual shale resistivity trend (Figure 3).

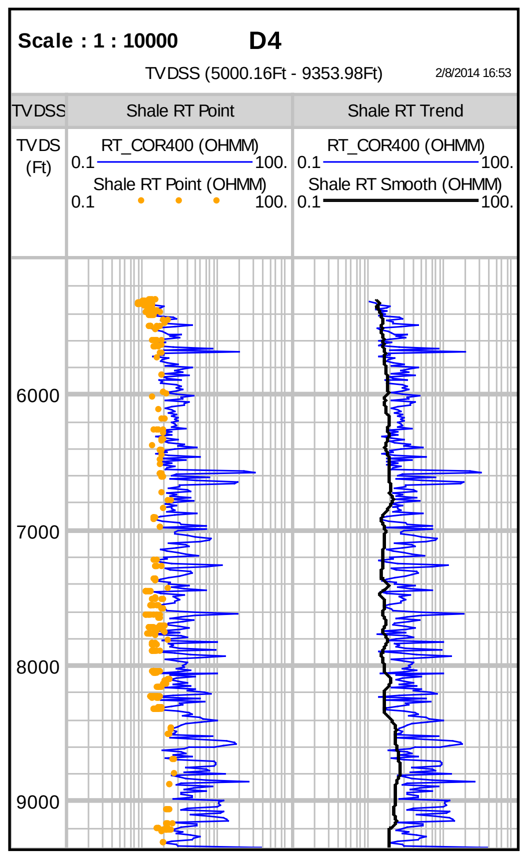

Figure 3. Shale resistivity trend is generated by filtering and smoothing all shale points.

NORMAL COMPACTION TREND

For this study, a normal compaction trend, NCT, is roughly constructed by estimating, on semi-log basis, a general trend within clean shales outside the reversal (abnormal pressure) interval (that is in the hydrostatic interval) and then utilized within the production section. Because wireline data in both the shallow and intermediate sections is not available and the onset of pore pressure in both sections is not seen in all wells, it can be difficult to establish the NCT in all wells**.** This is a likely cause of uncertainty in some intervals in this study. Matthews (2004) noted that most of the uncertainty associated with pore pressure prediction is related to the correct choice of NCT and Eaton (1975) has recommended that the NCT should be constructed using experience and all relevant available data.

However, in this area, the NCT can be calibrated and refined with actual pore pressure and mud weight data available within non-reversal section (hydrostatic) and it shows a consistent relationship between the resistivity reversal and the top of overpressure. Hence, it is reasonable to establish the NCT on semi-log basis, utilizing pore pressures measured outside reversals and in hydrostatic interval (Figure 4).

3. Results

EATON'S RESISTIVITY METHOD

Eaton's resistivity equation (1972) is used to construct estimated pore pressure curve. The range of the Eaton's exponent as used in this study varies from 0.6-0.7, because it has to be adjusted to provide the **best fit** between the estimated and measured pore pressure trends (Figure 4) and to be more consistent when applied in every well. This technique demonstrates similar well-matched results across the all selected wells.

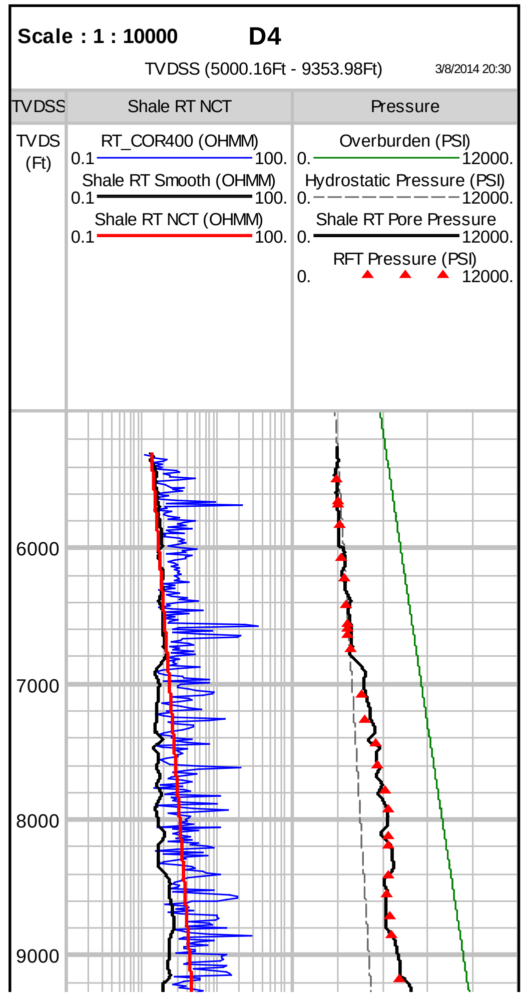

Figure 4. Shale resistivity NCT (red line) roughly constructed and extrapolated based on the hydrostatic interval. Estimated shale pore pressure (black line) compiled using Eaton resistivity method and compared to measure pore pressure collected from RFT.

4. Discussion

Amonpantang (2010) successfully used Eaton's sonic-based pore pressure prediction method for predicting subsurface pore fluid pressure in the Gulf of Thailand. This technique is commonly and successfully applied to many sedimentary basins worldwide and is typically preference to a resistivity-based method. In principle, the primary or compressional wave transmitted from the sonic tool only responds to bulk density of the rock, which is related to a change in solid to liquid ratio. During burial, increasing overburden stress causes sonic velocity to increase because pore fluid is expelled and porosity is reduced at the same time as sediment compacts. In contrast, resistivity tool (induction type) measures the conductivity in the rock. It responds to conductive formation fluids such as brine in the pore spaces. The similarity between resistivity and sonic responding to the rock framework is related to the change in the solid to liquid ratio. In the resistivity method this related to change in cross section area and length of an electrical pathway needed to conduct the electrical current in the rock. Hence, compacted sediments should be higher resistivity than uncompacted sediments. However, there can be significant variations in conductivity values that are the result of changes in salinity and temperature, and the amounts of non-conductive fluid (as well as organic matter content). These factors can be poorly constrained in subsurface studies and this makes an argument in term of reliability that possibly favors sonic-based pore pressure prediction over resistivity methods.

Eaton's resistivity approach, is not typically used, and so was studied herein. As outlined earlier, it uses the same conceptual framework as the sonic-based method to define pore pressure. However, poorly constrained changes in salinity and temperature and the presence of organic-rich shale affecting resistivity measurements can create difficulties for the pore pressure analyst, compared to the sonic-based method. This study establishes pressure prediction using resistivity can be a reliable technique in the Gulf of Thailand. With appropriate data understanding, preparation and filtering, the resolution, accuracy and reliability of

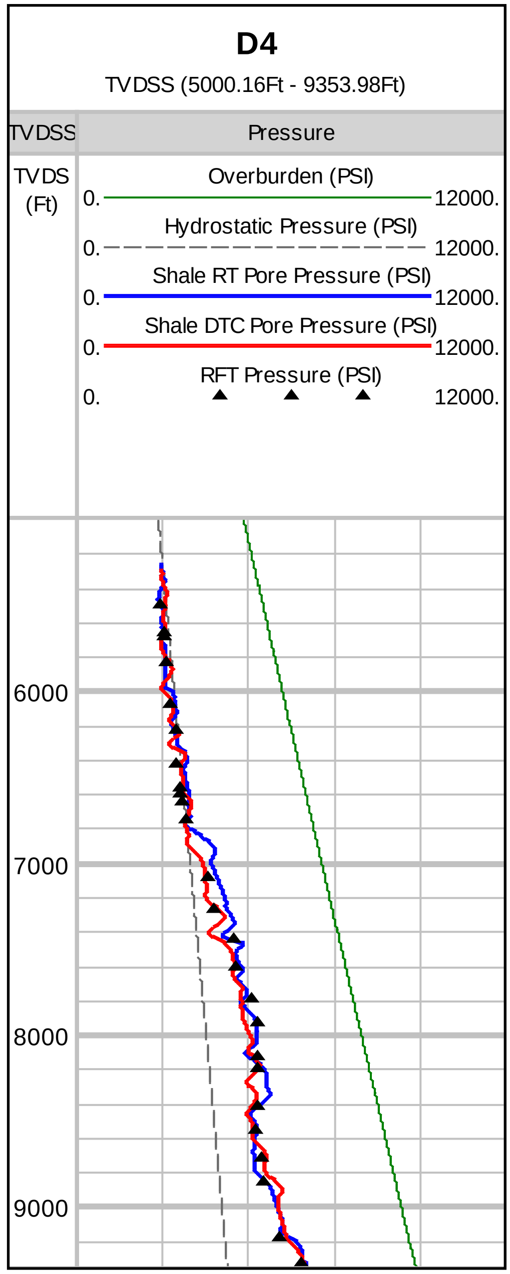

Figure 5. The plot demonstrates that resistivity-based pore pressure prediction is reliable at an acceptable level when compared with the predictions of the sonic-based method. Both overlie the RFT data (black triangles).

resistivity-based predictive curves increase. Output can be improved to where it provides an identical result with Eaton's sonic-based method. Importantly, resistivity logs are run in almost every petroleum well, while there are far fewer wells with a sonic log. This means the resistivity-based method has broader applicability compared to the sonic method.

5. Conclusions

The Eaton's resistivity-based pore pressure prediction procedure, as modified and applied in this study, has the potential to supplement and even replace sonic-based methods in the Gulf of Thailand. This is true both in terms of reliability and in improving cost efficiencies. The latter is so, because resistivity is an essential wireline tool, typically run in every well. In contrast, sonic is typically run only in selected wells. The methodology can be reliably applied to other fields in the Pattani Basin and many other other sedimentary basins worldwide, especially those dominated by shale-sand systems. This resistivity method produces an estimated pore pressure trend, which could be useful in areas where pore pressure profiles are not well defined and its application would facilitate an approach of "filling in the gaps" when determining top of overpressure. In addition, this methodology can be used as a real-time analytical technique that can integrate with offset well information, this enables an MWD operator to utilize the results immediately and so improve safety and drilling performance.

6. Acknowledgements

First of all, I would like to express my sincere thanks to my supervisor, Professor John K. Warren for his invaluable support and constant encouragement throughout the course of this research. I would like to thank Chevron Thailand Exploration and Production, Ltd. for the use of their data. I appreciate all Chevron Petrophysics team for their help and support through this research.

7. References

Amonpantang, P., 2010, An Overpressure Investigation by Sonic Log and Seismic Data in Moragot Field, Gulf of Thailand: Master's thesis, Chulalongkorn University, Bangkok, 64 p.

Bowers, G. L., 1995, Pore pressure estimation from velocity data: Accounting for overpressure mechanisms besides undercompaction: SPE Drilling & Completion, v. 10, p. 89-95.

Eaton, B. A., 1972, The effect of overburden stress on geopressure prediction from well logs: Journal of Petroleum Technology, v. 24, p. 929-934.

Eaton, B. A., 1975, The equation for geopressure prediction from well logs: Fall Meeting of the Society of Petroleum Engineers of AIME, Dallas, Texas.

Kamvan, J., 2013, Different Types of Organic-Rich Geological Markers in the Sub-Surface in the North Pailin Field, Pattani Basin, Gulf of Thailand: Master's thesis, Chulalongkorn University, Bangkok.

Matthews, M. D., 2004, Uncertainty-Shale Pore Pressure From Borehole Resistivity: Gulf Rocks 2004 the 6th North America Rock Mechanics Symposium (NARMS), Houston, Texas.