Development of a Pore Pressure and Fracture Pressure Gradient Prediction Model for few exploration blocks in Mannar and Cauvery Basins, offshore Sri Lanka

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Abstract: Availability of a pore pressure and fracture pressure gradient prediction model for petroleum well drilling is a basis for safety, cost effectiveness and the efficiency of the overall drilling program. Petrophysical data and measured pressure data of four wells previously drilled in the Mannar basin and Cauvery basin were reviewed to establish such a model for few petroleum exploration blocks in Sri Lanka. The pore pressure gradient prediction strategies used for the analysis are, Hottman and Johnson method, Ben Eaton method and D-exponent method. Hubbert and Willis method, Ben Eaton method and Matthews and Kelly method are the fracture pressure gradient prediction strategies used. Area specific variables including Poisson ratio and matrix stress coefficient were determined prior to fracture pressure gradient prediction. After a statistical analysis and comparison with well log data, a combination of Hottman and Johnson method and D-exponent (Eaton) method was selected as the best suited pore pressure gradient prediction model for the drilling area. The analysis of fracture pressure gradient strategies found that the Ben Eaton method is the best suited method for the area. After determining the suitable prediction methods, the Petrel software was used to visually interpret and analyze the results obtained. The research findings will help for future drilling operations and well planning in the specified area in Mannar and Cauvery basins.

Keywords: Sri Lanka, Mannar basin, Cauvery basin, Pore pressure gradient, Fracture pressure gradient, Poisson ratio, Matrix stress coefficient.

1. Introduction

Drilling problems, accidents and cost of drilling can be significantly reduced by the early recognition of abnormally high pore pressures (Hayes, 2001 and Mann, 1990). Understanding the pore pressure variation within a formation also helps in drilling plan to select the correct casing points, to design casings which allow an effective well drilling while maintaining well control and completion operations (Brahma *et al*, 2012 and Malallah & Nashawi, 2005). Due to the variety of important aspects in predicting the pore pressure and fracture pressure gradient as such, the value of the existence of such a prediction model for Mannar and Cauvery basins is enormous. The objective of this research was to develop a pore pressure and fracture pressure gradient prediction model for few hydrocarbon exploration blocks in Mannar and Cauvery basins.

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Since there are no any researches done related to the prediction of pore pressure and fracture pressure gradient for Mannar basin or Cauvery basin, this project has a great significance as a basis for safe and efficient petroleum well drilling in the aforementioned area.

Altogether, there are eleven petroleum exploration wells drilled in both Mannar and Cauvery basins, Sri Lanka since 1972. Two of them known as Dorado and Barracuda were drilled in 2011 in Mannar basin by Cairn (Lanka) Pvt. Ltd. and those two wells were succeeded with Gas discoveries (Petroleum Resources Development Secretariat, Sri Lanka/Exploration history, 2014). Depending on the availability of well data, previously drilled four wells were used for the analysis within the scope of this research.

2. Methodology

The existing empirical pore pressure and fracture pressure gradient prediction strategies were studied and several strategies were selected and used in the analysis. The required well data for the analysis of strategies selected were acquired from PRDS (Petroleum Resources Development Secretariat), Sri Lanka.

2.1. Identification and Review of Required Well Data

The required well data for the analysis of selected strategies were identified and collected. Pore pressure gradient prediction methods analysis required interval transit time data, overburden gradient, weight on bit, rate of penetration, normal pore pressure gradient etc. Required parameters for facture pressure gradient prediction analysis are mainly, the corresponding pore pressure gradient and overburden gradient. In addition to those, drilling mud weight, Leak off Test (LOT) data and measured pressure data were gathered and reviewed.

2.2 Selection of Prediction Strategies and Exploration Wells for the Analysis

Three pore pressure gradient prediction strategies and three fracture pressure gradient prediction strategies were selected for the analysis. The reasons for selection of those strategies are the availability of well data and the accuracy of the methods. The pore pressure gradient prediction strategies selected for the analysis are, Hottman and Johnson method, Ben Eaton method and D-exponent method. Hubbert and Willis method, Ben Eaton method and Matthews and Kelly method are the fracture pressure gradient prediction strategies selected.

Depending on the accessibility of data and existence of required data, four wells were selected for the analysis. They are; Palk Bay 01, Delft 01, Pedro 01 and Pearl 01. These four wells are included in four hydrocarbon exploration blocks (M1, C1, C2 and C3) in Sri Lanka.

2.3 Application of the Acquired Well Data for Each Prediction Strategy

Using the gathered well data, the selected prediction strategies were used to predict pore pressure and fracture pressure gradient variation with depth for each of the four wells selected. Separate plots were created for predicted values from each pore pressure gradient prediction strategy for each well.

2.4 Comparison of the Predicted Values from Each Strategy with the Measured Pressure Data

The predicted values of pore pressure gradient from three selected strategies were compared with the available pressure gradient data in well logs. The statistical parameters used for the comparison are the relative accuracy and the standard. The predicted fracture pressure gradient values were compared with the available fracture pressure gradient data and Leak off Test (LOT) data. Standard deviation of the predicted values was analyzed in the comparison.

2.5 Deciding the Most Suitable Pore Pressure and Fracture Pressure Gradient Prediction Strategy for the Drilling Area

By analyzing the statistical assessment results, the most accurate strategy/strategies were selected as the finalized pressure gradient prediction method. The strategy which was having the least standard deviation and highest relative accuracy was selected as the best strategy to predict the pore pressure gradient in the drilling area.

2.6 Formulation of the visual Pore Pressure and Fracture Pressure Gradient Prediction Model

After selecting the most suitable pore pressure gradient and fracture pressure gradient prediction methods, the Petrel software was used to create a visual interpretation of the pressure gradient model established.

3. Results and Discussion

After a detailed analysis of the prediction strategies, a combination of strategies of pore pressure gradient prediction and a single fracture pressure gradient prediction strategy were selected for the drilling area.

3.1 Analysis results of Pore Pressure Gradient Prediction Strategies

Hottman and Johnson method, Ben Eaton method and D-exponent method were analyzed using the well data of four wells selected. Each strategy required certain specific conditions to be used in the pressure prediction. For an instance, the observed interval transit time should be greater than the normal interval transit time to predict pore pressure gradient using the Hottman and Johnson method. The predicted pore pressure gradient values using each strategy were visualized relative to the measured pressure gradient data. Such a prediction values plot from Hottman and Johnson method analysis for Delft 01 well is shown in the figure below.

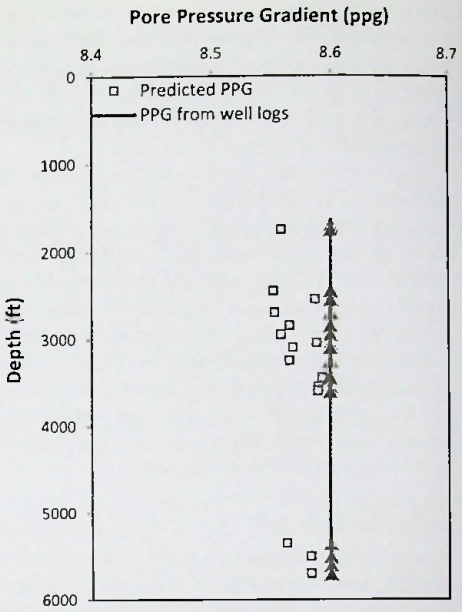

Figure 1: Predicted pore pressure gradient values using Hottman & Johnson method, relative to the measured pressure gradient data for Delft 01 well

3.2 Comparison results of Pore Pressure Gradient Prediction Strategies Applied

The results of the statistical analysis of prediction strategies can be summarized as follows.

Table 1: Statistical analysis results of pore pressure gradient prediction strategies

Term	PPG prediction Method			
	Hottman & Johnson	Ben Eaton	D-Exp. (Eaton)	D-Exp. (Ratio)
Std. Deviation	0.01	2.69	1.76	1.93
Mean	8.58	9.06	8.83	9.16
Rel. Accuracy	99.74	81.15	96.64	93.25

It is seen from the statistical analysis results that, the Hottman and Johnson method is the best suited method, but it can only be used when the observed interval transit time is greater than the normal interval transit time with in a formation. In other cases, the D-exponent (Eaton) method has to be used to predict pore pressure gradient in the drilling area.

3.3 Analysis results of Fracture Pressure Gradient Prediction Strategies

Hubbert and Willis method, Ben Eaton method and Matthews and Kelly method were analyzed using the well data and predicted pore pressure gradient values determined previously. The resulted prediction values plot using Ben Eaton method for Delft 01 well is shown in the figure below.

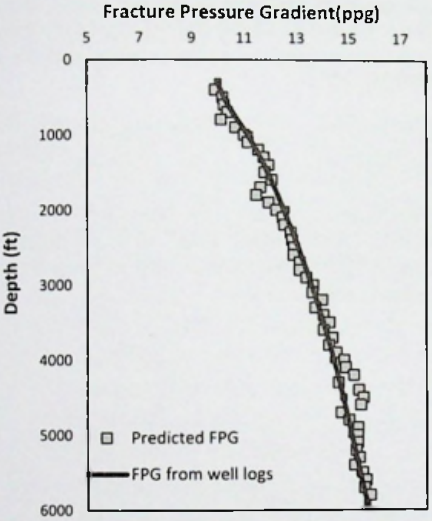

Figure 2: Predicted fracture pressure gradient values using Ben Eaton method, relative to the available fracture pressure gradient data for Delft 01 well

3.4 Comparison results of Fracture Pressure Gradient Prediction Strategies Applied

After analyzing the prediction strategies, the relative accuracy of fracture pressure gradient prediction from each strategy was calculated. The statistical analysis results are shown in the below table. According to those results, Ben Eaton method has the highest relative accuracy and hence most suitable for fracture pressure gradient prediction in the drilling area.

Table 2: Comparison results of fracture pressure gradient prediction strategies

Well	Term	FPG Prediction Method		
		Hubbert & Willis	Ben Eaton	Matthews & Kelly
Delft-1	Rel. Accuracy	91.89	98.44	98.52
Palk Bay-1	Rel. Accuracy	92.06	99.23	97.09
Pedro-1	Rel. Accuracy	85.30	92.19	93.14
Pearl-1	Rel. Accuracy	85.12	93.69	93.58
Avg.	Rel. Accuracy	88.59	95.88	95.58

3.5 Results of visualization and analysis of Pressure Gradient Predictions using the Petrel software

Well heads, well tops and predicted pore pressure and fracture pressure gradient logs were visualized using the software. Miocene, Oligocene, Eocene and Cretaceous are the major and common well tops found in the four wells. Following figure shows the depths (in ft) to each well top in the Pedro 01 well along with the predicted pore pressure gradient values represented with Color intensities.

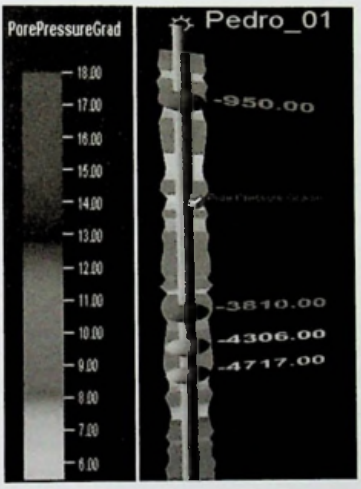

Figure 3: Depths to well tops along with predicted pore pressure gradient for Pero-01 well (Petrel output)

4. Conclusions

According to the results obtained from the analysis, the most suitable pore pressure gradient prediction method for the drilling area is a combination of Hottman & Johnson strategy and D-exponent (Eaton) strategy. The analysis of fracture pressure gradient strategies showed that, the Ben Eaton method is the most suitable fracture pressure gradient prediction method for the drilling area. The mathematical equations of those selected strategies are the model equations which can be used to predict pressure regimes in the drilling area. This prediction model is only applicable for the

specified exploration blocks in Mannar and Cauvery basins. Therefore this prediction area can be expanded by integrating the analysis of new well data.

The visualization of the results obtained can be effectively done by the use of Petrel software and further analysis can be done by integrating seismic interpretation. It is seen by analyzing the well reports of analyzed wells that, the drilling area was not having any abnormal pressure occurrences, but the prediction of pressure gradients are still important to ensure the safety of future drilling operations, since prospects in this drilling area is expanding.

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References

Brahma, J, Sircar, A and Karmakar, GP, 2012, *Pre-drill pore pressure prediction using seismic velocities data on flank and synclinal part of Atharamura anticline in the Eastern Tripura, India*, Retrieved Februatry 20, 2014, from link.springer.com/content/pdf/10.1007%2Fs13202-013-0055-0.pdf

Final Pressure Report, June-August 1976, *Summary of Pressure detection analysis for Marathon of Sri Lanka, Delft No. 01 well, Offshore Sri Lanka (Ceylon)*

Final Pressure Report, August- September 1976, *Summary of Pressure detection analysis for Marathon of Sri Lanka, Palk Bay No. 01 well, Offshore Sri Lanka.*

Final Well Report, August-November 1981, *CITCO Sri Lanka Petroleum Corporation Pearl No. 01, Offshore North-West Sri Lanka.*

Final Well Report, November-December 1981, *CITCO Sri Lanka Petroleum Corporation Pedro No. 01, Offshore North-West Sri Lanka.*

Hayes, D, 2001, *Predict Pore Pressure in Real time*, Retrieved April 20, 2013, from http://www.epmagcom/EP-Magazine/archive/Predictpore-pressurereal-time_3759.

Malallah, A and Nashawi, S, 2005, 'Estimating the fracture gradient coefficient using neural networks for a field in the Middle East', *Journal of Petroleum Science and Engineering*, Vol. 49, pp. 193-211.

Mann, DM, 1990, 'Prediction of pore fluid pressures in sedimentary basins', *Journal of Marine and Petroleum Geology*, Vol. 7, pp. 55-65.

*Petroleum Resources Development Secretariat (PRDS) Sri Lanka, official web site.*Retrieved March 08, 2014, from http:// www.prds-srilanka.com.