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Estimation of Overpressure Magnitudes and Equivalent Mud Weights in Niger Delta Formations using d_c-Exponent versus Depth Plots.

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ABSTRACT

This paper estimated the Overpressure magnitudes as well as the resulting "required mud weights" for safe drilling in three Niger Delta Wells (PNW_1, WSW_2, and WSE_1). PNW_1 revealed maximum overpressure magnitude at the depth of 16,000ft with pressure value of 13,120psig. WSW_2 showed maximum overpressure magnitude at the depth of 11,600ft with pressure value of 14,500psig while WSE_1 revealed an overpressure value of 12,050psig at the depth of 10,700ft considered as depth of maximum pressure. These were all derived based on plots of d_c-exponent versus depth; the required mud weights for safe drilling especially at the maximum overpressures were as well computed. PNW_1 is located at about 77.2km, N31.6°W of Port Harcourt, WSW_2 is located at about 65.2km, S61°W of Warri, while WSE_1 is located around 30.3km, S14.6°E of Warri; these towns are all in Nigeria. This method can stand alone as an Overpressure prediction and estimation tool since the parameters it requires are obtained while drilling.

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Introduction

Pore pressure prediction is a key factor in petroleum exploration and production operations. Accurate determination of pore pressure is of fundamental importance to prevent circulation losses or blowouts during drilling (Mouchet & Mitchell, 1989; Bourgoyne, *et al*, 1991). Because no direct method exists to measure pore pressure (espesially in shales), planning and execution of new boreholes relies upon indirect methods (Yoshida, *et al*, 1996).

Empirical models of the rotary drilling process have been proposed to mathematically compensate for the effect of changes in the more important variables affecting penetration rate. One of the first empirical models of the rotary drilling process was published by Bingham in 1965. Jorden and Shirly in 1966 proposed using the Bingham model to normalize penetration rate "R" for the effect of changes in weight on bit "W", rotary speed "N", and bit diameter "d_b", through the calculation of a d-exponent defined by

$$d_{exp} = \frac{\log\left(\frac{R}{60N}\right)}{\log\left(\frac{12W}{1000d_b}\right)} \quad (1)$$

In this equation, units for R, N, W, and d_b are ft/hr, rpm, k-lbf, and inch., respectively. The equation can be used to detect the transition from normal to abnormal pressure if the drilling fluid density is held constant. In normally pressured formation, the d-exponent tends to increase with depth. After abnormally pressured formation is encountered, a departure from the normal pressure trend occurs in which the d-exponent increases less rapidly with depth. In many cases, a complete reversal of the trend occurs and the d-exponent begins decreasing with depth. In 1971, Rehm and McClendon proposed modifying the d-exponent to correct for the effect of mud-density as well as changes in weight on bit, bit diameter, and rotary speed. After an empirical study, they computed a corrected d-exponent known as d_c-exponent, using

$$d_c\text{-exp.} = d_{exp}\frac{\rho_n}{\rho_e} \quad (2)$$

where ρ_n is the mud density equivalent to a normal formation pore pressure gradient and ρ_e is the equivalent mud density at the bit while circulating.

Herbert and Young (1972), using historical field data from several Louisiana Gulf Coast wells, developed equations based on regression analysis for predicting pore pressures. When the results of this analysis are applied to drilling data, the transition from normal pore pressure to overpressure can be predicted. This however can be done only on a geographically-regional basis. Correlations between the well log data and drillability have been developed by Gstalder and Raynal (1966) and El-Hadidi (1970). Acoustic transit time data from geophysical well logs can be used to predict rock drillability, provided the lithology is known. Mud logging aids in formation evaluation and detection of overpressured zones. As early as 1945, the use of mud-gas logging was recommended as an overpressure indicator and as a warning of impending blowouts (Pixer, 1945). Similarly, Rochon (1668) proposed mud- gas anomalies as an aid in controlling drilling mud hydrostatic head-pore pressure relationships. If formation permeabilities are extremely low, the degree of gas cutting can be roughly correlated with the amount of underbalance (Goldsmith, 1972).

Reduction in the specific weight of the drilling fluid at the mud flow line can be used as an additional indicator for gas cutting and the possible presence of overpressured formations. Consequently, continuous mud weight indicators have become an integral part of many on-site data collection and analysis units. Issenman and Lucon (1971) discussed a continuous mud weight recorder, which basically consists of a constant-height column through which mud from the wellhead outlet is circulated by a special pump at a constant flow rate. The weight of the mud is measured by a pressure gauge located at the bottom of the column and the transmitted

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to a recorder. Another high-resolution drilling fluid monitor system, which consists of pressure and density sensors, has been developed by Goddard et al. (1973). The measurements are based on the principle that the degree of absorption of gamma rays by a material is a function of the density of that material. With proper calibration, radioactive densometers provide density measurements with an accuracy of ±0.1 lb/gal for muds in 7-20 lb/gal specific weight range.

Geology of Study Area

Short and Stauble (1967) outlined the general geology of the Niger Delta. They attempted to explain the origin of the Niger Delta and established that the Tertiary deltaic fill of the Niger Delta is represented by a strongly diachronous (Eocene - Recent) sequence which is divided into three Lithofacies units namely: Akata Formation, Agbada Formation and Benin Formation respectively. Ekweozor and Daukoro (1984) carried out petroleum source bed evaluation of Tertiary Niger Delta. They stablished that the dominant sedimentary kerogen in the Niger Delta were the humic and mixed types. They also stated that habitats of the hydrocarbons are mainly the sandstone reservoirs in the paralic sequence of the Agbada Formation, where the hydrocarbons are characteristically trapped by growth faults at the crest of rollover anticlines. Stacher (1995) showed that the Niger delta basin consist of a series of depocenters while Evamy *et al*. (1978) showed that sedimentation in the depocenter is a function of the rate of subsidence with syndepositional growth fault upsetting the delicate balance. The map of the study area incorporating the positions of the Wells is shown in figure 1.

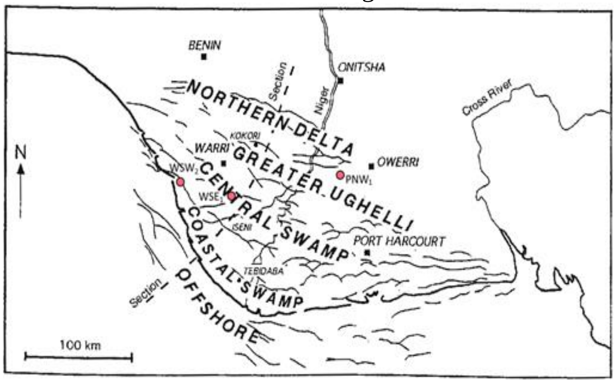

Figure 1. The Map of Niger Delta showing the locations of the Wells.

Corredor *et al* (2005) studied the structural style in the deep water fold and thrust belts of the Niger Delta. They defined two main types of imbricate thrust systems in the Niger Delta: "a single basal detachment level" that is typically near the top of the Akata Formation and "an imbricate system with multiple basal detachment levels" which causes massive structural thickening of the Akata Formation and refolding of shallow thrust sheets.

Theory and Methods

The d_c-exponent versus depth plot can be used to estimate the magnitude of overpressures. Here the readings are taken from the plot of d_c-exponent and depth as shown in fig. 2. The point of interest should be B because the maximum formation pressure occurred here unless otherwise desired. The formation pressure gradient (P_{fg}) will be derived using equation (3), (Rehm and Mc Clendon, 1971).

$$P_{fg} = 0.052\{7.65\log(d_{cn} - d^*_c) + 16.5\} \quad (3)$$

The formation pressure at the depth of interest (in this case H) is computed using equation (4). Finally the required mud density is computed using equation (5) which is the same as equation (3) but without the conversion constant 0.052.

$$\text{Formation pressure (psig)} = P_{fg} \times H \quad (4)$$

$$\therefore \text{ Required mud density} = 7.65\log(d_{cn} - d^*_c) + 16.5 \quad (5)$$

Point A is the transition to overpressured environment while point B is the point of maximum overpressure, d_{cn} is the d_c – exponent value corresponding to point of intersection of the normal pressure trend line and the horizontal line drawn from depth of interest (in this case H) which is usually the depth of maximum overpressure; $\mathbf{d_c^*}$ is defined by the d_c-exponent value at the depth of maximum overpressure.

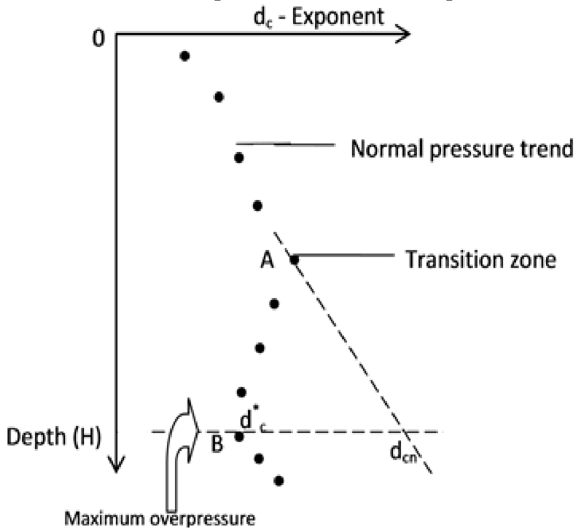

Figure 2. Sketch of d_c-exp Versus Depth plot in Overpressured zone.

Data Analyses

The data analyses for the three Niger Delta Wells studied are given as follows;

For PNW_1

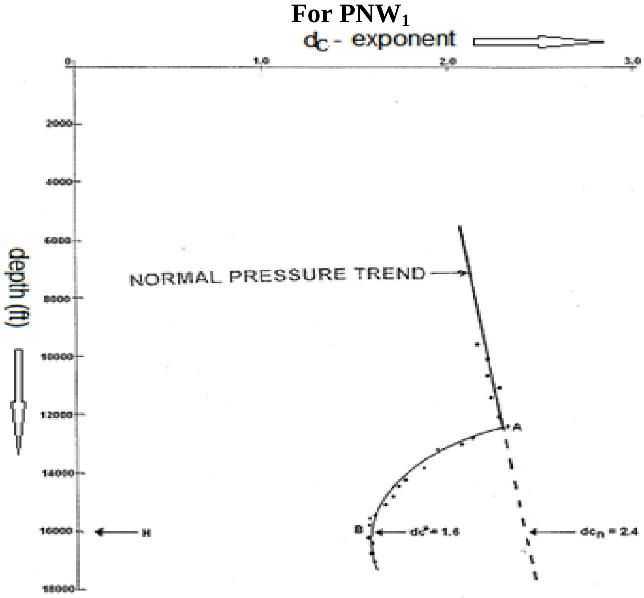

Figure 3 . Depth against d_c- exponent plot for PNW_1.

Computation of Maximum Overpressure Magnitude for PNW_1

From figure 3, and using equation (3);

P_{fg}= 0.052 [7.65log (2.4 - 1.6) + 16.5]
= 0.82psi/ft

Using equation (4), formation pressure at 16,000ft ;
= 0.82psi/ft x 16000ft
= 13,120psig

Finally, using (5);

Required mud density = 7.65log (2.4 - 1.6) + 16.5
= 15.8 lb/gal

For WSW_2

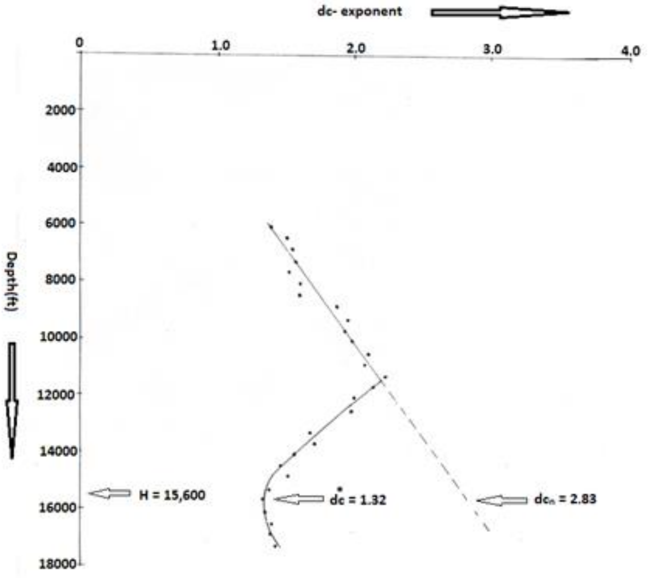

Figure 4. Depth against d_c- exponent plot for WSW_2

Computation of Maximum Overpressure Magnitude for WSW_2.

From figure 4, and using equation (3);

$$P_{fg} = 0.052 \{ 7.65 \log (2.83 - 1.32) + 16.5 \}$$
$$= 0.929\text{psi/ft}$$

Using equation (4), formation pressure at 15,600ft ;

$$= 0.929\text{psi/ft} \times 15{,}600\text{ft}$$
$$\approx 14{,}500\text{psig}$$

Finally, using (5);

Required mud density = $\{ 7.65 \log (2.83 - 1.32) + 16.5 \}$

= 17.9 lb/gal

For WSE_1

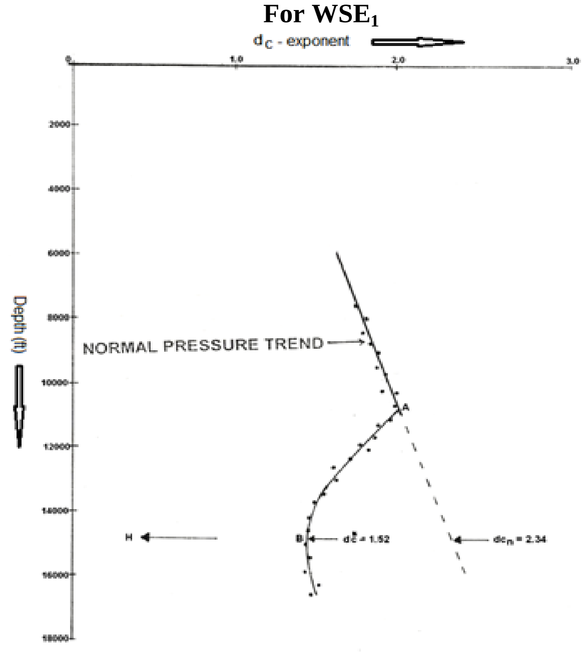

Figure 5. Depth against d_c – exponent plot for WSE_1

Computation of Maximum Overpressure Magnitude for WSE1.

From figure 5, and using equation (3);

$$P_{fg} = 0.052 \ [7.65\log (2.34 - 1.52) + 16.5]$$
$$= 0.82\text{psi/ft}$$

Formation pressure at about 14,700ft;

$$= 0.82\text{psi/ft} \times 14{,}700\text{ft}$$
$$= 12{,}050 \text{ psig}$$

Finally, using (5);

Required mud density = $[7.65\log (2.34 - 1.52) + 16.5]$

= 15.8 lb/gal

Discussion and Conclusion

PNW_1 located at about 77.2km N31.6°W of Port Harcourt Nigeria showed Overpressure trend that started at about 12,400ft and got to a maximum at about 16,000ft. The normal pressure trend line is in conformity with a normal pressure gradient of 0.42psi/ft stated for Niger Delta province (Fertl, 1976). The point B was selected as point of maximum overpressure due to its being the maximum deviation point after which the d_c-exponent value started reducing and would eventually track the normal trend line when pressure normalizes. The required mud weight value of 15.8 lb/gal was recommended for safe drilling at point B.

WSW_2 located at about 65.2km, S61°W of Warri Nigeria (plotted in fig.4) exhibited an overpressure that originated at about 11,600ft and reached a maximum at approximately 15,600ft. The Overpressure magnitude at the point of maximum pressure was computed to be 14,500psig thus requiring a mud weight of about 17. 9 lb/gal for safe drilling.

Well WSE_1, located at about 30.3km S14.6°E of Warri Nigeria started exhibiting Overpressure at point A (10,700ft) and got to a maximum at point B (approximately 14,700ft). This maximum overpressure yielded a magnitude of 12,050psig and required a mud weight of 15.8 lb/gal for safe drilling. It follows therefore that this method can predict Overpressures, estimate their magnitudes, and in turns estimate the mud weights required to drill such zones safely. The major advantage of this method lies in the fact that its related computations are made while drilling thus giving enough room to avert kicks and blowouts.

References

Bingham, M. G. (1965). A New Approach to Interpreting Rock Drillability, The Petroleum Publishing Co.Texas. p.121-128.

Bourgoyne, A. T., Chenevert, M. E., Millheim, K. K., and Young, Jr. (1991). Applied drilling engineering. SPE Textbook Series, 2.

Corredor, F., Shaw, J.H., and Bilohi, K. (2005). Structural Styles in the deepwater fold and thrust belts of the Niger Delta. *AAPG Bulletin, Vol.89*, No. 6 , pg.753-780.

Ekweozor, C. M., Daukoru, E. (1984). Petroleum source bed evaluation of Tertiary Niger Delta; Reply. *AAPG Bull 68*:391–394.

El- Hadidi, S., (1970). Use of Well Logging Data for Predicting of Rock Drillability. M.S. Thesis, Univ. of California, Berkeley, CA. p.90.

Evamy, B. D., Haremboure, J., Kamerling, P., Knaap, W.A., Molloy, F.A., & Rowlands, P.H. (1978). Hydrocarbon habitat of Tertiary Niger Delta: *American Association of Petroleum Geologists Bulletin*, v.62, p. 77-298.

Fertl, W.H., (1976). Abnormal Formation Pressures. Elsevier Scientific Publishing Company, Amsterdam., p. 1-4.

Goddard, R. D., Guest, R .J., and Anderson, T.O. (1973). High resolution fluid measurement improves drilling. Drilling Contractor, Mar/APR: 128-140.

Goldsmith, R. C. (1972). Why gas-cut muds is not always a serious problem. *World Oil*, 175(5): 51-54.

Gstalder, S. and Rayal, J. (1966). Measurement of some mechanical properties of rocks and their relationship to rock drillability. Trans. AIME, 237: 991-995.

Herbert, W. E. and Young, F. S. (1972). Estimation of formation pressure with regression models of drilling rate. *J Pet. Tech.*, 24: 9-15

Issenman, O. and Lucon, C. (1971). Present state of gas-logging techniques with use of a continuous mud indicator. *J. Can. Pet. Tech.*, 12: 9-11

Jorden, J. R. and Shirley, O. J. (1966). Application of drilling performance data to overpressure detection. *Journ. of Pet. Tech*., II : 1387-1394.

Mouchet J. P., & Mitchell, A. (1989). Abnormal pressure while drilling. Manuals techniques 2. Boussens, France, Elf Aquitaine Editions.

Nwosu, I. E. (2012). Prediction and Estimation of Overpressures in Niger Delta formations; before drilling and while drilling, Unpublished PhD Thesis. Imo State University Owerri, Nigeria..

Pixler, B. O. (1945). Some Resent Developments in Mud Analysis Logging. Falls Meet. *Soc.Pet.Eng., AIME*, Houston, TX, Oct. SPE 2036. P8.

Rehm, W.A. and McClendon, R. (1971). Measurement of formation pressure from drilling data *.SPE 3601; 46th AIME fall meet;* New Orleans, La.

Short, K.C. & Stauble, A.J. (1967). Outline of Geology of Niger Delta: *American Association of Petroleum Geologists*, Bulletin, v.51, p.761-779.

Stacher, P. (1995). *Present Understanding of the Niger Delta hydrocarbon habitate*. In: M. N Oti and G. Postman Eds. Geology of Deltas. A. A. Balkema, Rotterdam. Pp 257 – 267.

Yoshida, C., Ikeda, S., & Eaton, B. (1996). An investigative study of recent technologies used for prediction, detection, and evaluation of abnormal formation pressure in North and South America. Kuala Lumpur, Malaysia. September 9-11.