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Full Length Research Paper

Pore pressure prediction using seismic data: Insight from Onshore Niger Delta, Nigeria

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Pore pressure and fracture pressure predictions were made using seismically derived velocities from Onshore Niger Delta. Mild to moderate overpressure regime in the study area was predicted using Bowers' unloading model. The onset of mild overpressure (<0.6 psi/ft) in the area lies within the depth range of 6000-10000 ftss. The formation becomes moderately over pressured (<0.8 psi/ft) as the pressure increases with depth up to about 20000 ftss. Evidence of fluid volume expansion unloading mechanism in the area was depicted by the elastic rebounds, and hence the unloading effect, on the V_{int} – VES cross plots.

Key words: Pore pressure predictions, fracture pressure, seismic velocities, overpressure, unloading mechanism.

INTRODUCTION

Pore pressure prediction ahead of the drill bit is required for safe and economic drilling, especially in tertiary basin like the Niger Delta. Besides drilling a well, seismic survey is the only way to predict a potential geohazard subsurface zone *apri-ori.* Pioneering examples in the use of seismic data for pore pressure prediction include the works of Hottman and Johnson (1965), Pennebaker (1968) and Reynolds (1970, 1973).

Over the years, literature has been populated with works on the use of seismic data for predrill pore pressure prediction. Given seismic velocities with sufficient spatial resolution, a seismic – to – pore pressure transform can be performed. Of the various possible methods available, the effective stress method has become the preferred standard widely used in the industry, with the most popular methods being the Eaton's method (Eaton, 1975) and the Bowers' method (Bowers, 1995). In this paper, the Eaton's method and Bower's method are employed in the predrill pore pressure prediction. The problem of determining the parameters in the methods and their limitations are investigated. The approach uses prestack depth migration (PSDM) velocities from Onshore Niger Delta.

Geologic setting

The Niger Delta is a major geological feature of significant petroleum exploration and production in Nigeria, ranking amongst the world's most prolific

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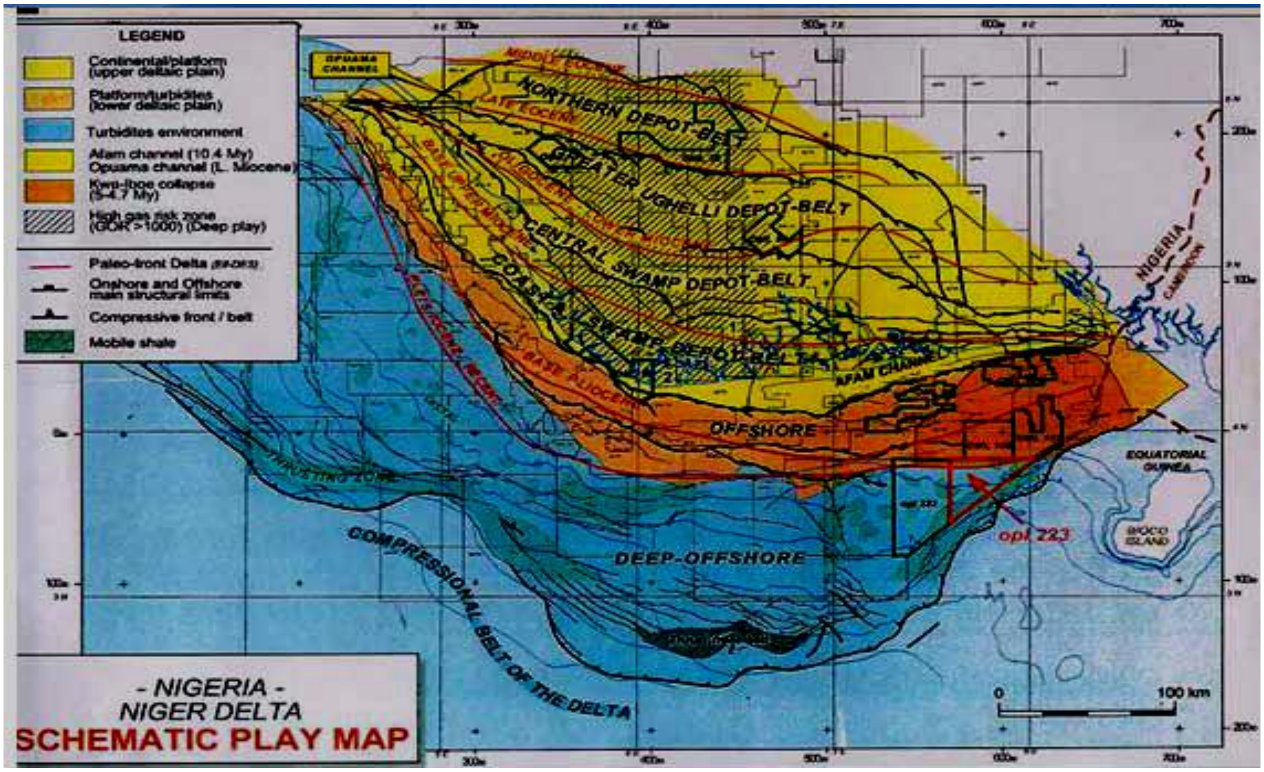

Figure 1. Section map of Niger Delta showing the depobelts (Nwozor et al., 2013).

petroleum producing Tertiary deltas. The Onshore Niger Delta is situated on the continental margin of the Gulf of Guinea on the West Coast of Africa and lies between latitude 4° and 6°N and longitude 4°3^{l} and 8°E. The geology of the Niger Delta has been extensively studied by several authors and is now well documented (Reyment, 1965; Short and Stauble, 1967; Murat, 1972; Doust and Omatsola, 1990).

The Niger Delta is bounded in the north by the Benin flank; an east-northeast trending hinge line south of the West African basement massif. The northeastern boundary is defined by the outcrops of the Cretaceous Abakaliki anticlines, extending further to the southeast as the Afikpo syncline and Calabar flank. The Niger Delta basin consists of three main lithostatic formations namely, the topmost Benin Formation which consists of massive continental fluviatile gravels and sands; the Agbada Formation which represents a deltaic facies and the Akata Formation which consists mainly of marine shales. The Akata shale which is significantly overpressured is believed to be the main source rock of the hydrocarbons, usually trapped in faulted rollover anticlines associated with growth faults. In the last 55 Ma, the Niger Delta which is predominantly composed of regressive clastic sequence has prograded southwards, forming some depobelts (Figure 1).

As exploration and production (E and P) of oil and gas in the Niger Delta advance into more precarious environments at greater depths, some wells have penetrated deep over pressured zones with reported incidents of well stability problems, lost circulation, mud losses, stuck pipes, well kicks and well blowouts. Thus pore pressure prediction before the drill bit has even become more critical.

THEORY AND METHODS

Pore pressure prediction from seismic interval velocities is based on the assumption that there is a constant regional relationship between acoustic velocity and effective stress. Hence most methods of pore pressure predications are based on Terzaghi's effective stress relation (Terzaghi, 1943) who expresses elastic wave velocity as a function of vertical effective stress. The effective stress σ is the pressure acting on the solid rock matrix. It is the difference between the overburden pressure S and the pore pressure P. Terzaghi's relation extended to solid rocks can then be written as:

$$\sigma = S - P \qquad (1)$$

The overburden pressure is the pressure due to the combined weight of the rock matrix and the fluids in the pore space overlying the formation of interest at a given depth. The overburden pressure can be expressed as integral of density:

$$S = g \int_0^z \rho(z)\, dz \qquad (2)$$

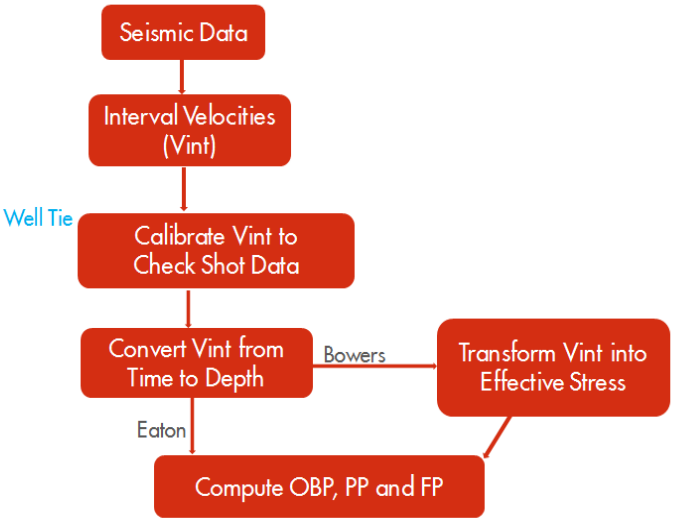

Figure 2. Workflow for seismic-based pore pressure prediction.

Where g is the acceleration due to gravity and ρ(z) is the bulk density which can be obtained from a density log, if available.

Different methods (algorithms) exist for seismic–based pore pressure prediction. In all the methods, the general approach is based on the comparison between the measured pore pressure indicators in the abnormal pressure zone with those observed in the normal pressure zone. However, in this work the Eaton's model and Bowers' model are employed. The Eaton's method (Eaton, 1975) in accordance with Terzaghi (1943) gives a direct transform of seismic interval velocity into pore pressure pp:

$$PP = P_{ob} - (P_{ob} - P_{hd})(V_{int}/V_{norm})^3 \qquad (3)$$

Where P_{ob} is the overburden pressure, P_{hd} is the hydrostatic pressure, V_{int} is the seismic interval velocity and V_{norm} is the shale velocity at normal pressure. This method however, has limitations when applied in geological complicated areas such as formations with uplifts or unloading effects. The method can only simulate unloading curves when the exponent in Equations (3) becomes greater than 3. The modified Eaton's method then becomes:

$$PP = P_{ob} - (P_{ob} - P_{hd})(V_{int}/V_{norm})^n \qquad (4)$$

Where the exponent n describes the sensitivity of velocity to differential stress and depends on the formation being investigated (n > 3). If pressure data from wells close to the proposed well are available, the exponent n can be adjusted until the predicted pressures at the calibration well match measured pressure data.

Bowers (1995) proposed that the compressional velocity V_p and the effective stress σ have a power relationship in the loading stage of the form:

$$V_P = V_{ml} + A\,\sigma^B \qquad (5)$$

Where V_{ml} is the compressional velocity at the mudline (about 5000 ft/s). The parameters A and B are calibrated with offset velocity versus vertical effect stress (VES) data. The loading curve of V_p – VES cross-plot of Equation (5) is however not obeyed when there is unloading effect, as have been reported in the Onshore Niger Delta (Nwozor et al., 2013; Opara et al., 2013). A higher than the velocity in the loading curve occurs at the same effective stress, resulting in the unloading curve having a flatter effective stress path than the initial (virgin) curve. Bowers (1995) proposed an empirical relation to account for the unloading regime:

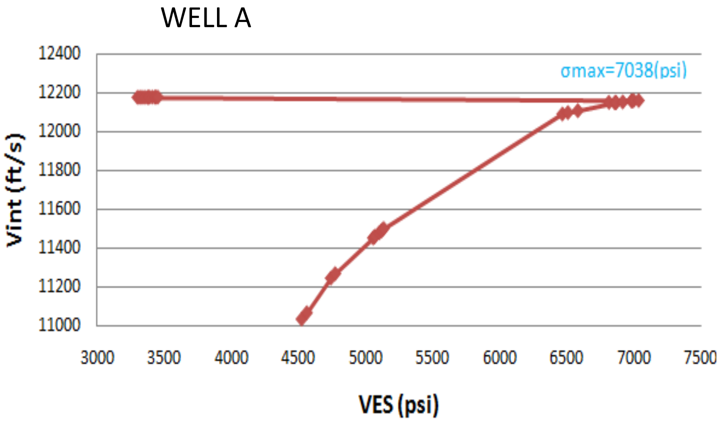

Figure 3. WELL A V_{int}–VES cross plot.

$$V_p = V_{ml} + A\left[\sigma_{max}\left(\frac{\sigma}{\sigma_{max}}\right)^{1/U}\right]^B \qquad (6)$$

Where U is the unloading parameter calibrated with local data and is a measure of how plastic the sediment is. σ_{max} is the maximum effective stress at the beginning of the unloading effect. A and B are as previously defined in Equation (5).

Pore pressure predictions

To predict the formation pressure, seismic interval velocities, check shot data and pressure measurements (RFT, MDT and LOT) in three wells within the study area were utilized. The workflow for the seismic–based pore pressure prediction is as shown in Figure 2. The software used was RokDoc 5.1 (ikonscience.com). The seismic–well tie was carried out by calibrating the interval velocities to well check shot data. Thereafter, time-to-depth conversion of the seismic interval velocities was carried out.

Eaton and Bowers methods were employed and their parameters determined. To employ the Bowers' unloading method, the maximum vertical effective stress, σ_{max}, was obtained from the V_{int}–VES cross plot of wells A and C as shown in Figures 3 and 4 respectively. The A and B parameters in Bowers' method (Equations 5 and 6) were given respectively as 2.26 and 0.82 for the formation while the U parameter was given as 3.1269.

Determining the fracture pressure

Fracture pressure is the pressure at which tensile fracture occurs in the formation. At this pressure, the rock structure of the formation is permanently deformed. The fracture pressure FP of the study area was calculated using the regional relation of the form:

$$FP = PP + STR\,(P_{ob} - PP) \qquad (7)$$

Where STR is the apparent stress ratio obtained from the available leak off test (LOT) data from offset wells in the area, PP and P_{ob} are respectively the pore pressure and overburden pressure already determined.

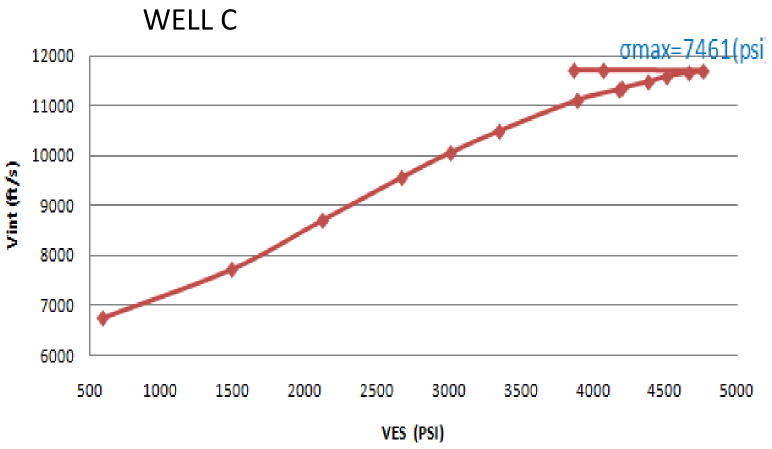

Figure 4. WELL C V_{int}-VES cross plot.

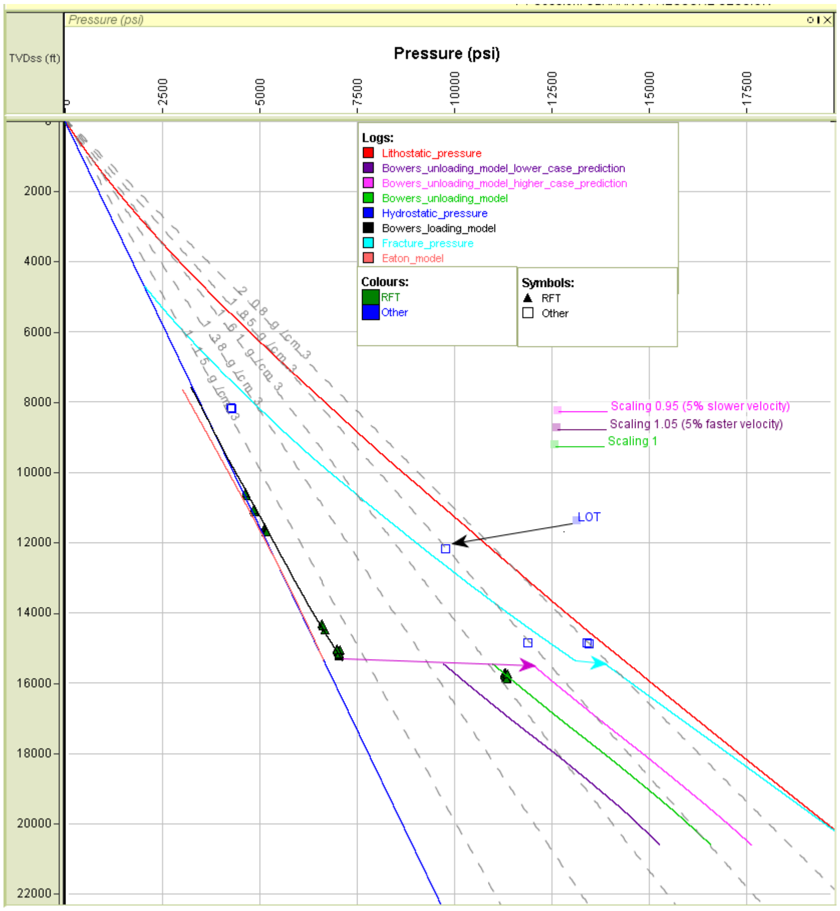

Figure 5. WELL A seismic-based pore pressure prediction.

RESULTS AND DISCUSSION

Figures 5, 6 and 7 show the pore pressure predictions and the fracture pressure estimations from wells A, B and C respectively. Uncertainty margin was determined on the pressure predictions by taking into account the error in the velocity data using the velocity scaling factor. A scaling factor of ± 5% was applied on the velocity field. The lower scaling factor of 0.95 (that is, 5% slower velocity) resulted in the higher case predictions while the

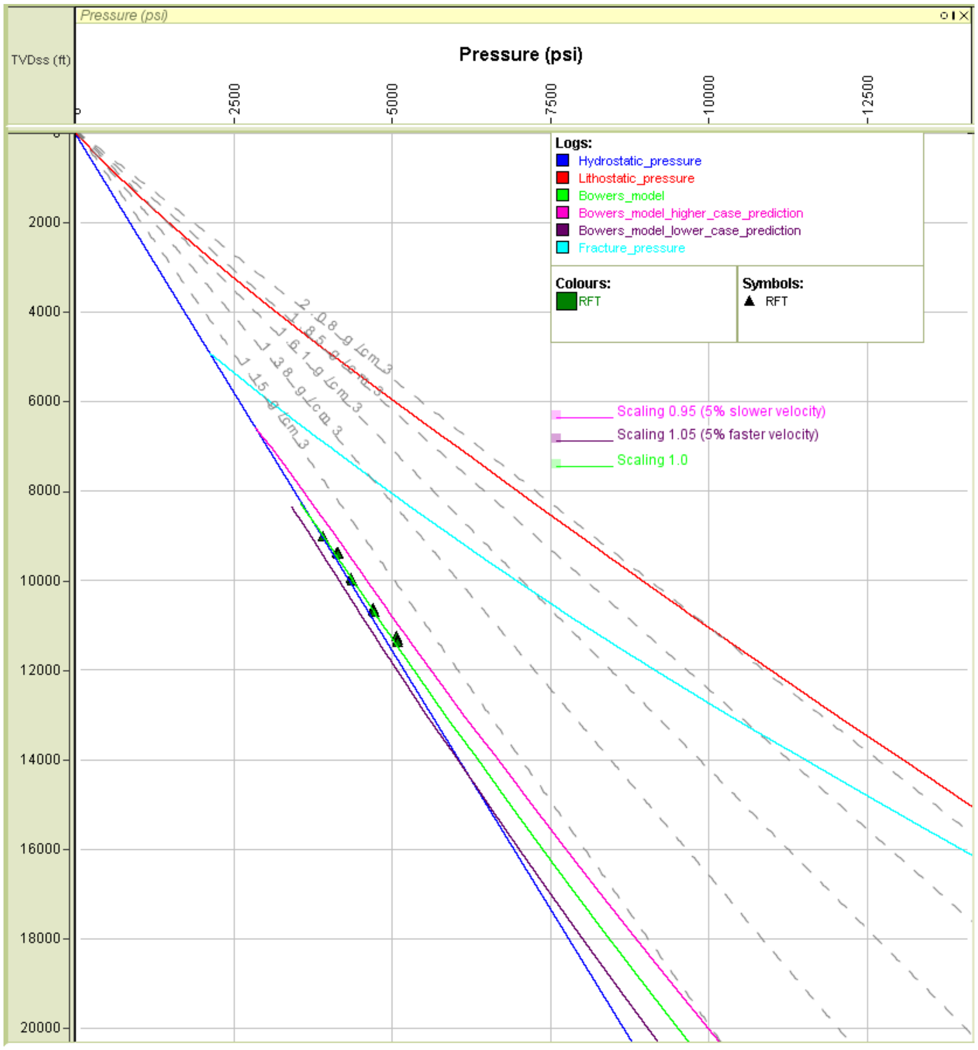

Figure 6. WELL B seismic-based pore prediction prediction.

higher scaling factor of 1.05 (that is, 5% faster velocity) resulted in the lower case predictions. Bowers' loading method was used to predict the pressures due to disequilibrium compaction while Bowers' unloading method predicted the pressure regime due to secondary overpressure mechanisms such as fluid volume expansion.

Overall, the results show that the study area is over-pressured, ranging from mild to hard overpressures. The onset of mild overpressures (< 0.60 psi/ft) in the area lies within the depth ranges of about 10,000 ftss in Wells A and B and about 6000 ftss in Well C. These pressures increase with depth to become moderately over pressured (<0.8psi/ft) in the three wells.

The original Eaton's method of exponent n = 3 when applied to Well A (Figure 5) under predicted the pressure, being almost hydrostatic. Further attempts to apply the method to Wells B and C did not yield reasonable/agreeable predictions with the measured pressures and were discarded. Thus the modified Eaton's method of exponent n > 3 could be more appropriate for the formation.

Conclusion

Predrill pore pressure prediction is a drilling programme essentially carried out in order to guard against dangerous drilling problems such as excessive cost overrun, well kicks and blowouts, lost circulation, stuck pipe and wellbore instability. Pore pressure and fracture pressure predictions were made using seismically – derived velocities from the Onshore Niger Delta.

The results show that the study area is over pressured, ranging from mild to moderate over pressure. Mild to moderate over pressure regime in the area was predicted using the Bowers' unloading method. Evidence of secondary over pressure mechanisms such as fluid

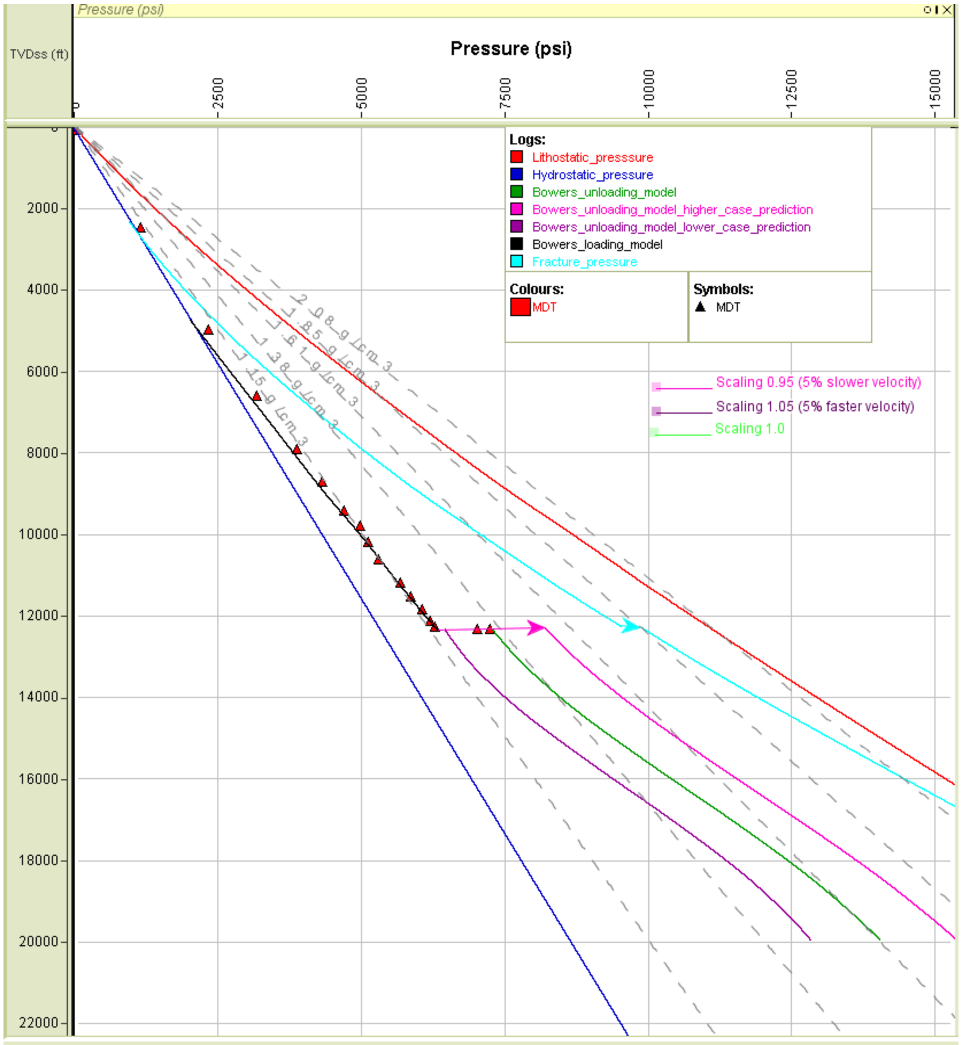

Figure 7. WELL C seismic-based pore pressure prediction.

volume expansion in Onshore Niger Delta is supported by the elastic rebounds, and hence the unloading effect, on the V_{int} – VES cross plots. Attempt to use the original Eaton's exponent method to predict the pressure of the formation failed or under predicted the pressure. The modified Eaton's method is therefore recommended for pressure predictions for deep wells, especially the high – pressure high – temperature (HPHT) campaigns in the Onshore Niger Delta.

Conflict of Interest

The authors have not declared any conflict of interest.

REFERENCES

Bowers GL (1995). Pore pressure estimation from velocity data; accounting for overpressure mechanisms besides undercompaction, SPE Drilling and completions.

Doust H, Omatsola E (1990). Niger Delta, in: Divergent/Passive Margin basin, Edwards JD, Santogrossi PA (eds.), AAPG Memoir 45:239-248.

Eaton BA (1975). The equation for geopressure prediction from well logs, Soc. Petr. Engineers, Paper SPE 5544.

Hottman CE, Johnson RK (1965). Estimation of formation pressures from log derived shale properties. J. Pet. Technol. 6:717-722.

Murat RC (1972). Stratigraphy and paleography of the Cretaceous and Lower Tertiary in Southern Nigeria in: Dessauvagie TFJ, Whiteman AJ (eds.), African Geology, Ibadan University Press, pp. 251-265.

Nwozor KR, Omudu MI, Ozumba BM, Egbuachor CJ, Onwuemesi AG, Anike OL (2013). Quantitative evidence of secondary mechanisms of overpressure generation: Insights from parts of Onshore Niger Delta, Nigeria, petr. Technol. Dev. J. 3(1):64-83.

Opara AI, Onuoha KM, Anowai C, Onu NN, Mbah RO (2013). Geopressure and trap integrity predictions from 3-D seismic data: Case Study of the Greater Ughelli Depobelt, Niger Delta. Oil and Gas Science and Technology – Rev. IFP Energies nouvelles, 68(2):383-396.

Pennebaker ES (1968). Seismic data indicate depth and magnitude of abnormal pressure, World Oil, 166:73-82.

Reyment RA (1965). Aspects of Geology of Nigeria, Ibadan University Press. Bull. Geol. Surv. Nigeria 1:95.

Reynolds EB (1970). Predicting overpressured zones with seismic data; World Oil 171:78-82.

Reynolds EB (1973). The application of seismic techniques to drilling techniques, Soc. Petr. Engineers, Preprint P. 4643.

RokDoc 5.1 www.ikonscience.com.

Short KC, Stauble AJ (1967). Outline of the Geology of the Niger Delta. Ass. Petr. Geol. Bull. 54:170-171.

Terzaghi K (1943). Theoretical soil mechanics, John Wiley and Sons, Inc.

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