

# Detecting and Predicting Over Pressure Zones in the Niger Delta, Nigeria: A Case Study of Afam Field.

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## Abstract

An investigation of the overpressure condition in Afam field was carried out using a suite of borehole logs and 3D seismic data obtained from Shell petroleum Development Company of Nigeria (SPDC) with a view to detecting and predicting abnormal pressure zones in the area.

The methodology employed knowledge of well lithology and more detailed information extracted from inverted seismic traces. The interval velocity data of some shot lines within the study field and its immediate environment were computed to ascertain the pressure variations and the geological model of the less known areas from seismic data. Using well data near the seismic trace for calibration, precise stratigraphic interpretation of the constructed interval velocity section was carried out. The overpressure zones were identified and probable hydrocarbon distribution pattern within the field was established and correlated with the geology of the study area.

The results obtained revealed five tops of overpressure (TOV) namely TOV 1, TOV 2, TOV 3, TOV 4, and TOV 5 at 1608.8m, 1884.1m, 2387.3m, 2708.9m and 3001.4m respectively derived from seismic and lithologic logs including their lateral variations. The plot of the Normal Compaction Trend versus velocities obtained from sonic logs also confirmed the identified overpressure zones. The five horizons representing the identified overpressure zones were picked on the 3D seismic sections at 1.42 s, 1.75 s, 2.01 s, 2.11 s and 2.30 s respectively, with thickness varying from 4.08 m to 50.58 m. In-addition, the water saturation ( $S_w$ ) and porosity ( $\phi$ ) values calculated showed that the overpressure zones were generally characterized by high water saturation (52 % to 80.36%) and low porosity (16.55 % to 30.80 %). Furthermore, four hydrocarbon-bearing zones, which were overlain by thin over pressured shale beds, were delineated at 2657 m, 2804 m, 2916.9 m and 3048 m respectively.

This case study shows how knowledge of well site lithology and detailed information from seismic data could enable prediction match well conditions with high fidelity thereby reducing drilling cost, prospect risk and improving safety.

**Keywords:** overpressure, compaction, interval velocity, Shale, amplitude inversion

## 1. Introduction

Abnormally high pore fluid pressures are encountered worldwide in formations ranging in age from the Cenozoic era (Pleistocene age) to the Paleozoic era (Cambrian age). Overpressure zones represent major cause of drilling hazards and one of the main challenges in exploration and exploitation of hydrocarbons reserves. Such pressures may occur as shallow as a few hundred meters below the surface or at depths exceeding 6100 meters and can be present in shale/sand sequences and/or carbonate-evaporite sections (Petroconsultants, Inc., 1996, Figure 1).

Overpressure is any pressure in excess of the hydrostatic pressure. Detection and evaluation of overpressured formations are critical to exploration, drilling and production of hydrocarbons since oil and gas distribution is related to regional and local subsurface pressures and temperatures. Knowledge of the expected pore pressure and fracture gradients is the basis for the efficient drilling of wells, with correct mud densities, the proper engineering of casing programs and the proper completion's which must be effective, safe and allow for the killing of the well without excessive formation damage. Various workers have carried out overpressure prediction with success in different regions of the world. For example, Brun *et al.*, (1985) employed vertical seismic profile techniques (VSP) to predict overpressure in the Niger Delta; also, Neuzil (1995) ascribed hydrodynamic phenomena to abnormal pressures encountered in wells. Traugott (1997) determined pore-pressure in various deep water environments in the world with success reported in all the fields investigated. Also, the integration of well logs and seismic data have been used to investigate the geology of varied basin across the globe, while various oil companies operating in the Niger Delta have applied seismic inversion to constraint 3D static reservoir models with the ultimate aim of reducing uncertainties associated with geological reservoir modeling.

The aim of this paper is therefore the detection and prediction of possible overpressure zones as well as the pressure distribution pattern in Afam field, located in OML11, onshore, Niger Delta, Nigeria, with a view to

providing information on how to reduce drilling cost, improve safety and assessment of prospect risks.

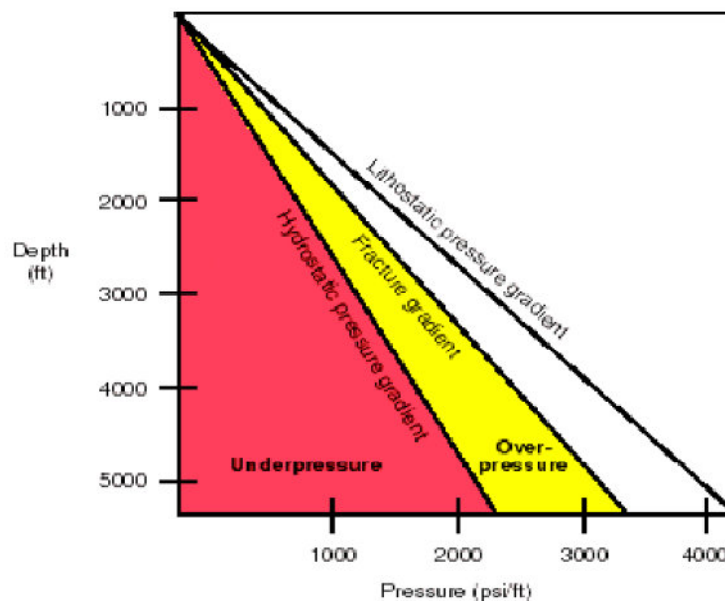


Figure 1. Relationship between pressure distributions and depth (After Petroconsultant, 1996)

## 2. Regional Geology

The Niger Delta Basin is located on the West African Continental margin on the apex of the Gulf of Guinea. The Delta underlies the coastal plain, continental shelf and slope of Nigeria and western Cameroon (Tertiary Cameroon Volcanic Trend), and the northern territorial waters of Equatorial Guinea. The Basin cuts across some Western African countries. In Western Cameroon and Equatorial Guinea region it is referred to as the Rio del Rey Basin. It is one of the major regressive sequence and most prolific Provinces in the world in terms of hydrocarbon. In Nigeria, the basin occurs between latitude 4<sup>0</sup>N and 6<sup>0</sup>N and Longitude 3<sup>0</sup>E and 9<sup>0</sup>E in the southern part of Nigeria and is considered one of the largest in the world. Also, the Niger delta is one of the world's largest deltas, with the sub aerial portion covering about 75,000 Km<sup>2</sup> and extending more than 300 km from apex to mouth. However, on a global sense the Tertiary delta covers approximately 211,000 Km<sup>2</sup>, and developed south-westwards out of the Anambra Basin and the Benue Trough. It formed at the site of rift triple junction related to the opening of the southern Atlantic starting in the Late Jurassic and continuing into the Cretaceous. Sedimentation began with Albian drift deposits following the Mesozoic rifting of the Atlantic. Sediments first filled the Benue Trough and by Late Eocene time they started to prograde across the existing continental slope into the deep sea (Figure 2). Since the Eocene, there has been continued seaward progradation responsible for extension of the continental margin to its present position (Haack *et al.*, 2002). The Niger Delta is Paleogene to Recent, wave-dominated delta and also extends into the northern Joint Development Zone (Nigeria-Sao Tome Principe).

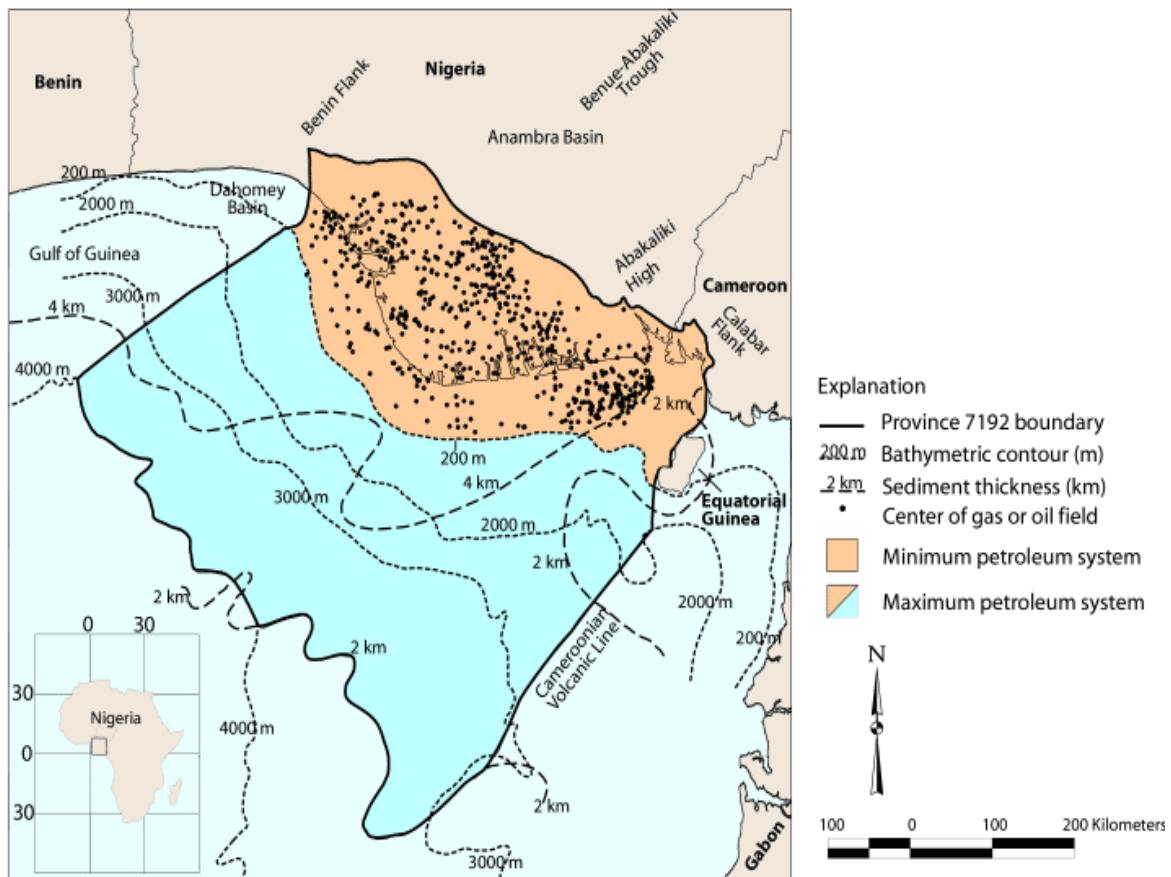


Figure 2. An Index Map of Nigeria and Cameroon. Map of the Niger Delta Showing Province Outline Maximum Petroleum System (After Petroconsultant, 2001)

The regressive wedge of clastic sediments, which it comprises, is thought to reach a maximum thickness of about 12 km. At the mouth of the Benue and Cross river system, it has been built out into the central Atlantic with the Niger-Benue River Complex being its main supplier of sediments but with minor input from the Cross River in the East (Doust and Omatsola, 1990). Three main rock-stratigraphic units have been proposed for the subsurface of the Niger delta (Short and Stauble, 1967; Frankl and Cordry, 1967; Avbovbo, 1978). These are the Akata, Agbada and Benin Formations. The Akata shales are mobile, under-compacted and typically overpressured. They are considered to be the main source rock of the Niger delta with the upper part considered mature source rock (Weber and Daukoru, 1975; Ekweozor and Daukoru, 1984). According to Avbovbo (1978), hydrocarbon generation in the Akata Formation probably migrated updip through growth faults to accumulate in the shallow reservoirs of the Agbada Formation. The formation probably underlies the whole Niger delta south of the Imo Shale outcrop (Short and Stauble, 1967).

### 3. Methodology

Overpressure detection and prediction was carried out using data sourced from Shell Petroleum Development Company of Nigeria (SPDC). The data include 3D seismic data with two-way travel time and a suite of borehole logs comprising Self Potential (SP), Gamma Ray (GR), Resistivity (ER), Density Neutron, Sonic and Acoustic Logs.

Interpretation of the sourced data was carried out using Seismic Micro-Technology Kingdom Suite 8.6 software. Interval velocity and density values of the seismic layers were computed from the seismic data. Acoustic impedance sections were prepared and used to construct the geologic model and accurate stratigraphy of the environment. *Normal compaction Trend* of shale was established from plots of shale velocities with depth. Possible overpressure zones were identified from well logs and correlated across the study area (Figures 3a and 3b).

Overpressure detection is based on the premise that pore pressure affects compaction-dependent geophysical properties such as density, resistivity and sonic velocity. Shales are the preferred lithology for pore pressure interpretation because they are more responsive to overpressure than most rock types. Consequently, overpressure detection in this research has been centered on shale deformation behaviour using resistivity, sonic

logs, SP and or gamma ray (GR) logs Figures 3a and b. The identified overpressure zones were in turn correlated with picked seismic horizons.

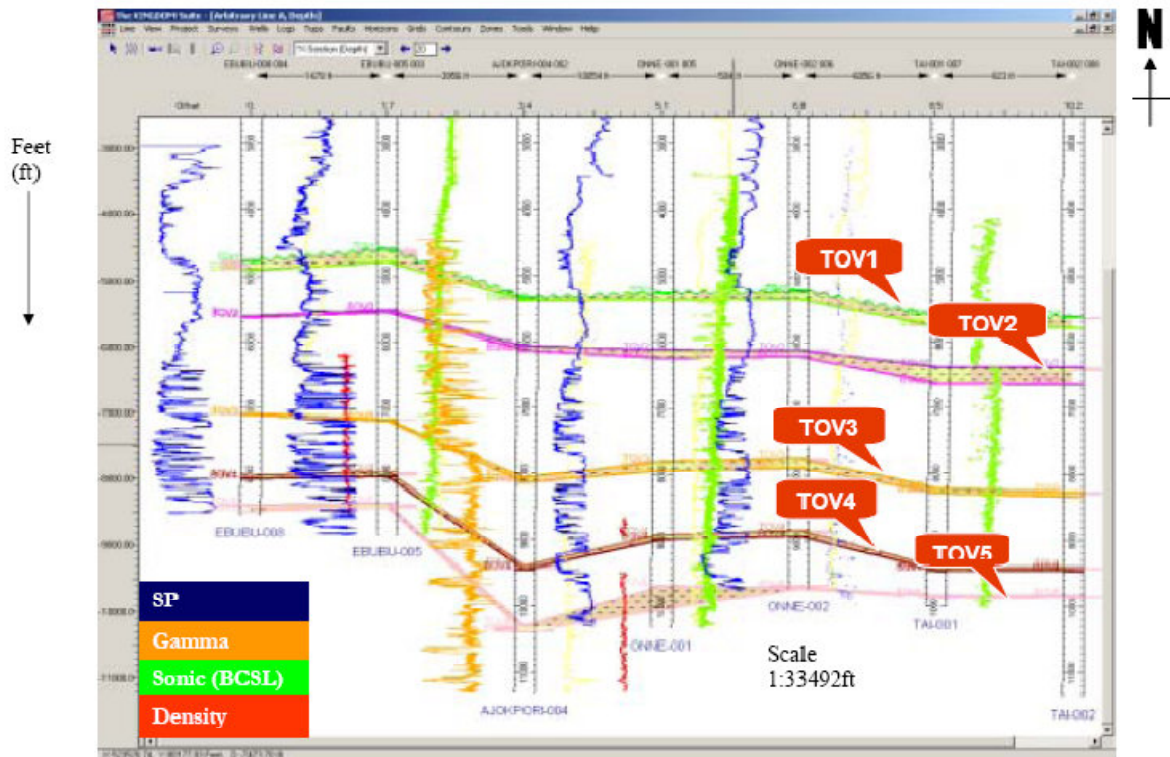


Figure 3a. Showing the tops and the bottoms of identified overpressure zones respectively

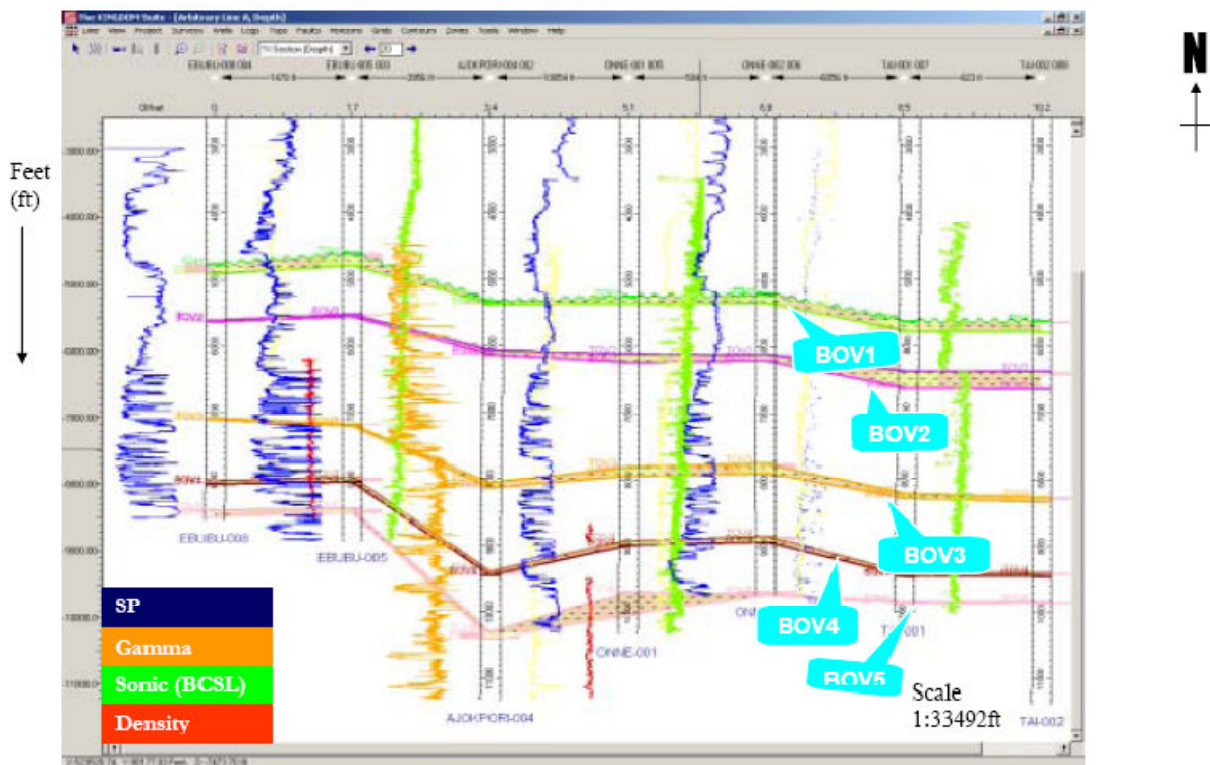


Figure 3b. Showing the tops and the bottoms of identified overpressure zones respectively



The poststack amplitude inversion concept is essentially based on 1-D inversion of seismic data visualizes the earth as a series of layers at each CMP location. Each layer is characterized by density, velocity, and layer thickness. Each layer has equal two-way time intervals. The procedure converts estimates of reflection coefficients into an image of acoustic impedance with depth. Lavergne and William (1977), Lindseth (1979) and Dobrin(1988) discuss the procedure in detail. Except for some modifications to take advantage of today's computing environment, the basic approach remains unchanged. For normally incident pressure waves, the reflection coefficients for layer interfaces are related to acoustic impedance by:

$$RC = \frac{(\rho_{k+1}V_{k+1} - \rho_k V_k)}{(\rho_{k+1}V_{k+1} + \rho_k V_k)} \quad (1)$$

Where  $RC$  is the reflection coefficients of the  $k^{\text{th}}$  interface and  $\rho_k V_k$  is the acoustic impedance of the  $k^{\text{th}}$  layer. Then, the acoustic impedance for the next  $(k + 1)^{\text{th}}$  layer is,

$$\rho_{k+1}V_{k+1} = \rho_k V_k \frac{(1+RC)}{(1-RC)} \quad (2)$$

In this study, traces were extracted from the well location at TAI-001 and away from TAI-001 on the eastern and western parts of the well to make room for lateral variation of velocity. True reflection coefficient ( $RC$ ) was computed from trace extracted at well with sonic log control and from the  $RC$  values, a scaling factor  $K$  was deduced to calculate erroneous  $RC_e$  values from the trace extracted at other locations on the seismic data where there are no wells..

Assuming  $\rho_k \approx \rho_{k+1}$

Then,

$$RC = \frac{(V_{k+1} - V_k)}{(V_{k+1} + V_k)} \quad (3)$$

The scaling factor  $K$  is given by;

$$K = \frac{A}{RC} \quad (4)$$

Where  $A$  is the amplitude.

$$RC_e = \frac{K}{A_0} \quad (5)$$

Where  $A_0$  is seismic amplitude values from traces extracted at locations east or west of the well.

Finally,

$$V_{k+1} = V_k \frac{(1+RC)}{(1-RC)} \quad (6)$$

Equation (6) was in turn used to determine the interval velocities at specified depths.

#### 4. Discussion of Results

The overpressure zones were identified and probable hydrocarbon distribution pattern within the field was established. Figure 3a and 3b shows the tops and the bottoms of identified overpressure zones respectively from the well logs. The overpressure zones delineated were correlated across the suite of logs used. From figures 3a and 3b, a distinct depth variation of the overpressure zone is evident. To further confirm the overpressure zones mapped, seismic amplitude inversion was carried out to ascertain the pressure variations using interval velocity values.

Prior to the seismic data inversion, the 3-D seismic data to be used were subjected to filtering (low frequencies to improve the signal to noise ratio for better evaluation of the overpressure zones). It has been reported by various authors among which are Bredehoeft (1994), Roberts and Nunn (1995) that overpressure investigation involving seismic data only are not reliable if the identified thin beds are thinner than typical wavelengths contained in the velocity curve. These hidden beds are usually the cause of unexpected pressure problems while drilling. Thus, it would be necessary to have better resistivity and porosity data made available for overpressure studies primarily for easy delineation and proper evaluations of overpressure zones.

From this study, the results obtained revealed five tops of overpressure (TOV) namely TOV 1, TOV 2, TOV 3, TOV 4, and TOV 5 at 1608.8m, 1884.1m, 2387.3m, 2708.9m and 3001.4m respectively derived from seismic and lithologic logs. Lateral variations in overpressure were also detected at these depths (Figures 3a and 3b).

In all, five horizons representing the identified overpressure zones were picked on the 3D seismic sections at 1.42 s, 1.75 s, 2.01 s, 2.11 s and 2.30 s respectively. The thickness of the various identified overpressure zones varied from 4.08 m to 50.58 m. Our computed velocity models correlate with the regional velocity models proposed by Elf Petroleum Nigeria (Figure 4). Also, series of faults ranging from listric to counter-regional faults were identified from the interpreted 3D seismic sections (Figure 5). According to Ekweozor and Daukoru (1994), these faults basically characterized the Niger Delta environments of Nigeria.

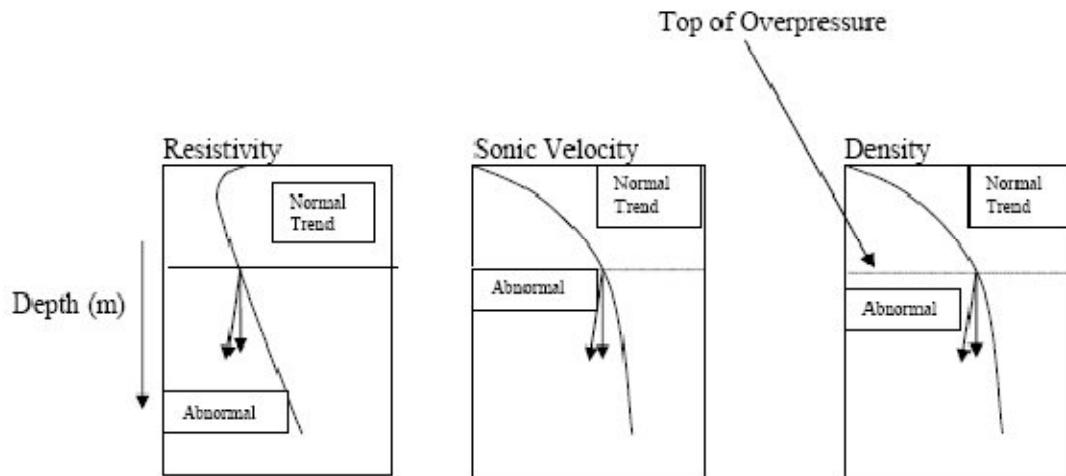


Figure 4. Wireline overpressure indicators. Shale resistivity, sonic velocity and density logs data fall below their normal trends. Resistivity changes not related to pore-pressure could be caused by pore water temperature and salinity. (After ENPL SPECIAL ISSUE, Overpressure, 2001/EP 2001-7023)

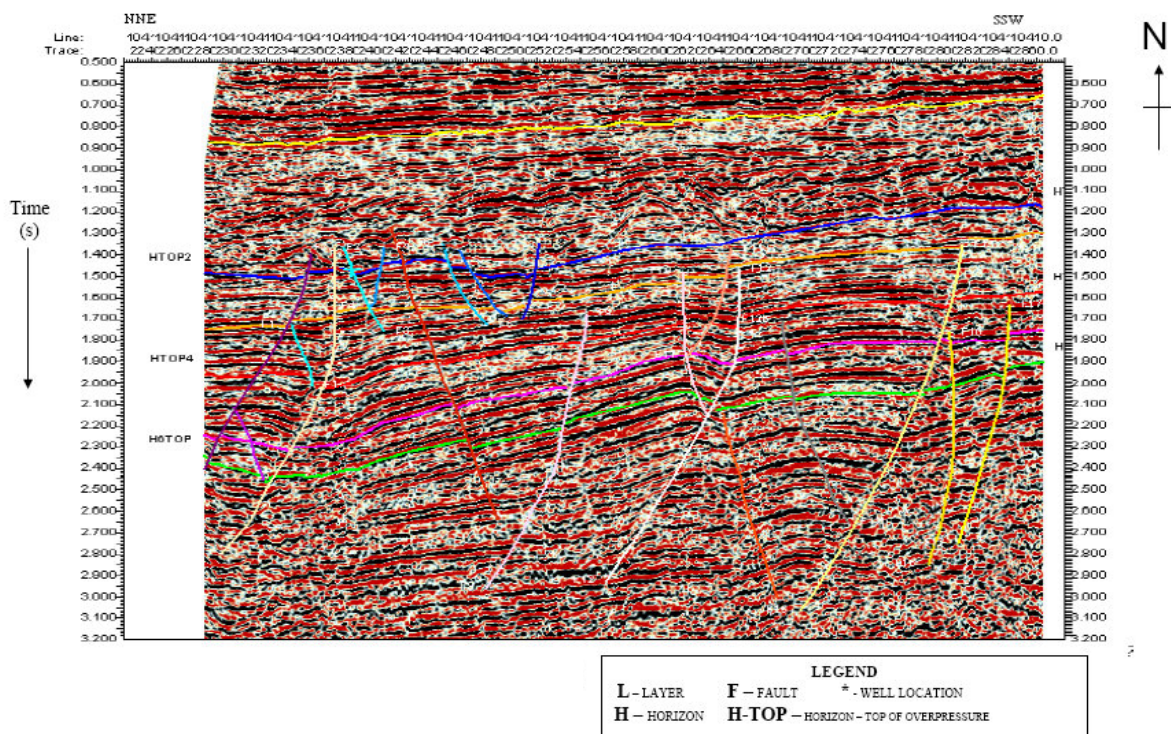


Figure 5. Mapped Faults, Horizons and Layers on Inline 10410

The plot of the *Normal Compaction Trend* versus velocities obtained from sonic logs also confirmed the identified overpressure zones (Figure 6). The sonic interval velocity (ft/s) plot is represented in purple while an interval velocity value (ft/s) from seismic trace inversion is indicated in brown. The thin dash orange coloured lines with dots represent the interval velocity (ft/s) from check shot data and the green straight line represents average velocity (ft/s). A good fit between the interval velocity values from sonic log and interval velocity values from seismic trace inversion is observed from this plot (Figure 6). Also, points of inversion of velocity were noticed in the plots of these velocities derived from seismic trace inversion and sonic velocities thus indicating overpressure.

The identified overpressure zones were further subjected to rigorous tests involving the computation of the water saturation ( $S_w$ ) and porosity values in these zones. The water saturation ( $S_w$ ) and porosity ( $\phi$ ) results obtained showed that the overpressure zones were generally characterized by high water saturation (52 % to 80.36 %),

and low porosity (16.55 % to 30.80 %). These suggest hydrocarbon saturation values ranging between 19.64 % and 48 %). Also, it was observed that four hydrocarbon-bearing zones, which were overlain by the thin overpressure shale beds, characterized 2657 m, 2804 m, 2916.9 m and 3048 m depths respectively. The derived hydrocarbon saturation values suggest that this field is possibly a marginal field. Although this assertion may not be absolutely correct as the dataset used represent a fraction of investigated field. If hydrocarbon exploitation is to take place in this field, these thin beds should be the principal targets. However, adequate planning and appropriate drilling techniques should be employed because of the presence of the identified overpressure zones. It is thus concluded from this work that overpressure zones in virgin fields lacking well-data information could be carried with data (Seismic and well-logs) available from adjacent fields. These dataset could be effectively used as *a priori* information for predicting overpressure zones in the surrounding fields.

## 5. Conclusion

Preliminary integrated approach used for the analysis of combined well-logs and seismic data in the Niger Delta revealed the presence of overpressure zones overlying thin beds saturated with hydrocarbon within the field investigated. Velocity conditioning is considered critical to a successful pressure analysis. This requires enhanced seismic acquisition, processing, and interpretation techniques. The conventional stacking velocities from seismic data are usually unsuitable for pressure work, unless these velocities are processed to yield rock or propagation velocities by integrating either with a rock model or with velocities from surrounding wells. We observe that inclusion of lateral changes in velocity is essential in obtaining consistent pressure changes within the basin. Non-inclusion of this parameter would result in overestimation of the estimated velocities, which may result in false values pore pressure. Also, seismic inversion improved the resolution of the derived velocity values but always required a reliable low-frequency model and calibration.

## 6. Acknowledgments

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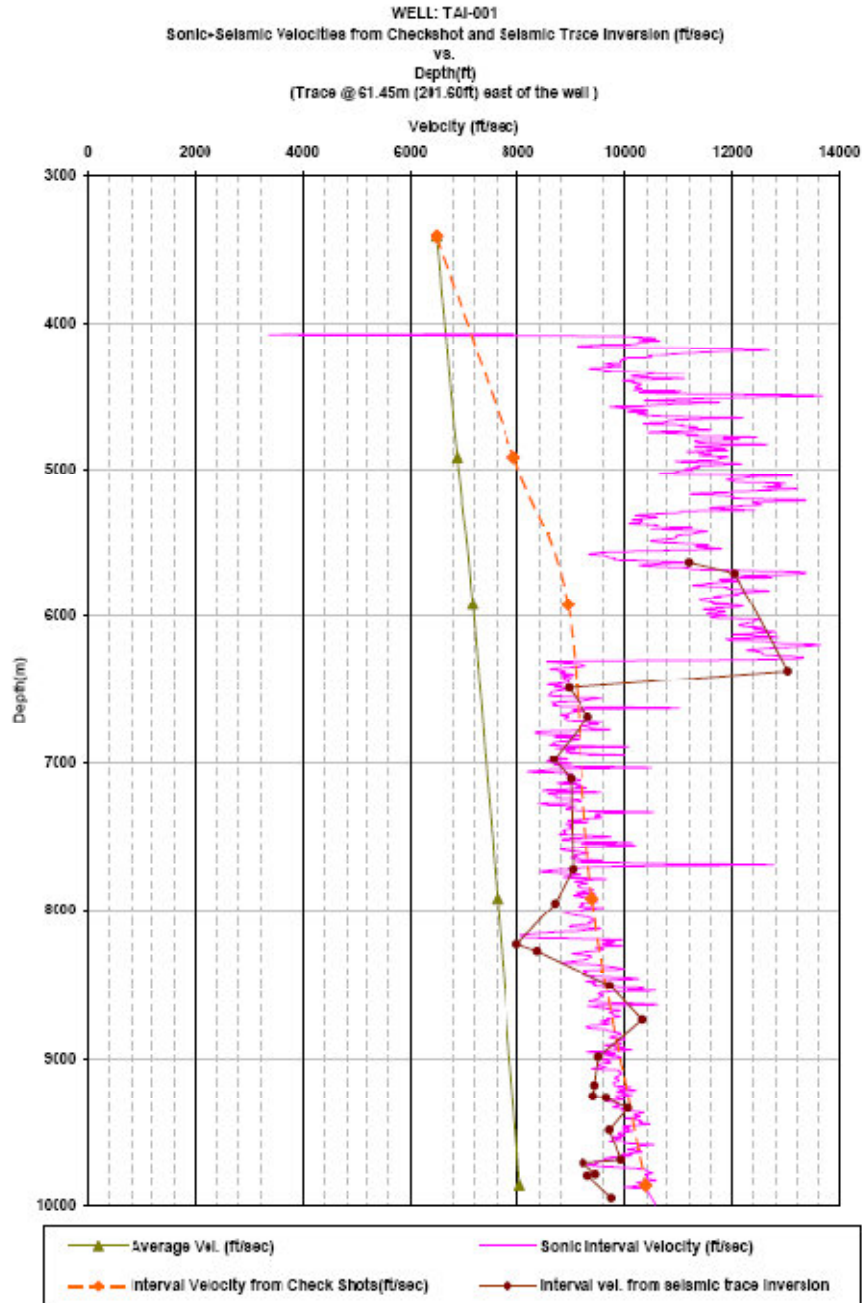


Figure 6. Comparing Interval Velocity Values from Sonic log and Seismic Trace Inversion at well TAI-001 (61.45m east of the well).