

# Geopressure and Trap Integrity Predictions from 3-D Seismic Data: Case Study of the Greater Ughelli Depobelt, Niger Delta

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**Résumé — Pressions de pores et prévisions de l'intégrité des couvertures à partir de données sismiques 3D : le cas du grand sous-bassin d'Ughelli, Delta du Niger** — Les campagnes de forages profonds dans le delta du Niger ont démontré la nécessité d'une analyse détaillée des surpressions et de l'intégrité des structures pour évaluer correctement les prospects. La prédiction des pressions interstitielles a pu être réalisée ici avant forage à partir de données sismiques 3-D du grand sous-bassin d'Ughelli, dans le delta du Niger. Ce travail a permis de prévoir les régimes de pression du sous-sol, de déterminer la hauteur de la colonne d'hydrocarbures, la continuité du réservoir et l'intégrité du piège. Nos résultats montrent que les surpressions sont fréquentes dans les formations sédimentaires profondes abritant les réserves les plus prolifiques d'hydrocarbures du delta du Niger. La profondeur de la zone de surpressions légères (< 0.60 psi/ftss) s'étend de 2 000 à 3 000 m sous le niveau marin. De même, la profondeur de la zone de fortes surpressions (> 0.60 psi/ftss) varie de 3 000 m à 10 km. La répartition des surpressions augmente avec la profondeur et vers la partie centrale du bassin. La variation de la profondeur du sommet des surpressions est liée à la présence de failles et de diapirs d'argile. Le sommet des surpressions est ainsi moins profond en présence de diapirs. Les failles postérieures aux dépôts ont contrôlé la configuration de l'enveloppe des surpressions et jouent encore un rôle dans les modifications récentes de la profondeur des surpressions. Dans cette région, les surpressions sont souvent associées à des structures de glissement (*roll-overs*) contrôlées par des failles de croissance, tandis que les pressions hydrostatiques sont observées dans les zones fracturées et au sommet des diapirs.

**Abstract — Geopressure and Trap Integrity Predictions from 3-D Seismic Data: Case Study of the Greater Ughelli Depobelt, Niger Delta** — The deep drilling campaign in the Niger Delta has demonstrated the need for a detailed geopressure and trap integrity (drilling margin) analysis as an integral and required step in prospect appraisal. Pre-drill pore pressure prediction from 3-D seismic data was carried out in the Greater Ughelli depobelt, Niger Delta basin to predict subsurface pressure regimes and further applied in the determination of hydrocarbon column height, reservoir continuity, fault seal and trap integrity. Results revealed that geopressured sedimentary formations are common within the more prolific deeper hydrocarbon reserves in the Niger Delta basin. The depth to top of mild geopressure (< 0.60 psi/ft) in the study area ranges from about 6 000 ft to 9 000 ft subsea. Similarly, the depth to top of hard geopressures (> 0.60 psi/ft) ranges from about 10 000 ftss to over 30 000 ftss. The distribution of geopressures shows a well defined trend with depth to top of geopressures increasing

towards the central part of the basin. This variation in the depth of top of geopressures in the area is believed to be related to faulting and shale diapirism, with top of geopressures becoming shallow with shale diapirism and deep with sedimentation. Post-depositional faulting is believed to have controlled the configuration of the geopressure surface and has played later roles in modifying the present day depth to top of geopressures. In general, geopressure in this area is often associated with simple rollover structures bounded by growth faults, especially at the hanging walls, while hydrostatic pressures were observed in areas with *k*-faults and collapsed crested structures.

## INTRODUCTION

The quantity of hydrocarbon accumulation is a function of generation, migration, entrapment, sealing and preservation. All of these factors are affected by the history of fluid movement in a thermo-chemical setting. Fluid movement within a basin depends primarily on pressure variation (Yu and Lerche, 1996). Thus, one can improve both hydrocarbon exploration, and latter oil production with a better understanding of the fluid pressure environment. Similarly, the additional costs of well blowouts and associated well bore problems while drilling have forced the drilling industry to obtain methods of pre-drill prediction of geopressured formations. Therefore an accurate prediction of subsurface pressure is crucial to avoid a wellbore blowout prior to drilling into the geopressured formation.

The hydrostatic pressure gradient is 10.5 kPa/m (0.454 psi/ft or 0.10732 kg cm<sup>-2</sup> m<sup>-1</sup>), and at the other extreme, the lithostatic gradient is about 22.6 kPa/m (1.0 psi/ft or 0.231 kg cm<sup>-2</sup> m<sup>-1</sup>). Thus, any reservoir with a hydrostatic gradient between 0.454 and 1.0 psi/ft is considered to be overpressured. The average total overburden (lithostatic) pressure gradient resulting from the combined pressure of the rocks (grain-to-grain or rock matrix stress) and their interstitial fluids are taken as 1.0 psi/ft (0.231 kg cm<sup>-2</sup> m<sup>-1</sup>). Similarly, fluids in the geopressured zones can exhibit pressures greater than 68 MPa (about 10 000 psi). Throughout the world, literature is filled with examples of geopressured formations recorded at depths of a few hundred feet to that greater than 20 000 ft. Indeed, geopressured formations are recorded in over one hundred and eighty (180) basins and sub-basins worldwide (Chilingar *et al.*, 2002). The objective of early formation analysis of abnormally pressured zones therefore is primarily to predict and identify these zones prior to drilling into them. The need for prior knowledge is motivated by the economic losses that are often experienced by suddenly drilling into an unrecognized geopressured region. Attention must be paid to pore fluid and rock stresses in sedimentary sequences, because the knowledge of vertical and lateral stress patterns in a depositional basin is helpful in evaluating its history and development. A thorough quantitative understanding of compaction mechanics, the relationship between the total overburden stress, effective stress, and pore stress (pressure) in fine-grained clastics is required to recognize the potential development of geopressured formations.

Nigeria is the largest oil producer in Africa, the eleventh largest producer of crude oil in the world and a member of the Organization of Petroleum Exporting Countries (OPEC). In 2006, total Nigerian oil production, including lease condensates, natural gas liquids and refinery gain, averaged 2.45 million bbl/d of which 2.28 million bbl/d was crude oil (EIA Report, 2007). If Nigeria hopes to increase its crude oil production to 4 million bbl/d by 2012, deeper potential targets in deepwater offshore and possibly beneath currently producing intervals onshore should be focused on. Exploration interest in the Niger Delta basin has therefore moved to mainly deep prospects onshore and deep/ultra deep prospects and plays offshore. However, the deep drilling campaign in the Niger Delta has demonstrated the need for a detailed geopressure and trap integrity analysis as an integral and required step in prospect appraisal. This is because different trapping scenarios can occur in which hydrocarbons are entirely lacking in a structure or are contained as a single or multi-phase in the respective hydropressured and geopressured sections. Similarly, the risk of dry or gas charged traps increases with depth and overpressure magnitude. For instance, AGIP Oil Nigeria drilled over sixty exploration wells with depths greater than 4 500 m (13 123.36 ftss), between 1979–2005 with most of these wells been hard pressured (Nwaufa *et al.*, 2006). Similarly, all of the deep wells (“HPHT” wells) drilled by Shell Petroleum Development Company of Nigeria Limited in the basin were overpressured (Opara, 2008). In most of these cases, the wells were abandoned, drilled without reaching the objective sequence, or with drilling prolonged unnecessarily to sometimes as long as seven months leading to astronomical rise in drilling cost. It should be noted however, that most of these problems were encountered despite the fact that the latest drilling practices were applied (Nwaufa *et al.*, 2006).

Safe exploitation of these deep prospects and plays would therefore largely depend on the ability to understand the controls on top seal strength, overpressure generation/distribution, and trap integrity, and then confidently incorporating these results into prospect evaluation and well design. This work is therefore aimed at developing a robust geopressure and trap integrity prediction and analysis of the Greater Ughelli depobelt using 3-D seismic velocity data. This is very important considering the current campaign for deeper wells, as the economic consequences of exploitation in areas with an unspecified risk of abnormal pressure profiles may range

from increased drilling costs due to hazards, to unrealized prospect potential. In addition the numerical results from the prediction of geopressed formations can serve as a reference against which other geological scenarios can be compared for their overpressured anomalies. Finally, by comparing case histories, one can obtain valuable clues for estimating current and paleo-geopressure conditions in the frontier basins that can be assessed prior to drilling (Yu and Lerche, 1996).

## 1 BACKGROUND GEOLOGY

The Niger Delta is the largest delta in Africa with a sub-aerial exposure of about 75 000 km<sup>2</sup> and a clastic fill of about 9 000 to 12 000 m (30 000 to 40 000 ft) and terminates at different intervals by transgressive sequences (Short and Stauble, 1967). The geology of the Niger Delta basin has been studied extensively by several authors and the geology is therefore sufficiently understood (Merki, 1971; Short and Stauble, 1967; Evamy *et al.*, 1978; Weber, 1990, 1991; Doust and Omatsola, 1990; Weber and Daukoru, 1975). The Onshore Niger Delta is situated on the Gulf of Guinea on the West Coast of Africa and lies between latitudes 4° and 6° N and longitudes 4°30' and 8°00' E (Fig. 1). The onshore portion of the Niger Delta Province is delineated by the geology of southern Nigeria and southwestern Cameroon (Fig. 2). The northern boundary is the Benin flank; an east-northeast trending hinge line south of the West African basement massif. The northeastern boundary is defined by outcrops of the Cretaceous on the Abakaliki High and further east-south-east by the Calabar flank – a hinge line bordering the adjacent Precambrian. The tectonic framework of the Niger Delta is related to the stresses that accompanied the separation of African and South American plates, which led to the opening of the South Atlantic.

The stratigraphy of Niger Delta is complicated by the syn-depositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation deposits (Fig. 3). Three major depositional cycles have been identified within Niger Delta (Short and Stauble, 1967; Doust and Omatsola, 1990). The first two, involving mainly marine deposition, began with a middle Cretaceous marine incursion and ended in a major Paleocene marine transgression. The second of these two cycles, starting in late Paleocene to Eocene time, reflects the progradation of a “true” delta, with an arcuate, wave- and tide-dominated coastline. These sediments range in age from Eocene in the north to Quaternary in the south (Doust and Omatsola, 1990). Deposits of the last depositional cycle have been divided into a series of six depobelts (Doust and Omatsola, 1990) also called depocentres or mega-sequences, separated by major syn-sedimentary fault zones (Fig. 1). These cycles (depobelts) are 30-60 kilometers wide, prograde southwestward 250 kilometers over oceanic crust into the Gulf of Guinea (Stacher, 1995), and are defined by syn-sedimentary faulting that occurred in response to variable rates of subsidence and sediment supply (Doust and Omatsola, 1990). A depobelt therefore, forms the structurally and positionally most active portion of the delta at each stage of its development. In comparison with other Tertiary deltas, depobelts may be likened to the pro-gradational wedges, or depocentres of the United States Gulf Coast (Galloway *et al.*, 1982).

The Niger Delta basin evolved in a protracted style where subsidence and sedimentation within a depobelt may have been facilitated by large scale withdrawal and seaward movement of undercompacted and geopressed marine shales under the weight of advancing paralic clastic wedge (Doust and Omatsola, 1990). At a certain stage however, further subsidence and sedimentation could no longer be accommodated and the focus of deposition shifted basinward to form a new depobelt. Similarly, syn-sedimentary and most post-sedimentary faulting ceased with the abandoned depobelt. Normal faults triggered by the movement of deep-seated, overpressured, ductile, marine shale have deformed much of the Niger Delta clastic wedge. Growth faults affecting the sequence within depobelts form the boundaries of macrostructures (or individual delta units), each with its own sand-shale distribution pattern and style. Depobelts or mega-structures comprise in fact families of genetically and temporally related growth fault trends, or macrostructures (Doust and Omatsola, 1989).

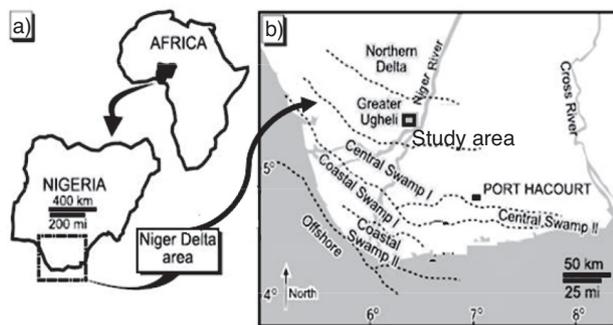


Figure 1

Map of the Niger Delta basin showing the different depositional (depobelts) belts (after Doust and Omatsola, 1990).

## 2 THEORY AND METHODS

Seismic attributes such as interval velocity provide a means of assessing pressure in the subsurface. This approach relies on the fact that seismic velocity is primarily a function of the

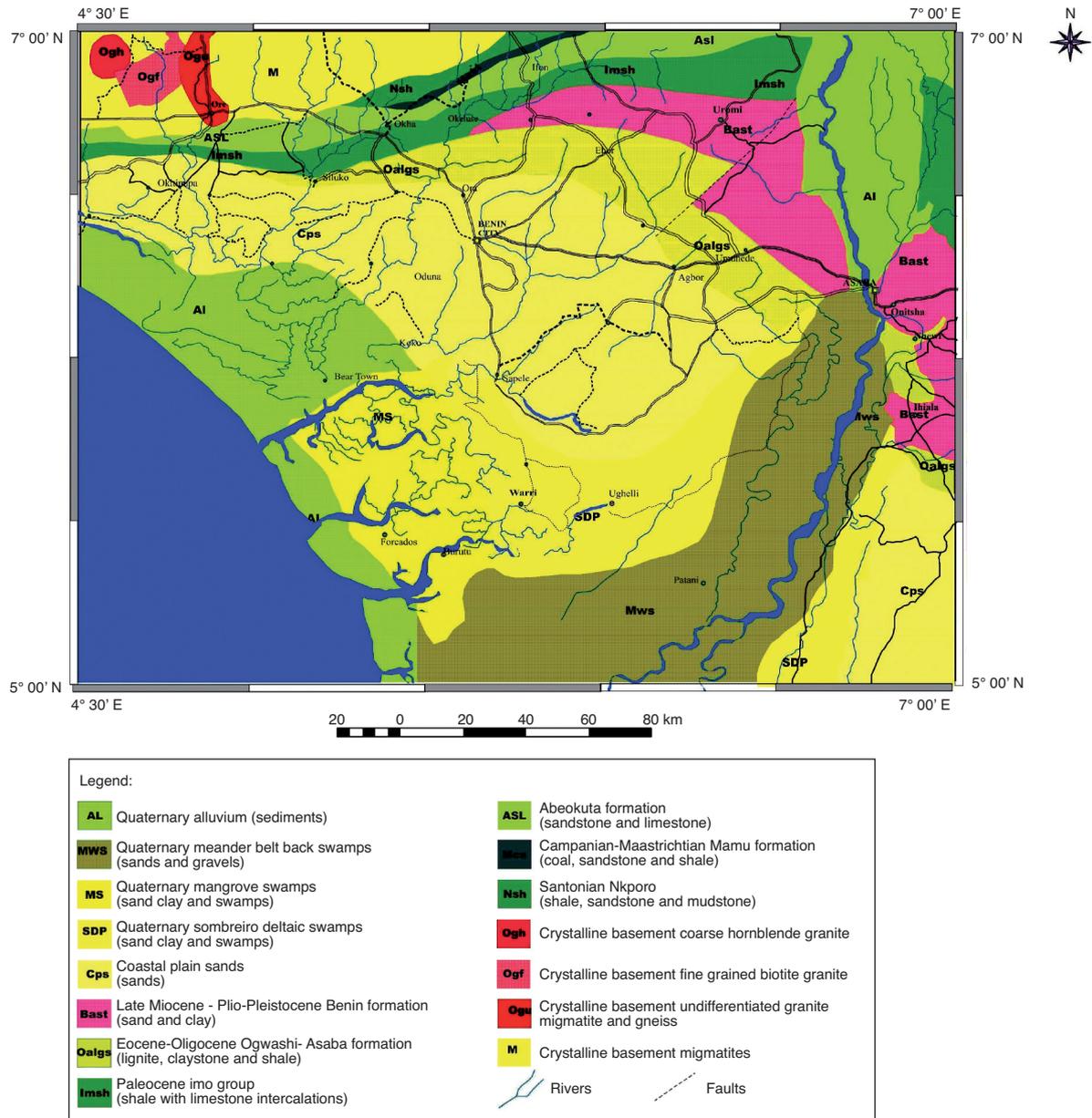


Figure 2

Regional geology map of the Niger Delta basin, Nigeria.

porosity of the sediments, which in itself is dependent on the vertical effective stress (compaction) that the rocks have undergone. With the advent of 3-D seismic and, more recently, 4-D seismic, it has become possible to make pressure predictions that are more reliable and create three-dimensional pressure profiles. In general, the seismic reflections are functions of acoustic impedance (product of velocity and density) and are influenced by reservoir pressure. On the other hand, the type of reservoir fluid impacts on the sonic

velocities. Shear waves and compressional waves respond differently to various reservoir fluids (and lithology) as well as reservoir pressure. These phenomena offer the following two practical applications:

- prediction of overpressures from seismic velocities before drilling;
- mapping reservoir fluid movement and dynamic changes of reservoir pressure using time lapse (4-D seismic).

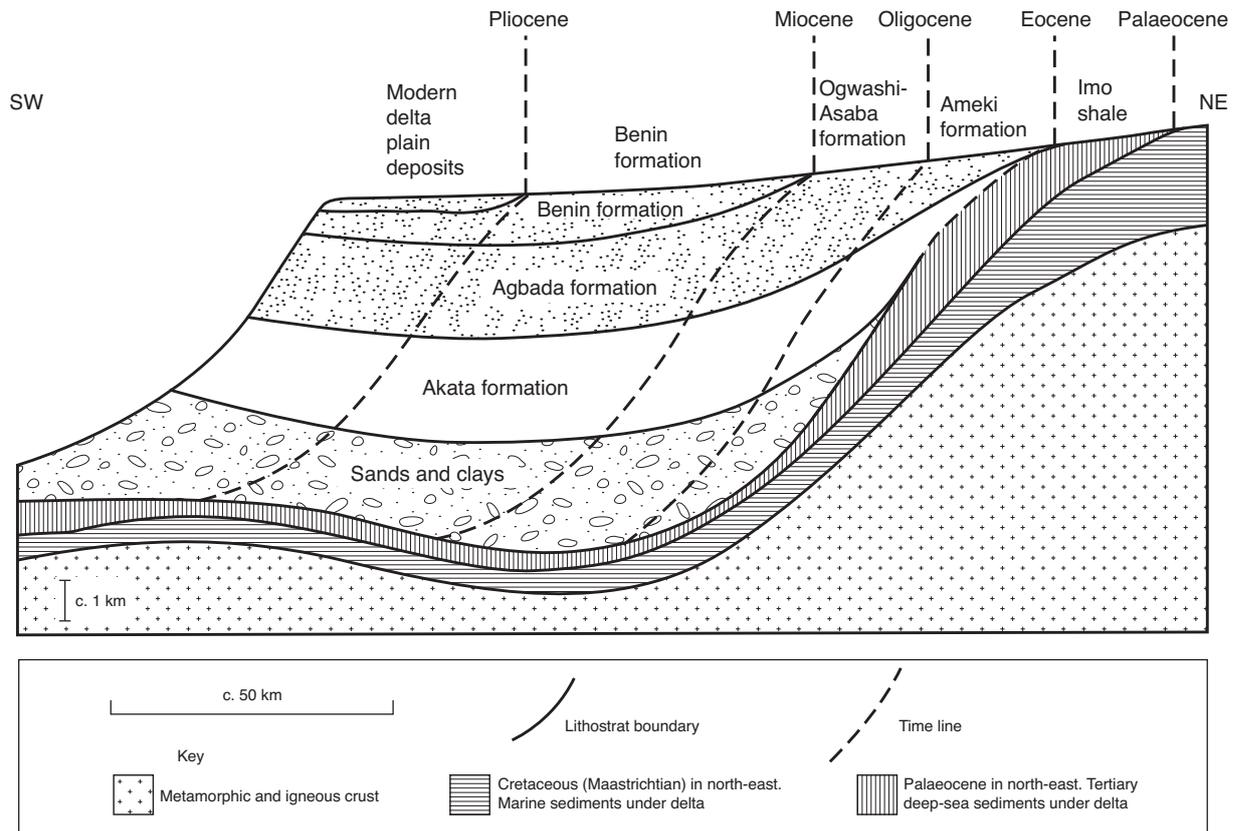


Figure 3

Litho-stratigraphic description of the Niger Delta basin showing the stratigraphic equivalences between the outcropping and the subsurface Niger Delta (after Wright *et al.*, 1985).

In general, most pore pressure methods use the seismically derived velocities as a basis for prediction. The seismic velocities are calibrated against velocities derived from sonic logs and petrophysical measurements. Under a normal pressure regime in the absence of hydrocarbon saturation, one would anticipate the sonic velocity to increase with depth. Geopressures are therefore indicated by significant changes in the sonic velocity with depth. These changes of course can have different origins, such as lithology, hydrocarbon saturation, formation temperature and, finally, formation pressure. The main objective of earlier studies on the use of seismic velocities for geopressure prediction concentrated on identifying sonic velocity changes without isolating the reasons for such changes (Eaton, 1972). However, in exploration areas with seismic shadow zones, where very little or no pressure information is available, the interval velocity method can be used.

The approach used in this study is that of inverse overpressure modeling using vertical effective stress method where the velocity and acoustic impedance inversion of seismic data were used to obtain geopressures. This technique has two major components:

- a rock property model that links effective stress, temperature and lithology to velocity;
- a subsurface image based upon high-resolution velocity analysis of seismic data.

The rock property transform is generated from an extensive database. The transform is model-based and considers the major cause of overpressure mechanisms, *e.g.*, under compaction. The model does not require either a local calibration or a normal trend analysis of Hottman and Johnson (1965), Eaton (1972) or Pennebaker (1968). It predicts effective stress directly, which is the most fundamental quantity for pressure prediction while the overburden pressure is estimated from a relation between velocity and density. There are five main applications of overpressure prediction from seismic data which include the following (Indrelid, 1997; Opara, 2008): reservoir continuity, maximum hydrocarbon column, trap integrity, fault sealing and subsurface pore pressure prediction.

Determining pore pressures from seismic interval velocities is based on the assumption that there is a consistent regional relationship between acoustic velocity and effective stress.

Offset well data in about forty (40) wells including exploration wells and sidetracks were used to assess the reliability of the link between shale acoustic velocities and pressure, and to establish appropriate density and overburden trends. Specifically, sonic logs, gamma ray and density logs were used for calibration while porosity, resistivity, spontaneous potential and caliper were used for quality control and lithologic correlation. Pressure data in the form of Repeat Formation Test (RFT), mud weights (mwt) and Leak Of Test (LOT) data were used. Other datasets used include checkshot data and temperature data. Sonic log velocities corrected for cycle skipping were then used to predict pressures in the offset wells and compared with direct pressure measurements, using the Tau Compaction model. The standard model compaction trend settings were adjusted where necessary to get the most consistent match between predicted pressure for shale acoustic velocity and actual measured pressure from the well. This method is purely empirical but has proven a valid approach in the Baram delta, Gulf of Mexico, North Sea and the Niger Delta basin (Krusi, 1994; Indreliid, 1997). Firstly, sonic velocities are related to effective stress by scaling the interval transit time as:

$$\tau = \frac{200 - ITT}{ITT - 150} \quad (1)$$

Then tau ( $\tau$ ) is related to effective stress by the relationship:

$$\tau = A \times \sigma_{eff}^B = A \times VES^B \quad (2)$$

where  $ITT$  = Initial Travel Time,  $\sigma_{eff} = VES$  = Vertical Effective Stress,  $\tau = \text{tau}$ ,  $A$  and  $B$  are parameters determined from the behaviour of the sonic log data in the normally pressured zone where effective stresses are known and are lithology dependent.

Seismic interval velocities were then extracted at proposed well locations and calibrated. Detection of possible presence of seismic velocity anisotropy was carried out by plotting seismic velocity data with borehole sonic log and checkshot data inverted to sonic velocities. The trend of the seismic velocity plot with respect to the borehole sonic was then used to detect presence of anisotropy or poor quality seismic data. Calibration functions ( $A$  &  $B$ ) generated in the study area were used with the seismic interval velocities corrected for anisotropy to provide reliable pre-drill subsurface pressure estimates using velocity to pressure transform software (VEL2PRE Software). For this study the calibration parameters generated are as follows:  $A = 168.40$  bar,  $B = 0.90$ , with standard deviation ( $dA$ ) =  $\pm 22.61$  bar and Correlation Coefficient ( $CC$ ) =  $0.964$ . Similarly, Skempton coefficient or Poro-elastic coefficient value of  $0.85$  was used. The overburden and adjusted model compaction setting were then used to calculate the pressure, overpressure, vertical effective stress and minimum effective stress at the prospect location.

### 3 PRESENTATION OF RESULTS

The fluid pressures in offset wells used in the calibration process were predicted using the calibration parameters  $A$  and  $B$ . This process was repeated in the wells not used in the calibration process for the purpose of validation. The accuracy of this prediction is noticed in the correlation of the predicted pressures with the measured RFT data in a correlation well (Oo-2 well); see Figure 4. The 3-D seismic velocity data was picked down to 6 s at an average of 250 ms interval on a grid of  $24 \text{ m} \times 24 \text{ m}$ . The seismic section revealed dense faulting and structural deformation (Fig. 5). Structural interpretation of the seismic data of the area revealed that the structural style is dominated by growth faulted rollover anticlines with footwall and hanging wall closures and collapsed crest faults, associated with shale diapirs (Fig. 6). The Root Mean Square (RMS) velocity data was converted to interval velocity using appropriate (medium) smoothing parameters as shown in Figure 7 below. Note that in this figure, the interval velocities are not erratic but some significant velocity variations can be observed. There is a major reversal in velocity associated with top of overpressures resulting from the influence of shale diapirs (mainly mud volcanoes) below 2.5 s. Similarly, these smoothed seismic velocity data were depth converted using the three different smoothing scenarios (low, medium and high); see Figure 8. Note that data from medium smoothing presented the best results as that from high smoothing scenario revealed that the data was over smoothed while that from low smoothing was very poor as no reversal could be clearly seen on the data. The analyzed seismic velocity data which has been depth converted were extracted at proposed well locations and compared with the checkshot and sonic velocities of offset wells for the purposes of identifying the velocity reversal zones, presence of anisotropy and bad seismic data (Fig. 9). However, it appears that the data quality is good enough since no considerable anisotropy effect was noticed. The calibration parameters ( $A$  &  $B$ , which relates the vertical effective stress at any depth to the porosity and density at the same depth) together with the seismic velocities corrected for anisotropy were used to predict the pore pressure field of the area. Figure 10 shows the pore pressure cubes of the study area generated from seismic data while a 3-D visualization of the pressure field with interpreted events, faults and wells are presented in Figure 11.

The predicted pressure volumes were then interpreted as a backdrop to seismic data as shown in Figure 12 below. The purpose of this is to predict the effects of trap integrity, reservoir continuity, sealing faults and maximum hydrocarbon column. Figures 12a-d all exhibited a very wide variation in predicted pressure below 2.5 s which indicated absence of connected reservoirs in the overpressured sections. Similarly, Figure 12c showed distinct changes across the faults in the overpressured section. This shows that the faults are sealing. A bigger difference in the predicted pressure across a fault

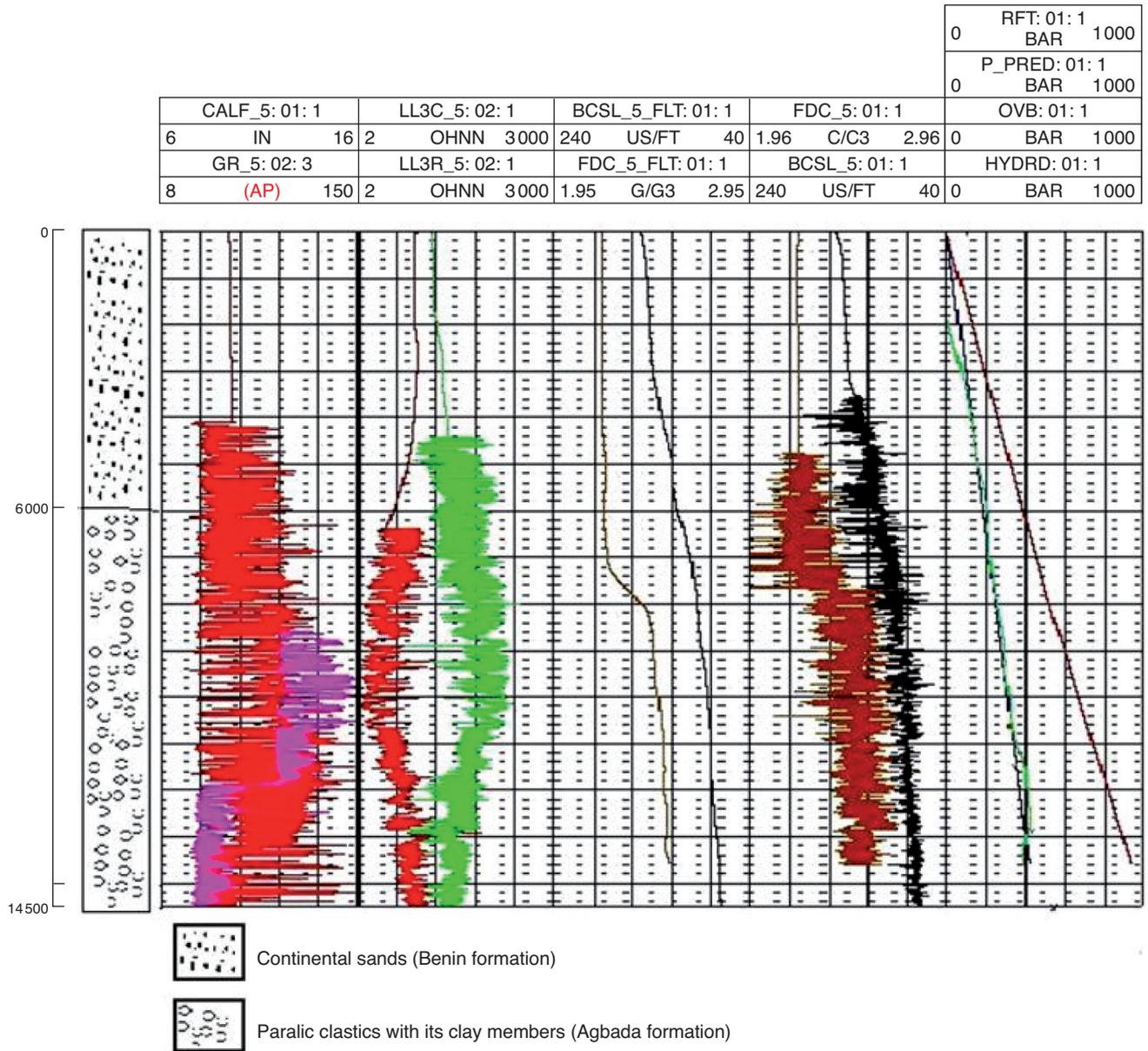


Figure 4  
Pore pressure prediction from sonic velocities in a calibration well (Oo-02 well).

indicates a higher risk of fault seal breakdown. Note that there are no visible changes across the faults in the normally pressured section. Similarly, in Figure 12d, the predicted MES (Minimum Effective Stress) at prospect A and B have the same value of 9 523-11 428 psi (68.75-82.51 MPa) while prospect C has an MES of 3 809-5 238 psi (27.5-37.4 MPa). This shows that prospects A and B have a much lower risk of trap breaching than prospect C. Similarly, this risk in prospect C is increased even more by considering the effects

of a potential hydrocarbon column. The structures of prospects A and B are low and hence a relatively short hydrocarbon column (hence small hydrocarbon buoyancy pressure) is expected in contrast to prospect C which has a higher relief. Filling the prospect with hydrocarbons would result in an even smaller minimum effective stress, and in all likelihood a blown trap. Hence, prospect B is ranked highest followed by A, while prospect C has the least ranking of trap integrity.

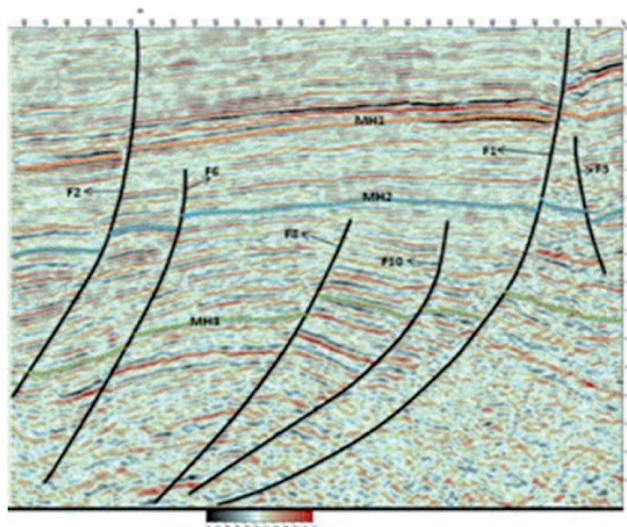


Figure 5  
3-D Seismic section of line 6 400 from the study area showing growth faulting.

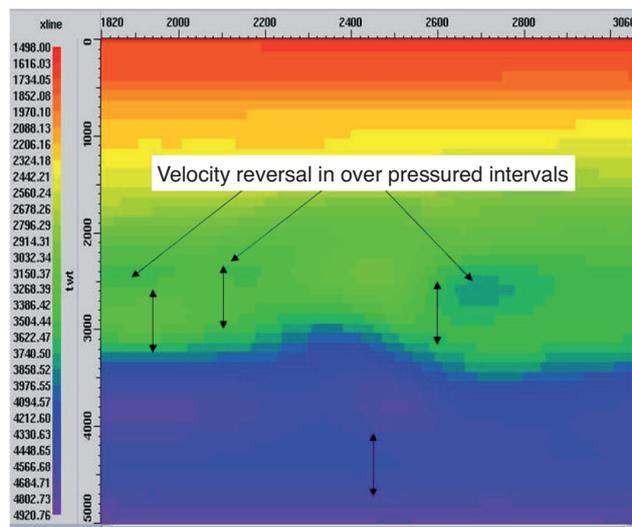


Figure 7  
Medium seismic velocity smoothing with smoothing distance and time interval of 10 m, 10 m and 50 ms showing velocity reversal zones.

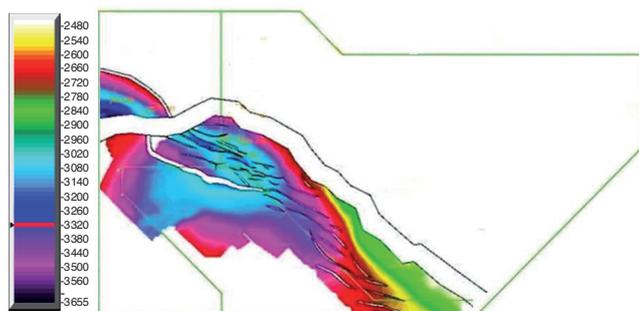


Figure 6  
Structural map of the MH<sub>3</sub> Horizon of 3-D seismic data of the study area.

## 4 INTERPRETATION AND DISCUSSION

Pore pressure prediction and interpretation in the Greater Ughelli depobelt, Onshore Niger Delta basin revealed that the onset of mild overpressures (< 0.60 psi/ft) in the study area lies within the depth ranges of about 6000 ftss in Oo-field, 8000 ftss around Ah-field, 9000 ftss in Og-field and about 10000 ftss at Is-field. Analysis of seismic data revealed that very high pressures (hard overpressures nearing lithostatic pressures) are expected at deeper intervals between 10000 ft to over 30000 ftss (3030.77 m to 9092.31 m ss).

Distribution of geopressures revealed a well-defined trend with depth to top of overpressures increasing towards the central part of the basin to a maximum depth of about 13000 ft (3940 m). This variation in the depth of top of overpressures within the area is believed to be related to faulting and shale diapirism with top of overpressure becoming shallower with shale diapirism and deeper with sedimentation. There seem to be no macro-structural trend of the geopressure profile in the study area, rather geopressures were observed in areas with simple rollover anticlines, especially at the hanging walls, while normal formation pressures were observed in areas with *k*-faulting pattern and collapsed crest structures. It is most likely that these fault patterns have serious implications on the formation pressure as they may have provided relief to potential pressure build-up (Nwaufa *et al.*, 2006). Hanging wall fault closures are most often sealing and therefore retains significant columns of hydrocarbons often leading to

Figure 13 is a typical pressure profile from fluid pressures predicted from the seismic velocity cube and extracted at well locations. In Ah-field, +500 psi above hydrostatic pressure (overpressure) is at about 6000 ftss and is taken to be the top of overpressure in the area. The top of overpressure can be seen to vary from 8000 ftss in Oo-field, to 9000 ftss at Og-field and then 11000 ftss at Is-field. Finally, maximum hydrocarbon column estimated from the predicted pressure depth plots in Figure 13 vary between 35 ft to 350 ft with an average column of 55 ft. This relatively short hydrocarbon column is associated with the fact that most of the reservoirs in the study area are not filled to their synclinal/anticlinal spill points.

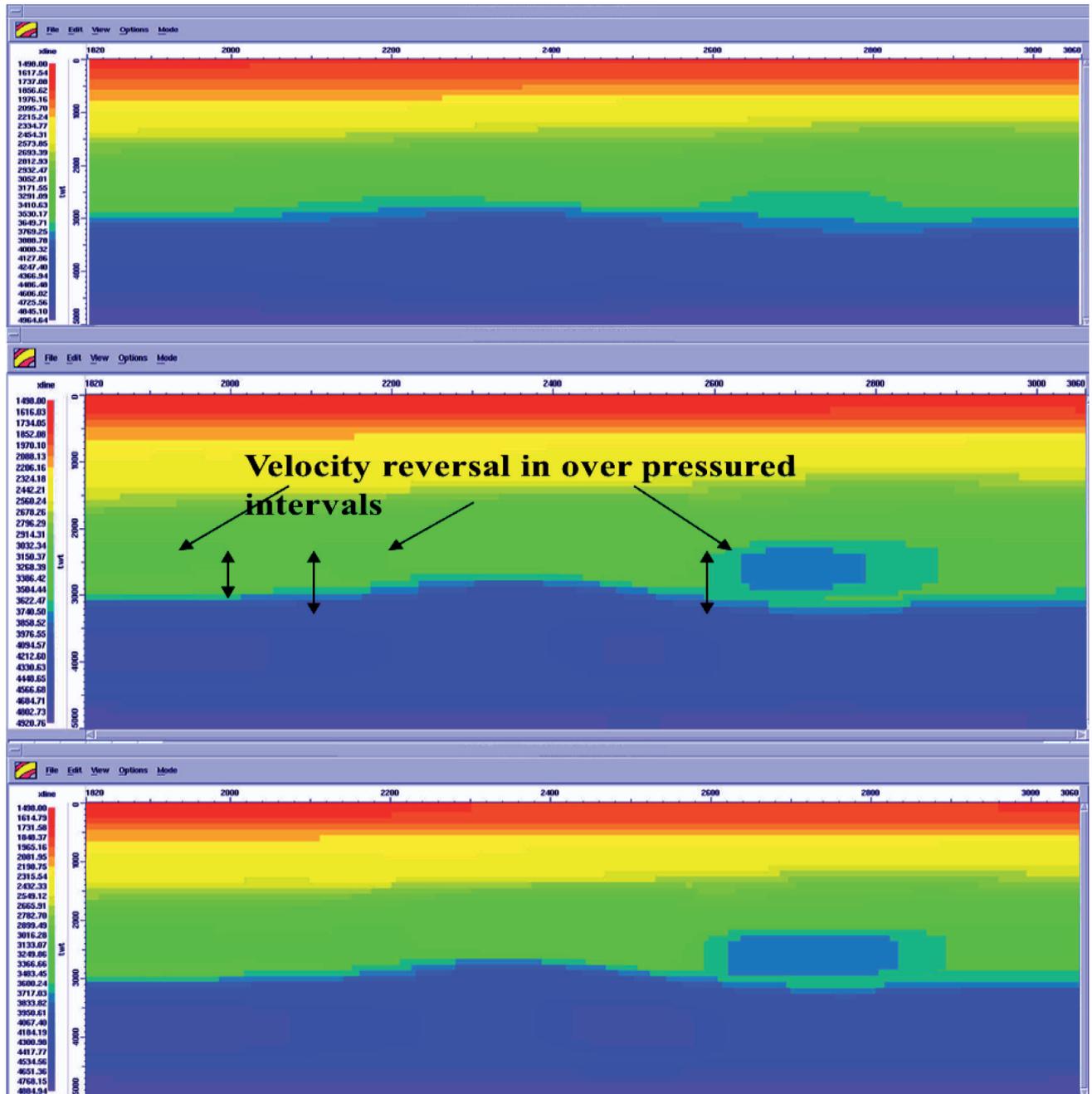


Figure 8

Depth converted seismic velocity models from the three smoothing scenarios: a) low smoothing, b) medium smoothing and c) high smoothing.

high minimum effective stress and fluid charging. Similarly, late hydrocarbon generation and shale diagenesis often leads to geopressures within upthrown shales (Evamy *et al.*, 1978). The subsurface of the Niger Delta basin is extensively deformed by growth fault structures and rollover anticlines

with hanging wall rollover anticlines developed because of listric-fault geometry and differential loading of deltaic sediments above ductile shales. These growth faults are characterized by thicker deposits in the downthrown (hanging wall) block relative to the upthrown block because sedimentation

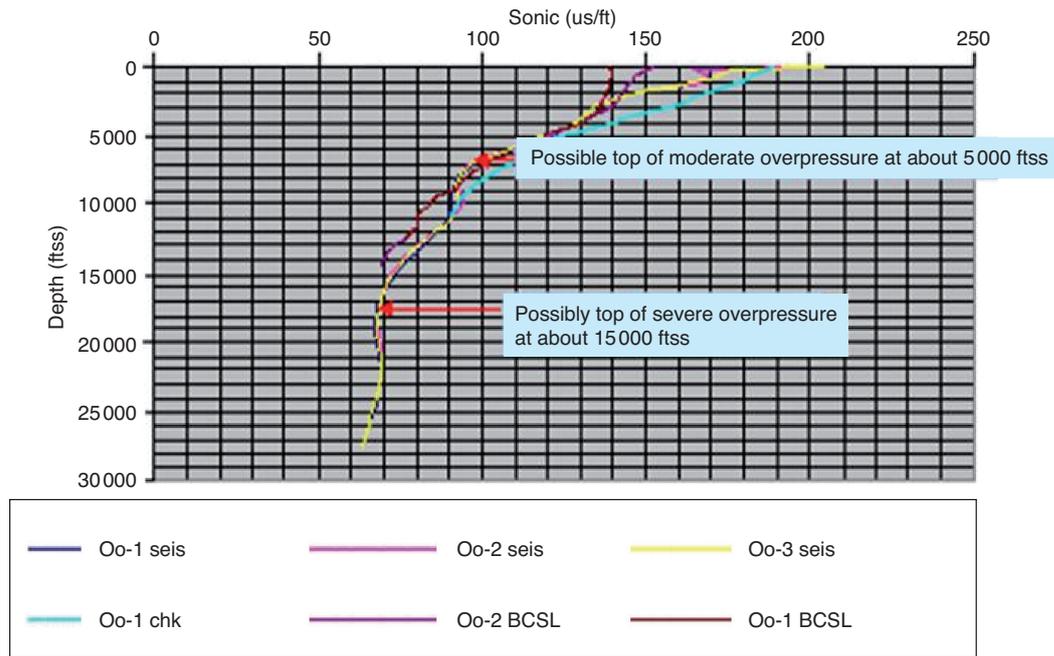


Figure 9

Calibration of seismic velocity data using sonic velocity data and checkshot data of Oo-field showing velocity reversal zones.

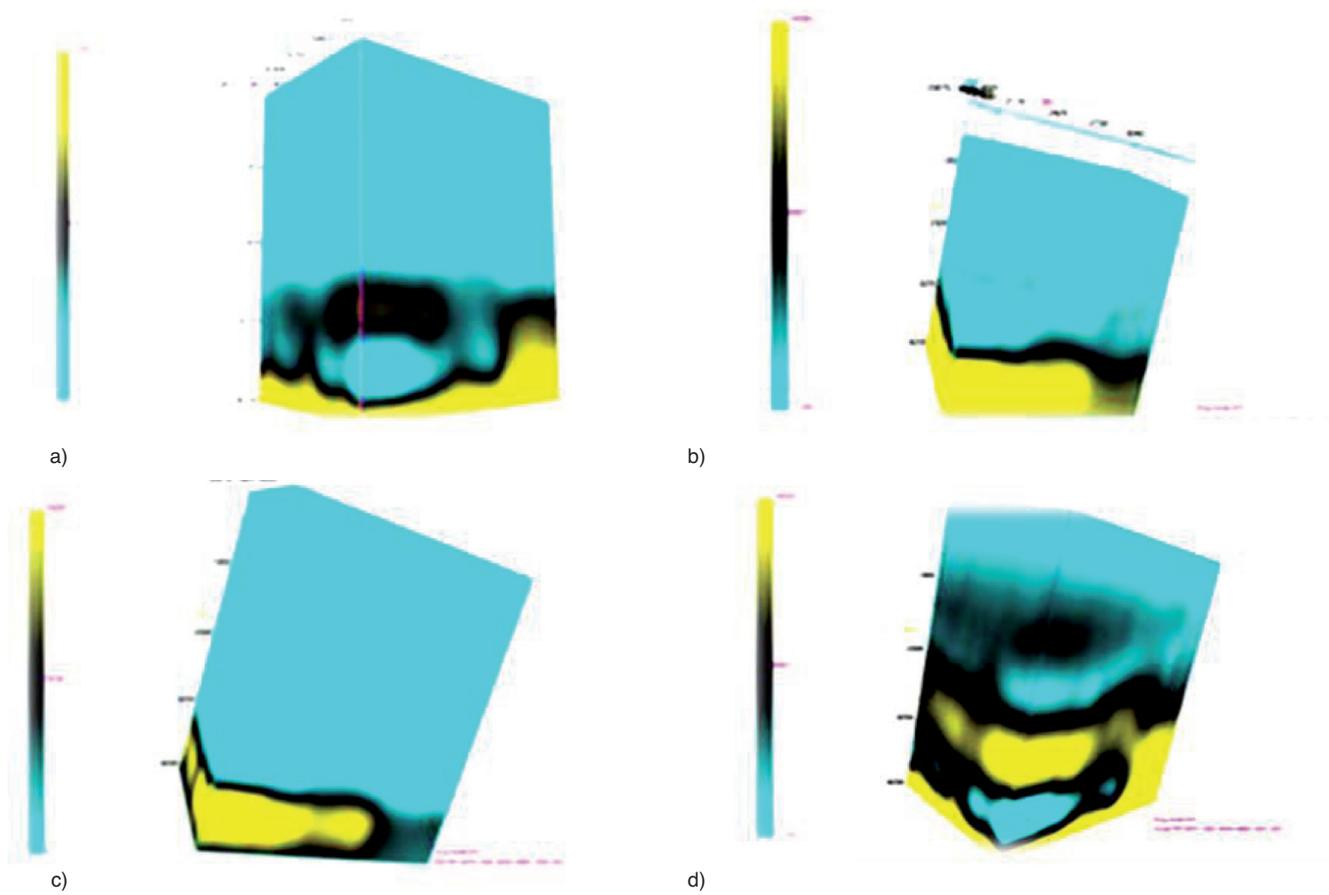


Figure 10

3-D pore pressure; a) 3-D vertical effective stress; b) 3-D minimum effective stress; c) 3-D overpressure; d) cube of the study area generated from 3-D seismic data.

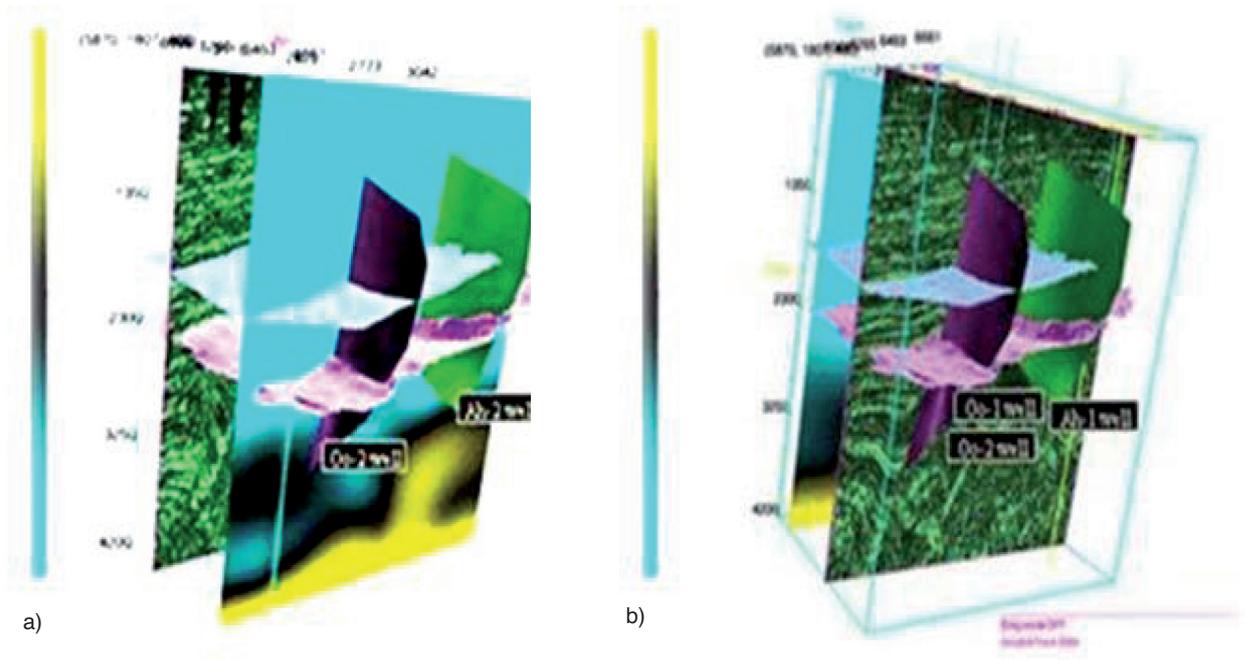


Figure 11

3-D Co-visualization of seismic data with seismic pressures, events, fault surfaces and wells.

is more rapid on the hanging wall with respect to the footwall leading to a thicker sediment pile at the hanging wall. This rapid sedimentation is believed to be responsible for the geopressures often encountered in the hanging walls of growth faulted rollover anticlines in the Niger Delta (Nwaufa *et al.*, 2006; Opara, 2008).

The importance of various types of faults in generating geopressured environments worldwide has been documented by several authors (Dickinson, 1953; Murray, 1961; Carver, 1968; Classen, 1968; Dickey *et al.*, 1968; Meyers, 1968; Harkins and Baugher, 1969; Jones, 1969; Fowler, 1970; Weber *et al.*, 1978). The pattern of abnormally high pressure zones appears to be related to the patterns of faulting contemporaneous with sedimentation and compaction. Similarly, the process creating these faults (growth faults) prevents the expulsion of water from the pores of argillaceous sediments during compaction and diagenesis, most often resulting to geopressures (Dickey *et al.*, 1968).

In addition, it was revealed that majority of the geopressured formations in the study area in particular and Niger Delta in general lie between the depth intervals of 6000 ft to 13000 ft (1820 and 3940 m) falling largely within the Agbada Formation. Previous studies by Ichara and Avbovbo (1985), Obah (1989), Weber and Daukoru (1975) and Opara (2008) have shown that geopressures in the Niger Delta often

occur at depths shallower than the Akata Formation. Geopressures in the Niger Delta result mainly from the rapid loading of the undercompacted shales of the Akata Formation by the sandy Agbada and Benin Formations. This is because the geopressured Akata Formation is in contact with the sandy paralic Agbada Formation in three different ways. In the first place, there is the vertical transition from continuous marine shale into paralic sediments. Secondly, there are lateral facies transitions and interfingering of sand and clay and thirdly, Akata shale is in many places in juxtaposition with Agbada paralic sediments across faults. In each of these cases, fluids expelled from the geopressured Akata shales may inflate (charge) the pressures in the adjacent sands (Weber and Daukoru, 1975). In addition, most of the mild geopressures within the Agbada Formation in the Niger Delta are believed to have resulted from undercompaction of the interbedded marine shales (possibly chemical compaction disequilibrium) of the lowermost Agbada Formation. Consequently, overpressures are often encountered before the Akata shale is reached. However, it is well known that the geopressures observed in parts of Niger Delta is not caused by undercompaction alone; fluid expansion mechanisms (fluid charging, shale diagenesis, and hydrocarbon maturation, all working together) also contributes a lot to overpressuring especially at great depth (Ichara and Avbovbo, 1985; Caillet and Batiot, 2003; Opara, 2008).

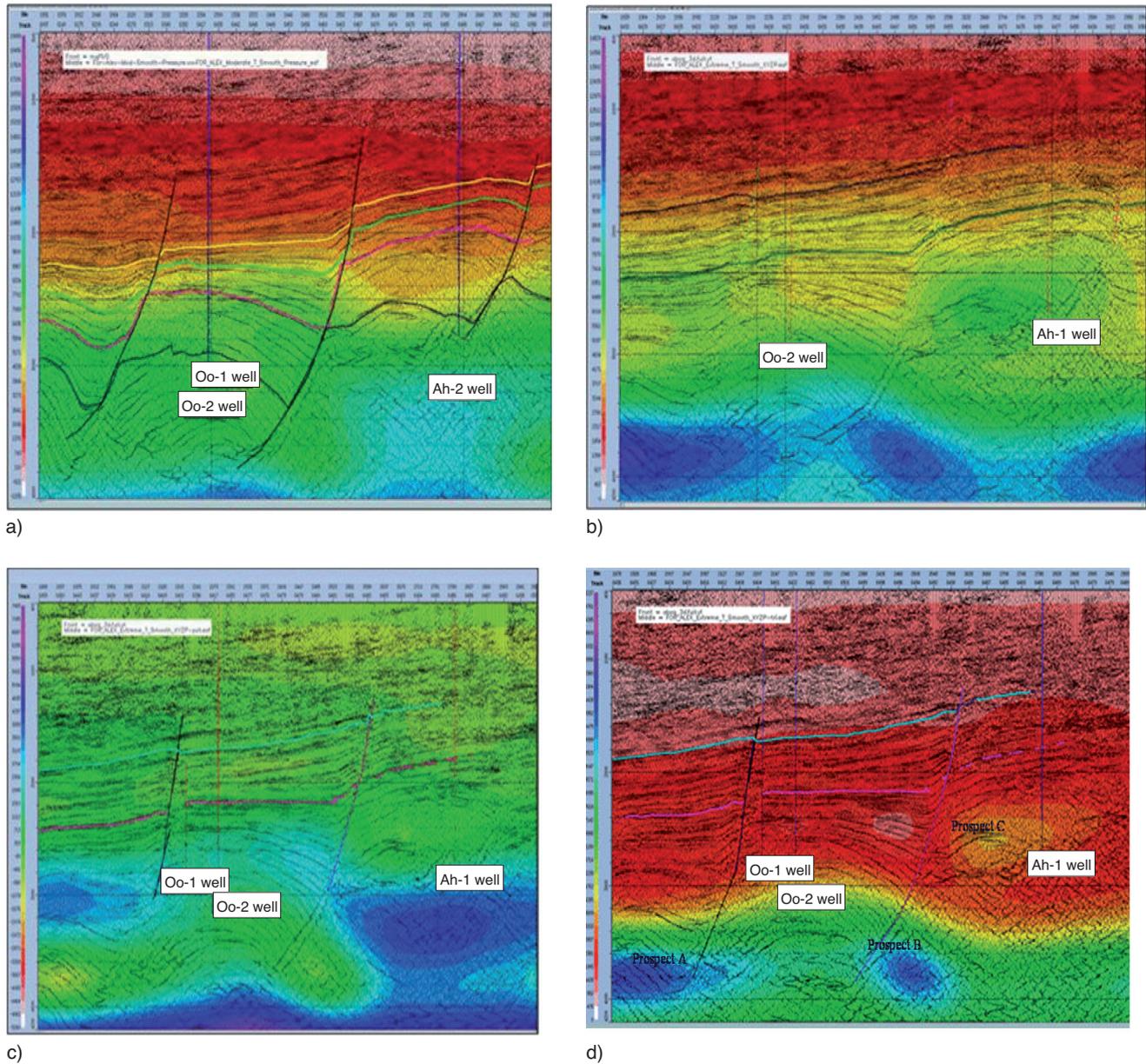


Figure 12

- a) Predicted fluid pressure volume overlaying the seismic section in the study area.
- b) Predicted VES overlaying the seismic section of the study area showing sealing/non sealing faults.
- c) Predicted overpressure volume overlaying the seismic section of the area showing sealing/non sealing faults.
- d) Predicted minimum effective stress volume superimposed on the section showing trap integrity.

## CONCLUSION

Finally, geopressures observed in rocks within the Niger Delta owe its distribution not only to their mechanisms but also to the re-distribution of fluids during and after the generation of geopressures, as a result of structure and stratigraphy.

Changes in formation relief, geometry and faulting play major roles in pressure distribution and re-distribution within the basin. Similarly, overpressure in the Niger Delta is not caused by mechanisms associated with undercompaction alone but also from fluid expansion mechanisms which correlates well with geopressures at depth. There seems to be

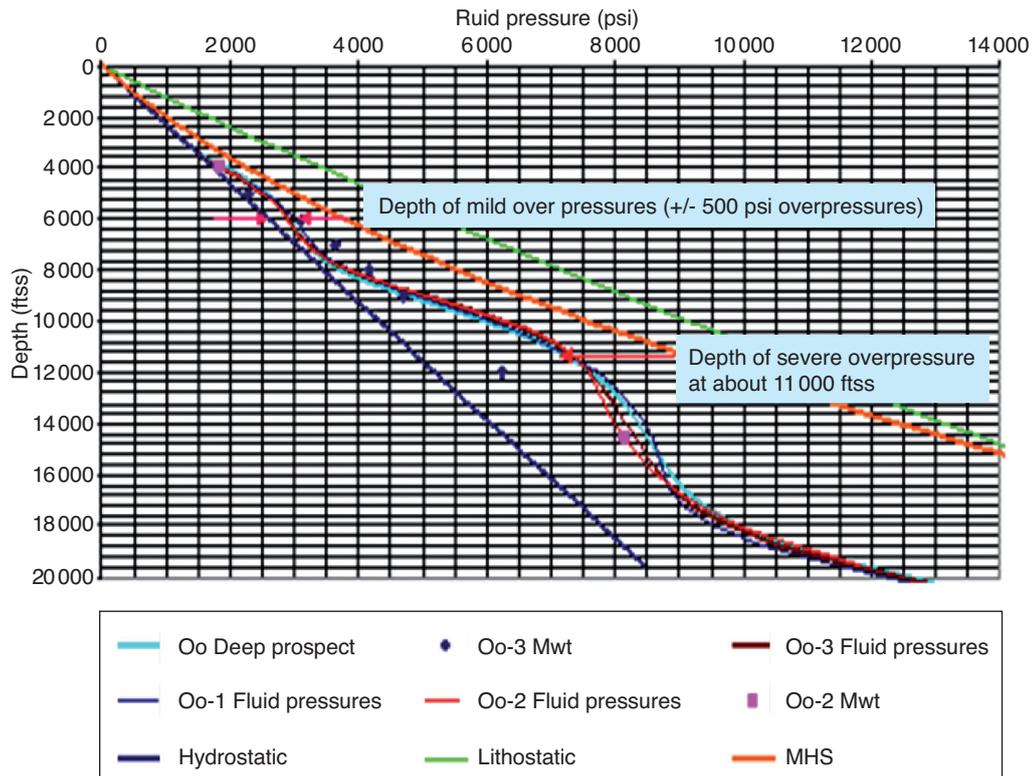


Figure 13

Fluid pressures predicted in the Oo-field from seismic velocity data in the study area.

a relationship between high overpressures and compaction disequilibrium, thermal (fluid) expansion mechanisms, shale diagenesis and in particular hydrocarbon generation in the Niger Delta basin (Opara, 2008).

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