Journal of Basic Physical Research ISSN: 2141-8403 prints, 2141-8411 online
Vol.7, No. 2 pp. 39-46, July, 2017. Available online at www.jbasicphyres-unizik.org

DYNAMIC CHARACTERIZATION OF RESERVOIR STRESS USING SEISMIC INVERSION IN UDAM FIELD, ONSHORE NIGER DELTA

E. K. Anakwuba and E. U. Aniwetalu
Department of Geological Sciences, Nnamdi Azikwe University, P. M. B. 5025, Awka, Nigeria

ABSTRACT

Characterization of dynamic reservoir changes in Udam Field due to production process has been undertaken using elastic impedance inversion of two seismic data acquired at different vintages. This was achieved by deriving low frequency model (initial guess impedance) from the base and the monitor which were inverted to create elastic impedance profile of the formation. The elastic impedance profile revealed reservoir fluid saturations, pressure regimes and by-passed hydrocarbon with commercial concentrations in the northern part of well A, well B and well D at time intervals of 1400-1500ms, 1300ms-1400ms and 1200-1350ms respectively. The results also indicate that high injected fluid concentration, which is associated with high pressure and minimal hydrocarbon concentrations, occurs at time intervals of 1600-1750ms, 1500-1750ms and 1500-1700ms in well A, B and D respectively. Well C is the most depleted well with very high pressure effects. The elastic impedance cubes of the inverted volumes delineate the onset of stress and the closure stress initiated during and after fluid injection programmes. The onset of stress reveals the potential brittle zones at the central part of the field while the closure stress reveals the stress plate overlying the predicted brittle zones. The crossplot of differential horizontal stress ratio and elastic modulus of the area indicates the trend of the fracture zones to be southeast to northwest direction. This is also consistent with the injection pattern in the study area. Therefore, understanding the stress distribution in the reservoir is vital in the reservoir management and well completion strategy.

KEYWORDS*: Reservoir stress, seismic inversion, stress orientation, geomechanics, 4 d seismic*

INTRODUCTION

Niger Delta has gradually assumed a status of the major petroleum provinces for oil and gas exploration in Africa. It plays host to over 500 active oil fields scattered around both onshore and offshore depobelts that are still undergoing production activities. Many of these oilfields have recorded decline in hydrocarbon production, which led to the application of enhanced recovery processes such as steam/water injection. The idea is to reactivate depleting reservoir pressure and reduce the viscosity of oil so as to improve displacement of hydrocarbon in the pore spaces. The recovery factor, by this technique accounts for about 30-40% of additional hydrocarbon generation depending on the formation rock geometries. During reservoir depletion pressure perturbations occur and this often results in coupling between the changes in pore-pressure and minimum horizontal stress [5, 13]. This also enhances changes in the effective and total stress distribution within the reservoir and its surrounding. Therefore, injecting fluid substance inside such reservoir could promote serious evolution of stress that may lead to fault reactivations, pore or casing deformation. This has potential to compromise estimation of storage capacity and injection rate. The deformation associated with the steam injection also affects rock properties such as acoustic wave velocity, bulk density, porosity and permeability that may lead to modifications of reservoir fluid flow, or induced micro seismicity, a phenomena that have profound impact on reservoir management [16]. The knowledge of reservoir stress build-up is vital in well management and completion strategies. It is already known that geomechanical effects of injection processes can be estimated from the reservoir using seismic inversion [7]. Several studies have revealed that petro-physical properties of rocks are influenced by changes in pore fluids, pressure and temperature which commonly occur during production in reservoirs [8, 6]. Their studies showed that saturations and fluids pressure changes can lead to detectable changes in reservoir rock geometries. More so, seismic inversion technique had been used to characterize changes in reservoir properties due to production process [11].

In this study, we therefore, analyzed the reservoir fluid flow and stress changes due to depletion or steam injection processes within the reservoirs and their surrounding, using elastic impedance

Corresponding Author's Email: **ek.anakwuba@Unizik.edu.ng**

inversion. This is hoped to promote understanding of reservoir fluid flow variations, pressure changes, and stress regimes in and around the reservoir as well as the direction of propagation in the field.

Location and Geology of the Study Area

The study area is located at about 50 kilometers southeast of Port Harcourt in the Central Swamp II, Onshore depobelt of Niger Delta, Nigeria (Fig. 1). The Niger Delta is situated on the continental margin of Gulf of Guinea in equatorial West Africa, at the southern end of Nigeria bordering the Atlantic Ocean between latitudes 3^o and 6^o and longitudes 3^o and 9^o. The onshore portion of Niger Delta is delineated by the geology of the Southern Nigeria and South-western Cameroun. The northern boundary is the Benin Flank, an east-northeast trending hinge line south of the West Africa basement massif. The north-eastern boundary is defined by the outcrops of the Cretaceous on the Abakaliki High and southeast by the Calabar Flank, a hinge line bordering the adjacent Precambrian. The Niger Delta is one of the most prominent basin in West Africa and actually the largest delta in Africa. It contains only one identified petroleum system referred to as the tertiary Niger Delta of Akata- Agbada petroleum system [3, 9,]. The Tertiary wedge of sediments in the Niger Delta consists of three diachronous units, which show an overall upward transition from marine prodelta shales (Akata Formation) through sand-shale paralic sequence (Agbada Formation) to continental sands and gravels (Benin Formation) [10, 2, 12, 4, 1, 15].

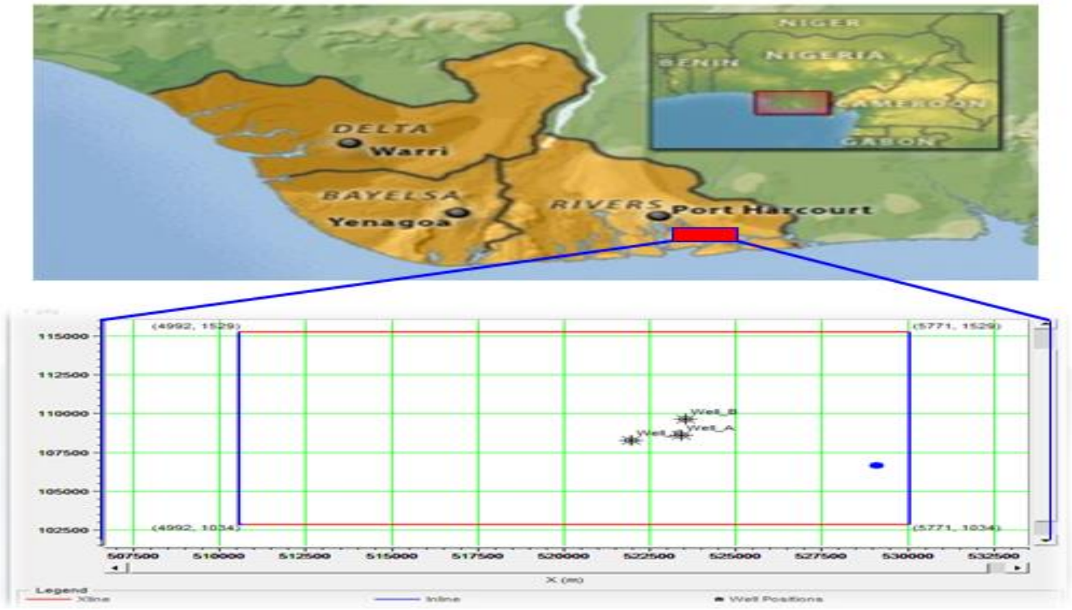

Fig. 1: The map of Niger Delta showing the base map of the study area

MATERIALS AND METHODS

The material used for this study includes suites of well logs and a twelve fold 3-D seismic survey acquired in the mid 1990 which covers about 140 square km^2. A 48 (forty-eight) fold repeat acquisition (4D seismic survey) was completed in July, 2010 over the original twelve fold survey. The sample intervals used for initial and the repeat surveys were 4 ms and 2 ms respectively. This implies Nyquist frequencies of 125 Hz and 250 Hz for the base and monitor respectively. As part of data quality, differences resulting from acquisition design and other non-production-related variations were minimized between the surveys. These were achieved by determining average correlation coefficients of the non-processed datasets and rough average bulk shift between the two seismic vintages. The shaping filter was finally applied and a significant level of improvement in the datasets was obtained between the two seismic vintages. Media filtering corrections were also applied to the well log data to minimise errors that might arise from high frequency spikes. This aid to smoothen the logs and remove the high frequency noise. Therefore, having properly corrected the data for errors, a low frequecy model (LFM) that reflects the true geology of the formation was derived from the seismic data (Fig. 2). The LFM is necessary because seismic data are bandlimited. If the model is neglected and seismic inversion carried out, the inverted physical properties would be relative or bandlimited too. Therefore, to interpret inverted data for petrophysical properties, for instance, absolute impedance is required. To obtain this, low frequency model was created to compensate for the missing band of the seismic data using well logs and horizons. The horizons define the reservoirs of interest. This was followed by postack inversion analysis of the well logs. This helps to estimate the inversion intervals in the well logs and their associated error profiles to check if it is within the acceptable limit for seismic inversion. Finally, typical elastic impedance inversion was created from the low frequency model using single inversion style. The elastic impedance slices that highlight the brittle, ductile and aligned fracture zones of the reservoirs were derived from the inverted seismic volumes and direction of their propagations predicted to guide further hydrocarbon exploitations and exploration in the field.

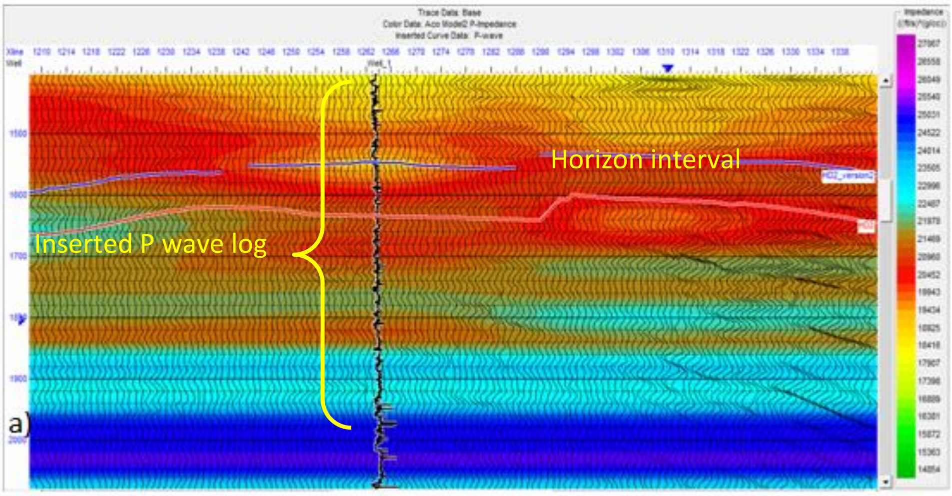

Fig. 2: The low frequency elastic impedance model of the seismic data

RESULTS AND DISCUSSION

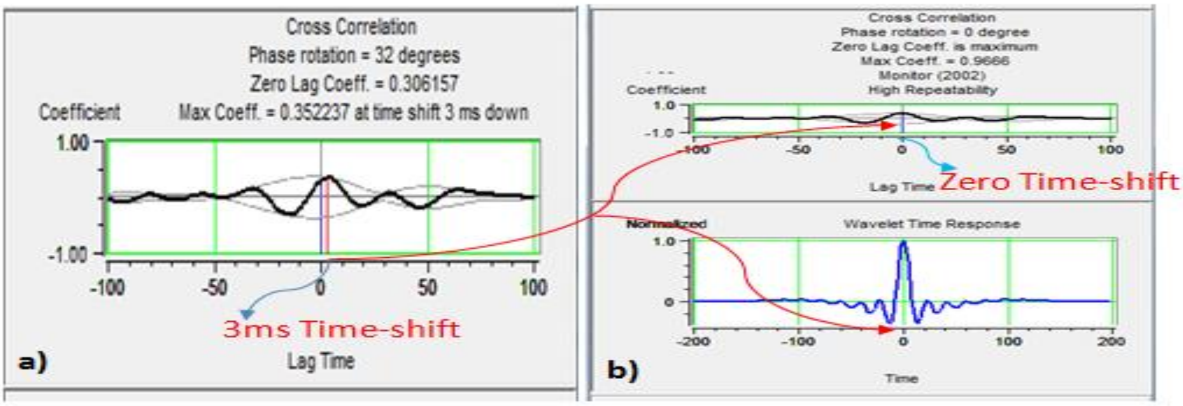

Fig. 3: The monitor and corrected data indicating static time shift and cross-coefficient

The result of data enhancement shows that variations in the static corrections are small, but still contribute to slight time-shifts above the reservoir interval (Fig.3a). The result shows maximum cross correlation value of 0.306 with time-shift of 3ms indicating velocity pull-down and thus, poor repeatability. This was corrected to zero time shifts with maximum cross correlation coefficient of 0.996 which indicate very good repeatability (Fig.3b).

The increase in large window time-shifts from zero to 3ms was as a result of random variations in amplitude events. The positive time-shift values indicate a velocity pull down in the events of the Time lapse survey. The resulting time-shifts was applied to the monitor survey to align corresponding events in time. The time-shift has been aligned to zero, indicating reliable static corrections and processing to match the survey. Large shifts of both positive and negative values were observed along the edges of the surveys. The large shifts are as a result of strong variation in the seismic events, and can be attributed to the presence of edge effects or increased levels of noise in lower fold areas of the field. However, the result of root-mean-square (RMS) values of the monitor data shows the normalized root-mean-square difference between the amplitude spectra of the surveys (Fig.4a-b). The quality of data processing increases confidence in the interpretation of production induced changes in the reservoir as revealed by elastic impedance inversion of the seismic vintages (Fig.5a-d). The inverted volumes indicate fluids and pressure variations in the field. The green-yellow band is hydrocarbon intervals, blue band is water saturated zones while pink band indicates high pressured zones in the field. However, the bounding horizons (HD2 and HD2_version 2) indicate high production-related effects - suggesting high water saturation and less hydrocarbon saturations, which are indication of production process. Well C appears to be the most depleted well with very high pressure effects. The bounded horizon shows no trace of hydrocarbon intervals.

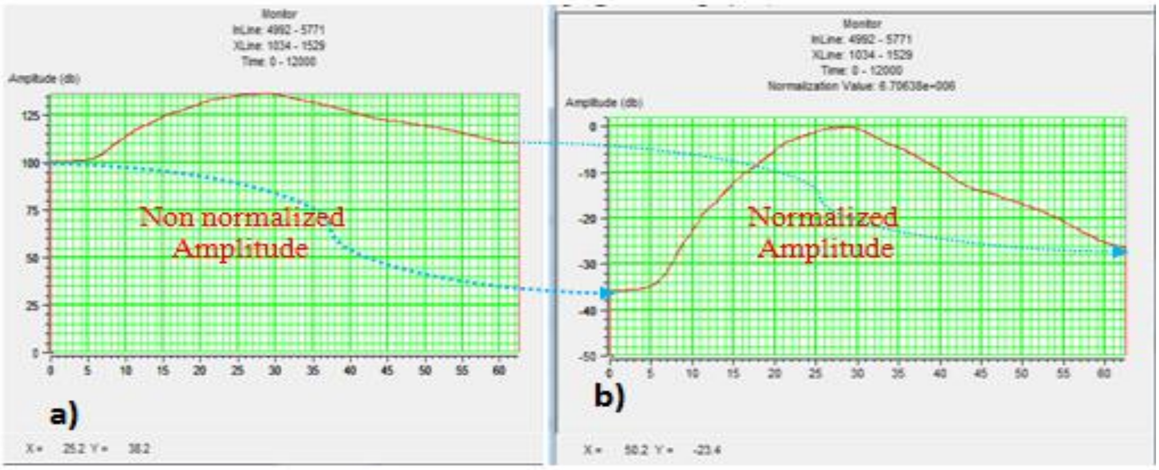

Fig.4: Comparing the initial and normalized amplitude spectra

The production rate in the well is very low with very high pressure capable of generating stress plates. The elastic impedance inversion showed the drainage pattern of the field thus providing first-hand information on by-passed hydrocarbons which are prevalent in the northern parts of the well A, well B and well D. These zones are dominated by green-yellow bands.

The pressure variations gave rise to fracture initiation, which was interpreted as the stress above which injection of fluids will cause the rock formation to fracture hydraulically. Similarly, closure stress occurs when fractures effectively close in the absence of proppants such as quartz crystals or magnesium oxides in the pore spaces. It is a point in the reservoir when there is a drying up of the fluids trapped in the pore spaces due to steam injection processes. As the fluid in the pore spaces decrease, the rock pore geometries contract, resulting in fractures. Therefore, the fracture initiation pressure presented potential brittle zones based on the observed elastic properties as shown in irregular black circle (Fig.6a). The color overlay indicates red and yellow band as ductile zones in the field (Fig.6b). The blue enclosure in the southeast and northwestern parts of the field represents the point of high pressure zones and increase in pressure at this point results in stress plate formation. The absence of pink band suggests period of stress initiation in the study area. At this point, the stress has not initiated major fractures in the field but has only given possible zones of fracture effects. Fig.7a indicates stress plates (pink band) overlying predicted brittle zones (blue). The color overlay

(Fig.7b) indicates onset of stress plates in the field. The stress plates overlie the predicted brittle zones. The blue band indicates brittle zones (zones with possible high stress effects which may result in fracturing). Green band highlights the region where swarms of fractures will occur in a brittle environment, the yellow band shows areas where aligned fractures may form and the red band indicates the ductile areas (areas that might not fracture regardless of the pressure effects). Stress plate orientation indicates the direction of the field fracture patterns which also represents the direction of maximum horizontal stress while the plate magnitude represents the differential horizontal stress ratio (DHSR). However, the relationship between differential horizontal stress ratio and elastic modulus has been shown through cross-plots (Fig.8). The result isolates brittle areas based on the orientation of the stress propagations in the study area. The optimal stress zones are areas that exhibit high Young Modulus. They are characterized as ideal areas for hydraulic fracturing (blue and pink color codes). The direction of stress propagation in the reservoir trends southeast to northwestern. This is also consistent with direction of injection process in the field.

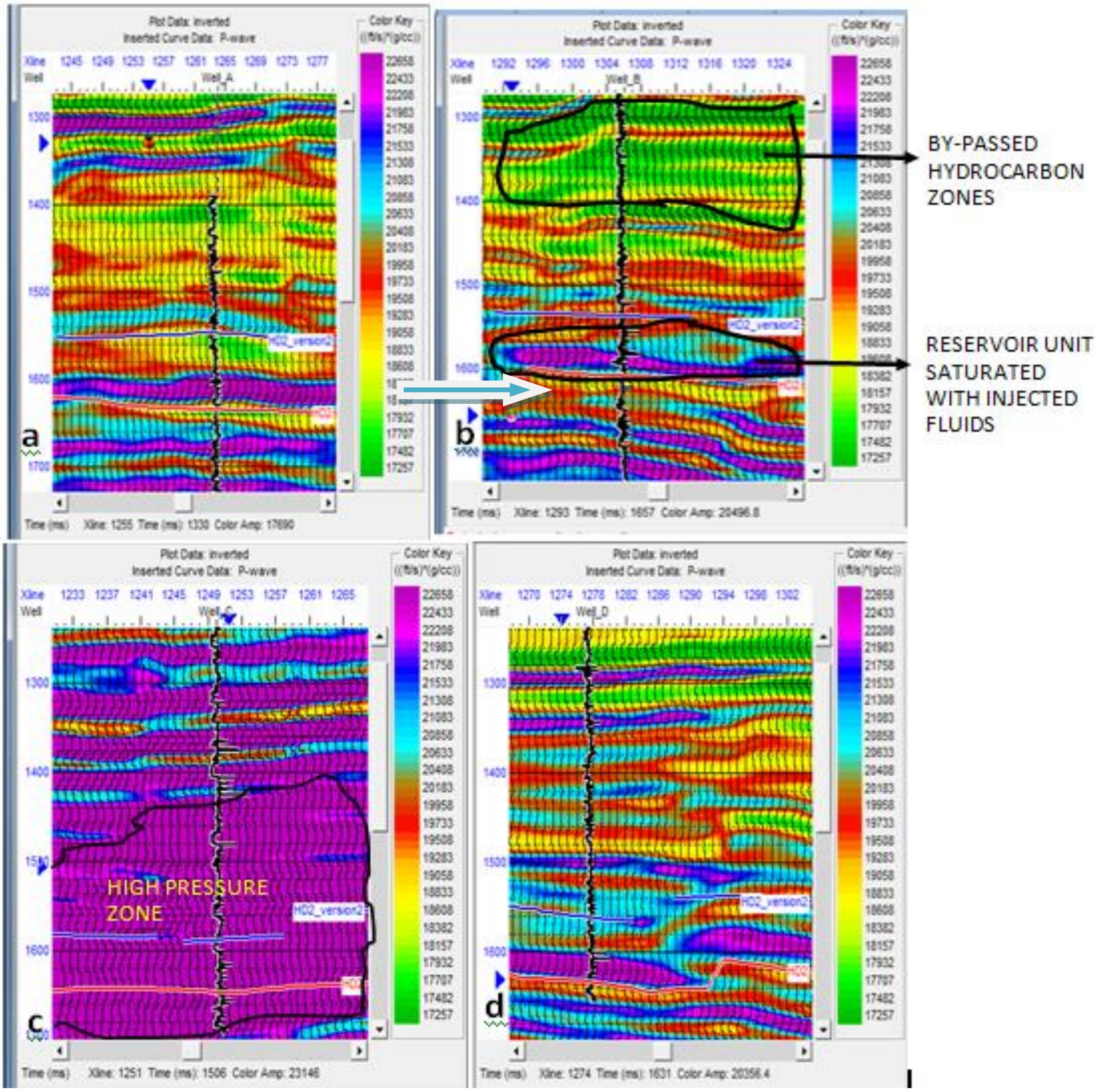

Fig.5: The effect of fluid and pressure on elastic impedance inversion

This direction is interpreted as the direction of the stress propagation in the field. The southeast – northwest stress orientation also follows similar pattern of injection programme in the field. The result implies that production-related changes through steam injection programme, among other factors can rewrite the reservoir stratigraphic and geomechanical patterns. Therefore, studying the effect of these production-related changes is vital in understanding of regions of high drilling risks and safe zones for further well placements.

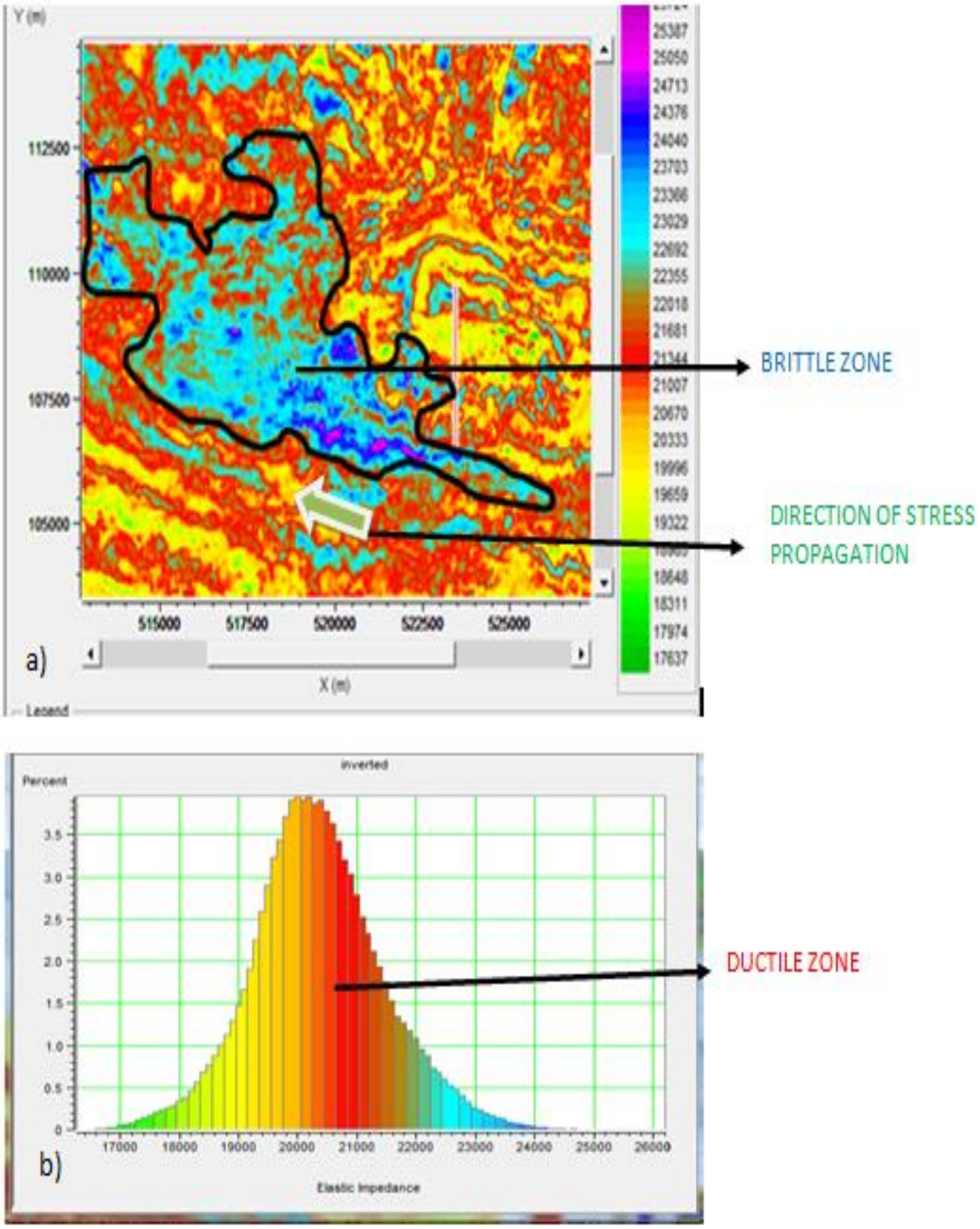

Fig. 6a-b: (a) Effect of fracture initiation pressure and (b) color overlay indicating onset of stress loading showing the ductile (red) and the brittle (blue) zones

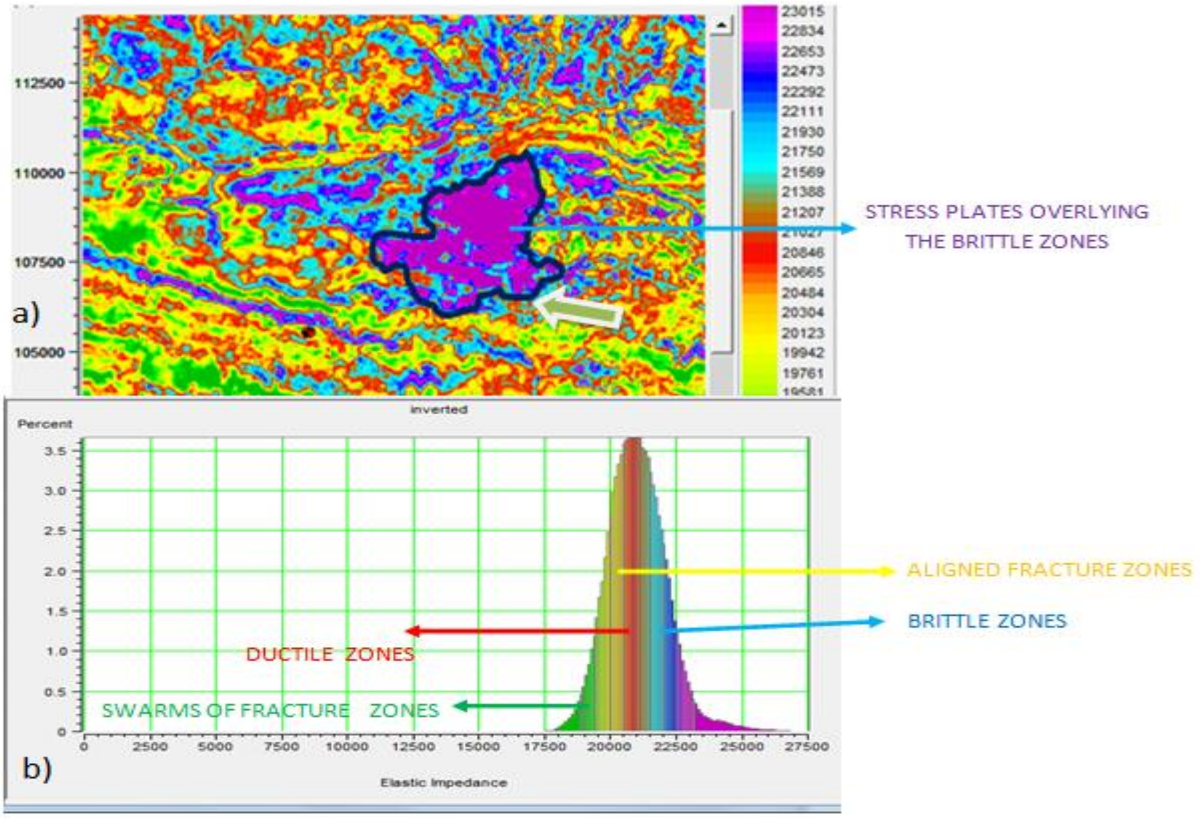

Fig 7.0a-b: Effect of stress plates overlaying brittle zones and (b) color overlay indicating onset of fracture closure

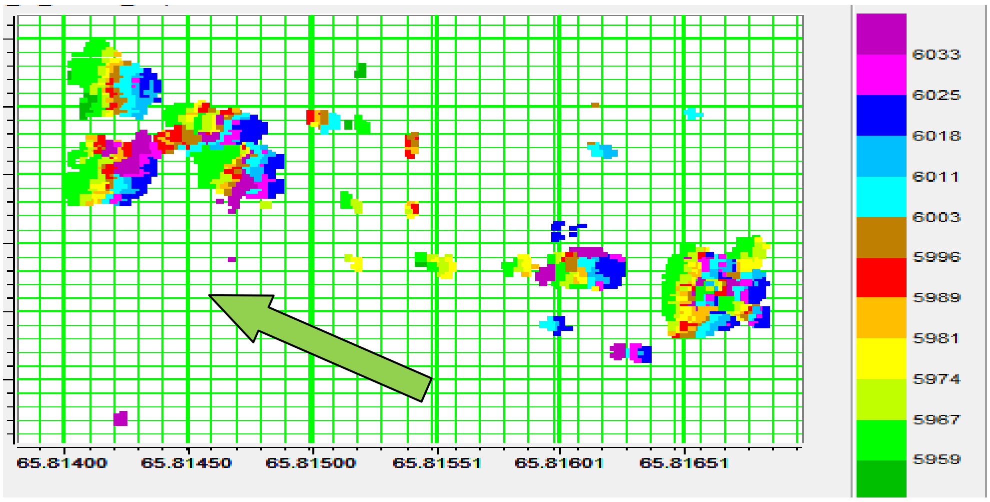

Fig.8.0: Crossplot of differential horizontal stress ratio and elastic modulus of the study area

CONCLUSION

Characterization of reservoir stress imposed by production-related effects has been undertaken using elastic impedance inversion. Seismic inversion simply transforms seismic attributes into formation properties that give qualitative information of reservoir condition. The inverted seismic data revealed the reservoir fluid saturation and production induced changes that are associated with reservoir depletion and injection processes. The result also revealed the bypassed hydrocarbon zones which are dominant in the northeastern parts of well D. Well C shows high pressure effect and depletion. As one toggle away from the well locations, the production related changes fade away and more hydrocarbon bypassed zones become more pronounced in the northern parts of the field. To represent this information along the horizons of interest, elastic impedance slices were derived from the inverted volumes. The result revealed two principal mechanisms of stress inducements in the reservoir due to depletion/fluid injection process. They are fracture initiation and closure stress. The fracture initiation pressure predicted zones of possible high stress impact on the reservoir which was validated by the closure pressure. The result also revealed high stress evolution in the central parts of the field. The trend of the propagation of the stress follows the injection pattern of SE-NW. Therefore, the study concludes that fluid injection programme among other factors, can alter reservoir rock geometries, paleocurrent imprints or stratigraphic configurations due to the pressure of the injection fluids. Therefore, understanding the reservoir geomechanical play due to production processes is vital in reservoir monitoring and management.

REFERENCES

[1] Adegoke, A. K. (2012). Sequence Stratigraphy of Some Middle to Late Miocene Sediments, Coastal Swamp Depobelts, Western Offshore Niger DeltaInternational Journal of Science and Technology .pp 18-20.

[2] Aizebeokhai A. P. and Olayinka. I. (2011). Structural and stratigraphic mapping of Emi field,offshore Niger Delta. Journal of Geology and Mining Research Vol. 3(2), pp. 25-38.

[3] Aniefiok E. I, Udo J. I, Margaret I. Sunday W. P., (2013). American Journal of Environmental Protection. Vol. 1 (4), pp. 78-90.

[4] Aniwetalu E. U. and Anakwuba E .K. (2015). Quantitative Characterisation of Groundroll (Rayleigh Waves) in the Western Niger Delta, Nigeria. Archives of Applied Science Research, Vol.(4), Pp 7-22

[5] Altmann, J., Müller, T., Müller, B., Tingay, M., Heidbach, O. (2010. Poroelastic contribution to the reservoir stress path. International Journal of Rock Mechanics and Mining Sciences, Vol. 47, pp.17-23.

[6] Batzle, M. and Wang, Z., (2002). Seismic properties of pore fluids: Geophysics, Vol. 57, No. 11, pp. 1396-1408.

[7] Cole, S., Lumley, D., Meadows, M and Tura, A. (2002). Pressure and saturation of 4D seismic data by rock physics forward modeling: 72nd Annual Internat. Mtg., Soc. Expl. Geophysics, Expanded Abstracts, pp. 2475-2478

[8] Lumley, D.E. (1999). Time-lapse seismic reservoir monitoring: Geophysics, vol. 66, no. 1 (January-February 2001); pp 50–53.

[9] Obiadi, I.I., B.M. Ozumba and P.L. Osterloff (2012). Regional sequence stratigraphic framework and structural evolution of eastern parts of the central swamp depobelt, Niger Delta, Nigeria. NAPE Bull., 24: 95-103.

[10] Obiekezie T.N. (2014). Hydrodcarbon exploration in Ondo Field in the Niger Delta Basin Nigeria, Using a three Dimensional seismic reflection survey. Scientific Research and Essays. Vol. 6 (17) pp.778-784

[11] Pendrel, J. (2006). Seismic inversion- A critical tool in reservoir characterization: Scandinavian Oil-gas magazine, pp. 19-22.

[12] Reijers, T. A. (2011). Stratigraphy and sedimentology of the Niger Delta. Geologos, 17 (3):133–162

[13] Settari, A, and Walters D.A. (2001). Advances in coupled geomechanical and reservoir modeling with application to reservoir compaction. SPE.Vol. 3(6), 334–42.

[14] Schutjens PMTM, Burrell R, Fehmers G, Hindriks K, Collins C, vander Horst J. (2007). On the stress changes in overburden resulting from reservoir compaction: Observations from two computer models and implicati for 4d seismic. Leading Edge; vol.26:628–34.

[15] Short, K. C., and Stauble, A.J. (1967). Outline of geology of Niger Delta: American Association of Petroleum Geologists Bulletin, v. 51, pp. 761-779.

[16] Zoback, M, and Zinke, J. (2002). Production-induced normal faulting in the valhall and ekofisk oil fields. Pure and Appl. Geophys. Vol. 159, pp.403–420.