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Computer-Simulated Delta (δ) For Vertical Transversely Isotropic (VTI) Media in Two Depobelts of the Niger Delta

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ABSTRACT

Thomsen's parameter (delta, δ) for Vertical Transversely Isotropic (VTI) media was estimated in two depobelts of the Niger Delta. This was based on seismic and well velocity data within common midpoint gathers for different offset ranges to extend anisotropic normal moveout correction in processing steps. A computer simulation was utilized to analyse the seismic and well velocity data at same interval after seismic-to-well tie. Results show that the values of the parameter, delta (δ) estimated from wells lie within the range $0.0 \leq \delta \leq 0.1$. This correlates better with the values of the same parameter obtained analytically with a combination of normal moveout velocity (V_{NMO}) from seismic and vertical velocity (V_o) from checkshot data. This result completely characterizes the VTI system in the area of study. It is useful for good subsurface imaging in depth repositioning and focussing in migration processes and reliably extracting reservoir fluids, lithology and pore pressure prediction from seismic data, and understanding time-to-depth conversion errors and non-hyperbolic moveout.

KEYWORDS: *Anisotropy, Depobelts, delta, Central Swamp, Greater Ughelli*

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I. INTRODUCTION

Seismic waves travel in anisotropic rock layers within the Niger Delta. Anisotropy is manifested in seismic data acquired within this region as anomalies in traveltime, waveforms and amplitudes. But most of the processing algorithms assume the ideal condition of isotropy. This faulty assumption leads to erroneous imaging and thus wrong interpretation. Better accuracy, higher resolution, wider spread length and improved ties between seismic data and well log require understanding and application of anisotropy. According to Iheanyichukwu et. al., 2010, inaccurate estimation or total disregard of anisotropy in seismic velocity accounts for suboptimal imaging especially in depth positioning and focusing even when prestack depth migration algorithm has been used. In most sedimentary basins, like the Niger Delta, comprising of about 70% shales, the type of anisotropy often observed is the vertical transverse isotropy (VTI) or polar anisotropy. This type of anisotropy can be quantified by estimating Thomsen parameter delta (δ).Therefore, measuring δ is very important, for processes like depth imaging. According to Toldi et.al (1999) the depth effects are carried by the parameter, δ which must therefore be measured with help of well control. This paper is aimed at estimating Thomsen's Parameter (δ) for transversely isotropic media in the vertical direction (VTI). The effect of anisotropy in the Niger Delta and the burden to see how delta (δ) can be more effective in correcting for anisotropy in the Niger Delta has motivated this study.

II. LOCATION AND GEOLOGY OF THE STUDY AREA

This study covers two depobelts: Greater Ughelli (Assa North) and Central Swamp (Kolo Creek) in the Niger Delta (Figure 1).The coastal sedimentary basin of Nigeria has been the scene of three depositional cycles. The first began with a marine incursion in the middle Cretaceous and was terminated by a mild folding phase in Santonian time. The second included the growth of a proto-Niger delta during the late Cretaceous and ended in a major Paleocene marine transgression. The third cycle, from Eocene to Recent, marked the continuous growth of the main Niger delta. A new threefold lithostratigraphic subdivision is introduced for the Niger delta subsurface, comprising an upper sandy Benin formation, an intervening unit of alternating sandstone and shale named the Agbada formation, and a lower shaly Akata formation. These three units extend across the whole delta and each ranges in age from early Tertiary to Recent. They are related to the present outcrops and environments of deposition. A separate member of the Benin formation is recognized in the Port Harcourt area. This is the Afam clay member, which is interpreted to be an ancient valley fill formed in Miocene sediments.

Subsurface structures are described as resulting from movement under the influence of gravity and their distribution is related to growth stages of the delta. Rollover anticlines in front of growth faults form the main objectives of oil exploration, the hydrocarbons being found in sandstone reservoirs of the Agbada formation. The Niger Delta is situated in the Gulf of Guinea and extends throughout the Niger Delta Province as defined by Klett and others (1997). From the Eocene to the present, the delta has prograded south-westward, forming depobelts that represent the most active portion of the delta at each stage of its development (Doust and Omatsola, 1990). These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km^2 (Kulke, 1995), a sediment volume of 500,000 km^3 (Hospers, 1965), and a sediment thickness of over 10 km in the basin depocenter (Kaplan and others, 1994). The Niger Delta Province contains only one identified petroleum system (Kulke, 1995; Ekweozor and Daukoru, 1994). This system is referred to here as the Tertiary Niger Delta Petroleum System. The maximum extent of the petroleum system coincides with the boundaries of the province. Tertiary Niger Delta deposits are characterized by a series of depobelts that strike northwest-southeast, sub-parallel to the present day shoreline (Figure 2). Depobelts become successively younger basinward, ranging in age from Eocene in the north to Pliocene offshore of the present shoreline. Depobelts, tens of kilometres wide, are bounded by a growth fault to the north and a counter-regional fault seaward. Each sub basin contains a distinct shallowing-upward depositional cycle with its own tripartite assemblage of marine, paralic, and continental deposits. Depobelts define a series of punctuations in the progradation of this deltaic system. Most Niger Delta faulting is due to extensional deformation. The exception is in the distal section, where overthrust faults form in the toe of the proto-Niger Delta. These extensional faults are normal and generally listric, comprising syndepositional growth faults and crestal tensional relief faults. These faults are synthetic or antithetic, running sub-parallel to the strike of the sub-basins. These synsedimentary faults exhibit growth strata above the downthrown block, as well as anticlinal (rollover) closures. Most hydrocarbon bearing structures in Niger Delta deposits are close to these structure-building faults, in complexly collapsed crest and faulted anticlinal structures. (Weber and Daukoru, 1975).

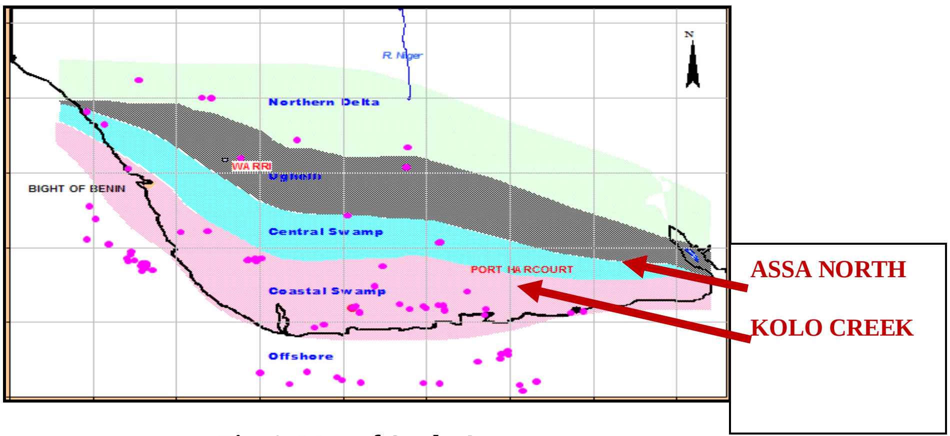

Fig. 1: Map of Study Area

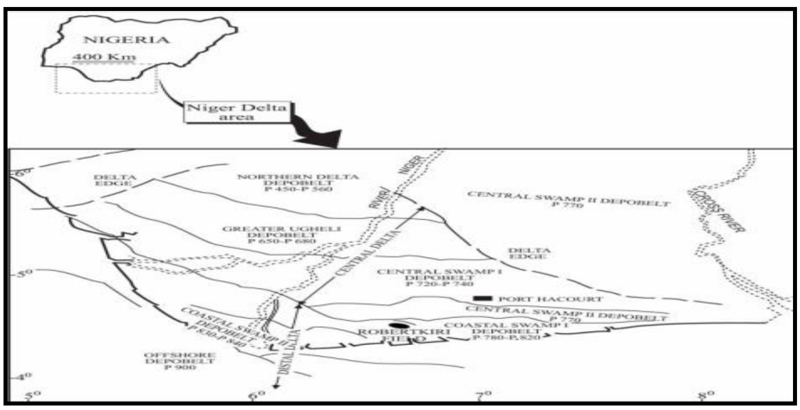

Fig. 2: Depobelts with their relative ages striking northwest – southeast. Kolo creek is located in coastal swamp 1(modified from Doust and Omatsola 1990)

III. THEORY

Anisotropy exists when the instantaneous velocity of a seismic wave is dependent upon the direction of propagation. The subsurface exhibits transverse isotropy (TI) when the velocity is symmetrical about a single axis of symmetry. The axis of symmetry is governed by the origin of the anisotropy and can be vertical (VTI), horizontal (HTI) or tilted (TTI) in the general case (Hawkins *et al*, 2001). Alkalifah and Tsvankin (1994) proposed an anisotropic non-hyperbolic NMO equation and also a technique to invert it for the estimation Thompsen's anisotropic parameters. Thomsen (1986) introduced a more effective and scientific measure of anisotropy. He introduced the constants ε, γ and δ, as effective parameters of measure of anisotropy. According to Thomsen, delta (δ) is the most critical measure of anisotropy and it does not involve the horizontal velocity at all in its definition.

Thomsen's delta (δ) Anisotropic Parameter : Thomsen's delta (δ) anisotropic parameter, a short offset effect, is difference between V_{NMO} and true vertical velocity (V_0) $\delta = 1- V_{NMO}/V_o$. This parameter is responsible for the mismatch between seismic and well depth. It can best be estimated by using a combination of seismic velocity and accurate check shot data.

Stacking Velocity, V_{NMO} : According to Dix (1955), stacking velocity is the V_{NMO}. This is the velocity value determined by velocity analysis and is the value used for common-midpoint stacking. It is derived from the normal moveout equation used commonly to shift events at non-zero offsets to their equivalent zero offset time and is given by the Equation:

$$T^2 = T_0^2 + \frac{X^2}{V_{NMO}^2} \qquad (1)$$

Where X is the variable separation of the shot point and receiver for a common-reflecting-point sequence of shots, T is the travel time at X, and T_0 is the vertical time.

Checkshot Velocity : Checkshot velocity is derived from the checkshot survey. This is a type of borehole seismic survey designed to measure the seismic travel time from the surface to a known depth. P-wave velocity of the formations encountered in a well-bore can be measured directly by lowering a geophone to each formation of interest, sending out a source of energy from the surface of the earth, and recording the resultant signal.

IV. METHODOLOGY

Thomsen parameter (delta, δ) was computed, using 123Di software.

Work Flow

[1] On the traverse view, select file name
[2] Change to interval velocity
[3] Click on Autoscan to Load wells
[4] Open a map view, load wells and take a line across the wells
[5] Load top markers
[6] On velocity function manager, toggle file name.
[7] Take seismic velocity along the well path at same interval and compare with checkshot.
[8] Select well logs (V_p, GR and Density Logs)
[9] Change polarity of synthetic, XCOR, maximum and minimum time display to suit seismic-to-well match.
[10] On the correlation window of the seismic-to-well tie, derive filter/wavelet.
[11] Get updated checkshot data
[12] Do a depth conversion on the seismic gathers and toggle ASCII format
[13] Equally toggle paths and velocities on the spectra window
[14] Use F-secure to transfer file to excel
[15] On excel spreadsheet, create a column for interval velocity from the well (V_o) and another interval velocity from seismic (V_{NMO})
[16] Apply the delta formula, $\boldsymbol{\delta = 1-V_{nmo}/V_o}$
[17] Plot the delta profile
[18] Plot Seismic velocity and checkshot velocity for comparison.

Seismic-to-Well Tie : Seismic-to-well tie was done with updated checkshot data in order to achieve accurate delta, (**δ)** value. The checkshot velocity, V_o was extracted along the well path at 200ft interval, same with the seismic velocity, V_{NMO}. Both V_{NMO} and V_o have times at the same interval. The seismic data are of high quality and assumed to be with no significant AVO effects.

Determination of Thompsen's Delta, (δ) Parameter : Thompsen's delta (**δ)** which is the difference between seismic velocity (V_{NMO}) and true vertical velocity (V_0) is computed for the two depobelts by the equation:

$$\delta = 1 - \left(\frac{V_{NMO}}{V_0} \right) \tag{2}$$

Delta, (δ) Profile : The various values of delta (**δ)** obtained for the depobelts were plotted against depth using different Wells to create the delta profile.

Crossplot of Seismic Velocity versus Checkshot Velocity: A crossplot of seismic velocity, (V_{NMO}) with checkshot (V_0) against depth was done to observe the onset of anisotropy within these two depobelts.

V. RESULTS

Thompsen's Delta, (δ) for Greater Ughelli Depobelt (Assa North)

Figure 3.0 shows the delta (**δ)** profile using Well 001 in Assa North in the Greater Ughelli depobelt. The point with the highest velocity concentration is observed to be around the 0.1.

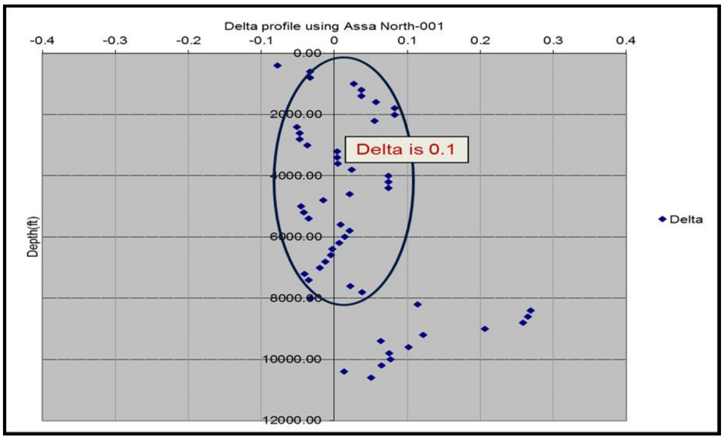

Fig. 3.0: Delta Profile

Onset of Anisotropy : The Crossplot in Figure 4.0 shows the trend of both velocities with depth. This observed trend starts deviating at 6000ft on the checkshot velocity curve. This deviation is equally observed on seismic as the onset of anisotropy. This confirms the effect of anisotropy in this depobelt.

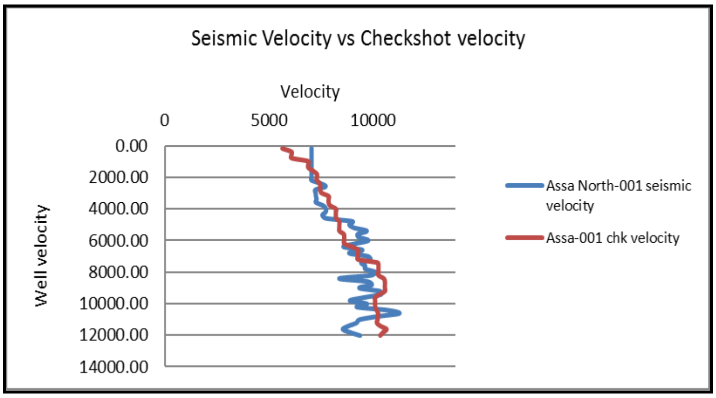

Fig. 4.0: Crossplot of Seismic Velocity against Checkshot Velocity For Assa North

Thompsen's Delta, (δ) for Central Swamp Depobelt; Kolo Creek : Figure 5.0 shows the delta (**δ)** profile in Kolo Creek in the Central Swamp depobelt. The point with the highest concentration of data is observed to be around the 0.0. The velocity concentration which is marked by blue dots are highly concentrated around 0.0 showing that delta (**δ)** is from -0 to 0. All others are scattered. Delta at 0.0 gave the best imaging results in data processing.

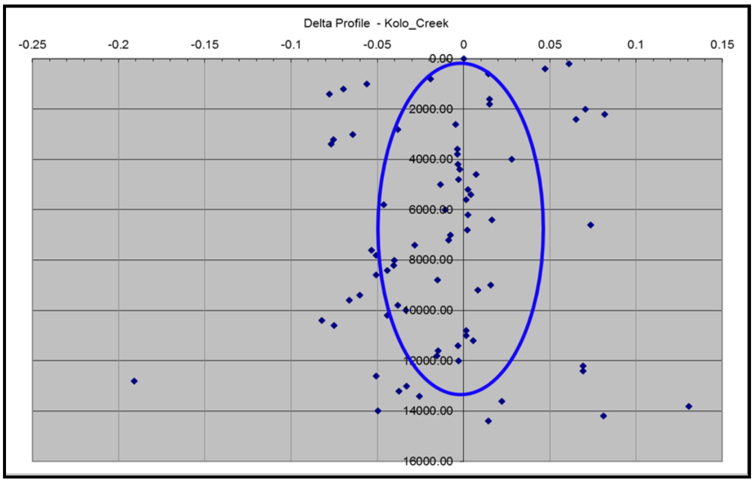

Fig. 5.0: Kolo Creek Delta Profile

Onset of Anisotropy : The deviation in the checkshot started quite earlier, at about 2000ft (Fig. 6.0). On the seismic velocity curve, the onset of anisotropy in this field is from 1800 to 2100ft corresponding to the deviation on the checkshot curve. This shows that the effect of anisotropy started approximately at that depth.

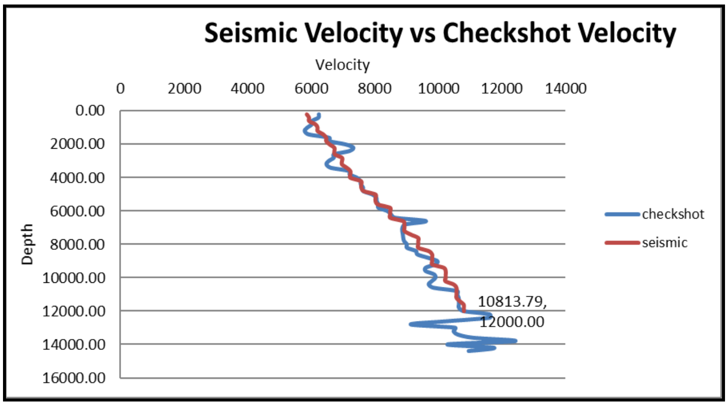

Fig. 6.0: Crossplot of Seismic Velocity vs Checkshot Velocity For Kolo Creek

CONCLUSION AND RECOMMENDATIONS : Estimation of anisotropy parameters is an important aspect in seismic data analysis. Thomsen's anisotropic parameter, δ has an effect on depth calculations. The delta, δ estimation is highly dependent on the estimation NMO velocity. The error analysis of estimated delta, δ underscores the importance of accurate estimation of NMO velocities. Extending this analysis to the real field data, it was discovered that the delta **(**δ) values for Assa North and Kolo Creek fields were computed to be 0.1 and 0.0 respectively. Shales show very significant anisotropy. It can be seen that in greater Ughelli depobelts, the value of delta **(**δ**)** is 0.1 while in central swamp depobelts the value of delta (δ) is 0. So if delta (δ) is not calculated for and used during processing to correct for anisotropy, there will be great mismatch in seismic and well data. This can result in drilling of dry holes. With the results from these two fields in different depobelts, effects of anisotropy can easily be reduced if the correct values of delta are incorporated during processing. It is therefore recommended that delta **(**δ**)** be calculated for all wells and depobelts and an anisotropy model produced in the Niger Delta. This will help to correct for anisotropy across the Niger Delta.

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