Scientia Africana, Vol. 13 (No.1), June 2014. Pp178-185
ISSN 1118 - 1931

ESTIMATION OF ANISOTROPY PARAMETERS USING INTRINSIC ROCK PROPERTIES IN A SELECTED SWAMP FIELDS IN NIGER DELTA

I. P. C. Okorie, A. O. Sofolabo and A. Balogun

Geosciences Group,
Department of Physics/Applied Geophysics,
University of Port Harcourt,
Port Harcourt, Rivers state, Nigeria
[adekunle.sofolabo@uniport.edu.ng, ayomide.balogun@uniport.edu.ng,
Iheanyichukwu.okorie@uniport.edu.ng].

Received: 15-01-14
Accepted: 10-04-14

ABSTRACT

Total disregard of anisotropy in seismic velocity analysis often accounts for suboptimal imaging especially when prestack depth migration algorithm is used in depth positioning and focusing. The type of anisotropy commonly observed in most sedimentary basins, like the Niger Delta, which comprises of about 70% shale, is the Vertical Transverse Isotropy (VTI), which often affects imaging processes. This type of anisotropy can be accurately quantified by estimating the three Thomsen parameters namely: epsilon (ε), delta (δ) and gamma (γ), determination of these parameters will greatly enhances the accurate imaging of events subsurface in prestack depth migration which is used for the proper placement of the events. For this study, the Thomsen parameters, which were derived from well log suites of selected swamp fields of the study area, were used to completely characterize the vertical transverse isotropy (VTI) of the system in our study area, a total of five elastic stiffness moduli were estimated and the values obtained were subsequently used in the estimation of the anisotropy parameters needed. The following values were estimated for the anisotropy parameters from the selected wells; parameter delta (δ) values estimated lies within the ranges $-0.16 \le \delta \le 0.13$*, while for parameter epsilon (ε), the values lies within the ranges* $-0.07 \le \varepsilon \le 0.11$*. The values for parameter gamma (γ) estimated lies within ranges* $-0.42 \le \gamma \le 0.4$ *while the values for eta (η) lies within the ranges* $-0.13 \le \eta \le 0.27$*, respectively. The anisotropy parameters values estimated for the selected swamp fields correlate well (0.95%) with the values of the same parameters obtained analytically with a combination of seismic moveout velocity* (V_{NMO}) *and vertical velocity from the check-shot data. The anisotropy estimated was found to be higher in shale than in sands, while P-wave anisotropy parameters are observed to be generally smaller than S-wave anisotropy parameters. In the study area, the plots of the anisotropy parameters within the depobelt show a weak anisotropy for the study area.*

INTRODUCTION

The Cenozoic Niger Delta sedimentary basin is known to be housing significant hydrocarbon reserves and as a result will always attract exploration interests. For there to be a successful exploration for these resources there is the need to integrate all the necessary and available data and employ advanced technologies to mitigate the exploration and drilling risks. In situations

where detailed knowledge of rock properties is necessary for optimum development, the surface seismic techniques, though employed extensively in exploration to predict gross rock properties, do not provide adequate and extensive information needed for exploration. When well logging, which is believed to provide in-situ measurements of rock properties, is combined with surface seismic measurements, it furnishes an improved knowledge of the subsurface of the earth, which is needed for assessing the economical value of hydrocarbon resources.
In geophysics, velocity and density are the basic desirable properties of the rocks. Other rock attributes, which are impedance, Poisson's ratio and elastic moduli, are derived from the basic rock properties. Rock property estimation from seismic measurements (surface seismic or sonic log) is designed to recover the velocity structure with depth including its spatial distribution within the Earth, or other internal rock parameters such as porosity or permeability (Claerbout, 1994). A simplification of the mathematical framework and a reduction of the calculation time are desirable to achieve this. Furthermore, features within or near a reservoir must be located more precisely and this elevated level of resolution requires an in-depth understanding of the seismic character of the subsurface. For example, the success of depth imaging and amplitude variation with offset (AVO) analysis depends on the accuracy of the velocity with which the seismic data is processed.

Marko and Schmitt (1998) explained that our understanding of the anisotropic properties of sedimentary rocks is limited, and, despite this concern, determining the anisotropy remains elusive. To enhance accurate velocity modeling, an understanding of seismic anisotropy isimportant and one of the challenges to geophysicists is to investigate the relationships between physical rock properties and observed seismic response, and to develop inversion techniques to be able to detect the properties seismically. For a suitable description of a Vertical Transverse Isotropic (VTI) media, like the Niger Delta, a thorough estimation of these Thomsen's parameters is necessary, This type of anisotropy can be accurately quantified by estimating the three Thomsen parameters namely: epsilon (ε), delta (δ) and gamma (γ) including the an-ellipticity parameter eta (η) (that derives its significance from the two parameters namely, epsilon (ε) and delta (δ)). There is the need to develop a methodology to efficiently determine these anisotropic constants for an accurate description of the subsurface velocity structure of the Niger Delta.

MATERIALS AND METHOD

Method of estimation from logs

This study employed the use of a suite of standard logs comprising gamma ray (GR), density (RHOB), porosity (POR), and dipole sonic logs comprising compressional (V_P) and shear (V_S) wave velocities. These logs were newly acquired from the Central Swamp depobelt (Fig. 1) in Niger Delta where the evidence of anisotropy has been observed and they exhibit a wide range of data quality. In spite of this, the logs were carefully checked for quality and completeness before they were used for the anisotropic modeling. These logs were all provided in LAS format.

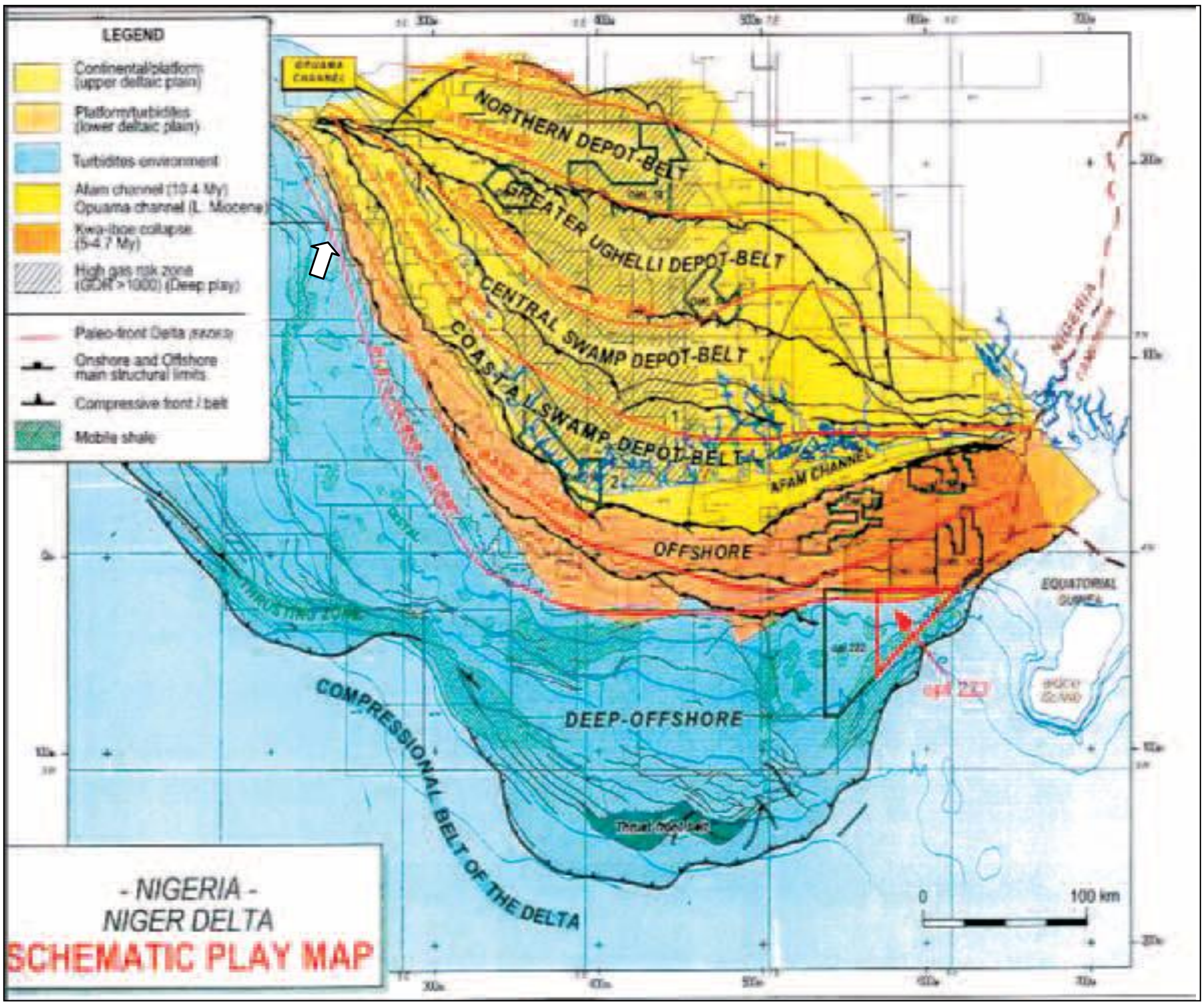

Figure 1: **Map of Niger Delta showing the depobelts (After Weber, 1971). Central Swamp depobelt (indicated with an arrow).**

The aim of this study is to estimate the anisotropy parameters epsilon ε, delta δ, gamma γ, and eta ŋ from the five independent elastic constants using the above mentioned well logs.

In Figure 2, the complete suite of logs from the well in Central Swamp (Well A) employed for the research are displayed. RokDoc, interpretation software was used in processing and editing these logs before they were used in estimating these parameters.In the anisotropic modeling, the initial task is to solve for the five independent elastic constants (C_{11}, C_{13}, C_{33}, C_{44} and C_{66}) for weak anisotropy and which describes how seismic waves propagate through a transversely isotropic medium with vertical symmetry in the matrix below:

$$C_{\alpha\beta} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & 0 & 0 & 0 \\ & c_{11} & c_{13} & 0 & 0 & 0 \\ & & c_{33} & 0 & 0 & 0 \\ & & & c_{44} & 0 & 0 \\ & & & & c_{44} & 0 \\ & & & & & c_{66} \end{bmatrix}$$

C_{44} is the out-of-plane shear modulus; C_{66} is the in-plane shear modulus; C_{11} is the in-plane compressional modulus; C_{33} is the out-of-plane compressional modulus, and C_{13} is an important constant that controls the shape of the wave surfaces.

A transversely anisotropic medium with a vertical symmetry has three anisotropic parameters: ε, γ and δ (Sayers 2005, Jones et. al., 2003, Kebaili and Schmitt 1996, Thomas and Pasolofosam 1997) and they are related to the elastic constants by the following using Thomsen (1986) notation:

$$\boldsymbol{\varepsilon} = \frac{C_{11}-C_{33}}{2C_{33}} \qquad 1.0$$

$$\boldsymbol{\gamma} = \frac{C_{66}-C_{44}}{2C_{44}} \qquad 2.0$$

$$\boldsymbol{\delta} = \frac{(C_{13}+C_{44})^2-(C_{33}-C_{44})^2}{2C_{33}(C_{33}-C_{44})} \qquad 3.0$$

$$\eta = \frac{\varepsilon-\delta}{1+2\delta} \qquad 4.0$$

Method of estimation from seismic

The data made available were used for the estimation of the Thomsen parameter delta (δ) only. The data utilized were Pre-Stack Depth Migrated seismic data, interval normal moveout velocity (V_{NMO}) and check-shots obtained from the well under study. This study employed the use of 123DI, a Shell-developed UNIX-and-Linux-based software package used for seismic operations. The package is mainly used in interpretation of seismic works.

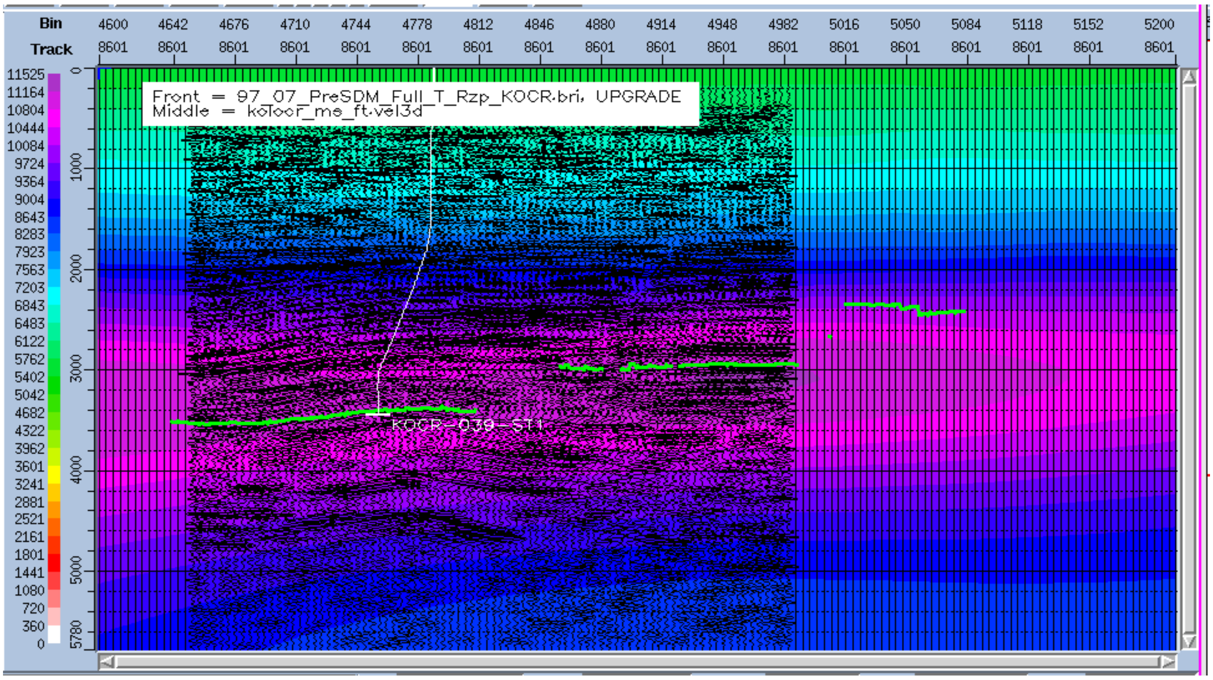
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Figure 2: **An Earth Model (on the background) and the Pre-Stack Depth Migrated data (on black) of the Central Swamp field with the trajectory of the Well under study.**

RESULT

Calculation of the Thomsen's parameter δ from interval velocities and checkshots

Calculation of V_{nmo}^{i}

The Dix equation (equation 5.0) was used in order to obtain the normal moveout velocities in any layer '*i*' for each of the resampled depths. The Dix formula (Dix 1955) was applied to the NMO velocities from the top $V_{nmo}(i-1)$ and the bottom $V_{nmo}(i)$ of the layer (Alkhalifah and Tsvankin, 1995).

$$\left[V^{i}_{nmo} = \frac{t_0(i)V^{2}_{nmo}(i) - t_0(i-1)V^{2}_{nmo}(i-1)}{t_0(i) - t_0(i-1)}\right] \quad 5.0$$

t_0 is the 2 way zero offset traveltime for an individual layer.

Calculation of V^i_0

V^i_0 is the interval vertical velocity. This can be estimated from well logs or Checkshot measurements. In this study velocities were estimated from the check-shots recorded at the well located on the seismic line.

Calculation of δ^i

Using both of the velocities V^i_{nmo} and V^i_0 the value of δ^i can be estimated using the relation:

$$V_{nmo}(p) = V_0(p)\sqrt{1+2\delta} \qquad 6.0$$

This is transformed into:

$$\delta^i = \frac{1}{2}\left[\frac{\left(V^i_{nmo}\right)^2}{\left(V^i_0\right)^2} - 1\right] \qquad 7.0$$

where V^i_{nmo} is the 'interval nmo' velocity and V^i_0 is the vertical velocity.

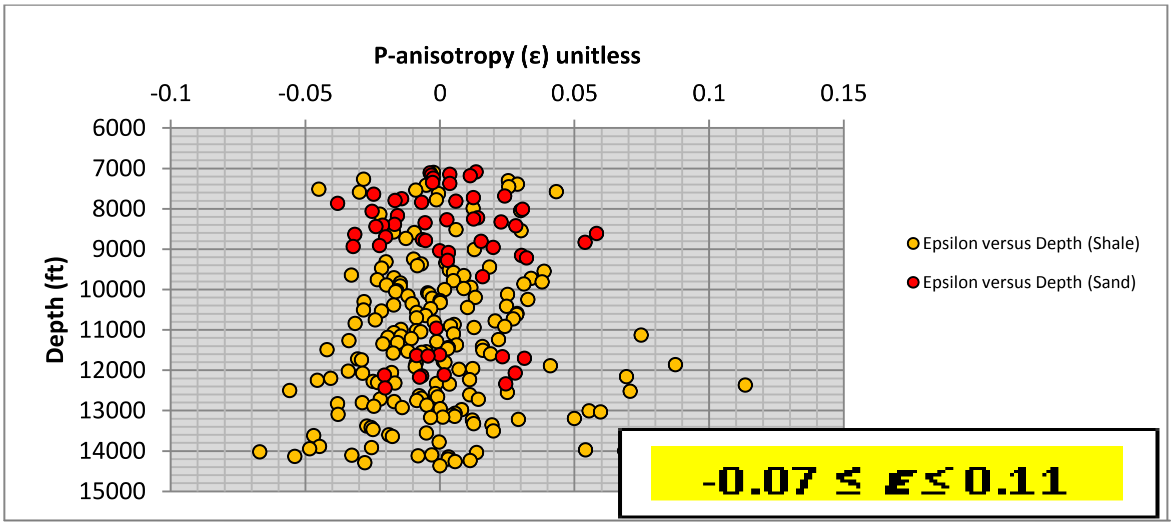


Figure 3a: **Epsilon (ε) (*P-wave anisotropy*) versus Depth.**

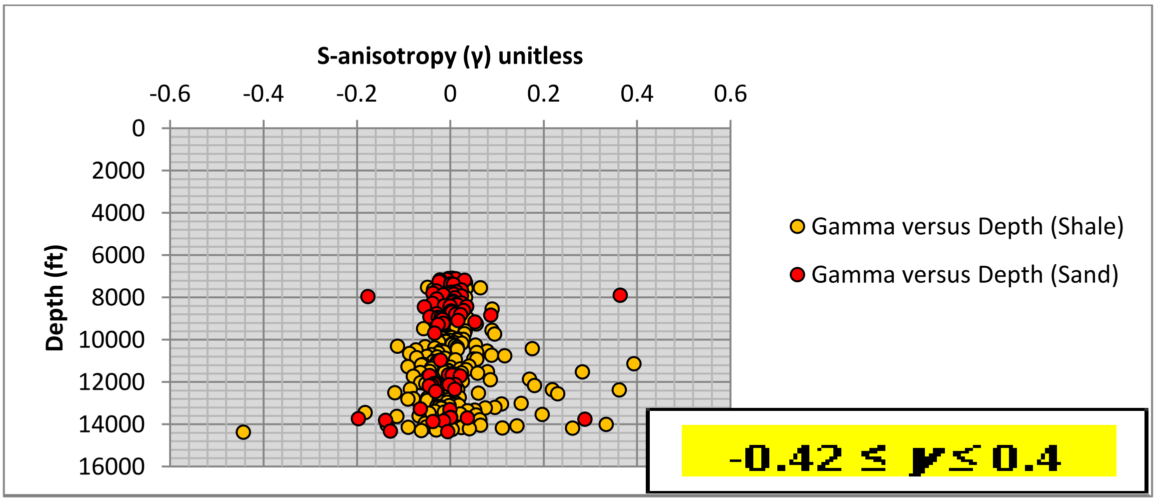


Figure 3b: **Gamma (γ) (S-*wave anisotropy*) versus Depth.**

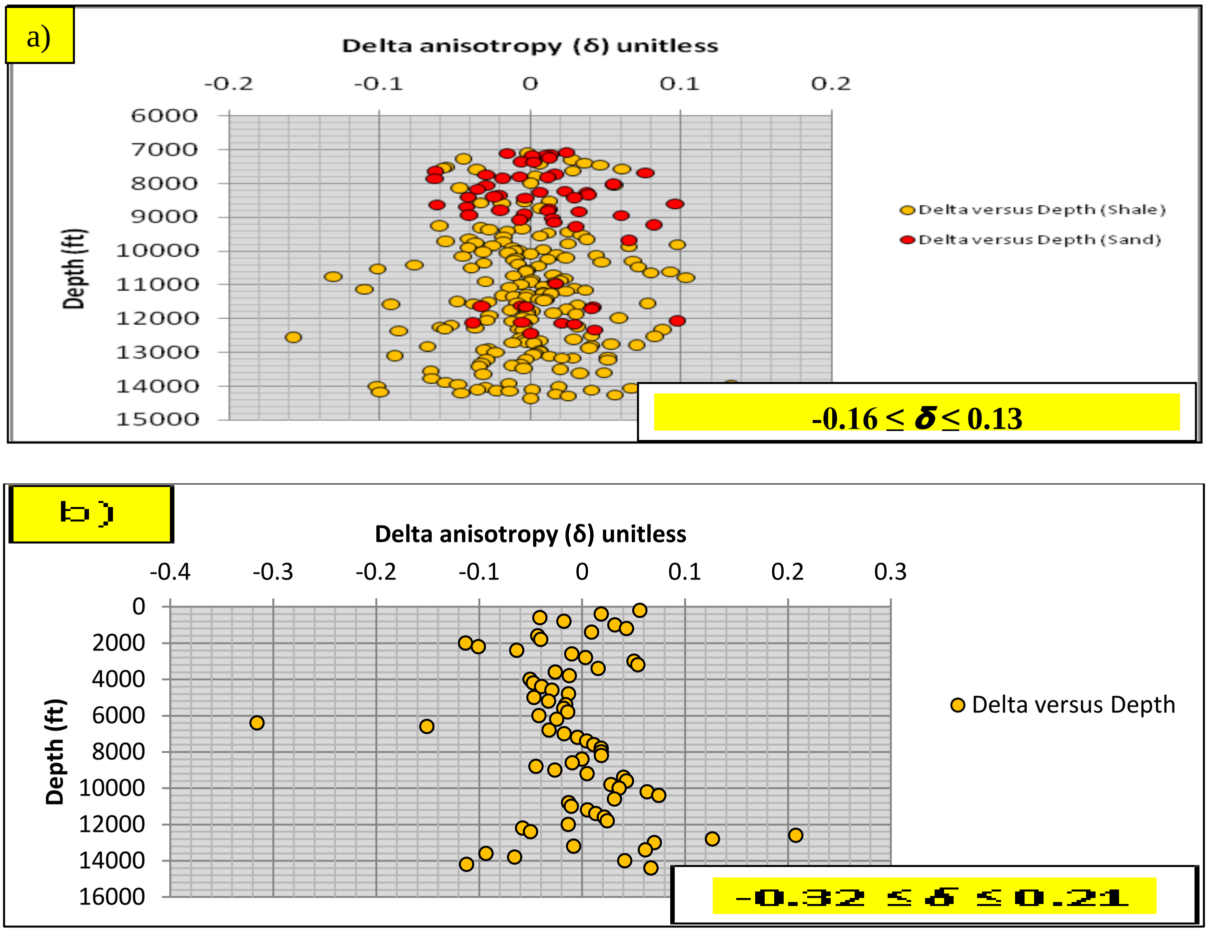
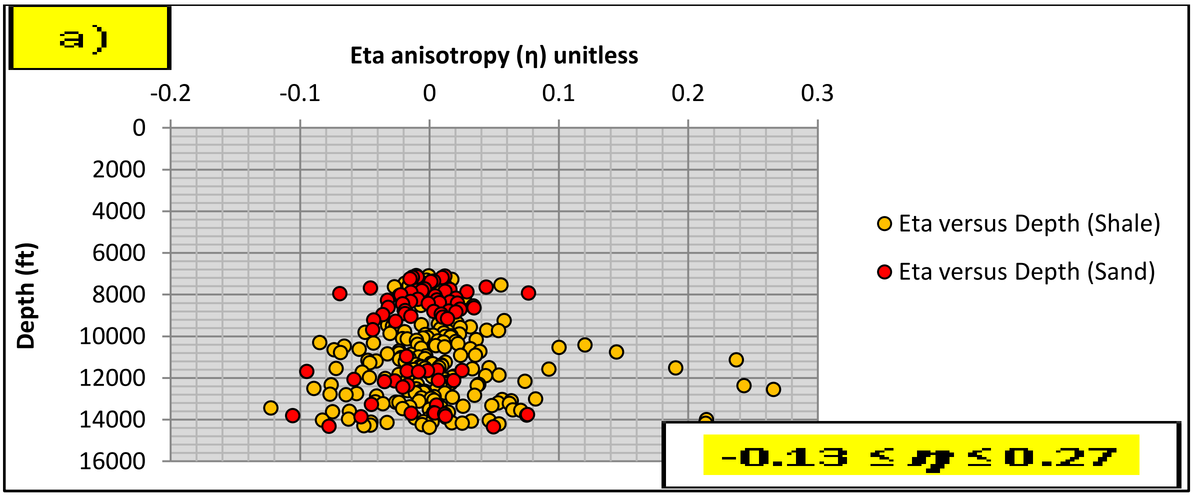


Figure 4: **Delta (δ) anisotropy versus Depth. (a) δ obtained from well data; (b) δ estimated using V_{nmo} from seismic and checkshot.**



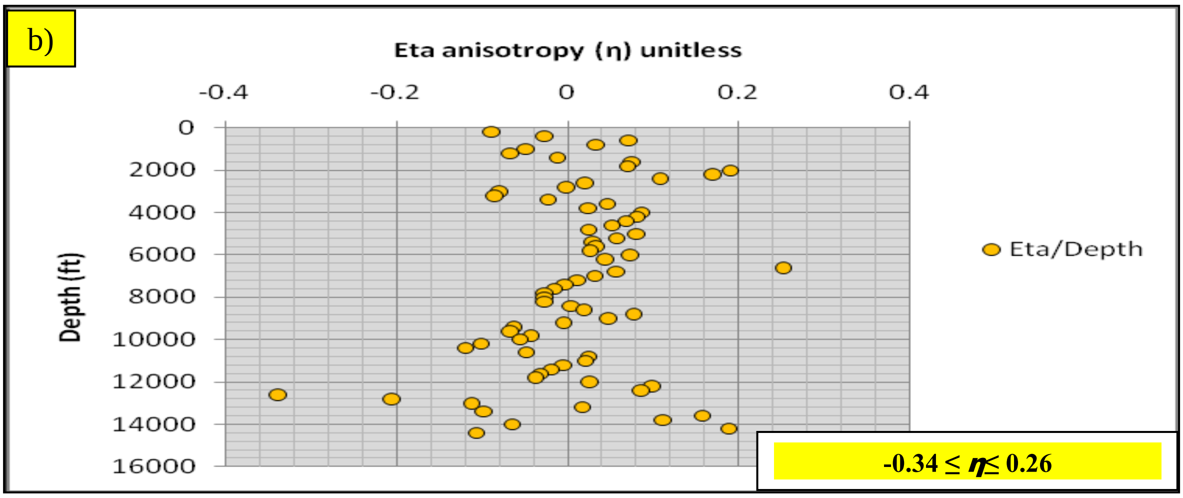


Figure 5: **Eta anisotropy (η) versus Depth. (a) ŋ obtained from well data; ŋ estimated from seismic using δ-ŋ relations.**

DISCUSSION

Plots of the anisotropy parameters with depth are as shown in Figures 3 through 5 with the different behaviours of shales and sands displayed. In Figures 3a, 3b, 4a, 4b. 5a and 5b, we observed that the sand bodies tend to align within the zero value range; while the shale bodies tend to show a rhythmic increase with depth. The delta (δ) and eta (ŋ) anisotropies estimated using V_{nmo} from seismic and checkshot; and δ-η relations were used as control to compare with the estimation from well data. The range of values for δ *and* η obtained from the well data compares favourably with those of the seismic and checkshot.

Anisotropy from this study is much higher in shales than in sands as shown in the plots. The P-wave anisotropy parameters are also generally smaller than the S-wave anisotropy parameters. The plots of anisotropy parameters within this depobelts show a weak anisotropy.

We thank Shell Petroleum Development Company for providing both the well and seismic data and the different software used in this study.

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