



Use of Time-Depth Conversion in Velocity Modeling of Well Data from an Onshore Field Dataset, Niger Delta Area, Nigeria

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ABSTRACT: The estimation of subsurface velocity is very important in seismic reflection as it controls the quality of the depth images, which is the basis of most geological interpretation. In this paper, time depth conversion technique had been used to develop a one-dimensional velocity model of an onshore field, using a layer-cake method in creating the model and seismic interpretation program to build the velocity model. The Sonic data and the checkshot data of field obtained were converted to time images to represent the true geological depth. The resulting velocity obtained from the model ranges from 188-2677ms⁻¹, which is a true reflection of the subsurface layers velocities (from the unconsolidated to consolidated layers velocities) of most Niger Delta area.

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Depth conversion methods can be separated into two broad based categories, namely the Direct Time Depth Conversion Method and Velocity Modeling Method. Both methods when carried out effectively will accurately tie existing wells and effectively predict depth. A technique that models the true velocity in the subsurface for depth conversion and produces velocity variations for each layer due to the fact that the velocity is not constant with depth is known as the Velocity Modeling Technique. A good seismic image may not be sufficient enough as the only tool required for an exploration or field development interpretation, but the combination of good well ties and reliable depth conversion are also required for good exploration or appraisal well development. Although both Geologist and Geophysicist approach the depth conversion techniques in different dimension, while the geologist believes that if there are no wells, then depths conversion and accurate depth of the well cannot be determined, the geophysicist believes that with accurate imaging through seismic and velocities information, the depths can be determined, although

imaging velocities are not good tools generally suitable for true depth conversion (Iverson and Tygel, 2008). Most seismic interpretation are performed in time domain, which is quick and acceptable for many situations, but does not replicate a true geology of the subsurface, it is of necessity to convert processed information in time domain to good interpretable information in depth, and this requires accurate velocity determination and good velocity modeling (Cameron *et al.*, 2008). Depth conversion is a technique employed to remove the structural ambiguity inherent in time and verifies the structure and presents them in a more meaningful geological sense in depth. Geological and engineering reservoir modeling studies are always in depth, it enables the interpreter to integrate seismic depth with geologic, petrophysical and production data (Tieman, 1994). Depth conversion involves imaging, so as to obtain the best image and predict depths away from wells, thus, simplest function of depth conversion involves converting some measurable time quantities into some understandable values in depth (Crabtree *et al.*, 2001).

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To create an image of the subsurface using seismic measurements, elastic wave propagation is modeled in the subsurface and based on the interpretation of the model, there is need to evaluate the types and depths of geological structures present, which will give effective evaluation of the hydrocarbon potential, accurate site exploration and production wells, thus a good depth conversion process is required.

MATERIALS AND METHODS

Study Area/Geology of Niger Delta: The study area is located at an onshore Field, onshore Niger Delta Area of Nigeria. The Niger Delta is located on the West African continental margin at the southern end of Nigeria bordering the Atlantic Ocean and is situated in the Gulf of Guinea, which formed triple junction during continental break up in the cretaceous and is one of the most prolific hydrocarbon systems in the world. The Niger Delta, situated at the apex of the Gulf of Guinea on the west coast of Africa, extends throughout the Niger Delta Province and the Delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development from the Eocene to the present, (Doust *et al.*, 1990) and covers an area of about 75 000 km² (Figure 1). These depobelts form one of the largest regressive deltas in the world with an area of some 300,000 km² (Kulke, 1995), a sediment volume of 500,000 km³ and a sediment thickness of over 10 km in the basin depocenter. The Delta sequence comprises of an upward coursing regressive association of tertiary clastics up to 12km thick, which is divided into three lithofacies namely marine clay stones and shale's of unknown thickness at the base, alterations of sandstones, siltstones and clay stones, in which the percentage increases upward and lastly the alluvial fans at the top (Short and Stauble, 1967).

The Niger Delta Province contains only one identified petroleum system (Ekweozor and Dakoru, 1994). This system is referred to here as the Tertiary Niger Delta (Akata – Agbada), Petroleum System. The maximum extent of the petroleum system coincides with the boundaries of the province.

Modeling: There are three basic modeling equations used in this study

Average Velocity: This is the unit distance of a medium divided by the time taken for the wave front to cross the distance

$$V_{ave} = \frac{\text{Distance Travelled}}{\text{Travel Time}} = \frac{\sum Z}{\sum T} \quad 1$$

Interval Velocity: This is the average velocity V calculated over the distance Z , if the depth interval covers a number of rock beds

$$V_{inst} = \frac{Z_i}{T_i} \quad 2$$

A specific form of the interval velocity is given by the Dix formula (Dix, 1995), where the interval velocity is defined in terms of the two way travel time rather than the discrete difference.

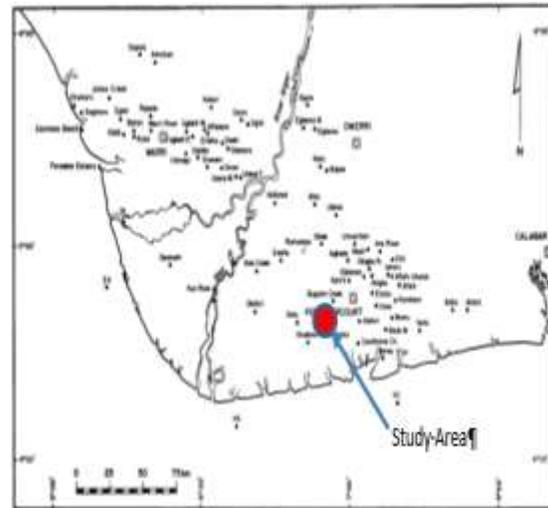


Fig 1: Map of Niger Delta Area showing the location of the Study Area

Instantaneous Velocity: This is the derivatives of the distance travelled with respect to travel time, which can be approximated when derived over an interval that is sufficiently short

$$V_{inst} = \frac{Z_2 - Z_1}{T_2 - T_1} \quad 3$$

The simplest way to describe such variation is to model instantaneous velocity as a linear function of depth:

$$V_{inst}(Z) = V_0 + kZ \quad 4$$

Where $V_{int}(z)$ is the instantaneous velocity at depth Z , and V_0 and k are the intercept and slope of the line (Schultz, 1999).

During sedimentation, compaction leads to an increase in rock stiffness and incompressibility, resulting in a commensurate increase in velocity with depth, despite increase in density. It is generally accepted and often confirmed by measurement, at least in clastic rocks,

that initial compaction can be well described by a linear, vertical instantaneous velocity gradient within the layer, this is commonly represented by the popular model of instantaneous velocity (Equation 4). This model describes the increases of velocity with depth using just two parameters, namely the instantaneous velocity at the reference surface - V_0 and a compaction gradient $k_{compact}$ (usually denoted k), which defines the rate of increase in velocity with depth. For a layered macro-model, the instantaneous velocity model is used and still defined by two parameters, given as

$$V_{inst}(z) = V_{0_top} + Compact(Z - Z_{top}) \quad 5$$

The instantaneous velocity remains the best velocity modeling because of its compaction trend and burial effect to the rock or sediment (gives a good interpretation and description of the geology of the area), which the average velocity cannot do. The instantaneous velocity has high frequency and high degree of resolution than the average velocity model. For most 1-D Velocity model, the instantaneous velocity modeling is often applied.

Materials: The log suite of the study area used are the sonic log, Gamma ray log, Caliper log, Density log, Resistivity log and the Checkshot data for three different wells.

Table1: Availability of Data/Material provided from Field of Study Area

	Sonic Log	Gamma Ray Log	Caliper Log	Density Log	Resistivity Log	Well Makers	Checkshot
Well A	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Well B	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Well C	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Methods: The program was used to access all necessary data and also performed depth-conversation as all the seismic interpreted data were uploaded and stored in the program database. Layer velocities may vary with depth as a result of burial age, lithology or combination of both factors, hence building a velocity model requires the appropriate method. For this work a layer cake technique is used (Figure 2), the layer cake method assumes that velocity increases linearly with depth (Schultz, 1999) as a normal compaction trend in shales, taken into account that velocity can vary due to lithological of fluid effects.

The wells were loaded into the interpretation workstation (SISMAGE™) using their deviation survey and the following iteration steps taken.

Each geological marker corresponds to a mapped horizon (in Two Way Time -TWT) over the study area. The time – depth relationship at each well is calibrated to tie the geological makers with the seismic horizons. Three well makers were identified namely:

- Seabed
- Horizon A (Hor. A)
- Horizon B (Hor. B)

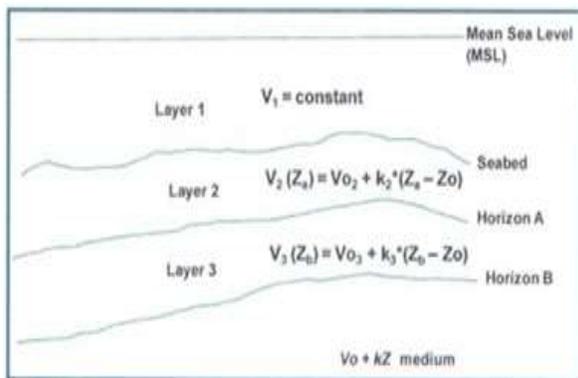


Fig 2: Layer Cake Velocity Method (Ref: Schultz, 1999)

While the seismic horizons identified are

- Seabed - 1D VelMod,
- HorA – 1D VelMod and
- HorB – 1D VelMod

This is a multilayer approach that takes into account velocity variation due to lithological or fluid effects, assuming that the instantaneous velocity increases linearly with depth

To build the velocities model a simple workflow of the process is given in Figure 3. But due to the problems associated with sonic transit time acquisition, the checkshot survey is used to provide a closer value of seismic data than the sonic log. This drift correction gives the calibrated time – depth function $T = f(z)$ (Schultz, 1999) curve, this enable us to switch between depth and the vertical time domains.

The $V_0 - k$ for each layer are derived from a linear regression using $V_{inst} = V_0 + k * (Z-Z_0)$. Where V_0 is the reference velocity at the reference depth Z_0 and k is the compaction gradient. The following results were obtained.

$$V_{inst} = f(Z) \quad 6$$

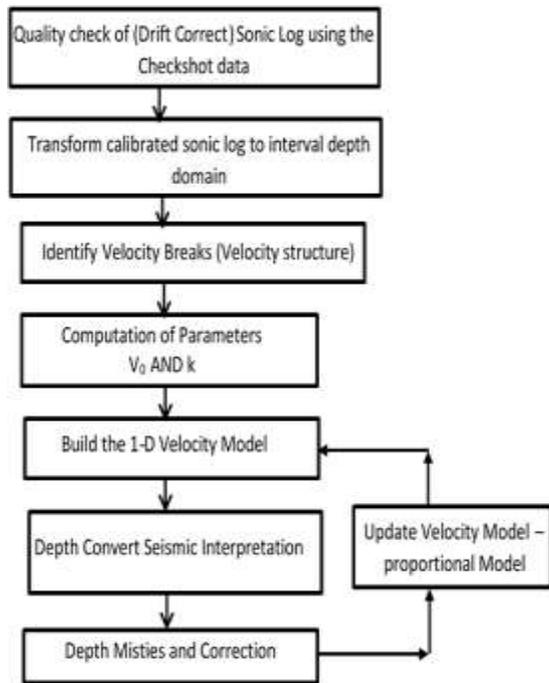


Fig 3: Workflow for 1-D Velocity Model Building

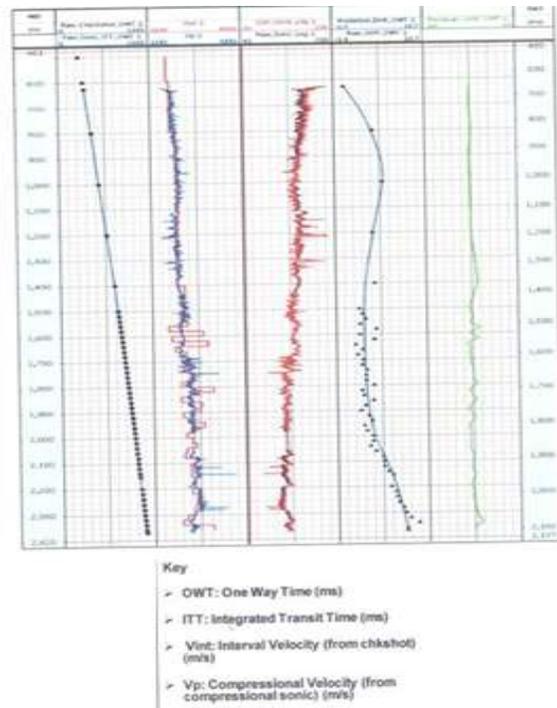


Fig 4: Process of Drift Correction of the sonic log

RESULTS AND DISCUSSION

The results obtained after several iteration are presented below, the drift correction of the sonic log with the available check shot. This drift correction gives the calibrated time – depth function $T = f(z)$ curve, which enable us to switch between depth and the vertical time domains (Fig 4). After the drift correction, the calibrated sonic logs of the wells are transformed into the interval velocity – depth domain. This allows us to observe any velocity trend due to any velocity structure where the $V_0 - k$ pair can be defined per layer (Fig 5). After drift correction, the calibrated sonic logs of the wells are transformed onto the interval velocity depth domain. This is to allow for observing possible velocity trend due to normal compaction or otherwise. The velocity structures are defined using the determined parameters namely: V_0 and K per each layers using the linear regression expression (Equation 7)

$$V_{inst} = V_0 + K (Z - Z_0) \quad 7$$

Where V_0 is the reference velocity at the reference depth Z_0 and K is the compaction gradient. The computed values are shown in Table 2.

Table 2: Computed values of V_0 and k for each layers

Layer	Formation	V_0 (ms ⁻¹)	k (s ⁻¹)	Reference
0	Floating Datum	0	0.00	N/A
1	Seabed	1488	0.00	Seabed
2	Hor A	1811	0.42	Seabed
3	Hor B	2603	0.03	Seabed
4	Below Hor B	2777	0.00	Seabed

From the computed values of V_0 and k computed, the 1-D velocity model is build using the SISMAGE™ program (represent the layer defined). A layer cake model was built using the program (Figure 6).

After building the geological models with reference to depth, it is necessary to convert the time interpreted seismic horizons to depth.

The 1-D velocity model is applied to convert the seismic interpreted horizons. If the resulted model is not satisfactory, an iterated process is repeated as indicated in the workflow. For correction of misties observed in Figure 7, a Geostatistical method known as Kriging is used to correct for the misties (Figure 8).

A Kriging Variogram is Fig 8. A series of iterations was performed which includes all the processing sequence and work flow, especially the drift correction from the provided sonic log, on which the reference velocity model was built, using the reference velocity (V_0) and the compaction gradient (k).

The parameters were used to build the layer cake velocity model.

The validity of the model was checked by converting the time horizon to depth. The conversions of the Two Way Time (TWT) map to the corresponding Depth maps are generated for the Seabed and selected horizons (Figures 9-11).

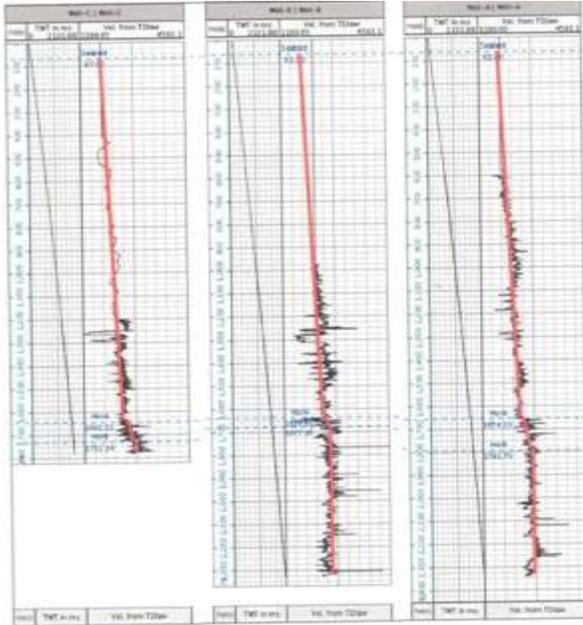


Fig 5: Calibration of Sonic log using the Checkshot Data

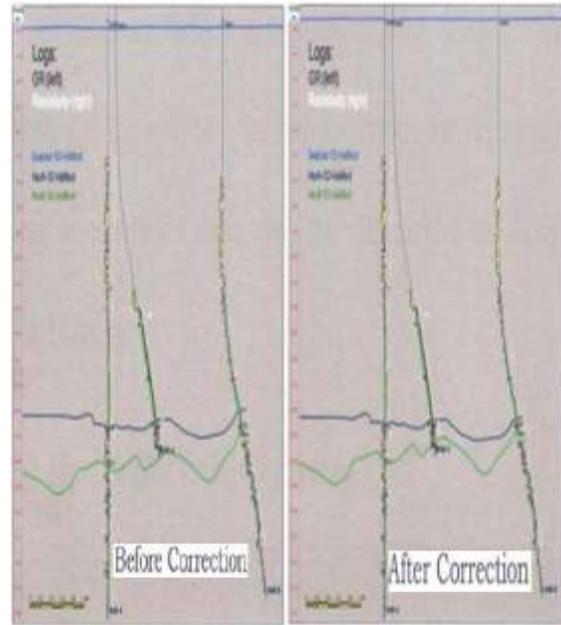


Fig 7: Kriging the Model to correct for Mistie before and after correction at the Wellbore

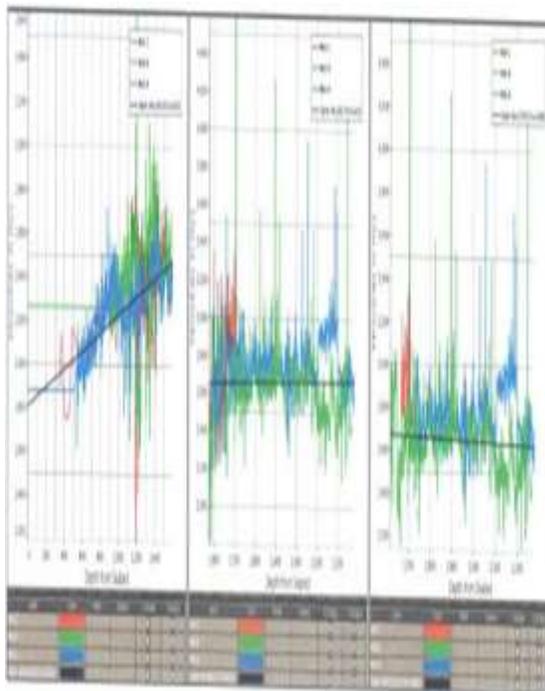


Fig 6: Various depths from the sea bed

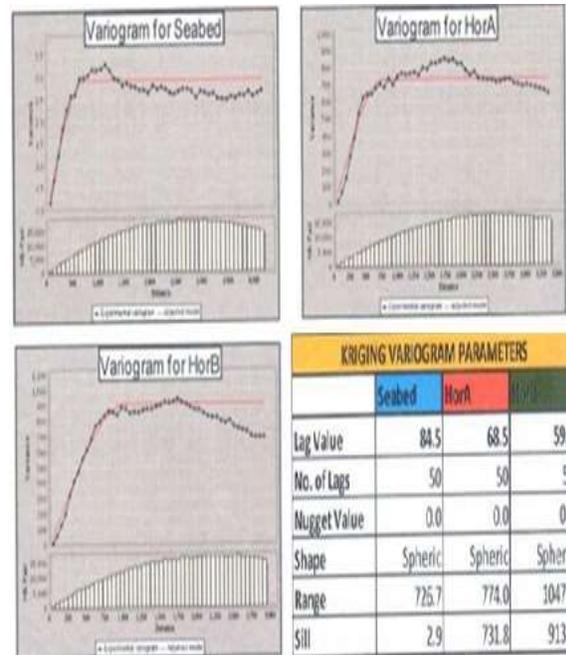


Fig 8: Geostatistical Method of correcting for Misties (Kriging) and Variogram parameters.

Table 3: Misties between Seismic Makers and Sea Bed Maker

Well Makers	Well A		Well B		Well C	
	Before Correction	After Correction	Before Correction	After Correction	Before Correction	After Correction
Seabed	27.96	0.08	26.5	0.00	24.65	-0.13
Hor A	11.56	0.17	-39.56	-0.50	0.53	0.11
Hor B	30.13	-0.04	4.57	-0.32	63.43	0.37

Note: Depth misties = Seismic Marker – Well Maker.

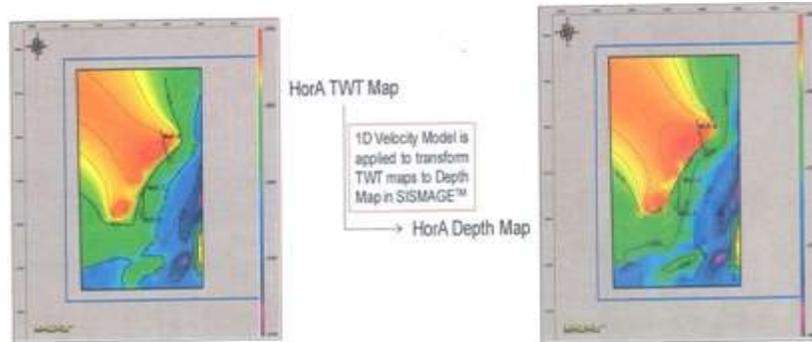


Fig 9: The conversion of the Horizons-A TWT map to Depth Map (1-D Velocity Modeling)

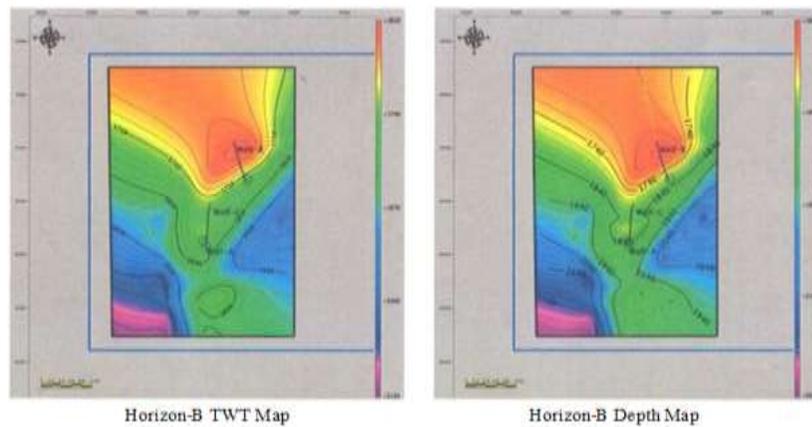


Fig 10: The conversion of the Horizons TWT map to Depth Map (1-D Velocity Modeling)

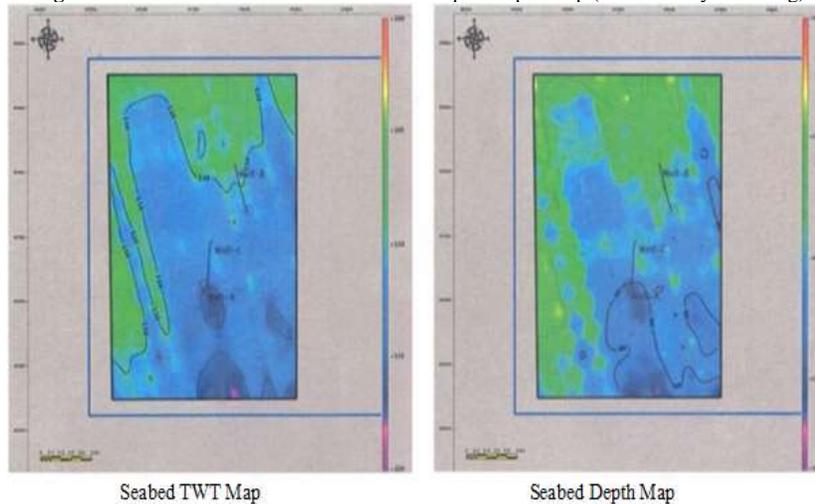


Fig 11: The conversion of the seabed TWT map to Depth Map (1-D Velocity Modeling)

Conclusion: The study has shown the use of time depth conversion in velocity modeling of the subsurface layers of the study area. The One-Dimensional velocity model was built using an iterative technique which allows the combination of several data sets input. The velocity components of the subsurface layers were determined combining the well sonic data with the check shot data, using a layer cake model, which incorporates the structural and lithological information by constraining them in ways that the velocity structure follows defined

geological pattern. The layer cake approach follows a compaction trend and this allows for the inclusion of any anomaly that might be encountered when wells are drilled in the field. The velocity model built modelled correctly the study area from the two way time map to depth map (commonly referred to depth conversion).

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REFERENCES

- Alaminiokuma, GI; Ugbor, CC (2010). Analytical Velocity Model for Depth Conversion in the Subsurface Facies of Agbada Formation in the Niger Delta, Nigeria. *Pacific Journal of Science and Technology*. 11(1), 563-575
- Al – Chalabi, M (1979). Velocity determination from Seismic Reflection data. In: Development in Geophysical Exploration Methods, 1-68.
- Cameron, M; Fomel, S.; Sethian, J (2008). Time to depth conversion and seismic velocity estimation using time migration velocity. *Geophysics*, 73, 205-210.
- Crabtree, N; Hill, D; Velt-Meijer (2001). Depth prediction from a pre-stack depth image: A case study of Dutch North Sea. *Society of Exploration Geophysicist (SEG) Abstract*, 12-21
- Dix, CN (1955). Seismic velocities from surface measurements. *Geophysics*, 20, 68-86.
- Doust, H; Omatsola, E; Edwards, JD; Santogrossi, PA (1990). Divergent/Passive Margin Basins. *Association of American Petroleum Geologists (AAPG) Memoir*, 48, 201-238.
- Duru, CA; Ugwu, SA; Nwankwoala, HO; Ugbena, KE (2018). “3-D Seismic Interpretation, Velocity Modeling and Well Log Analysis of TM-Field, Western Niger Delta”. *World Engineering and Applied Sciences Journal*, 9(3), 67-85.
- Ekweozor, CM; Dakoru, EM (1994). North Delta depobelt portion of the Akata – Agbada: In Petroleum system, Niger Delta, Nigeria, In: Magoon, L.B. and Dow, W.G (ed.), *The Petroleum System; from sources to trap. Association of American Petroleum Geologists (AAPG) Memoir*, 60, 599-613.
- Guillaume, P; Audebert, F; Chazanoel, N; Dirks, V; Zhang, X (2004). Flexible 3-D finite offset tomography velocity modeling, *Geophysics*, 54, 191-199.
- Iverson, E; Tygel, M (2008). Image ray tracing for joint 3-D seismic velocity estimation and time to depth conversion, *Geophysics*, 73, 99-114.
- Kim, YC; Hurt, WB; Mapher, LJ; Starich, PJ (1997). Hybrid Migration: A cost effective 3-D depth imaging technique, *Geophysics*, 62, 568-578.
- Kulke, H (1995). Regional Petroleum Geology of the world. Part II: Africa, America, Australia and Antarctica: Berlin, Gebruder Borntraeger, 143-172.
- Martin, T. and Marcus, B. (2019). “An innovative Approach to Automation for Velocity Model Building”. *First Break*, 37 (6), 57-65.
DOI: <https://doi.org/10.3997/1365-2397-n0033>.
- Merki, PJ (1970). Structural Geology of the Cenozoic Niger Delta African Geology, University of Ibadan Press, 1-268.
- Ogbamikhumi, A.; Aderibigbe, OT (2019). “Velocity Modeling and Depth Conversion Uncertainty Analysis of onshore Reservoir in the Niger Delta Basin”. *Journal of the Cameroon Academy of Sciences*. 14 (3).
DOI: <https://dx.doi.org/10.4314/jcas.V14i3.7>.
- Schultz, P (1999). The seismic velocity model as an interpretation asset. 1999 Distinguished Instructor Short Course, Society of Exploration Geophysicist (SEG) Distinguish Lecture Series, 2, 1-25.
- Short, KC; Stauble, AJ (1967). Outline of Geology of Niger Delta. *Association of American Petroleum Geologists (AAPG) Bulletin*, 51, 761-779.
- Siliqi, R.; Bousquie, N (2007). An elliptic time processing base on a shifted hyperbola approach. *Society of Exploration Geophysicist (SEG) Annual Conference Expanded Abstracts*, 2245-2249.
- Sofolabo, AO; Dagogo, T.; Diri IJ (2018). Velocity Modelling Using Well Data: Depth Conversion “A Case Study Of K-Field, Onshore Niger Delta Area”. *IOSR-Journal of Applied Geology and Geophysics (JAGG)*. 6(4), 18-26.
- Tieman, HJ. (1994). Investigating the Velocity–depth ambiguity of reflection traveltimes. *Geophysics*, 59(11), 1763-1773.