Research Article

VELOCITY MODELLING AND DEPTH CONVERSION UNCERTAINTY ANALYSIS OF ONSHORE RESERVOIRS IN THE NIGER DELTA BASIN

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Abstract

Depth uncertainty is one of the major uncertainties associated with hydrocarbon field development. This uncertainty mostly arises due to the complexity of the subsurface, paucity of data, time-to-depth conversion, seismic picks, fault positioning and well ties. These uncertainties explain the non-uniqueness of models built and can have a significant impact on fluid contact and hydrocarbon in-place evaluation. To manage depth uncertainty, The Polynomial and Vo_K method were adopted to build velocity models for depth conversion and residual analysis for several reservoir levels to determine the method that will give the best depth residuals. Depth conversion residual analysis result of both velocity models for the reservoirs studied gave average depth residual of less than 50ft for reservoir levels below 9000ft. As the depth increases, the polynomial method derived average residual becomes unreliable with depth uncertainty of over 100ft for the deeper MOT reservoir, compared to 11. 65ft of the Vo_K method for the same reservoir. This was expected at depth since the polymonial method adopts average velocities while the Vo_K method uses instantaneous velocity. Hence, the latter is expected to give a better result at great depth during depth conversion and should be preferably employed for velocity modeling and depth conversion study of reservoir in the Niger delta Basin.

Key Words: Depth-Conversion, Velocity-Modelling, Polynomial-Function, Vo_K -Function, Niger-Delta.

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Résumé

L'incertitude de la profondeur est l'une des principales incertitudes associées au développement des champs d'hydrocarbures. Cette incertitude est due en grande partie à la complexité du sous-sol, à la rareté des données, à la conversion de la profondeur, aux pics sismiques, au positionnement des défauts et aux liaisons de puits. Ces incertitudes expliquent la non-unicité des modèles construits et peuvent avoir un impact significatif sur le contact fluide et l'évaluation in situ des hydrocarbures. Pour gérer l'incertitude de profondeur, la méthode Polynomiale et Vo_k ont été adoptées pour construire des modèles de vitesse pour la conversion de profondeur et l'analyse résiduelle pour plusieurs niveaux de réservoir afin de déterminer la méthode qui donnera les meilleurs résidus de profondeur. Le résultat de l'analyse résiduelle de conversion en profondeur des deux modèles de vitesse pour les réservoirs étudiés a donné une profondeur résiduelle moyenne inférieure à 50 pieds pour les niveaux de réservoir inférieurs à 9 000 pieds. Au fur et à mesure que la profondeur augmente, le résidu moyen obtenu par la méthode polynomiale devient peu fiable avec une incertitude de profondeur de 100 pieds pour le réservoir MOT plus profond, comparé aux 11,66 pieds de la méthode Vo_K pour le même réservoir. Cela était attendu en profondeur puisque la méthode polynomiale adopte des vitesses moyennes tandis que la méthode Vo_K utilise la vitesse instantanée. Par conséquent, ce dernier devrait donner de meilleurs résultats à grande profondeur lors de la conversion en profondeur et devrait être utilisé de préférence pour la modélisation de la vitesse et l'étude de la conversion en profondeur du réservoir dans le delta du Niger.

Mot-clé: Conversion de profondeur, Modélisation de la vitesse, Fonction_mini_ polynomiale V0_K-Function, Niger-Delta,

Introduction

Assessment of uncertainties is critical for a field development decision making process (Thore et al., 2002; Azeke et al., 2009 and Euan et al., 2011). Considering the high investment associated with developing a reservoir deems it necessary to quantify and manage the uncertainties captured in reservoir models (Yang et al., 2013). It is important that uncertainties related to the fluid distribution, fluid contact and especially depth conversion are addressed. Singh et al., 2009 identified Depth uncertainty associated with velocity model building and depth conversion of features interpreted from seismic time as critical and impact on volumetric estimation.

Velocity model building is the platform that helps convert seismic volumes, lines and/or events from seismic time to depth. There are different methods of building velocity models depending on the available data (Abrahamsen, 1993) and on the residual calculated from the well tops. Some of the available techniques include; Calibrated Seismic velocity cube, Polynomial Method and the V_0-K (Instantaneous Velocity-Gradient) Function.

In most hydrocarbon fields, there exists a gradual increase in velocity with depth because of compaction. As a result, it is easier to model the subsurface geology as simple horizontal layers of different constant velocities in a time-depth plots as discrete linear segments, typical of the commonly used polynomial method of velocity modeling (Dix, 1955; Hubral and Krey 1980). The complexity of the Niger Delta Basin (complex fracture system, unconformities, facies changes and most especially the variability in the rate of sediment deposition) results in rapid variation in the subsurface velocities. Hence, the instantaneous velocity modeling technique (V_0-K) will better capture the rapid changes in velocities especially at great depth. Since the depo-belts of the Niger Delta basin become more complex from proximal to distal, it is also expected that this technique will be very reliable when evaluating more distal and complex hydrocarbon fields in the basin.

Despite the shortcoming of the polynomial method, just few published work in the Niger Delta basin employs the V_0-K for depth conversion (Alaminiokuma and Ugbor, 2010; Sofolabo *et al.,*2018*).* In the absence of the more reliable calibrated depth migrated seismic velocity data (which is always the case), two well based velocity modeling techniques (The Polynomial and the V_0-K methods) were examined in the present study. The study is a comparative one that practically compares both techniques to highlight the shortcoming of the polynomial method for depth conversion in the Niger Delta Basin especially at great depth.

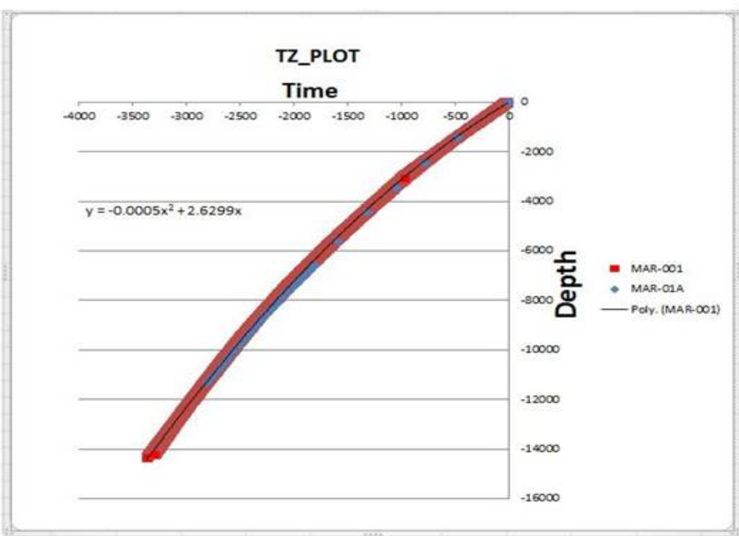
The study field is located within the Niger Delta Bain. The Basin is a major geological feature that accounts for the entire hydrocarbon production at present-day Nigeria (Whiteman, 1982), It ranks among the world's most prolific petroleum producing Tertiary Deltas (Selley, 1997). Three major lithostratigraphic units have been defined, corresponding respectively with the loose continental sands of the Benin Formation (Oligocene-Recent), Parallic Agbada Formation (Eocene-Recent) and the under compacted shales of the Akata Formation (Paleocene-Recent) Short and Stauble (1967). Most of the prolific reservoirs are embedded within the intercalated Agbada Formation. The field is a simple, elongated, East-West trending rollover anticline bounded by growth faults. Hydrocarbons have been encountered as stacked reservoirs in the sand-shale sequence of the Agbada formation.

Materials and Methods

Depth conversion was done using two velocity modeling methods (with well data provided by Shell Petroleum Development Company (SPDC) Nigeria); the Polynomial Function and V_0-K function. Before the velocity models were built, velocity analysis was carried out using a plot of True vertical depth sub-sea (TVDSS) versus two-way time (TWT) with check shot data sets from all the available wells. It involves analyzing the velocity data sets and the nature of the subsurface layers for consistency.

The polynomial method is a velocity function that depicts the time-depth relationship of a field irrespective of the number of layers present in the subsurface but does not take account of the local variation of velocities at the shallower layers. Hence it is expected to be more accurate when dealing with shallower objectives. The higher the order of the polynomial, the more accurate is the equation. However, the coefficient of the higher order becomes so infinitesimal that higher orders (beyond 3) become unnecessary. The polynomial function method involves the use of the updated velocity function obtained from seismic to well tie process that describes the velocity trend in the study area. A trend line is defined from the plot of true vertical depth sub-sea (TVDSS) against two-way travel time (TWT) of the updated velocity, and the corresponding third order polynomial equation is obtained (figure 1). The plot shows a linear relationship at the objective interval. There is no separation between the two-velocity data which indicates that there is no lateral variation in velocities.

This equation was used to generate a periodic time-depth pairs at interval of 50ft to build the velocity model from a time surface defined at 1000ms. The interval periodicity can be reduced around the time value of the horizon of interest. An advantage of the Polynomial method is that the polynomial equation generated can be used to extrapolate time depth relationship for depths below that covered by the check shot data. The key disadvantage of it is that there may be much uncertainty introduced in those areas without check shots.



TWT	TVDSS		TWT	TVDSS
0	0		-2000	-7238.85
-100	-268.324		-2100	-7704.27
-200	-546.502		-2200	-8179.54
-300	-834.535		-2300	-8664.66
-400	-1132.42		-2400	-9159.64
-500	-1440.17		-2500	-9664.48
-600	-1757.76		-2600	-10179.2
-700	-2085.21		-2700	-10703.7
-800	-2422.52		-2800	-11238.1
-900	-2769.68		-2900	-11782.4
-1000	-3126.7		-3000	-12336.5
-1100	-3493.57		-3100	-12900.4
-1200	-3870.29		-3200	-13474.2
-1300	-4256.87		-3300	-14057.9
-1400	-4653.3		-3400	-14651.4
-1500	-5059.59		-3500	-15254.8
-1600	-5475.73		-3600	-15868.1
-1700	-5901.73		-3700	-16491.1
-1800	-6337.58			
-1900	-6783.29			

Figure 1: A plot of Depth in TVDSS against the Two-way Time to generate the Polynomial Function.

Vo-K models velocity increase as a result of burial compaction and it assumes velocity changes linearly with depth by describing the time-depth relationship with a straight line. It employs the instantaneous interval velocity of each successive layer. Hence the cumulative effect of the contribution of local velocity variation in each of the overlying layers influences the velocity profile of deeper layers. This is the case in reality during surface seismic wave propagation and acquisition. Therefore, it is expected to be more accurate to ascribe velocity to deeper rock layers than the polynomial method. The necessary inputs into this velocity modelling technique are the updated TWT (msec) and TVDSS (ft) values obtained from the seismic to well tie process. The interval velocities of the layers are calculated and plotted against the corresponding depth to produces an average of the different estimated values of Vo and K. The equation that defines the velocity function can be described by the equation of a straight line (equation 1).

$$V = V_0 + KZ \qquad 1$$

Where V = Velocity at any depth Z; V_0 = Instantaneous velocity; K = gradient (It reflects the effects of compaction as unconsolidated sediments becoming buried over time); Z = depth (TVDSS).

V_0 is referenced to the datum of the velocity model while K is the slope of the straight line. The two values can be used to calculate the velocity at any depth. But for 2D and 3D depth conversion purposes, they are employed to build a velocity model. The velocity modeling process can be done iteratively to ensure a more accurate process.

These two models were used separately to depth convert the time surfaces of the reservoirs of interest and comparison of depth residuals were made to select the most optimum for depth conversion at various reservoir levels.

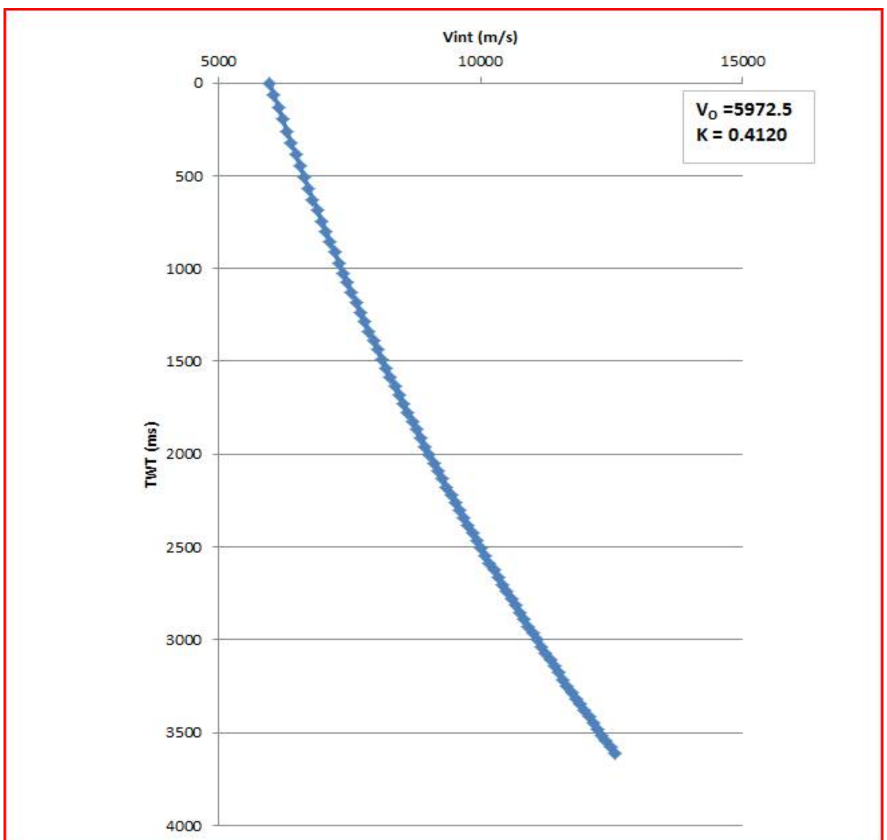


Figure 2: Final plot of the interval velocity against the TWT. Vo = 5972.5ft/s, K = 0.4120s^{-1}

Results

The result of seismic to well tie performed on one of the four available wells is presented in figure 3, with the four reservoir levels displayed. Sand A is the shallowest reservoir sand and occurs at depth of 6410.78ft while MOT Sand is the deepest reservoir studied and it occurred at a depth of 9777.74ft.

Depth conversion results of both the V_0_K and Polynomial methods are presented in tables 1to 8. The measured depth (Md) to the well top in the sand, the true vertical depth (Z) to the sand top and the depth recovered from each well top from the depth converted seismic horizon are displayed alongside the depth residual (The difference between the depth values of the well top from each well and the depth value to the top from the depth conversion result). A negative depth residual indicates that the depth conversion process displaces the reservoir to a greater depth than where it occurs in the subsurface, while a positive depth residual signifies that the depth converted result has placed the reservoir at a shallower depth.

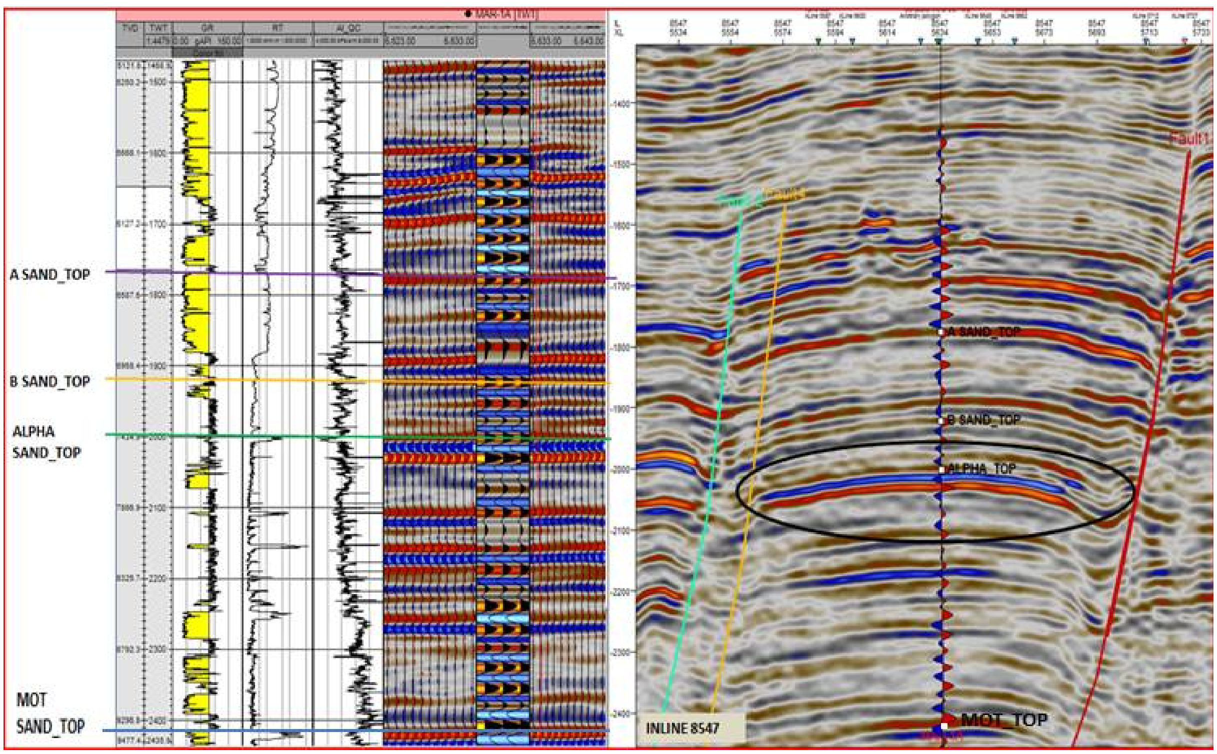


Figure 3: Seismic to well tie done on the four reservoir levels use for this study.

Table 1: Depth residuals for A-Sand using the Polynomial Function.

A_poly	Well	Md	Z-value	Horizon Value(Ft)	**Depth Residual**
	MAR-008	6636.08	-6506.77	-6516.02	**9.25**
	MAR-009	6830.66	-6490.63	-6486.92	**-3.71**
	MAR-01	6398.22	-6353.89	-6319.05	**-34.84**
	MAR-01A	6452.43	-6410.78	-6377.75	**-33.03**

Table 2: Depth residuals for A-Sand using the V_0_K Function

A_ V_0_K	Well	Md(Ft)	Z-value(Ft)	Horizon Value(Ft)	**Depth Residual**
	MAR-008	6636.08	-6506.77	-6562.57	**55.79**
	MAR-009	6830.66	-6490.63	-6532.95	**-42.32**
	MAR-001	6398.22	-6353.89	-6360.40	**6.51**
	MAR-01A	6452.43	-6410.78	-6434.43	**23.65**

Table 3: Depth residuals for B Sand using the Polynomial Function.

B_poly	Well	Md(Ft)	Z-value(Ft)	Horizon Value(Ft)	**Depth Residual**
	MAR-008	7359.93	-7160.90	-7173.08	**12.18**
	MAR-009	7535.93	-7140.56	-7127.71	**-12.84**
	MAR-01	7034.99	-6983.71	-6949.01	**-34.84**
	MAR-01A	7096.49	-7053.95	-6998.97	**-54.97**

Table 4:Depth residuals for B-Sand using the V_0_K Function

B_ V_0_K	Well	Md(Ft)	Z-value(Ft)	Horizon Value(Ft)	**Depth Residual**
	MAR-008	7359.93	-7160.90	-7229.58	**68.67**
	MAR-009	7535.93	-7140.56	-7180.38	**39.82**
	MAR-001	7034.99	-6983.71	-7000.95	**17.24**
	MAR-01A	7096.49	-7053.95	-7050.54	**-3.41**

Table 5: Depth residuals for Alpha Sand using the Polynomial Function.

ALPHA_Poly	Well	Md(Ft)	Z-value(Ft)	Horizon Value(Ft)	**Depth Residual**
	MAR-008	7807.51	-7565.62	-7579.59	**13.97**
	MAR-009	7991.87	-7529.79	-7531.35	**1.56**
	MAR-01	7417.66	-7362.16	-7350.62	**-11.54**
	MAR-01A	7435.89	-7392.98	-7348.51	**-44.47**

Table 6: Depth residuals for Alpha-Sand using the V_0_K Function

ALPHA_ V_0_K	Well	Md(Ft)	Z-value(Ft)	Horizon Value(Ft)	**Depth Residual**
	MAR-008	7807.51	-7565.62	-7640.06	**74.44**
	MAR-009	7991.87	-7529.79	-7593.15	**63.36**
	MAR-001	7417.66	-7362.16	-7406.53	**44.38**
	MAR-01A	7435.89	-7392.98	-7407.23	**14.25**

Table 7: Depth residuals for MOT sand using the Polynomial Function.

MOT_Poly	Well	Md(Ft)	Z-Value(Ft)	Horizon Value(Ft)	**Depth Residual**
	MAR-009	10825.82	-9924.3	-9750.88	**-173.42**
	MAR-008	10527.1	-10011.35	-9870.01	**-141.34**
	MAR-01A	9826.1	-9777.74	-9674.49	**-103.25**
	MAR-001	9960.02	-9896.54	-9803.16	**-93.38**

Table 8: Depth residuals for MOT sand using the V_0_K Function

MOT_ V_0_K	Well	Md(Ft)	Z-Value(Ft)	Horizon Value(Ft)	**Depth Residual**
	MAR-009	10825.82	-9924.3	-9888.96	**-35.34**
	MAR-008	10527.1	-10011.4	-10014.28	**2.93**
	MAR-01A	9826.1	-9777.74	-9808.95	**31.21**
	MAR-001	9960.02	-9896.54	-9943.88	**47.33**

The summary of the various average depth residuals and standard deviation (Depth Uncertainty) at the reservoir levels derived from the application of the two velocity model techniques for depth conversion are presented in table 9. The TVDSS for each of the reservoir levels in the well that was used for well tie operation (MAR-01A well) are presented in column two to give an idea of depth positions of each reservoir level studied.

Table 9: Summary of Average depth Residual and Standard Residuals for both Methods at the four reservoir levels

Reservoir Level	Sand Depth in MAR-01A Well (Ft)	V_0_K Average Depth Residual (Ft)	Poly. Average Depth Residual (Ft)	V_0_K Standard Deviation (Ft)	Poly. Standard Deviation (Ft)
A_Sand	6410.78	32.07	-15.58	21.54	21.85
B_Sand	7053.95	30.58	-22.58	30.93	28.86
ALPHA_Sand	7392.98	49.12	-10.12	26.35	24.7
MOT_Sand	9777.74	11.65.	-127.84	31.30	36.52

Discussions

One of the major outputs of the seismic to well tie process aside tying the defined well tops to their corresponding reflectors on seismic is an updated velocity function (Time-Depth Relationship) that served as input into the velocity modelling processes for depth conversion. The time horizons for the reservoir levels were interpreted and depth converted using velocity models built with both the V_0_K and Polynomial methods.

The results of the depth conversion were compared at the studied reservoir levels to test the consistency of the velocity models at various depths to determine the method that will give the lower residuals value as the accepted model for depth conversion. Residuals above 50ft are seen as too large and as such the velocity model will be unacceptable for use. Comparing the average residuals and standard deviation values for both method at the four reservoir levels (Table1 to 9), it was evident that the polynomial method when used for depth conversion gave lesser average residual and standard deviation especially at shallow depth. Overall, both techniques can be adopted for depth conversion at shallow levels since the average residuals are less than 50ft.

As depth becomes greater, the effect of local variation in velocity in the overlying layers becomes a challenge for the polynomial method since it adopts average velocities and does not cater for such local velocity changes. Hence, the result of depth conversion as evident in the MOT reservoir (Table 9) becomes unreliable with an average residual of over 100ft and a greater standard deviation. At such depth, the V_0_K method proves effective since it employs instantaneous velocity (Alaminiokuma and Ugbor, 2010) which considers the local velocity variations and contributions of the overlying layers, with average residual values less than 50ft and similar to results of Sofolabo *et al.,* 2018. These lower residuals values of the V_0_K method attempts to place the depth converted surface closest to the actual subsurface depth in the well.

Generally, structural uncertainty is mainly due to uncertainty in seismic picks, depth conversion technique and limited well penetrations. To manage this uncertainty, low and high case top structure map can be generated by adding the depth uncertainty from the best depth conversion result to the base case top structure and tying back to well tops. Depth uncertainty is derived by computing the standard deviation of the residuals at each well (Table 9). This depth uncertainty can be used to generate different realizations of the reservoir top structure map after tying it at well locations by building low and high case structural models form the base case since there are no depth uncertainties at well locations.

Conclusion

Structural (depth) uncertainty was evidently a challenge in the study field due to limited well penetrations. To manage this uncertainty, two velocity modeling technique; the V_0_K and Polynomial method were adopted to build velocity models for depth conversion. Four reservoir levels at various depths were analyzed for depth residual after depth conversion to select the best technique with the least average residuals and standard deviation to employ for depth conversion. Both methods gave standard deviation and depth uncertainty of less than 50ft at the shallow reservoir levels. At greater depth, the Polynomial method became unreliable and gave depth uncertainty greater than 50ft. This study revealed that at shallow depth, both methods can be reliably employed for depth conversion. But as at greater depth where the geology becomes more complex and velocities more variable, the V_0_K method becomes the more reliable technique to adopt for depth conversion in order to reduce the associated depth uncertainty as much as possible. It is also expected that the uncertainties associated with the polynomial method could be greater in more distal depo-belts field due to the increase in structural complexity. Since the V_0_K method is reliable, we therefore recommend that it should be preferably employed for velocity modeling and depth conversion study in hydrocarbon fields of the Niger Delta Basin.

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