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Velocity Modelling Using Well Data: Depth Conversion "A Case Study Of K-Field, Onshore Niger Delta Area"

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Abstract: *An important aspect of seismic reflection processes is the evaluation of subsurface velocity (Velocity Modeling), which is a major step in geological and geophysical interpretations; the values obtained are used to controls and check the quality of the depth of subsurface images obtained. One main limitation in velocity modeling is its non-uniqueness, because several velocity models can produce same subsurface images, thus several iterations is needed to generate a robust velocity model, although achieving a good well tie can be very challenging.This paper developed a velocity model ofthe study area (K-Field, Niger Delta Area) usinga layer-cake methodto create the required model.Seismic interpretation program "SISMAGE^{TM}" was used to build the velocity model for the area. Therobustvelocity model developed incorporatesthe well sonic data and the checkshot data, by accurately converting time images to their true geological depth; while the validity of the model was confirmed by converting the time horizons to corresponding depth horizons.The developed velocity model accurately depth convertthe study area data using the calculated velocities for the subsurface layers, which were subsequently used to compute layers parameters such as the reference velocity (V_0) at the interface depth (Z_0) and the compaction gradient (K) using the calibrated sonic logs provided.A true velocity of the area was obtained which ranges between 253ms^{-1} and 2547ms^{-1}.*

Keywords: *Modeling, Horizons, Conversion, Velocity, Depth, Kirging, Checkshot, Compaction.*

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I. Introduction:

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).

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 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.

In a direct time-depth conversion, a time horizon is converted to depth directly,without regard to the structure of the velocity variation, thus, depth calculated via the direct time-depth conversion method can only be assessed by calculating the prediction error at known well location (1-Dimensional),but this is a potentially flawed quality check (QC) method because the depths being predicted are the depths used to develop the prediction equation (Schultz, 1999).

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**.

Velocity modeling can therefore be said to be a more an advance method to direct time-depth conversion method. The main difference between direct true depth conversion method and velocity modeling method is that direct time depth conversion uses pre-velocities (assumed velocities) while velocity modeling method uses more precise velocities of the subsurface layers by simply dividing the subsurface layers and defining the velocity of each layer as we attain a greater depth subsurface layers, having in mind, the fact that velocity changes with depth.

II. Location Of The Study Area/Geology Of Niger Delta

The study area is located at Field- K, 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 andthe 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 km^2 (Figure 1).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 $km^3$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.

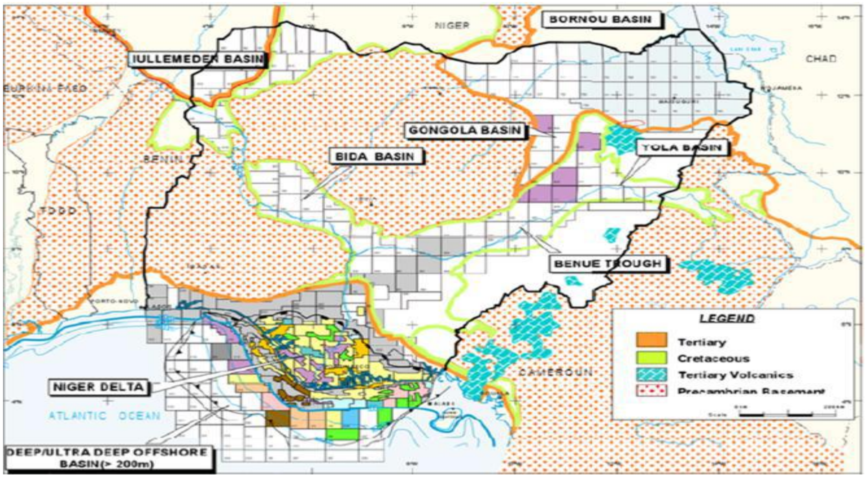


Figure 1: Geological map of Nigeria showing the Niger Delta Basin (ref: Total Nig. Plc.)

III. Literature Review:

Velocity model can be obtained from sonic log, which is used to estimates the velocity value of the subsurface from signals that propagate in the vertical direction and at a frequency up to 20,000Hz (Al-Chalabi, 1979). Iverson et al. (2008) uses velocity field representation and conversion of time image to true geological depth, they asserted that the velocity fields associated with a depth migrated image is not usually smooth, while Kim et al. (1997) uses seismic velocity estimation and the time to depth conversion of migrated images so as to remove structural errors inherent in time migration.

Dix (1955) used the velocity estimation analysis to convert time migrated image to its true depth in a lateral homogenous medium, provided the Dix formula is used, the analysis established theoretical relations between the time migrated velocity and seismic velocity in 2-D and 3-D using paraxial ray tracing theory. Guillaume et al. (2004) uses the post stack depth migration (PSDM) technique for velocity picking to establish a standard depth velocity model and it also ensure high signal to noise (S/N) with unfolded reflector and focused diffractions over the entire offset range.

THEORETICAL BACKGROUND:

Velocity Modeling:

This is a process used to generate velocities that represent the earth's velocity, especially in depth conversion, such that images in time domain are converted to their true geological depth while considering the accrued misties. In velocity modeling the true velocity of the subsurface is modeled, which gives a better resolution of the dimension of the image when used for depth conversion.

Types of Modeling Velocity

In a multi-layer depth conversion, the section is divided into separate geological layers, each of which likely has a different, but internally consistent, interval velocity or velocity versus depth function. A separate velocity model is built for each layer, top of the first layer is usually the seismic datum, then the base of that layer becomes the top of the next layer and the conversion is repeated, layer by layer, down to the last horizon of interest. These layers may not be of exploration interest on their own, but are important because they form the overburden above the zones of interest and may contain significant velocity variation. There are three levels in velocity modeling. These are:

- Average Velocity -Interval Velocity - Instantaneous Velocity

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

$$V_{ave} = \frac{\text{Distance travelled}}{\text{Travel time}} = \frac{\sum Z}{\sum T} \qquad 1$$

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

$$V_{int} = \frac{Z_i}{t_i} \qquad 2$$

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.

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

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

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

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

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_o 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

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

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.

$$V_{int} = \left[\frac{\left(t_2 V_{rms2}{}^2 - t_1 V_{rms1}{}^2\right)}{\left(t_2 - t_1\right)}\right]^{1/2} \qquad 6$$

V_{int} = Interval Velocity, t_1 = Travel time for first reflector, t_2 = Travel time for second reflector,
V_{rms1} = Root mean square velocity of 1st layer, V_{rms2} = Root mean square velocity of 2nd layer.

IV. Materials/Methods:

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.

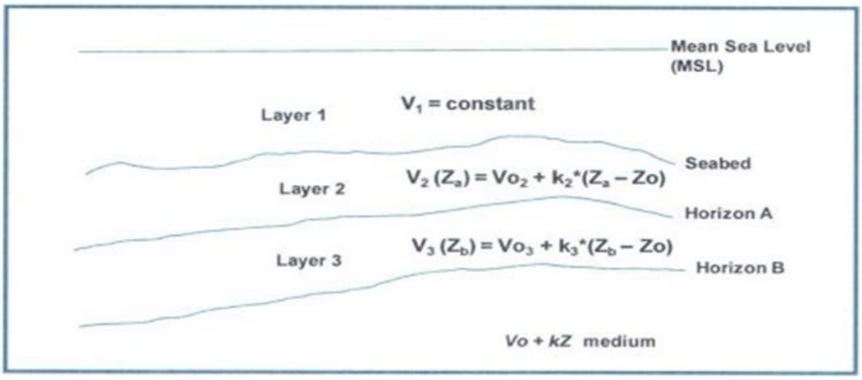


Figure 2: Layer Cake Velocity Method (Ref: Schultz, 1999)

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

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

The wells were loaded into the interpretation workstation (SISMAGE^{TM}) 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 (HorB)**

While the seismic horizons identified are

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

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. Thus the sonic value is integrated with the checkshot values or VSP (performing drift correction).

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 (Figure 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_o – k pair can be defined per layer (Figure 5).

The $V_o - k$ 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.

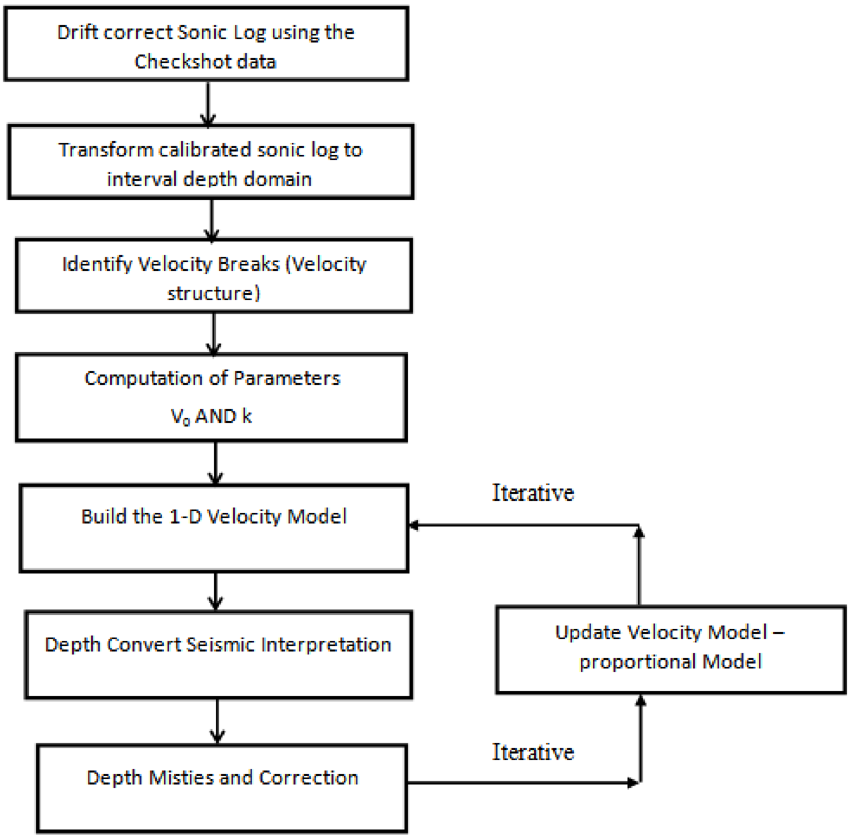


Figure 3: Workflow for 1-D Velocity Model Building.

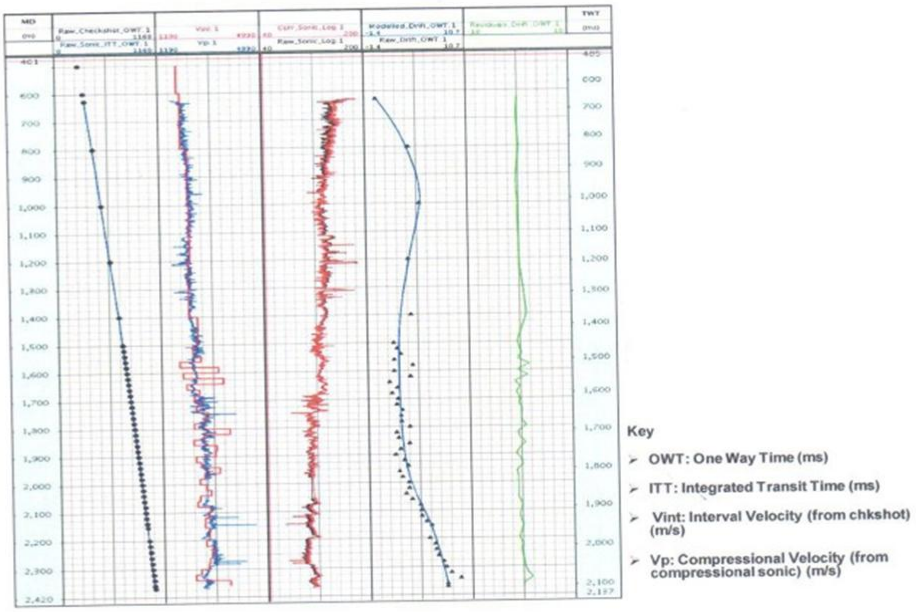


Figure 4: Process of Drift Correction of the sonic log

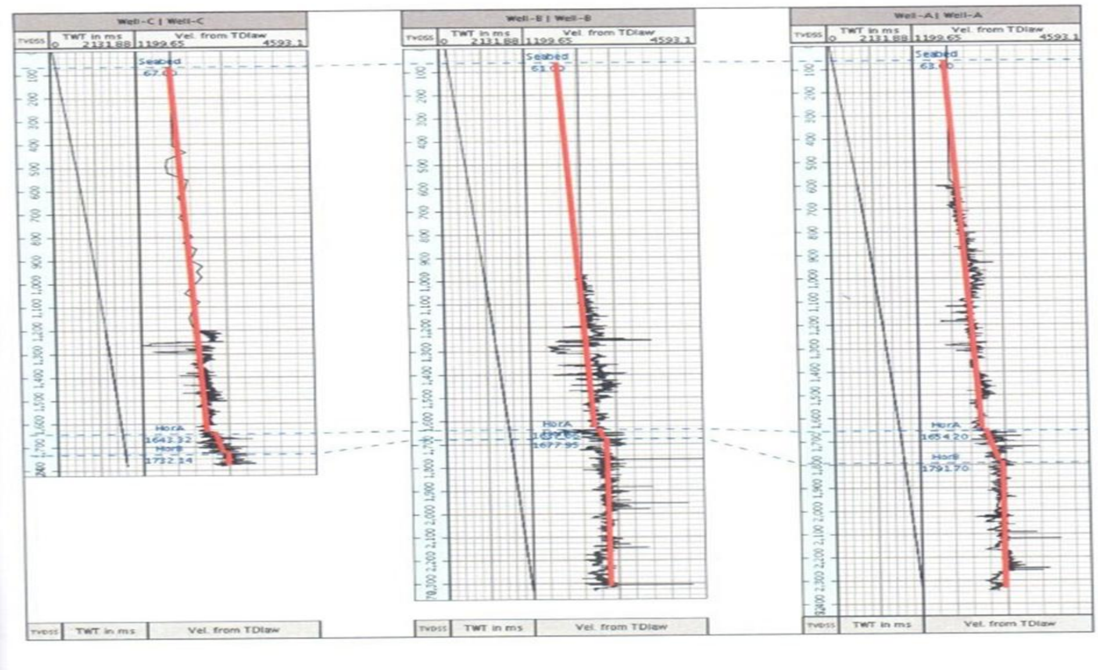


Figure 5: Calibration of Sonic log using the Checkshot Data

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_o and K per each layers using the linear regression expression

$$V_{inst} = V_o + K (Z - Z_o)$$

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

Table 2: Computed values of V_o 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	HorA	1811	0.42	Seabed
3	HorB	2603	0.03	Seabed
4	Below HorB	2777	0.00	Seabed

From the computed values of V_0 and k computed, the 1-D velocity model is build using the SISMAGE^{TM}program (represent the layer defined). A layer cake model was built using the program (Figures 6 and 7)


Water or replacement velocity 1488.0 m/s Datum 0.0 m

Layer cake construction

Current layers in model

Layer top horizon	Velocity law
Seabed-1D-VelMod.Gridding	v0 =1488.0; K =0.0;
HorA-1D-VelMod	v0 =1811.0; K =0.42;
HorB-1D-VelMod	v0 =2603.0; K =0.03;
HorB-1D-VelMod	v0 =2777.0; K =0.0;

Figure 6: Layer Cake Velocity Model Built using SISMAGE Program

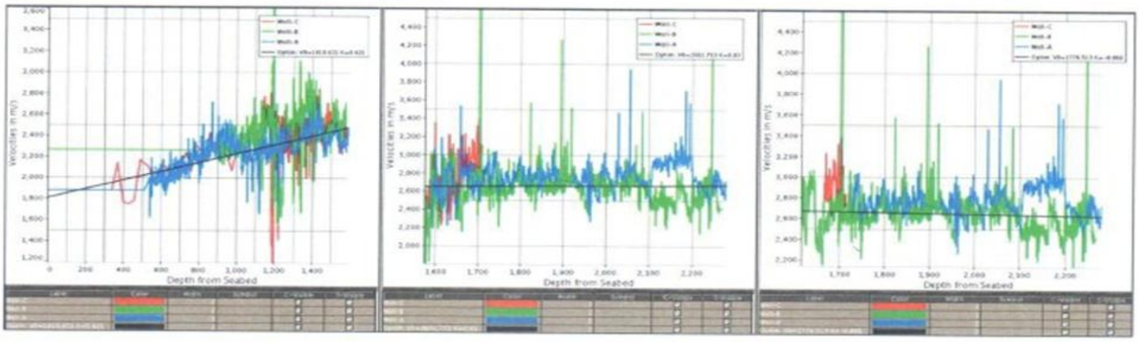


Figure 7: Various depths from the sea bed

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 (Figure 8). If the resulted model is not satisfactory, an iterated process is repeated as indicated in the workflow.

V. Results and Discussion:

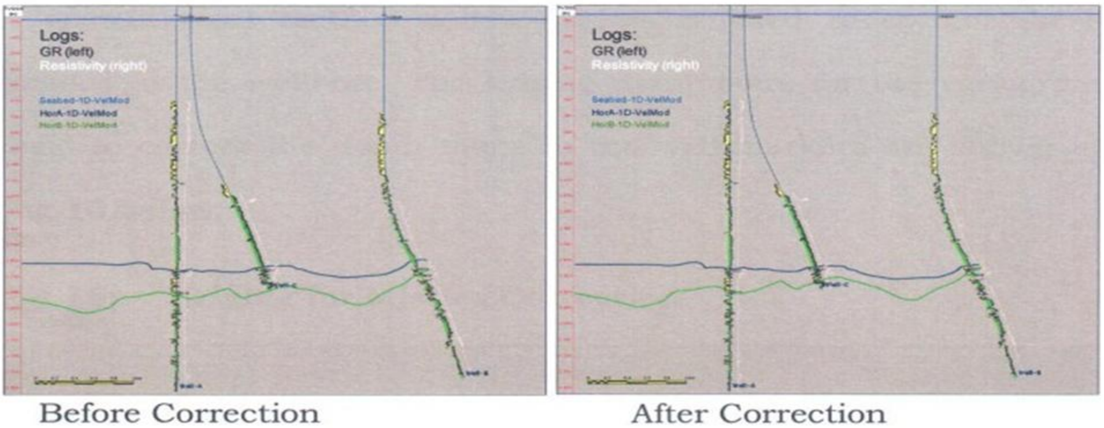


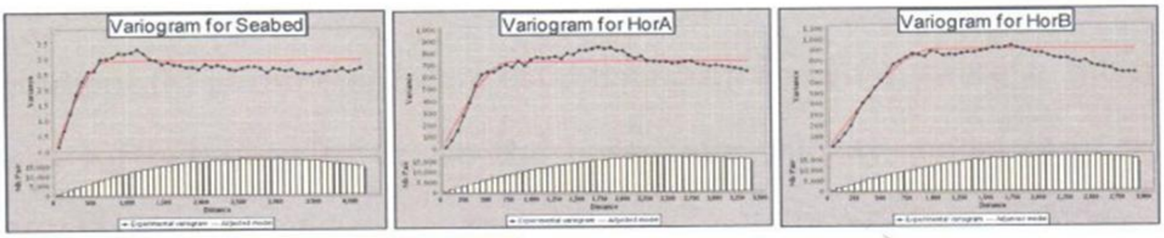
Figure 8: Kriging the Model to correct for Mistie before and after correction at the Wellbore

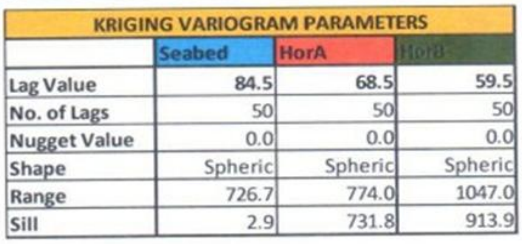
Table 3: Misties between Seismic Makers and Sea Bed Maker

	Well A		**Well B**		**Well C**	
Well Makers	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.

For correction of misties observed in Figure 8, a geostatistical method known as Kriging is used to correct for the misties (Figure 9). A Kriging Variogram is shown below



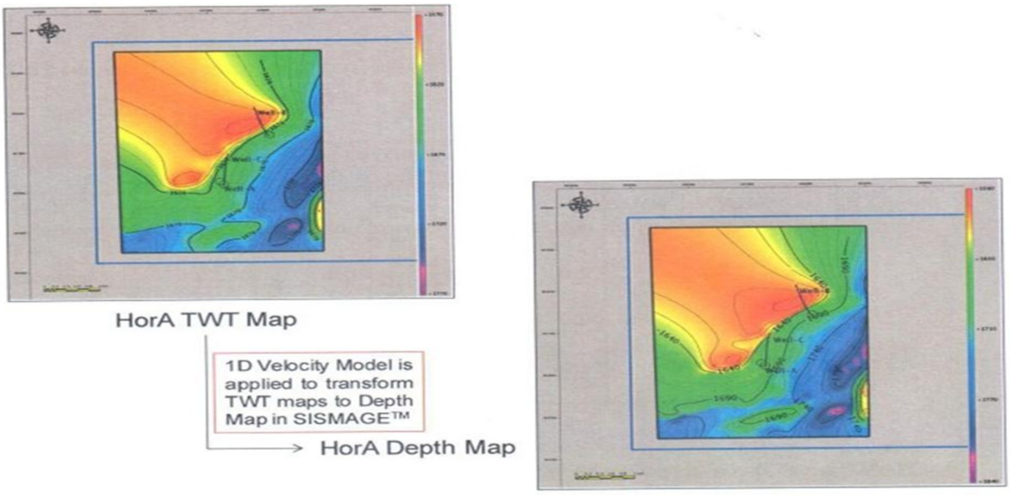


KRIGING VARIOGRAM PARAMETERS

	Seabed	HorA	HorB
Lag Value	84.5	68.5	59.5
No. of Lags	50	50	50
Nugget Value	0.0	0.0	0.0
Shape	Spheric	Spheric	Spheric
Range	726.7	774.0	1047.0
Sill	2.9	731.8	913.9

Figure 9: Geostatistical Method of correcting for Misties (Kriging) and Variogram parameters.

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_o) and the compaction gradient (k). Theseparameters 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 (Figures10-12).

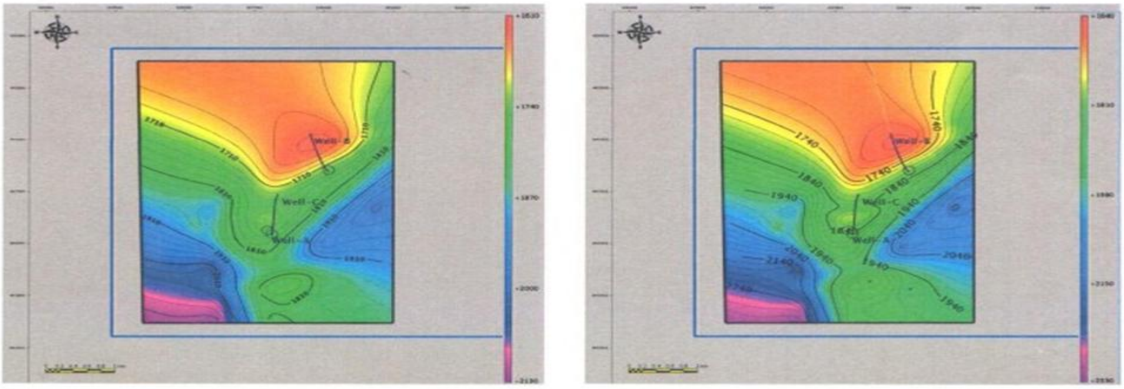


HorA TWT Map

1D Velocity Model is applied to transform TWT maps to Depth Map in SISMAGE™

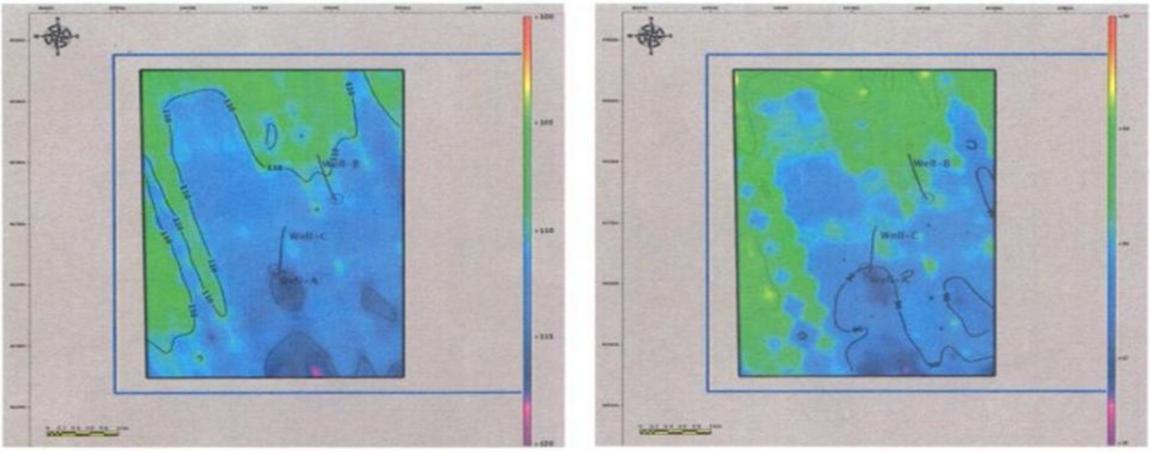
HorA Depth Map

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



Horizon-BTWT Map | Horizon-B Depth Map

Figure 11: The conversion of the Horizons B TWT map to Depth Map (1-D Velocity Modeling)



Seabed TWT Map

Seabed Depth Map

Figure 12: The conversion of the seabed TWT map to Depth Map (1-D Velocity Modeling)

VI. Conclusion

The study has shown the process of modeling the velocity of the subsurface layers of the study area. The 1-D velocity model built uses an iterative technique which allows the combination of several data sets. The velocity components were determined from combining the well sonic data with the check shot data. A layer cake model incorporates the structural and lithological information by constraining them in ways that the velocity structure follows defined geological layers.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 was able to modelled the study area from the two way time to depth (Depth conversion).

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