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Research Paper

Velocity Modeling for Structural Traps Evaluation and Interpretation of TM-Field in Niger Delta

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The quest for optimization in the Oil and Gas Exploration and Production (E&P) industry has been the driving force for the innovation trends experienced in the industry. Amongst others, velocity modelling module has led to the accurate and precise velocity determination for complete interpretation of subsurface inhomogeneity and true depth positioning from the generated time section of the surfaces of TM-Field located between longitudes 6p77’80.11 - 6p80’77.71 (Easting) and latitudes 4p61’74.50 – 4p62’93.33 (Northing) within the western region of the Niger Delta Area. 3D seismic interpretation and three velocity models- LinVel velocity model, Average cube velocity model, polynomial velocity model were used to delineate the subsurface structures and true depth positioning of the TM-Field respectively, using the schlumberger petrel software 2013 version. The processes included but not limited to data loading, frequency analysis, well correlation and top picks, spectrum analysis, fault mapping and horizon picking, time surface generation, attribute analysis, velocity modelling and depth surface positioning and error correction. Two horizon of interest B1 and B6 resulting from the synthetic and seismic tie were identified and mapped, which gave good attribute signature (i.e. amplitude) for Fluid content in conformity with the correlation. A convolution of the different velocity models with the generated time surfaces gave depth positioning. But with the residual corrections of the error analysis, it is observed that the average cube velocity model was better in accurate depth positioning as its error margin from well top is minimal when compared to others. The 3D and the velocity models used, especially average cube velocity model, proved effective in the evaluation, imaging and positioning of the true depth of the TM-Field, which has led to a better understanding of the TM-Field geologic structural geometry, reservoir architecture for optimal recovery of hydrocarbon accumulation (proven) and to evaluate the potentials identified (unproven).

Keywords: Traps, faults, velocity model, structure, horizon, Niger Delta

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Introduction

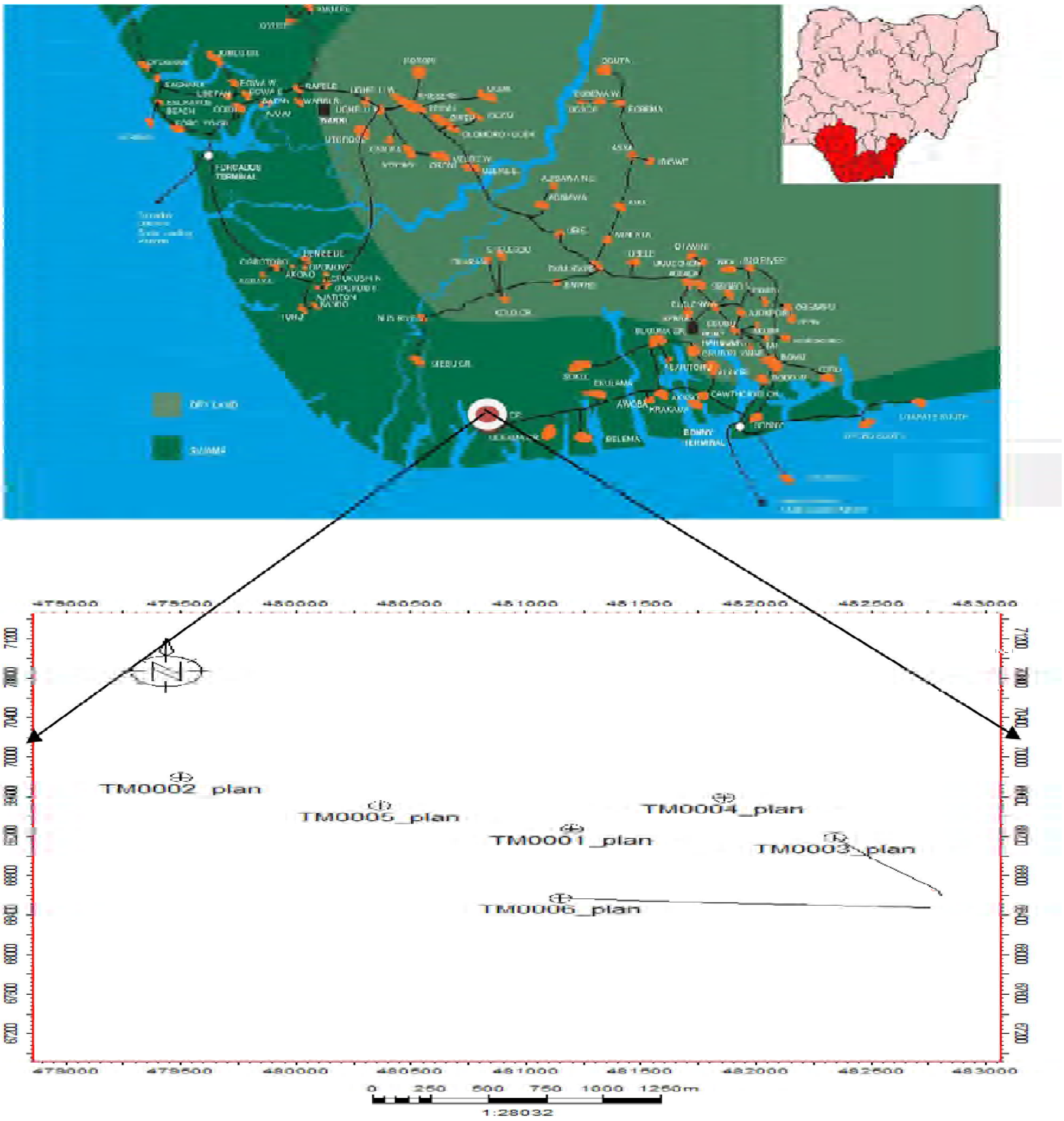
Exploration (acquisition, Processing and interpretation) is a vital component of the Oil industry, whose evolution trend has not only improved production, but has also enhanced potentiality and discoverability through the application of innovation modules resulting from researches, hypothesis and theories. Accurate and precise velocity determination for true depth conversions, and complete interpretation of subsurface inhomogeneity, is technologically driven in seismic prospecting, and has greatly affected positively the locations and extractions of hydrocarbon (Merki, 1972; Avbovbo, 1978; Bustin, 1988; Beka & Oti, 1995). Seismic velocities are important in accurate determination of dynamic time corrections, indications of changes in lithology, porosity and pore fluid (Zseller, 1982; Onuoha, 1983). The sensitivity of velocity values to numerous geological factors, such as age, composition, porosity, density, overburden pressure, etc. makes it possible for it to be an interpretative tool, though very difficult to determine the velocity contribution of each of the geologic factors to the entire effect as they are closely inter-related. 3-D seismic interpretation approach was used here, which involves picking and tracking lateral consistent seismic reflectors, for the purpose of mapping geologic structures, stratigraphy and reservoir architecture (Faust, 1951).

Discovery of more reserves for optimal exploitation is the goal of all sub-surface professionals (Petroleum Geoscientist and Engineers) in the oil and gas industry. The uncertainties resulting from poor definition of reservoir architecture, has been a major challenge in the oil and gas industry, from exploration stage through to development and production of hydrocarbon, therefore this study would define the prospective reservoirs, the subsurface structures using velocity delineation, with the ultimate goal of positioning the structures to its true subsurface depth for minimal risk in development and productions, with all other factors remaining constant and normal (Ugwueze, 2015). Interpretation of 3D seismic data along with well log analysis provides information of “TM” field’s reservoir architecture, prospective hydrocarbon zones, in their true subsurface depth. The 3-D method understands the spatial or 3-D nature of the problem to be resolved. The increased details from the technique allows for better structural (or stratigraphic) delineations. Therefore, the ultimate goal of this study is to show the prospective horizon’s true reflectivity of the subsurface of the ‘TM field’ and delineate the structural surface (true position) of the subsurface reflector(s) for proper interpretation, hence; volumetric calculations, reservoir engineering can proceed with less uncertainty in definition of hydrocarbon in place.

Location of the Study Area

The “TM” Field lies between longitudes 6’77’80.11 – 6’80’77.71 (Easting) and latitudes 4’61’74.50 – 4’62’93.33 (Northing), located within the western region of the Niger Delta Area (Figure 1). “TM” field trapping elements include those associated with simple rollover structures, major boundary growth faults, antithetic and synthetic faults, as well as collapsed crest structures (Short & Stauble, 1967; Weber, 1971; Burke, 1972; Doust & Omatsola, 1990; Ekweozor & Daukoru, 1984, 1994).

Figure 1: Niger Delta map adopted from Google and the study area with six wells adopted from Petrel



Materials and Methods

Kingdom Suite and Schlumberger Petrel 2013 was used for the interpretation of the entire data sets used in this study. Both Kingdom and Petrel are PC Windows-based software application which covers a wide range of workflows from seismic interpretation to reservoir simulation. A project 'TM Velocity Modelling' was created in Petrel for this project and available data were loaded, and the seismic quality check was done in Kingdom Suite before interpretation began. The available sets of data collected for this study include 3D Seismic data, Well Logs (Gamma ray, Resistivity, Neutron-Density and Sonic, Spontaneous, Calliper, etc.) and one check shots

Figure 2 shows the workflow used for this study with detailed explanation of each step in relation to the objectives and scope of the study.

Data Quality Assessment

The set of data given was checked for quality and any challenges that might arise using the data. During the quality check of the data, different challenges where identified:

(1) The well logs data was not in a software recognizable ASCII format, but was edited and converted before loading.

(2) Only TM0001 has check shots, which was distributed amongst the wells. With all the wells having Depth, GR, Calliper, SP, Resistivity, Density, etc.

(3) Well TM0003, TM0004 and TM0006 were the wells with deviation data.

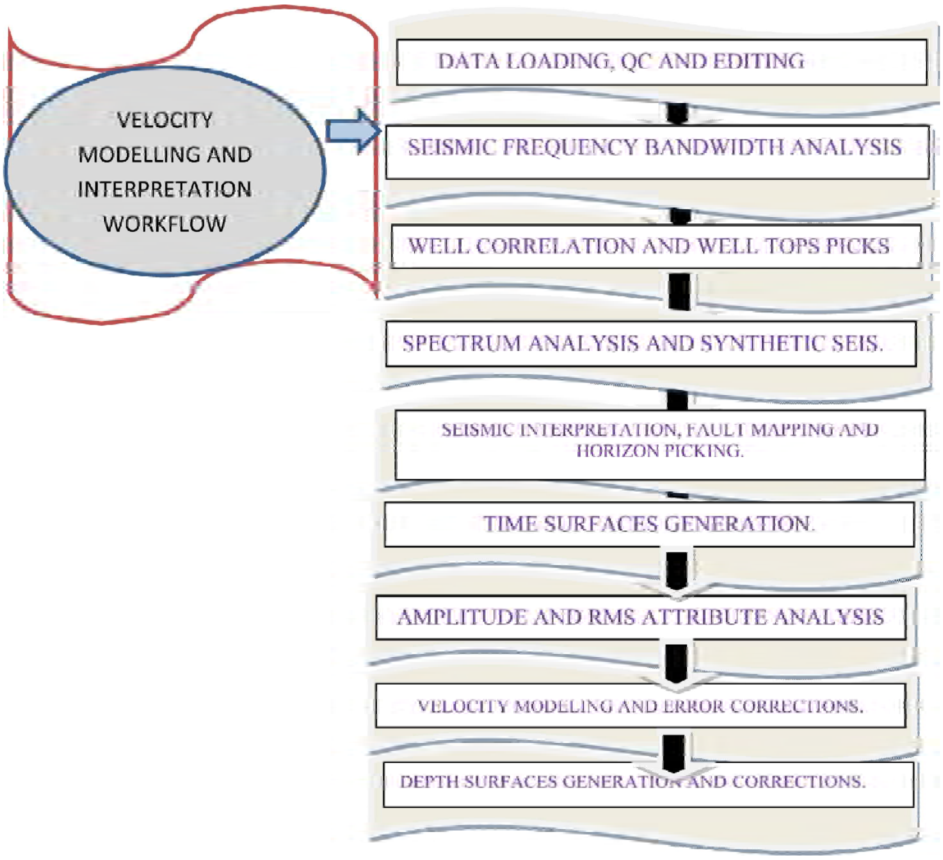
(4) Frequency analysis of the seismic volume was carried out to check

(5) The frequency bandwidth that can resolve the reservoir layers.

Data Loading and Importation of Logs

All the given data both logs and seismic were imported into the petrel after corrections, editing,

Figure 2: Seismic Velocity Modelling Workflow



and creation of the project in the software to get them ready for 3D interpretation. Well folder was inserted in the input pin of petrel and well head imported first into the folder. The well head is in ASCII format containing well header information organized in columns, normally six columns consisting of the well names, their unique well identifier surface.

X-coordinates, surface Y-coordinate, Kelly bushing valve (in project units) and the measured depth value in project units. Once the importation was successful it appeared in the well attribute folder under the well folder. When the importation of the well head was completed, the well logs, the deviation logs and check shot were imported respectively after correction, which are now in ASCII format. The check shot was taken from TM0001 well. The location of the loaded logs with respect to the project map is as shown in Figure 2 and the wells containing Gamma-Ray logs in Figure 3.

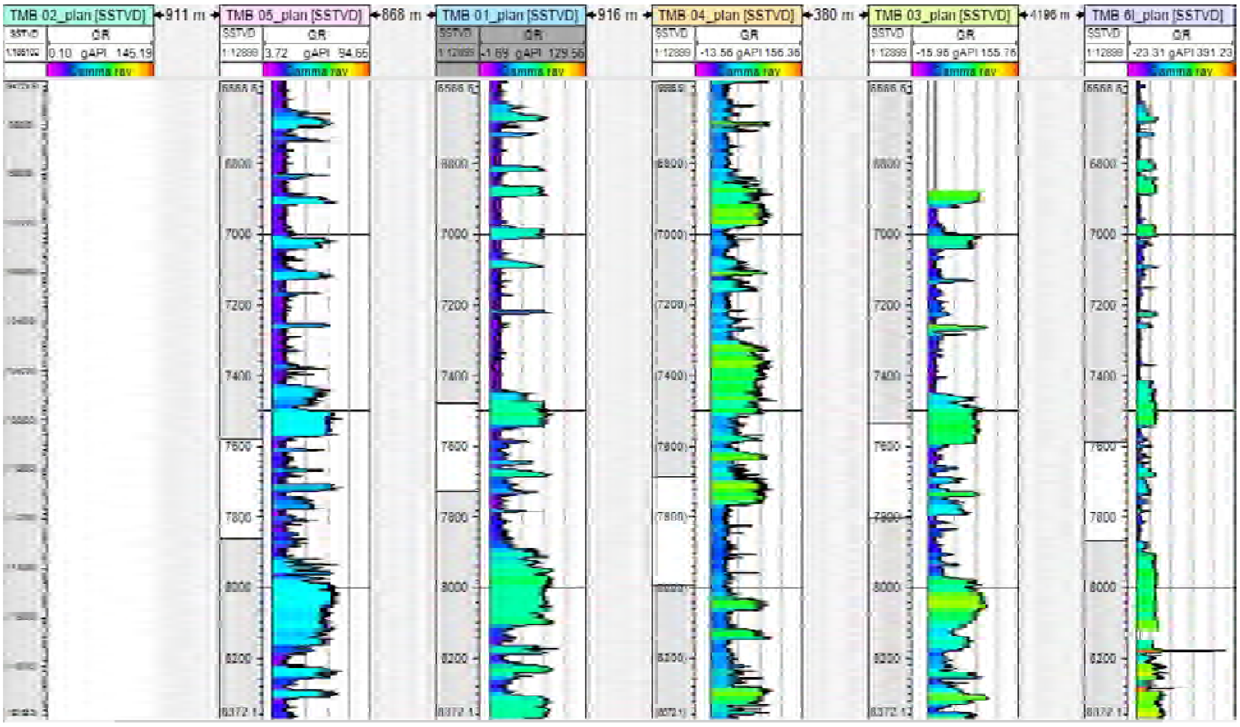
Velocity Modelling

Here, the zones in space where the velocity of the horizon B1 and B6 can be described in a common manner were defined, and that was done in reference to the default datum in making velocity model process known as the time datum, using the:

(1) Surface – from the wells parameters provided by the T-Z(Check shots) and well tops

(2) Horizon (3D grid) gotten from the interpolation of seismic cube to the generated synthetic seismograph which was dully mapped as earlier stated.

Figure 3: Wells of TM0002, TM0005, TM0001, TM0004, TM0003, TM0006 Displayed on a Petrel Well Section Window with Gamma Ray log Reflections



A set of velocity information exist for the depth conversion process

- Interval velocity model ($V= V_{int}$)
- LinVel model ($V= V_0 + KZ$)
- AdlinVel Model ($V= V_0 + K(Z-Z_0)$)
- Average Cube Velocity Model
- The Polynomial Velocity Model

These are available in the petrel 2013 software, but are applicable to specific functions and conditions. To enhance our confidence level in depth conversion three velocity model methods were used and they are as follows:

- LinVel model ($V = V_0 + KZ$)
- Average Cube Velocity Model
- The Polynomial Velocity Model

Here, time and velocity increases with depth and this is in conformity with the TM field data, with K having a value range of 0 to –0.2

Linvel Model ($V= V_0 + KZ$)

The LinVel model ($V = V_0 + KZ$) was used here as it gives room for the heterogeneity factor K in velocity variation in both XY direction (in length unit) starting from the datum velocity V_0 where $Z = 0$.

At each point in an interval, the velocity at that point is $V_0 + kZ$.

After calculation:

$$Z = Z_0 + \left(\frac{V_0}{K} + Z_0\right)\left(e^{K(T-T_0)} - 1\right) \quad ...(1)$$

where Top time is T_0, base time is T and top depth is Z_0.

$V = V_o + KZ$ (also known as LinVel) ...(2)

At each XY location, the velocity changes within the vertical direction by a factor of k. V_o represent the velocity at datum, and Z, the gap (in length units, not time) of the point from datum. NB: V_o is the velocity at $Z = 0$, not the top of the zone and will therefore be much lower than the velocities seen in the layer, possibly even negative in extreme cases. As time and depth decrease downwards, negative values of k result in velocities that increases with depth. Typical values for k are between 0 and –0.2.

$V = V_o + k(Z – Z_o)$

(also known as AdlinVel) ...(3)

As above, here the values are measured relative to the top of the zone. For example, V_0 represents the velocity at the pinnacle of the zone and $(Z – Z_o)$ represents the distance between the point and the top of the zone. Again, a negative effect of k results in velocities that increase downwards. Typical values for k are between 0 and –0.2.

$V = V_0 + KT$ ...(4)

This is the same as $V = V_0 + K*Z$ except that it is for conversion to the time domain.

TZ curves from the TM001 well were available for time to depth conversion within the TM field 3D Seismic area. An average velocity function was calculated from the well TZ data.

The B1 and B6-sands TWT horizons were depth converted using a polynomial function established from the Average TDR plot of 4 wells data in TM field. A relationship represented by the following 2nd order equation was generated and adopted for velocity modelling implemented in Petrel as $V = V_0 + V_{int}$ method. All the calculated depth surfaces were analysed for depth residuals per well.

$$\text{Depth} = 0.0005(\text{TWT})^2 - 2.756\text{TWT} + 46.499$$

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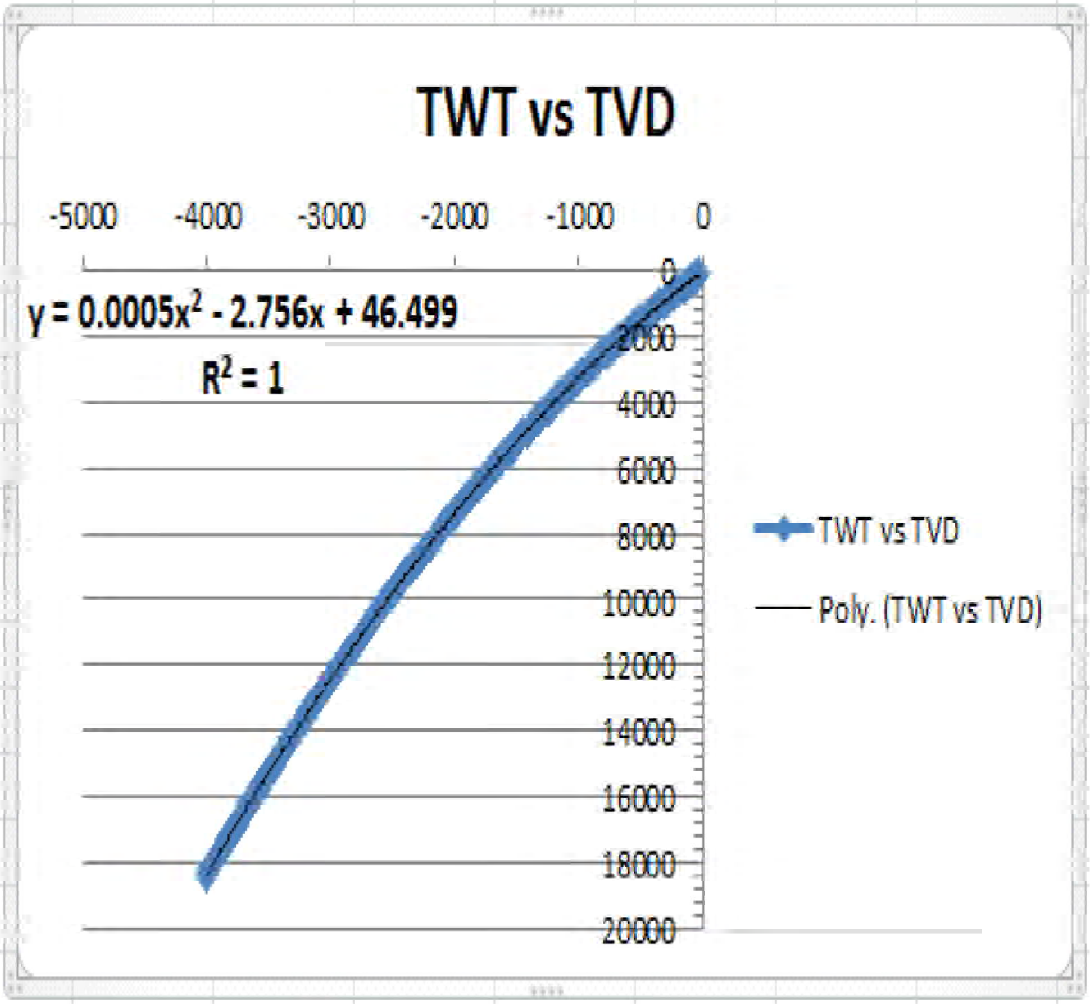
Average Velocity Model

To build an Average Velocity cube from check shots, first is to create log from the average velocity and resample it, say 10 feet interval to give more densely gridded velocity sampling. The corresponding two way time (TWT) of the velocity is interpolated and used to replace the MD, thereby changing the MD-Velocity table to TWT-Velocity table. The velocity information is scaled up in property modelling module and distributed in a 3D grid within the TM field using moving

Figure 4: Plot of TM Well Checkshots



average algorithm, and the resultant velocity cube is showed in the diagram below (Figure 6).

The 3D grid average velocity property cube is converted to average velocity seismic cube as shown below. This Average velocity Seismic cube is used to build a layered cake Average Velocity model used for depth conversion. However, all these three methods cannot be applied to the deep Reservoir beyond TM001 well penetration due to the fact that all these methods derived its velocity information from TM001 check shot, therefore cannot account for both lateral and vertical velocity variation beyond well penetrated area within TM field. Figure 5 shows different

Figure 5: Different Situations in the 3D Grid That are Handled by the Program, As Mentioned Previously, All Nodes Are Depth Converted (Adopted From Petrel Manual)

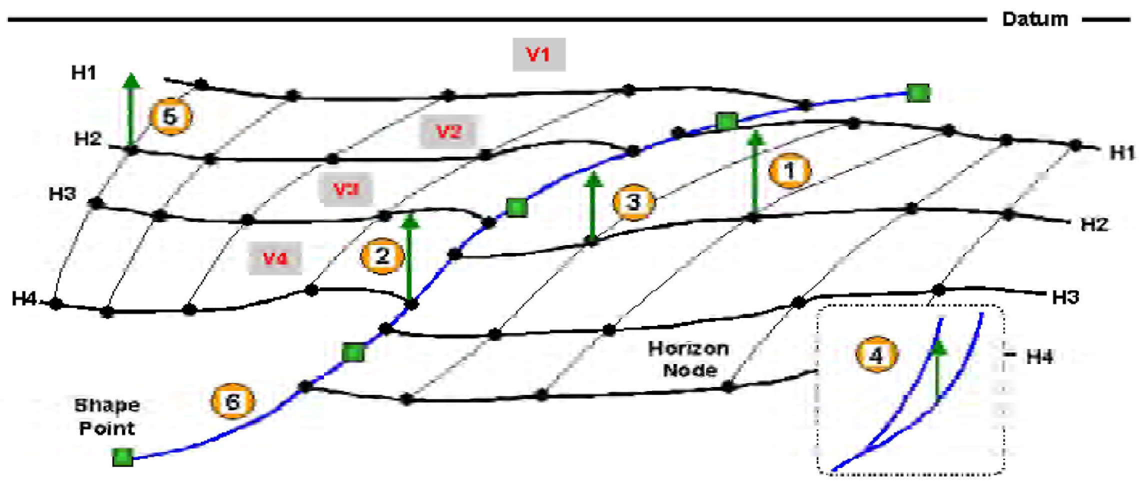


Figure 6: Average Velocity Property Distributed in 3D Grid Using Moving Average Method

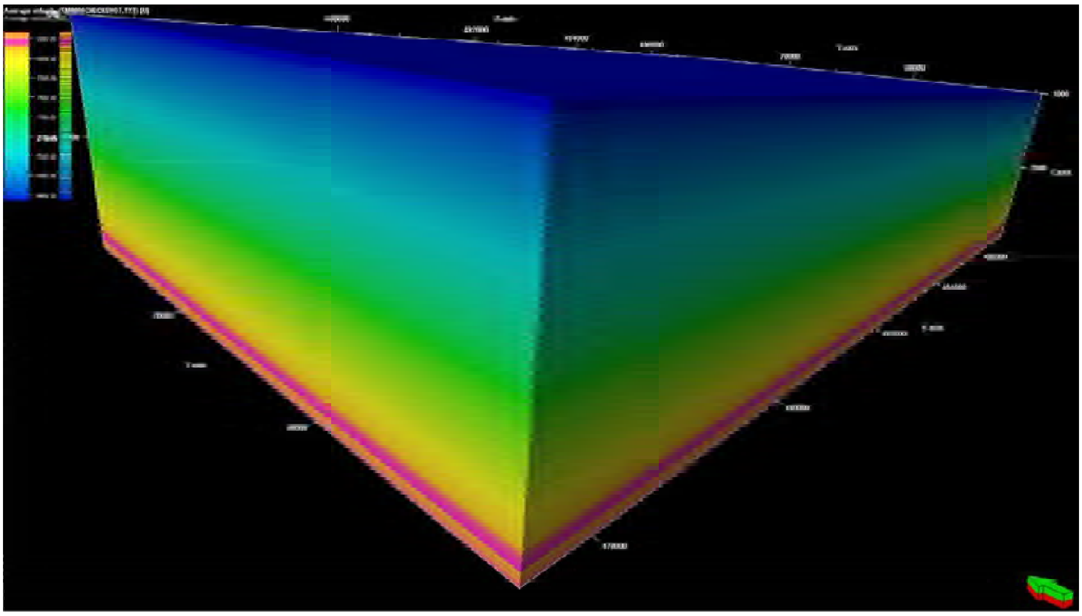
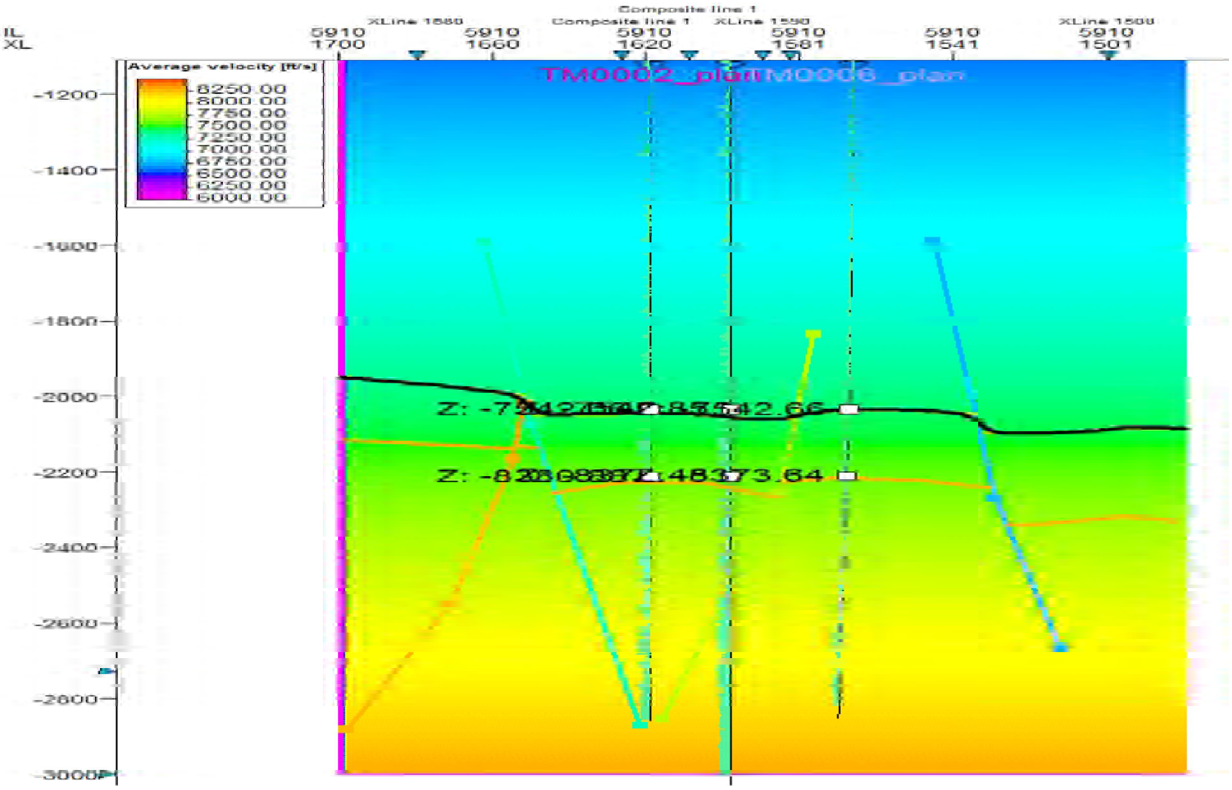


Figure 7: Xline 1629 Average Velocity Seismic Cube Showing the Vertical Velocity Variation Within TM Field



situations in the 3D grid that are handled by the program in which all nodes are depth converted.

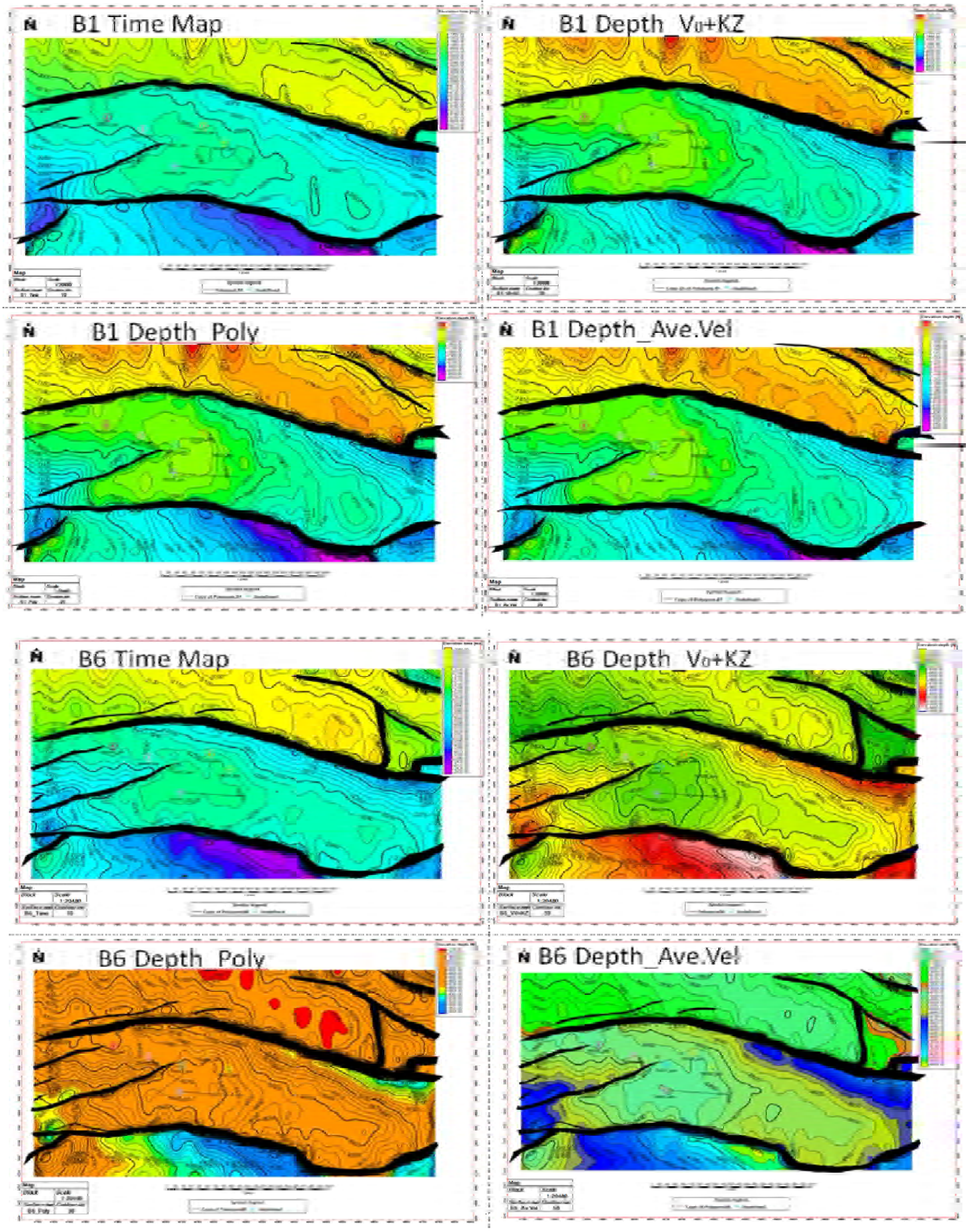
Discussion

The dominant subsurface structures in TM field are syn- and post-sedimentary listric normal faults, the major boundary growth-fault trends cross the field from northwest to southeast, and hydrocarbon accumulations occur in roll-over anticlines in the hanging- walls of growth faults, where hydrocarbons are trapped in the dip fault closures.

Two horizons mapped were Horizon B1, Horizon B6 in line with identified reservoirs and lateral continuity of these horizons was in the given seismic data. The 6 wells penetrated through the created horizons, and time maps were generated from the horizon and used to generate depth maps using the three velocity models. Surface seismic attributes such as amplitudes, RMS, etc. were extracted from the time surfaces which were used for better visualization and interpretation of the morphological and reflectivity characteristics of the reservoir. Surface Attributes mapped showed good result of maximum amplitudes and the extracted values which are good for fluid content identification and lithology contrasts.

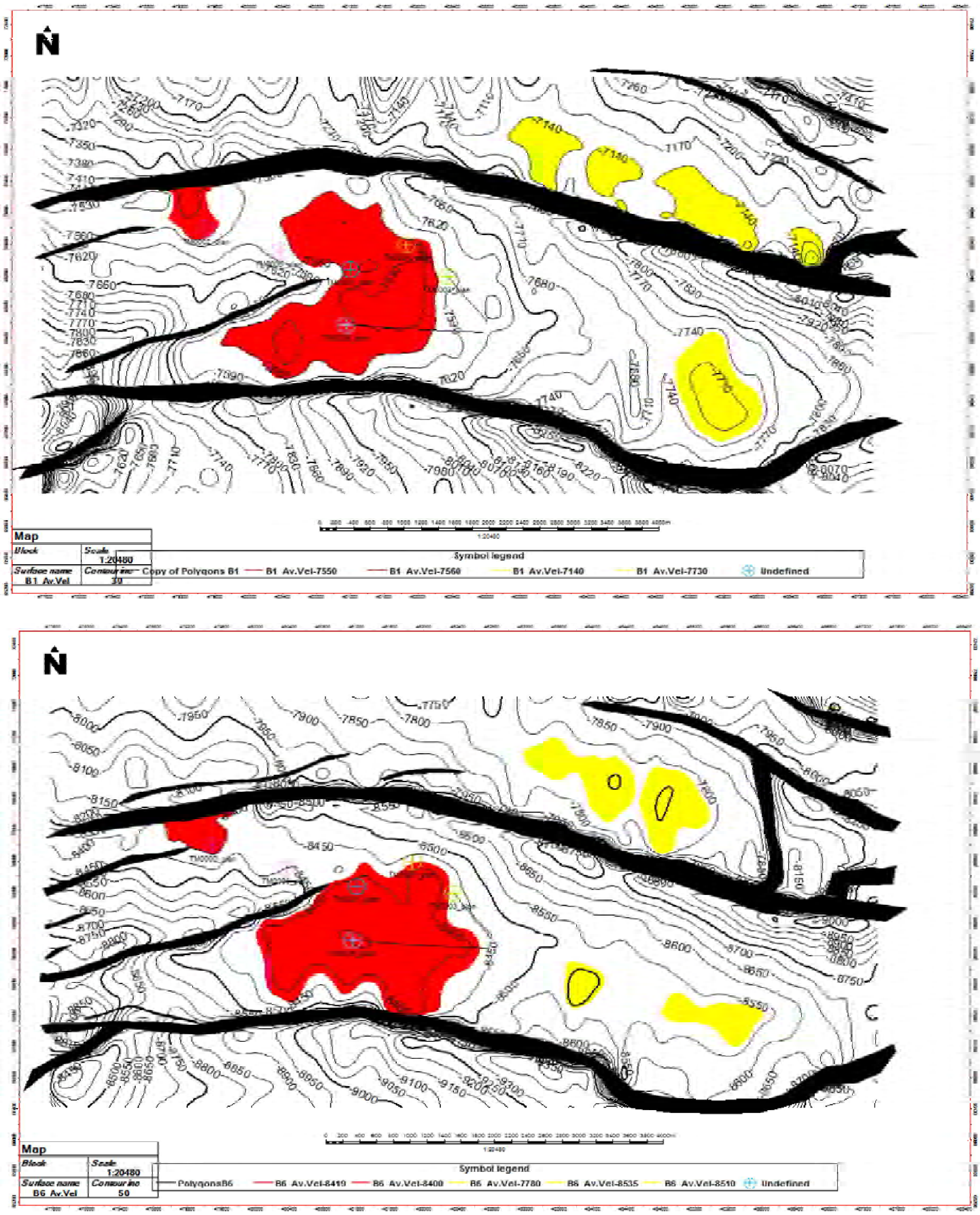
The results of the velocity models on the interpretation of the TM Field when convolved with the time surface, gave a depth surface but with a further correction done on the depth using the residual differences, it helped to reposition the depth surfaces at its true positions giving a throw difference within the range of -3 to 6ft in the case of average velocity model for B1 considered to be the best amongst the three methods of velocity models due to its minimal error margins from the well top, and is then used in converting to depth that gave rise to the structural outlooks of the horizons both the proven and potential areas. Figure 8 is the depth map of B1 and B6 reservoir

Figure 8: Depth Map of B1 and B6 Reservoir Converted Using Different Velocity Models



converted using different velocity models while Figure 9 is the structural outlook of the proven and potential opportunities of B1 (A) and B6 (B).

Figure 9: A Structural Outlook of the Proven and Potential Opportunities of B1 (A) and B6 (B)



Conclusion

Combinations of 3D seismic interpretation and well logs have proved to be an effective tool in the evaluation and imaging of the subsurface in search of oil and gas. It offers reliable means of reducing geological uncertainty by imaging the geological structures, stratigraphic and reservoir architecture. The results obtained from this interpretation of 3D seismic volume, well log analysis and true positioning of the subsurface structures using the velocity models lead to a better understanding of "TM" Field geologic structural geometry, reservoir architecture and ultimate discovery of hydrocarbon accumulations, and to evaluate the exploration potentials. The trapping mechanism in "TM" field is a major boundary growth fault and its associate rollover anticline. More reservoirs were discovered but with major interest on B1 and B6 surfaces which have showed proven and potential opportunities of the 'TM' field.

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