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3-D Seismic Interpretation, Velocity Modeling and Well-Log Analysis of Tm-Field, Western Niger Delta

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Abstract: 3-D seismic interpretation and well log analysis contributes to precise velocity determination for complete interpretation of subsurface inhomogeneity and true depth positioning from the generated time section of the surfaces. In this study, 3-D 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 integrated processes involed data loading, frequency analysis, well correlation and top picks, spectrum analysis, fault mapping and horizon picking, time surface generation, attribute analysis as well as velocity modelling and depth surface positioning/error correction. Results of the study revealed two horizon of interest, B1 and B6 which results from the synthetic and seismic tie. These were identified and mapped, and gave good attribute signatures (i.e. amplitude) for fluid content which is consistent and in conformity with the correlation. This study have shown that velocity modelling is an essential important ingredients in interpretation of seismic data for proper and true depth positioning which further reduces the risk involved in depth estimation and well development. More so, average cube velocity model amongst others proved better due to it minimal error margin from the well top, further confirming the importance of proper velocity modelling for accurate depth conversion and determination.

Key words: 3-D model · Faults · Velocity model · Structural geometry · Western Niger Delta

INTRODUCTION

The 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 [1-4]. Seismic velocities are important in accurate and precise determination of dynamic time corrections, indications of changes in lithology, porosity and pore fluid [5, 6].

Nigeria as a nation has several sedimentary basins amongst which, the Niger Delta located at the southern part of Nigeria, is the most active and sought after basin, due to its proliferation in hydrocarbon habitats and it's position (both onshore and offshore), irrespective of its challenges which could be syn-depositional, turbulence, etc. The Niger Delta, ranks as one of the major hydrocarbon provinces of the world with ultimate recovery presently estimated at close to 40 billion barrels, with its gas potentials gradually assuming greater importance, and may eventually equal or even outstrip oil as revenue sources having been estimated at over 40 billion cubic feet reserves. Niger Delta surface area is over 300,000 km^2 which is small when compared to other petroleum provinces of the world, and has varying sizes of reservoir thickness and volumes.

The 3-D seismic data acquisition started with Nun River in 1986 by SPDC, lead to the realization of the enormous advantage that 3-D data sets gave, in terms of areal coverage, and accuracy in positioning, exploration, and appraisal wells, as well as in assisting field development. The use of 3-D, showeda significant change to field development and reserves figures, leading to more effective planning for appraisal and development drilling. A lot of geological, geophysical and geochemical data has been accumulated over the 60 years of exploration and production in Niger Delta, and considerable declassification of such data has enabled the broad reconstruction of the petroleum geology of the Niger Delta, both onshore and offshore [7]. Without

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further enumerating on the origin of hydrocarbon in Niger Delta, which is believed to have originated from sedimentary rocks containing organic matter, the hydrocarbon of Niger Delta are generated by the source rock (shale's of Akata Formation) before being moved or transferred to the reservoir rocks (Agbada Formation) along fault and carrier beds mostly accumulated by structural and stratigraphic traps [8]. Three distinct hydrocarbon systems in southern Nigeria (offshore/Onshore) - Lower Cretaceous, Upper Cretaceous-Lower Paleocene, and Tertiary are recognized on the basis of geochemical data [9]. The Tertiary system is smaller than the Upper Cretaceous-Paleocene system, and is predominant of gas prone source rock [10]. The distribution of hydrocarbon is very complex, and so the need for velocity modelling, to further enhances the recoverability.This study therefore, is constrained to 3D seismic interpretation workflow using the petrel software version 2013, with the ultimate goal of detecting hydrocarbon accumulations zones; delineate their structural extent, and their true position in "TM" field.

Location of the Study Area: The study area, "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.

The Niger Delta region as a Tertiary delta framework covers around 300,000 km^2 and incorporates the geologic degree of the Tertiary Niger Delta (Akata-Agbada) Petroleum System. It is situated on the West African mainland edge at the peak of the Gulf of Guinea [11]. Hydrocarbon have been found in majority of the depobelts of the Niger Delta sandstone having a place with the fundamental deltaic arrangement (the 'paralic grouping' of regular utilization). The majority of the accumulations happen in roll-over anticlines in the hanging-walls of growth faults, where they may be caught in both dip and fault terminations.

Tectonics and Structures: The structural system of the mainland edge along the West Coast of tropical Africa is controlled by Cretaceous break zones communicated as trenches and edges in the profound Atlantic. The break zone edges subdivide it into individual basins, the Cretaceous Benue-Abakaliki trough, which cuts far into the West African shield. The trough is a fracture triple intersection connected with the opening of the South Atlantic. In this area, fracturing began in the Late Jurassic and persevered into the Middle Cretaceous [13].

In the Niger Delta region, breaking decreased out in the Late Cretaceous. In the wake of an end to the cracking, gravity tectonics turned into the essential deformational process. Shale versatility instigated inner twisting and happened in light of two procedures [14]. First, shale diapirs formed from loading of poorly compacted, over pressured prodelta and delta-slope clays (Akata Formation) with the aid of the better density delta-front sands (Agbada Formation). Secondly, slope instability came about because of a lack of lateral basin ward support for the underneath-compacted delta slope clays (Akata Formation, Figure 2). For any given depobelt, gravity tectonics finished before deposition of the Benin Formation, and is communicated in complex structures, including shale diapirs, roll-over anticlines, collapsed increased fault crest, consecutive elements, and steeply plunging, firmly separated flank faults [15]. These faults for the most part balance diverse parts of the Agbada Formation and levelled into separation planes close to the top point of the Akata Formation [16].

The most striking basic components of the Cenozoic Niger Delta complex are the syn-sedimentary structures which twist the delta generally, underneath the Benin sand facies. The majority of the faults are listric normal faults; other incorporated structures are growth faults, flank faults, counter provisional faults, antithetic faults and broken down peak structure (Figure 3). These structures shape the significant hydrocarbon catching systems in Niger Delta.

Methods of Study

Data Loading: All the given data both logs and seismic were imported into the petrel after corrections, editing, and creation of the project in the software 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

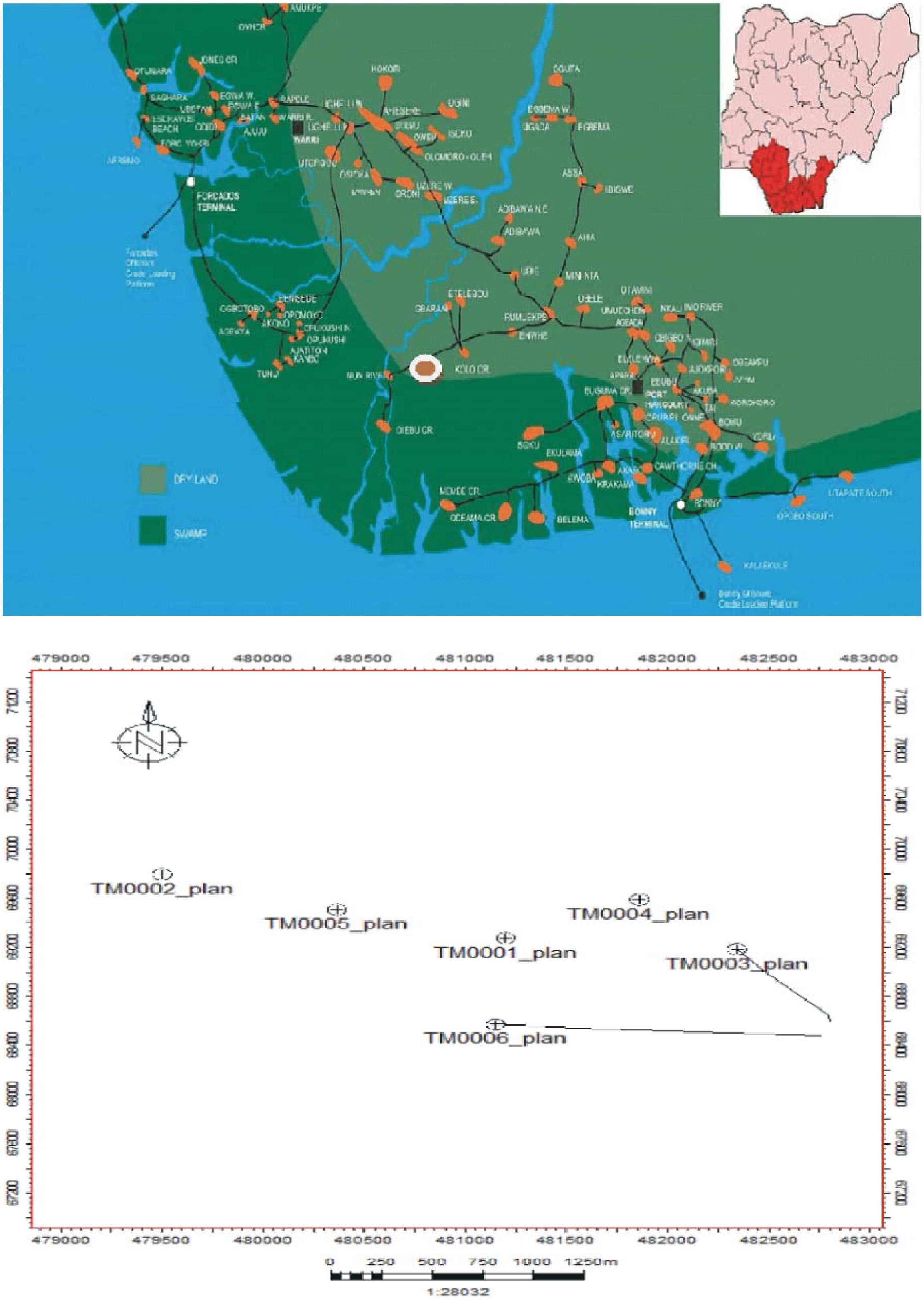


Fig. 1: Niger Delta map adopted from Google and the study area with six wells adopted from Petrel

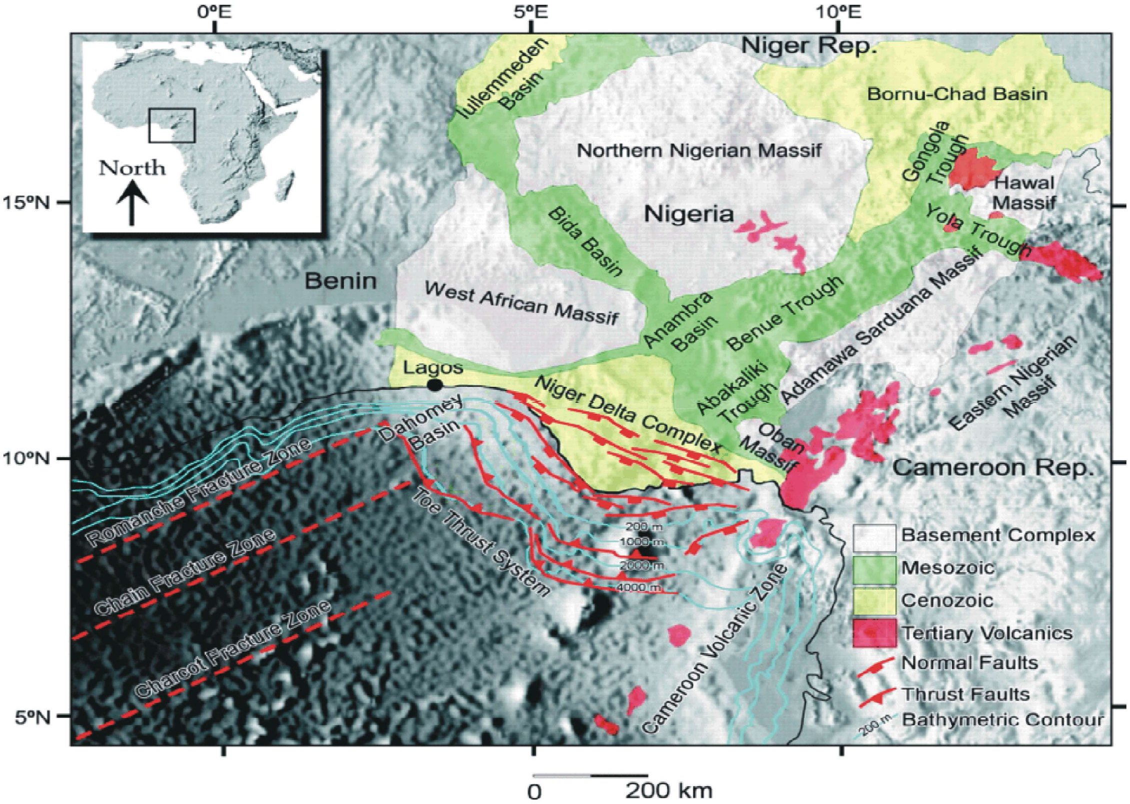


Fig. 2: Niger Delta district demonstrating the fundamental sedimentarybasins and tectonic features [12].

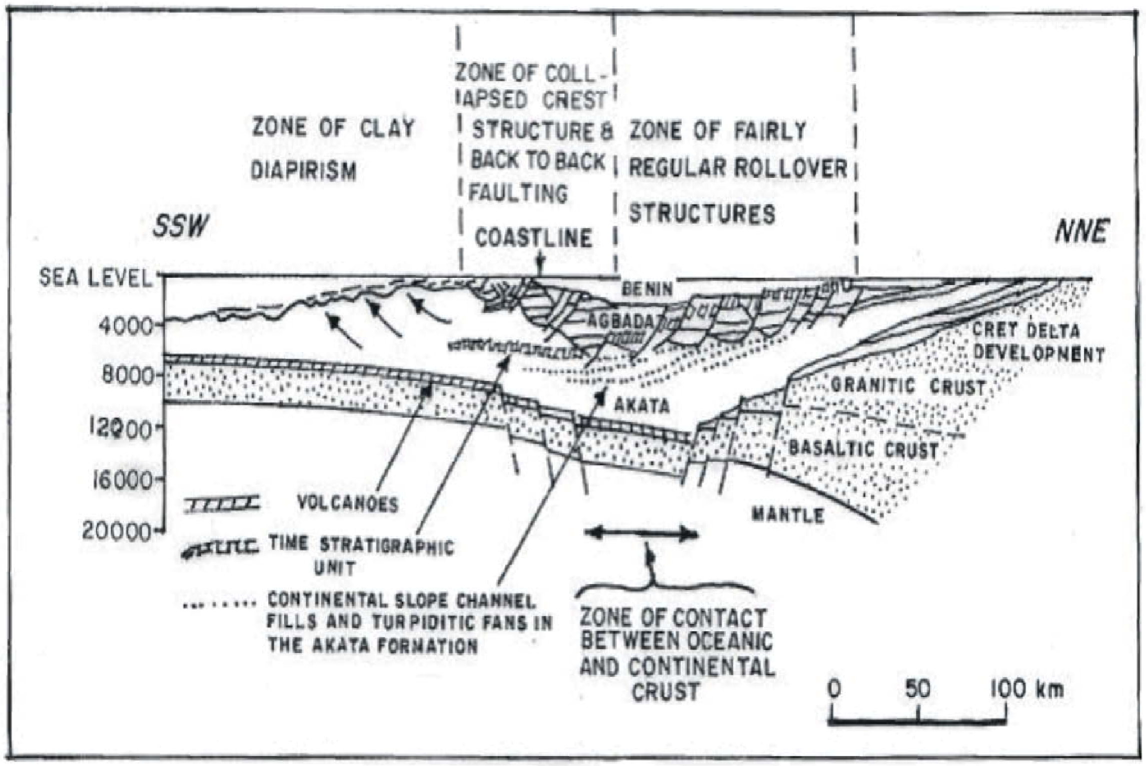


Fig. 3: Schematic Dip Sections of the Niger Delta structures and traps [1].

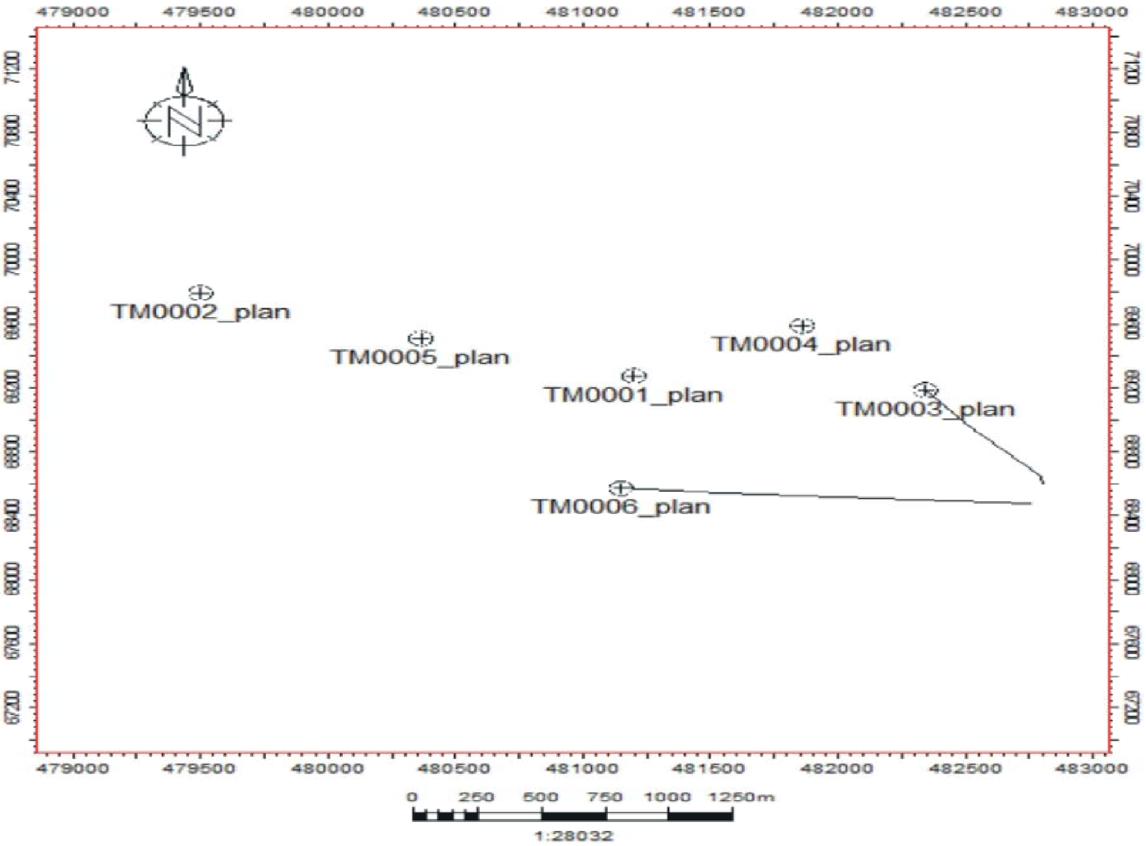


Fig. 4: Base map showing location of the six wells on the map.

imported respectively after correction, which are now in ASCII format. The check shot was takenfrom TM0001 well. The location of the loaded logs with respect to the project map is as shown in Figure 4, and the wells containing Gamma-Ray logs in Figure 5.

Importation of Seismic Data: Here a seismic main folder and seismic survey were inserted in the input pin of petrel, and the seismic data imported into the folder with the right format of SEG-Y import preset parameters, and was scanned afterwards before realizing. Once this was done the seismic data appeared in the input pin with inline, cross line and z-line (3D Format).The imported seismic cube helps to quality-check (QC) and understands the frequency bandwidth of the seismic, and the dominant frequency that can resolve the layers as shown in the figure 6 below. This QC is carried out in Kingdom Suite interpretation software and it helps to give information on the frequency needed for well to seismic calibration.

Lithology Delineation and Well Correlation: The process of well log correlation was based on litholog (Lithostratigraphic Correlation), using the Gamma Ray log of the given wells (Figure 5). Well log correlation process involves the display of the 6 given wells and the logs in a well section window and the creation of marker picks (well tops) using similar log motifs.

Synthetic Seismogram and Seismic To Well Tie: Well ties are completely crucial part of modelling and interpretation. They provide a method of successfully identifying horizons to pick out, and estimating the wavelet for inverting seismic data to impedance. Well-seismic ties allow well data,in units of depth, to be correlated to seismic data, in units of time. This allows us to relate horizon tops identified in a well with specific reflections on the seismic section. There are several methods for carrying out the well to seismic tie. Two methods were used (Generation of synthetics seismic and tying it to seismic volume, and use of well tops). Sonic and density logs are used to generate a synthetic seismic trace. The synthetic trace is compared to the real check shot. In petrel the well to seismic tie was done using the following procedures:

- Generation of synthetic seismic
- Synthetics to seismic volume tie

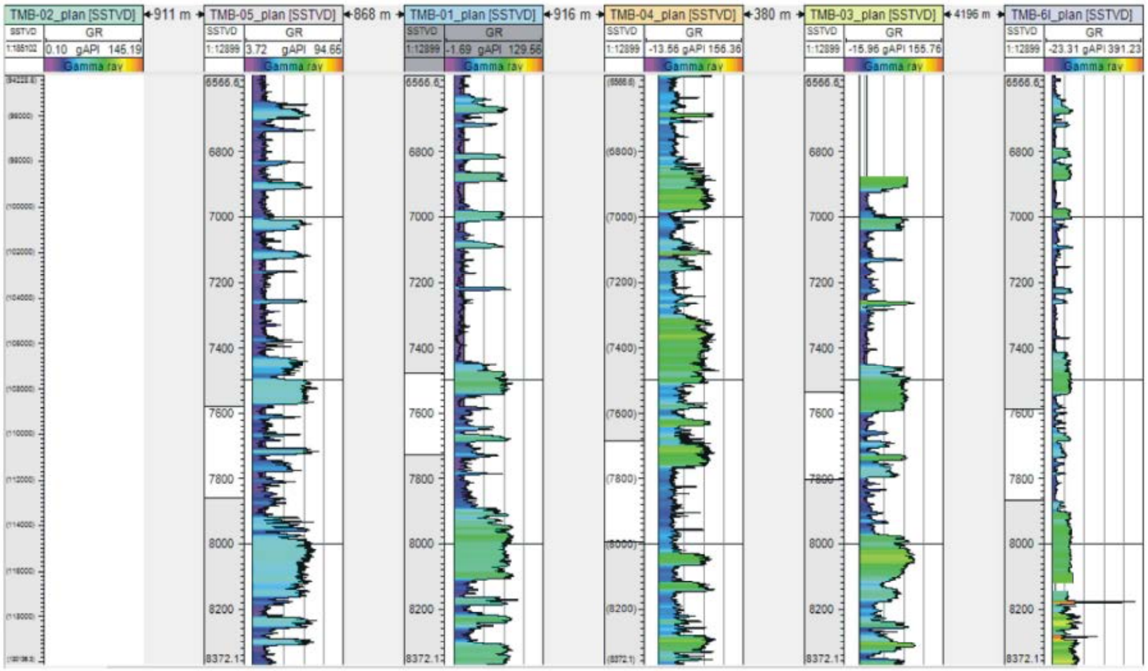


Fig. 5: Wells of TM0002, TM0005, TM0001, TM0004, TM0003, TM0006 displayed on a Petrel well section window with Gamma Ray log Reflections.

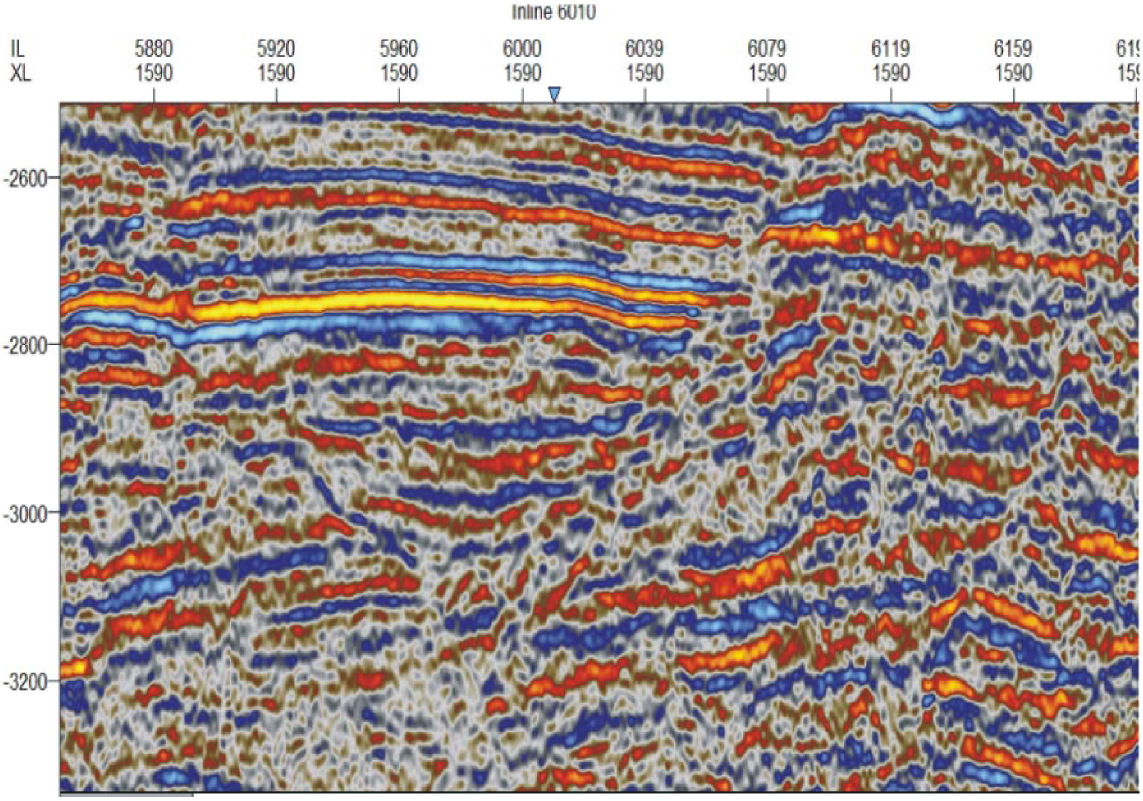
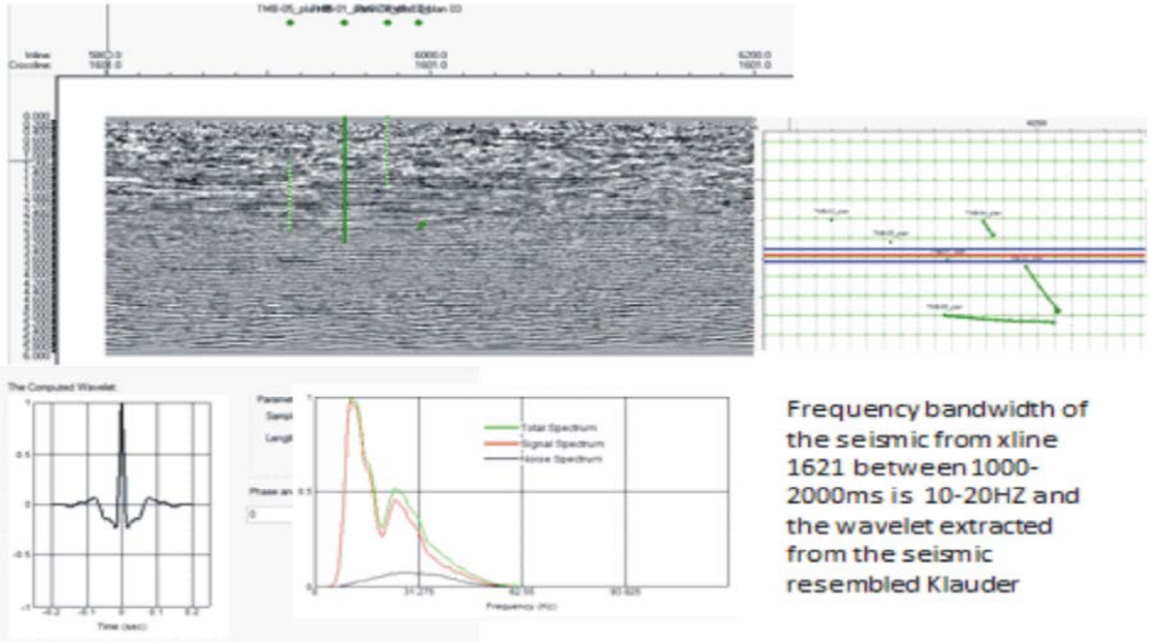


Fig. 6: Seismic Time inline 6010 showing growths fault and its associate rollover anticline, and collapse stress pattern typical of Niger Delta.



Frequency bandwidth of the seismic from xline 1621 between 1000-2000ms is 10-20HZ and the wavelet extracted from the seismic resembled Klauder

Fig: 7: Frequency Bandwidth Check from the seismic data provided.

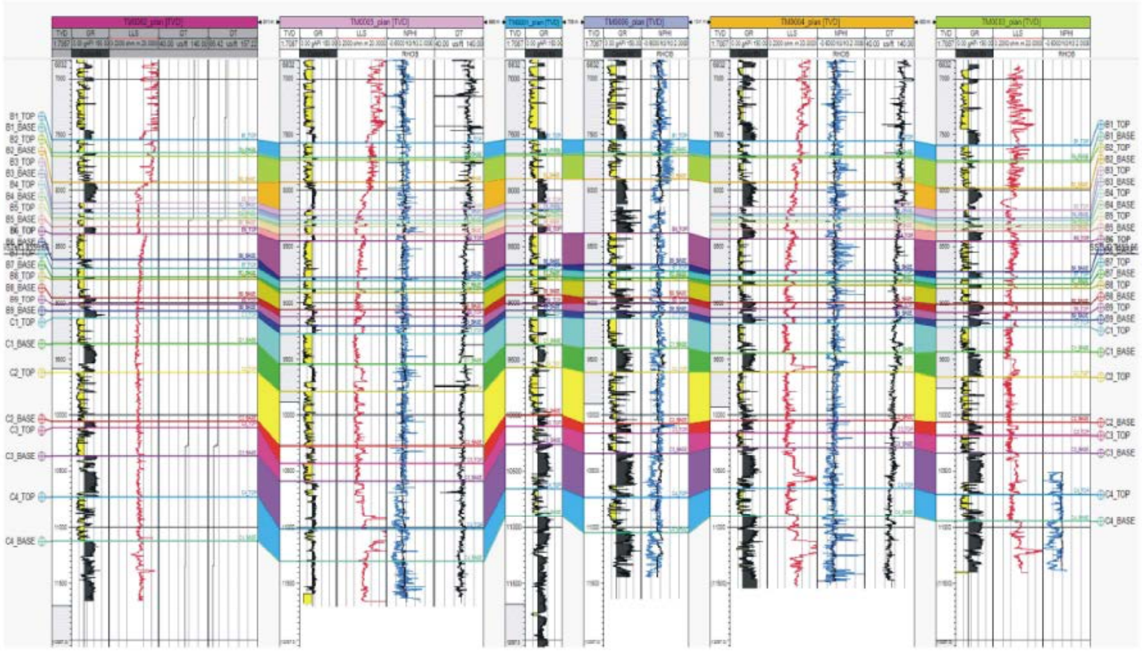


Fig. 8a: Lithology correlation of the six wells

The synthetics tool that understands stratigraphy in the process pin in petrel was selected and the various parameters for generating synthetics and tying it to seismic were inputted using check shots well TM0001. Well TopB1 shows that the synthetic generated seismogram tied with seismic volume as expected (Figure 8b).

Fault Interpretation: Faults were interpreted on seismic volume primarily based on the subsequent criteria:

- Reflection discontinuity at fault plane.
- Vertical displacement of reflection.
- Abrupt termination of seismic events/ truncations.

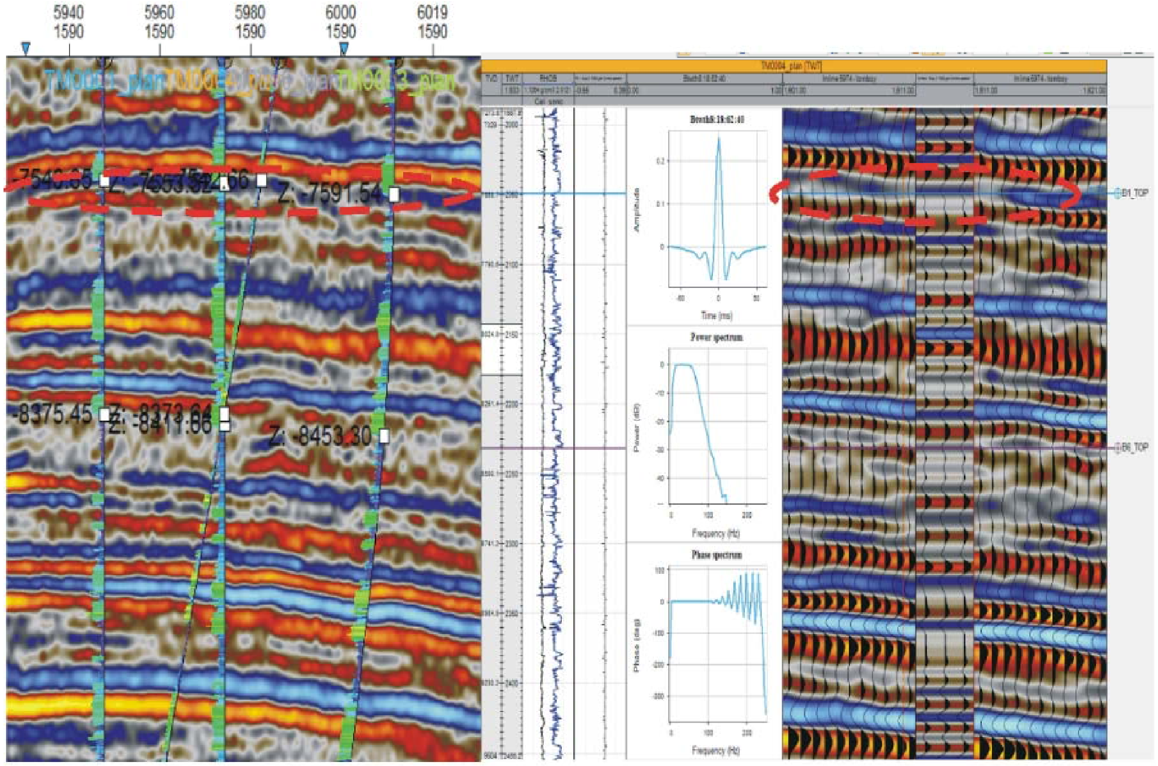


Fig. 8b: Sonic, Neutron; Synthetic seismic and Seismic volume tied at the well tops B1 and B6

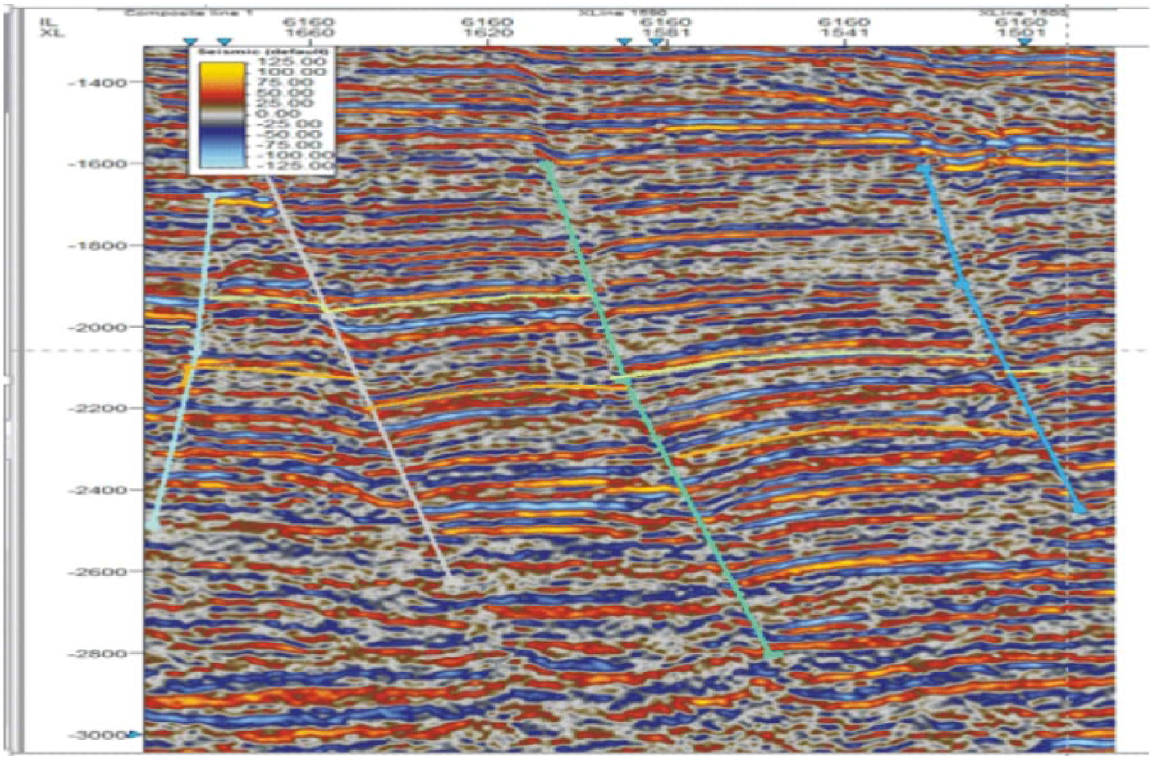


Fig. 9: Seismic volume showing the structural trend and the horizon of “TM” Field.

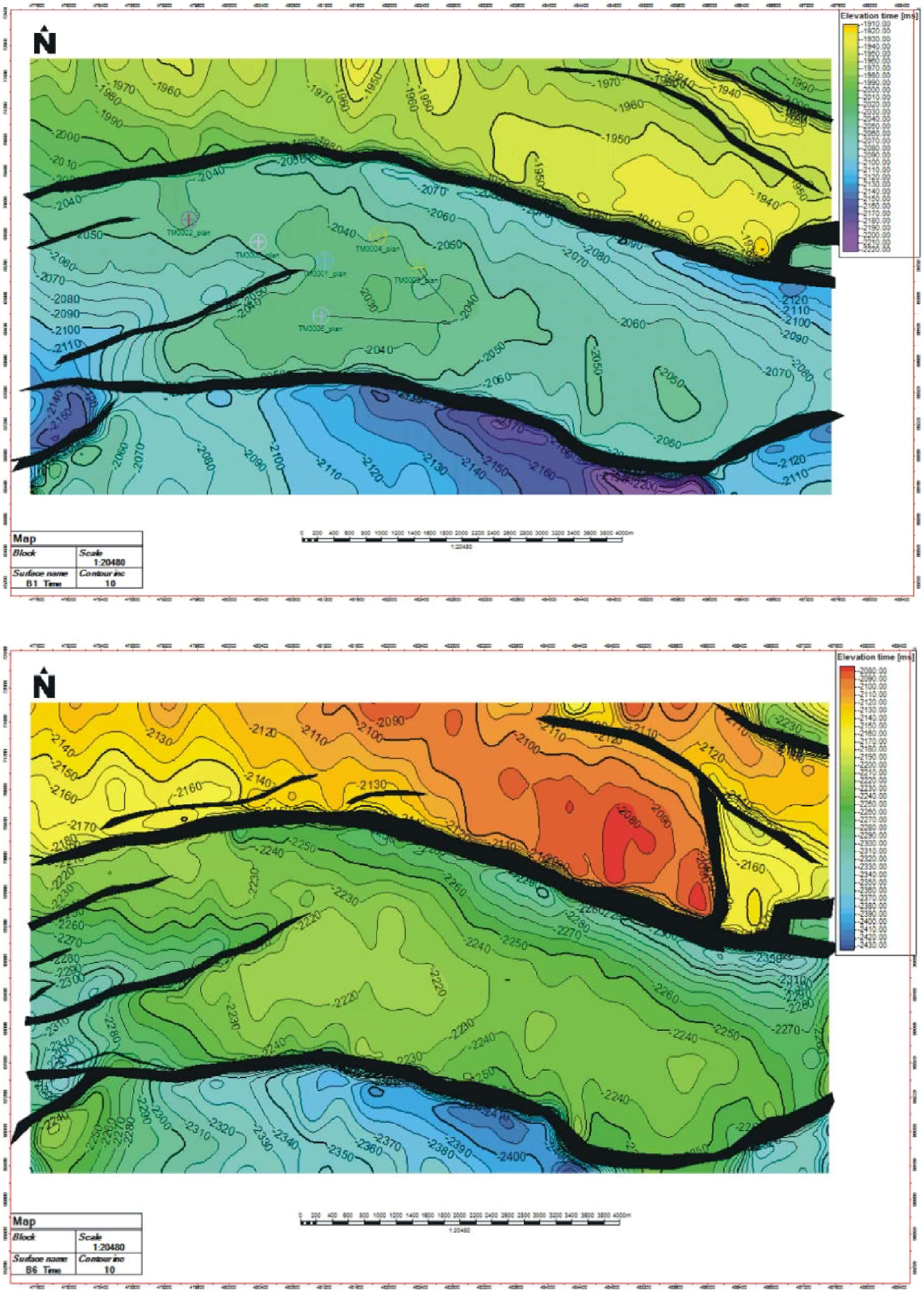


Fig. 10: Time surface maps B1 and B6 before correction, showing rollover anticline structure surfaces

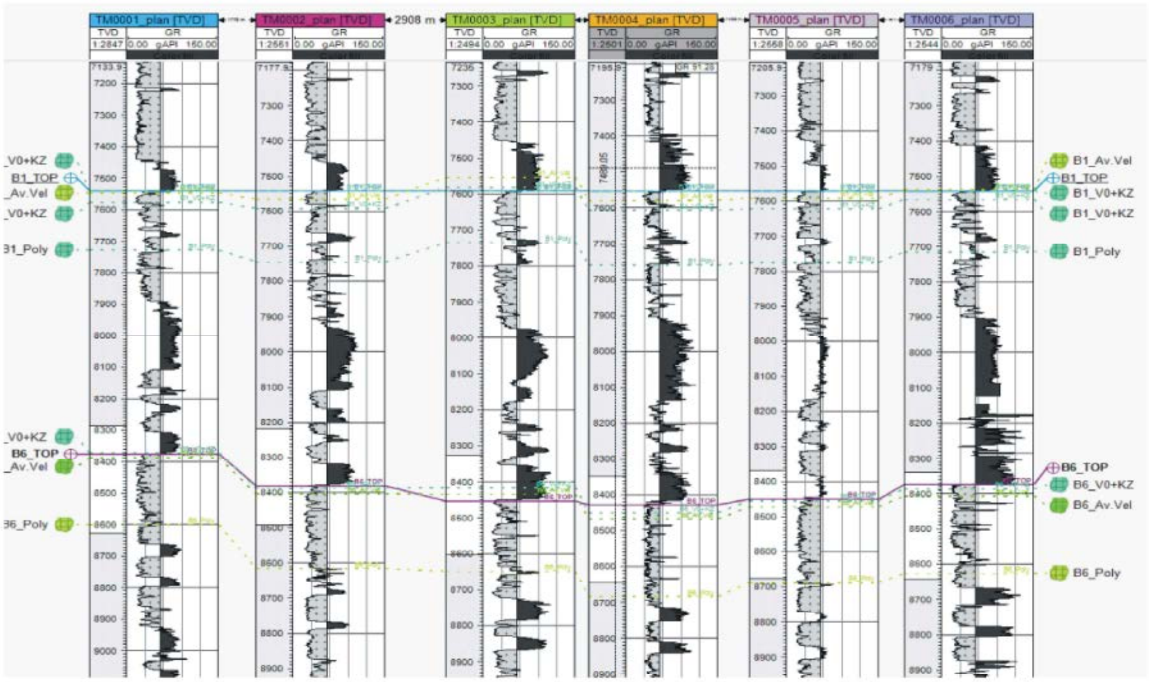


Fig. 11: Error analysis of depth conversion with different velocity models

Fault interpretation in this project was done by drawing of fault segments, on areas where the above named fault identification criteria were seen on the seismic volume. Major boundary growth faults trending NS-WE in this seismic volume were interpreted and the associated synthetic and antithetic faults with its associated collapse crest (Figure 8b).

Horizon Picking: A horizon represents isochronous geologic time units. It is the interface between two distinct rock layers. It is associated with non-stop and dependable reflection on the sections that appear over a large area. For this study, 2 key horizons (Horizon A, Horizon B) of interest where picked using well tops as a guide based on high resistivity responds and corresponding to Density Neutron responds in zones identified. The horizons were picked manually at 10 line-intervals on both inline and cross line. The fault line and fault type (Antithetic and Synthetic faults) were respected as the picking was done (Figure 9).

Time and Depth Map Generation

Time Map

The surfaces were then generated with the make/edit surface tool under utilities, where the created boundary and picked horizon were inputted and various settings like the geometry and algorithm were set to the right parameter and changes implemented. This was done for the two horizon picked, and the time are displayed in map window (Figure 10).

Time to Depth Conversion: This is a process that involves the conversion of the time surface map to depth map. For achievement of converting of the time maps to depth, a time depth relationship was created which is the development of a velocity model. A velocity model was developed using the make velocity model under geophysics in the process window in petrel and the created surfaces were inputted and corresponding well tops with the velocity constant to use in the making of the velocity model pop up box and apply. The velocity models used are showed in Figure 11. Two Depth surface map was generated as showed in Figure 12.

Seismic Interpretation

Fault and Horizon Mapping

The seismic data is a zero phase, SEG polarity data with a likely boundary growth fault trending NS-WE and associated synthetic, antithetic faults and collapse crest structures. The fault lines observed on the seismic data is more than seven. Two horizons (horizon B1, horizon B6) identified in the well were picked using well top time and were manually tracked in 3D through the volume. The horizon picks are on the crest of rollover anticline corresponding with the trough amplitudes.

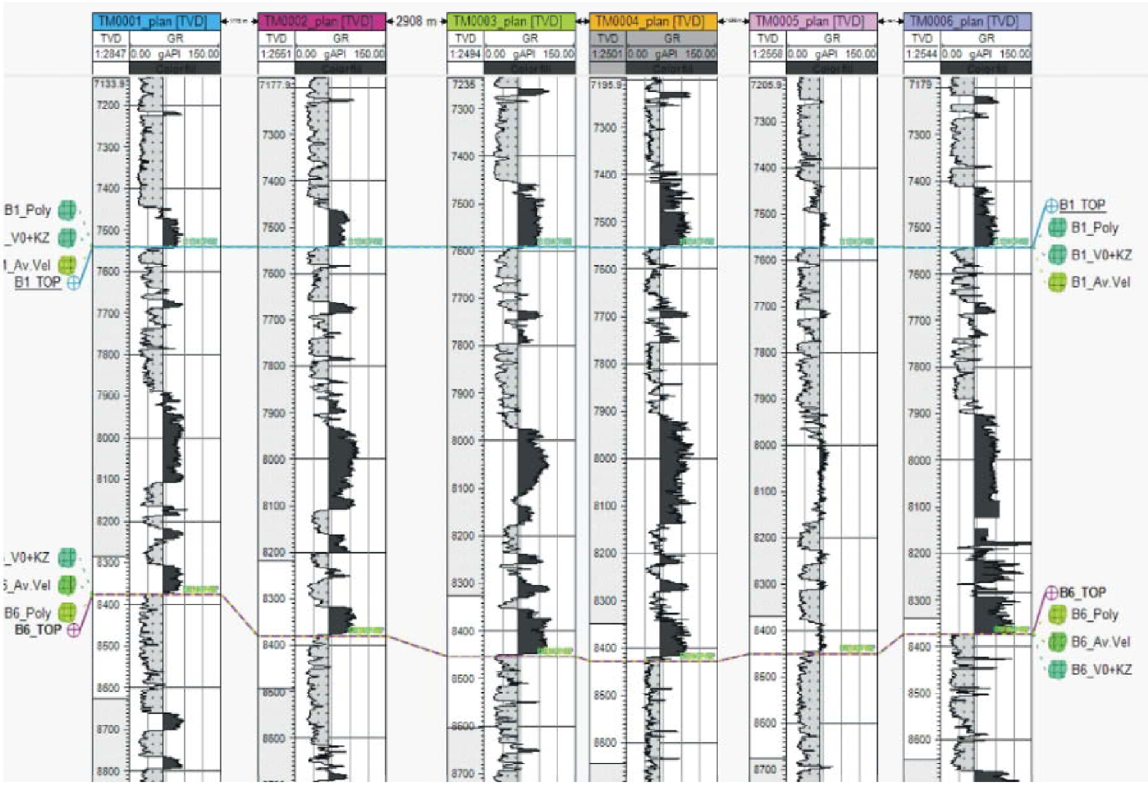


Fig. 12: Corrected B1 & B6 depths matching with the well tops

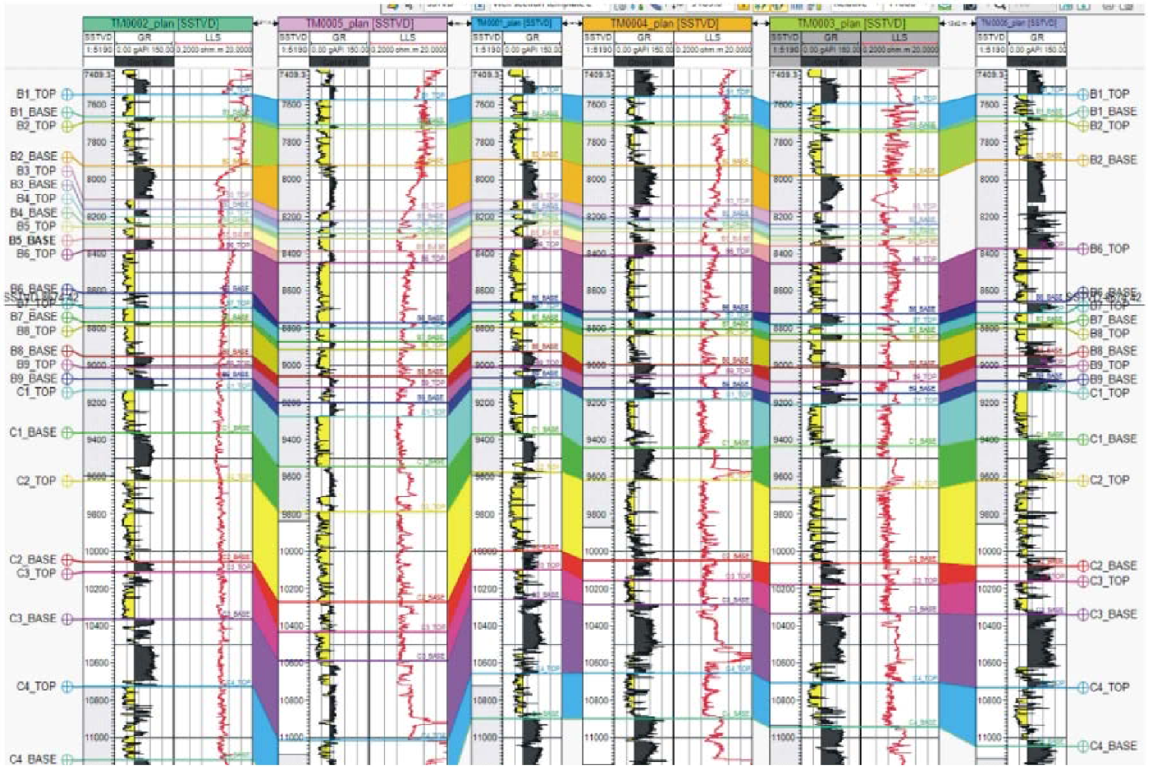


Fig. 13: Well log analysis and correlation showing the ten well tops identified

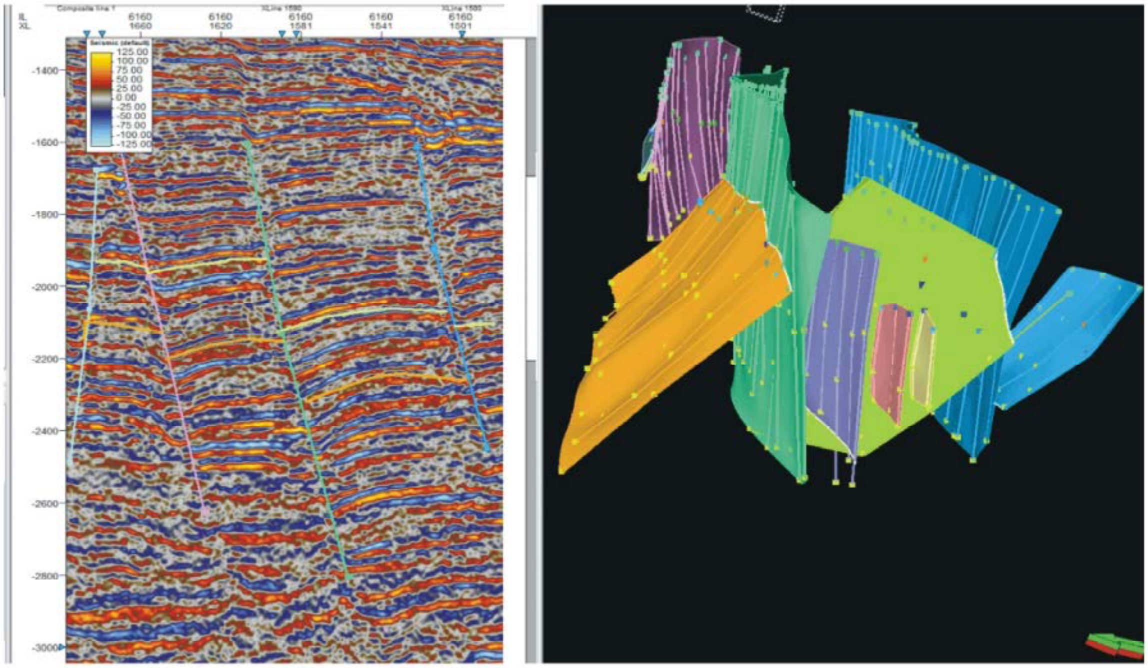
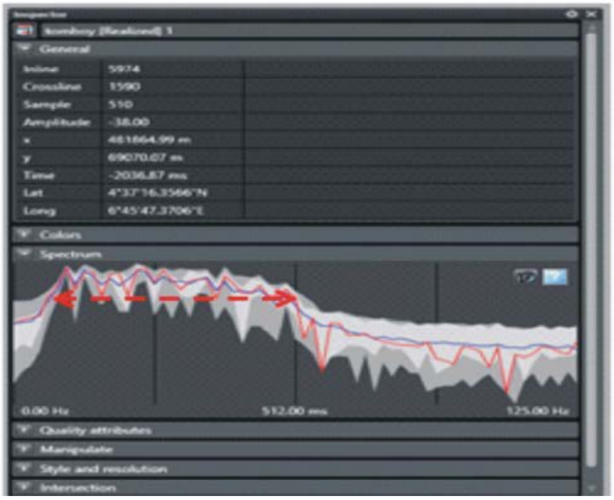


Fig. 14: Fault/Horizon interpretations and the fault model



Inline	5974
Crossline	1590
Sample	510
Amplitude	-38.00
x	481864.99 m
y	69070.07 m
Time	-2036.87 ms
Lat	4°37'16.3566"N
Long	6°45'47.3706"E

Dominant frequency at seismic loop corresponding to B1 well top is 8hz to 62 Hz which is useful for wavelet generation

Fig. 15: Frequency Spectrum Analysis Within well Top B1 in Well 4

Seismic Frequency Analysis: The seismic frequency analysis started with the data frequency bandwidth check, which enables us to extract the appropriate wavelet needed for the generation of synthetic seismograph of wells-to-seismic tie (Figure 16). From the many gates (ranges) of frequency bandwidth tested, it was observed that the best frequency bandwidth gotten from the data is within the range of 8-62Hz, which gave me a Klauder Filter wavelet resemblance (one of the known Filter wavelets), as can be seen in the spectrum analysis (Figure 17).

The generated synthetic seismograph from the wells was then tied alongside the reflection from the main seismic volume to have a perfect match of reflection in relation with the identified well tops of interest, after which we transpose the seismic volume with the well tops alongside the generated synthetic seismograph, to identify the horizon of interest B1 and B6 in the seismic volume (Figure 5), for onward mapping of the identified horizons with reservoir potentials from the wells earlier correlated. An isochron map (time map) of the horizons B1

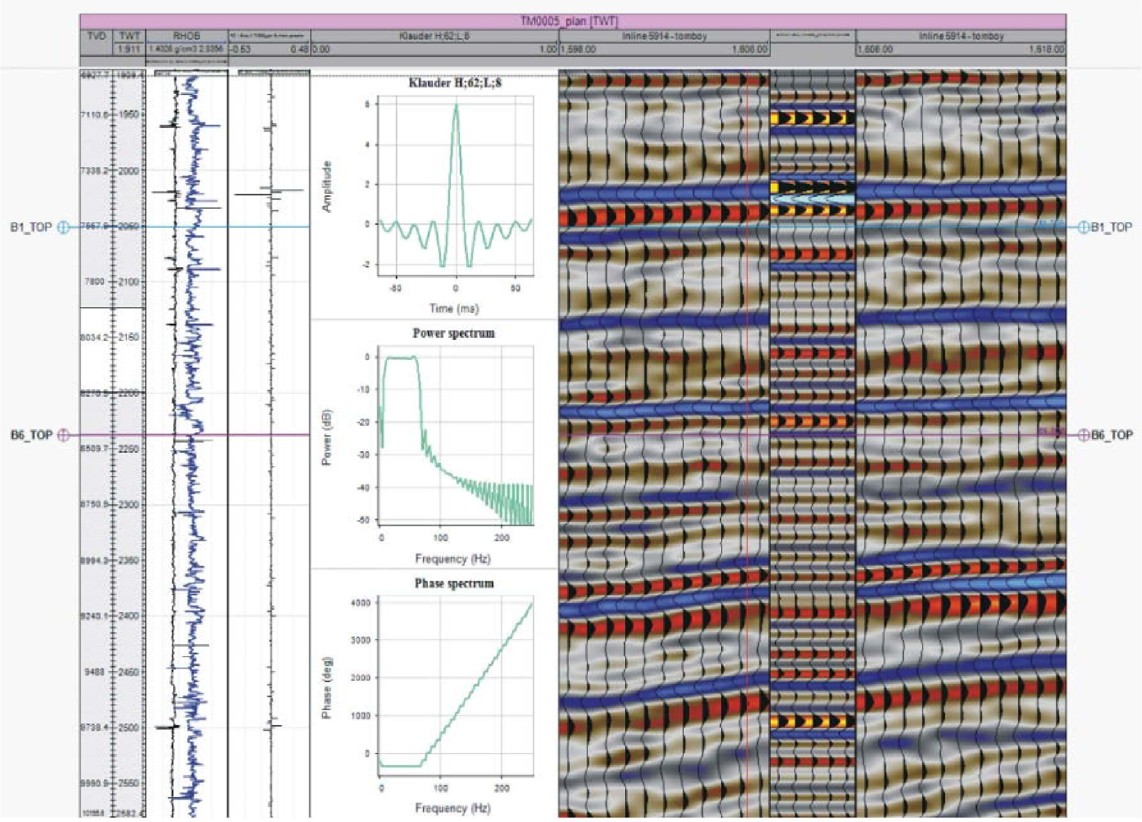


Fig. 16: Synthetic seismographs generated using the Klauder wavelet

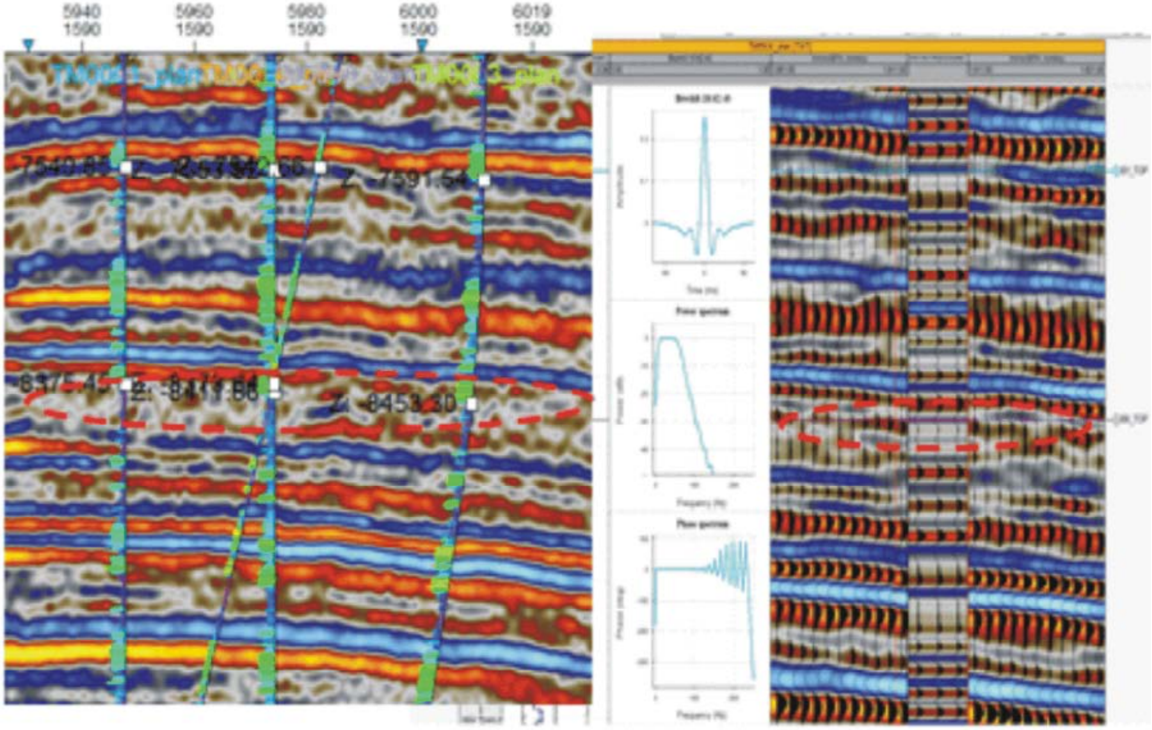


Fig. 17: Seismic to well tie and the generated synthetic seismograph tied to well tops B1 and B6.

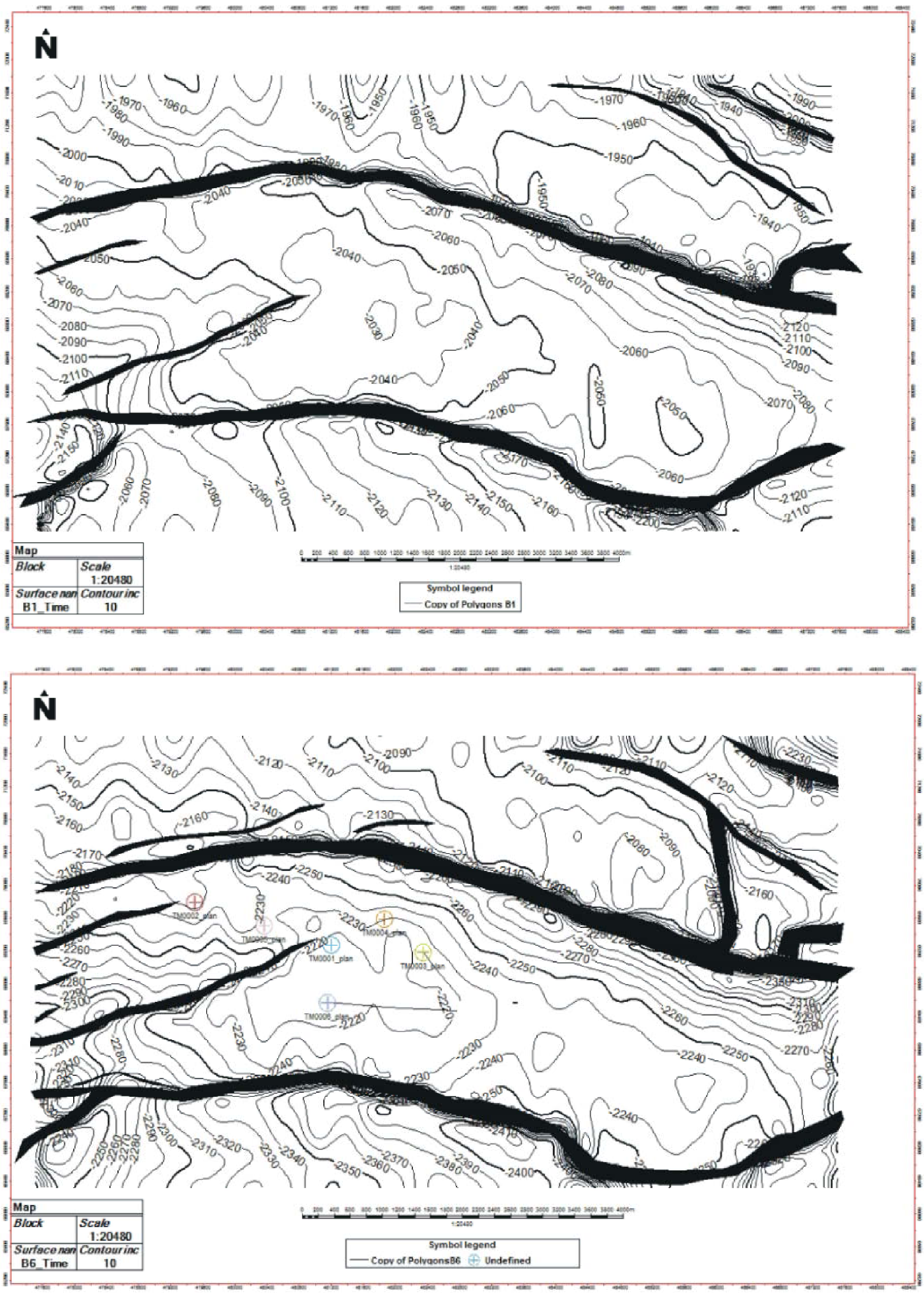


Fig. 18: Time surfaces for Horizon B1 (A) and B6 (B).

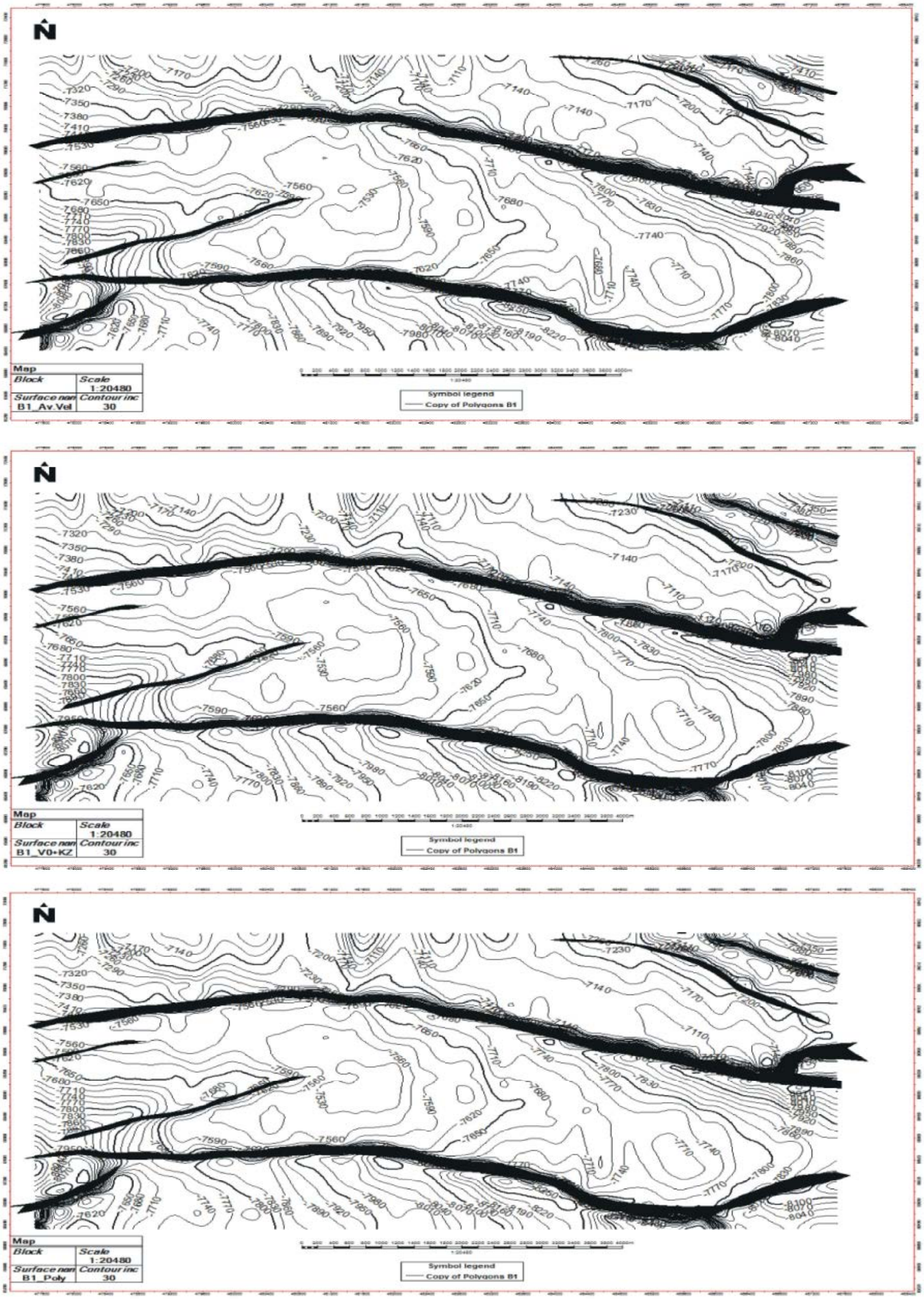


Fig.19: Depth surfaces for Horizon B1 using the three different velocity models

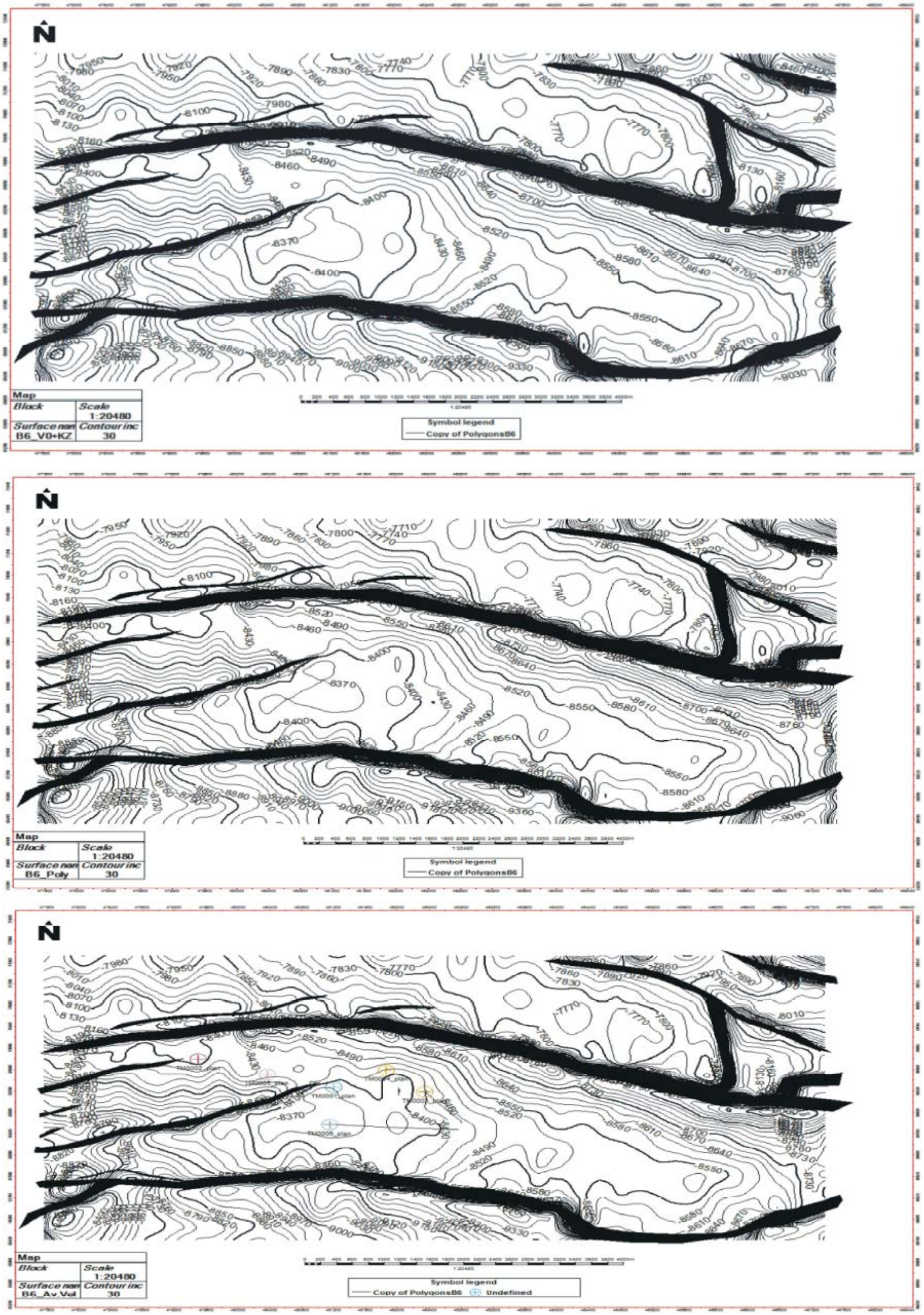
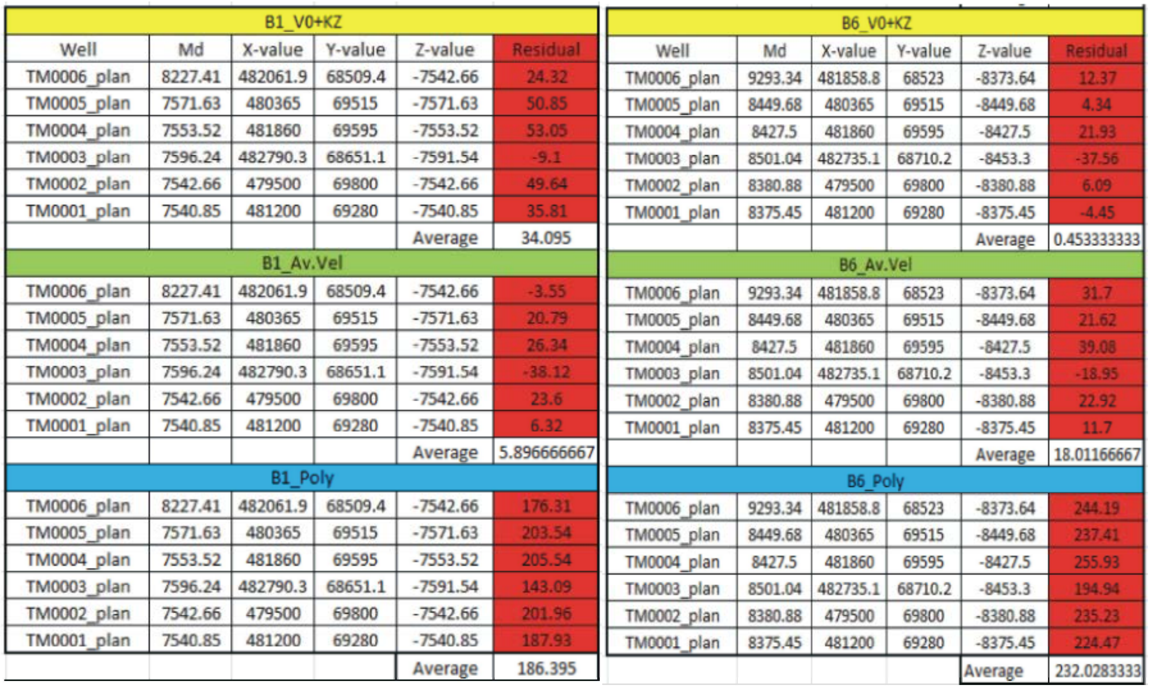


Fig. 20: Depth surfaces for Horizon B6 using the three different velocity models



B1_V0+KZ					
Well	Md	X-value	Y-value	Z-value	Residual
TM0006_plan	8227.41	482061.9	68509.4	-7542.66	24.32
TM0005_plan	7571.63	480365	69515	-7571.63	50.85
TM0004_plan	7553.52	481860	69595	-7553.52	53.05
TM0003_plan	7596.24	482790.3	68651.1	-7591.54	-9.1
TM0002_plan	7542.66	479500	69800	-7542.66	49.64
TM0001_plan	7540.85	481200	69280	-7540.85	35.81
				Average	34.095
B1_Av.Vel					
TM0006_plan	8227.41	482061.9	68509.4	-7542.66	-3.55
TM0005_plan	7571.63	480365	69515	-7571.63	20.79
TM0004_plan	7553.52	481860	69595	-7553.52	26.34
TM0003_plan	7596.24	482790.3	68651.1	-7591.54	-38.12
TM0002_plan	7542.66	479500	69800	-7542.66	23.6
TM0001_plan	7540.85	481200	69280	-7540.85	6.32
				Average	5.896666667
B1_Poly					
TM0006_plan	8227.41	482061.9	68509.4	-7542.66	176.31
TM0005_plan	7571.63	480365	69515	-7571.63	203.54
TM0004_plan	7553.52	481860	69595	-7553.52	205.54
TM0003_plan	7596.24	482790.3	68651.1	-7591.54	143.09
TM0002_plan	7542.66	479500	69800	-7542.66	201.96
TM0001_plan	7540.85	481200	69280	-7540.85	187.93
				Average	186.395

B6_V0+KZ					
Well	Md	X-value	Y-value	Z-value	Residual
TM0006_plan	9293.34	481858.8	68523	-8373.64	12.37
TM0005_plan	8449.68	480365	69515	-8449.68	4.34
TM0004_plan	8427.5	481860	69595	-8427.5	21.93
TM0003_plan	8501.04	482735.1	68710.2	-8453.3	-37.56
TM0002_plan	8380.88	479500	69800	-8380.88	6.09
TM0001_plan	8375.45	481200	69280	-8375.45	-4.45
				Average	0.453333333
B6_Av.Vel					
TM0006_plan	9293.34	481858.8	68523	-8373.64	31.7
TM0005_plan	8449.68	480365	69515	-8449.68	21.62
TM0004_plan	8427.5	481860	69595	-8427.5	39.08
TM0003_plan	8501.04	482735.1	68710.2	-8453.3	-18.95
TM0002_plan	8380.88	479500	69800	-8380.88	22.92
TM0001_plan	8375.45	481200	69280	-8375.45	11.7
				Average	18.01166667
B6_Poly					
TM0006_plan	9293.34	481858.8	68523	-8373.64	244.19
TM0005_plan	8449.68	480365	69515	-8449.68	237.41
TM0004_plan	8427.5	481860	69595	-8427.5	255.93
TM0003_plan	8501.04	482735.1	68710.2	-8453.3	194.94
TM0002_plan	8380.88	479500	69800	-8380.88	235.23
TM0001_plan	8375.45	481200	69280	-8375.45	224.47
				Average	232.0283333

Fig. 21: Residual analyses for the three different Velocity models of B1 and B6 depth map

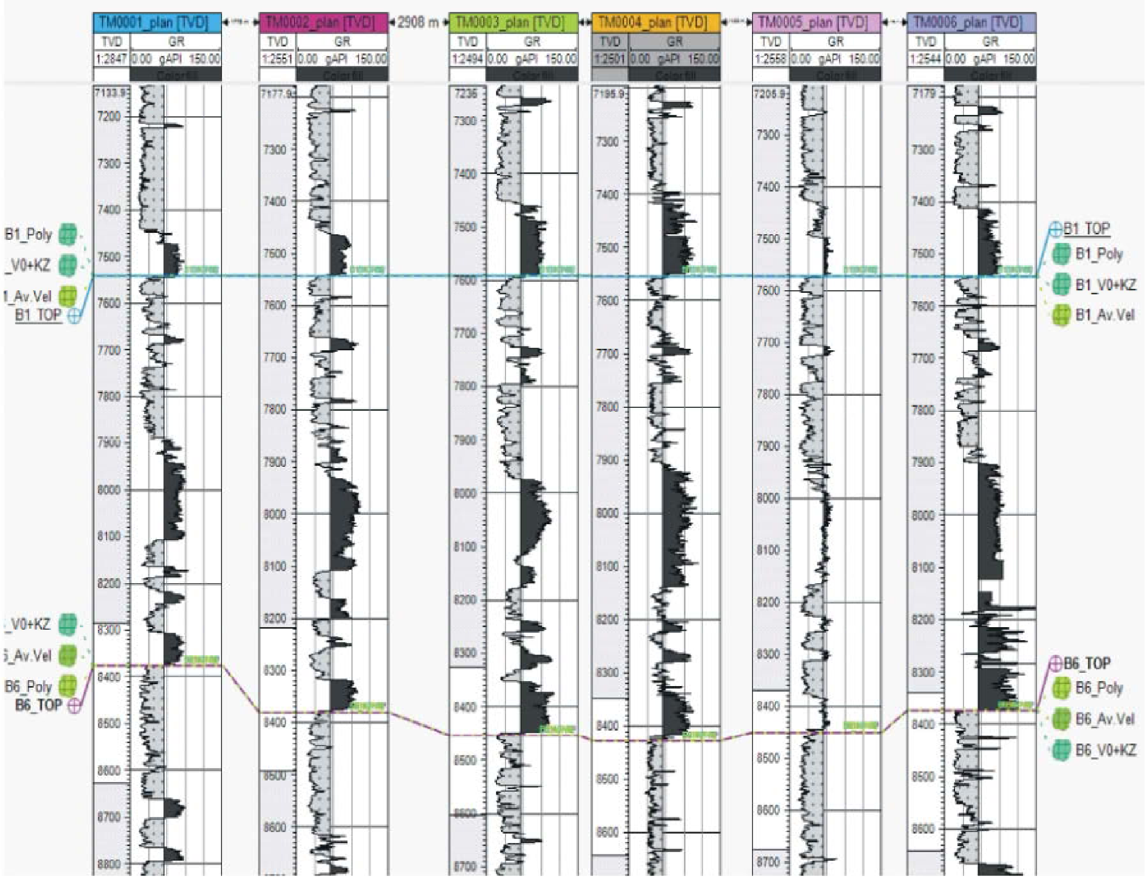


Fig. 22: Corrected B1 & B6 depths matching with the well tops

and B6 were then generated after mapping (Figure 6) which is in time, needed to convolve with the velocity model to generate the isopach map (Depth map). Amplitude and Root Mean Square attributes was then carried out on the horizons of interest to ascertain the potentiality of the reservoir identified with hydrocarbon content as have shown by the resistivity logs and density logs during the well correction section and was found to be in conformable with the structure.

Time and Depth Surfaces: The following time surfaces were generated from the interpreted horizons:

Figure 4.8 Depth surfaces for Horizon B6 using the three different velocity models:

DISCUSSION

The corrections/adjustments in the initial depth surfaces of horizon B1 and B6 was made using the difference in residuals as shown in the error analysis (i.e. the values after corrections) to generate the actual depths and structure of the B1, B6 surfaces of the TM field (Figure 6). The uncertainties connected to interpolating velocities far from well control makes domain conversion a critical steps in the modelling process, which summarizes and assures confidence in the true depth position of these proven hydrocarbon potentials and the potential opportunities too.

The process of seismic interpretation of TM field using the average velocity cube model was more precisely accurate than the other two models as the error margins from the well top is smaller compared to others

Seismic interpretation is an art that requires skill and good knowledge in geology and geophysics, the process of evaluating and identifying reservoir zones in a field is based on the ability of the interpreter to make use of available data in interpreting various parameters with a minimal error margin. Well log interpretation was done to differentiate sand and shale with gamma log, the resistivity shows the hydrocarbon bearing sands with resistivity log and a combination of Neutron-Density was used to different fluid type.

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 (Figure 9), but with a further correction done on the depth using the residual differences, it helped to reposition the depth surfaces at its true positions as can be seen in Figure 10, 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.

CONCLUSION

Combinations of 3-D 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 3-D 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.

This study have shown that velocity modelling is an essential important ingredients in interpretation of seismic data for proper and true depth positioning which further reduces the risk involved in depth estimation and well development.Average cube velocity model amongst others proved better due to it minimal error margin from the well top, further confirming the importance of proper velocity modelling for accurate depth conversion and determination. Directly deriving from this study, the following recommendations are made:

- Further studies should be carried out on the environment of depositional and stratigraphic analysis to further confirm the depospace and the proven opportunities.
- Fault seal analysis should be carried out to determine sealing capacity and integrity of the major boundary fault that developed the rollover anticlinal trap.
- Appraisal well should be drilled and logged to the depth of reservoir B1 through B6 to ascertain the proven opportunities if possible, all things been equal.

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