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Appraisal Well Positioning Using 3D Seismic and Well Data in the 'TSL' Field, Niger Delta.

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Abstract

This study focused on the evaluation of 'TSL' Field by defining the structural geometry and reservoirs characteristics so as to identify the upside hydrocarbon potential within the field for increased hydrocarbon recovery. 3D seismic data and two well logs data were studied to determine the geophysical and petrophysical characteristics of the reservoirs. Structural configuration of the field was established by fault interpretation and horizon mapping of the top of identified reservoirs. Results showed that reservoirs penetrated by the 'TSL' Well are characterized by rollover anticline with two structural culminations (Eastern and Western). It revealed that Well TSL-01 penetrated the Western culmination at the flank while suggesting a likely exploratory potential at the Eastern culmination. Petrophysical results further suggest the presence of larger volumes of oil and gas down dip of U4 and U7 reservoirs situated between 6000 ft. and 8000ft. with appreciable porosity values range of 21% to 26%. Consequently, an appraisal well is proposed to investigate the hydrocarbon accumulation in these reservoirs at the up-dip positions for the purpose of increasing oil production. This study also proposed a well path trajectory that is made up of a vertical section of 2800 ftss, below this section is the North-East inclination of about 2.8 degrees at every 100 ft.

Keywords: *Synthetic seismogram; Seismic interpretation; Petrophysical analysis; Structural culmination*

Introduction

The hydrocarbon field undergoes five major phases, these are the Exploration, Appraisal, Development, Production and Abandonment (Singh et al. 2017). A successfully drilled exploratory Well may reveal the presence of hydrocarbon reservoir, but the level of uncertainty around exploratory Well is high. This makes taking field development decision at this stage risky (Singh et al. 2017, Gluyas 2018). Therefore, it is important to drill appraisal Well in order to reduce the impact of this risk during exploration and production of hydrocarbon fields. Appraisal Wells are the supplementary Wells drilled after hydrocarbon discovery has been made for the determination of the size of hydrocarbon deposit. They are used to decide whether and how to develop a field. Information from this Well are important to evaluate drill stem tests, build-up tests, core cuttings, fluid samples and so on (Sanei et al. 2020, Klungtvedt and Saasen 2022). An appraisal Well also gives better information about the geology of the area and also confirm the thickness of the lithologies within the field. Appraisal entails precise strategies designed to improve activities that will protect production profitability.

Demirmen (2001) used Value of Information (VOI) method to validate proposed appraisal Well locations. The VOI is the difference in the worth of developing between the project with appraisal and without appraisal Well in place. A positive VOI result implies that the benefits outweigh the costs and having appraisal Well in place is justified. A vertical appraisal Well was drilled to evaluate an exploration prospect in an onshore Niger Delta field (Anyiam et al. 2010). This Well revealed a significant oil column within the sandstone reservoir intervals. Three appraisal targets that were drilled helped to review potential development decision for maximum economic gain (Burdett and Haskett 2012). In order to reduce uncertainties in the optimization of reservoir development, Singh et al. (2017) used the value of information gathered from appraisal Well to sets the stage for successful development of the project through concept selection, detailed design and execution for maximized economics benefits under acceptable residual risks. An appraisal of potential hydrocarbon zones in Masila Oil field was performed by Alshayef et al. (2018). The investigation involved the integration of various thematic layers of multi-criteria factors affecting the hydrocarbon reservoirs using the information from both the geophysical and Wells data from the field. The outcome provided comprehensive results and assessment of hydrocarbons in the oil field which is also suitable for other areas as well. Hossain et al. (2021) focused on the identification of gas zones, reserve estimation and identification of new prospects. The potential location for drilling possible appraisal Well in gas field within the Eastern fold belt of Bengal basin was identified by integrating four wireline logs and seismic data. Oguadinma (2017) integrated high-resolution seismic data, Well logs and biostratigraphic information for the re-evaluation of the Vim field. The study revealed that the failing Wells in the field penetrated the wrong target. Also, newly identified leads showed that detailed structural analysis is crucial in hydrocarbon evaluation in the Niger Delta. In some reservoirs within the Niger Delta basin, techniques such as model-based seismic inversion methodology coupled with a Probabilistic Neural Network has been used to identify hydrocarbon reservoir zone before the positioning of appraisal Well (Edet et al. 2023). Reservoir productivity and prospect determination were also studied in the Niger Delta basin by Kudipmfon et al. (2023), Amonieah and Chukwu (2024) and Allo and Ogundimu (2024). Although, many reservoirs in the Niger delta have been found to have appreciable porosity and permeability (Opiriyabo and Mfonobong, 2024), it recommended that this field is revisited with Wells re-positioned for better hydrocarbon recovery.

The ‘TSL’ Field is a marginal field that encounter a number of hydrocarbon-bearing intervals at the shallow and deeper levels. The deeper levels have not recorded significant hydrocarbon presence due to its proximity to the Akata formation (Doust and Omatsola 1990). The shallow levels situated within the reservoir bearing Agbada formation are the main reservoir units and interest in this study. Well TSL-01 penetrated most of the shallower level reservoirs in down dip positions. Logging operations have been performed in the some of the reservoirs encountered by the Well. However, uncertainty still exist in the determination of the presence and fluid type in the up dip of the Well penetration points. This study aims to determine the optimal positioning for appraisal wells by integrating 3D seismic and well data with the least risk at the crest of the structure.

Geological setting

The Niger Delta basin (Figure 1) which covers a land area in excess of 105,000 km^2 remains the most prolific and economic sedimentary basin in Nigeria (Avbovbo 1978). It was ranked by the United State Geological Survey world energy assessment as the twelfth richest in petroleum resources, with 2.2% of the world’s discovered oil and 1.4% of the world’s discovered gas (Klett et al. 1997). According to Weber (1987), the delta is a more prolific province per unit of surface area than the Gulf Coast of Texas and Louisiana. In Niger delta, petroleum is produced from sandstones and unconsolidated sandstones of the Agbada Formation which is characterised by alternating sandstones and shale units varying in thickness from 100 to 15,000 ft (Short and Stauble 1967). The Niger Delta has been intensively investigated geologically and geophysically (Doust and Omatsola 1990, Thompson and Snedden 1999, Aizebeokhai and Olayinka 2011, Nyantakyi 2013, Akinmosin et al. 2016, Tarek 2020). The TSL Field located within the northeast–southwest trending Opuama Canyon, was discovered in 1979 by exploration Well TSL-01. The canyon, which cuts into underlying sediments up to 4500 feet (Orife and Avbovbo 1982) was developed on the Western flank of the Niger Delta in the middle of Miocene (Figures 2a and 2b). It cuts through underlying sediment at the base of the Lower Miocene to top of Oligocene (Emujakporue and Enyenihi 2020, Doust and Omatsola 1990). The Canyon was created by slumping of delta front sands leaving a large submarine canyon.

The Niger Delta is situated in the Southern Nigeria margin of the Gulf of Guinea (Figure 1) and composes of sediments deposited under marine to continental settings (Frankl and Cordry 1967). Several workers have studied the stratigraphy of the Niger delta (Kulke 1995, Whiteman 1982, Weber and Daukoru 1975, Burke 1972, Short and Stauble 1967). The 'TSL' Field is located within the Opuama Canyon. The channel cuts into underlying sediments up to 4500 feet (Igbinigie and Ogbamikhumi 2022, Orife and Avbovbo 1982). The canyon was developed in the western side of the Niger delta in the middle of Miocene, cutting the underlying sediment in the base of the lower – Miocene-top of Oligocene (Munyithya et al. 2020, Doust and Omatsola 1990). The elongated future trends from the north east to the southwest. This study area is situated within latitude $4^0$00E and $6^0$00E, and longitude $5^0$00N and $7^0$00N. Tectonically, the Niger delta can be regionally divided into the western and eastern lobes as illustrated in Figure 1, separated by the Charcot Fracture Zone (Corredor et al. 2005). The Chain Fracture zone confines the western lobe to the north while the Fernando Po fracture zone restricts the southern delta lobe to the southeast.

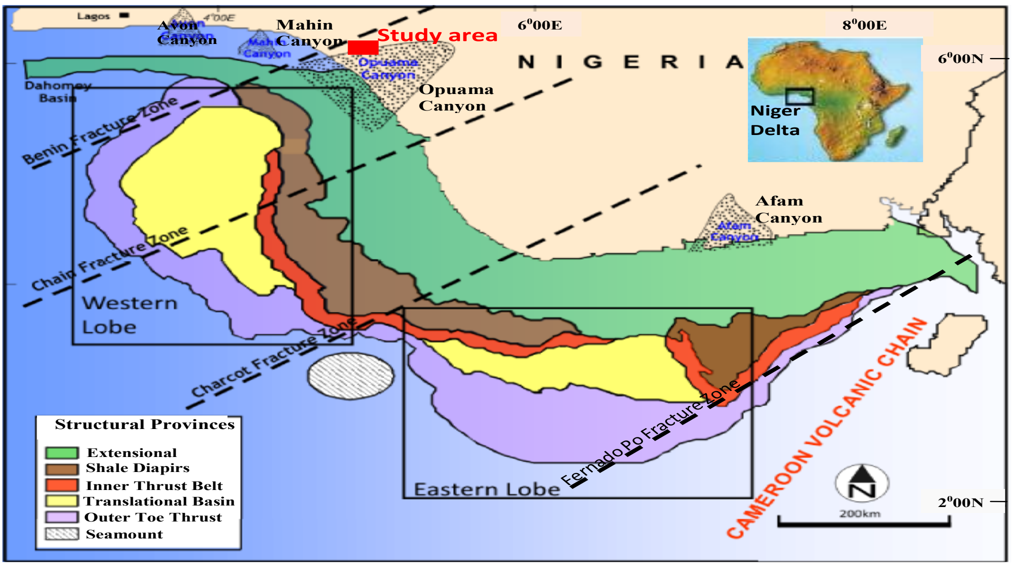

Figure 1: Map of Niger delta showing the structural provinces and the fracture zones (Modified from Matthew (Matthew et al. 2010).

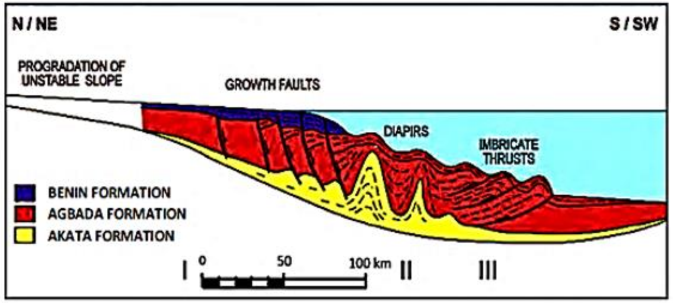	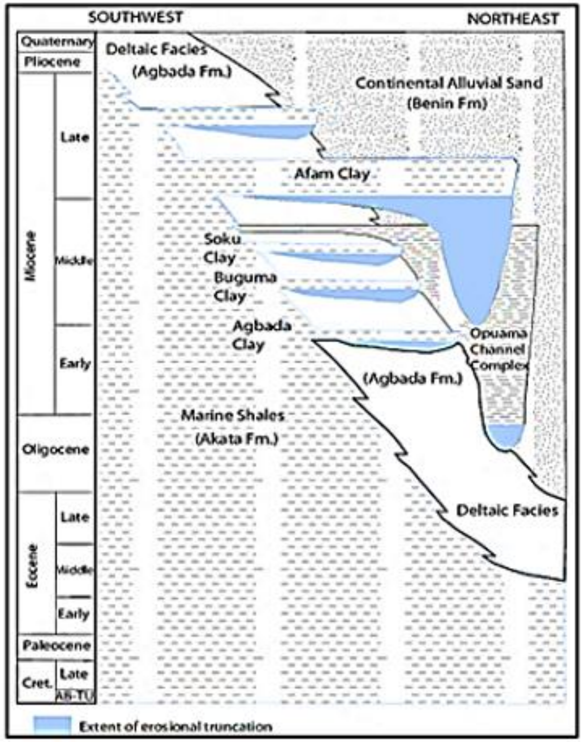
Figure 2a: Schematic cross section through the Niger Delta: I - Upper extension zone; II – Transitional zone; III – Lowere extensional zone	**Figure 2b**: Stratigaphic colum howing the fromation of the Niger Delta (Tuttle et al. 1999). Modification from Douts and Omotosola (1990)

Methodology

Data Quality Assurance

To minimize seismic data uncertainties and biases in acquisition, processing, and interpretation, the survey design was carefully and optimally designed. Precise source-receiver placement, and robust noise reduction during acquisition. Also, the correct velocity modeling was applied to allow for seismic multiple suppression. Moreso, multi-disciplinary validation approach was applied during interpretation to enhance accuracy and reliability in subsurface characterization.

Advanced quality control measures were implemented to ensure accuracy and reliability of well log data during well logs acquisition. Corrections were also made for borehole and environmental effects during processing. Multiple independent data sources were also integrated during interpretation which helped to minimizing uncertainties and biases while enhancing subsurface characterization.

Petrophysical evaluation and seismic interpretation

The data used in this study consist of 3D onshore seismic data which covers an area of about 50 km^2 (Figure 2c). The Tsekelewu (TSL-01) and Opuekeba (OPK-7) Wells consist gamma ray log (GR), Formation Density Compensated log (FDC), sonic log, neutron log, resistivity and density logs used to calibrate the seismic data. Analysis and interpretation of seismic volume and Well data were carried out on the platform of Seismic Micro Technology (SMT) and Petrel (2012 version). Synthetic seismogram was generated from the sonic log, density log and checkshot data from Well TSL-01. The synthetic seismograms were generated by using geological parameters such as rock density, velocity, and layer thickness. In this process well-log data were used to calculate acoustic impedance contrasts and convolved with a wavelet to simulate the recorded seismic response. Synthetic seismograms serve as a bridge between well data and seismic surveys. By comparing synthetic traces with real seismic records, helped to correlate well information with seismic reflections and identified some geological features such as reservoirs or faults. The synthetic seismogram was used to calibrate the seismic data. Adjustment for environmental corrections and adherence to established industry guidelines

Seismic events (horizon) were mapped based on the result of the synthetic seismogram. Lithological correlation was performed using the identified flooding surface which helped in establishing stratigraphic column within the study area. Pay sands penetrated by TSL-01 were identified using combination of gamma ray, resistivity and sonic logs. Petrophysical parameters of the identified sand bodies including porosity (Φ), Net to Gross (NTG), Water Saturation (S_w) were calculated. Fault identification and mapping was based on reflection discontinuity at fault planes and abrupt termination of lithological events. Horizons were picked on seismic sections after calibrated with formation tops encountered by Well TSL-01. Depth structure maps with contour interval of 50 ft. were then obtained using check shot data from Well TSL-01. Hydrocarbon typing was based on the neutron and density logs overlay. Horizons, time slices and erosional surface were interpreted across the seismic volume. Two velocity functions were derived from reservoirs above and below Top of reservoir U1 shown in respective Equation 1 and Equation 2 that account for variation across major boundary with depth (Z). These functions helped to correlate the depth based well log information to the time-based seismic data.

$$V(z) = 1860 + 0.328 * Z \quad (1)$$

$$V(z) = 2845 + 0.125 * Z \quad \text{m/ sec below top U1} \quad (2)$$

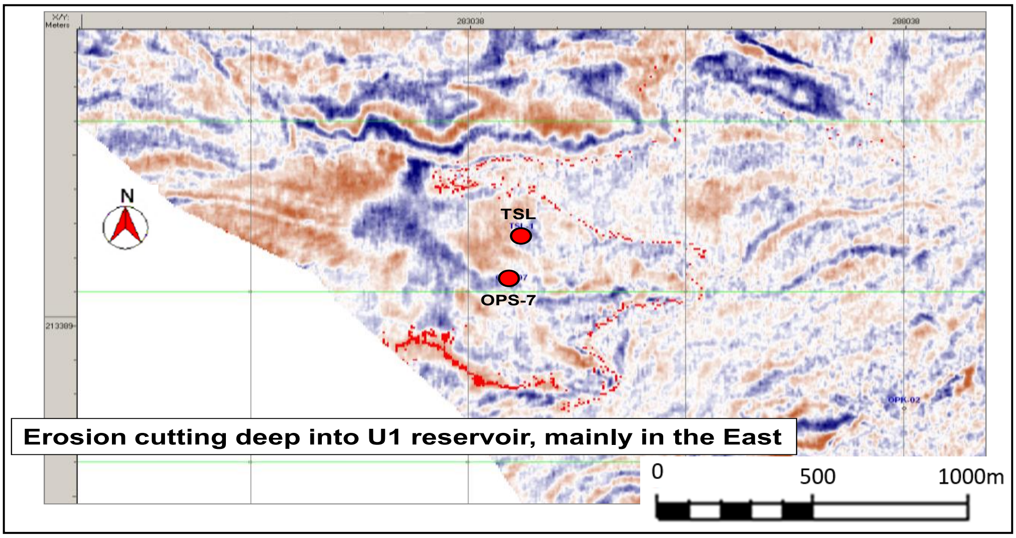

Figure 2c: Timeslice 1548 showing extent of seismic coverage, Well locations and Erosional effect.

Volumetric analysis of TSL-01 structure

Deterministic Stock Original Oil in Place (STOOIP) and Original Gas in Place (OGIP) were estimated for the TSL-01 hydrocarbon bearing reservoirs using Bateman equations (Bateman, 1910). From the STOOIP estimates, several probabilistic volumetric estimates were generated from which the P90, P50, and P10 estimates were selected. For each reservoir, the Mid Case porosity value was applied based on mild expectation and the reservoir average porosity determined from petrophysical evaluation.

Probabilistic range of STOOIP was generated for the TSL-01 reservoirs as follows:

i. Low (or Proven) Case: In this volumetric case, it has been assumed that the oil columns are limited to those known from the current Well penetrations.
ii. Mid Case: In this case, the structures are oil filled to the crest but the eastern culminations do not exist as interpreted or do exist but are not hydrocarbon bearing – Western culmination only
iii. High Case: In this case, the structures are oil filled to the crest. Both eastern and western culminations have common contacts and are filled to their crests with the same hydrocarbon types as the main field areas) – Western + Eastern culmination.

Results and Discussion

Geological correlation and petrophysical analysis of pay sands

The Geological correlation panel of OPK-07 and TSL-01 is displayed in Figure 3 which revealed the different reservoir units within the field. The stratigraphic column was divided into two by a Maximum Sequence Boundary (MSB) (Figure 3) that marked the base of the overlying Benin formation. Preceding this formation are the paralic sequences of the Agbada formation made up of alternating epochs of sand and shale prone intervals. The sands constitute the reservoirs, while the shales constitute the source rocks and caprocks system in the field. Six hydrocarbon sandstone reservoirs (U1, U2, U4, U5, U7 and U8) were identified. Several Flooding Surfaces (FS) which defines boundaries that separate overlying younger strata with deep facies from underlying strata with shallow facies. Reservoir tops interpreted from the seismic data using a synthetic seismogram are shown in Figure 4. On the synthetic seismogram, reservoir markers at U1 (Top and Base), U2 Top, U4 Top and Top U7 produced good fit on seismic Inline 5425. Seismic time of reservoirs with strong reflection, the equivalent Well locations in time and time difference between seismic and well is shown in Table 1. The summary of petrophysical parameters of the hydrocarbon sands identified in Well TSL-01 is shown in Table 2 with U8 divided into upper (U8U) and lower (U8L) reservoir sections.

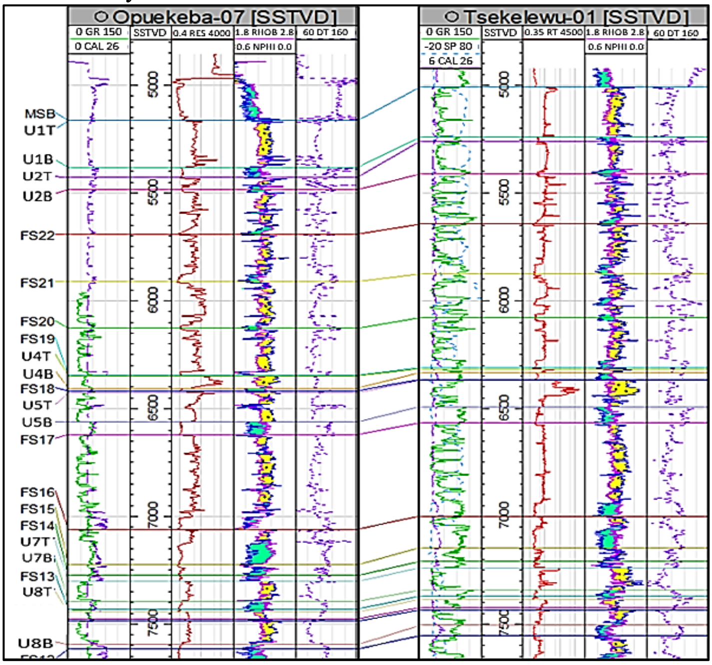

Figure 3: Reservoir Sand Correlation Panel of OPK-07 and TSL-01 wells.

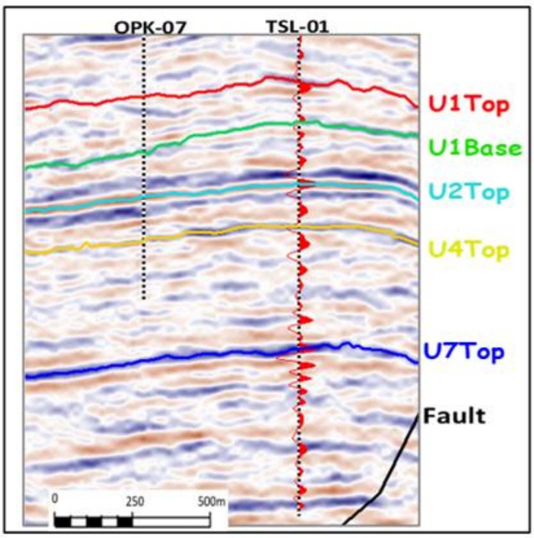

Table 1: Time difference in the ties of well and seismic

Well TSL-01			
Horizon	Well data T	Seismic T	dT
U1 top	1.473	1.459	0.014
U1 base	1.518	1.530	-0.012
U2 top	1.643	1.643	0.000
U4 top	1.736	1.722	0.014
U5 top	1.749	-	-
U7 top	1.941	1.944	-0.003
U8 top	1.968	-	-

Figure 4: Well to Seismic Tie of TSL-01 on Inline 5425 showing the horizon

Table 2: Petrophysical Results of Hydrocarbon Sands in Well TSL-01. The True Vertical Depths subsea (TVDss) are in feet (ft.).

Reservoir	Top TVDss (ft.)	Base TVDss (ft.)	Contact TVDss (ft.)	N/G %	Phi %	S_w %	S_h %
U1	5006	5237	5031	97	26	46	54
U4	6313	6332	6332	63	23	47	53
U5	6366	6489	6433	90	23	29	71
U7	7237	7341	7237	97	21	35	65
U8-U	7384	7505	7407	97	25	49	51
U8-L	7433	7445	7445	61	22	66	34

The depth structure maps showing scaled amplitude distribution revealed in Figures 5 to 7 indicate a roll over anticline structure around the two Wells, bounded by East-West trending growth faults in the Northern and Southern areas. Erosional surface cuts deep into the reservoirs and terminates the eastern extension of the structure in reservoir U1 (Figure 5). This reservoir is strongly eroded thereby limiting its extension to the East. An anticline structure which defines a single culmination in the North-South direction characterized reservoir U1. In Figure 6, two structural culminations (Western and Eastern), separated by a saddle defines reservoir U4. In this case, the culmination trend in the West-East direction forming two peaks of anticlinal structures. Figure 7 revealed a single culmination of the anticlinal structures. The Western and Eastern culminations are not separated in reservoir U8. It also trends in the similar direction like reservoir U4.

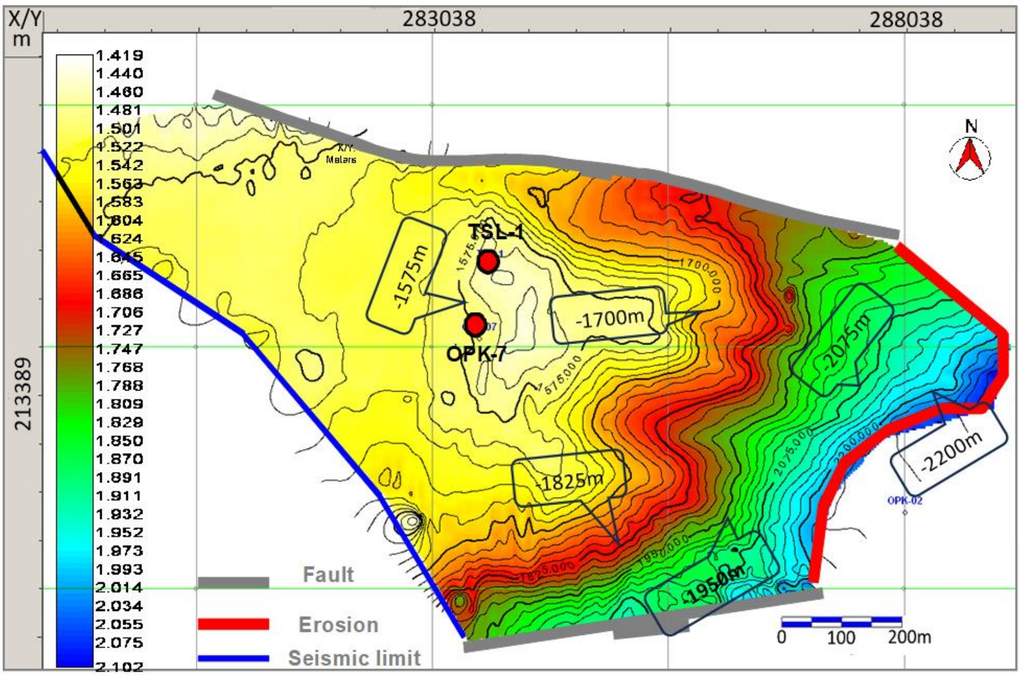

Figure 5: Structural Depth Map of Reservoir U1 showing roll over anticline structure around the two Wells, Erosional Surface, Fault and Seismic limit.

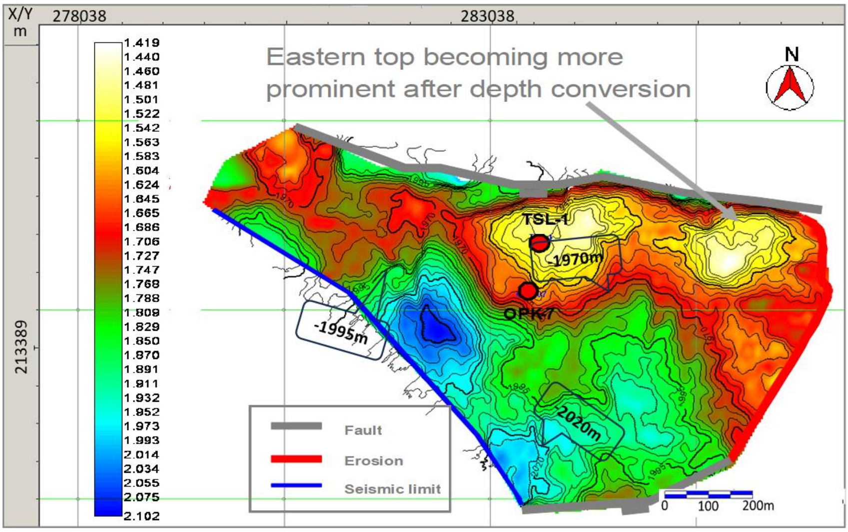

Figure 6: Structural Depth Map of Reservoir U4 showing a roll over anticline structure around the two Wells, Western and Eastern culminations.

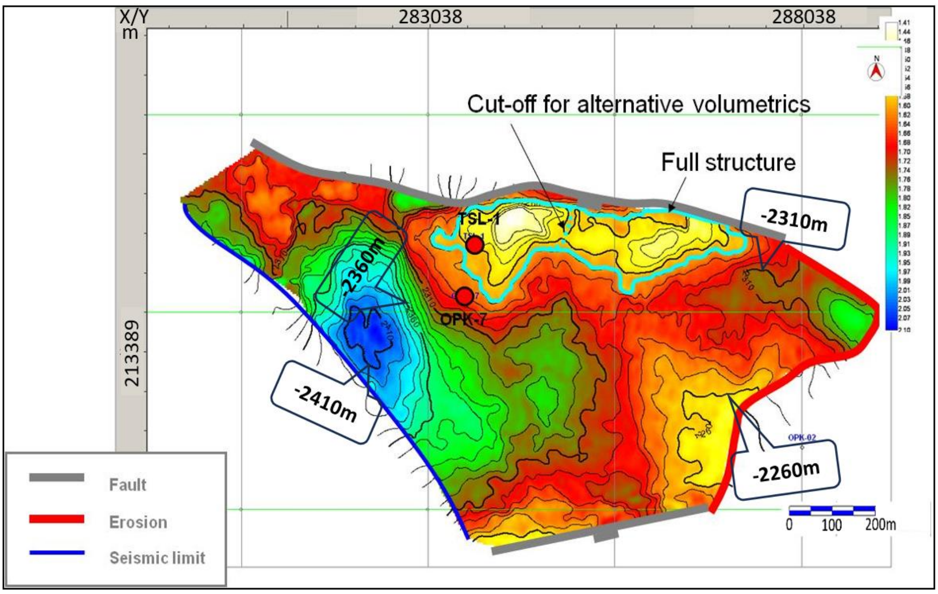

Figure 7: Structural Depth Map of Reservoir U8 showing the combined culmination of the two anticlinal structures.

Hydrocarbon distribution in reservoirs

The Mid Case probability scenario of hydrocarbon presence illustrates hydrocarbon distribution maps of reservoirs U1, U4, U5 and U7 shown in Figures 8 to 11. It revealed that Well TSL-01 impacted the flank of the structure where it encountered Oil Water Contact (OWC) at reservoir U1 (Figure 8). This Well also encountered Gas Water Contact (GWC) at reservoir U4 (Fig. 9) and predominantly gas saturated reservoir U5 (Figure 10). It also penetrated reservoir U7 at OWC as shown in Figure 11. Furthermore, at reservoir U1, the structure is limited by the erosion in the Eastern part of the structure while at the reservoir U4, the two structural culminations (Western and Eastern) became more obvious. Well TSL-01 impacted U5 at the flank of the structure encountering thin oil rim and thick gas at the crest of structure. At the U5 and U7 levels, the two structural culminations are also evident with a saddle between them. It impacted the reservoir at the flank of the structure of reservoir U7, encountering an oil up-to situation. The volume of oil and gas were estimated from all the identified reservoir and presented in the volumetric analysis results in Table 3. Estimated volume of oil in Million Stock Tank Barrels of oil (MMstb) for the low, mid and high probability cases ranges are 13.0,33.9 and 67.1 respectively. While the estimated Billions Standard Cubic Feet (Bscf) in place of gas are respectively 26.5, 29.5 and 56.6 for the low, mid and high probability cases.

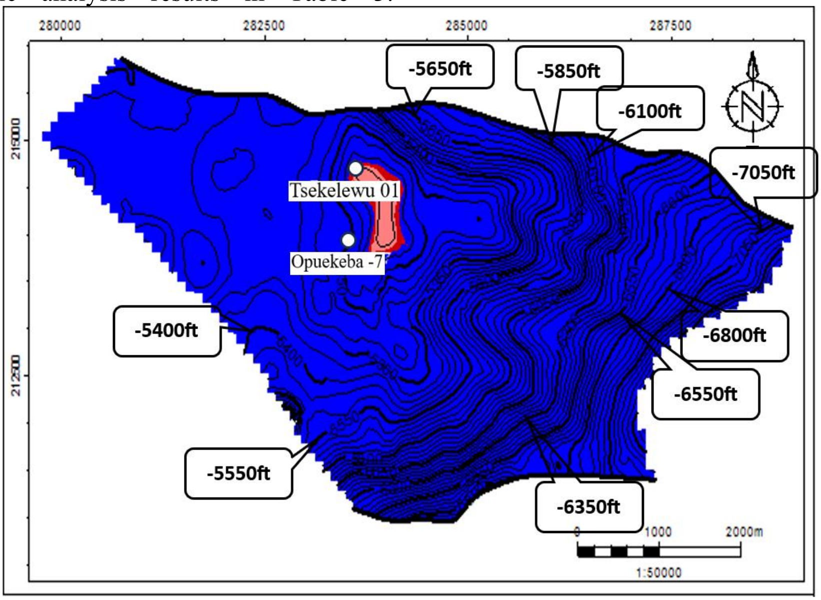

Figure 8: Depth Structure Map of U1 Reservoir Top Showing Oil Accumulation (Red colour).

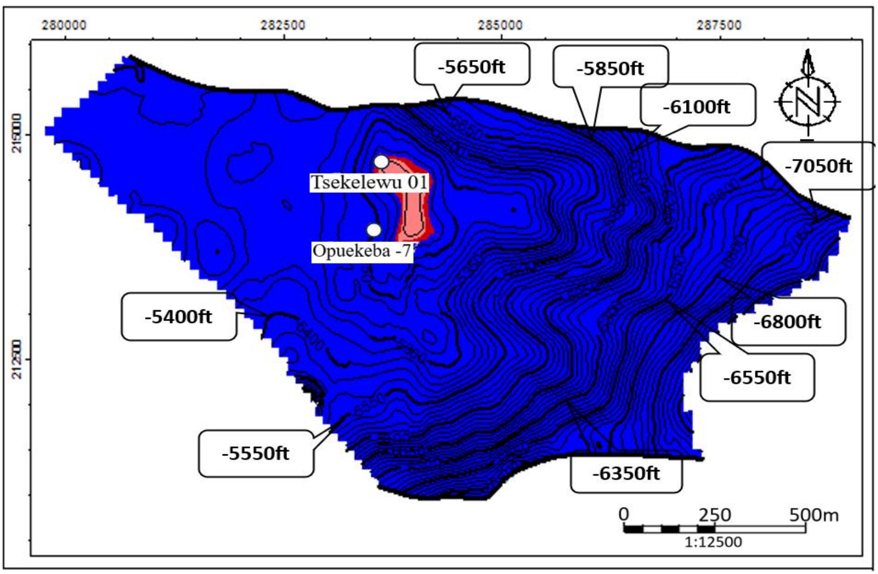

Figure 9: Structural Depth Map of Top U4 Showing Gas Accumulation (Green colour).

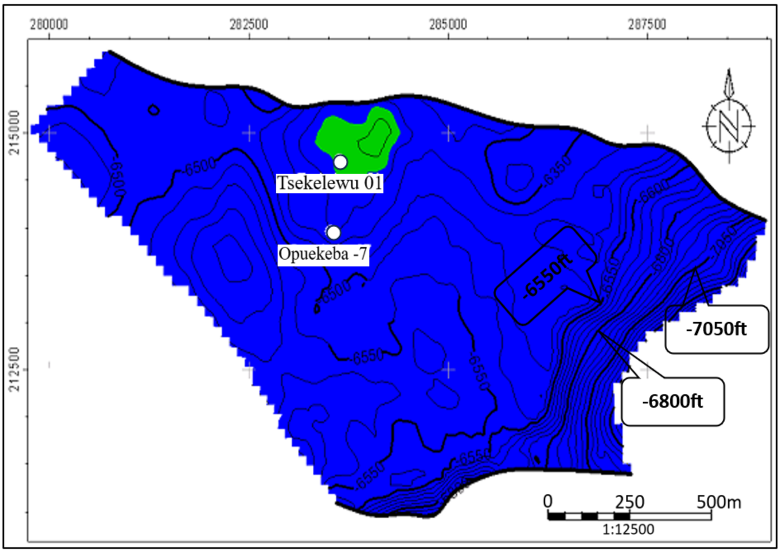

Figure 10: Structural Depth Map of Top U5 Showing Hydrocarbon Accumulation**.**

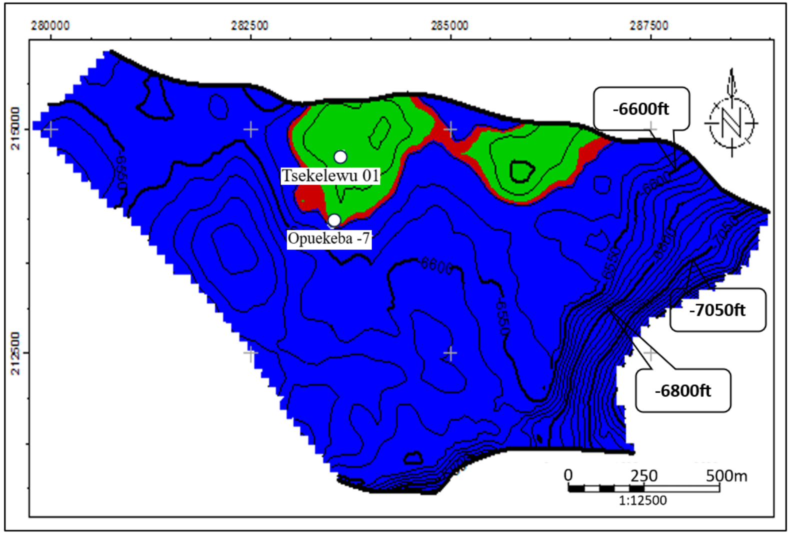

Figure 11: Structural Depth Map of Top U7 Showing Hydrocarbon Accumulation

Table 3: TSL-01 Volumetrics Results Summary

Reservoir	Top Structure [ft. TVDss]	Contact [ft. TVDss]	NTG [%]	Φ [%]	Sw [%]	Low Case MMstb	Mid Case MMstb	High Case MMstb	Low Case Bscf	Mid Case Bscf	High Case Bscf
U1	5006	5031	97	26	46	1.8	2.5	2.5			
U4	6313	6332	63	23	47				0.8	1.7	2.6
U5	6366	6433	90	23	29	5.5	5.5	8.9	25.7	27.8	44.3
U7	7237	7253	97	21	35	2.3	14.0	30.3			
U8-U	7384	7407	97	25	49	3.0	8.4	17.2			9.7
U8-L	7433	7445	61	22	66	0.4	3.5	8.2			
TOTAL						13.0	33.9	67.1	26.5	29.5	56.6

Appraisal Well Planning

Figure 12 shows the West-East cross section through the proposed Well (Appraisal - 01) and the fluid distribution. The main targets of the proposed appraisal Wells are the U5, U7 and U8 reservoirs where significant hydrocarbon volumes can be identified. The proposed Appraisal-01 Well was planned to impact the reservoirs at the crest of the structure to reduce uncertainties in fluid type at the crest of the structure. The planned trajectory of the proposed Appraisal-01 campaign with the least risk was proposed at surface location about 210 m East of TSL-01 as shown in the West-East cross section with fluid distribution (Fig. 12). The Appraisal-01 Well, is planned to encounter the same stratigraphy as TSL-01 and also designed to hit reservoir U1 at approximately the same level as TSL-01 but near the tops of levels U5 and U8. Further appraisal Well planning prognoses of the subsurface reservoir targets are given in Table 4. It illustrates coordinate of the surface location in UTM, depth to reservoir tops and the expected fluids based on this study. Also, tolerance level of +/- 50 m which allows for adjustment of the appraisal Well trajectory.

Trajectory of Appraisal - 01 Well

The appraisal Well is projected to be drilled as a deviated Well with a maximum inclination of 38.5 degrees (Figure 13, Right). It consists of a straight section (North -South) from surface to 2800 TVDss, followed by a build-up section that trend in the Nort-East direction at 2 deg. per 100 ft up. The top of the reservoir U1 equals approximate 5000 ft. (Total Vertical Depth SubSea, TVDss) or about 5200 ft. (Measured Depth, MD). Deep into the formations, the trajectory inclination reached about 38.5 degrees. The proposed Well trajectory on seismic section is shown by the schematic (arbitrary) path in Figure 13 (Left).

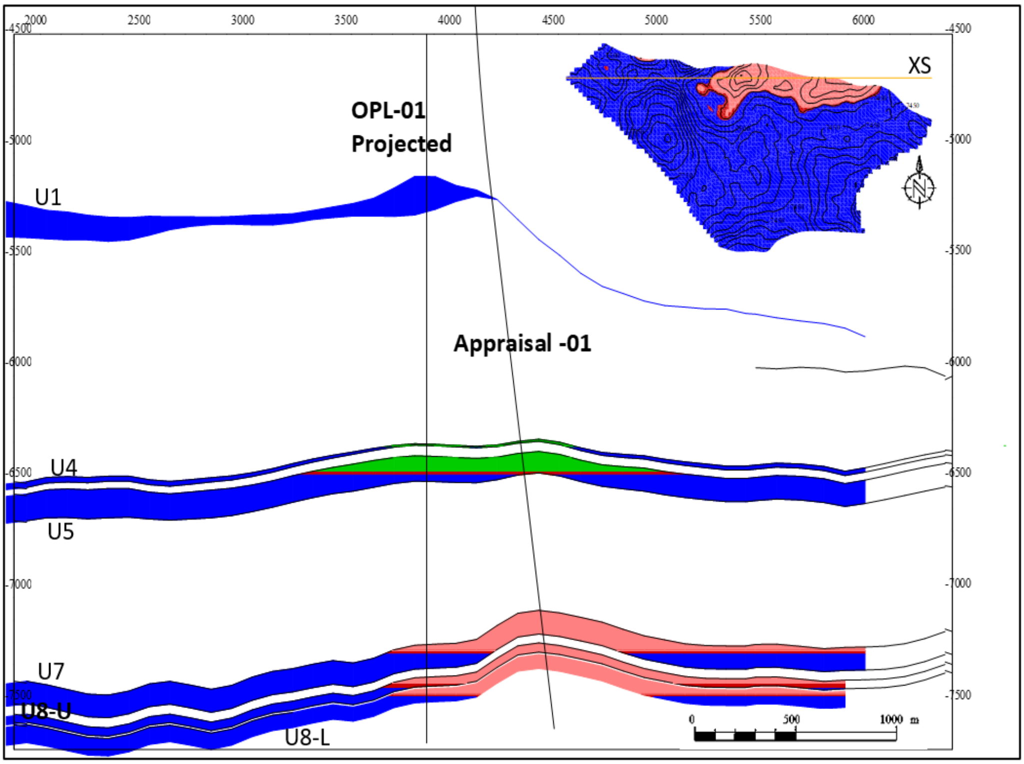

Figure 12: West-East Structural Cross Section (XS) through the Proposed Appraisal-01 Well. It shows the drilled OPL-01 vertical well and the deviated appraisal well. Reservoir U1 is filled with brine (blue) while U4 and U5 are saturated with oil (green). Reservoirs U7 and U8 (U8-U and U8-L) are gas saturated.

Table 4. Subsurface Targets and Tolerance of Appraisal-01 Well

Location	**Depth** (ft. TVDSS)	**Expected Fluids**	**Coordinates (m)** (UTM) **North**	**East**
Surface Location			214600m	283800m
	- 5008	Oil	214657 +/- 50m	283895 +/- 50m
	- 6292	Gas	214922 +/- 50m	284056 +/- 50m
	- 6347	Oil/Gas/Water	214934 +/- 50m	284063 +/- 50m
	- 7060	Oil/Water	215081 +/- 50m	284152 +/- 50m
	- 7200	Oil/Water	215109 +/- 50m	284170 +/- 50m

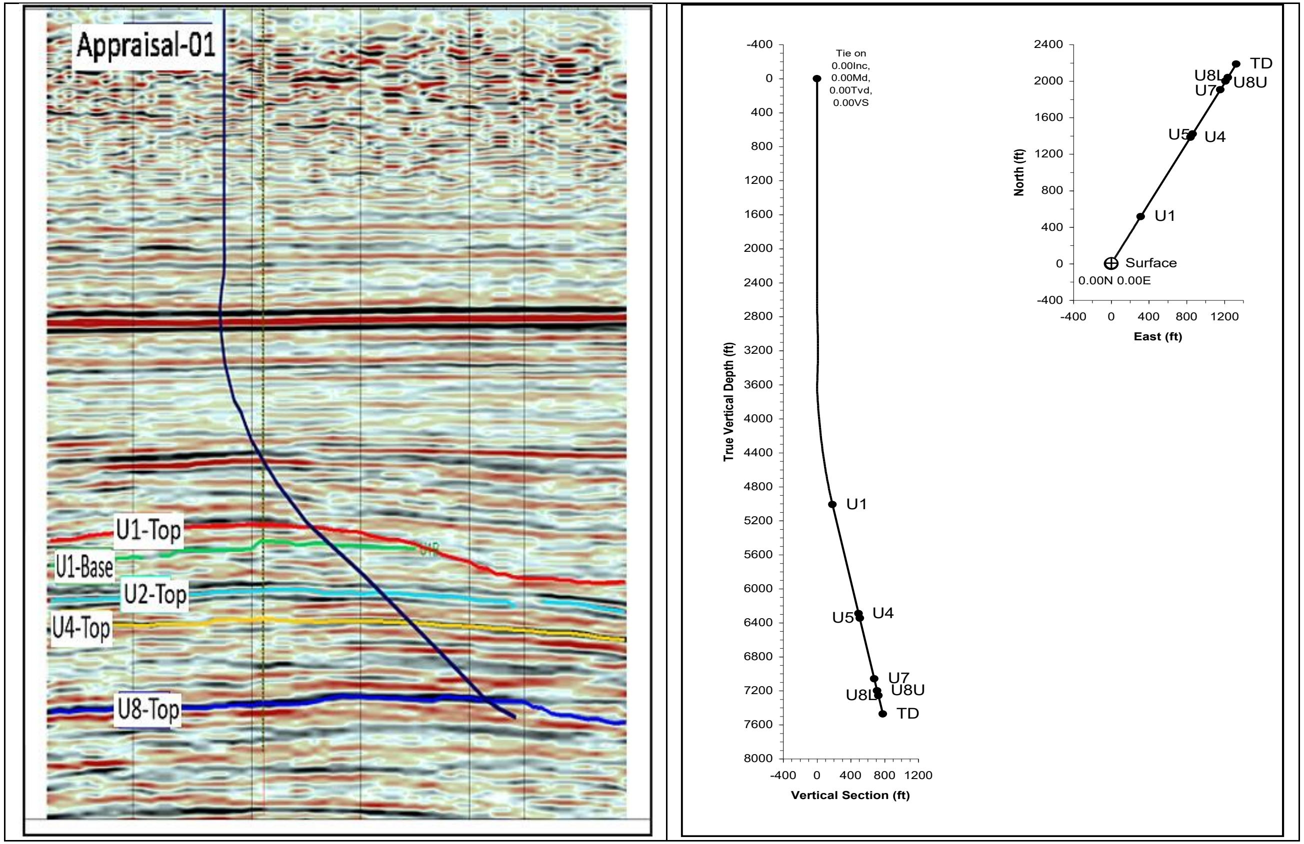

Figure 13: (Left) Arbitrary Line through the Trajectory of the Appraisal well (Zoomed in Vertically). (Right) Profile of the Proposed Appraisal - 01 well

Conclusions

The interpretation of 3D seismic and Well data has revealed that 'TSL' structures are multi-level reservoirs, characterized by simple roll-over anticlines bounded by West-East trending faults. The mapped sands indicate good reservoir properties with Net to gross ratio of over 90%, water saturation values are between 29% and 66% while the hydrocarbon saturation values is about 70%. The volumetric estimates especially away from Well TSL-1 carry uncertainties which supports the drilling of appraisal Well penetrating the structural culminations for possible full field development. The identified two distinct structural culminations (Western and Eastern extensions) in the main reservoirs (U5, U7 and U8) helped in positioning the appraisal Well. To this effect, the study proposed an appraisal Well to test up-dip potential of major reservoirs at the culminations with oil saturation (U4 and U5) while U7 and U8 are gas saturated. The trajectory of the appraisal Well has both the vertical and the inclined path at 2.8^0 at every 100 ft for a precise target of the reservoir crest. This proposed Well was designed with least risk of encountering reservoir overpressure, hydrocarbon migration, spills and well bore instability that are commonly associated with this basin. The findings in this study have helped to identify a location to drill an appraisal Well. This will help to increase hydrocarbon production with the corresponding economic gain from this field.

Acknowledgments

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