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Hydrocarbon Prospectivity in the West Waha and Worsham-Bayer Fields, Delaware Basin

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Abstract:- The west Waha and Worsham-Bayer field, located within the Delaware Basin of western Permian Basin, represents a significant hydrocarbon province with substantial production potential. This study aims to reevaluate the hydrocarbon resources and optimize recovery strategies for these fields by integrating seismic interpretation, petrophysical analysis, and volumetric assessment. Using data from 3D seismic reflection volumes, well logs, and production records, the research applied advanced techniques including seismic-to-well ties, structural and sequence stratigraphic interpretations, and fault-seal analysis. Key findings highlight the identification of four major reservoirs: UML, TF, FF, and ELB. The ELB reservoir, characterized by very high porosity, high permeability, and low water saturation, emerged as the most promising target for hydrocarbon production. The TF and FF reservoirs also demonstrated high potential, while the UML reservoir showed moderate characteristics but high-water saturation. Volumetric assessments supported these findings, confirming the ELB reservoir's exceptional hydrocarbon potential. The study recommends drilling deeper into the Ellenburger Formation with Wells 42 and 98 to exploit deeper targets, acquiring additional 3D seismic data towards the southeastern basin, and employing enhanced seismic resolution for better facies distribution understanding. Furthermore, the development of a 3D reservoir model incorporating fracture networks and a detailed fault-seal analysis are advised to optimize hydrocarbon recovery. This research provides a comprehensive evaluation of the West Waha and Worsham-Bayer fields, offering actionable insights for maximizing hydrocarbon production through targeted exploration and advanced reservoir management strategies.

Keywords:- *Hydrocarbon, Delaware Basin, Seismic Interpretation, West Waha, Volumetric Assessment.*

I. INTRODUCTION

The Delaware Basin is a hydrocarbon-rich sedimentary basin within the Permian Basin's Western sector. The basin covers around 6.4 million acres in far West Texas and South Eastern New Mexico (Horne et al., 2022). It is located in an arid southwestern portion of the United States of America. Its history as a separate basin dates from the Early Carboniferous, but its roots began in the late Proterozoic Era, probably as a north-south trending aulacogen. Through much of the Paleozoic Era, the basin and its predecessors formed a confined depression surrounded by carbonate shelves. In this depression, organic debris was preserved. Burial converted this material to kerogen and then to hydrocarbons. Deposition of thick evaporite strata during the Late Permian formed a seal that preserved the hydrocarbons and facilitated their migration to porous carbonate reservoirs in the surrounding shelves. In the basin, deeper burial caused the conversion of heavier hydrocarbons into gas in the older rocks, whereas paraffinic oils in younger strata accumulated in smaller reservoirs. There were three chief intervals of hydrocarbon generation in the basin: (1) Middle Ordovician, Late Devonian, and Mississippian; (2) Middle Pennsylvanian; and (3) Early and Middle Permian. The accumulations of gas and oil in the basin have been largely undisturbed by the mild tectonic activity since the end of the Permian. The region was practically unaffected by the Laramide deformation. Thus, it remains an important oil- and gas-producing province (Hills, 1983). As sedimentary basins in general are important to the petroleum industries of the world, so is the Delaware basin important to the industry of the West Texas-New Mexico area. In light of the basin's rich history of hydrocarbon generation and accumulation, this study re-evaluates the existing resources and proposes solutions for brownfield redevelopment and incremental recovery in the West Waha and Worsham-Bayer fields. The study aims to optimize hydrocarbon recovery from these fields by applying innovative techniques and strategies that will increase production and extend the economic life of the reservoirs.

II. GEOLOGY

The Delaware Basin, located in New Mexico and Texas, is a significant geological feature with a complex history (Figure 1). It is a structural depression, bordered by the Central Basin Platform and the Guadalupe Mountains (Haigler, 1962; Haruna et al., 2014). The basin's early history is linked to the Tobosa basin, with the rise of an Early Pennsylvanian median ridge marking its separation (Adams, 1965). The basin's sediments of 20,000ft, which accumulated during the Pennsylvanian and Permian periods, were largely clastic due to the deep waters in the basin (Adams, 1965). The Delaware Mountain Group (DMG) within the basin is a key area for hydraulic fracturing flowback and produced water disposal, with its lithology and reservoir properties playing a crucial role in mitigating potential risks (Smye, 2021). The offshore region adjacent to the basin, particularly the

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Baltimore Canyon Trough, is also of interest due to its potential petroleum resources (Benson, 1989; Ali & Chaudhry, 2014). The basin also contains Cenozoic fill deposits, attributed to evaporite solution (Maley, 1953). The formations of the Delaware Basin are mainly comprised of carbonate reef deposits and shallow marine clastic sediments. From youngest to oldest (or shallowest to deepest), formations include Bell Canyon, Cherry Canyon, Brushy Canyon, Bone Spring (including Avalon Shale), and Wolfcamp.

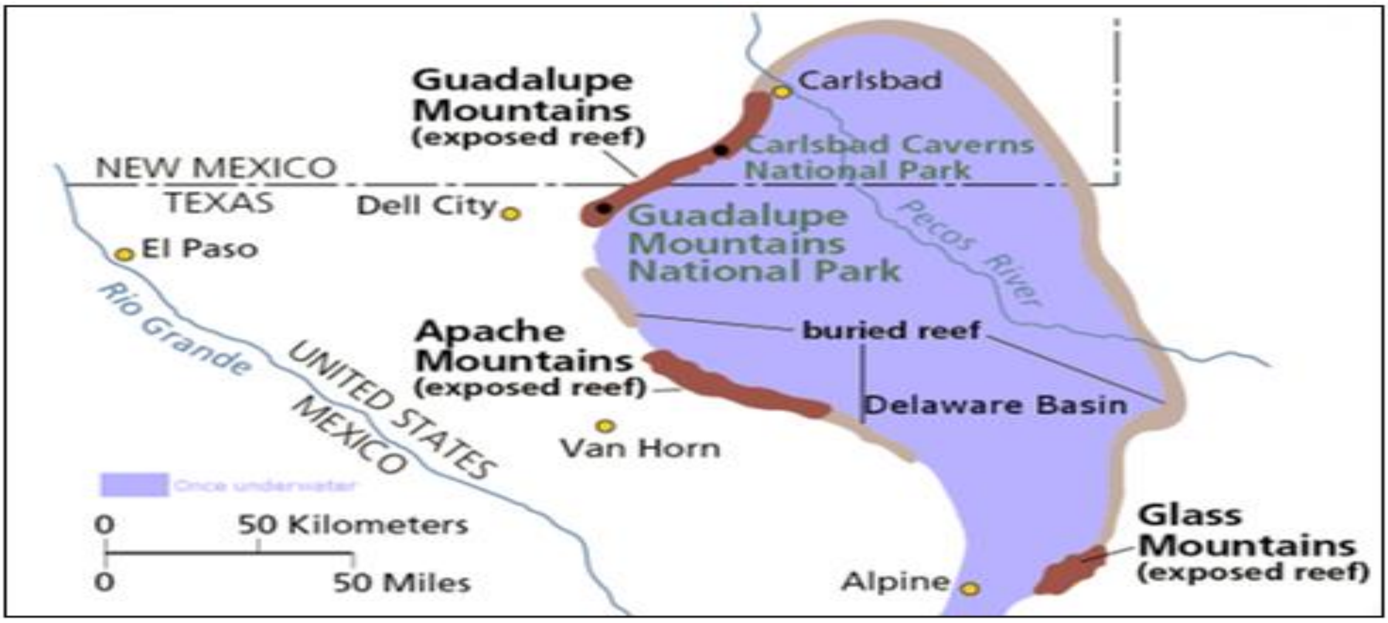

Fig 1: Map Showing the Area Covered by the Delaware. (Gotten from SEG WIKI)

The West Waha and Worsham-Bayer fields are located Onshore within the Delaware Basin, Western Permian Basin, it covers an aerial extent of 20 Square miles (51.8 Km^2) (Figure 2). Three decades ago, approximately 800Tcf of natural gas was estimated in the United States reservoirs and only half of the original 20Tcf of natural gas in place has been recovered in Texas (Holtz and Garrett, 1997; Ademola, 2009). The focus in this study is to re-evaluate the hydrocarbon resources of the basin and all the play elements, and to suggest solutions for real field development and for incremental recovery.

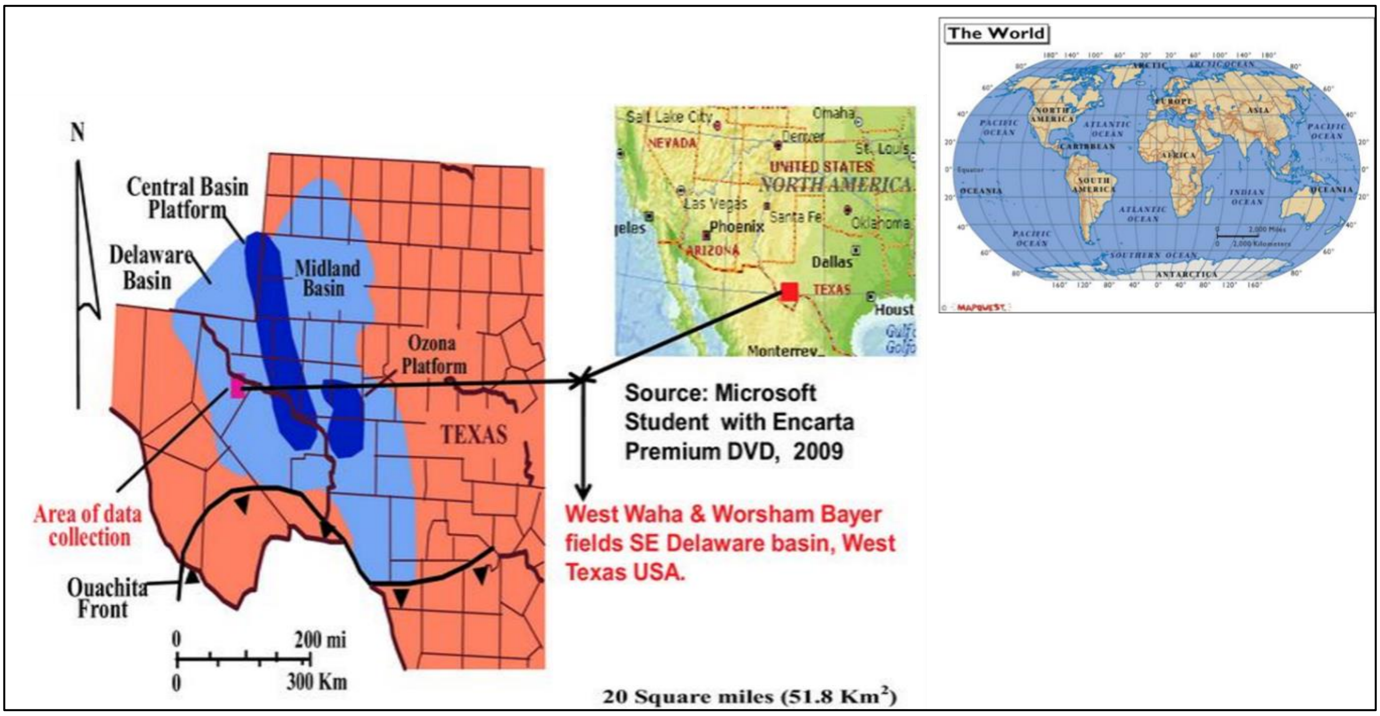

Fig 2: Location of West Waha and Worsham-Bayer Field, Southeastern Delaware Basin, West Texas (Hardage and Hentz, 1998)

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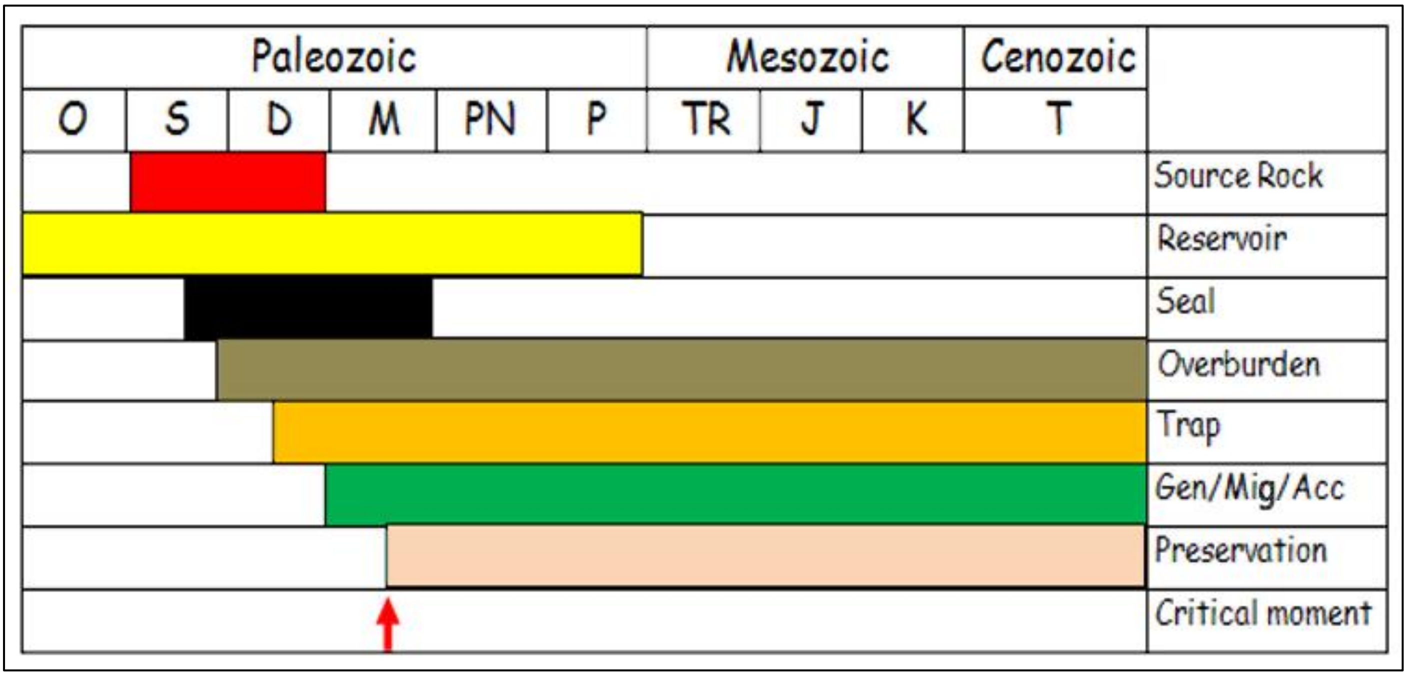

Fig 3: Event Chart Showing the Temporal Relationship of Essential Elements and Processes (Modified from Katz et al. 1994)

This event chart is a geological timeline that outlines the key stages in the formation and preservation of a petroleum system (see Fig. 3). It is divided into three main eras: Paleozoic, Mesozoic, and Cenozoic, which are further subdivided into specific periods.

The event chart, as modified by Kalz et al. (1994), provides a visual representation of the geological history and key stages in the development of a petroleum system. It shows the timing of source rock deposition, reservoir formation, seal formation, overburden deposition, trap formation, hydrocarbon generation/migration/accumulation, preservation, and the critical moment. This information is crucial for understanding the potential for hydrocarbon exploration and production in a given area.

➢ *Source Evaluation was done for the Woodford Formation and the Following was Noted:*

- The Total Organic Carbon (TOC) was from 1.7wt.% to 4.9wt.%
- The Kerogen type within this basin is Type II & III Kerogen
- Widely proven source rock with effective thickness of 0 – 300ft
- Maturation index of >1.2 indicates gas and condensate generative window.

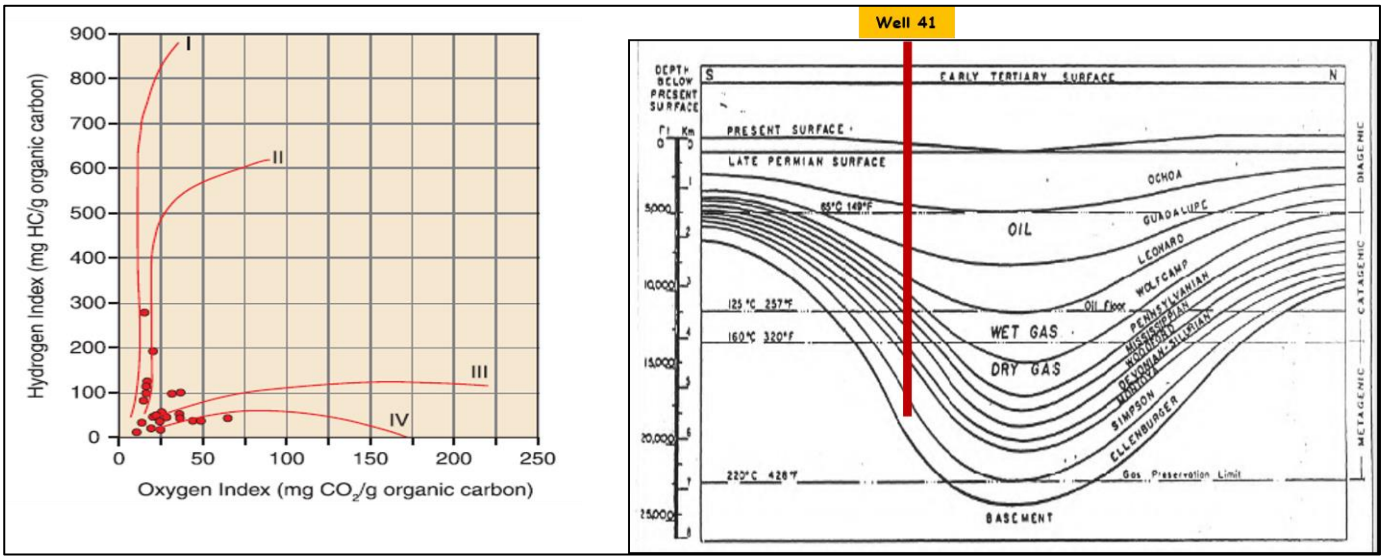

Fig 4: **(**a) Shows the Kerogen Type of the Older Paleozoic Source Rocks (Katz et al., 1994) (b) Burial History Chart of the Delaware Basin.

III. MATERIALS AND METHODS

A. Data Sources

The dataset for this study was provided by the Nigerian Association of Petroleum Explorationists (NAPE) as part of the Basin Evaluation Competition, 2014 (BEC, 2014). The dataset includes (Figure 5):

- **3D Seismic Reflection Volume**: A 20 square miles post-stack, time-migrated seismic reflection volume in SEG-Y format.
- **Well Logs**: Data from 12 wells, including log suites (gamma ray, resistivity, sonic, density, and neutron logs), checkshot surveys, and production data.
- **Checkshot Survey**: Provides time-depth information used for seismic-to-well ties.
- **Production Data**: Historical production data from the wells.

B. Software and Tools

- **Petrel Software**: Used for detailed well log interpretation, seismic data interpretation, synthetic seismogram generation, and time/depth map creation.

C. Seismic Data

- **Format**: SEG-Y, post-stack, time-migrated.
- **Characteristics**: The data is presented as zero phase, SEG reverse polarity. In this convention, peaks (red) represent increasing acoustic impedance, while troughs (blue) indicate decreasing acoustic impedance.
- **Bin Spacing**: 50.00 meters in both inline and cross-line directions.

D. Well Data

- **Wells**: Twelve wells were used to integrate seismic and well log data.
- **Logs**: Includes gamma ray, resistivity, sonic, density, and neutron logs.
- **Checkshot Survey**: Provides time-depth relationships for accurate seismic-to-well ties.
- **Production Data**: Historical data relevant to reservoir performance.

E. Seismic to Well Tie

- **Method**: A synthetic seismogram was generated for Well 29 using sonic and density logs along with the Time-Depth Relationship (TDR) from the checkshot data.
- **Wavelet Extraction**: The deterministic wavelet method was applied to the seismic data to convolve reflection coefficients, generating synthetic seismograms (see Figure 6).
- **Tie Accuracy**: The seismic-to-well tie achieved 80% certainty, with reservoir tops correlating with seismic troughs.

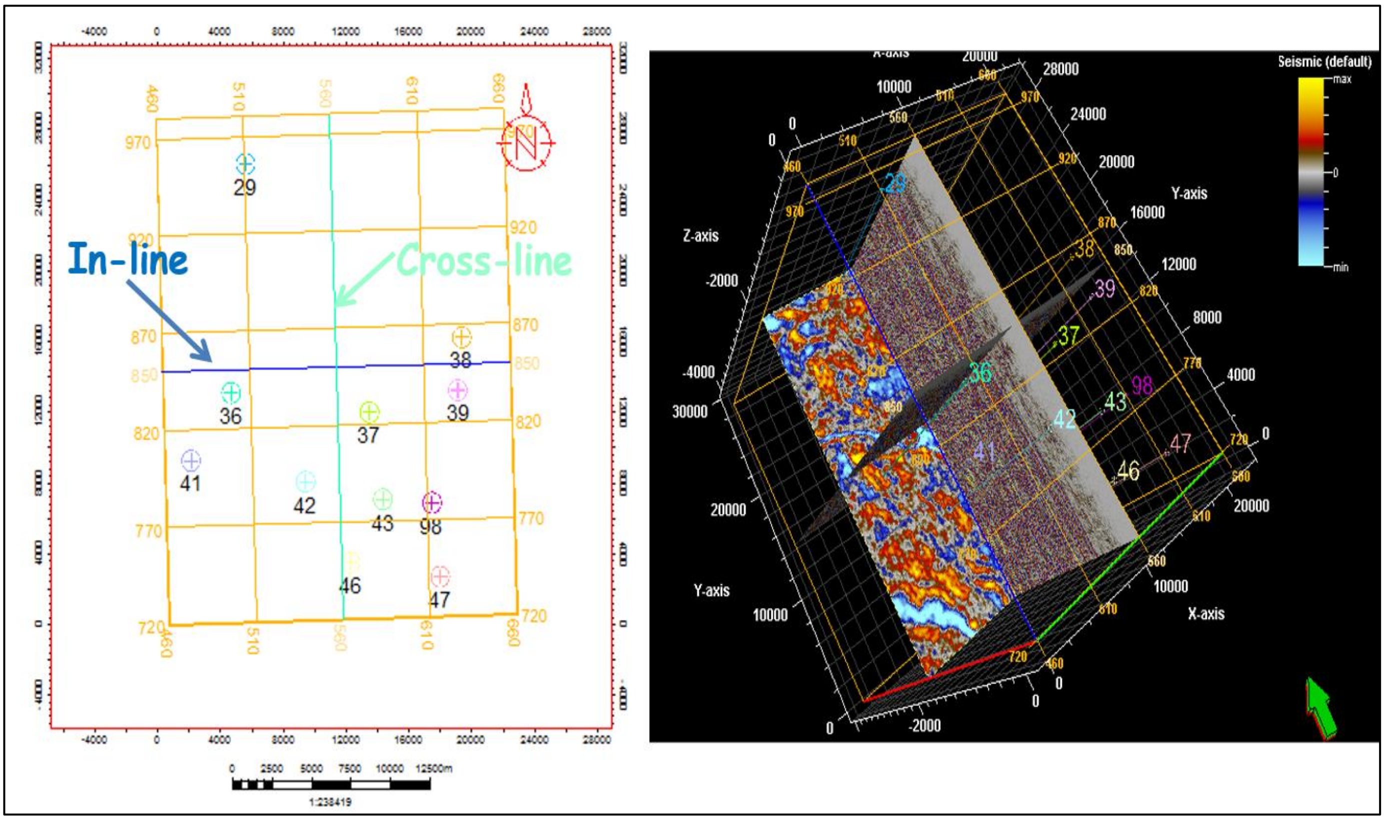

Fig 5: (a) Base Map of the Study Area (b) 3D View of the Seismic Volume

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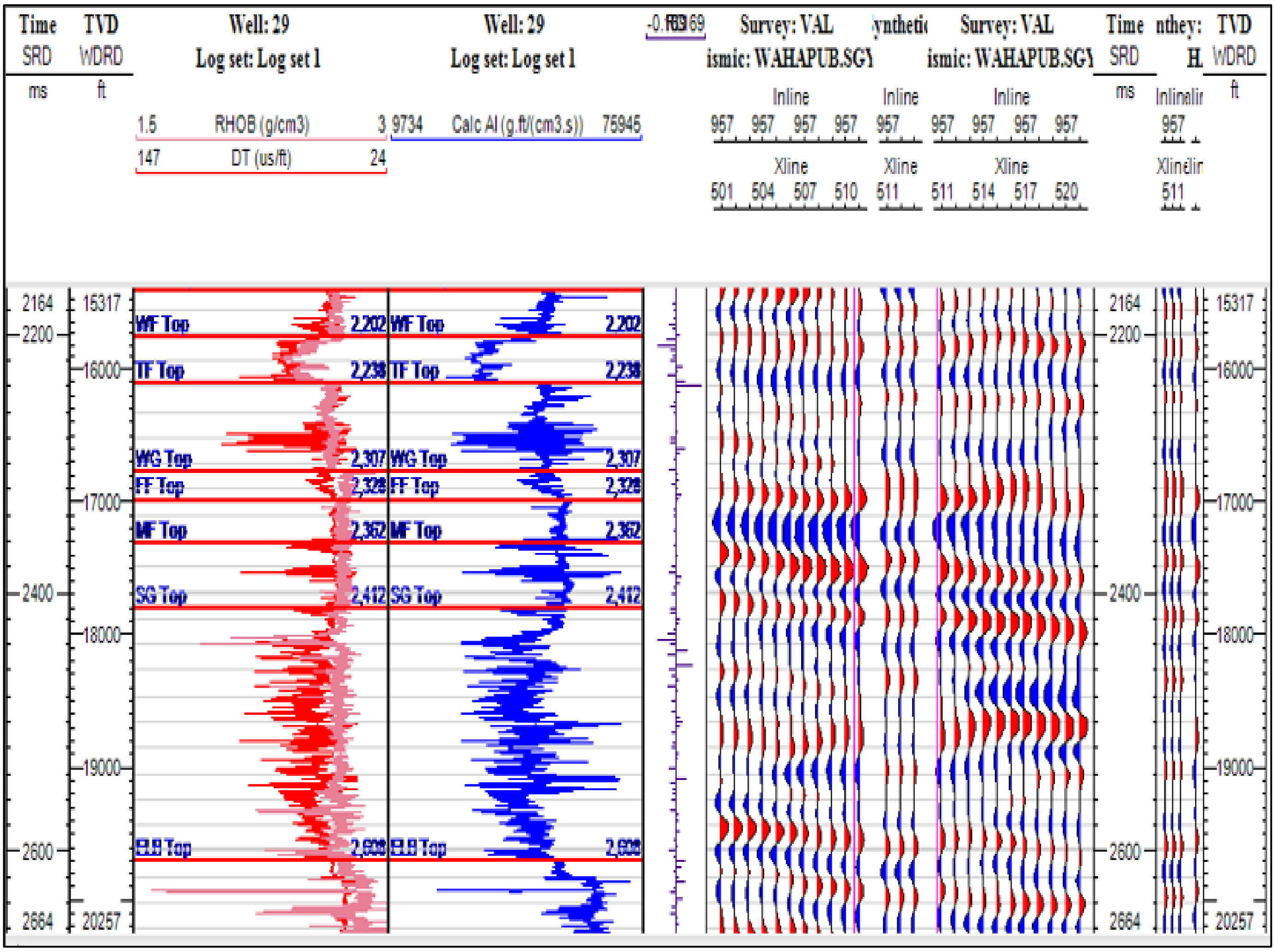

Fig 6: Well 29 Synthetic Seismograms used for the Seismic-To-Well Tie

F. Seismic Interpretation

➢ *Structural Framework:*

- Utilized the 3D seismic volume for interpretation.

➢ *Procedure:*

- **Identification of Reflectors**: Strong seismic reflectors were identified using well ties.
- **Fault Identification**: Faults were identified on seismic sections.
- **Horizon Picking**: Manual picking of horizons on inlines and crosslines. Fault interpretation was specifically carried out on every 5th inline section to capture structural features.

G. Sequence Stratigraphic Interpretation

- **Well Log Analysis**: Performed to understand the depositional sequence model of the field.
- **Directional Analysis**: Interpretation extended towards the southeastern direction of the basin.

H. Time-Depth Conversion

- **Method**: Time-depth conversion was performed for five horizons using a combination of checkshot data and the layer cake velocity model method.
- **Equation**: V=V0+K·ZV = V_0 + K \cdot ZV=V0+K·Z

✓ V = Velocity
✓ V0 = Well TDR surface
✓ K = Well TDR constant
✓ Z = Depth (ft)

I. Structural and Seismic Attribute Analysis

- **Objective**: To create accurate structural maps and analyse subsurface features.
- **Direct Hydrocarbon Indicators (DHIs)**: Used to image details such as faults, folds, and fracture networks, which are crucial for understanding hydrocarbon-bearing beds.
- **Multi-Attribute Seismic Analysis**:

✓ **Volume Attributes**: Computed from the entire 3D seismic cube to create a new cube with specific attribute information.

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- ✓ **Surface Attributes**: Computed from single horizons, between surfaces, or between a surface and a constant time window, providing detailed insights into subsurface structures.

This comprehensive approach integrates various data sources and methodologies to enhance the accuracy of subsurface modelling and hydrocarbon exploration efforts.

IV. RESULTS AND DISCUSSION

A. Structural and Seismic Interpretation

The structural and seismic interpretation of the West Waha and Worsham-Bayer fields provided significant insights into the geological framework of the area.

B. Faults Interpretation:

- ➢ *Fault Identification:*

A total of six faults were identified and mapped in the study area. Faults were categorized based on their characteristics and impact on seismic reflections. Major faults, labeled F1 to F3, were distinguished by their significant influence on the seismic data, including abrupt terminations of reflections and noticeable distortion of amplitudes around the fault zones. Minor faults, labeled F4 to F6, exhibited less pronounced features but were still crucial in understanding the structural complexity of the area (see Figure 7).

- **Fault Characteristics**: Major faults typically display a greater displacement and more pronounced disruption in the seismic reflections, leading to noticeable changes in the dip and amplitude of seismic events. Minor faults, while less impactful, provide additional detail on the structural nuances of the reservoir.

C. Horizon Mapping:

- ➢ *Horizon Identification:*

- Four key horizons (reflectors) were identified and mapped across the field. These horizons are labeled H1, H2, H3, and H4 (see Figure 8).
- **Mapping Technique**: Horizons were mapped based on negative (blue) amplitudes on the seismic sections. These negative amplitudes correspond to the top of sandstone reservoirs, as confirmed by the synthetic seismogram used in the seismic-to-well tie.
- **Structural Maps**: Time and depth structure maps were generated for each horizon to study the structural configuration and architecture of the mapped reservoirs. These maps are essential for understanding the spatial arrangement of the reservoirs and the implications for hydrocarbon extraction.

D. Sequence Stratigraphic Interpretation

- ➢ *Depositional Sequence Model:*

- **Galloway's Model**: The sequence stratigraphic interpretation was guided by Galloway's depositional sequence model, which is used to identify and analyze sedimentary sequences and their boundaries.
- **Identified Surfaces**:
- ✓ **Maximum Flooding Surfaces (MFS)**: Two MFS were identified, marking the highest levels of flooding within the depositional sequences. These surfaces are critical for understanding the timing of sea level changes and their impact on sediment deposition.
- ✓ **Transgressive Surfaces (TS)**: Two TS were identified, indicating periods of rising sea level and the associated transgressive events that affect sedimentation patterns.
- ✓ **Sequence Boundary (SB)**: A sequence boundary was identified, representing a significant shift in sediment deposition or a break in the sedimentary record.

Figure 9 Shows the depositional sequence model and the identified surfaces, providing a visual representation of the stratigraphic framework within the field.

The structural and seismic interpretations reveal a complex fault system and detailed horizon mapping that are crucial for understanding the reservoir architecture in the West Waha and Worsham-Bayer fields. The identification of both major and minor faults highlights the structural complexity and potential challenges in hydrocarbon extraction. The mapping of horizons and the generation of time and depth structure maps provide valuable insights into the spatial arrangement of the reservoirs.

The sequence stratigraphic interpretation, based on Galloway's model, enhances the understanding of the depositional history and sea-level changes that influenced sedimentary patterns. The identification of MFS, TS, and SB surfaces is essential for constructing a comprehensive depositional model and predicting reservoir behaviour.

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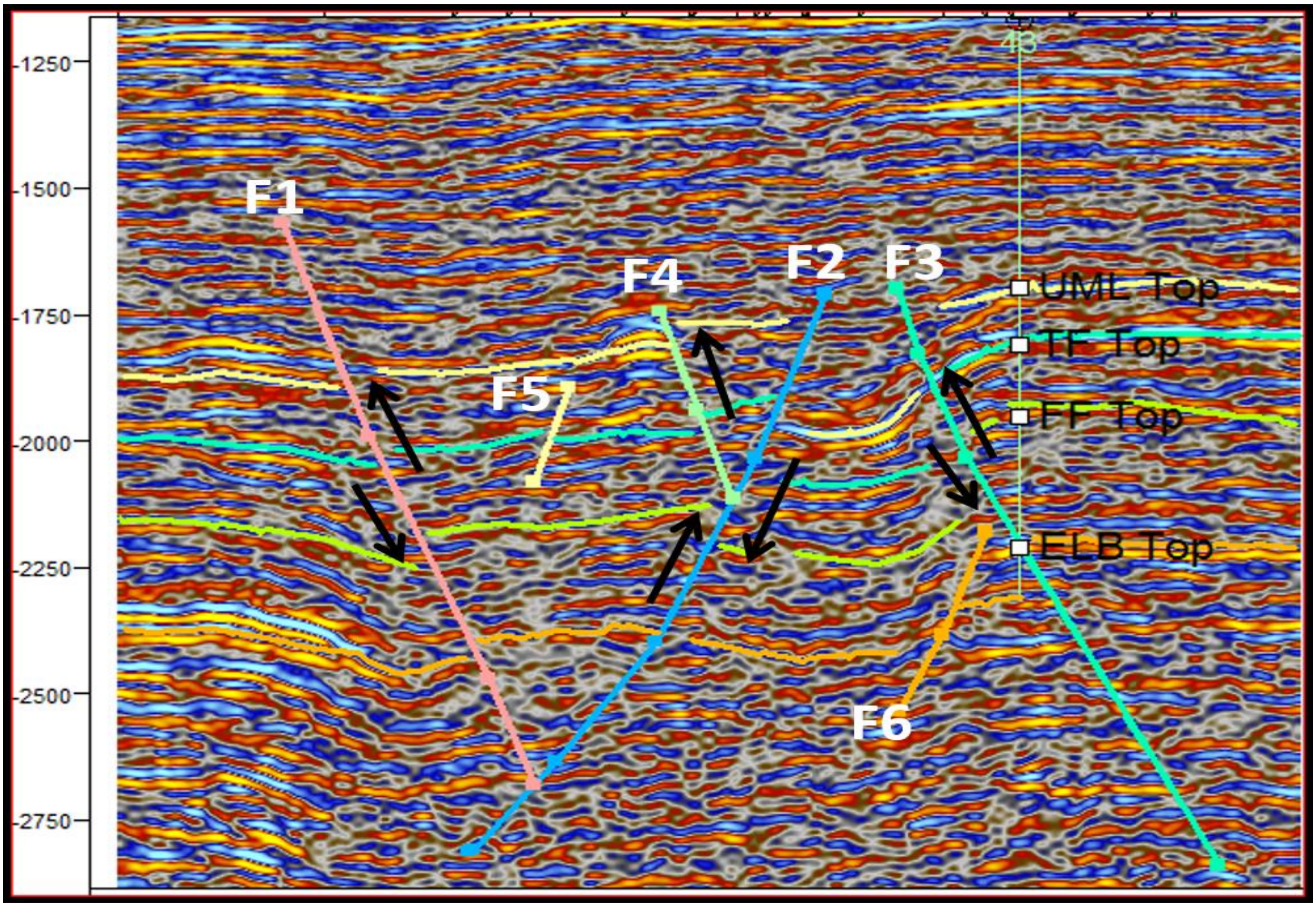

Fig 7: Fault and Horizon Mapping on Seismic Inline Section

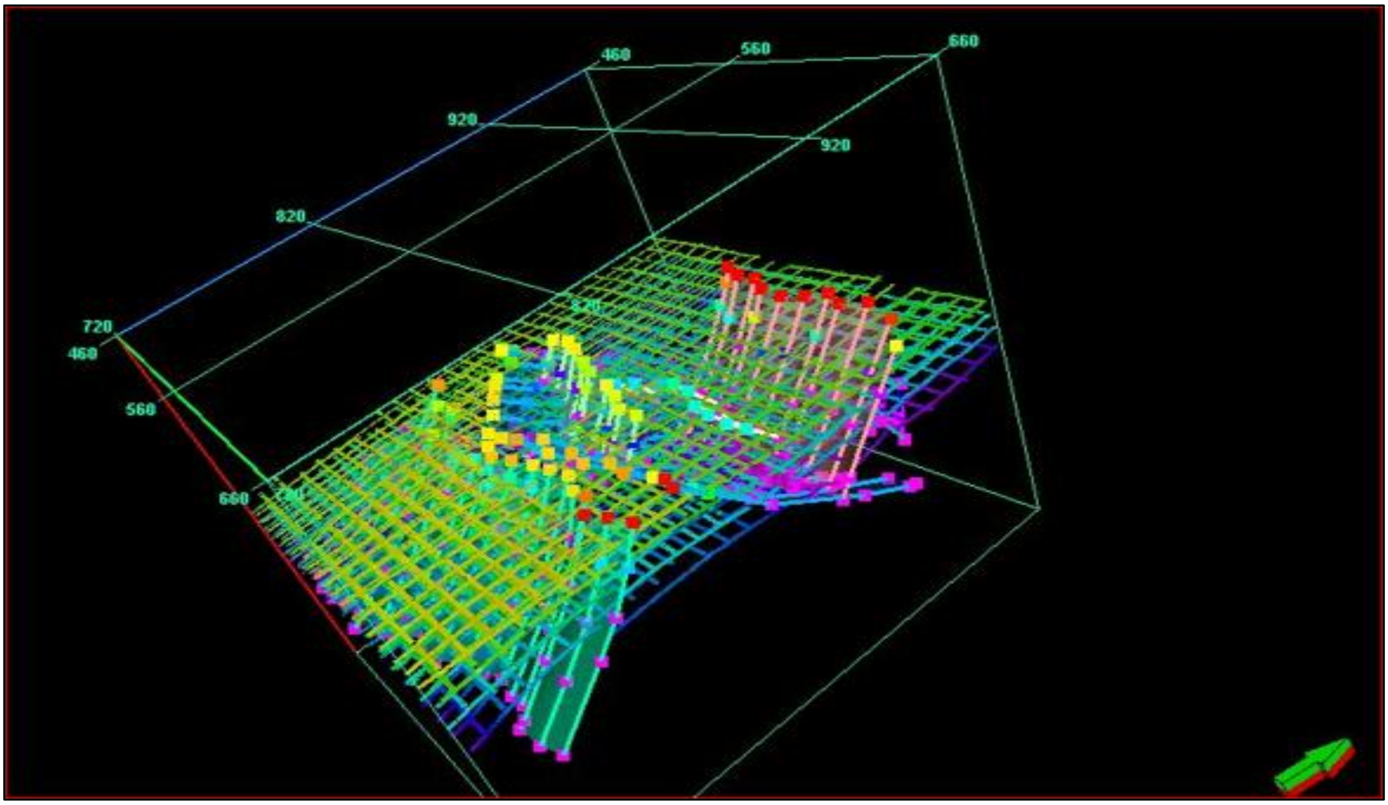

Fig 8: Diagram Showing the Interpreted Horizon Picks and Fault Sticks

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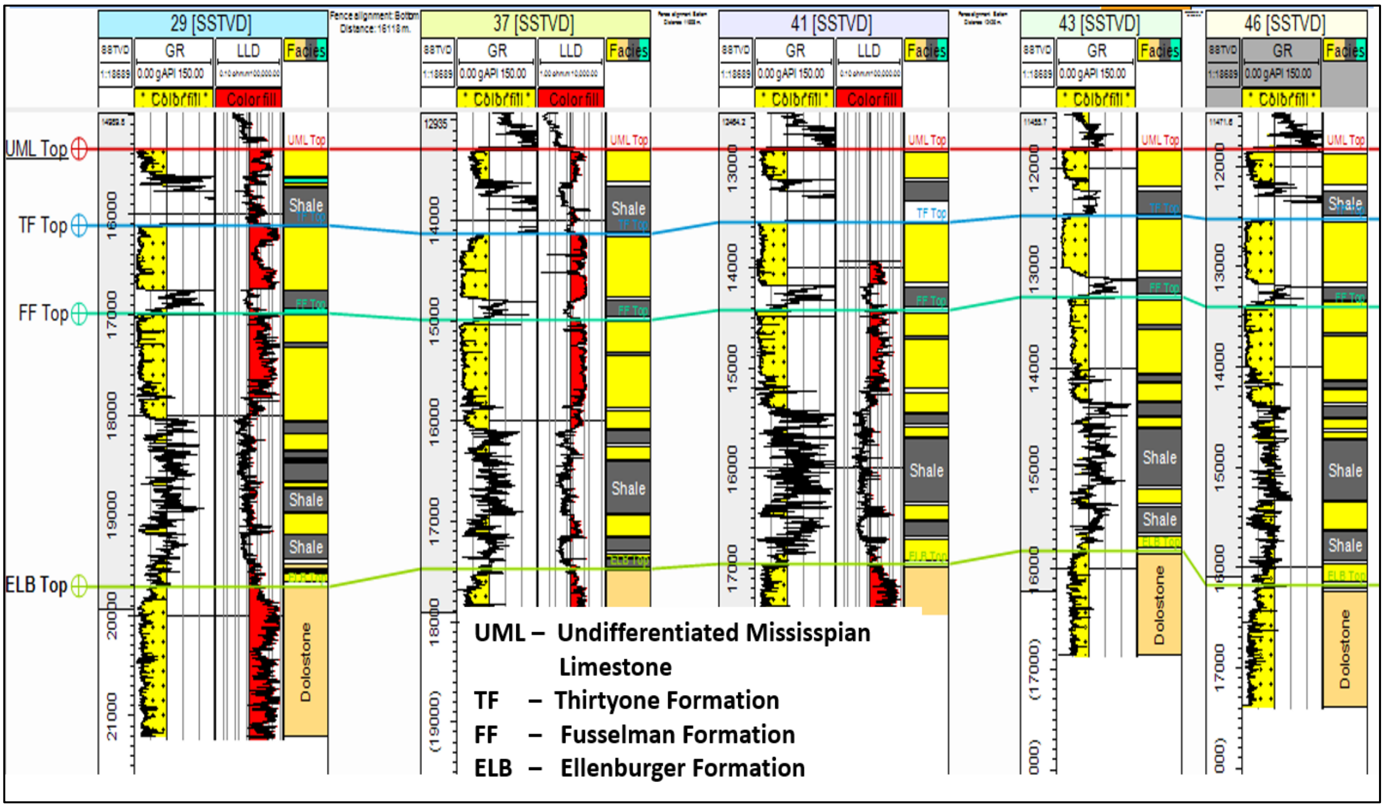

Fig 9: Well-Log Sequence Stratigraphic Interpretation using Galloway 1989 Depositional Sequence Model

V. HORIZON MAPPING AND STRUCTURAL ANALYSIS

A. Horizon Identification and Mapping:

- Horizon Labels: Four Key Horizons were Identified and Mapped Across the Seismic Volume:

✓ UML Top
✓ TF Top
✓ FF Top
✓ ELB Top (see Figure 4.1 for a visual representation of these horizons).

➢ *3D Grid Generation:*

The horizon mapping was displayed as a 3D grid, which was instrumental in creating structural maps of the reservoirs. This 3D grid allowed for the detailed visualization of the spatial distribution of the horizons.

B. Time and Depth Conversion:

- **Time Surface Maps**: The time surface maps generated for each horizon were depth converted to align with drilling operations, which occur in the depth domain.
- **Conversion Method**:

✓ A **Third-Order Polynomial Function** was used for the time-to-depth conversion. This method ensures a more accurate conversion of time structure maps to depth, reflecting the true subsurface conditions.

✓ The forecast area for depth conversion was set at 400 by 400 units (see Figure 10).

- **Time Structure Maps**: Figures 11 and 12 show the time structure maps for the two mapped horizon surfaces. These maps illustrate the time-based configuration of the horizons before conversion to depth.
- **Depth Structure Maps**: The depth maps, generated from the converted time maps, reveal the structural closures within the reservoirs. These closures are crucial for identifying potential hydrocarbon traps.

C. Structural Features:

- **Structural Closures**: The depth maps show significant structural closures that are primarily two-way fault-dependent closures. These closures are important because they represent areas where hydrocarbons could accumulate, especially if the faults act as seals.
- **Fault Influence**: The structural closures observed are influenced by faulting, with some faults acting as seals that trap hydrocarbons. Faults also facilitate hydrocarbon migration, suggesting that hydrocarbon migration paths are likely through these faults and within the carrier beds.
- **Hydrocarbon Accumulation**: Potential hydrocarbon accumulation sites are identified where the depth maps show closures, particularly where faults are sealing. These closures provide favorable conditions for trapping hydrocarbons, making them prime targets for further exploration and drilling.

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The horizon mapping and structural analysis reveal important details about the subsurface geology of the West Waha and Worsham-Bayer fields. The conversion of time maps to depth maps allows for a more accurate assessment of the structural configuration and potential hydrocarbon traps. The identification of structural closures, particularly those influenced by faulting, highlights areas with significant potential for hydrocarbon accumulation.

The observed structural closures, dependent on fault seals, suggest that hydrocarbon migration and accumulation are likely to occur in these areas. This understanding is crucial for optimizing exploration and drilling strategies, as it directs efforts towards locations with the highest potential for successful hydrocarbon production.

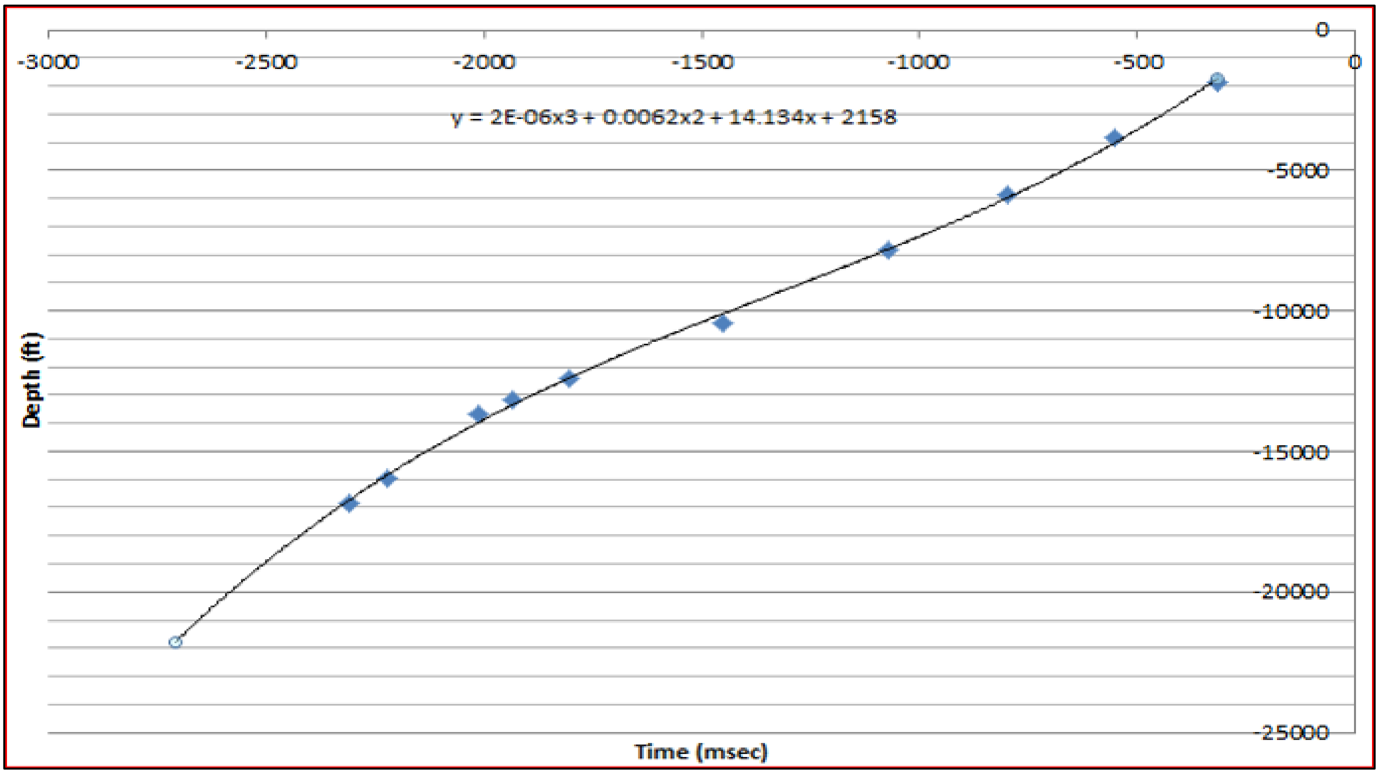

Fig 10: Third Order Polynomial Function Created for Tz with a Forecast of 400 by 400 Formation

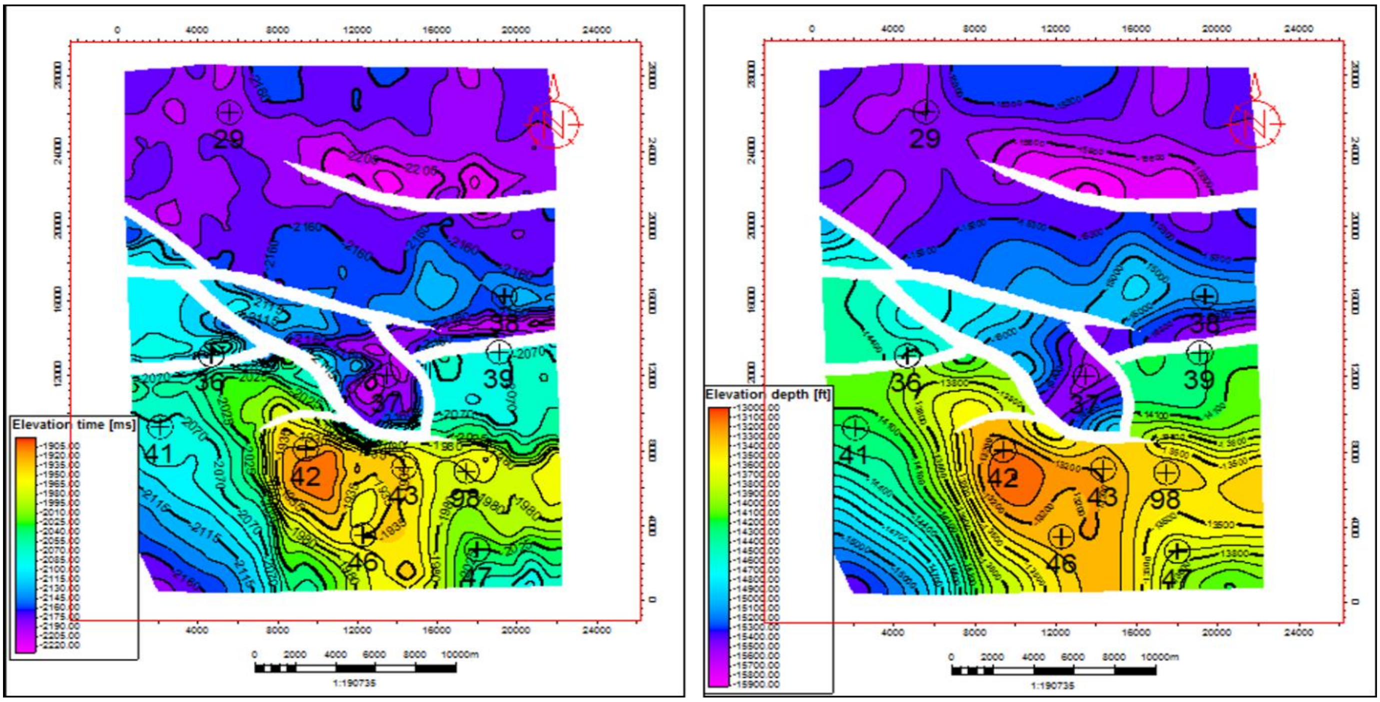

Fig 11: (a) Time Structure Map for the Fusselman Formation. (b) Depth Structure of the Fusselman Formation

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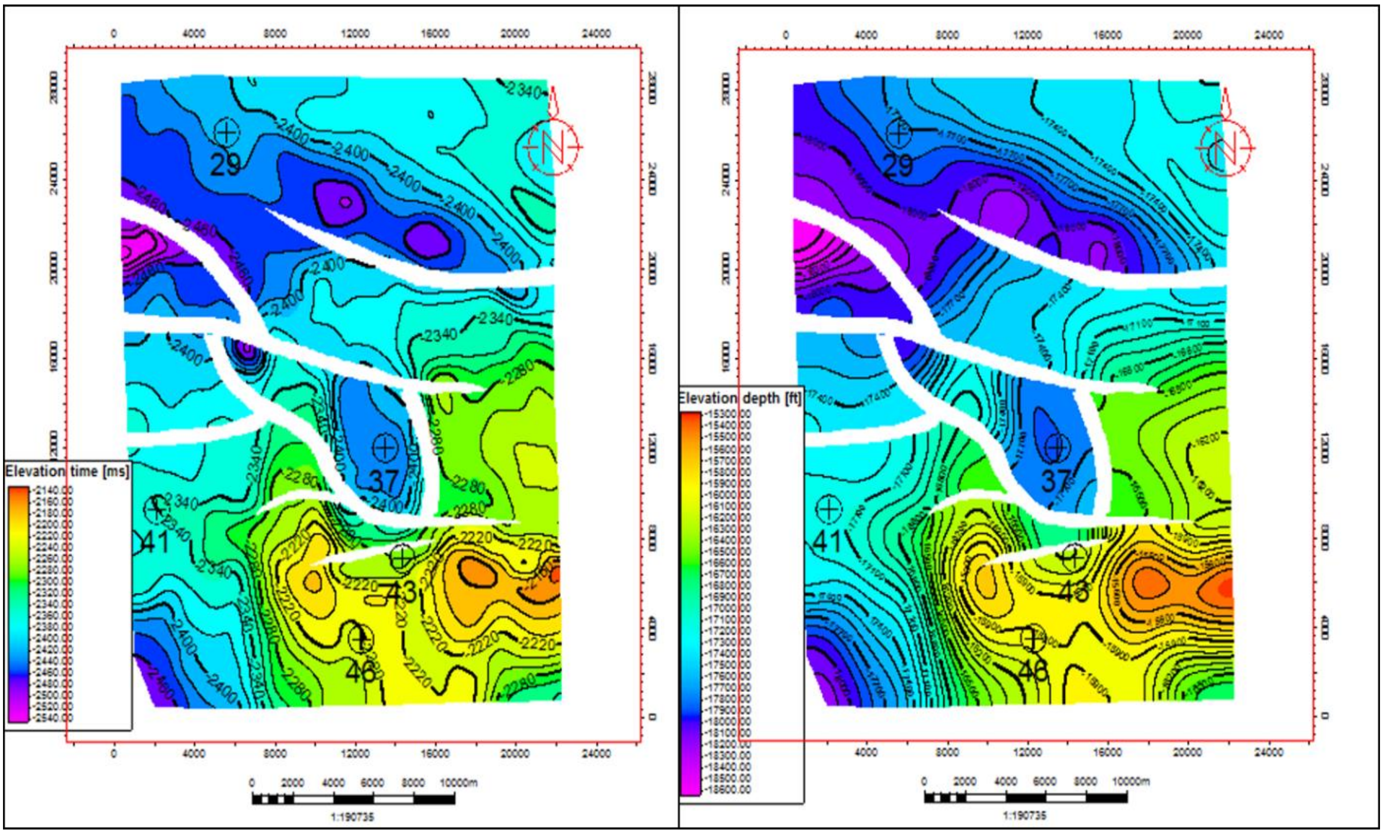

Fig 12: (a) Time Structure Map of the Ellenburger Formation. (b) Depth Structure of the Ellenburger Formation

From the Ellenburger formation targets we identified that there 2 deeper targets for Well 42 and 98 (see figure 13). The production data provided showed the productivity profiles of the wells that penetrated the Ellenburger formation (see figure 14).

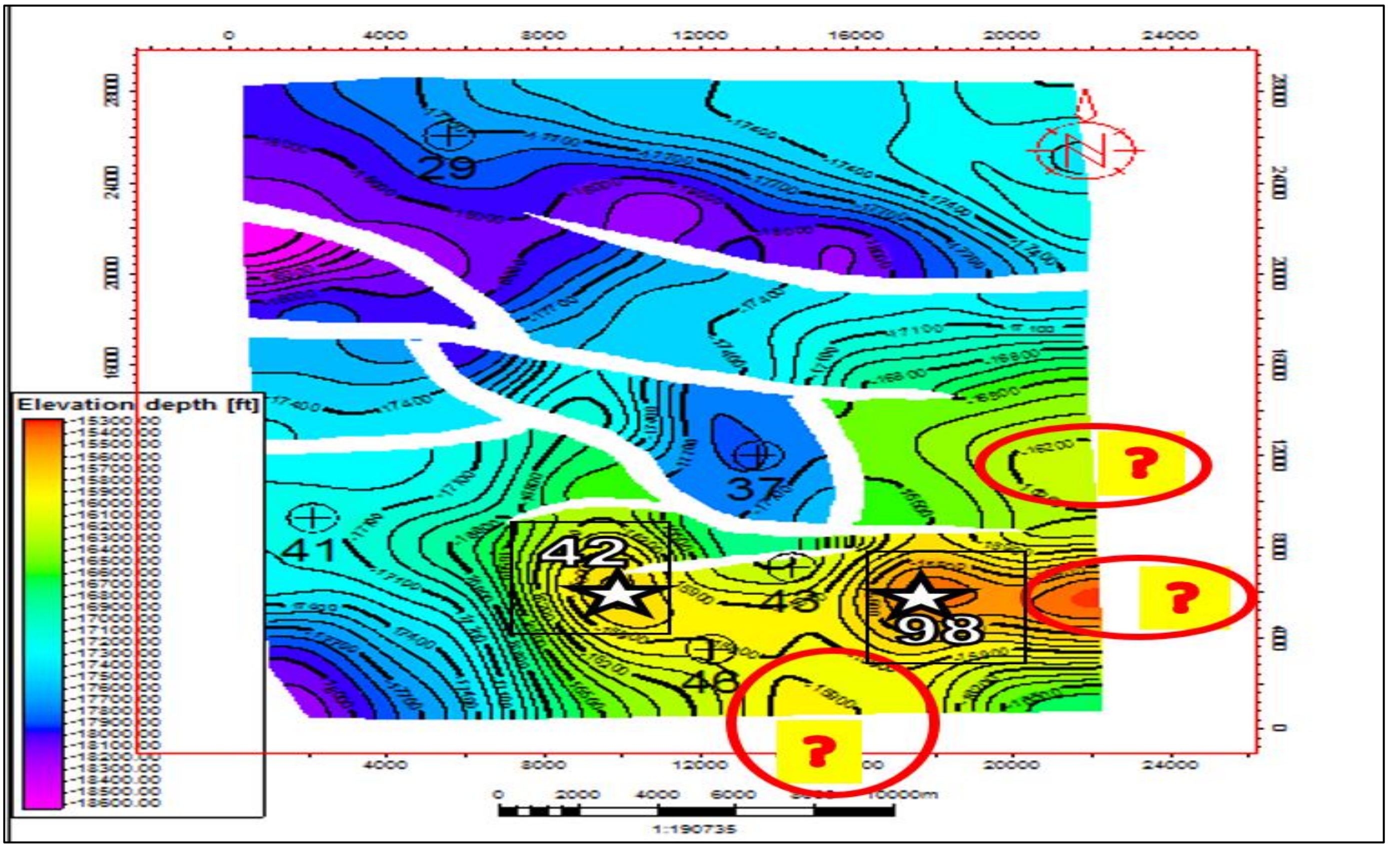

Fig 13: Ellenburger Formation Top with Well Insert (Wells 42 and 98) Deeper Targets Position

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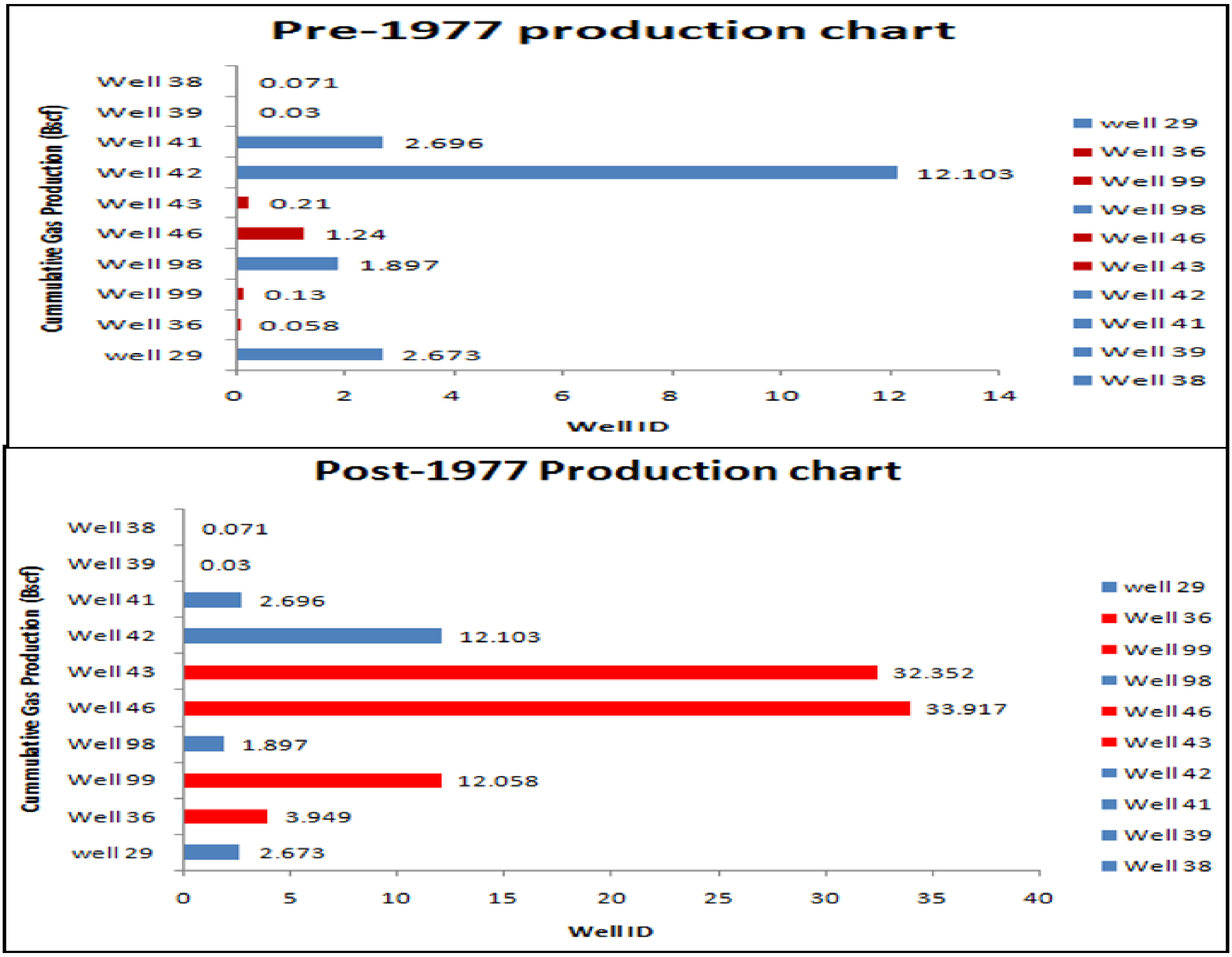

Fig 14: Production Profiles of Wells that Penetrated the Ellenburger Formation

VI. PETROPHYSICAL PARAMETERS AND VOLUMETRIC ASSESSMENT

A. Petrophysical Parameters Analysis

Petrophysical parameters for Well 29 were analyzed to evaluate the characteristics and quality of the reservoirs in the West Waha and Worsham-Bayer fields. The key parameters examined include porosity, permeability, and water saturation, which are critical for assessing hydrocarbon potential and reservoir quality.

B. Reservoir Analysis:

➢ *UML Reservoir:*

- Porosity: Moderate
- Permeability: Moderate
- Water Saturation: Relatively High
- Interpretation: The moderate porosity and permeability suggest that the UML reservoir has some potential for hydrocarbon production, but the high water saturation indicates a significant amount of water in the pore space, which may affect overall productivity.

➢ *TF Reservoir:*

- Porosity: High
- Permeability: High
- Water Saturation: Moderate
- Interpretation: The high porosity and permeability of the TF reservoir, combined with moderate water saturation, suggest good potential for hydrocarbon production. This reservoir is likely to be productive and has favorable characteristics for extraction.

➢ *FF Reservoir:*

- Porosity: High
- Permeability: High
- Water Saturation: Moderate
- Interpretation: Like the TF reservoir, the FF reservoir's high porosity and permeability indicate good hydrocarbon potential and productive capacity. The moderate water saturation suggests that while there is some water presence, it is manageable.

➢ *ELB Reservoir:*

- Porosity: Very High
- Permeability: Very High
- Water Saturation: Low
- Interpretation: The ELB reservoir stands out with very high porosity and permeability, coupled with low water saturation. This combination indicates an excellent potential for hydrocarbon production and high-quality reservoir rock. The low water saturation enhances the attractiveness of this reservoir as it implies less water interference and more space for hydrocarbons.

The petrophysical parameters provide a clear picture of each reservoir's characteristics. The ELB reservoir is identified as the most promising for hydrocarbon production due to its very high porosity, high permeability, and low water saturation. The other reservoirs also show potential, with the TF and FF reservoirs being particularly noteworthy for their good hydrocarbon-producing qualities.

C. Volumetric Assessment

A volumetric assessment was performed to quantify the estimated hydrocarbon reserves in the reservoirs. This assessment provides an estimate of the total amount of hydrocarbons that can be recovered from the field. The results of the volumetric assessment are summarized in Table 2.

(Note: Replace "[Insert Value]" with actual values obtained from the volumetric assessment.)

The volumetric assessment results confirm the potential identified through petrophysical analysis. The ELB reservoir, with its superior petrophysical properties, is expected to have the highest estimated reserves, aligning with its identified potential for high-quality hydrocarbon production. The TF and FF reservoirs also show substantial reserves, supporting their favourable production characteristics. The UML reservoir, while having moderate parameters, still contributes to the overall reserve estimates but may require additional strategies to manage its water saturation.

By combining the insights from petrophysical parameters with volumetric estimates, reservoir engineers and geologists can design effective development strategies to optimize hydrocarbon extraction. The ELB reservoir is positioned as the key target for future exploration and production efforts due to its exceptional reservoir qualities.

Table 1: Calculated Petrophysical Parameters for Well 29

Reservoir	Gross (ft)	Net (ft)	Average NTG	Porosity (%)	Sw	Permeability (mD)
UML	256.28	201.14	0.78	14	0.42	107.23
TF	630.83	505.32	0.80	20	0.35	171.20
FF	216.85	196.23	0.90	19	0.40	143.11
ELB	1498.22	1231.32	0.82	22	0.20	205.5

Table 2: Calculated Volumetric Assessment for Well 29

Reservoir	GRV (Acre ft)	Average NTG	Porosity (%)	Sw	FVF	GIIP (BCF)
UML	1087.78	0.78	14	0.42	0.0034	19,176
TF	842.50	0.80	20	0.35	0.0034	10,688
FF	527.98	0.90	19	0.40	0.0034	22,544
ELB	1362.69	0.82	22	0.20	0.0034	62,201
Total						**114,607**

➢ *Geologic Chance of Success*

- **Source:** Wordford Shale = 1
- **Reservoir:** Ellenburger Fm = 0.80
- **Trap:** Anticlinal = 1
- **Seal:** Simpson Shale = 1
- **Well count: 4** = 1
- **Chance of success** = 0.80

VII. CONCLUSION

The West Waha and Worsham-Bayer fields exhibit substantial hydrocarbon potential, with the ELB reservoir emerging as the most promising for high-quality production. The integration of petrophysical data, structural interpretations, and volumetric assessments provides a solid foundation for optimizing exploration and production strategies. By addressing the recommendations for deeper drilling, enhanced seismic data acquisition, improved seismic resolution, detailed 3D modeling, and fault-seal analysis, the field's hydrocarbon recovery can be significantly increased. These efforts will contribute to extending the economic life of the reservoirs and maximizing the field's production potential.

Deep Delaware hydrocarbon play- Val Verde Older Paleozoic has been identified to be one of the major hydrocarbon play within the field. Four reservoirs, one major source rock, inter-reservoir seals and down to basin faults acting as Migration pathway were recognized within the field. Two deeper targets were identified within the deeper Ellenburger Formation:

- Well 42 Deep
- Well 98 Deep

➢ *The Deeper Ellenburger Formation is a of HighStand System Tract and it is Recommended that:*

- Wells 42, and 98 should be drilled deeper to increase production
- More 3D Seismic data should be acquired basin ward (South-Eastern Direction)
- Improved seismic resolution should be used to understand facie distribution
- A 3D modeling of the reservoir to incorporate fracture networks, their initiation and distribution pattern to improve yield.
- Fault-seal analysis should be carried out to obtain detailed information on the effect of faulting on the juxtaposition of the formations and hydrocarbon migration.

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