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Integrated Approach to Well Revitalization Using Reentry and Geosteering in the Zelten Field, Sirte Basin, Libya

Mohsen Al Mabrouk[1] and Saleh Emhanna[2]

1. Sirte Oil Company - Libya
2. Petroleum Engineering Department, Ajdabiya University- Libya
Email: Mohsenbarca16@gmail.com

Abstract

This project evaluates an integrated reentry drilling and geosteering strategy to enhance oil recovery in the mature Zelten Field, located in the Sirte Basin, Libya. The field is characterized by challenges such as reservoir depletion, thin hydrocarbon columns (~10 ft), high water cuts (up to 90%), and aging vertical well infrastructure. The main objective is to address these limitations by combining reentry drilling with geosteering to increase reservoir contact, reduce water production, and optimize hydrocarbon recovery, while also assessing the economic feasibility through well performance and payback analysis. To achieve this, Petrel and OFM software were utilized for reservoir modeling, visualization of reservoir geometry, simulation of production scenarios, and identification of optimal reentry points forming a data-driven decision-making framework.
The approach involved sidetracking existing wells (X1-6 and X2H-6) and applying advanced real-time geosteering techniques. The results demonstrated significant production improvements: reentry wells stabilized between 300 and 700 BOPD, with water cuts reduced to 5.5–35%, while a new horizontal geosteered well (X3H-6) achieved an initial rate of 4,781 BOPD with zero water cut. Productivity indices significantly increased, and economic analysis indicated short payback periods, confirming the cost-effectiveness of this approach. Overall, the integration of reentry and geosteering technologies presents a viable solution for revitalizing mature carbonate reservoirs, extending field life, and improving operational efficiency.

Keywords: Zelten Field, Reentry, geosteering, Carbonate reservoirs, Sidetracking

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النهج المتكامل لإحياء الآبار باستخدام إعادة الدخول والتوجيه الجيولوجي في حقل زلطن، حوض سرت، ليبيا

محسن علي المبروك[1] و صالح أمحمد أمهنى[2]

1. شركة شرت لإنتاج وتصنيع النفط والغاز – ليبيا
2. قسم الهندسة النفطية – كلية الهندسة – جامعة أجدابيا – ليبيا

ملخص

تُقيّم هذه الدراسة استراتيجية متكاملة لإعادة الدخول إلى الآبار والتوجيه الجيولوجي (Geosteering) بهدف تعزيز إنتاج النفط في حقل زلطن الناضج، الواقع في حوض سرت بليبيا. يواجه الحقل عدة تحديات، منها نضوب المكامن، ووجود أعمدة هيدروكربونية رقيقة (حوالي 10 أقدام)، وارتفاع نسبة المياه المصاحبة (حتى 90%)، بالإضافة إلى البنية التحتية القديمة للآبار الرأسية. تهدف هذه الاستراتيجية إلى التغلب على تلك التحديات من خلال دمج إعادة الدخول مع التوجيه الجيولوجي لزيادة التماس مع المكمن، وتقليل إنتاج المياه، وتحقيق أفضل استرجاع للنفط، إلى جانب تقييم الجدوى الاقتصادية عبر تحليل أداء الآبار وفترة الاسترداد .تم أُستخدم برنامجا Petrel و OFM في نمذجة المكمن، وتصوّر تركيبه الجيولوجي، ومحاكاة السيناريوهات الإنتاجية، وتحديد نقاط إعادة الدخول المثلى، مما شكّل إطاراً لاتخاذ قرارات مبنية على البيانات. شمل النهج حفر آبار جانبية من آبار قائمة (X1-6 وX2H-6) واستخدام تقنيات توجيه جيولوجي متقدمة في الوقت الحقيقي. أظهرت النتائج تحسناً ملحوظاً في الإنتاج؛ حيث استقر إنتاج آبار إعادة الدخول بين 300 و700 برميل نفط يوميًا، وانخفضت نسب المياه إلى ما بين 5.5% و35%، في حين سجل البئر الأفقي الجديد الموجه جيولوجيًا (X3H-6) معدل إنتاج أولي بلغ 4,781 برميل يوميًا بدون مياه مصاحبة. كما شهدت مؤشرات الإنتاجية تحسناً كبيرًا، وأكد التحليل الاقتصادي قصر فترة الاسترداد، مما يبرهن على جدوى هذا التوجه من حيث الكفاءة والتكلفة. بشكل عام، يُظهر دمج تقنيات إعادة الدخول والتوجيه الجيولوجي فعالية كبيرة في إحياء المكامن الكربوناتية الناضجة، وتمديد عمر الحقول، وتحسين الكفاءة التشغيلية.

الكلمات المفتاحية :حقل زلطن، إعادة دخول، التوجيه الجيولوجي، المكامن، الحفر الجانبي

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1. Introduction

Reentry drilling has become a critical technique for enhancing production and extending the life of mature oil fields. By reusing existing wellbores, this approach significantly reduces drilling costs and environmental impact compared to drilling new wells, while offering a practical means to tap into remaining reserves (Ahmed, 2010; Economides and Wattenbarger, 2017). Reentry operations are particularly valuable in declining fields where infrastructure is already in place, and targeted intervention can yield substantial production gains (Jin et al., 2019). However, achieving success in such operations requires addressing complex subsurface challenges using advanced technologies most notably geosteering, which enables precise control of the well trajectory to maintain contact with productive intervals in real time (Zou and Fan, 2018). Despite expected future advancements, reentry drilling is anticipated to remain a vital strategy for sustaining production in legacy fields such as those in the Sirte Basin (Emhanna et al., 2020).

A prime example is the Zelten Field, the largest oil field in the Gulf of Sidra, Libya. The Zelten Field is a mature carbonate reservoir within a structural high of the Sirte Basin and has been producing for over 60 years (Hallett and Clark-Lowes, 2016). However, its productivity has declined in recent years due to reservoir depletion, water encroachment, and outdated vertical well infrastructure. Despite these challenges, considerable untapped reserves remain, particularly in Layer 4 of the Zelten Porosity. This layer contains slender hydrocarbon columns supported by active aquifers conditions that render conventional vertical wells ineffective for achieving high recovery.

The Zelten Formation is stratigraphically divided into three main units: the Upper Zelten (Zelten Member), the Zelten Porosity (Layers 4 and 5), and the Lower Zelten. Layer 4, the focus of this study, is the primary pay zone in the late stage of the field's development. It is lithologically composed of coralgal micrite, argillaceous molluscan micrite, and Discocyclina-foraminiferal calcarenite facies. Layer 4 exhibits favorable reservoir characteristics, including a thickness ranging from 16 to 56 feet, porosity values between 15% and 20%, and permeability between 50 and 300 mD (Belhaj et al., 2024). Nevertheless, its narrow productive interval and the presence of strong aquifer support create a highly challenging environment for oil recovery using traditional methods.

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To address these technical limitations, an integrated development approach combining reentry drilling and geosteering has been applied in selected wells within the Zelten Field. Reentry operations enable access to bypassed reserves through sidetracking existing wells, while geosteering ensures optimal placement within the thin pay zones. This combination not only improves reservoir contact but also enhances hydrocarbon recovery and reduces water production. In the Zelten Field, these techniques have been successfully applied in the reentry and sidetracking of horizontal wells (e.g., X1-6 and X2H-6), as well as in a vertical-to-horizontal conversion and new horizontal drilling (e.g., X3H-6).

The need for such advanced methods is underscored by the fact that Layer 4 is technically demanding: it averages only 10 feet in thickness and exhibits water cuts as high as 90% in some wells. These conditions have led to premature shut-in of several vertical wells and significant reservoir productivity loss. Traditional drilling practices are insufficient to manage these complexities, reinforcing the need for high-resolution steering technologies and refined drilling strategies.

In this context, geosteering has proven indispensable for the development of thin and structurally complex reservoirs (Fig, 1). It allows for continuous adjustments to the drilling trajectory in real time, thereby maximizing productive interval exposure and mitigating the risks associated with poor well placement (Aadnøy and Cooper, 2019). The integration of geosteering with reentry drilling represents a modern solution for rejuvenating mature fields.

Accordingly, this study aims to:

- Evaluate the technical challenges and production limitations associated with developing Layer 4 in the Zelten Field, particularly in the context of thin hydrocarbon zones and high water cut؛
- Assess the effectiveness of combining reentry drilling with geosteering to improve reservoir exposure, reduce water production, and enhance oil recovery; and
- Analyze the economic feasibility of this integrated approach by examining case studies of selected wells, with emphasis on production performance, payback periods, and return on investment.

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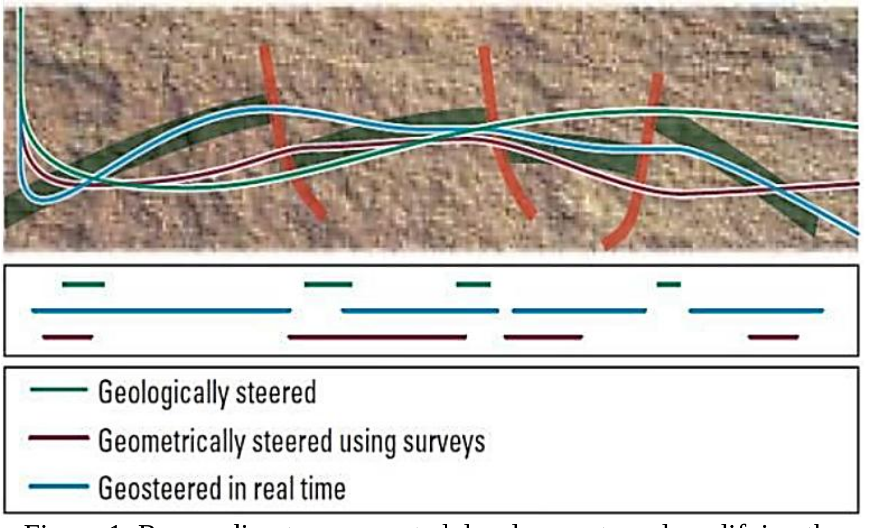

Figure 1: Responding to unexpected developments and modifying the drilling trajectory (Kootiani, 2014).

Through this evaluation, the study contributes to ongoing efforts to optimize recovery from mature fields using innovative, cost-effective, and field-proven techniques.

2. Methodology

To effectively model the reservoir and evaluate the impacts of re-entry drilling, two specialized software applications will be employed: Petrel and OFM. These tools provide advanced capabilities for:

- Visualizing well spacing, fault networks, and the overall geometry of the reservoir.
- Constructing extraction and production maps to simulate changes in reservoir performance.
- Identifying the most suitable locations for well re-entry based on predictive analysis.

The integration of these software solutions ensures a comprehensive and data-driven approach to optimizing reservoir development and enhancing hydrocarbon recovery.

3. Results and Discussion

This study was conducted on three wells in the Zelten Field, specifically targeting Layer 4. It included two reentry wells and one newly drilled well (Fig, 2). The objective was to evaluate the

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effectiveness of advanced drilling techniques in a challenging reservoir characterized by thin pay zones and high water production.

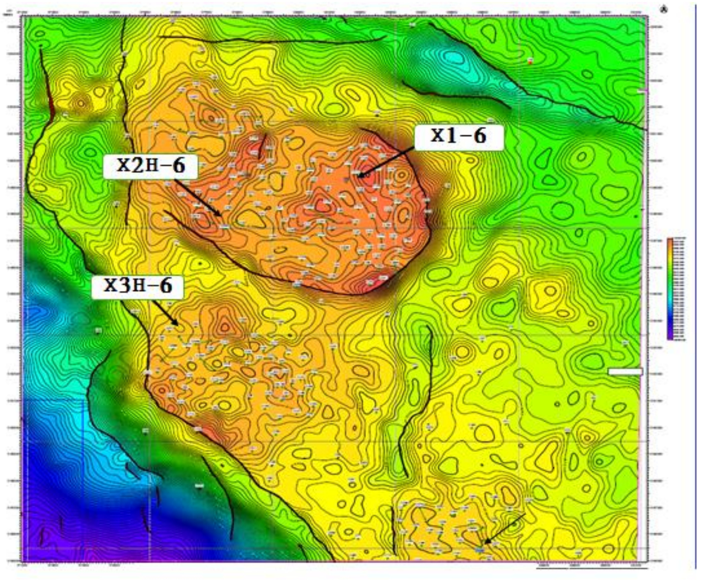

Figure 2: Structure map of the Top Zelten horizon indicating the locations of the selected wells used in this study (Prepared by the authors).

3.1 Well X1-6

3.1.1 Well X1-6 Summary

Well X1-6 was drilled and completed as an open hole oil producer targeting the Zelten Porosity in November 1961. Initial production was 3,100 bopd (Barrels of Oil per Day) with 0% water cut. By May 1965, production peaked at over 20,000 bopd, still with 0% water cut. The well has been shut-in since 2014, with cumulative oil production totaling 44.04 MMSTB (Million Standard Cubic Feet of Gas per Day). At the time of shut-in, the well was producing 260 BOPD with 80% water cut. All nearby offset wells are also currently shut-in. This well is planned to be drilled as a reentry well by opening a widow in 7" casing and be completed as horizontal well on top of the Zelten Porosity layer as it is shown in the attached.

3.1.2 Well X1-6 Reentry and Sidetrack Trajectory Plan

Well X1-6 was originally drilled in 1961 as an open-hole producer targeting the Zelten Porosity, with peak production reaching over 20,000 bopd and a cumulative output of 44.04 MMSTB before being shut-in in 2014 due to high water cut. As part of the 2023

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drilling program, a reentry and sidetrack operation is planned to restore production.

The plan includes setting a whipstock at 4,030 ft inside 7” casing, building angle to 89.65° to reach a horizontal section starting at 6,350 ft MD, and continuing to 7,988 ft MD with a 1,639 ft lateral. A 5” liner and gas lift system will be installed (Fig, 3). The use of horizontal drilling and geosteering aims to maximize reservoir contact and enhance recovery from the Zelten Porosity (Fig, 4).

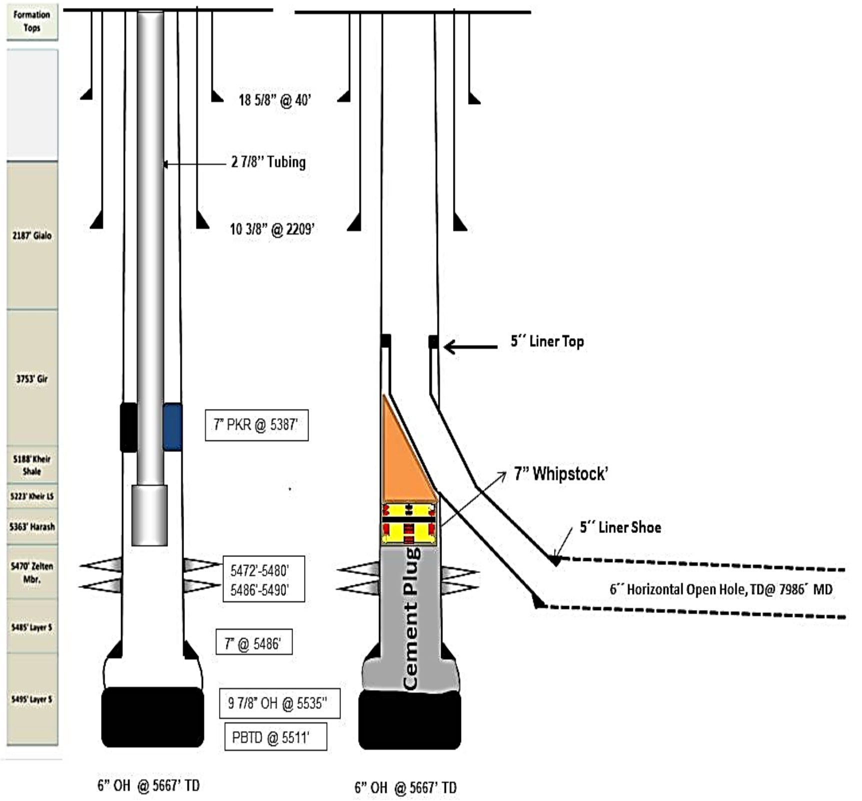

Figure 3: Wellbore Schematic Showing Pre- and Post-Reentry Design for reentry Operation for the X1-6 Well (Edited by the authors).

Figure 4 presents a comprehensive geosteering and formation evaluation log for a horizontal well drilled into Layer 4, the designated target reservoir. The top section illustrates the geological cross-section with color-coded formations, including multiple Harash sublayers and the Zelten Member, along with the actual wellbore trajectory and planned path. The “No Go Zone” is marked below 5020 ft TVDSS to avoid unproductive or risky intervals.

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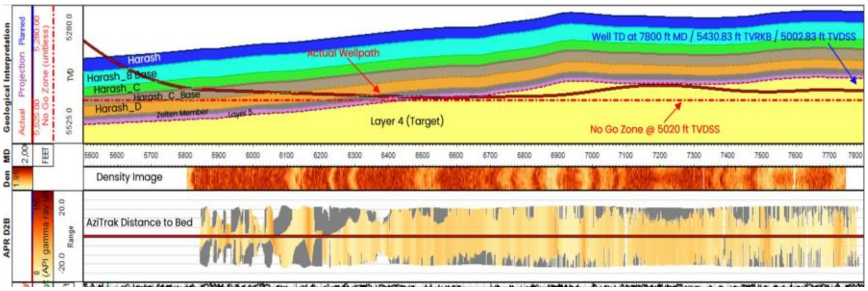

Figure 4: Geosteering Log of Layer 4 in the horizontal section in the X1-6 Well (Edited by the authors).

3.1.3 Petrophysical Analysis of Well X1-6 (Zelten Member, Layer 4)

A detailed petrophysical analysis was conducted on Well C39-6 within Layer 4 of the Zelten Member, utilizing a suite of wireline logs, including Gamma Ray (GR), Resistivity, Density, and Neutron Porosity logs (Fig, 5).

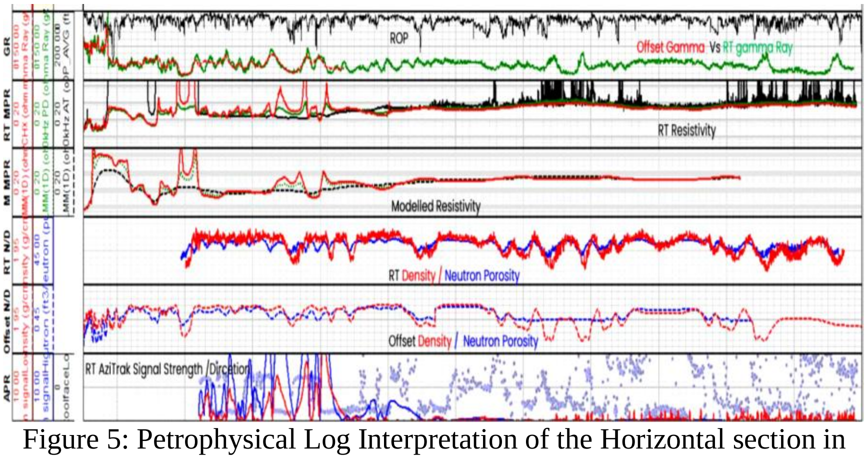

Figure 5: Petrophysical Log Interpretation of the Horizontal section in the Well X1-6 in Layer 4, Zelten Member (Edited by the authors).

The shale volume (Vsh) was calculated using the GR log through the standard linear equation:

$$Vsh = \frac{(GR\_\log - GR\_clean)}{(GR\_shale \quad - GR\_cleane)}$$

For example, assuming GR_log = 70 API, GR_clean = 30 API, and GR shale = 110 API, the resulting Vsh is 0.50. Across the logged interval, the shale volume ranges from 0.1 to over 0.6, with an average of approximately 0.35.

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Porosity was derived from both Density and Neutron logs, where clean Limestone intervals showed consistent log overlap, indicating hydrocarbon-bearing zones. The interpreted porosity ranges between 8% and 28%, with an average of around 20% in productive intervals.
The gross reservoir thickness is estimated at 140–150 ft. Applying cutoff criteria of GR < 75 API, Vsh < 0.4, and porosity > 10%, the calculated net pay thickness is 118.3 ft. Lithologically, the section comprises interbedded limestone and shale, with limestone serving as the primary reservoir rock. Overall, the petrophysical parameters suggest fair to good reservoir quality, with zones of clean Limestone, moderate to high porosity, and significant hydrocarbon potential.

3.1.4 Production Performance of the X1-6 Well

The production history of Well X1-6 spans from 1961 to 2025, showing distinct phases of performance. During the initial depletion phase (1961–1966), the well achieved peak rates of 24,455 bopd of oil and 12,016 MCF/d of gas in 1964, with negligible water cut, indicating excellent reservoir conditions. From 1967 to 1973, performance declined due to increasing water cut (up to 83%) and pressure depletion.
The well was intermittently shut in during low-price periods (1973–1974, 1994–2022) and resumed under various revitalization efforts. After a 2023 reentry, production stabilized at 700 bopd oil, 500 MCF/d gas, and 5.5% water cut. A surface test on 26 December 2024 (Table 3.1) reported a wellhead pressure of 254 psig and reservoir pressure of 2250 psia (Fig, 6).

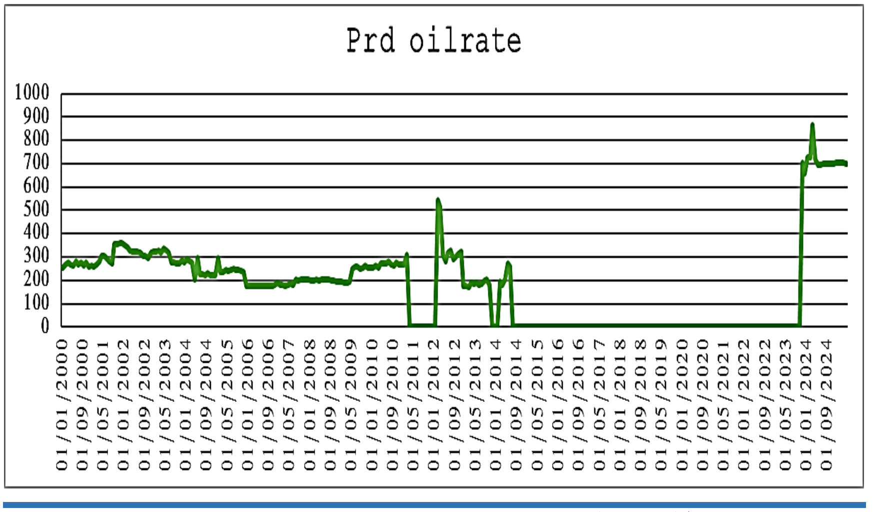

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Figure 6: Well X1-6 performance before and after reentry (Prepared by the authors).

Table 1: Post-reentry surface test data for Well X1-6.

Main Results							
Date	Well Head				Fluid Properties		
26-Dec-24	Choke	WHP (Psig)	WHT (°C)	Sep. P (Psig)	Q Oil (bopd)	Q Gas (Mscf/d)	Q Water (bwpd)
	40"	254	43.89	121	700	500	35

- **Productivity Index (PI) Calculation:**

$$PI = \frac{q}{P_r - P_{wf}}$$

Where:
q: Production rate (STB/day) = 700, STB/day
Pr: Reservoir pressure (psia) =2250, psia
Pwf: Bottomhole pressure (psia) =1820 psia

$$P_i = \frac{\mathbf{700}}{\mathbf{2250 - 1820}} = \mathbf{1.62\,STB/day\,/psi}$$

PI=$\mathbf{1.62}\,\boldsymbol{STB/day\,/psi}$ indicating moderately productive well under current conditions.

3.2. Well X2H-6

3.2.1 Well X2H -6 Summary

Well X2H -6, completed in 1999 as a horizontal producer in the Zelten Porosity, initially yielded 550 bopd with 75% water cut but declined to 20 bopd and 98% water cut by 2001, leading to shut-in in 2003 after producing only 0.3 MMstb. Nearby wells showed significantly better performance, indicating localized reservoir issues. A reentry was conducted using geosteering and GyroSphere tools, drilling a new horizontal section at 265°N (original was 228°N) to access more productive zones (Fig, 7). The well reached 7,176 ft MD, successfully applying modern technology to revitalize this mature North Zelten asset.

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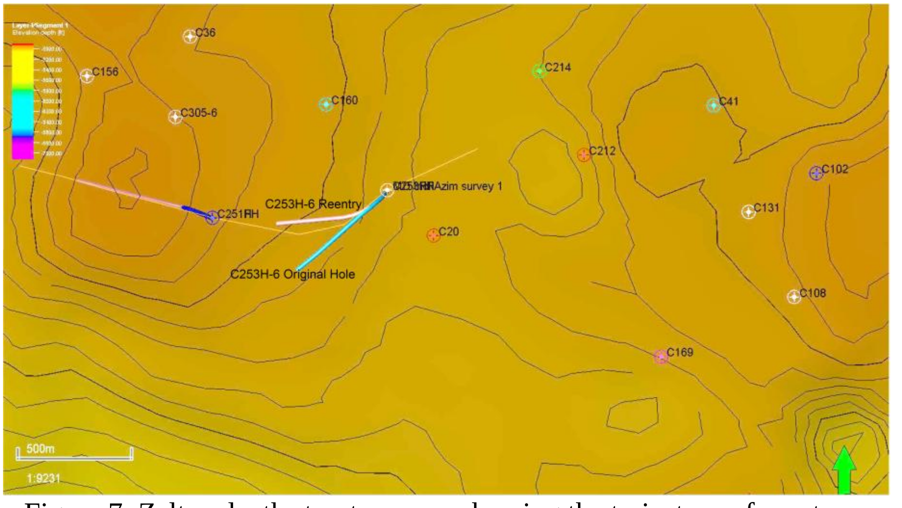

Figure 7: Zelten depth structure map showing the trajectory of reentry Well X2H -6 (Edited by the authors).

3.2.2 Trajectory of Well X2H -6

The 2021 reentry of Well X2H-6 aimed to enhance reservoir contact and recover bypassed hydrocarbons in the Zelten Formation. The original trajectory was abandoned due to poor performance, and a sidetrack was drilled from a new kickoff point at 5,725 ft MD. The new trajectory included a horizontal section starting at 6,033 ft MD and ending at 7,116 ft MD, guided by geosteering tools like the GyroSphere system (Fig, 10). The well was completed with 3½" tubing, an ESP at 5,608 ft MD, and flow control devices. This operation improved well placement and productivity through optimized trajectory planning.

3.2.3 Petrophysical analysis of the X2H-6 (Zelten Member, Layer 4)

The analyzed interval displays a predominantly Limestone lithology, as indicated by consistently low gamma ray readings and supported by the inversion model in the curtain section. Interbedded shale layers are evident from occasional spikes in gamma ray values, suggesting the presence of thin shaly intervals. The calculated shale volume (Vsh) ranges mostly between 10% and 30%, with an average around 20–25%, reflecting relatively clean reservoir sands with minimal clay content.

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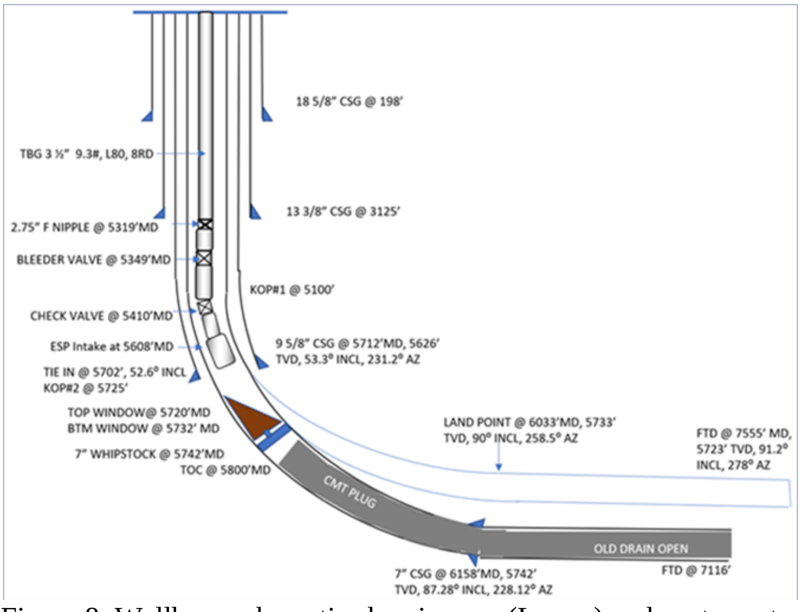

Figure 8: Wellbore schematic showing pre (Lower) and post-reentry (Upper) design for sidetracking operation for X2H -6 Well (Prepared by the authors).

The gross thickness of the interpreted reservoir zone spans approximately 100 feet, extending from 5700 to 5800 feet true vertical depth (TVD), as observed on the curtain section. Within this interval, the net thickness - representing the cumulative thickness of productive, clean Limestone -was estimated to be about 75–80 feet, yielding a high net-to-gross ratio of approximately 0.75 to 0.8.

Porosity analysis from the GeoSphere inversion model indicates values ranging between 6% and 22%, with clean sand layers typically exhibiting porosities in the range of 14–20%. The average porosity for the interval is calculated at approximately 16–18%, which is consistent with good-quality Limestone reservoirs.

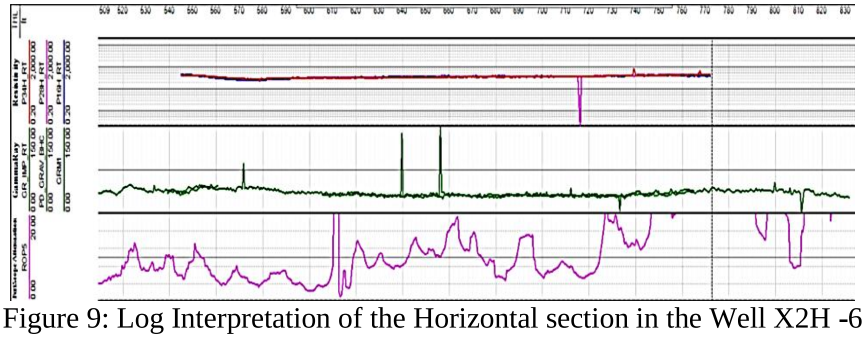
Figure 9: Log Interpretation of the Horizontal section in the Well X2H -6 in Layer 4, Zelten Member (Edited by the authors).

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3.2.4 Production Performance of the X2H-6 Well:

Well X2H-6 demonstrated two distinct production phases before and after reentry. Initially, from 1999 to 2000, oil production peaked at approximately 500 bopd, accompanied by a high water cut with water rates exceeding 1,200 bwpd, suggesting early water breakthrough. Gas production remained relatively stable around 300 Mscf/d. Due to declining performance; the well was shut in until its re-entry in 2014. Post reentry, oil production significantly improved, peaking at 800 bopd before gradually stabilizing between 300–400 bopd.

Water production was notably reduced, ranging from 500 to 700 bwpd, indicating improved reservoir management or better isolation of water zones. Gas output also increased intermittently, peaking around 400 Mscf/d. The reentry successfully revitalized the well, restoring commercial viability and improving fluid production profiles, though the gradual decline post-peak suggests ongoing reservoir depletion or operational limitations.

Table 2: Post-reentry surface test data for Well X2H-6.

Main Results							
Date	Well Head				Fluid Properties		
9-Jul-24	Choke	WHP (Psig)	WHT (°C)	Sep. P (Psig)	Q Oil (bopd)	Q Gas (Mscf/d)	Q Water (bwpd)
	"64	300	61.11	242	410.78	147	890

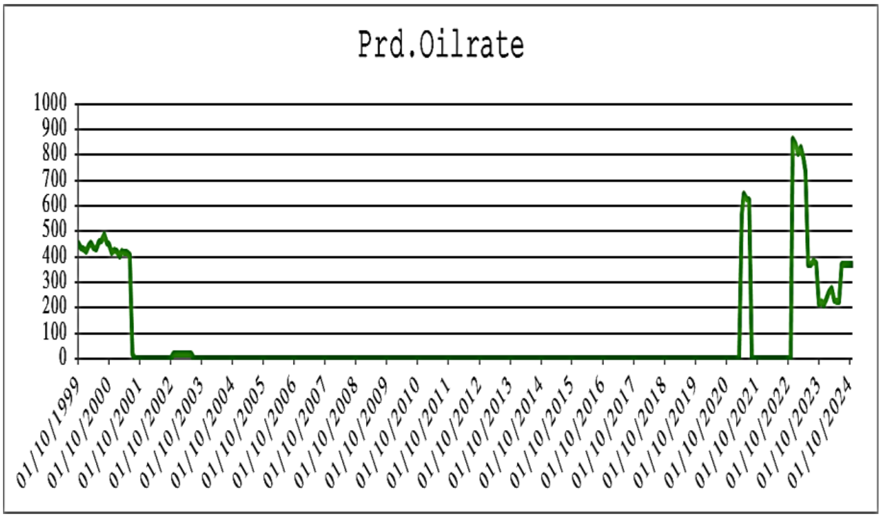

Figure 10: Well X2H-6 performance before and after reentry (Prepared by the authors).

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- **Productivity Index (PI) Calculation:**

$$PI = \frac{q}{\bar{p} - p_{wf}}$$

Where:
q: Production rate (STB/day) = 410.78, STB/day
Pr: Reservoir pressure (psia) =2250, psia
Pwf: Bottomhole pressure (psia) =1820 psia

$$P_i = \frac{410.78}{2250 - 1820} = 0.95\,STB/day\,/psi$$

PI = 0.95STB/day/psi. This value reflects the well's moderate productivity following re-entry, indicating reasonable reservoir deliverability under current operating conditions.

3.3 Well X3H-6

3.3.1 Well X3H-6 Summaries

Well X3H-6 was drilled and completed in 2024 as a horizontal producer targeting Layer 4 of the Zelten Porosity reservoir. The well was planned based on the success of previous horizontal and re-entry wells in the area and executed using advanced geosteering technologies to ensure optimal reservoir contact.

Upon completion, Well X3H-6 achieved an impressive initial oil production rate of 4781 bopd with a 0% water cut, indicating excellent reservoir quality and effective well placement (Table 3). This performance highlights the high productivity potential of Layer 4 in the Zelten Formation and validates the horizontal drilling strategy adopted for development in this area.

Table 3: Post-reentry surface test data for Well X3H-6.

Main Results							
Date	Well Head				Fluid Properties		
14-May-25	Choke	WHP (Psig)	WHT (°C)	Sep. P	Q Oil (bopd)	Q Gas (Mscf/d)	Q Water (bwpd)
	64/64"	325	42.22	190	4781	0.507	0

3.3.2 Trajectory of Well X3H-6

Well X3H-6 was drilled as a deviated well to maximize reservoir contact within the target zone. The well trajectory commenced at a

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Kick-Off Point (KOP) at 4,600 feet measured depth (MD), initiating a gradual deviation from vertical. The top of the 7" liner was set at 5,296 ft MD (5,271.5 ft true vertical depth, TVD) with an inclination of 25.5°, marking the start of the build section.
A 7" packer was installed around 5,500 ft MD (5,497 ft TVD) at an inclination of 33.5°, followed by completion components including a 2.31" F nipple at 5,540 ft MD, a 10-ft pre-perforated pup joint, and a 2.25" R nipple at 5,562 ft MD.
The 7" liner casing shoe was landed at 5,983 ft MD (5,755 ft TVD) with an inclination of 68°. The well reached its landing point (LP) at 6,225 ft MD (5,800.2 ft TVD), transitioning to a horizontal section with an inclination of 90.09° and azimuth of 118.56°. The final total depth (TD) was 7,700 ft MD and 5,790 ft TVD, maintaining a horizontal trajectory with a maximum inclination of 91.09° and azimuth of 119.85°.

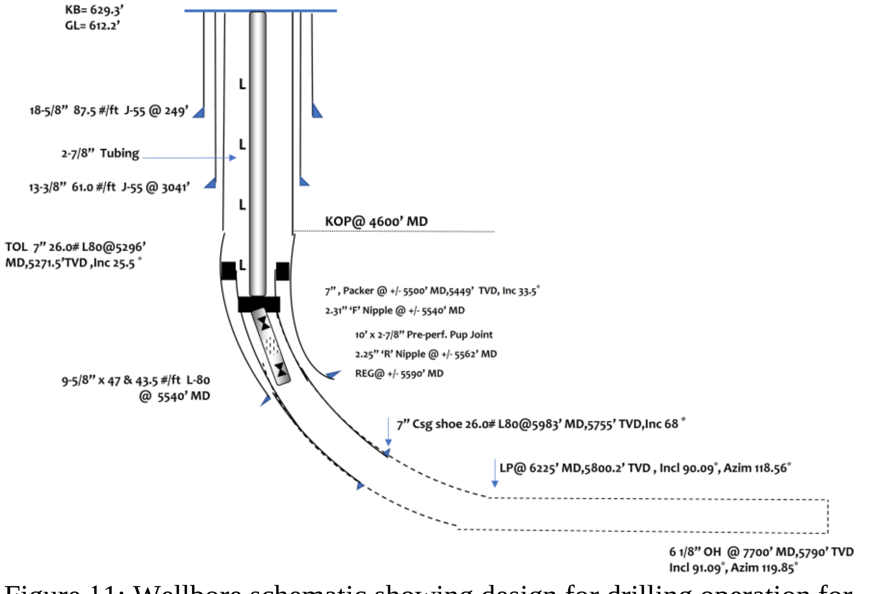

Figure 11: Wellbore schematic showing design for drilling operation for X3H-6 Well (Prepared by the authors).

3.3.3 Petrophysical analysis of the X3H-6 Well (Zelten Member, Layer 4)

The petrophysical evaluation of Well X3H-6 indicates a predominantly clean limestone reservoir, as inferred from the gamma ray (GR) log, which shows an average reading of approximately 50 API. Using standard clean and shale GR baselines

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of 30 and 100 API respectively, the calculated shale volume (Vsh) is 29%, confirming moderate clay content within the formation.
Lithological interpretation based on GR and color lithology tracks suggests the interval comprises mainly clean limestones with minor shale interbeds. From drilling data, the gross reservoir thickness is 1,475 feet (depth interval: 770–6,225 ft), while the net pay thickness, calculated using a net-to-gross ratio (N/G) of 0.71, is 1,047 feet. Porosity, estimated from the density log using a matrix density (ρma) of 2.65 g/cc and fluid density (ρf) of 1.0 g/cc, and an average bulk density (ρb) of 2.25 g/cc, falls within the range of 20%–28%, with an average of 24%.
These results demonstrate a high-quality reservoir characterized by good porosity, moderate shale volume, and substantial net pay, supporting the well's strong hydrocarbon storage and flow potential. These petrophysical attributes justify further development of the interval and enhance confidence in the productivity of the target reservoir.

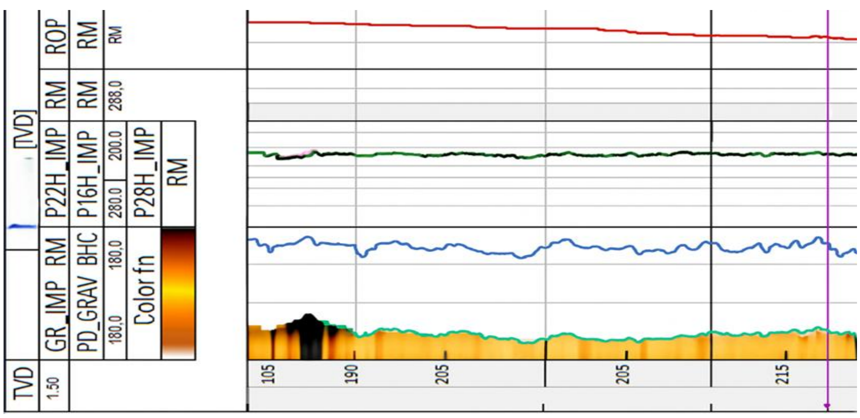

Figure 12: Petrophysical log analysis of Layer 4 from Well X3H-6 (Edited by the authors).

3.3.4 Technical Analysis of Well X3H-6:

- **The Inflow Performance Relationship (IPR)**

The IPR chart for Well X3H-6 illustrates the relationship between the stock tank liquid rate (STL) and bottomhole pressure. The X-axis represents STL (STB/day), while the Y-axis shows pressure (psia). Multiple IPR curves are plotted for different reservoir pressures: 2500 psi (green), 2450 psi (red), and 2400 psi (blue), along with a fixed vertical lift performance (VLP) curve at 300 psi surface pressure (orange) (Fig. 13).

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The curves demonstrate a typical decline in production rate with decreasing reservoir pressure. At 2500 psi, the flow rate is approximately 4623 STB/day, which reduces to 4405 STB/day at 2450 psi and 4167 STB/day at 2400 psi. At the actual reservoir pressure of 2472 psi, the operating point corresponds to about 4501 STB/day, validating the trend observed in the IPR curves.

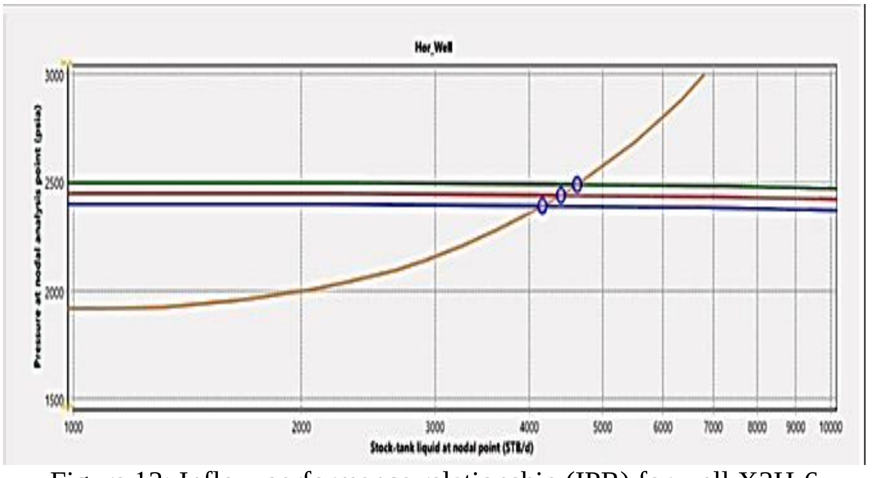

Figure 13: Inflow performance relationship (IPR) for well X3H-6 (Prepared by the authors).

- **Productivity Index (PI) calculation:**

The productivity index was calculated using the formula:

$$PI = \frac{q}{\bar{p} - p_{wf}}$$

q: Production rate (STB/day) = 4842, STB/day
Pr: Reservoir pressure (psia) = 2472, psia
Pwf: Bottomhole pressure (psia) (From well report data) = 1650 psia

$$P_i = \frac{4842}{2472 - 1650} = 5 \cdot 89\, STB/day\,/psi$$

This PI value indicates a highly productive well under current reservoir conditions.

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4. Economic Evaluation of Additional Oil Production from Wells X1-6, X2H-6, and X3H-6

a. Well X1-6

An economic analysis was conducted for Well X1-6 to determine the viability of its proposed development. The estimated total capital investment required for this project is $ 12,420,000, with the aim to sustain a production rate of 700 barrels of oil per day (bbl/day). At a base case scenario of $60 per barrel, the calculated daily revenue is $42,000, yielding monthly revenue of $1,260,000 and an annual revenue of approximately $15.33 million.

The payback period is determined by dividing the total project cost by the yearly revenue:

Payback Period = 12,420,000 / 15,330,000 ≈ 0.81 years (about 9.7 months)

To further assess project resilience, a sensitivity analysis was performed across three oil price scenarios ($50, $60, and $70/bbl) and three production levels (600, 700, and 800 bbl/day). The best-case scenario $70/bbl with 800 bbl/day resulted in an annual revenue of $20.44 million and a payback period of only 0.61 years (7.3 months). Even under the most conservative assumptions, the investment is recovered in 1.13 years, proving the project economically sound.

b. Well X2H-6

The economic performance of Well X2H-6 was evaluated for a post-reentry production increase from 0 to 370 bbl/day, with a capital expenditure of $4,896,839. Under a base oil price of $60/bbl, the project generates $22,200 daily, $666,000 monthly, and $8.1 million annually. The payback period is:

Payback Period = 4,896,839 / 8,103,000 ≈ 0.6 years (about 7.25 months)

Scenario-based analysis revealed that, in the worst-case scenario ($50/bbl and 270 bbl/day), the payback is 0.99 years (12 months), while the best-case ($70/bbl and 470 bbl/day) yields a short payback of 0.41 years (5 months). The results confirm that the project is economically robust across a wide spectrum of price and production conditions.

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c. Well X3H-6

Well X3H-6 was economically evaluated after successful completion as a horizontal producer targeting the Zelten Porosity reservoir. The total capital expenditure amounted to LD 20,000,000 (equivalent to $4,000,000). The well achieved a high sustained production rate of 4,781 bbl/day. At a base oil price of $60/bbl, the project generates $286,860/day, $8.61 million/month, and $104.71 million/year. The payback period in this scenario is exceptionally short:

Payback Period = 4,000,000 / 286,860 ≈ 14 days

Sensitivity analysis under oil prices of $50 and $70/bbl showed payback periods of 16.7 days and 12 days, respectively.
These findings highlight the exceptional financial performance and rapid cost recovery of the X3H-6 well.

5. Conclusions:

- The integration of reentry drilling and geosteering techniques has been a vital step in revitalizing the mature Zelten Field in the Sirte Basin, Libya.
- The present study reveals severe challenges associated with mature oil fields, particularly thin hydrocarbon pay and high water cut.
- The wells X1-6, X2H-6, and X3H-6 study confirms that application of advanced drilling technologies has the ability to effectively enhance reservoir contact, optimize production rates, and decrease water production (Reentry wells cut 45–85% water).
- The successful reentry operations not only restored production in formerly shut-in wells but also demonstrated the capability for optimizing hydrocarbon recovery from existing infrastructure.
- The results show that reentry drilling, combined with precise geosteering, can lead to considerable improvements in production efficiency and economic performance.
- Additionally, the findings emphasize the importance of continuous innovation and improvisation in drilling methods in order to meet the evolving challenges of mature fields. As pressure increases for the oil and gas industry to be more resource efficient and reduce expenses, the synergistic

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approach detailed in this paper presents a fine model for other producers seeking to optimize production in similar circumstances.

- The economic studies of wells X1-6, X2H-6, and X3H-6 are very profitable and have high return on investment within a variety of market conditions. In every instance, payback is comfortably less than one year even for conservative projections. This highlights the strong financial health and viability of future development activities for these wells.
- Finally, rejuvenation of the Zelten Field through reentry drilling and geosteering not only ensures the future sustainability of Libyan oil production but also provides the basis for developing future oil fields throughout the world that are mature.

6. Recommendations

- **Invest in Technology:** Adopt advanced drilling and geosteering tools to improve well performance and reservoir contact.
- **Improve Reservoir Management:** Conduct regular monitoring and analysis to support effective well intervention decisions.
- **Promote Collaboration:** Encourage knowledge sharing among industry stakeholders to enhance reentry and geosteering practices.

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