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Effect of Reefs and Faults on Oil Reservoir Performance - Case Study: Carbonate Reservoir, Southern Iraq

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Abstract

The study area is located in an unstable region within the Mesopotamian basin of the Arabian plate. It is surrounded by several oil fields that produce hydrocarbons from NW-SE-trending anticline formations, which are compatible with the direction of the Zagros folded axis. The study area is characterized by the presence of bubble point pressure discrepancy at the same productive reservoir unit, which raised several doubts about the faults or reefs that led to this phenomenon and the future impact on the development strategy of the study area. The study aimed to assess how faults and reef affect the development plan for carbonate oil reservoir. The process involves three steps tailored to fit the specific characteristics of the research area before the development strategy of oil production. The first step was creating a seismic model to identify any irregular amplitudes of reflected events and abrupt discontinuities, which could indicate either a reef or a fault. This was followed by creating a geological model based on faults and reef, developing a reservoir model, and conducting historical matching. The study proved the presence of a fault and excluded the presence of a reef. Four development plan scenarios were created for a 20-year period based on the probabilities of the fault and reef. The study found that case four had the most favorable results among all the cases. This case showed a production plateau that lasted for seven years with slight fluctuations.

Keywords: Carbonate reservoir, development strategy, reef, fault, oil production.

تأثير الفوالق والحيد المرجاني على الخطة التطويرية لإنتاج النفط – دراسة حالة: مكمن الحجر الجيري- جنوبي العراق

الخلاصة:

تقع منطقة الدراسة في منطقة غير مستقرة ضمن حوض الرافدين من الصفيحة العربية. وهي محاطة بالعديد من حقول النفط التي تنتج الهيدروكربونات من تكوينات الخطوط المحدبة التي تتجه شمال غرب وجنوب شرق البلاد، والتي تتوافق مع اتجاه محور زاغروس المطوي. وتتميز منطقة الدراسة بوجود تباين في ضغط النقطة الفقاعية في نفس الوحدة المكمنية الإنتاجية مما أثار عدة شكوك حول الصدوع أو الشعاب التي أدت إلى هذه الظاهرة وتأثيرها المستقبلي على استراتيجية التنمية في منطقة الدراسة. هدفت الدراسة إلى تقييم مدى تأثير الفوالق والشعاب المرجانية على خطة تطوير مكمن الحجر الجيري النفطي. تتضمن العملية ثلاث

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خطوات مصممة لتناسب الخصائص المحددة لمنطقة البحث قبل استراتيجية تطوير إنتاج النفط. كانت الخطوة الأولى هي إنشاء نموذج زلزالي لتحديد أي سعة غير منتظمة للأحداث المنعكسة والانقطاعات المفاجئة، والتي يمكن أن تشير إما إلى وجود حيد مرجاني (شعاب مرجانية) أو فالق. وأعقب ذلك إنشاء نموذج جيولوجي يعتمد على الفالق والشعاب المرجانية، وتطوير نموذج الخزان، وإجراء المطابقة التاريخية. وأثبتت الدراسة وجود فالق واستبعدت وجود شعاب مرجانية. تم إنشاء أربعة سيناريوهات لخطة التطوير لمدة 20 عامًا بناءً على احتمالات الفالق والشعاب المرجانية. ووجدت الدراسة أن الحالة الرابعة كانت لها النتائج الأكثر إيجابية من بين جميع الحالات. أظهرت هذه الحالة ثبات الإنتاج لمدة سبع سنوات مع تقلبات طفيفة.

1. Introduction:

Accurately estimating the oil initially in place (OIIP) is crucial in the oil and gas exploration and production industry. The precision of the reserve estimate depends on utilizing petrophysical data in both the volumetric approach and the simulation method [1], [2], [3], [4]. Well logs play a significant role in evaluating reservoirs and exploring oil and gas reserves in the petroleum industry. Many petrophysical characteristics, such as porosity, hydrocarbon saturation, thickness, area, and permeability, should be considered when evaluating a reservoir. Besides, a reservoir's finalization, extraction, and assessment may be influenced by various factors like reservoir geometry, formation temperature and pressure, and lithology [2], [5], [6].

The Volumetric Method estimates the oil initially in place (OIIP) by analyzing various rock features of the reservoir, including porosity, net-to-gross ratio, initially water saturations, and reservoir thickness. In contrast, the Material Balance Method is a dynamic approach that uses production and pressure data to predict the OIIP [2], [7], [8]. In order to construct the Dynamic Model, essential data must be provided, such as pressure-volume-temperature (PVT) characteristics, special core analysis (SCAL) results, production data, and pressure measurements. Once the model is initialized, it will compute the oil initially in Place (OIIP). If the calculated value is deemed acceptable, a simulation will be conducted over a specific time to match the historical production data. This process is conducted to validate the model's dynamic performance and ensure it resembles the reservoir [9], [10], [11]. Most geologic maps and models are based on 3D seismic data, which must describe reservoir heterogeneity, vertical zonation, lateral compartmentalization, and the factors that lead to anisotropy or directional fluid flow in the reservoir [4], [12], [13], [14]. Seismic reflections produce accurate graphical depictions of the subsurface and geologic features. They provide seismic data, velocity, and times contours maps for identifying structural, stratigraphic, and seismic facies traps. In addition to sedimentary analysis of basins, it is used to interpret the interior sedimentary architecture in terms of environmental paleogeographic depositions [15], [16], [17], [18]. In the study area, there was an

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issue with the bubble point discrepancy in the carbonate formation. It prompted a thorough re-evaluation of the formation to identify its causes, including faults and reefs. To investigate the issue, the seismic survey was re-evaluated with the subscription of log data, including density, sonic, and VSP, an essential component of the comprehensive re-evaluation of the formation or reservoir. The goal was to detect whether faults or reefs were responsible for the problem of reservoir compartmentalization and determine the correct probability by historical matching of the reservoir model. After constructing a static model based on two probabilities, fault and reef, the study will address the effect of reefs and faults on the development plan of oil production for more than 22 years and their impact on reservoir behavior.

2. Geological settings

The study area is situated in southern Iraq, and the oil deposits in the field were first discovered by the seismic survey crew of the National Oil Company in 1984 [19]. The study region, a heterogeneous carbonates reservoir, is the most significant reservoir in the field and other oilfields in southern Iraq. The carbonate reservoir covers an area of about 31 km in length and 10 km in width and has a depth of 2283 m at the top of the structure at the X-1 well. The thickness of the reservoir is approximately 130 m.

The research region is located in an unstable region within the Mesopotamian basin of the Arabian plate [20], as shown in Figure (1). It is surrounded by several oil fields that produce hydrocarbons from NW-SE-trending anticline formations, which are compatible with the direction of the Zagros folded axis [21].

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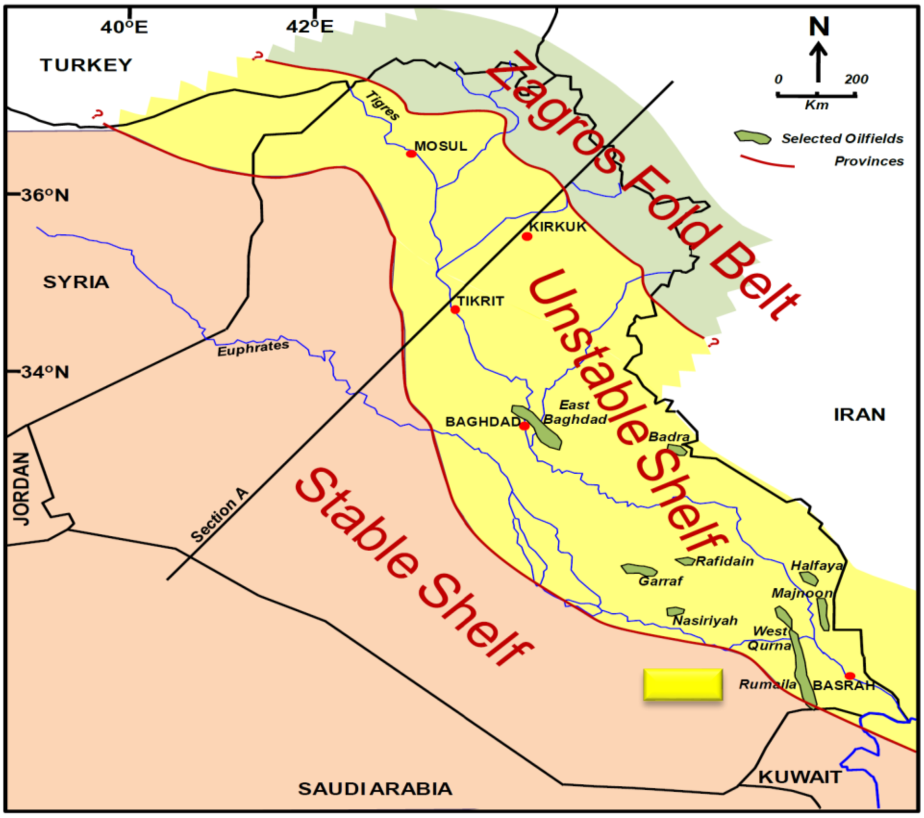

Fig. (1): Tectonic provinces of Iraq [21]

3. Materials and Methods

Data preparation is crucial before constructing seismic, static, and dynamic models using the Petrel platform for subsurface modelling and interpretation. The process involves three steps tailored to fit the specific characteristics of the research area before the development strategy of oil production. These steps are as follows:

1. Re-evaluating the 3D seismic survey: The data includes a 3D seismic survey with the subscription of (well top, sonic, density, and VSP) to detect faults and reefs that cause discrepancies in bubble point pressure. The seismic analysis detected many irregular amplitudes of reflected events and abrupt discontinuities, indicating either a reef or a fault, as shown in Figure (2).
2. Building the static model: The static model is based on two possibilities, reef and fault, with no differences in the distribution of petrophysical properties and the calculation of oil in place in both cases.

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3. Building the dynamic model: The dynamic model is used to verify the correct possibility. History matching is conducted according to gas production (observed and simulated) to determine the presence of faults and reefs. The result of history matching proved the presence of faults (blue line) and ruled out the presence of reefs (red line), as shown in Figure (3).

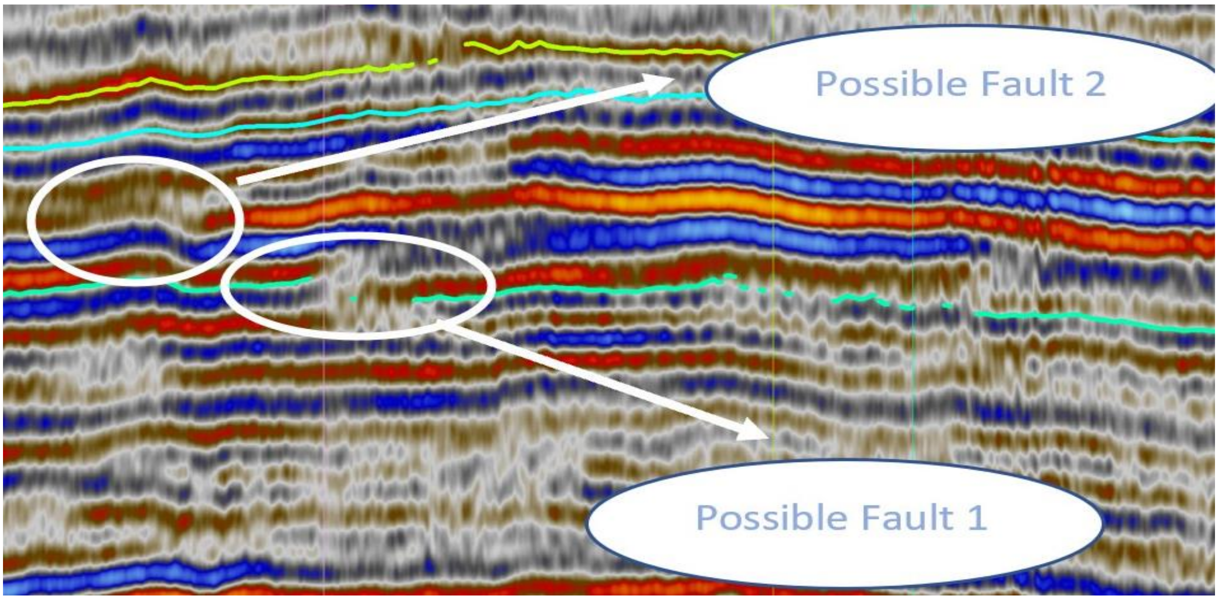

Fig. (2): Location of possible faults on seismic inline section.

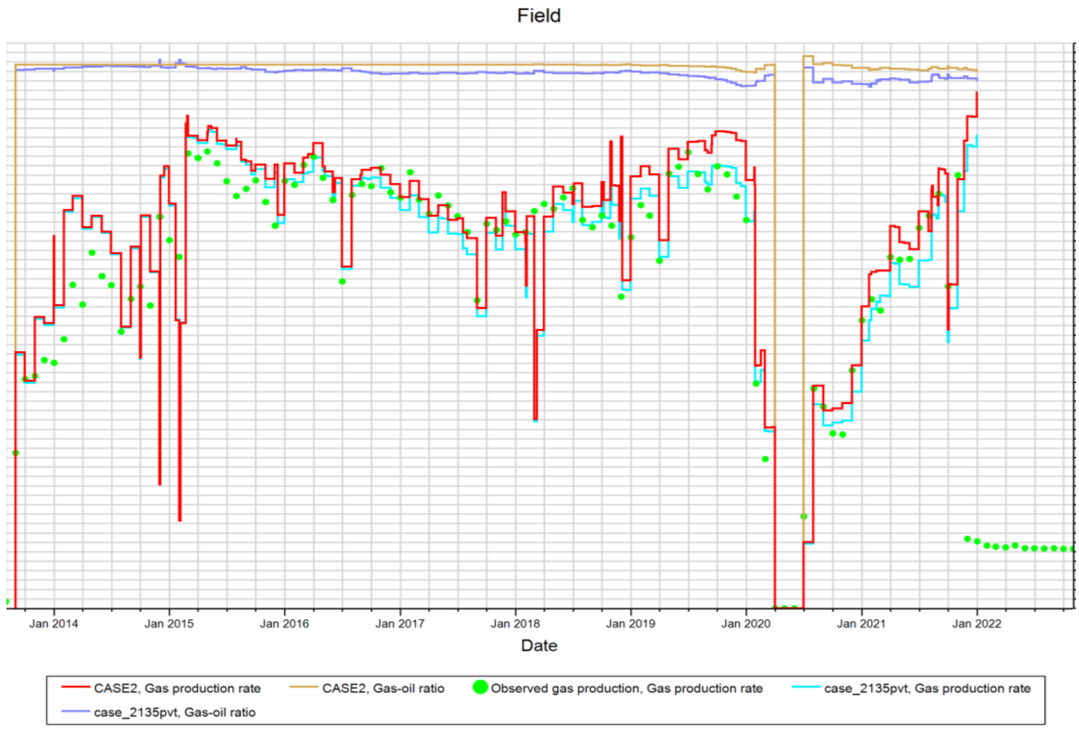

Fig. (3): History matching for case fault and reef in the study area.

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The development plan is a crucial element in managing future production and monitoring reservoir decline. It serves as the foundation for reservoir development. Over the next 20 years, the development plan has been implemented in four cases: two cases (one and two) with existing wells for the fault and reef probability and two cases (three and four) with additional production wells to supplement the future production plan and to understand the behavior of the fault and reef cases.

4. Results and Discussion

4.1 Case One

This strategy was developed based on the carbonate reservoir's reef probability as well as 117 existing wells (97 produced, 20 injected). The strategy results show that the field's highest production rate was 130 MSTB/D in mid-2024. The production rate remained steady for about three years before gradually declining to 78 MSTB/D by the end of the period. The percentage of water cuts remained constant for two years and then gradually increased, reaching a final predicted value of 57%. The field's cumulative oil volume was reported at 1.01 MMMSTB, as shown in Figure (4).

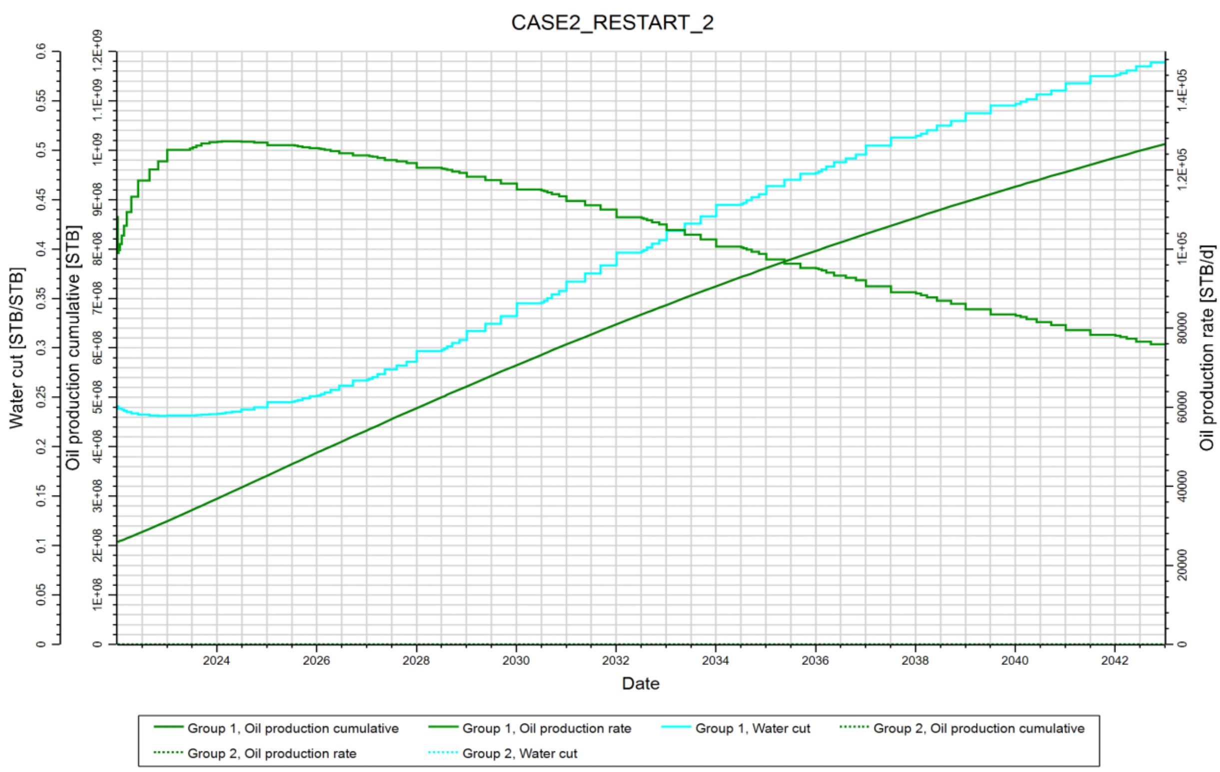

Fig. (4): The results of strategy for case one

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4.2 Case Two

This strategy was developed based on the carbonate reservoir's fault probability in addition to the same input data from the wells in case one. The strategy results show that the field's highest production rate was 140 MSTB/D in 2024. The production rate remained steady for about three years before gradually declining to 78 MSTB/D by the end of the period. The percentage of water cuts remained constant for two years and then gradually increased, reaching a final predicted value of 60 %. The field's cumulative oil volume was reported at 1.03 MMMSTB, as shown on Figure (5).

4.3 Case Three

This strategy depends on the possibility of a reef with the addition of 20 producing wells named (test1, test2, ..., test20) distributed based on permeability and oil saturation of the carbonate reservoir, as seen in Figure (6). According to the strategy results, the highest production rate in the field was 130 MSTB/D in mid-2029. This production rate remained steady for approximately seven years with minor fluctuations before gradually declining to 78 MSTB/D by the end of the period. The percentage of water cuts remained constant for three years before gradually increasing, reaching a final predicted value of 57%. The field's cumulative oil volume was also reported at 1.06 MMMSTB, as illustrated in Figure (7).

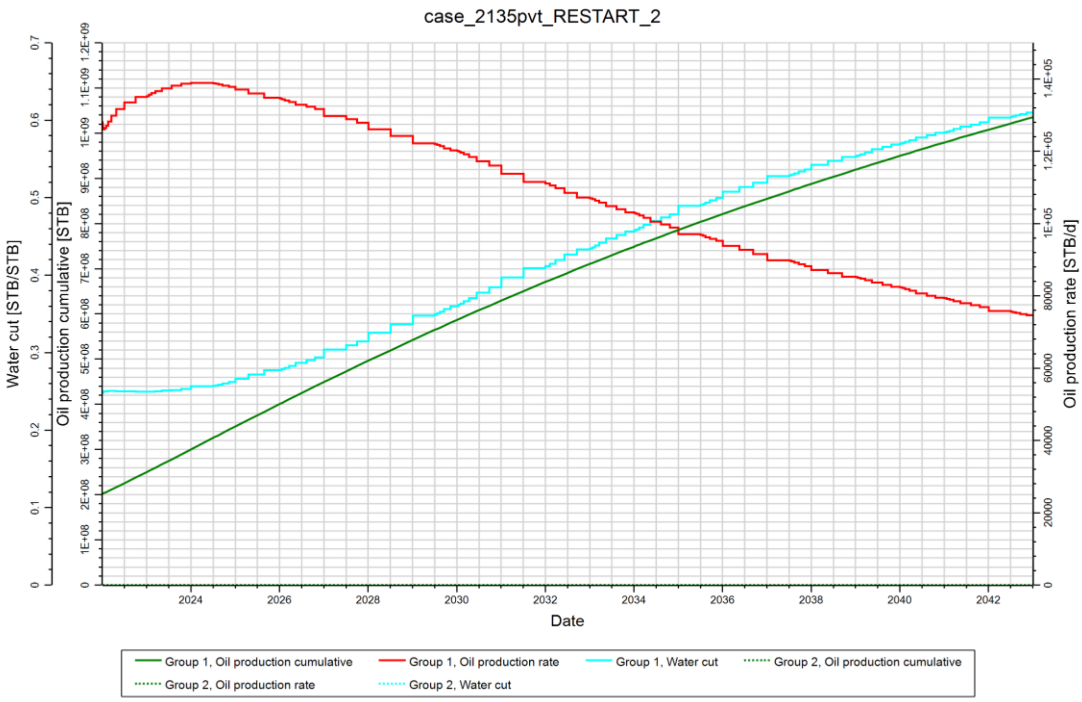

Fig. (5): The results of strategy for case two

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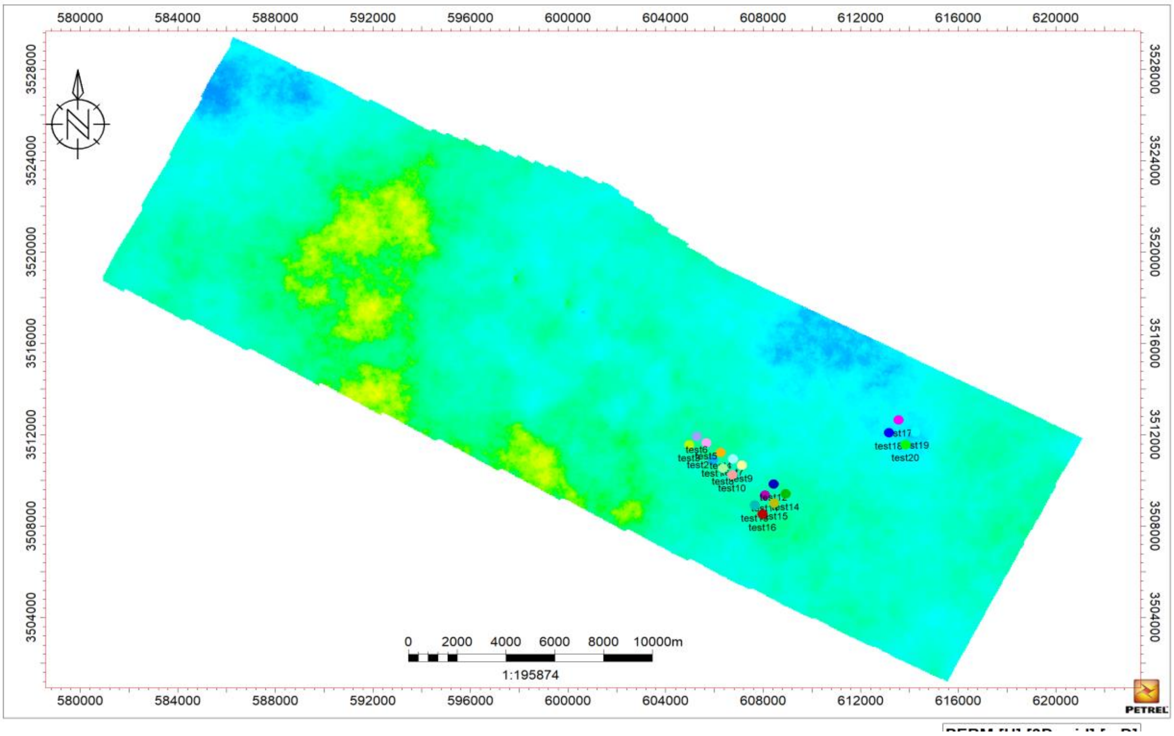

Fig. (6): Location of additional wells on permeability map of the carbonate reservoir

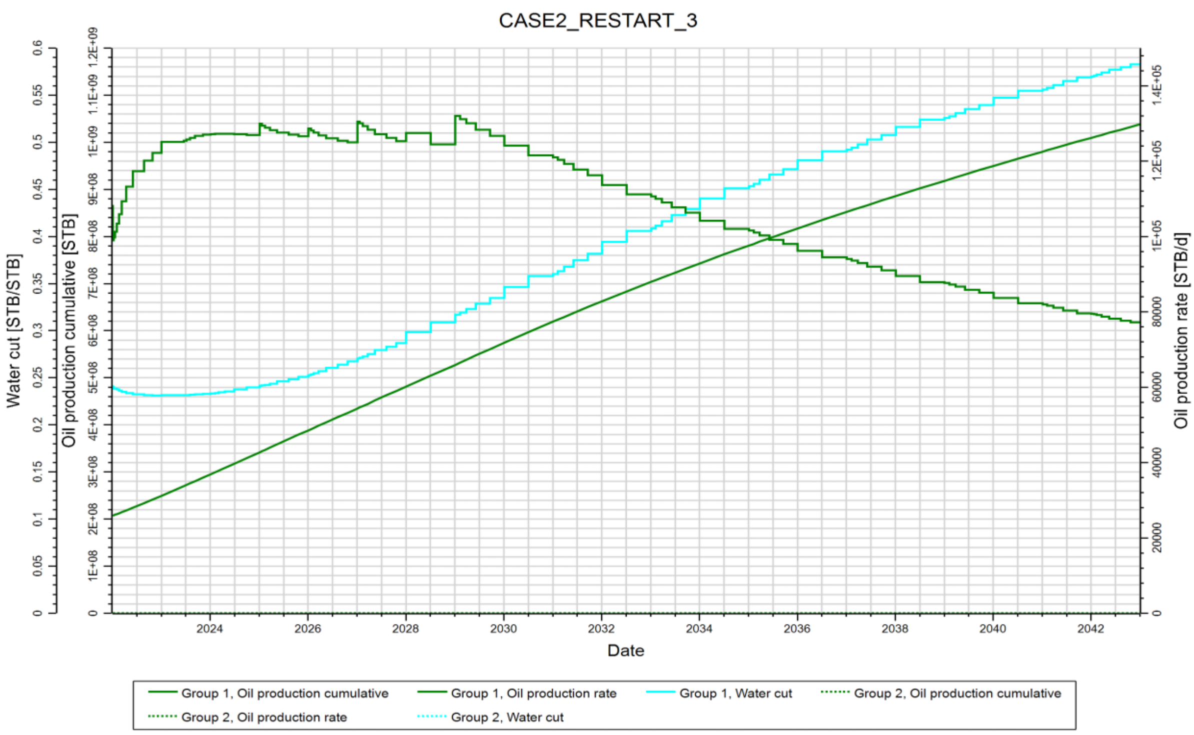

Fig. (7): The results of strategy for case three

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4.4 Case Four

This strategy utilizes the same inputs as case three based on the fault probability. According to the results, the field's highest production rate of 140 MSTB/D was recorded at the beginning of 2025. For almost seven years, the production rate remained steady with slight fluctuations before gradually declining to 76 MSTB/D by the end of the period. The percentage of water cuts remained constant for three years before gradually increasing to a predicted value of 60% by the end. The field's cumulative oil volume was reported at 1.09 MMMSTB, as shown on Figure (8).

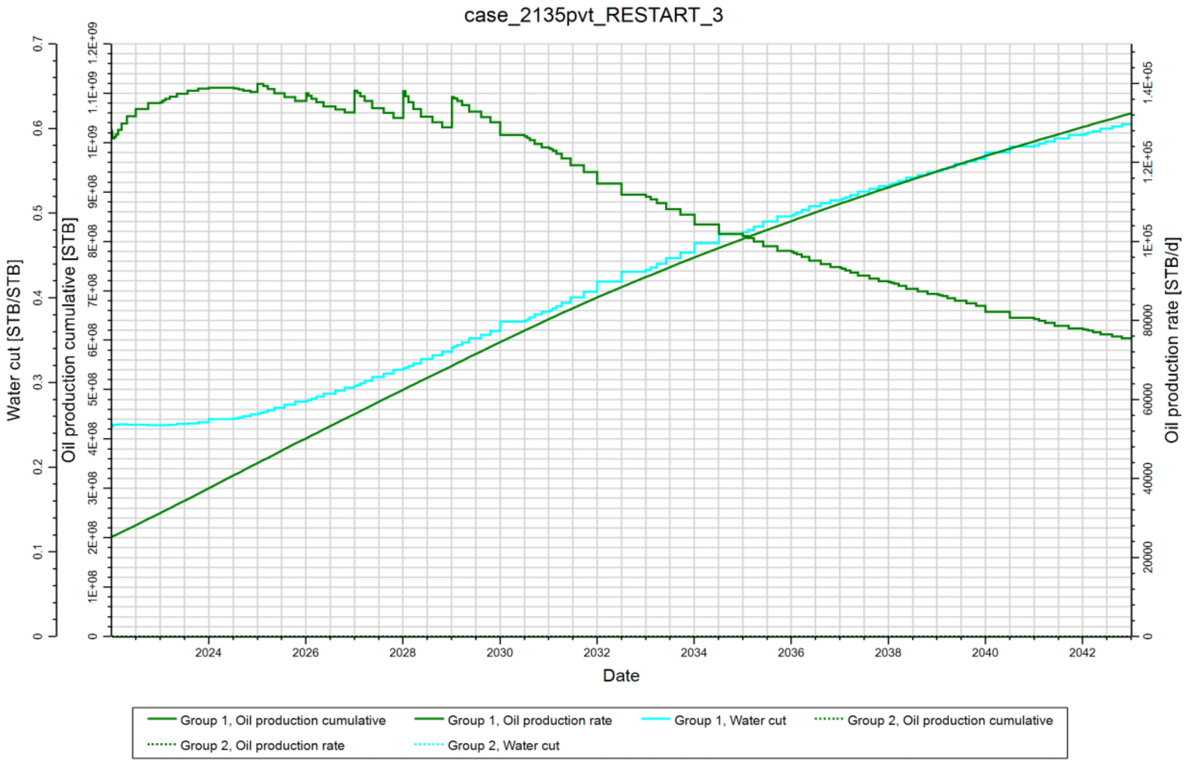

Fig. (8): The results of strategy for case four

5. Conclusion

1. The carbonate reservoir in the study area is inside an unstable region of the Mesopotamian basin of the Arabian plate and bounded by several fields that produce hydrocarbon from massive NW-SE-trending anticline formations, which are typically compatible with the direction of the Zagros folded axis.
2. The producing reservoir unit has a discrepancy in bubble point pressure, raising questions about the faults or reefs that caused it and its future impact on the development plan.

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3. The process involves three steps, including seismic, static, and dynamic models, tailored to fit the research area's specific characteristics before the oil production development strategy.
4. The seismic analysis detected many irregular amplitudes of reflected events and abrupt discontinuities, indicating either a reef or a fault.
5. The result of history matching dynamic simulation and based on seismic and static models proved the presence of faults and ruled out the presence of reefs.
6. The development plan has been implemented over the next 20 years in four cases: two cases with the current wells for fault and reef probability and two cases with the same input data as well as additional production wells.
7. The study found that case four had the most favorable results among all the cases. This case showed a production plateau that lasted for seven years at a rate of 140 MSTB/D with slight fluctuations. The cumulative oil volume of the field was reported to be 1.09 MMMSTB.

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