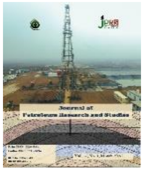
Journal of Petroleum Research and Studies

journal homepage: https://jprs.gov.iq/index.php/jprs/

Print ISSN 2220-5381, Online ISSN 2710-1096



Analysis of Fault Zone and Fractures in Cretaceous Formations of X Oil Field Using Well Logs and Drilling Operations Data

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Article Info

Received 14/11/2024
Revised 24/02/2025
Accepted 02/03/2025
Published 19/03/2026

DOI: http://doi.org/10.52716/jprs.v16i1.1040

Abstract

The X Oil Field, located in the Salah al-Din Governorate of northern Iraq. This study investigates the subsurface properties of Cretaceous formations (M, H, K) and Late Jurassic Chia Gara Formations, focusing on fault systems, fracture networks, and lithological changes affecting porosity and permeability. The research integrates well logs, thin rock sections, and drilling data, employing advanced analytical techniques such as petrophysical modeling to delineate subsurface fault zones.

Key findings include the identification and classification of fault zones into core, damage, and non-damage zones using Yamada's Model. Core fault zones exhibit high fracture densities (up to 8 fractures/meter), mixed rock facies, and enhanced secondary porosity values averaging 15%, making them critical conduits for hydrocarbon migration. Damage zones show moderate fracturing (2–4 fractures/meter) with reduced porosity impacts, while non-damage zones serve as stable references. These results were validated through caliper log, gamma-ray log, and drilling indicators like mud loss and penetration rates.

This study provides quantitative insights into fracture density, porosity, and permeability, offering a robust framework for optimizing reservoir management and hydrocarbon extraction strategies. The findings contribute to a broader understanding of fault systems in Cretaceous reservoirs, aligning with similar studies in analogous geological settings. By emphasizing sustainable resource management, this research enhances the economic feasibility of the X field and offers transferable methodologies for fields with comparable structural complexities.

Keywords: X Oil Field, Well Logs, Fault Systems, Porosity, Drilling operations Data.

تحليل منطقة الصدع والكسور في التكوينات الطباشيرية لحقل X النفطي باستخدام سجلات الآبار وبيانات عمليات الحفر

الخلاصة

حقل X النفطي، الذي يقع في محافظة صلاح الدين شمال العراق. تهدف هذه الدراسة إلى التحقيق في الخصائص تحت السطحية لتكوينات العصر الطباشيري (M، H، K) وتكوين جياكارا من العصر الجوراسي المتأخر، مع التركيز على أنظمة الفوالق، شبكات الكسور والتغيرات الصخرية التي تؤثر على المسامية والنفاذية. استخدمت الدراسة بيانات تسجيل الآبار، المقاطع الصخرية الرقيقة، وبيانات عمليات الحفر، واعتمدت التحليل لتحديد مناطق الكسور التحت سطحية.

النتائج الرئيسية شملت تحديد وتصنيف مناطق الفوالق إلى مناطق أساسية، مناطق تضرر، ومناطق غير متضررة باستخدام نموذج ياماد. أظهرت المناطق الأساسية كثافة عالية من الكسور (تصل إلى 8 كسور/متر)، واختلاط أنواع الصخور، وقيم مسامية ثانوية محسنة بمتوسط 15%، مما يجعلها قنوات رئيسية لهجرة الهيدروكربونات. أما مناطق التضرر فتظهر كسورًا معتدلة (2-4 كسور/متر) مع تأثيرات مخفضة على المسامية، بينما تُعتبر المناطق غير المتضررة مرجعًا مستقرًا. تم التحقق من هذه النتائج باستخدام سجلات قياس قطر البئر (Caliper logs)، سجلات الأشعة كاما، ومؤشرات الحفر مثل فقدان الطين ومعدلات الاختراق.

تقدم هذه الدراسة رؤى حول كثافة الكسور، المسامية والنفاذية، مما يوفر إطارًا قويًا لتحسين إدارة المكامن واستراتيجيات استخراج الهيدروكربونات. تسهم النتائج في فهم أوسع لأنظمة الفوالق في خزانات العصر الطباشيري، بما يتماشى مع دراسات مشابهة في بيئات جيولوجية مماثلة. وبإعطاء الأولوية لإدارة موارد مستدامة، تعزز هذه الدراسة الجدوى الاقتصادية لحقل X وتقدم منهجيات قابلة للتطبيق على حقول ذات تعقيدات بنيوية مشابهة.

1. Introduction

Rifts are fragile structures formed under stress and are widely distributed in the Earth's upper crust, exhibiting significant changes in shape and displacement with increasing depth [1]. These structures play a critical role in hydrocarbon reservoirs by influencing fluid flow dynamics, well stability, and porosity distribution. Polished fault surfaces, known as "slickensides," serve as key markers for understanding fault movement and directionality [2], [3]. The X oil field, located in northern Iraq, has been the subject of multiple geological studies aimed at enhancing the understanding of its structural framework and reservoir characteristics. However, despite these efforts, significant gaps remain in the existing literature.

Previous studies have provided valuable insights into the geological structure of the X field. For instance, one study conducted a detailed analysis of sedimentary basin patterns, lithological facies, and secondary porosity distributions, identifying the H Formation as the primary hydrocarbon-bearing unit, with cap rocks in the Tanuma Formation. In contrast, the Chia Gara Formation was found to have limited reservoir potential due to low porosity values averaging 8–10% [4]. Other studies focused on major faults, such as F1 and F2, which divide the field into three structural zones: the northeastern shoulder, the central graben (low basin), and the southwestern shoulder. These studies revealed that fault activity ceased during the Late Cretaceous after the deposition of the H Formation, with minimal Alpine tectonic influence and no evidence of folding [5]. Seismic data further highlighted structural variations, including a thickness range of 250 m in the northeastern shoulder to 650 m in the graben, significantly impacting hydrocarbon distribution [6].

Despite these contributions, previous research has notable limitations. Conventional well log techniques, such as gamma-ray, resistivity, and M-N plots, have been effective in detecting fractures and secondary porosity zones but often lack precision without calibration using advanced image log data [7]. Additionally, earlier studies have reported inconsistent porosity and permeability values, with secondary porosity ranging from 5% to 15% in fractured zones, depending on lithology and fault intensity. These discrepancies highlight the need for more accurate methodologies to quantify fault-related reservoir properties. Furthermore, while recent advancements in petrophysical modeling, such as using neutron porosity to estimate rock mechanical properties, have improved well stability and reservoir management, their application remains underutilized in fields like X [8].

This study addresses these gaps by integrating well log data (Gamma Ray, Neutron, Density, Caliper) with drilling operation parameters, such as mud loss and penetration rates, to identify fault zones and fracture networks in the X field. The novelty of this approach lies in its ability to enhance the accuracy of fault characterization through a simplified methodology based on readily available data. By focusing on core, damage, and non-damage fault zones, this research provides new insights into how faults and fractures impact hydrocarbon exploration and production. Specifically, it aims to resolve inconsistencies in porosity and permeability estimates, offering a robust framework for optimizing reservoir management. Expected outcomes include refined porosity values (up to 15% in core fault zones) and improved strategies for targeting high-potential hydrocarbon migration pathways, ultimately contributing to the sustainable development of the X field.

1.1. Study Area

The X oil field is located in Salah al-Din province in northern Iraq, and extends over an area of about 160 square kilometers (10*16 kilometers). The X oil field is located within a relatively flat topographical area, with low terrain and limited variation, characterized by sedimentary plains that run along the Tigris River. This area is part of the sedimentary plain, a geological range characterized by clayey and sandy deposits formed during successive geological periods due to river activity and sea level changes. The topographic characteristics of the X field area are characterized by a largely flat surface with slight slopes towards the Tigris River, (Figure 1).

Topographic elevations in the area are low, ranging from 50 to 80 meters above sea level. This flat terrain provides a suitable environment for drilling operations, enhances easy access to drilling sites, and supports the efficient implementation of development strategies within the field, but on the other hand, it represents a problem as it is agricultural areas used by the people of the region in agriculture.

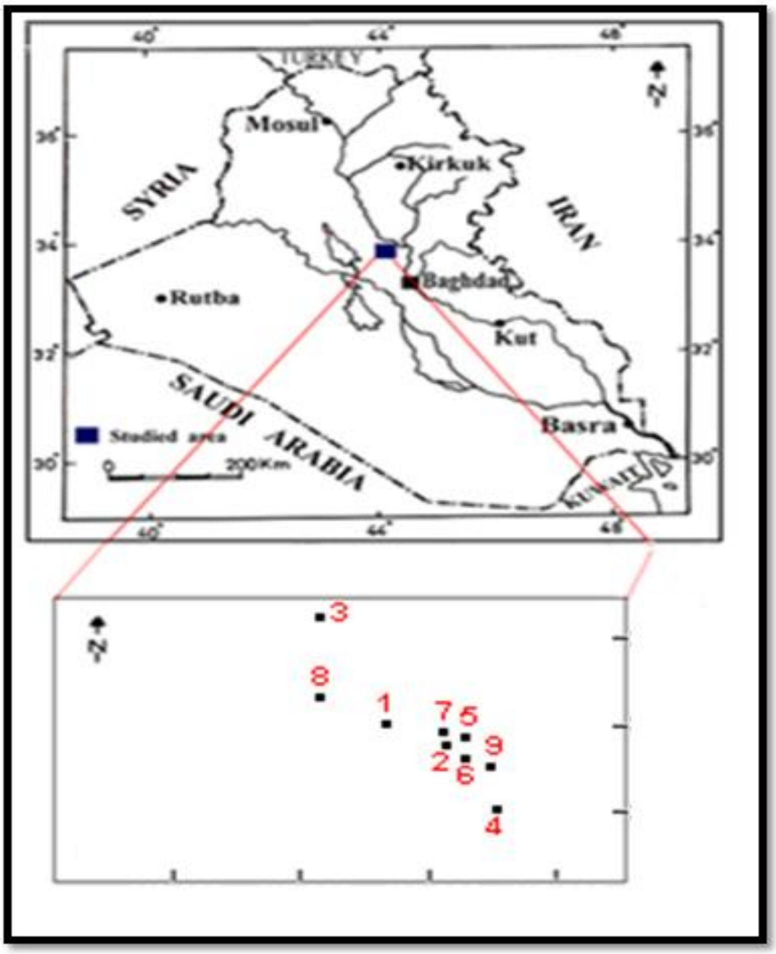

Fig. (1): Location map of the research area.

2. Material and methods

The methods used in this research focused on integrating well log analysis, lithological data, and drilling observations to identify subsurface fractures (faults) within the X Oil Field. This approach combines geological, and drilling indicators, including mud loss data, to precisely delineate fracture zones and fault boundaries. Below are the primary materials and methods applied in the research.

2.1. Well Log Analysis:

Well logs serve as the main data source for subsurface investigation, providing detailed information about lithology, porosity, and fracturing. The following specific logs were employed to interpret fracture zones in the X Field (well X.1, 2, 3, 4):

- **Caliper Log**: A well diameter (Caliper) log is a tool used during drilling processes to measure the diameter of a well in inches, which helps detect any abnormal changes compared to the original diameter designed for drilling. Expansions in diameter often indicate the impact of fractures that cause a loss of stability of the walls of the well.
  Changes in the diameter of the well may also result from the nature of geological formations. For example, weak formations such as Marl may cause the diameter to narrow due to swelling of the walls, while shale may lead to large expansions as a result of wall collapse during excavation. Not every inflation in the diameter of a well is considered evidence of fractures or cracks, as mechanical factors, such as poor control of drilling fluid properties, may be responsible for these changes. To ensure accurate interpretation, well diameter log data is combined with other records, such as the Neutron, Density and the Gamma Ray Logs. This integration enables improved data analysis, accurately distinguishing between changes caused by geological characteristics and those caused by operational factors.
- **Gamma Ray (GR) Log**: The GR log detects natural radioactivity in formations, which helps in differentiating lithology and assessing fracture zones. The GR values alongside other indicators, such as caliper log expansion, often suggest zones with increased porosity due to fracturing.
- **Formation Density (FDC) Log**: The FDC log measures bulk density, which helps to evaluate porosity and fracture density. Anomalies in density readings in conjunction with other logs often point to fractured intervals.
- **Compensated Neutron Log (CNL)**: The CNL log, which measures hydrogen content, indirectly provides porosity estimates. High readings in fractured zones indicate areas with secondary porosity enhancements.

2.2. Lithological Data Analysis:

Description of rock cutting samples to identify rock facies, which provided important insights into the geological formation and its units, thus supporting the credibility of log readings such as Gamma, Neutron and Density, enhancing the accuracy of the well diameter (Caliper) reading.

2.3. Drilling Indicators:

Drilling indicators, including mud losses, penetration rates, and core recovery, help identify subsurface fractures and faults. Mud loss and high ROP suggest fractured zones, while core recovery provides additional confirmation, supporting precise fracture zone mapping.

2.4. Stratigraphic Correlation and Structural Interpretation:

The research included comparative analysis of stratigraphic thicknesses across wells to identify potential fault displacement. Thinning or missing sequences suggest faulting, as seen in the Makhul, K, Mishrif, and Rumaila Formations [9].

2.5. Data Integration and Fault Zone Classification

The Yamada's Model is a geological model used to classify different areas in rock layers based on the density of fractures. This model focuses on zoning into three main types [16]:

1. Core Fault Zone: This is the area closest to the fault, where the high density of fractures, cracking and surface fragmentation is obvious. In these areas, rock facies overlap and mix and change significantly. These areas are important for studying the density and extension of fractures and the potential migration of hydrocarbon liquids.
2. Damage Zone: This area has less severe secondary fractures compared to the main fault zone. This area is determined using data from well diameter records and drilling indicators that show the presence of fractures, but are less dense.
3. Non-Damage Zone: This is the area that does not have major secondary fractures. They are used as a reference area for comparison with fault-affected areas to determine the impact of faults on rock layers.

3. Stratigraphic Framework

The X field is one of the fields in which near completed stratigraphy formations have been recorded extending from the Late Jurassic -Cretaceous to Tertiary [4]. These formations were reviewed using three main sets of data: the study of thin sections, the analysis of available well logs, and previous studies that inspected this field and its surroundings.

The study of thin sections contributed to providing accurate insights into sedimentation environments by analyzing rock facies and their micro components using thin sections under a microscope, and comparing them to facies extracted from geophysical logs such as Gamma Rays, Neutrons and Density. In addition, combining these data with seismic sections helped to identify and confirm the existence of normal faults (F1 and F2). Geophysical logs play an important role in connecting layers between different wells by analyzing changes in the physical properties of rocks. Furthermore, previous stratigraphy studies [4], [5], [6] provided a comprehensive historical framework that helped interpret data and guide the analysis process. This integration of thin sections, geophysical logs, and previous studies is necessary to modify and refine the stratigraphic sequence of the X field, contributing to a more accurate and reliable geological understanding.

The formations in the X Oil Field, organized by geological age: [4]

- **Tertiary age (**Aaliji, Jaddala, Palani, Tarjil, Ibrahim, Basal Anhydrite Bed, Serikagni, Euphrates, Dhiban, Jeribe and Lower Fars Formations).
- **Cretaceous age (**Makhul, Zangura, Garagu, Shuaiba, Nahr Umr, Mauddud, Mahilban, Rumaila, Mishrif, Kifl, K, Tanuma, Saadi, Kometan, M, H and Shiranish Formations).
- **Jurassic age (**Alan, Sargelu, Najmah, Gotnia and Chia Gara Formations).

The region in middle Iraq, particularly west of the Tigris River, holds significant hydrocarbon reservoirs within certain formations, as detailed below:

1. Campanian–Lower Maastrichtian Reservoir: This reservoir is within the upper part of the M Formation and the lower part of the H Formation (Tables.1, 2 and 4).
2. Turonian Reservoir: This is found in the upper part of the K Formation (Tables.3 and 4).
3. Late Jurassic (Tithonian) Reservoir: Represented by the Chia Gara Formation, this reservoir is a key source of hydrocarbon reserves in the region.

Layers greatly affect reservoir performance and distribution, with variations in stratigraphy properties such as porosity and permeability leading to uneven fluid transport efficiency and hydrocarbon accumulation [10]. In formations such as M, Harth, and Chia Gara, stratigraphic changes can produce isolated areas within the reservoir, limiting its continuity. In addition, tectonic factors such as faults and stratified discontinuity affect communication between layers, affecting the distribution of hydrocarbons [11]. Understanding these factors is essential to improving development and production strategies in the field.

H Formation: The H formation shows a wide variation in the thickness of the hydrocarbon column, ranging from 96 meters in the X-3 well to 202 meters in the X-2 well. This variation indicates possible effects of tectonic agents or changes in the sedimentation environment. The net Pay thickness also varies greatly, with only 80 meters in the X-3 compared to 201 meters in the X-2, reflecting a variation in reservoir quality and continuity. The presence of the lowest oil column undocumented in some wells indicates that there is no confirmed oil-water contact (O.W.C) and its extension to the formation that is located downward (M Formation), Tables (1) and (2).

M Formation: This configuration exhibits thinner reservoir characteristics compared to H Formation, with a total thickness between 32 meters (X-9) and 41 meters (X-5). The thickness of the hydrocarbon column ranges from 6 m (X-9) to 19 m (X-6), reflecting complications in the distribution of hydrocarbons probably due to changing rock and porous facing. The X-9 well shows the lowest hydrocarbon column thickness and net thickness, which may indicate connectivity or prison quality issues for the reservoir rock in this part of the field.

K Formation: This formation shows relatively better continuity in the thickness of the hydrocarbon column, reaching 66 meters in most wells (X-4, X-6 and X-9). The total thickness of the formation is between 83 meters in X-3 and 118 meters in X-4, indicating possible effects of sedimentation agents on the thickness of the formation. The "Lowest Oil" registration is only available in some wells (such as X-2 and X-4), highlighting the need to try to document the hydro-oil contact (O.W.C) that has not been accurately and uniformly identified in drilled wells.

Table (1): Reservoir properties of H Formation in X Field (All depth in meters)

Wells	**X-1**	**X-2**	**X-3**	**X-4**	**X-5**	**X-6**	**X-7**	**X-8**	**X-9**
Formation top(below MSL)	1621.4	1629.4	1568	1683	1668	1643	1636	1599.4	1674
Total thickness of formation	523	385	634	499	358	367	368	511	359
Top Reservoir (below MSL)	1876	1807	1890	1924	1835	1808	1803	1839	1833
Hydrocarbon column thickness	168	202	96	161	186	197	195	161	196
Net thickness	148	201	80	93	181	188	192	144	194
Lowest oil(below MSL)	2044		1986	2085				2000	
O.W.C.									

Table. (2): Reservoir properties of M Formation in X Field (All depth in meters)

Well	X-1	X-2	X-3	X-4	X-5	X-6	X-7	X-8	X-9
Formation top(below MSL)		2014.4			2026	2010	2003		2033
Total thickness of formation		39			41	39	39		32
Top Reservoir (below MSL)		2015			2026	2011	2005		2034
Hydrocarbon column thickness		18.6			14	19	16		6
Net thickness		18			13	18	17		5
Lowest oil(below MSL)		2033			2040	2030	2023		2040
O.W.C.									

Table (3): Reservoir properties of K Formation in X Field (All depth in meters)

Well	X-1	X-2	X-3	X-4	X-5	X-6	X-7	X-8	X-9
Formation top(below MSL)	**2393.4**	**2254.4**	**2497**	**2475**	**2276**		**2245**	**2382.4**	**2271**
Total thickness of formation	104	111	83	118	116		114	110	114
Top Reservoir (below MSL)		**2254**			**2276**	2011	**2245**		**2272**
Hydrocarbon column thickness		58			66	19	66		66
Net thickness						18			
Lowest oil(below MSL)		2311			2342	2030	2311		2338
O.W.C.									

4. Structural Elements of the Research Area

The X Field's structural elements are defined by significant fracture systems, which are key to enhancing reservoir properties, fluid flow, and hydrocarbon recovery. These fractures increase secondary porosity and permeability, essential for efficient production [12], [13]. Lithological facies descriptions, well logs, and drilling data such as mud loss and hydrocarbon shows help identify fracture locations, supporting better reservoir management and well drilling planning [14], [15]. Accurate fracture mapping is vital for optimizing fluid flow and improving overall reservoir evaluation and recovery [16], [17].

The detection of fracture zones in the X Field employs both direct and indirect methods, including [4]:

1. **Mud Loss Locations:** Fracture density correlates with mud loss within stratigraphic units. Identifying the boundaries of mud loss zones offers indirect evidence of fractures.
2. **Caliper and Other Logs:** Fractures are inferred indirectly using caliper logs, supplemented by other logs such as Gamma Ray (GR), Formation Density (FDC), and Compensated Neutron Log (CNL), as well as lithological facies descriptions.
3. **Penetration Rate:** High penetration rates in dense, hard rock formations indirectly suggest the presence of fractures.
4. **Core Recovery:** Elevated core recovery rates in dense, hard rock formations directly indicate fractures.
5. **Repetition or Omission of Stratigraphic Units:** Variations in stratigraphic unit continuity within the drilling sequence can reveal structural disruptions, suggesting fracture zones.

These methods collectively facilitate accurate fracture mapping, which is crucial for optimizing reservoir evaluation and designing effective drilling strategies.

Fault Zones in the X Field are categorized into three areas (Figure 2):

- Core Fault Zone: This central zone features intensely fractured lithological layers, often containing breccia. In well X-3, lithological facies mixing was observed at depths of 2637-2745 meters RTKB, attributed to challenges in facies identification. This interval has been provisionally assigned to the Mahilban/Rumaila Formation.
- Damage Zone: Here, lithologic layers exhibit moderate fracturing with prevalent tensile joints on either side of the fault plane. These joints are detected through caliper logs and corroborated by drilling data, such as mud losses and core recovery ratios.
- Non-Damage Zone: This zone, which lies beyond the influence of the fault plane, consists of lithological layers unaffected by fault-related fracturing.

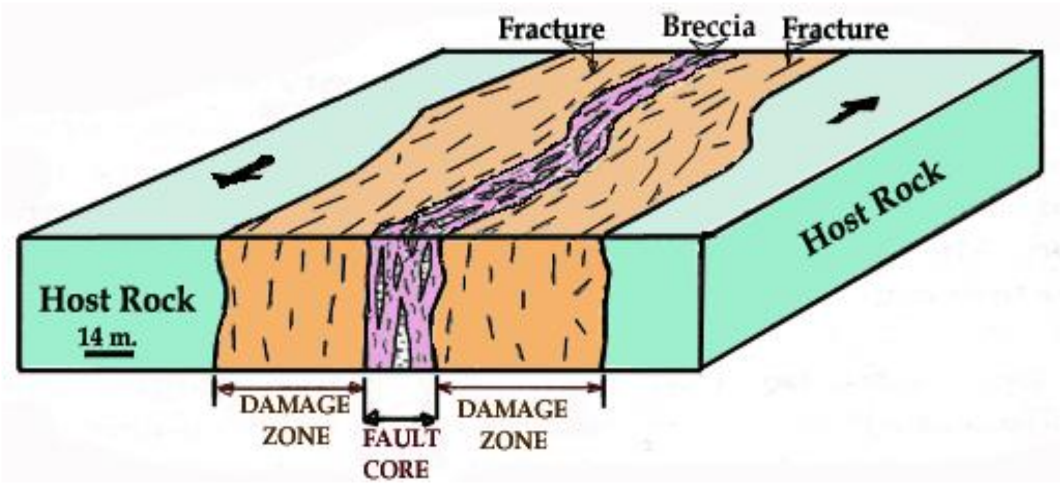

Fig. (2): shear zone [18]

The density of structural features like fractures increases with proximity to the strain zone (faults). Observations from subsurface stratigraphic sequences align closely with fracture zones [18], correlating with fault depths identified via seismic surveys conducted by oil companies and structural field maps.

4.1. Subsurface Fractures in the X Field

The identification of subsurface fractures is essential for enhancing secondary porosity and permeability in hydrocarbon reservoirs, thus boosting production. Fracture zones in the X Field were identified using caliper logs, GR, FDC, CNL, and dip meter logs, along with lithologic facies and drilling data (notably mud losses). Summarized observations for specific wells are provided below:

4.2. Well X-1 Observations (Figures 3 and 4)

1. Makhul Formation Thickness Reduction: Due to faulting, the Makhul Formation's thickness is reduced to approximately 387 meters, compared to 571 and 579 meters in wells X-2 and X-3.
2. CNL and FDC Log Readings: High CNL readings between 3700-3805 meters RTKB in the Makhul Formation, along with FDC readings exceeding 3 g/cm³ from 3705-3805 meters RTKB, indicate dense lithology.
3. GR and Caliper Log Variations: Low GR readings between 3665-3885 meters RTKB, with caliper expansions up to 36 inches between 3743-3800 meters RTKB, indicate potential fractures.
4. Dipmeter Log Deviations: The dip meter log in the Makhul Formation from 3700-3805 meters RTKB shows significant structural disturbance.
5. Mud Loss: Complete mud loss at 3995 meters RTKB suggests the presence of a major fault (labeled F2) within the Makhul Formation between 3742-3800 meters RTKB.

4.3. Well X-3 Observations (Figure 5)

1. Stratigraphic Sequence Reduction: Faulting resulted in a 342-meter reduction, cutting through the lower K Formation and removing the Kifl, Mishrif, Rumaila, and upper Mahilban Formations.
2. Fracture Indicators in Logs: An increased caliper reading without corresponding GR increases between 2575-2850 meters RTKB suggests fractures and a possible fault.
3. Mud Loss: Recorded mud losses at 2710 meters RTKB indicate fault activity.

These data suggest that the fault intersects the Kifl, Mishrif, Rumaila, and upper Mahilban Formations at depths of 2575-3850 meters RTKB

4.4. Well X-4 Observations (Figure 6)

1. Thickness Reduction: Faulting caused a 205-meter reduction in the Rumaila Formation’s lower part and the Mahilban Formation’s upper part.
2. Caliper and GR Log Consistency: Elevated caliper readings without a corresponding GR increase between 2825-2863 meters RTKB indicate fractures.
3. Mud Loss: Mud loss between 2841-2845 meters RTKB suggests the presence of the fault.

These observations support the presence of fault F2 traversing the Rumaila and upper Mahilban Formations between 2825-3863 meters RTKB.

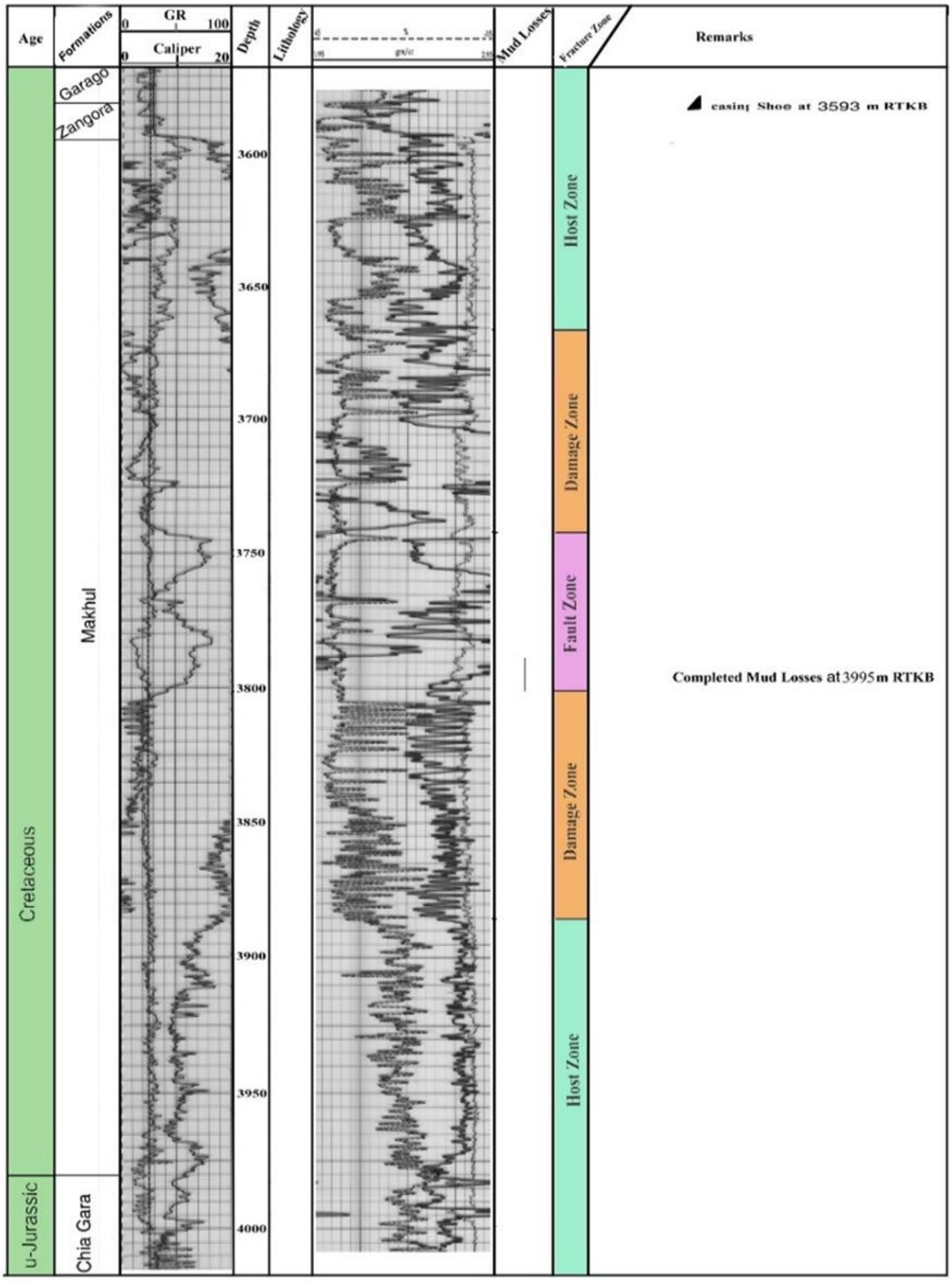

Fig. (3): Fracture zone in the research area (X-1)

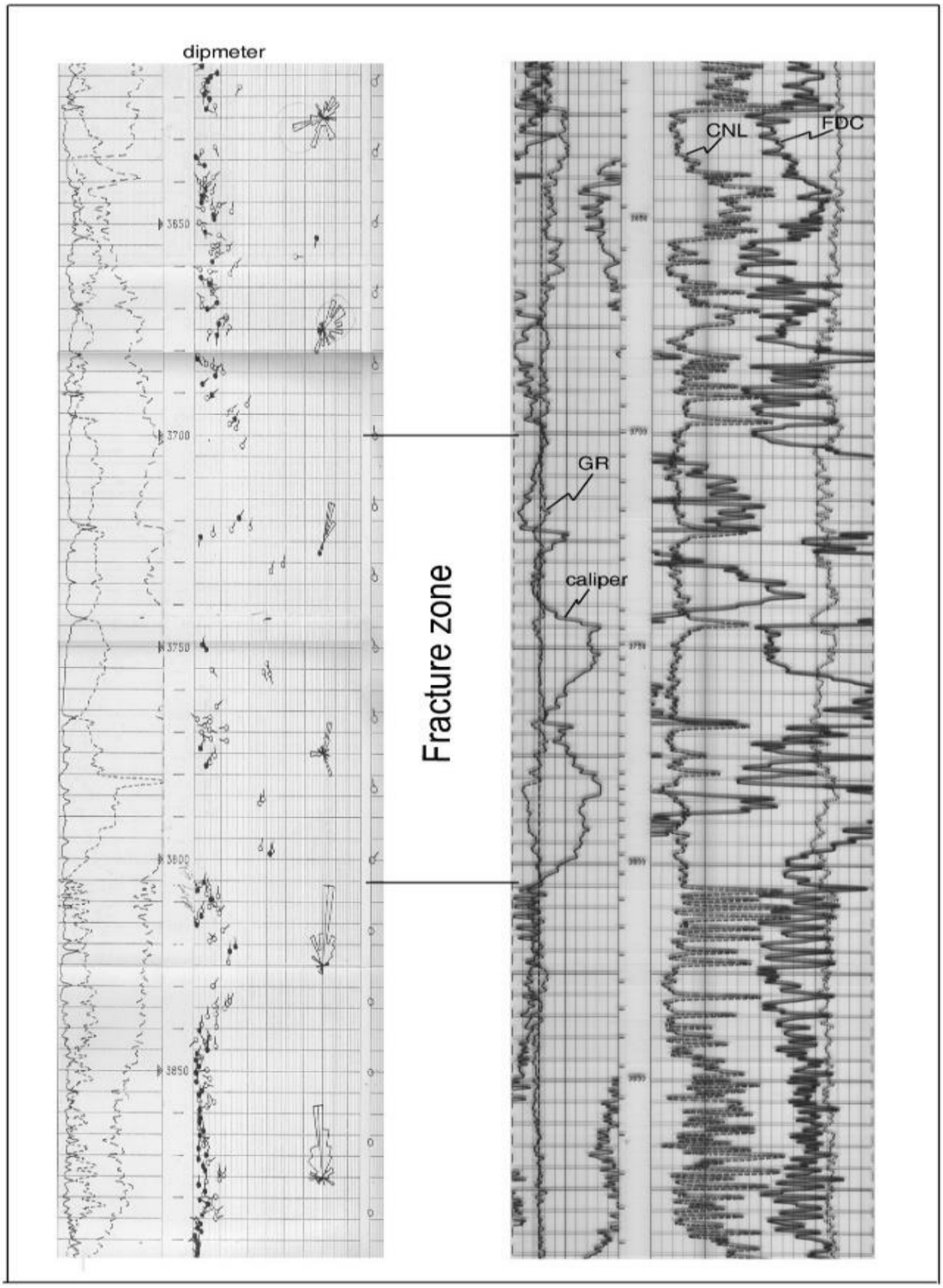

Fig. (4): Fracture zone in the research area (X-1).

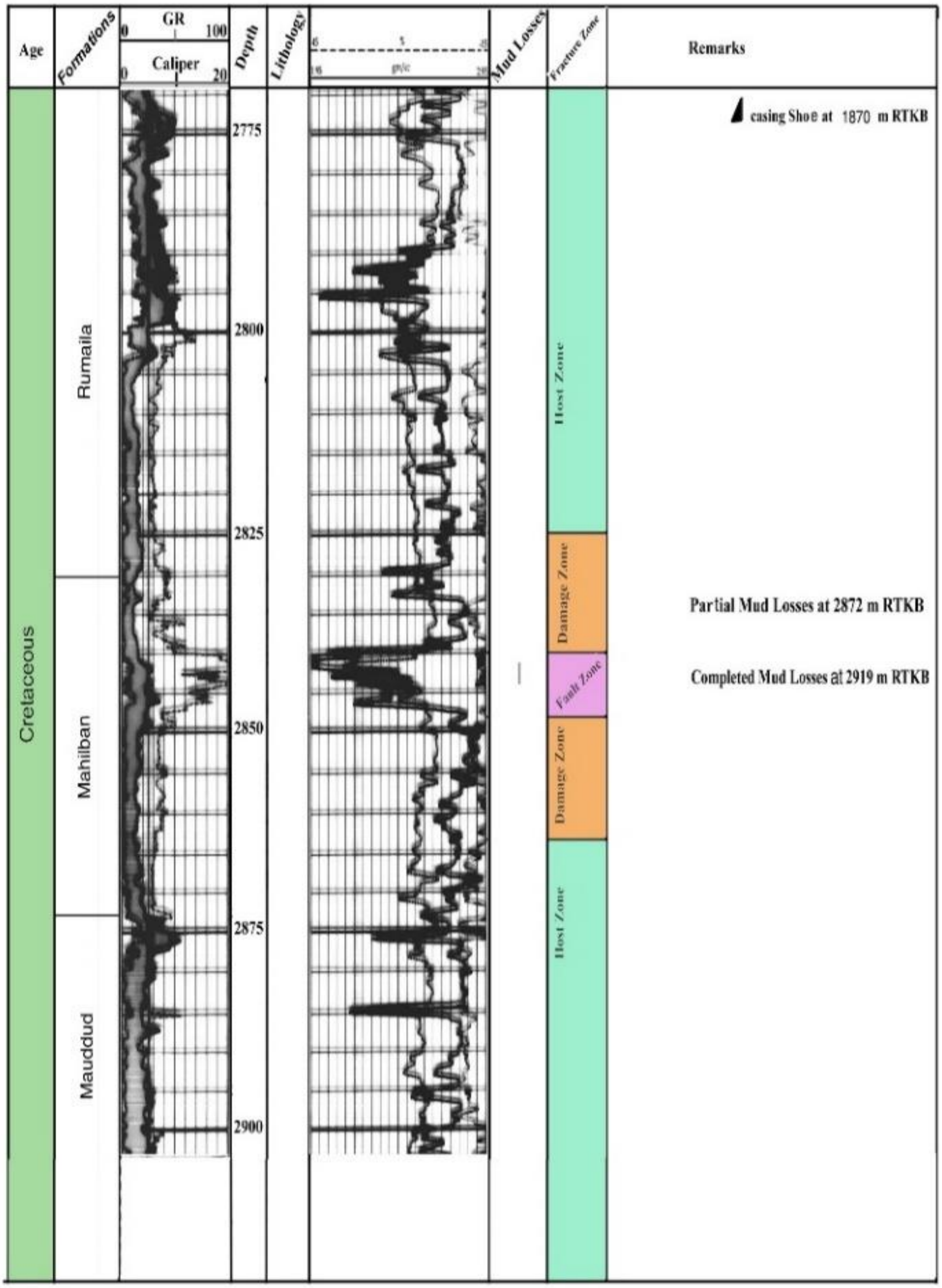

Fig. (5): Fracture zone in the research area (X-3).

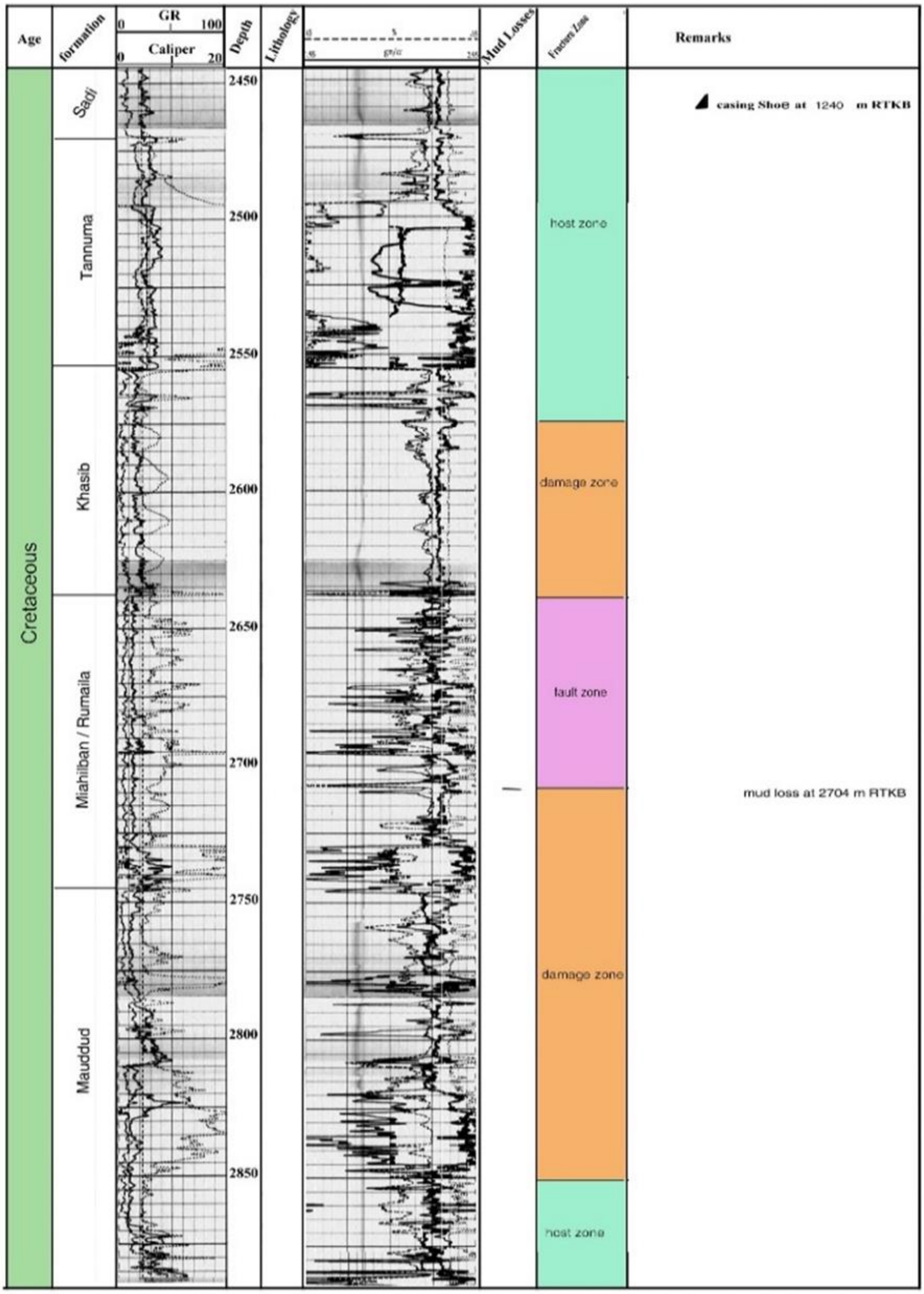

Fig. (6): Fracture zone in the research area (X-4)

5. Results and Discussion

The X Oil Field represents a significant hydrocarbon resource with a well-defined structural framework and notable reservoir potential. This research emphasizes the identification of fracture and fault zones within the X Field through an integration of well log data, lithological analysis, and drilling indicators, generating a comprehensive map of fracture distribution and fault impacts on hydrocarbon reservoirs.

5.1. Fault Zone Analysis

Fault zones in the X Field notably impact reservoir quality by altering porosity and permeability, essential for hydrocarbon storage and flow. Faults were categorized into core, damage, and non-damage zones based on deformation intensity [18], following:

- *Core Fault Zone*: Exhibiting intense fracturing and lithological mixing (up to 8 fractures/meter),, this zone was identified in intervals such as 2637-2745 meters RTKB in the X-3 well within the Mahilban/Rumaila Formation, indicating high strain and fault proximity.
- *Damage Zone*: Moderate fracturing and jointing were observed here, significant for understanding fluid migration. For instance, caliper and mud loss data in the X-1 well identified the damage zone within the Makhul Formation. (2- 4 fractures/meter),
- *Non-Damage Zone*: This outer zone displayed minimal fracturing and served as a baseline for distinguishing structurally stable intervals within the stratigraphy.

5.2. Fracture Distribution and Reservoir Implications

Fractures, crucial for secondary porosity, were mapped using caliper, gamma ray (GR), formation density (FDC), and compensated neutron logs (CNL), with corroborating lithological and drilling data:

- *Well X-1*: Reduced thickness in the Makhul Formation increased fracture density, indicated by caliper expansions and low GR readings (3665-3885 meters RTKB), with complete mud loss at 3995 meters RTKB suggesting a major fault (F2). This fracturing enhances permeability, although wellbore stability could be challenging due to instability (Figure.7).
- *Well X-3*: Increased caliper readings between 2575-2850 meters RTKB and mud losses at 2710 meters indicated fractures. A 342-meter reduction in the stratigraphic sequence impacted the K, Kifl, Mishrif, Rumaila, and Mahilban Formations. The fractures suggest potential zones for hydrocarbon migration and trapping.

- *Well X-4*: Elevated caliper readings and mud loss from 2825-2863 meters RTKB confirmed fault F2 and a 205-meter reduction in the Rumaila and Mahilban Formations. This fracturing enhances porosity, beneficial for hydrocarbon storage and extraction, though fluid dynamics and stability must be managed.
- Correlation of fractures to production rates: The X-1 well, which recorded a high flow rate (3346 barrels/day), indicates the presence of effective fractures that promote rapid fluid transport. The X-3 well, which has a low flow rate (386 barrels/day) in the pressure test (PT), may reflect the presence of limited fractures or less efficient porosity, (Table 4).
- Fracture Distribution in Different Formations: H Formation shows relatively high production rates in most wells, suggesting the role of natural fractures in enhancing flow. For example, in the X-6 well, the oil flow rate reached 1000 bbl/d at pressure 3054 psi. Fertile formation in wells such as X-2 and X-7 also shows good production, reflecting the role of secondary fractures that affect reservoir continuity, (Table 4).

5.3. Stratigraphy and Reservoir Formation Analysis

The stratigraphy in the X Field indicates key hydrocarbon reservoirs in Upper Cretaceous formations, including the M, H, K, and Chia Gara Formations (Figure.7). Structural disturbances and thickness variations reveal fault displacement:

- *Reservoir Quality*: Fractured formations, such as the H, K, and Chia Gara, show favorable porosity and permeability, enhancing reservoir potential.

5.4. Data Integration for Fault and Fracture Mapping

Well logs, lithological data, and drilling indicators such as mud losses facilitated precise subsurface mapping:

- *Enhanced Fault Zone Identification*: The integration of multiple logs and drilling indicators, including mud loss, was effective in locating fractures.
- *Implications for Well Planning*: Mapping fracture zones provides essential guidance for optimized well placement, reservoir evaluation, and targeted hydrocarbon extraction strategies.

The effect of fault displacements (F1 and F2) on formations and reservoirs. these displacements lead to the division of the reservoir into smaller sectors, which affects the hydraulic connection between the different parts of the reservoir, in areas where faults occur diagonally, as shown between F1 and F2, there may be an increase in porosity and permeability as a result of the development of fractures. However, in areas of "barrier facies", these faults act as an obstacle to communication between the beads, but in the place of formation of the H the contact remains between the graben and northeastern shoulder (Figure 7).

Table (4): Reservoir characterizes in X Field

Well	Fms.	type of test	Test interval R.T.K.B(m)	Fluid	Flow rate bbl./d	Pressure (psi)	API	Remark
X-1	H	DST	1922-1965	Oil		3346		
	H	MFE	2039-2049	Oil				
	H	Comp.	2086-2100	Oil Water		2991		
	Saadi		2317.5-2361	Water		3783		
X-2	H	DST	1924-1940	Oil		3196		
	K	DST	2325-2343	Oil		3810	21	
X-3	H	PT	1956-1963	Oil	386	2805		
	H	DST	1968-1982	Oil		3096	15	
	H	PT	2002-2010	Water mud			16	
X-4	H	MFE	2042-2035	Heavy Oil	140		16.6	
	H		2074-2083	Heavy Oil	120	2978	15.2	
	H		2171-2174.4	Heavy Oil	500	3429	19.1	
X-5	K		2347-2357	Heavy Oil	400	3586		
X-6	H	MFE	1992-2022	Oil		3295		
	H	Comp.	1995-2022	Oil	1000	3054		
X-7	H	Comp.	1942-1951	Oil	400	3216		
	K	O.H	2309-2357	Oil Water	1260	3875		
X-8	H	Comp.	1905-1910	Oil	500	3039		
	H	Comp.	2005-2015	Oil	500	3220		
	K		2455-2465	Water				
X-9	H	Comp.	1962-1972	Oil	400	3207		
	H	Comp.	2015-2025	Oil	300	3165		
	K	Comp.	2340-2350	Oil	400	2337		

5.5. The economic feasibility of the research lies in the following:

The economic feasibility of this research is rooted in its ability to enhance hydrocarbon extraction, reduce drilling risks, and optimize exploration strategies. By identifying fault zones and fracture networks, the study provides critical data that could boost production rates by up to 20% in high-porosity core fault areas and cut drilling-related costs by 15%. These projections are consistent with findings from similar studies that highlight significant economic benefits from targeted fault analysis.

However, realizing these advantages depends on the adoption of advanced technologies, such as real-time well logging and image log calibration, which involve implementation costs. Despite this, the research supports sustainable economic growth in energy sector while offering scalable solutions that can be applied.

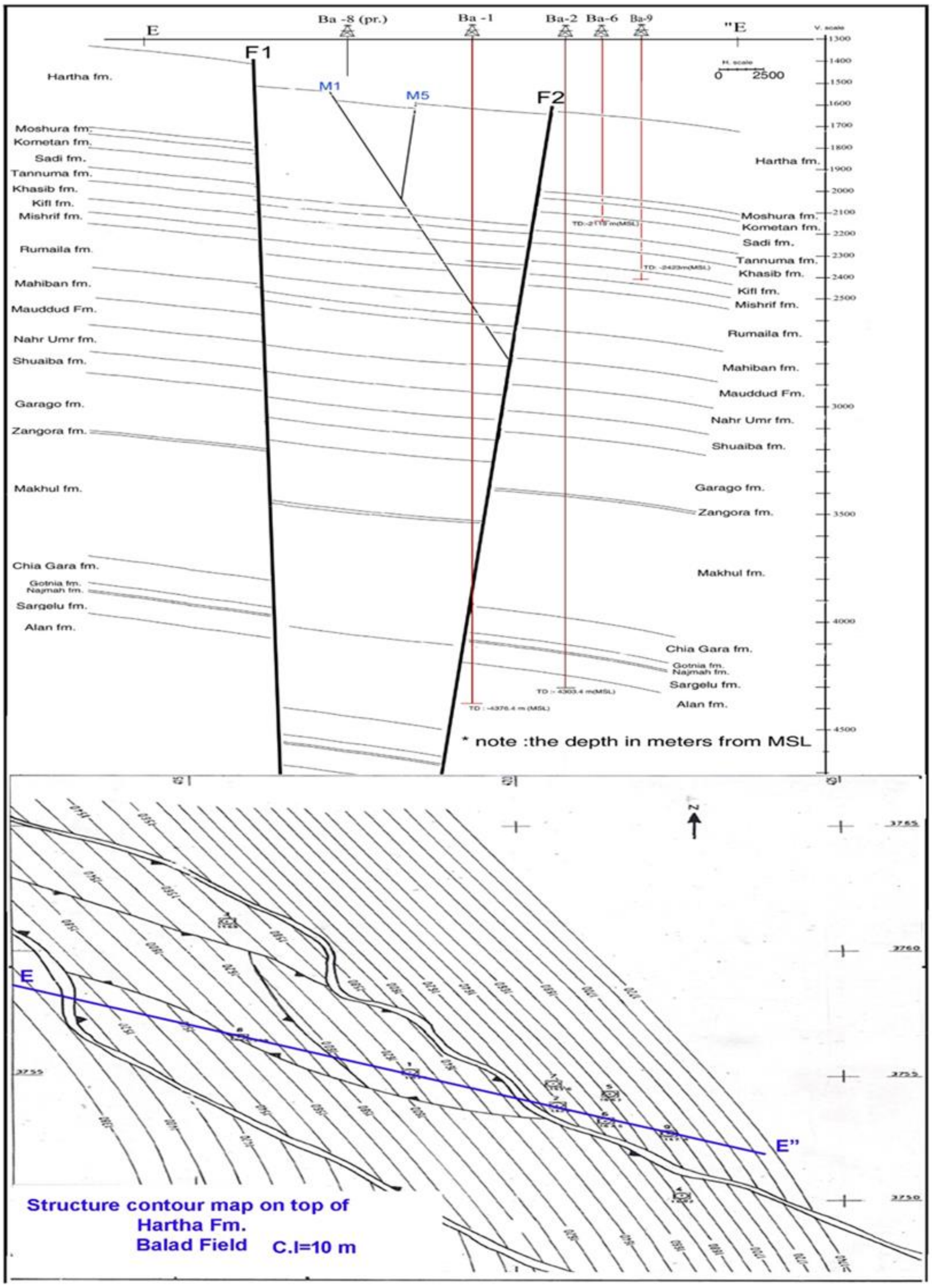

Fig. (7): Geological cross section E-E" in the research area.

6. Conclusions

This research on the X Oil Field provides valuable insights into its structural framework, reservoir quality, and hydrocarbon extraction potential:

1. Fault zones in the X Field were systematically identified and classified as core, damage, and non-damage zones. This categorization aids in understanding the structural impact on reservoir properties like porosity and permeability, which are critical for effective hydrocarbon storage and flow.
2. Determine fracture networks through well logs, such as caliper and gamma-ray, identified zones with enhanced secondary porosity. These fractures are key for hydrocarbon migration and provide high-priority targets for drilling.
3. The findings provide a foundation for future production strategies, supporting targeted reservoir management, new locations of produce wells, and enhanced oil recovery plans, all of which contribute to the field's sustainable development and profitability within Iraq's oil sector.

Author Contributions Statement: Ahmed I. S. Al-Naemi contributed to the Conception; Methodology; Data Analysis and Interpretation; Writing Original Draft; Writing – Review & Editing. Arjan M. Mahdi contributed to the Data Curation and Analysis; Literature review. Marwan I. Al-Eisa contributed to the; Investigation/ Experiment; Data Interpretation; Literature review. Mohammed R. Al-Jubori contributed to the Literature review; Writing Original Draft. All authors have read and approved the final version of the manuscript.

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