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# A Comprehensive Assessment of Natural Fractures in the Mishrif Formation: Slide Studies, Core Samplings, Borehole Imaging, and Logging Techniques

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**Abstract**

The Mishrif Formation in the Rumaila oilfield is a prolific carbonate reservoir with significant hydrocarbon production. However, the role of natural fractures in enhancing reservoir characteristics remains poorly understood. This study aims to characterize and identify naturally occurring fractures within the Mishrif Formation using a multi-methodological approach integrating core and thin section analysis, borehole image logs, and conventional well logs. Results indicate different types of natural fractures, such as open, filled, vuggy, and propped fractures. The open type dominates the field; thus, the potential for oil production from this formation is high. Fracture orientation analysis revealed that the N-W and S-E directions have the largest percentage of fractures, making these areas favorable for drilling more wells. The main conclusion of this research is that the use of integrated methods enables the characterization and quantification of natural fractures, significantly contributing to the efficient management of oil reservoir units.

**Keywords:** multi-methodological, hydrocarbon recovery, image logs, natural fractures, increased production.

# تقييم شامل للكسور الطبيعية في تكوين مشرف: دراسه من خلال الشرائح وعينات اللباب والتصوير البئري والمجسات

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**الخلاصة**

إن تكوين المشرف في حقل الرميلة النفطي عبارة عن خزان غزير للكربونات مع إنتاج كبير من الهيدروكربونات. ومع ذلك، فإن دور الكسور الطبيعية في تعزيز خصائص المكمن لا يزال غير مفهوم بشكل جيد. تهدف هذه الدراسة إلى توصيف وتحديد الكسور التي تحدث بشكل طبيعي داخل تكوين مشرف باستخدام تحليل متعدد الادواة يدمج تحليل الشرائح واللباب ، وسجلات صور البئر، وسجلات الآبار التقليدية.

تم تحديد أنواع الكسور المتعددة، بما في ذلك الكسور المفتوحة، والمملوءة، والمتعرجة، والمسنودة (شبه المملوءة).

تم إنشاء الارتباطات بين وجود الكسر وزيادة المسامية كما هو موضح بواسطة السجلات النيوترونية والصوتية، مما يشير إلى دور حاسم للكسور في تعزيز تدفق الخزان. يمكن تحقيق توصيف شامل للكسر من خلال الجمع

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بين مصادر البيانات المتنوعة. تحمل هذه المعلومات آثارًا كبيرة على إدارة المكامن وتحسين الإنتاج، مما يوفر
إرشادات قيمة لصناعة النفط ومضاعفة استخلاصه من المكامن ذات التكسرات الطبيعيه .

## 1. Introduction

Naturally fractured carbonate oil reservoirs represent a captivating geological phenomenon that has garnered substantial attention within the petroleum industry. The detection of the type, shape and size of these fractures can help to understand the way that the solutions move and help in oil and gas detecting. Investigating and extracting hydrocarbons from the reservoir that contain natural fractures is a massive problem for the oil industry, considering their importance in hydrocarbon production and the deep technical complexity they entail [1]. Natural fractures play an important role in determining petrophysical properties such as permeability and porosity. Therefore, characterization of these fractures is of important in oil industry. Mishrif Formation is considered is one of the most important oil reservoirs in Iraq which considered as carbonate-rich reservoir [2]. Essential information on this formation and the existence of fractures can be detected by different tools such as well logging and the study of core and thin sections. Borehole imaging is one of the fastest and most reliable ways to collect subsurface data [3]. Borehole imagery (FMI) is being incorporated into reservoir models during drilling progressively. The FMI allows you to comprehend geologic settings by viewing borehole pictures of rock.

The aim of the study is to characterize the natural fractures in the Mishrif Formation, located in the North Rumaila oilfield, southern Iraq, using various techniques. These techniques include core data, thin sections, conventional borehole logging, and borehole imaging. The objective is to quantify the influence of fractures on the petrophysical characteristics within the Mishrif Formation. This, in turn, will enable more efficient and cost-effective reservoir management.

## 2. Geological setting

A group of wells in the North Rumaila field were chosen for the study of natural fractures in the Mishrif Formation. Rumaila field is situated around 45 kilometers west of Basrah city, between the longitudes 47º14'46" - 47º26'14" Easting and latitude 30º5'5.7" - 31º12'41" Northing. It has a total area of 1600 km². The Mishrif Formation is a large hydrocarbon resource located in the southern region of the nation. It is found in various oil fields, notably Rumaila and Zubair Figure 1. The Rumaila oilfield is structurally complicated, with a twofold simple and asymmetric anticline dip, with a pronounced N-E trend along its long axis. This geological system comprises two important domes: North Rumaila (NR) and South Rumaila (SR). The whole construction spans 12 kilometers in breadth and 83 kilometers in length [4]. The North Rumaila structure is an extended anticline that runs approximately north-south. The flanks slope by around three degrees, with a slight asymmetry where the western side is steeper than the eastern flank Figure 1 It gently descends southward, creating a saddle that divides it from South Rumaila. Regarding Iraq's tectonic divisions, the North Rumaila structure is located in the Mesopotamian zone's Zubair subzone. This location is part of the Arabian plate quasiplatform foreland, situated in the drooping basin of the Mesopotamian zone. The Takadid Quarna and Basrah-Zubair faults form the northern and southern boundaries of this zone, respectively [5]

The Rumaila oil field's lithostratigraphic column includes clastic, carbonate, and evaporite rock cycles. The stratigraphic column runs from bottom to top and comprises the following formations: Sargelu, Naokelekan, Najmah, Gotnia, Sulaiy, Yamama, Ratawi, Zubair, Shuaiba, Nahr Umr, Mauddud, Ahmadi, Rumaila, Mishrif, Khasib, Tanuma, Saadi, Hartha, Shiranish, Tayarat, Umm Er-Radhuma, Rus, Dammam, Ghar, Lower Fars, Dibdibba[6] Figure 2. The Zubair and Mishrif formations are notable reservoirs in this series, and Sargelu, Sulaiy, Yamam, and Ratawi are the source rocks. The names of the cap rocks are Rus, Tanuma, Shiranish, and Gotania. Layers of coral-reef, rudist, and algae limestones may be found in the Mishrif Formation, which is a complex geological unit that was first recognised as organic detrital limestone[7]. the Mishrif Formation split into five units. The MB1 and MB2 units were distinguished by very effective porosity[8]. According to petrophysical characteristics, the Mishrif Formation is made up of multiple reservoir units separated by impermeable cap rock zones.The major reservoir units are (MA&MB)[9].The Mishrif Formation (Late Cenomanian-Early Turonian) is located stratigraphically within the Kifil and Rumaila formations. The top surface of the Mishrif Formation displays variations, transitioning either to the Kifil Formation or being confined by an erosional surface separating the Early and Late Turonian, represented by the Khasib Formation.

The Rumaila Formation underlies the Mishrif Formation, and the contact between the two formations is gradational and conformable. Comprising a complex sequence of limestone rocks, the Mishrif Formation reflects the environmental conditions during its deposition. These parameters vary from the outer/open shelf environment with depositional settings for organic accumulations to a lagoonal/open shelf environment with limited circulation in the interior shelf The Mishrif succession recognizes five associated facies: deep marine, shallow open marine, shoal, Rudist biostrom, and shallow limited marine[10]. Mid-ramp environments, characterized by burrowed wackestones and packstones with peloids and fragmented bivalve and echinoderm grains, predominate on the moderately sloping Mishrif shelf. These environments are bedded and resistant. The mid-ramp environment is followed by a shoal environment consisting of peloidal-skeletal packstone, grainstone, and occasionally rudstone. This environment contains bigger bioclasts. The habitat of bivalves, echinoderms, and rudist clams is characterized by huge resistive mottles that reflect bioclasts against a conductive backdrop, suggesting fluid penetration of the high porosity. Back-shoal environments have diverse energy levels, fauna, and grain sizes. Packstone and wackestone are commonly found, but their presence is intermittent. During periods of sediment starvation, diagenesis occurs, resulting in intense cementation and grain alteration. Image facies show prominent, irregular mottles against a conductive background, indicating fluid invasion of local porosity. The lithology found in the Mishrif Formation gives information. on the various depositional settings and their development throughout time. The thickness of the formation in southern Iraq varies between 200 and 150 meters. However, as one approaches the Iraqi-Iranian border, the thickness of the structure grows, reaching more than 350 meters, [11]

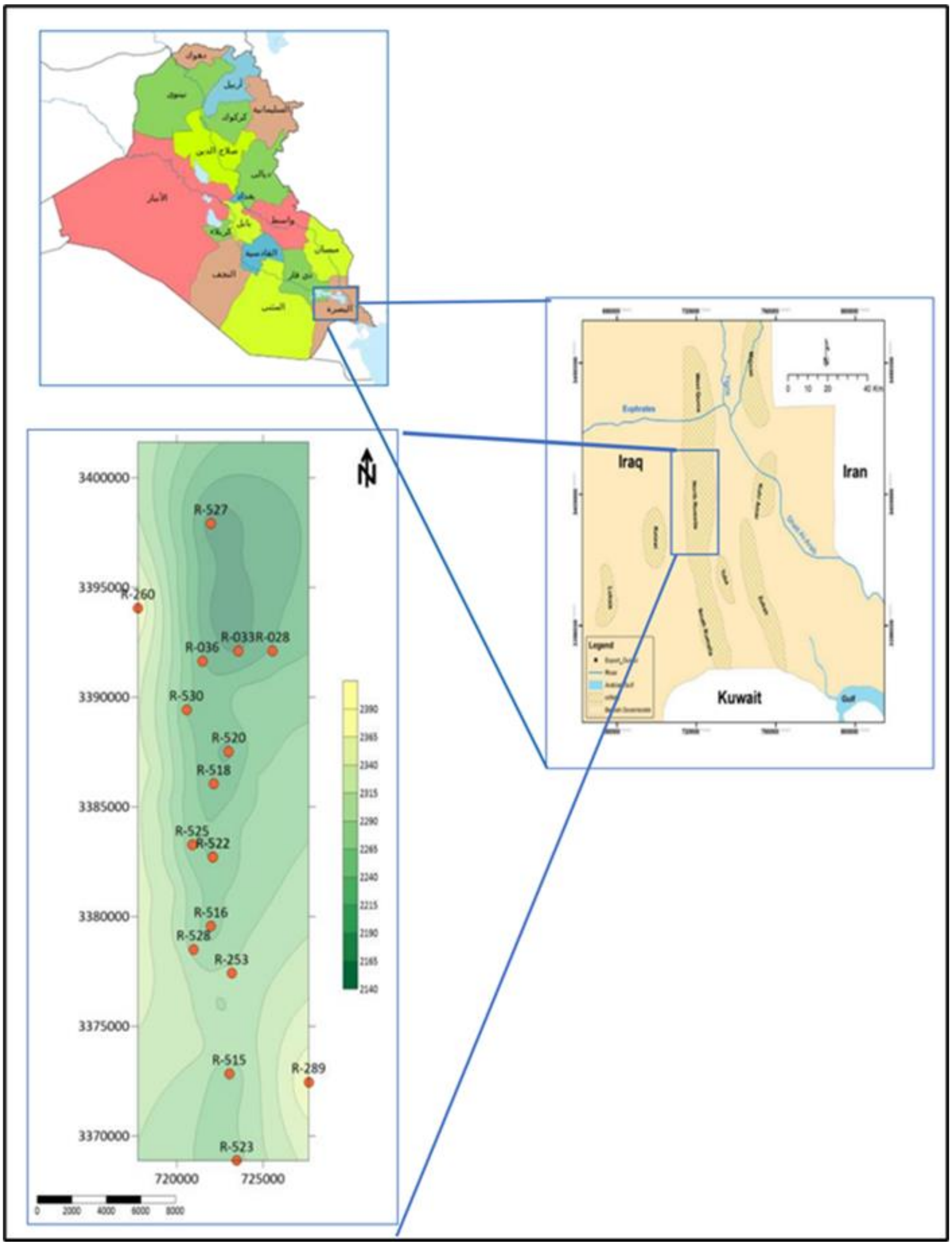



**Figure 1:** Location map of the study area: a) Map of Iraq, b) Basrah oil fields, c) Structural map of the top Mishrif Formation in North Rumaila oil fields, indicating the wells under study[12].

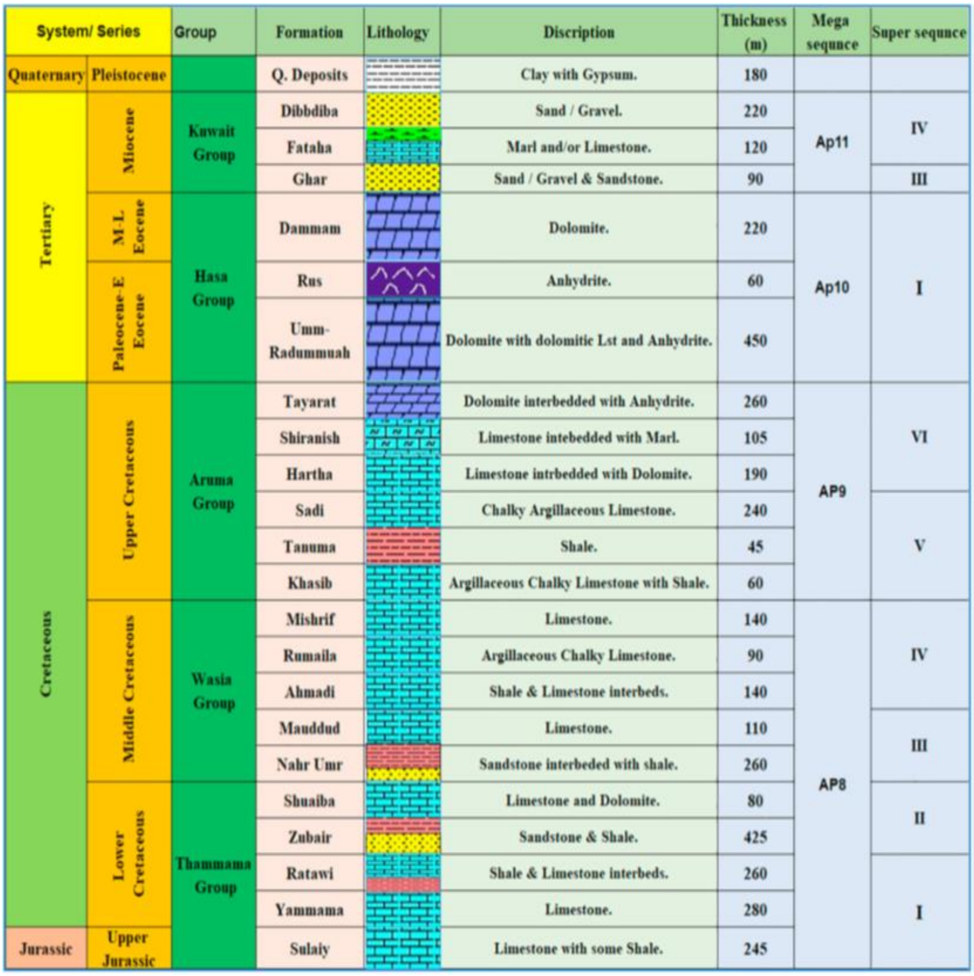



**Figure 2:** the south of Iraq Stratigraphic column [13]

## 3. Methodology

The methodology encompasses the collection of geological and petrophysical data, as well as the subsequent analysis of these data to elucidate the key characteristics of the formation.

1.Data Collection: Gathering previous studies and reports: The initial phase involved the comprehensive collection of prior studies, structural maps, and final geological reports relevant to the Rumaila oil field. These sources provided essential background information and data sources.

2.Core and thin sections examination: Fractures were classified using core and thin section analyses. A detailed examination of geological formations was provided by these analytical methods, focusing in particular on the presence and characteristics of fractures.

3. Image Log Interpretation: The Interactive Petrophysics (IP) software was utilized for analysis logs and calculation of petrophysical characteristics.

## 4. Results and discussion

### 4.1 Study of fractures from thin-section and core

The following types of fractures are the fractures that had been detecting from the core and thin section:

•Diagenetic fractures: Diagenesis is the process of chemical and physical transformations in sedimentary rocks during deposition and lithification, resulting in fracture formation. compression, the cementation process, and the expansion of minerals The Mishrif Formation undergoes many diagenetic processes that affect reservoir rock characteristics and enhance porosity[14] (Figure 3 a, b, e).

• **Thermal fractures:** These fractures are generated owing to thermal stress caused by temperature variations in the rock. They can be caused by heating or cooling of the rock, or by the circulation of hot fluids through the rock. These fractures can be small and localized, or large and extensive, depending on the temperature gradient and the nature of the rock [15](Figure 3 c, d, f, g, h, i) and (Figure 4).

Classification of fractures in core samples can also be based on their orientation, such as vertical, horizontal, or inclined fractures. Additionally, fractures can be classified based on their spacing, aperture[16]

•**Open Fractures**: Fractures with a significant opening or gap between the fractured surfaces (Figure 3 f, g) (Figure 4 d,e, g).

•**Filled Fractures**: Fractures with minimal or no opening between the fractured surfaces (Figure 3 a,b, e) (Figure 4a, b,c, d, e, f, g, h).

• **Partially healed (propped)**Pores loaded with minerals (resistive),while others are conductive. (Figure 3 a, b, c, i) (Figure 4 a, b, c,h).

• **Solution-enlarged(vuggy)**: Some sections are - Solution-enhanced fractures that eventually develop vuggy or cavernous. (Figure 3 c, d, e, h) (Figure 4 a)

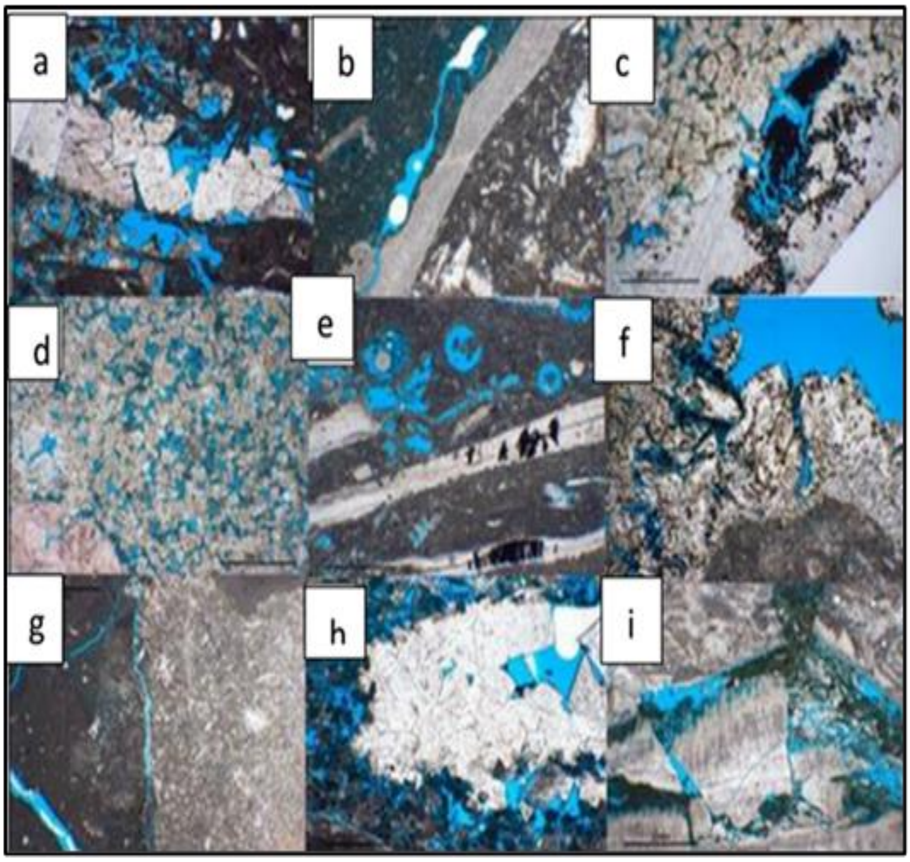



**Figure 3:** Thin section shows naturally fracture on Mishrif Formation (a: R-289 depth 2448.44- 020511, b: R-028 depth 2246.71-020516, c: R-260 depth 2445.4-010831, d: R-036 depth 2260.32-010830, e: R-028 depth 2231.24-020516, f: R-028 depth 2306.75-020516, g: R-028 depth 2302.16-020516, h: R-253 depth 2381.73-020514,i: R-028depth 2322.18-020516).

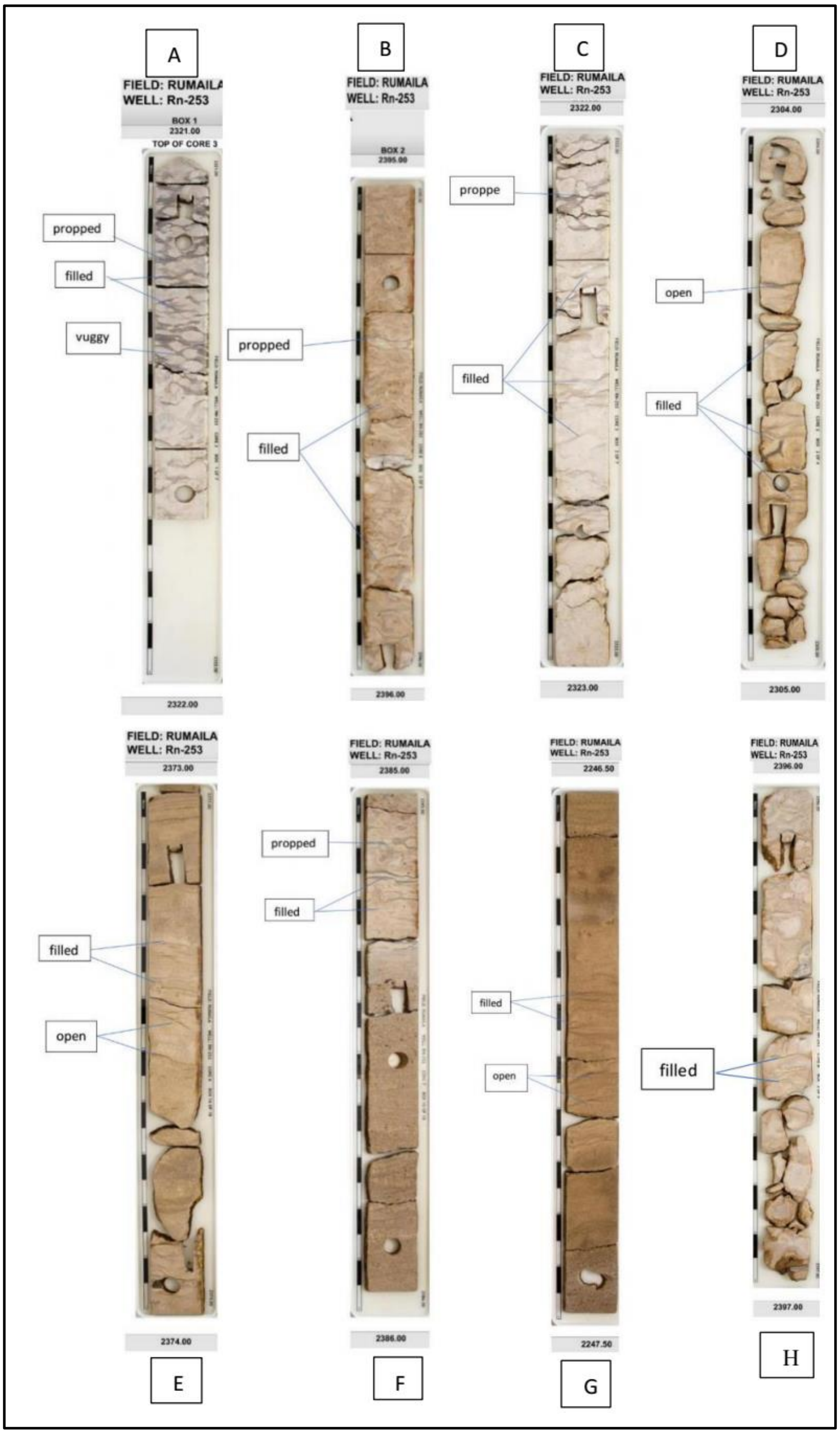



**Figure 4:** Fractures classification on Mishrif Formation, well (R-253 a : depth 2321-2322,b: depth 2395-2396, c:depth 2322-2323, d:depth 2304-2305, e:depth 2373-2374, f:depth 2385-2386, g:depth 2246.50-2247.50, h:depth 2396-2397 ).

**4.2 The type of naturally fractures from image log and well logging**

Fractures can be classified based on their various morphological properties [17]. A fracture might be open that appears to us in dark color , healed (filled with minerals) seems to us in light color, propped (some areas are filled with minerals, while others are conductive)appear to us as a dark and light space , or vuggy(solution enhanced) [18]

**• Open Natural Fractures**

These fractures are a natural part of the geological formation and are caused by tectonic movements, localized stress conditions, or both. These fractures are usually planar in form and vertical in position (dip more than 75 degrees). Since the drilling solution or mud usually enters the fracture aperture during drilling and forms a thin layer with conductivity significantly differing resistivity from the surrounding rock matrix, open fractures may be easily seen on image logs. The current of electricity flows differently as a result of this difference in resistivity inside the conductive layer, setting it apart from currents flowing through a uniform depth Figure 5 depths 2247,2248, 2249.

**• Filled Fractures**

The previous description of mud entering cracks relates to open fractures (natural, induced by drilling, or breakouts). Mud cannot penetrate filled fractures due to mineral fluid cementation. Figure 7 depth 2275.5.

**• Partially healed**

Pores are filled with minerals, whereas others are conductive fractures in rocks that have partially healed are those that have undergone some healing. This healing process involves the sealing or closing of fractures via diverse geological mechanisms. Unlike vuggy or cavernous formations, which involve the formation of pore spaces, partially healed fractures indicate that the initial fractures have been sealed or closed, see Figure 5 depth 2245, Figure 6 depth 2272,2273 and Figure 7 depth 2272.5.

**• Solution-enlarged(vuggy)**

Some sections are - solution-enlarged fractures that eventually turn vuggy or cavernous, The phrase "enlarged fractures" often refers to rock fractures that have undergone a widening or dilatation process. When these cracks mature into vuggy or cavernous formations, more minerals are typically dissolved or removed, forming empty spaces or cavities inside the rock. This process is frequently connected with certain geological conditions and can be attributed to various variables such as chemical weathering, groundwater dissolving, or other erosional processes, Figure 6 depth 2268.

Analyzing how various logging instruments react to the properties of the surrounding rock formations is necessary to densify fractures utilizing gamma ray (GR), neutron, density, and resistivity logs. Each log can aid in the diagnosis of fractures in the following ways

- **Gamma Ray (GR) Log:**

Features: Natural radioactivity released by the formation is measured by gamma-ray logs[19].

Fracture Indication: The natural radioactivity of the surrounding rock changes as fractures allows fluids to pass through them. There may be fractures present if gamma ray values rise.

- **Neutron Log:**

Features: Hydrocarbons or water are indicated by the neutron porosity of the formation, which is measured by neutron logs[20].

Fracture Indication: Variations in neutron porosity can be caused by fractures serving as pathways for fluid flow. Fractured zones may be revealed by anomalies in neutron log data.

**• Density Log:**

Features: Density logs quantify the formation's bulk density, which is correlated with the rocks' composition[20].

Fracture Indication: Variations in density might result from voids inside a fracture or from the fracture's composition differing from that of the surrounding rock. A rapid drop in density values might indicate that there are fractures present.

• **Resistivity Log:**
Features: Resistivity logs quantify the formation's electrical resistivity, which is correlated with the fluid content and rock conductivity[21].
Fracture Indication: Fractures show differing resistivity values from the surrounding rock and may serve as fluid routes. Resistivity reading anomalies might indicate the existence of fractures.

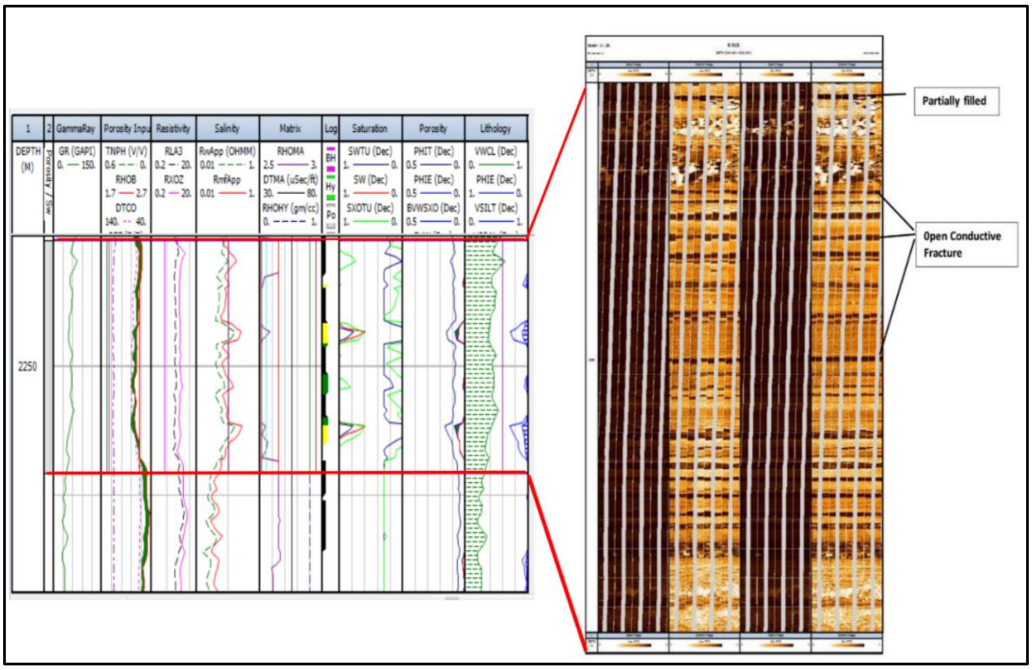



**Figure 5:** CPI and image log of well R-515 depth (2244-2254m). The petrophysical chart highlighted in red corresponds to the well imaging .

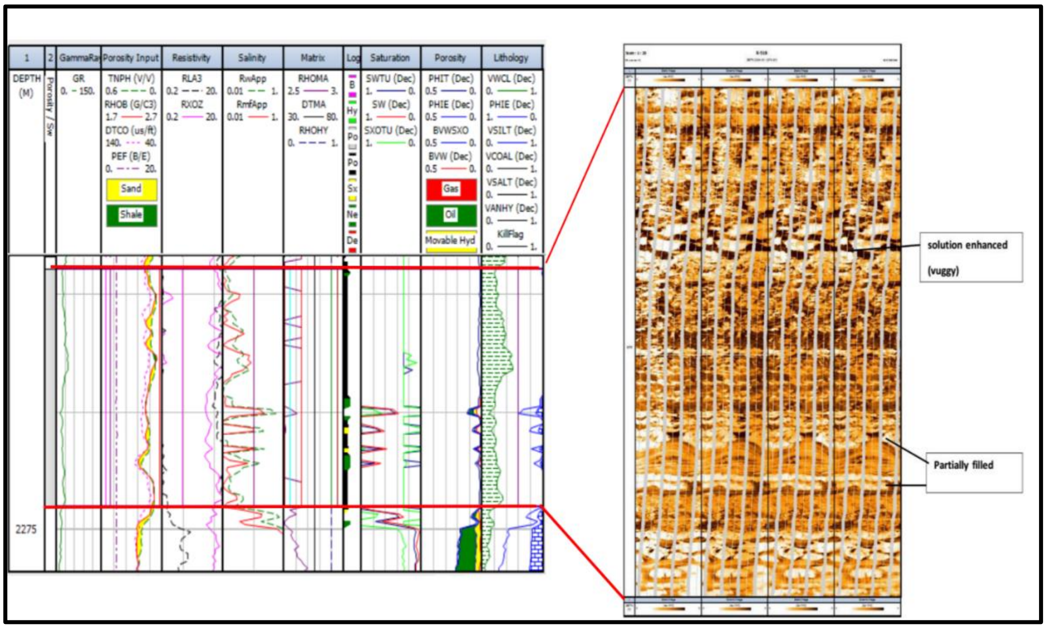



**Figure 6:** CPI and image log of well R-518 depth (2264-2274) The petrophysical chart highlighted in red corresponds to the well imaging .

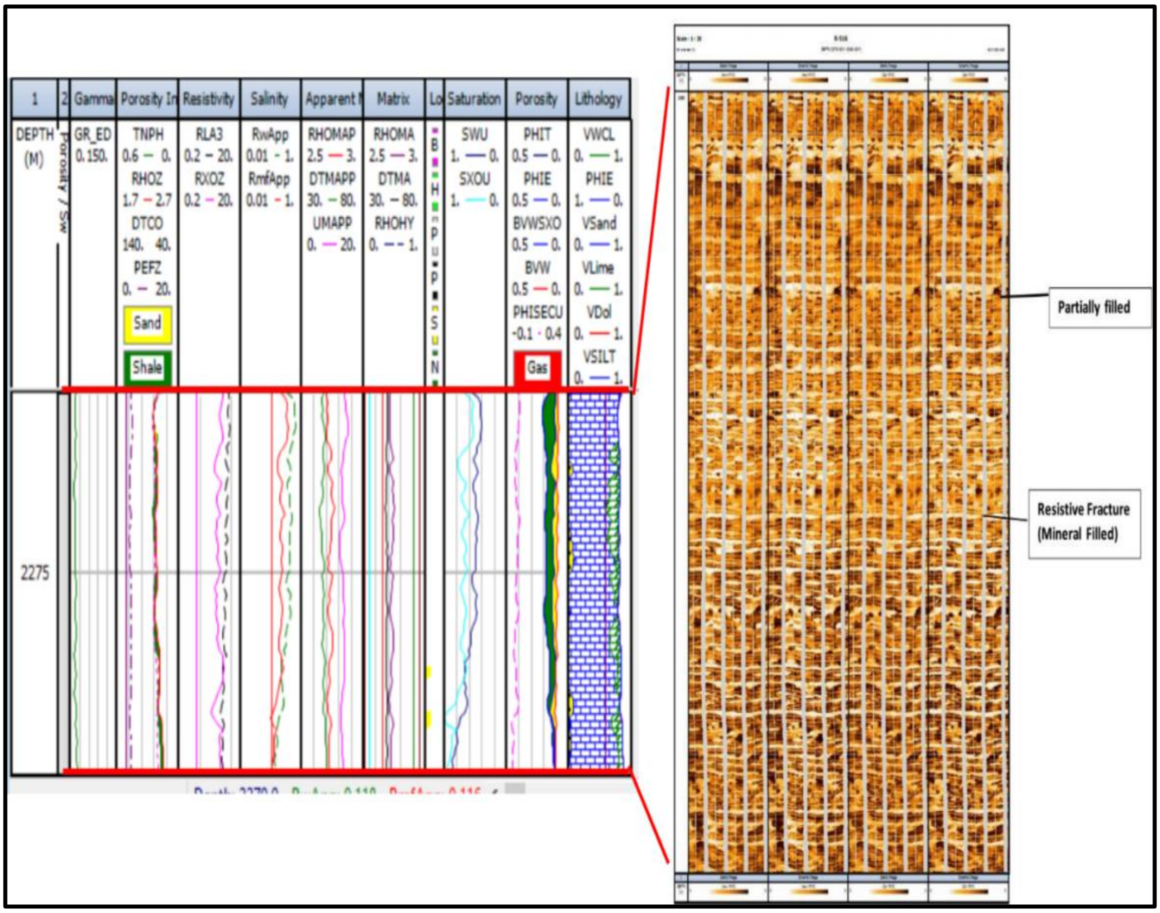



**Figure 7:** CPI and image log of well R-516 depth(2270-2280) The petrophysical chart highlighted in red corresponds to the well imaging .

The study of natural fractures in this formation using various methodologies leads to a better knowledge of the types of fractures. This enables the observation of the same fracture structure in numerous forms by inspection using slides, core samples, and borehole imaging. This vivid image improves our comprehension of the fracture type. The shape and properties of fractures may be easily seen under the microscope while studying slides. These investigations help to determine the kind and orientation of fractures, as well as the surrounding rock constituents as shown in Table 1. In addition to slides, obtaining rock samples (cores) provides a direct understanding of fractures and their properties. The distribution and orientations of fractures may be noticed in the core, assisting in the interpretation of the geological behaviour of fractures. Borehole imaging systems enable the accurate monitoring of fractures in wellbore walls with great precision. These pictures can help detect the distribution of fractures in the surrounding rock strata. They also show conductive fractures, which seem black, and non-conductive fractures, which appear lighter due to the presence of deposits within them. Logging techniques offer readings on the characteristics of the rocks in the well, which may vary owing to cracks. Analyzing these logs can help us understand the prevalence and nature of fractures in the subsurface layers

**Table 1:** well number with depths and types of fractures

| Well number | depth | Diagenetic | Thermal | open | Filled | Partially healed | vuggy |
|---|---|---|---|---|---|---|---|
| R-289 | 2448.44- 020511 | * | | | * | * | |
| R-028 | 2231.24-020516 | * | | | * | | * |
| R-028 | 2306.75-020516 | | * | * | | | |
| R-028 | 2246.71-020516 | * | | | * | * | |
| R-028 | 2302.16-020516 | | * | * | | | |
| R-028 | 2322.18-020516 | | * | | | * | |
| R-260 | 2445.4-010831 | | * | | | * | * |
| R-036 | 2260.32-010830 | | * | | | | * |
| R-253 | 2381.73-020514 | | * | | | | * |
| R-253 | 2321-2322 | | * | | * | * | * |
| R-253 | 2395-2396 | | * | | * | * | |
| R-253 | 2322-2323 | | * | | * | * | |
| R-253 | 2304-2305 | | * | * | * | | |
| R-253 | 2373-2374 | | * | * | * | | |
| R-253 | 2385-2386 | | * | | * | * | |
| R-253 | 2246.50-2247.50 | | * | * | * | | |
| R-253 | 2396-2397 | | * | | * | | |
| R-515 | 2247 | | | * | | | |
| R-515 | 2248 | | | * | | | |
| R-515 | 2249 | | | * | | | |
| R-515 | 2245 | | | | | * | |
| R-518 | 2272 | | | | | * | |
| R-518 | 2273 | | | | | * | |
| R-518 | 2268 | | | | | | * |
| R-516 | 2272.5 | | | | | * | |
| R-516 | 2275.5 | | | | * | | |

### 4.3 Fractures orientation

Fracture orientation describes the direction or alignment of a fracture surface in relation to its surroundings. Fractures in geology can occur in a variety of orientations based on stress, rock type, and geological structures. Understanding fracture direction is critical for many applications, including petroleum exploration, groundwater management, and geotechnical engineering. Fracture orientations are frequently expressed as compass directions or angles relative to a reference axis[22]. For instance, fractures can be classified as:

- Horizontal fractures: These fractures run parallel to the horizontal plane. They can be caused by tensile forces acting perpendicular to the fracture plane.
- Vertical fractures: These fractures are perpendicular to the horizontal plane. They may be caused by horizontal compressive stresses.
- Oblique fractures:are fractures that occur at an angle to both the horizontal and vertical planes.
- Dip and strike: are common terms used in geology to characterize fractures 8 and 9. The strike is the compass direction of a horizontal line on the fracture plane, and the dip is the perpendicular angle between the fracture plane and the horizontal plane.

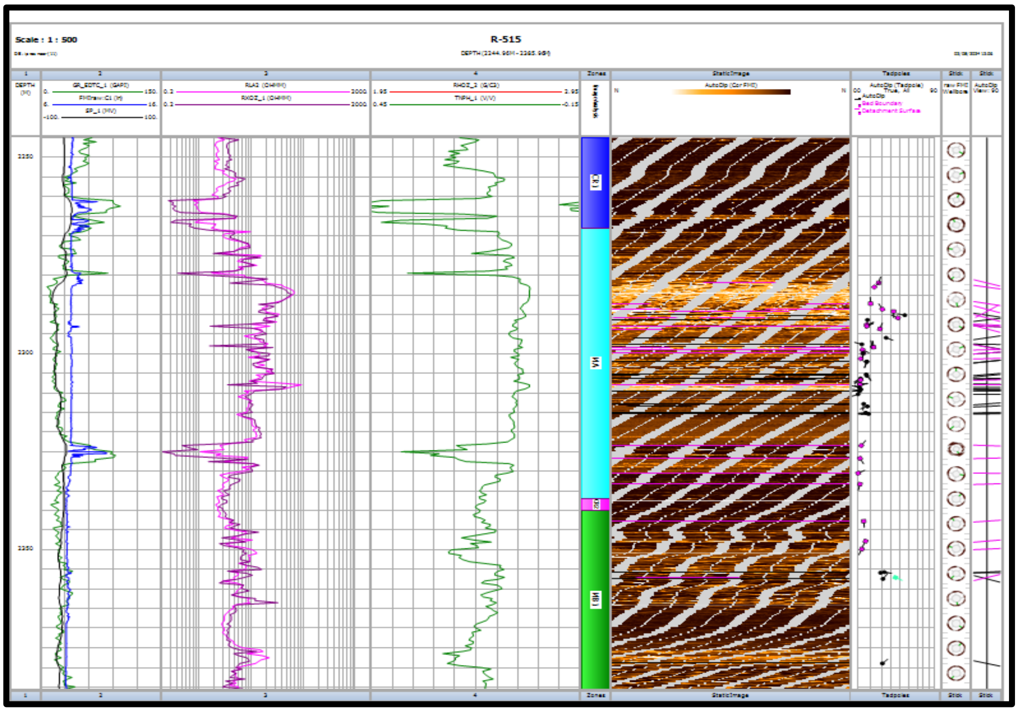


**Figure 8:** fractures and bed orientation of well R-515 with image log and well logging

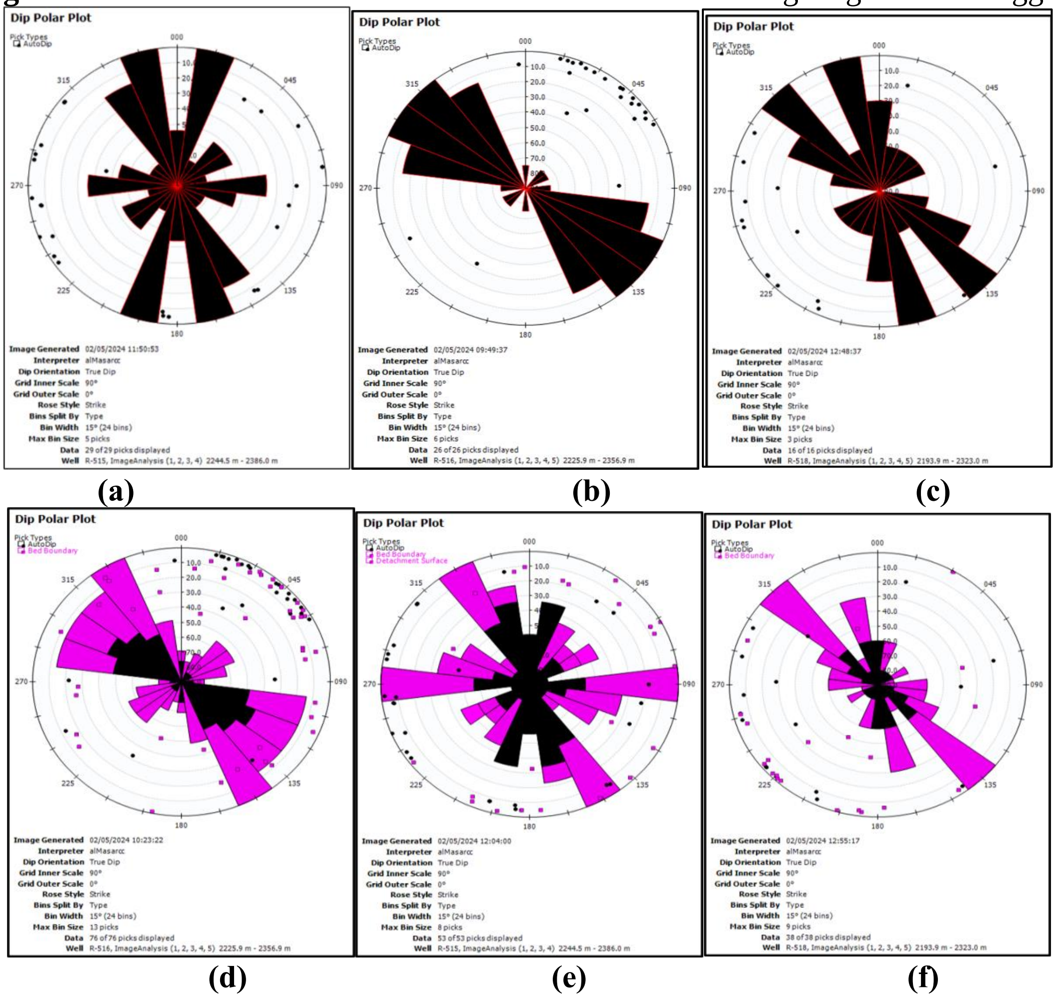
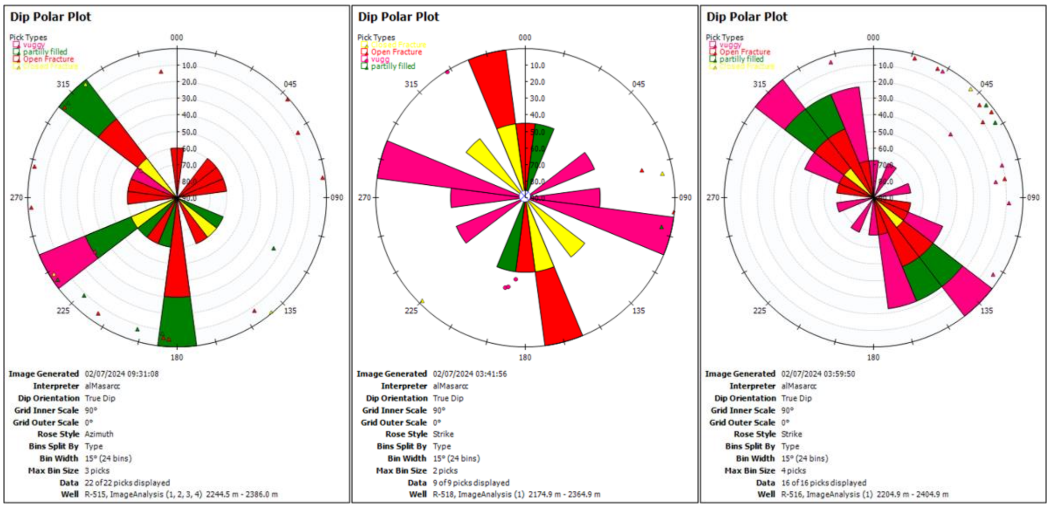


**Figure 9:** fractures and bed orientation of well R-515, R-516 and R-518. (a), (b) and (c) Rose diagram representing fractures sets (d), (e) and (f) Rose diagram of bed and fractures orientation

Understanding fracture orientation aids geologists and engineers in predicting subsurface structural behaviour, fluid flow pathways, and rock formation mechanical stability. In geological investigations and engineering projects, fracture orientations are determined using a variety of techniques, including field observations, borehole imaging, seismic surveys, and remote sensing.

Knowing and understanding the direction of the fractures, and their type, allows us to know the direction of the hydrocarbon's flow inside the reservoir or well, especially open fractures and solution enhanced (vuggy). Knowing their direction is essential in determining the presence of hydrocarbon as shown in Figure 10. It shows the types of fractures present in each well, their direction and number and cambering between them in Table 2.




(a) (b) (c)

**Figure 10:** Rose diagram showing the type and orientation of fractures (a) well R-515 (b)well R-518 (c) well R-516

**Table 2:** Comparing between the wells by fractures types number and their direction

| Well number | Open fractures | Closed fractures | Partially filled | Solution enhanced(vuggy) | Fractures Direction |
|---|---|---|---|---|---|
| R-515 | 11 | 3 | 6 | 2 | N-W<br>S-W |
| R-518 | 2 | 2 | 1 | 4 | N-W<br>S-E |
| R-516 | 6 | 1 | 2 | 7 | N-W<br>S-E |

It appears from the above that the percentage of open fractures is the largest percentage, as it appears in Figure 10 (a) for well R-515. The number of open fractures is (11) and the number of vuggy is (2). Therefore, these fractures will show us an increase in productivity. As for Figure 10 (b) for well R-518 It appears to us that the percentage of open fractures is somewhat small (2), so it is possible that productivity is medium to low. As for Figure 10(c), the percentage of open fractures is also significant (6), which indicates a potential increase in productivity. From the Table 2 we can see that the directions N-W and S-E have the most essential percentage of fractures and that, indicating the direction of oil pumping. In addition to the number and direction of fractures the connectivity and length of fractures play a minor role in permeability increase and productivity as well.

## 5.Conclusions

1- The thorough method of integrating multiple techniques, such as thin section analysis, core examination, borehole image logs, and conventional well logs, proves helpful in the successful detection and characterization of naturally fractured zones within subsurface formations.

2- Identifying fractures in thin sections and cores at the microscopic level provides a fundamental understanding of the rock fabric and assists in determining the existence of fractures. This small-scale perspective complements the macroscopic observations collected through various approaches. As we identify the types of fractures based on the size of the aperture (open, filled (healed), partly filled, and vuggy.

3- Borehole image logs provide a direct visual picture of the wellbore wall, allowing for the determination of fracture direction, aperture, and distribution, as well as the detection of resistive and conductive layers. Using borehole image logs improved our capacity to observe and interpret cracks in situ. This real-time imaging greatly aids in fracture identification and characterization.

4- Quantitative petrophysical analysis advancements can enable more exact measurements of rock characteristics, assisting in the characterization of fractured zones. This includes advances in quantitatively assessing fluid content and lithological fluctuations using neutron, density, and resistivity records.

5- The combined interpretation of data from thin sections, cores, borehole image logs, and traditional well logs is the strength of this multidisciplinary method. The identification of consistent patterns or d abnormalities across different datasets provides a solid platform for fracture detection and characterization. Cross-referencing and confirmed observations from several approaches improves the results' dependability.

6- The direction of fractures in the well led us to detect the productivity location

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