Palacký University Olomouc

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Downgrading the reserves in the Taq Taq oil field in the Kurdistan Region of Iraq. What went wrong?

Bachelor thesis

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Petroleum Engineering (B0724A330002)

Fulltime study

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Downgrading the reserves in the Taq Taq oil field in the Kurdistan Region of Iraq. What went wrong?

Anotace:

Ropné pole Taq Taq je jedním z důležitých ropných polí v povodí Zagros, které je velmi důležité pro vládu irácké oblasti Kurdistán. V posledních letech se produkce ropy z tohoto velkého ropného pole drasticky snížila, ze 148 000 barelů denně na 4 500 barelů denně. Sběr dat a různé studie provedené na formacích rezervoárů v tomto ropném poli ukazují, že tyto formace mají mnoho zlomů. Zásobníky tohoto ropného pole lze rozdělit na dva hlavní typy, rozbité zásobníky typu 1 a rozbité zásobníky typu 2. V rozlomených nádržích typu 1 jsou zlomy odpovědné za skladování i dodávku uhlovodíků. Na druhé straně je rozlomená nádrž typu 2 uložena v matrici a dodávána přes zlomeniny. Pečlivým zkoumáním různých rysů tohoto pole bylo zjištěno, že v jeho studních došlo k fenoménu vodního kužele. Jedním z nejdůležitějších důvodů výskytu tohoto jevu na poli Taq Taq je typ rozbité nádrže a nadměrná těžba ropy v krátkém časovém období na tomto poli. Existuje mnoho řešení k vyřešení tohoto problému, jedním z nejlepších dostupných řešení pro vyřešení problému vodního kužele v ropném poli Taq Taq je použití horizontálních vrtů.

Klíčová slova: pánev Zagros; Taq Taq ropné pole; Nádrže na zlomeniny; Vodní kužel; Horizontální studny

Anotation:

Taq Taq oil field is one of the main oil fields in the Zagros basin, which is very important for the government of the Kurdistan Region of Iraq. In recent years, oil production from this large oil field has decreased drastically, from 148,000 barrels per day to 4,500 barrels per day. Data collection and various studies conducted on the reservoir formations in this oil field show that these formations have many fractures. The reservoirs of this oil field can be divided into two main types. Fractured reservoirs type 1, and fractured reservoirs type 2. In fractured reservoirs type 1, fractures are responsible for both the storage and delivery of hydrocarbons. But fractured reservoir type 2 storage is provided by the matrix and delivery is provided through the fractures. By carefully examining the various features of this field, it was found that the phenomenon of water coning has occurred in its wells. One of the most important reasons for the occurrence of this phenomenon in the Taq Taq oil field is the type of reservoir being fractured and the over-production of oil in a short period of time in this oil field without drilling new wells. There are many solutions to solve this problem, one of the best solutions available to solve the problem of water coning in the Taq Taq oil field is to use horizontal wells.

Keywords: Zagros basin; Taq Taq oil field; Fractures reservoirs; Water coning; Horizontal wells

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Number of annexes: 0

I declare that I have prepared the bachelor's thesis myself and that I have stated all the used information resources in the thesis.

In Olomouc, June 28, 2023 ………………………………………………

Mohammed Saeed Mohammed

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Mohammed Saeed Mohammed

Palacký University Olomouc

28.06.2023

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1 Introduction

The Zagros Basin is a sedimentary basin, which means that it is formed by the accumulation of sediments over millions of years (Nairn and Alsharhan, 1997). The basin has a complex geological history and has been influenced by tectonic activity, including the collision of the Arabian and Eurasian plates, which resulted in the formation of the Zagros Mountains (Nairn and Alsharhan, 1997). Zagros basin is known as one of the most important energy-supplying regions in the world. This area, which extends from the south of Turkey to the Persian Gulf, contains the most important hydrocarbon resources in the world (Amirshahkarami et al., 2007). The first oil well in the Middle East in the Masjid Suleiman in Iran in 1908 and the first hydrocarbon reservoirs in carbonate rocks have been identified in the Kirkuk in 1930 in the Kurdistan region of Iraq both located in the Zagros basin (Sorkhabi, 2010). After extensive studies and identification of different hydrocarbon fields in this area, it was determined that most of the hydrocarbon reservoirs in this area are carbonate rocks.

The study of carbonate reservoirs is more complicated than sandstone reservoirs and on another hand, this area has been affected by different geological events in different geological periods (Sherkati and Letouzey, 2004). For this reason, the study of hydrocarbon reservoirs in the Zagros basin is particularly complicated, and oil companies in this area have always faced various problems. For instance, one of the problems that the oil companies operating in this region have faced in recent years in the Taq Taq oil field is the phenomenon of a sudden downgrading of the reserves and a decrease in oil production in the Taq Taq oil field. The Taq Taq oil field is located in the Kurdistan Region of Iraq (Figure 1).

This oil field represents an important source of oil for the Kurdistan Region of Iraq (Figure 2). Taq Taq oil field was discovered in 2005 and has estimated recoverable reserves of around 356 million barrels of oil (Genel Energy website).

Figure 1 The Taq Taq oil field is located in the Kurdistan region of Iraq (Garland et al., 2015).

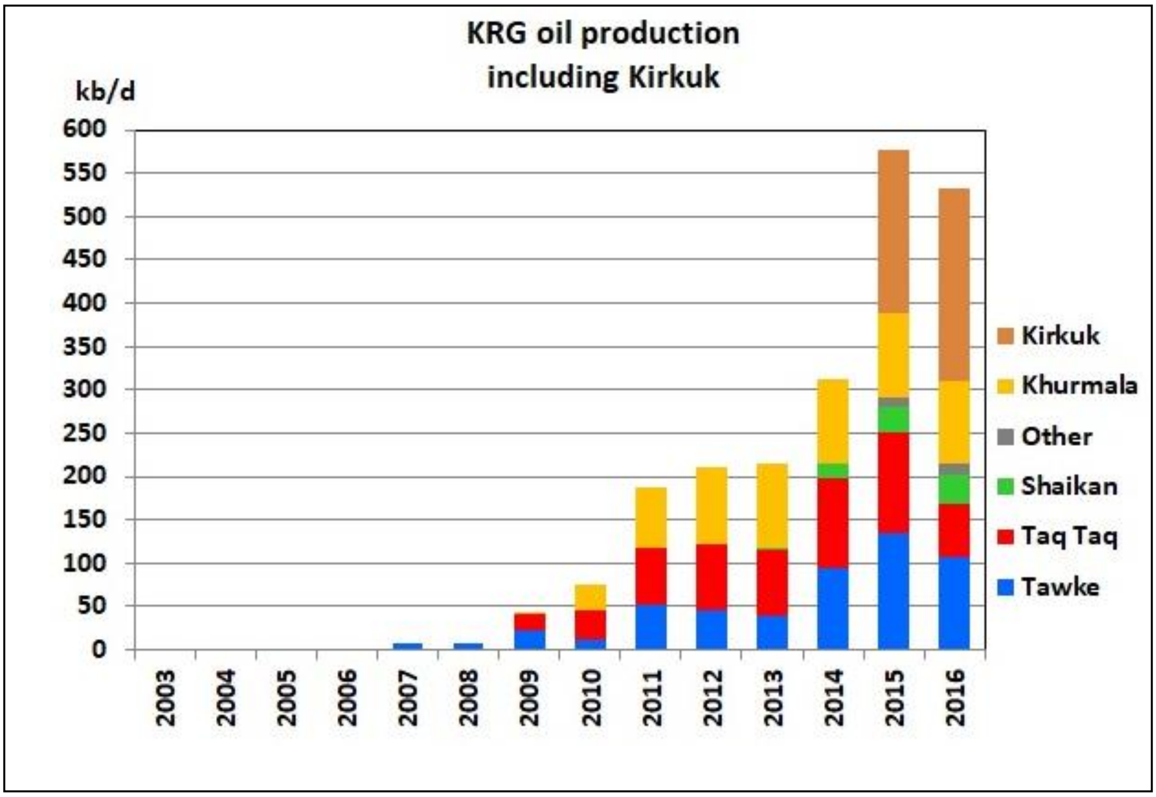

Figure 2 The most important oil fields in the Kurdistan region of Iraq (genel energy website)

The field is situated within the Zagros fold and thrust belt, which is a complex geological region characterized by folding and faulting resulting from the collision of the Arabian and Eurasian tectonic plates (Reif et al., 2012). The most important formations that have been identified as reservoir rocks in this field are the upper Qamchuqa, Kometan, Shiranish, and Pila spi formations (Figure 3; Garland et al., 2010). The lithologies of these reservoirs are mainly composited of rocks such as limestone, dolostone, marl, and shale (Figure 3). Taq Taq oil field reservoirs are fractured reservoirs and their formations have been affected by complex diagenesis processes in different stages (Baban and Ranyayi, 2013; Rashid et al., 2020), for this reason, it is relatively difficult to predict the recoverable reserves of these reservoirs and their accurate modeling, and relatively more complex methods for modeling is required (Hosseinzadeh et al., 2022; Kosari et al., 2017). The initial studies conducted in this field seem to have predominantly neglected the unique geological setting of the field under investigation, along with its distinct lithological and reservoir characteristics.

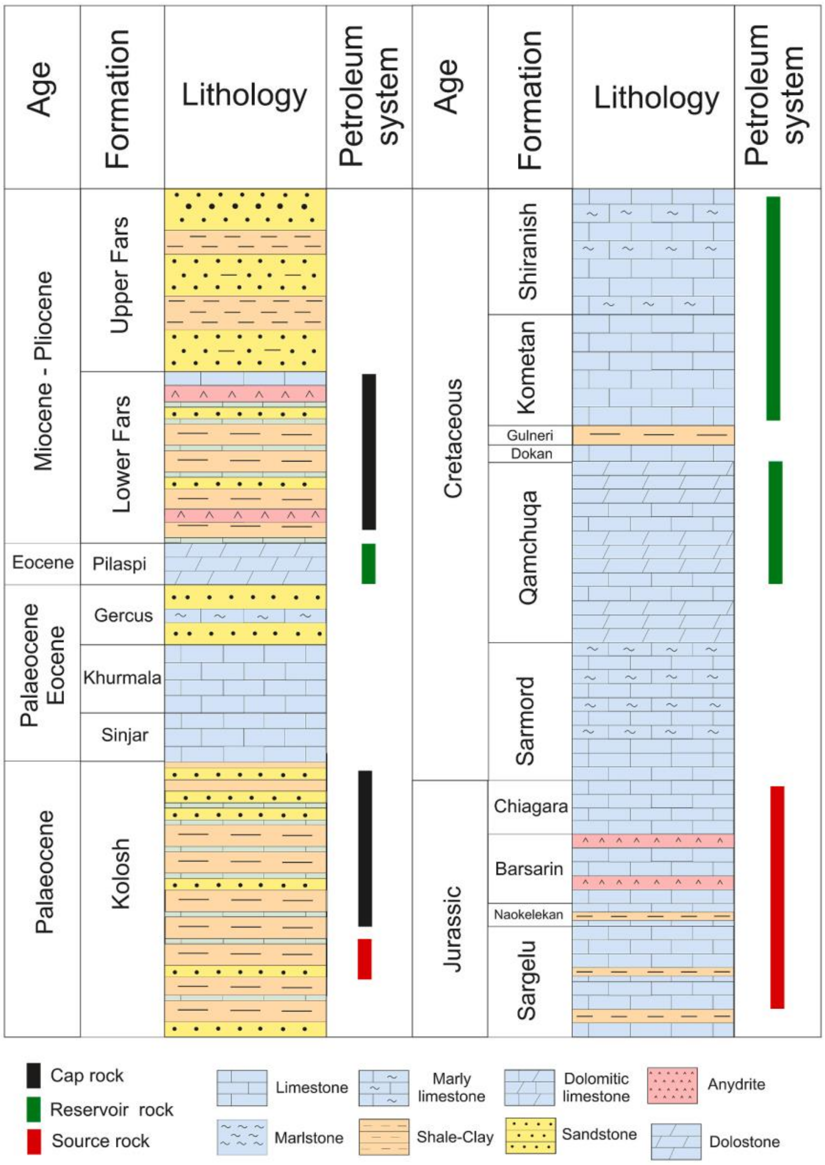

Figure 3 Stratigraphy column at Taq Taq oil field, showing lithology, reservoirs, formation names and approximate ages (Rashid et al., 2023).

In addition, in recent years, due to political issues, oil production from various wells in this field has been done in an unprincipled manner. In a short period of time, the volume of oil production from this field has greatly increased.

As has been mentioned, the Taq Taq field reservoirs are of the fracture reservoir type, and illogical produce of them quickly causes water coning (Ahmadi et al., 2014; Namani et al., 2007), which in turn causes a decrease in oil production and an increase in underground water in the reservoir. For this reason, in a short period of time, the proportion of water produced from the reservoir is higher than the oil produced. This situation is one of the most important problems faced by companies in the Taq Taq oil field.

The purpose of this study is to collect general and basic information about the fractured carbonate reservoirs of the Taq Taq oil field and to investigate the most important factors and problems that have caused the reduction of oil production in recent years in this important oil field. Particularly, to the fact that most of the reservoirs in the Zagros region in the Kurdistan region of Iraq are fractured carbonate reservoirs, this problem may occur in the future for other important oil reservoirs in this area.

2 Methodology

In this study, the meta-analysis method has been used for a comprehensive and detailed investigation of the most important problems of the TaqTaq oil field. Meta-analysis is a statistical method used in research to combine and summarize the results from several studies on a particular topic (Moore et al., 2012; Berman and Parker, 2002). In this method, researchers collect data from various research and analyze the results to recognize common patterns (Figure 4). The purpose is to provide a more comprehensive and objective summary of the research evidence than is possible with a single study. It helps researchers to identify patterns and trends that may not be clear from single studies and to draw more generalizable conclusions about the research subject. This method is able to help to address some of the limitations of single studies. For instance, individual studies may have small data and a short view of the problem, but combining data from different studies can help to better understand the major problem. Overall, meta-analysis is a strange tool for combining research evidence and can provide valuable insights into a wide range of research topics.

The purpose of this study is to the issues and problems that are the main reason for the decrease in oil production in the TaqTaq oil field. To answer this question and find a suitable solution for this thesis, it has been tried to collect important sources and study them carefully.

A careful study of these sources gives an overview of the most important problems in the Taq Taq oil field. Researchers have studied this important oil field in the Kurdistan region of Iraq using a special method and presented results from their point of view.

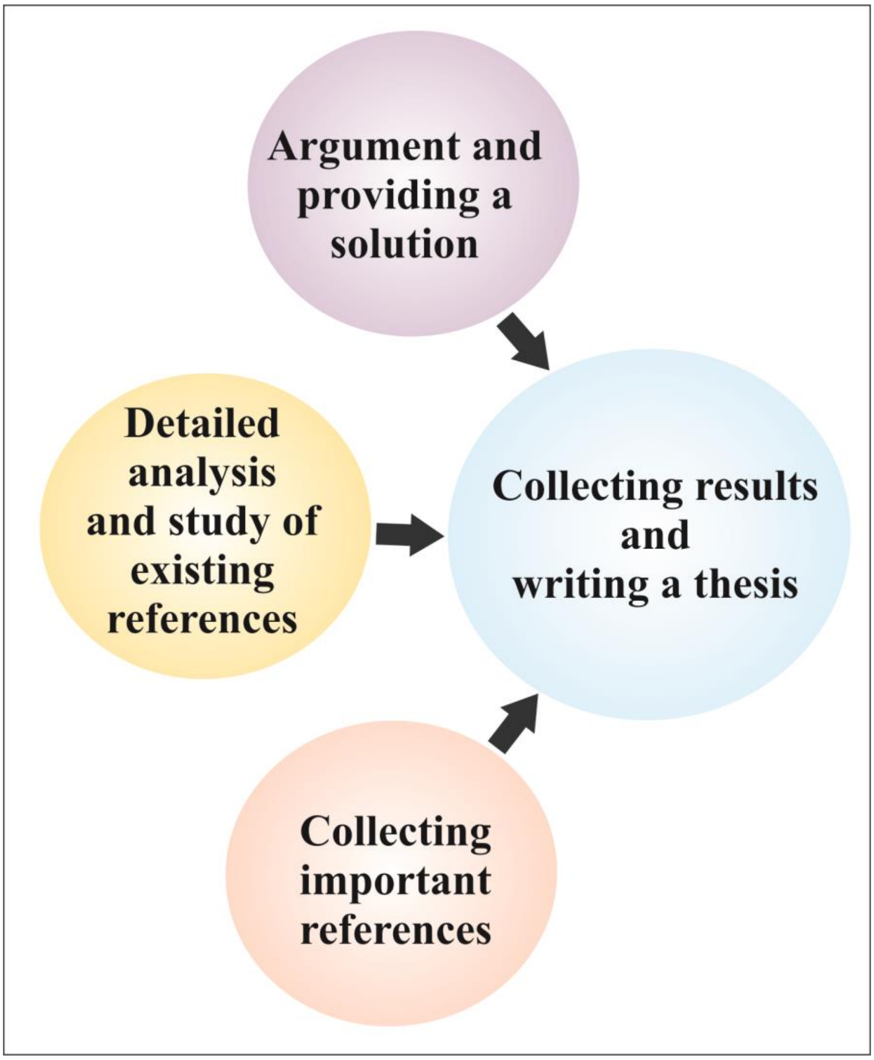

Figure 4 Methodology chart for thesis writing.

For this reason, in this study, various articles have been studied and carefully analyzed so that acceptable results can be presented regarding the problems of this oil field from both geological and petroleum engineering perspectives. It is also possible to discuss these problems with a more detailed view and reach acceptable results.

Researchers have used different data in various studies, the most important of these data can be things such as checking different logs (gamma, sonic, image log), geophysical data such as seismography, various petrophysical data such as porosity and permeability and Geological data such as examination of microscopic thin sections. These data are obtained from different wells that have been drilled in the Taq Taq oil field.

3 Results

Taq Taq oil field was discovered for the first time in 1978 (Garland et al., 2015). Oil production started in earnest in this field in 2006. Currently, 35 wells are active in this field. The amount of oil production in the Taq Taq oil field in 2015 was nearly 148,000 barrels of oil per day Over the past 7 years, this amount of oil production has decreased sharply and reached 4521 barrels of oil per day (Figure 5). The most important geological formations that as reservoirs in this field are called Shiranish Formation (Campanian–Maastrichtian), Kometan Formation (Turonian–Santonian), and Qamchuqa Formation (Aptian–Albian). Each of these formations has its own lithology and unique characteristics (Garland et al., 2015; Rashid et al., 2023; Figure 3).

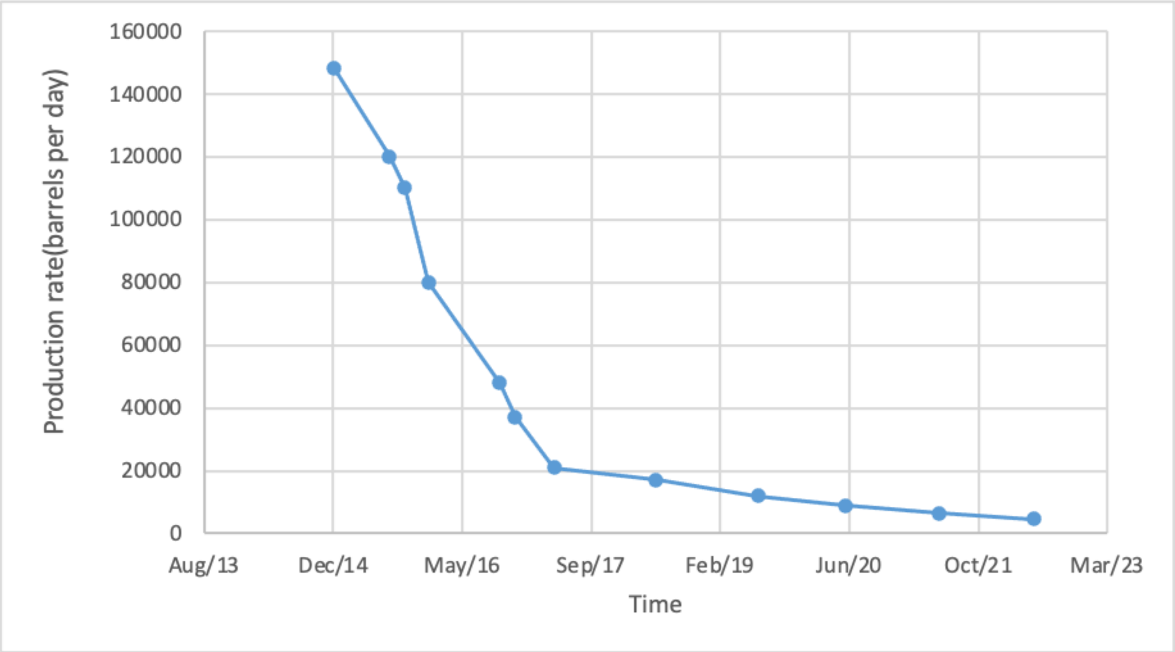

Figure 5 Chart of oil production from the Taq Taq oil field between 2014 and 2022 (genel energy website).

3.1 Stratigraphy

The Shiranish Formation is about 350 meters thick in the Taq Taq anticline (Figure 3; Garland et al., 2015). Its lithology is mainly composed of limestone and argillite limestone in the upper parts. This formation is mostly composed of mudstones with very little matrix porosity, but the high number of fractures in this formation has raised it as a reservoir with high permeability (Garland et al., 2015; Figure 6A-C).

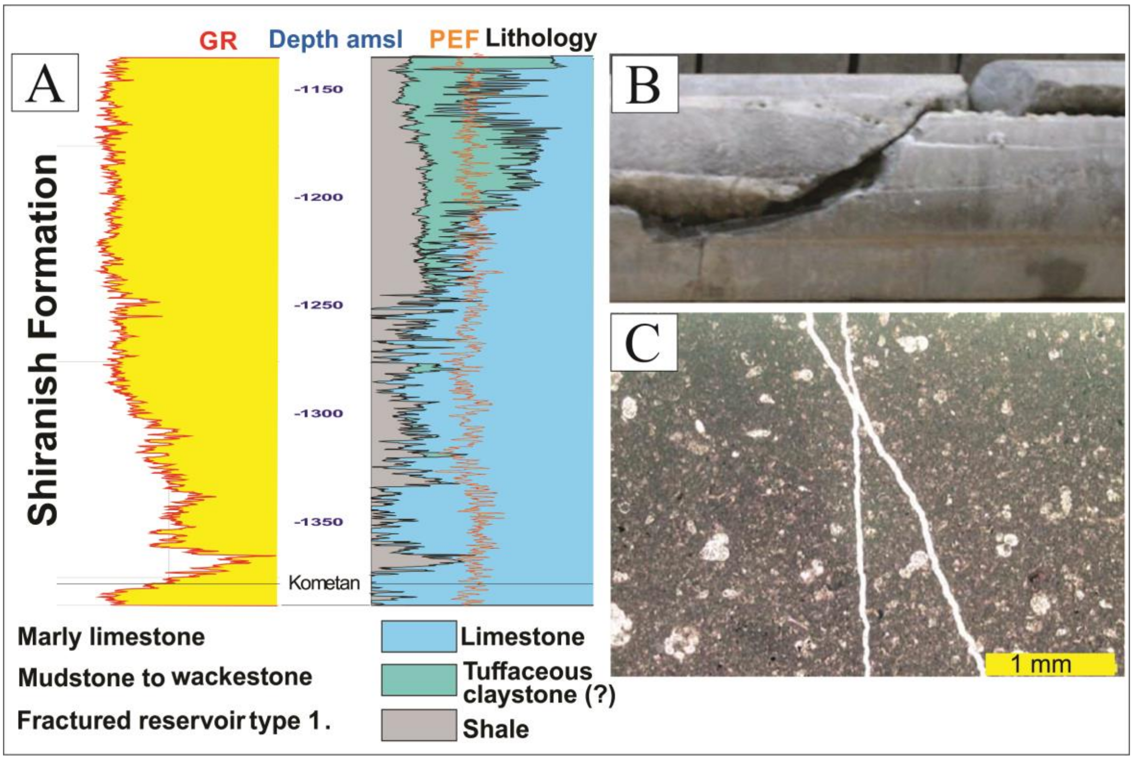

Figure 6 Shiranish Formation (A) routine well logs data (B) open fractures in the core; (C) microscopic image (PPL) showing foraminifera and cemented fractures (modified after Garland et al., 2015, what did you modify?).

The Kometan Formation with 120 meters of thickness is lithologically similar to Shiranish Formation but without the main argillaceous part and it is mostly composed of deep marine limestone. The fracture percentage in the Kometan Formation is higher than Shiransh Formation, which must an important reason for increasing the permeability of Kometan Formation. The evidence shows that wherever the percentage of fractures has been observed in this Formation, more dolomitization has occurred and the porosity of the matrix has increased (Garland et al., 2015; Figure 7A-C)

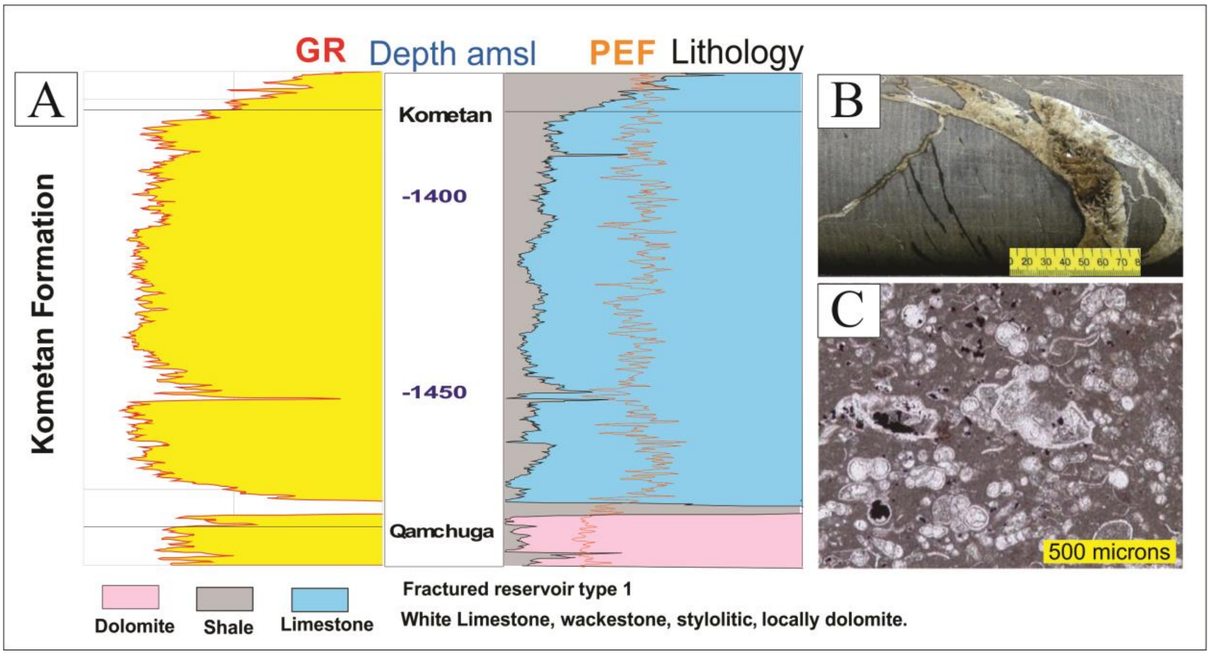

Figure 7 Kometan Formation (A) routine well logs data (B) fractures in the core (C) microscopic image (PPL) showing foraminifera packstone (modified after Garland et al., 2015).

The Qamchuqa Formation comprises over 300 m of microcrystalline dolomite, originally wackestones to grainstones whose original fabrics are locally preserved. The upper part of the Qamchuqa shows a karst fabric of interconnected vugs and fracture fill. Due to the high porosity of the matrix, the Qamchuqa Formation has become an important hydrocarbon reservoir. Also, high fractures are observed in this Formation, which is an important feature for oil recovery in the rock matrix (Garland et al., 2015; Figure 8A-C).

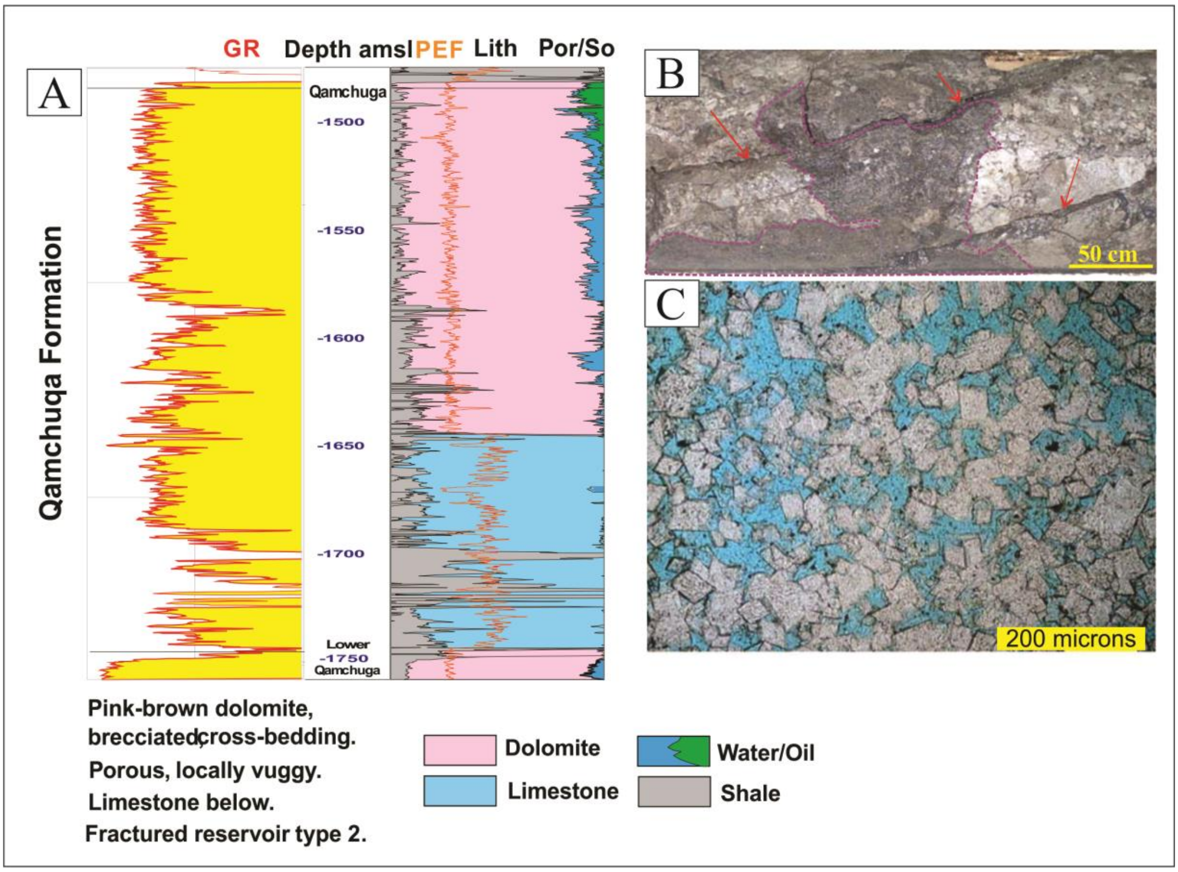

Figure 8 Qamchuqa Formation (A) routine well logs data; (B) fractures in the outcrop red arrows and more porosity in the matrix (purple line) (C) microscopic image (PPL) showing dolomite crystals with Intercrystalline porosity (blue part) (modified after Garland et al., 2015).

3.2 Anticline structure

The Taq Taq Anticline is a structural feature that was formed by tectonic activity in the Zagros fold and thrust belt, a region of active deformation in the Middle East (Rashid et al., 2023; Le Garzic et al., 2019). The anticline has a roughly north-south orientation and is approximately 15 kilometers long and 5 kilometers wide (Rashid et al., 2023). The geology of the Taq Taq Anticline is complex and heterogeneous, with multiple fault zones, stratigraphic variations, and structural complexities that can influence the distribution and production of oil (Rashid et al., 2023).

The 2D image of the seismic section of the Taq Taq anticline shows severe faulting in this anticline (Rashid et al., 2023; Figure 9). These faults were formed due to the compressional stress in the Zagros basin. The high number of faults in Cretaceous age formations has caused widespread fractures in oil reservoirs (Garland et al., 2015). Most of the fractures in the reservoirs of this anticline are open fractures, and some factors such as the presence of oil in these fractures or the uplift of sediments and the decrease of pressure in the underlying layers are the most important of these factors to open the fracture (Garland et al., 2015; Rashid et al., 2023).

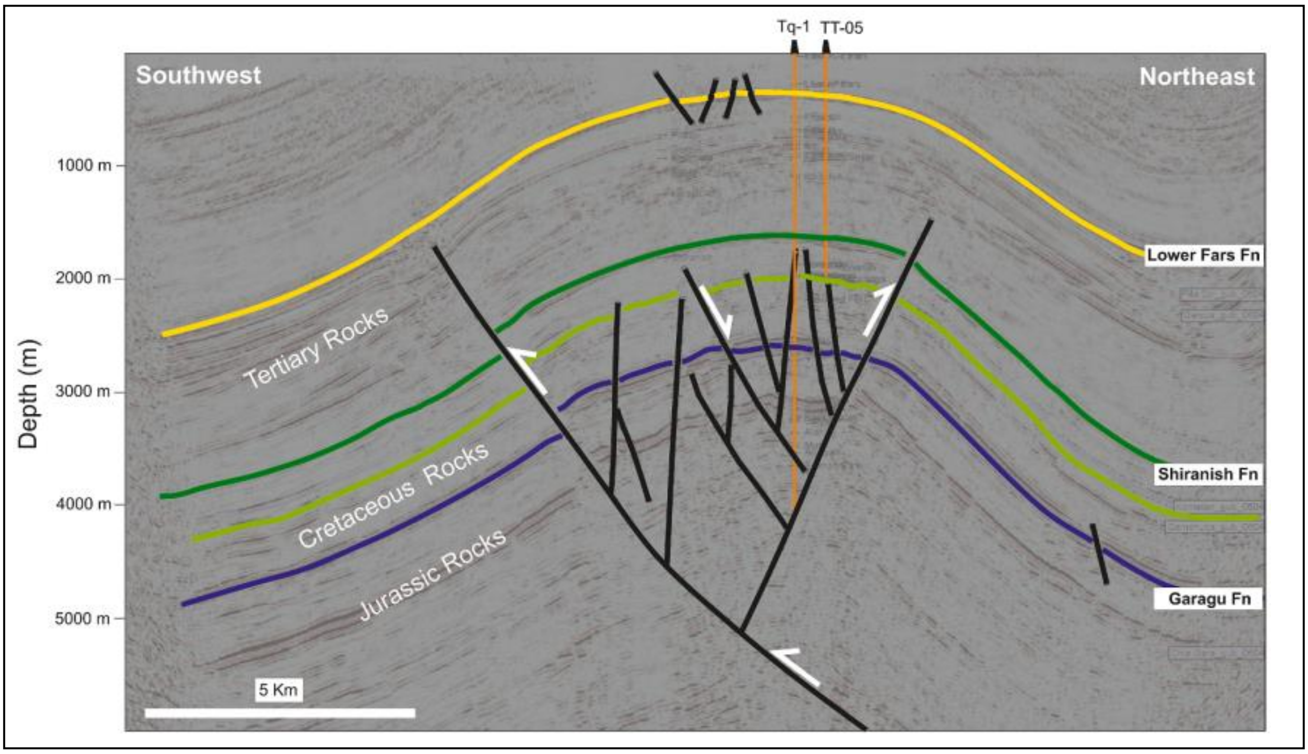

Figure 9 Interpreted NE-SW seismic cross-section of the Taq Taq anticline (modified after Rashid et al., 2023).

3.3 Petrophysical properties of the reservoirs

Various studies based on the data prepared from the core and logs such as gamma-ray, PEF log, and sonic, lithology as well as different types of porosity and its amount have been identified in different reservoirs in the Taq Taq oil field (Al-Qayim and Rashid, 2012; Baban and Ranyayi, 2013). Based on the studies conducted, different zones with different porosity and permeability have been identified in the reservoir formations of the Taq Taq field (Garland et al., 2015; Figure 10).

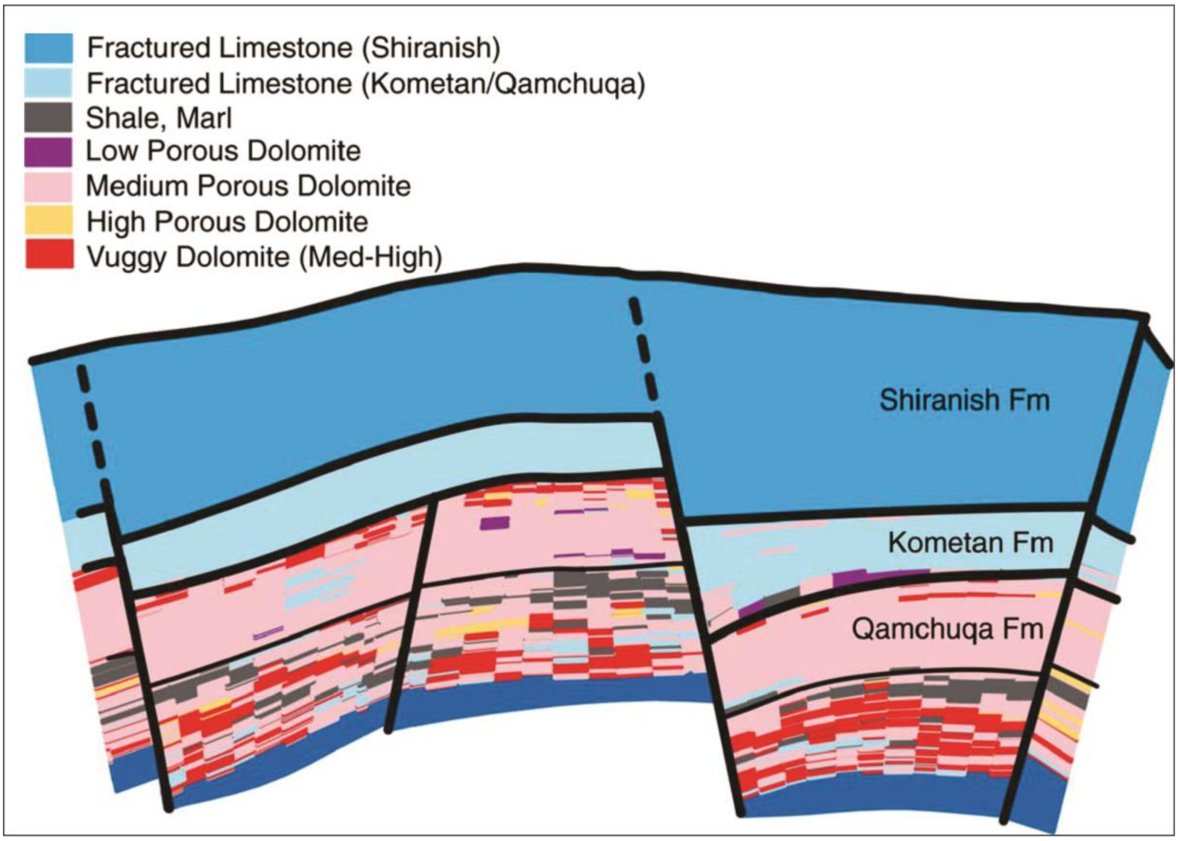

Figure 10 Porosity development model in the Taq Taq oil field reservoir Formations (not to scale) (modified after Garlan et al., 2015).

Among these zones, the following can be mentioned. Fracturing limestone, low-porous dolomite, medium-porous dolomite, high porous dolomite, medium-porous vuggy dolomite, and high-porous vuggy dolomite.

The drilling tests conducted in well No. 1 of the Taq Taq field in 1978 showed the high productivity of the Shiransh formation in this oil field (Garlan et al., 2015; Baban et al., 2020). Despite the fact that the studies conducted showed the low porosity of this Formation (Garlan et al., 2015; Baban et al., 2020; Rashid et al., 2023). The reason for this high productivity in this Formation was the existence of high fractures in the Shiransh Formation (Figure 11A-C). Also, recent studies showed high productivity in Shiranish and Komitan Formations, that's why these Formations are called type 1 fractured reservoirs.

On another hand, several studies have shown that the porosity of the matrix in the upper parts of the Qamchoqq Formation is close to 11.7%, and the permeability in this part is close to 0.1-10mD (Figure 12A and B; Garlan et al., 2015; Rashid et al., 2023). It can be said, dolomitization through hydrothermal processes in the Qamchuqa Formations has increased the porosity of the matrix in this formation. For this reason, parts of the Qamchuqa Formation have been introduced as type 2 Fractured reservoirs (Garlan et al., 2015).

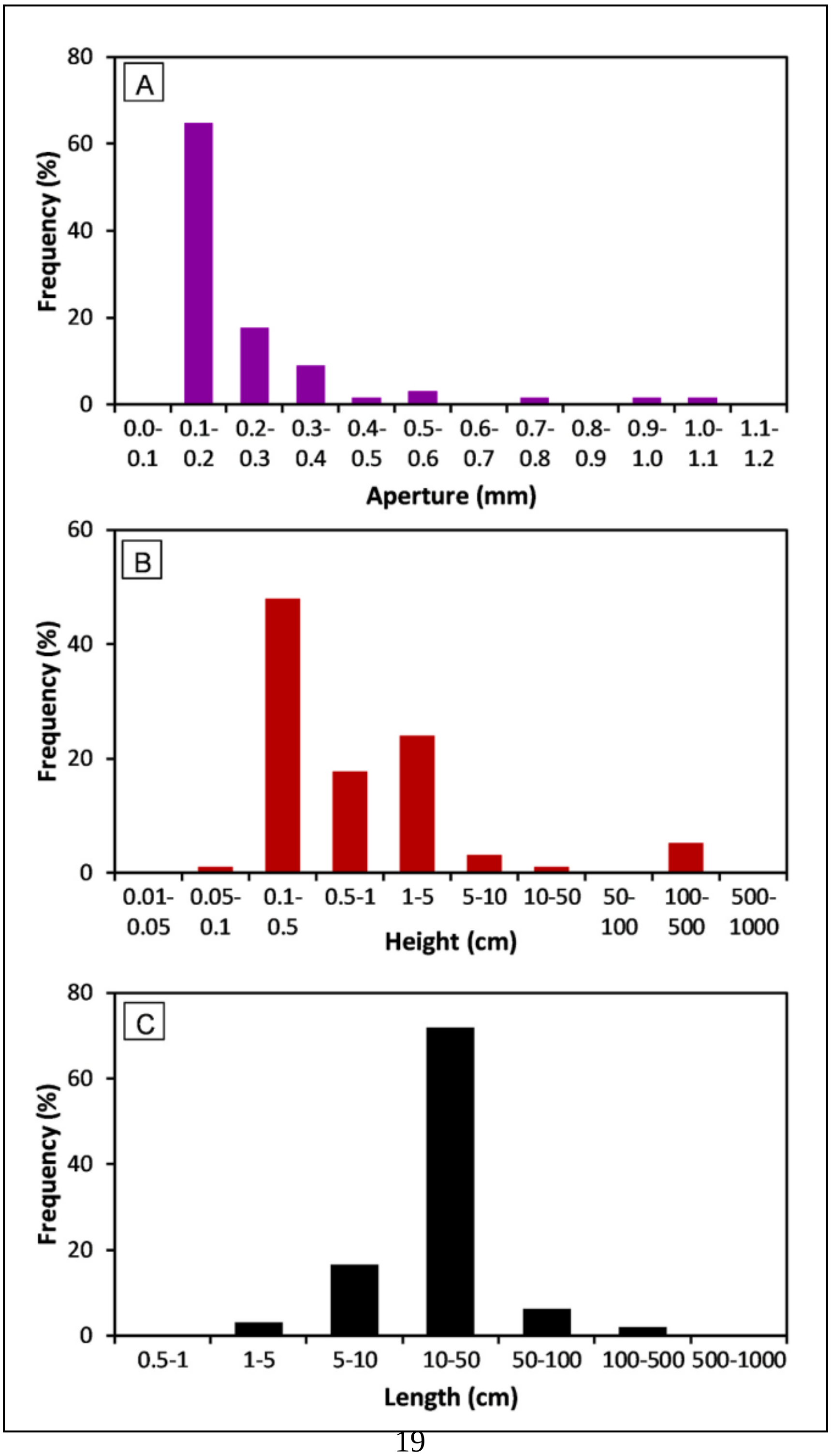

Figure 11 Histogram of the frequency of different fractures investigated in the Taq Taq reservoirs. (A) shows the average Fracture aperture (mm). (B) shows the height of fractures (cm) and (C) shows the length of fractures (cm) (Rashid et al., 2023).

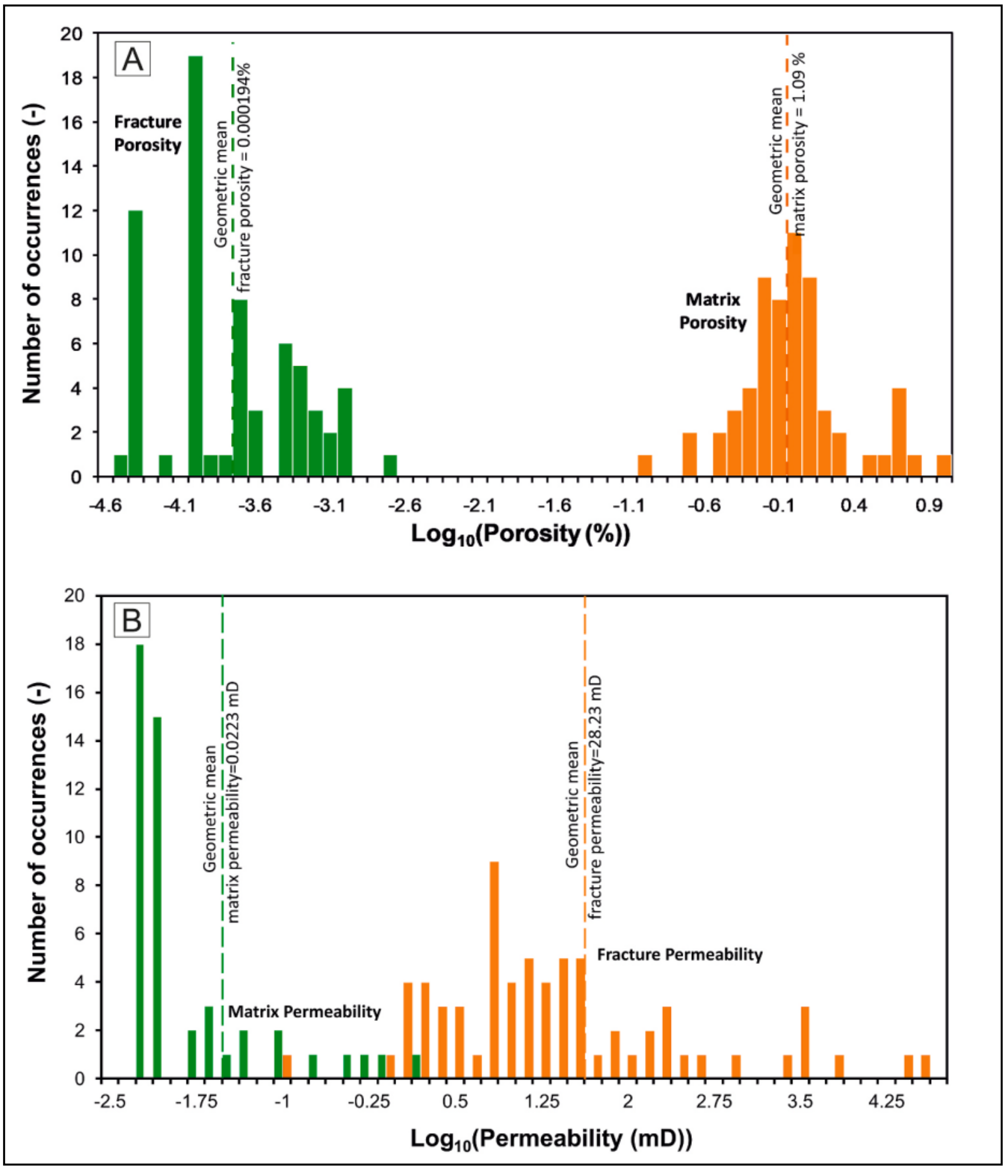

Figure 12 Porosity and permeability histogram of the Taq Taq field reservoirs. (A) Histogram of measured matrix porosity and calculated fracture porosity. (B) Histogram of matrix permeability and fracture permeability measurements from core samples (Rashid et al., 2023).

Various tools such as XRMI borehole image logs (Figure 13), WSTT dipole sonic logs, and oriented cores were obtained from the initial appraisal wells and were used to study the fractures in the Taq Taq oilfield reservoirs in detail (Figure 14A and B; Al-Qayim and Othman, 2012; Garlan et al., 2015; Baban et al., 2020; Rashid et al., 2023). And the obtained data were analyzed by powerful software like FRACA (Garlan et al., 2015). At the same time, surface data were also used for the detailed study of fractures. The studied fractures were divided into four categories: open fracture, semi-open fracture, cemented fractures, and microfractures (Rashid et al., 2023).

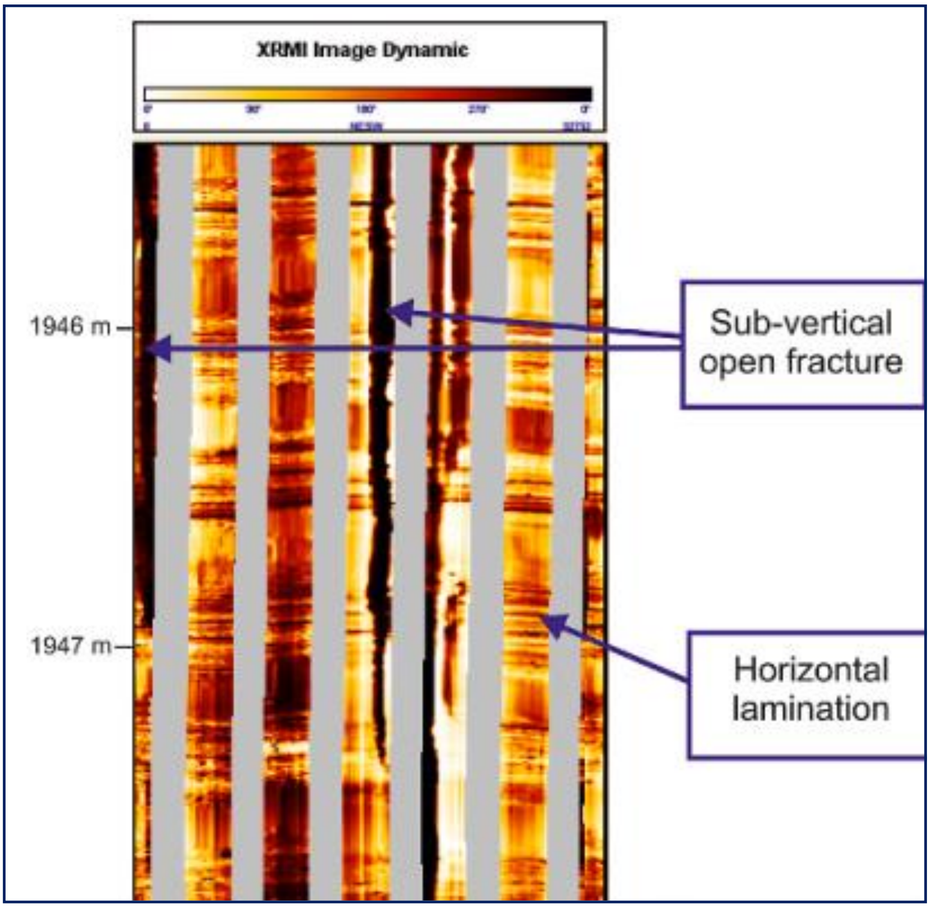

Figure 13 Fracture types observed on XRMI micro-resistivity image logs of one of the Taq Taq well.

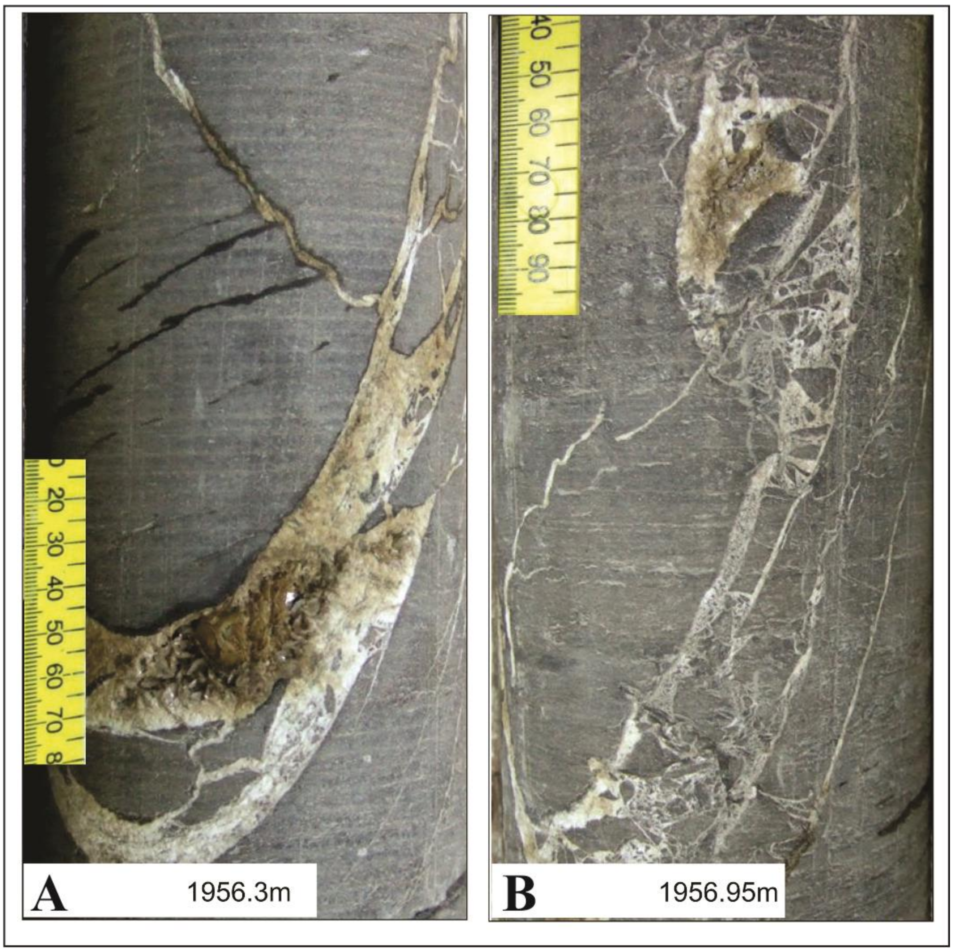

Figure 14 (A and B) Fracture types in cores of limestone and argillaceous limestone from the Shiranish Formation in the Taq Taq oil field (Rashid et al., 2023).

3.4 Organic Geochemistry

Oil produced from the reservoirs of the Taq Taq field with Cretaceous age indicates a 48 API gravity with low viscosity and a low GOR of approximately 25 scf/bbl which is a great benefit and unusual for the safe drilling and completion of all development wells (Al-Qayim and Othman, 2012). The most important source rocks of the Taq Taq oil field are the Sargelu and Naokelekan Formations of the Jurassic Age (Al-Qayim and Othman, 2012; Garlan et al., 2015). One of the other organic geochemical characteristics of oil in this field is the low amount of sulfur in oil (300 ppm) which is much less compared to other oil fields in the region.

4 Discussion

Currently, nearly 35 active wells in this oil field are producing oil (genel energy website). The sharp decrease in oil production in this field in recent years has attracted the attention of many petroleum engineers and petroleum geologists in this area. This sharp decrease was such that in a short period of 7 years (2015-2022), oil production from this field decreased by 143,479 barrels per day (Figure 5). In addition, the production ratio of water to oil in this field increased sharply, which indicates the phenomenon of water coning in this important oil field (Figure 15A and B).

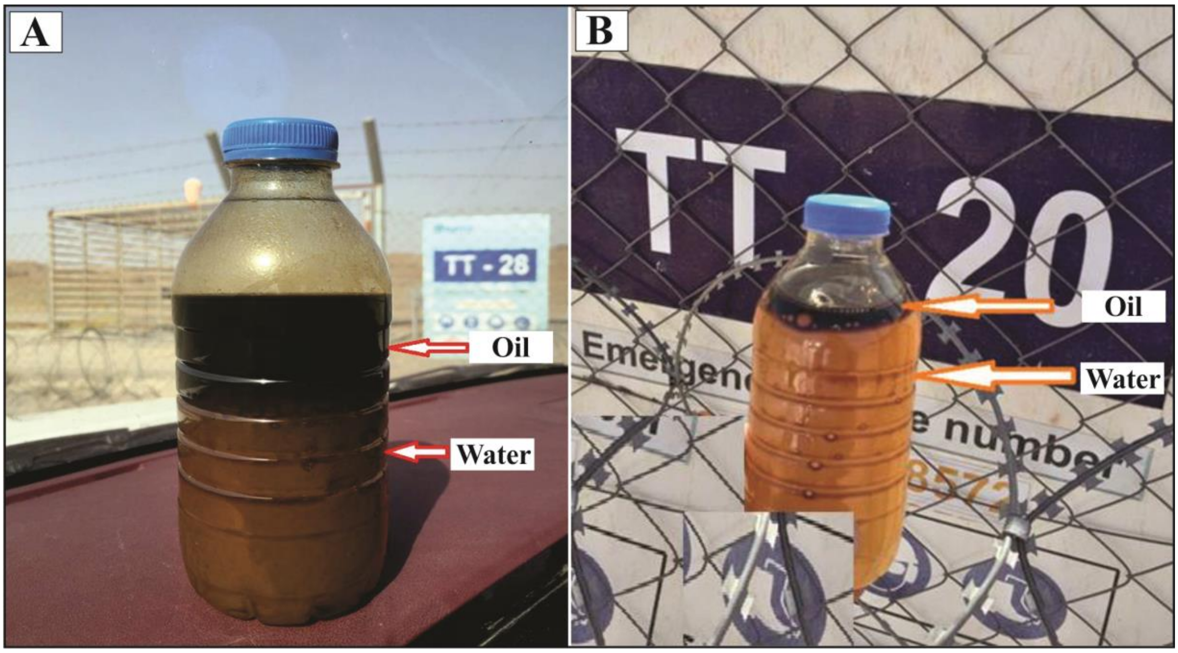

Figure 15 Oil samples of the (A) well TT 28 and (B) well TT 20 in 2023 in the Taq Taq oil field.

4.1 Investigating the phenomenon of water coning

Water coning is a phenomenon that occurs in oil reservoirs when water from the underlying aquifer or injected water rises towards the production well due to the pressure differential between the oil and water zones (Figure 16; Namani et al., 2007; Zendehboudi et al., 2014 Abdel Azim, 2016). This can cause a reduction in oil production and an increase in water production. The term "coning" comes from the shape of the water zone as it rises towards the well, which takes the form of a cone with its apex at the well. The shape of the cone is determined by the permeability contrast between the oil and water zones, the vertical distance between the zones, and the rate of oil and water production. Water coning is a common issue in many oil reservoirs in the Middle East due to their geologic characteristics and long history of oil production (Shadizadeh and Ghorbani, 2001; Namani et al., 2007; Karami et al., 2014). Several factors can contribute to water coning in oil reservoirs. The most important of these can be mentioned below:

(I) Permeability contrast (II) Reservoir pressure (III) Production rate (IV) Reservoir heterogeneity. In the following, we will examine each of them and their role in increasing the production ratio of water to oil in Taq Taq oil field (Sobocinski and Cornelius, 1965; Tu et al., 2007; Abobaker et al., 2021; Schlumberger website).

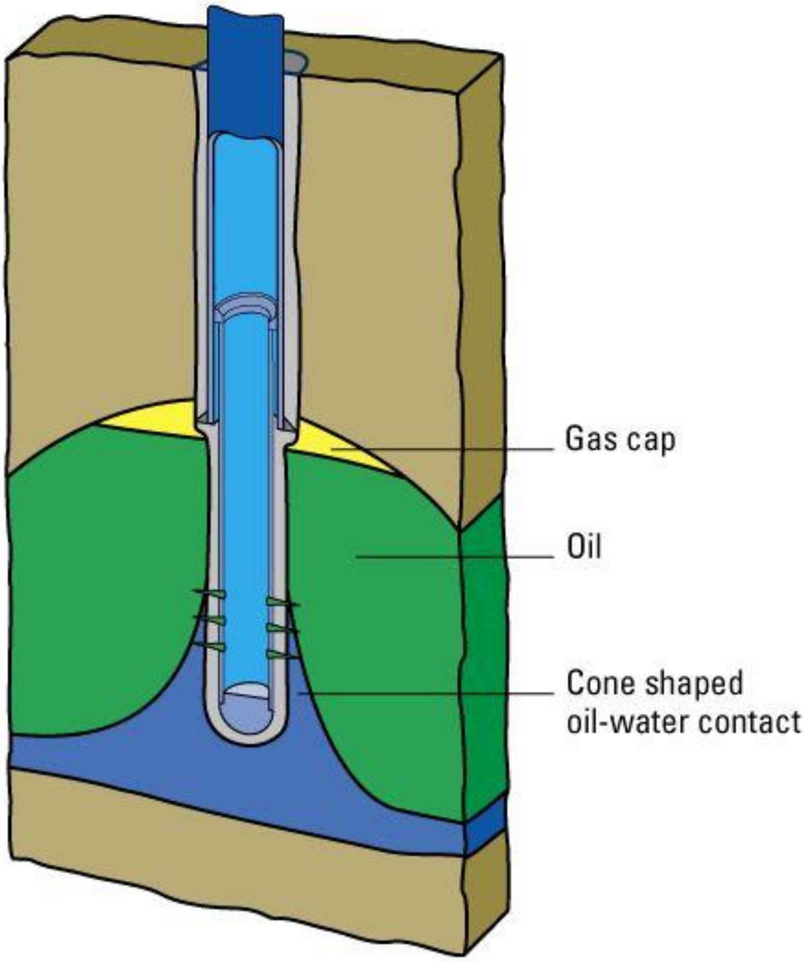

Figure 16 Schematic model form of the phenomenon of water coning in oil wells (Schlumberger website)

4.1.1 Permeability contrast

Permeability contrast between the oil zone and the water zone is an important factor that can influence the occurrence of water coning in oil reservoirs. Permeability contrast refers to the difference in permeability between the oil zone and the water zone (Galijasevic, 2015; Abdel Azim, 2016). If the permeability contrast between the oil and water zones is high, it can create a large pressure drop around the wellbore, which can exacerbate water coning (Abdel Azim, 2016). This is because the water can easily flow towards the wellbore due to the higher permeability of the water zone, while the oil is trapped in the lower permeability oil zone (Galijasevic, 2015; Abdel Azim, 2016). This can result in an increase in water production and a decrease in oil production.

On the other hand, if the permeability contrast is low, the pressure drop around the wellbore is less, which can reduce the impact of water coning (Wang et al., 2015). This is because the oil and water are able to flow more uniformly towards the wellbore, reducing the amount of water production and improving the recovery of oil (Galijasevic, 2015; Abdel Azim, 2016). Overall, the permeability contrast between the oil zone and the water zone is an important factor that needs to be carefully considered when designing the production strategy for an oil reservoir, in order to manage the impact of water coning and optimize the recovery of oil (Baykin and Golovin, 2018).

The role of permeability contrast between the oil zone and the water zone in water coning in the Taq Taq oil field can be significant. The Taq Taq oil field is a complex and heterogeneous reservoir that contains both high-permeability and low-permeability zones. This heterogeneity can lead to variations in the flow of fluids within the reservoir, which can exacerbate the water coning phenomenon. In the Taq Taq oil field, the permeability contrast between the oil and water zones can vary depending on the location and depth of the well.

If the oil zone in Taq Taq oil field has relatively low permeability and the water zone has relatively high permeability. This can lead to a significant pressure drop around the well, which can lead to water intrusion and the production of excessive amounts of water.

4.1.2 Reservoir pressure

Reservoir pressure plays a critical role in determining the flow behavior of fluids within an oil reservoir (Wang et al., 2009; Al-Wahaibi et al., 2014; Udegbunam et al., 2017). When a well is drilled and produced, the pressure in the reservoir near the wellbore decreases due to the removal of fluids (Al-Wahaibi et al., 2014). As the pressure drops, the oil, gas, and water zones within the reservoir can start to mix, leading to the phenomenon of water coning (Al-Wahaibi et al., 2014). In general, the pressure gradient within the reservoir affects the direction of fluid flow and the relative proportion of oil, gas, and water produced from the well (Al-Wahaibi et al., 2014). As the pressure decreases, the relative permeability of the oil and gas zones may decrease, making it more difficult to produce these fluids (Wang et al., 2009; Al-Wahaibi et al., 2014). This can lead to an increase in the water cut of the produced fluids, as more water is drawn into the wellbore from the surrounding aquifer (Wang et al., 2009).

Overall, the reservoir pressure is an important factor to consider when designing and managing the production of an oil reservoir. By maintaining or managing the pressure gradient within the reservoir, operators can help to minimize the impact of water coning and maximize the recovery of valuable hydrocarbon resources (Al-Wahaibi et al., 2014; Udegbunam et al., 2017).

In the Taq Taq oil field, reservoir pressure also plays a critical role in the occurrence of water coning. The field is characterized by a complex geology and a heterogeneous reservoir, which can make it difficult to manage the pressure gradient and control the movement of fluids. As the production rate of the well increases, the pressure in the reservoir near the wellbore can drop, creating a pressure differential between the oil and water zones. If the pressure in the oil zone is lower than the pressure in the water zone, it can lead to the influx of water into the wellbore and the phenomenon of water coning.

4.1.3 Production rate

Production rate is an important factor that can influence the occurrence of water coning in oil reservoirs (Kleppe and Morse, 1974; Van den Hoek and Geilikman, 2003; Davarpanah and Mirshekari, 2018). When oil is produced from a reservoir, a pressure drop is created around the wellbore, which can cause the water in the reservoir to migrate towards the wellbore (Van den Hoek and Geilikman, 2003). This can result in water breakthroughs and the production of excessive amounts of water, leading to reduced oil production and potentially damaging the reservoir (Van den Hoek and Geilikman, 2003). If the production rate is too high, it can create a larger pressure drop around the wellbore, which can exacerbate water coning. This is because the larger pressure differential between the wellbore and the reservoir can increase the rate of water influx into the wellbore, leading to more water production and less oil production (Ahmed, 2010). On the other hand, if the production rate is too low, it can also lead to problems (Van den Hoek and Geilikman, 2003; Davarpanah and Mirshekari, 2018). This is because the lower production rate may not be sufficient to maintain the pressure around the wellbore, which can cause the water to migrate towards the wellbore and cause water breakthroughs (Raghavan and Vignes, 1996).

The best production rate for an oil reservoir depends on various factors, such as the reservoir's characteristics, the type of production system used, and the market conditions. Identifying the optimal production rate requires careful analysis and evaluation of these factors. The most important things that should be paid special attention to in the production rate include:

Understand the reservoir characteristics: To determine the best production rate, it is important to understand the reservoir's physical properties, such as permeability, porosity, and thickness. This information can be obtained through geological surveys and well-testing (Raghavan and Vignes, 1996).

Evaluate the type of production system: The production system used to extract oil from the reservoir can affect the optimal production rate. Different production systems, such as vertical wells, horizontal wells, and hydraulic fracturing, have different production rates and efficiencies (Anifowose and Junaid, 2013).

Analyze production data: Historical production data can provide valuable insights into the reservoir's behavior and performance. Analysis of production data can help identify production trends, decline rates, and the impact of different production rates on oil recovery (Anifowose and Junaid, 2013).

Use reservoir simulation: Reservoir simulation is a tool that can help predict the behavior of the reservoir under different production scenarios. It can be used to evaluate the impact of different production rates on the reservoir's performance and optimize the production strategy (Van den Hoek and Geilikman, 2003).

By considering these factors and using appropriate tools, such as reservoir simulation, the best production rate for an oil reservoir can be identified. It is important to note that the optimal production rate may change over time as the reservoir's characteristics, production system, and market conditions evolve. Regular monitoring and evaluation are therefore essential to ensure that the production rate remains optimal.

In 2014, due to the political conditions of the Iraqi Kurdistan Regional Government and the budget deficit, oil extraction from this oil field increased (Figure 17). This production of more oil was done without adding new oil wells and only through the old wells of this field. It seems that this increase in harvesting also played an important role in creating the phenomenon of Water coning (Figure 18).

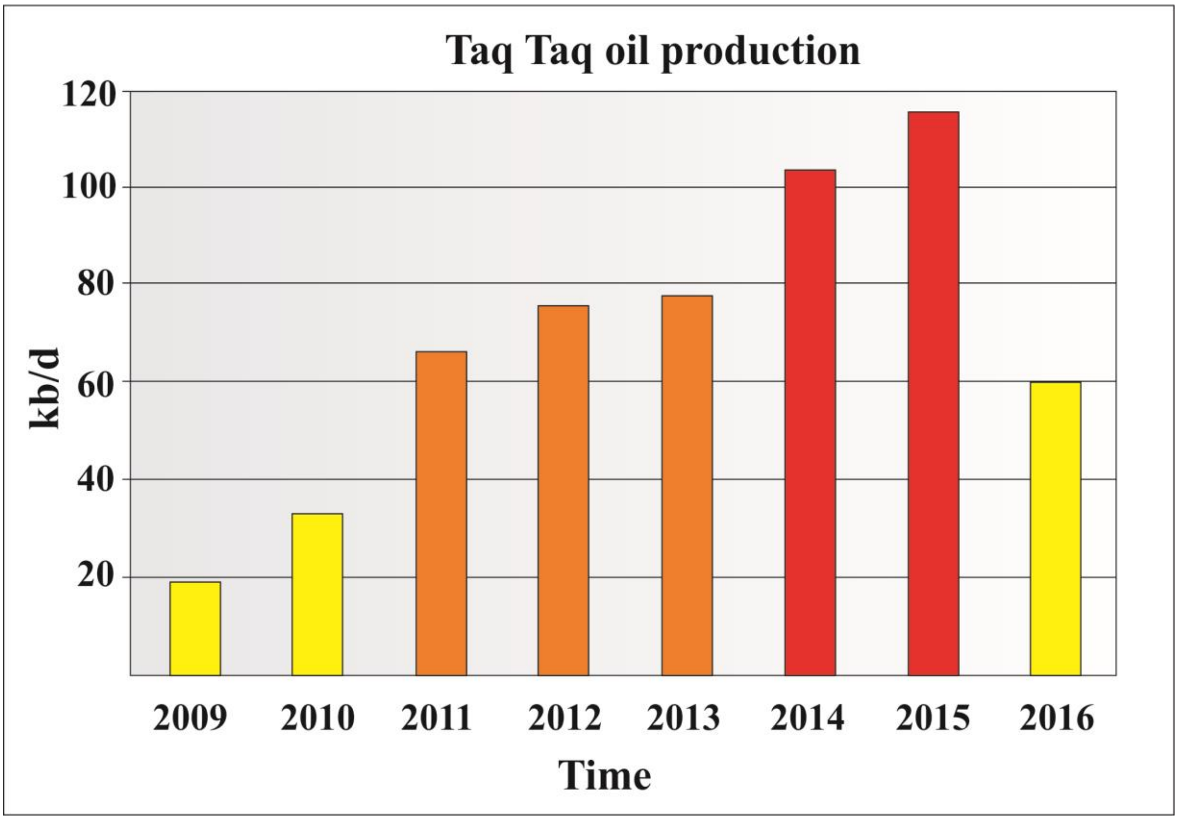

Figure 17 Increase in oil production between 2009 and 2015 in the Taq Taq oil field (modified after the genel energy website).

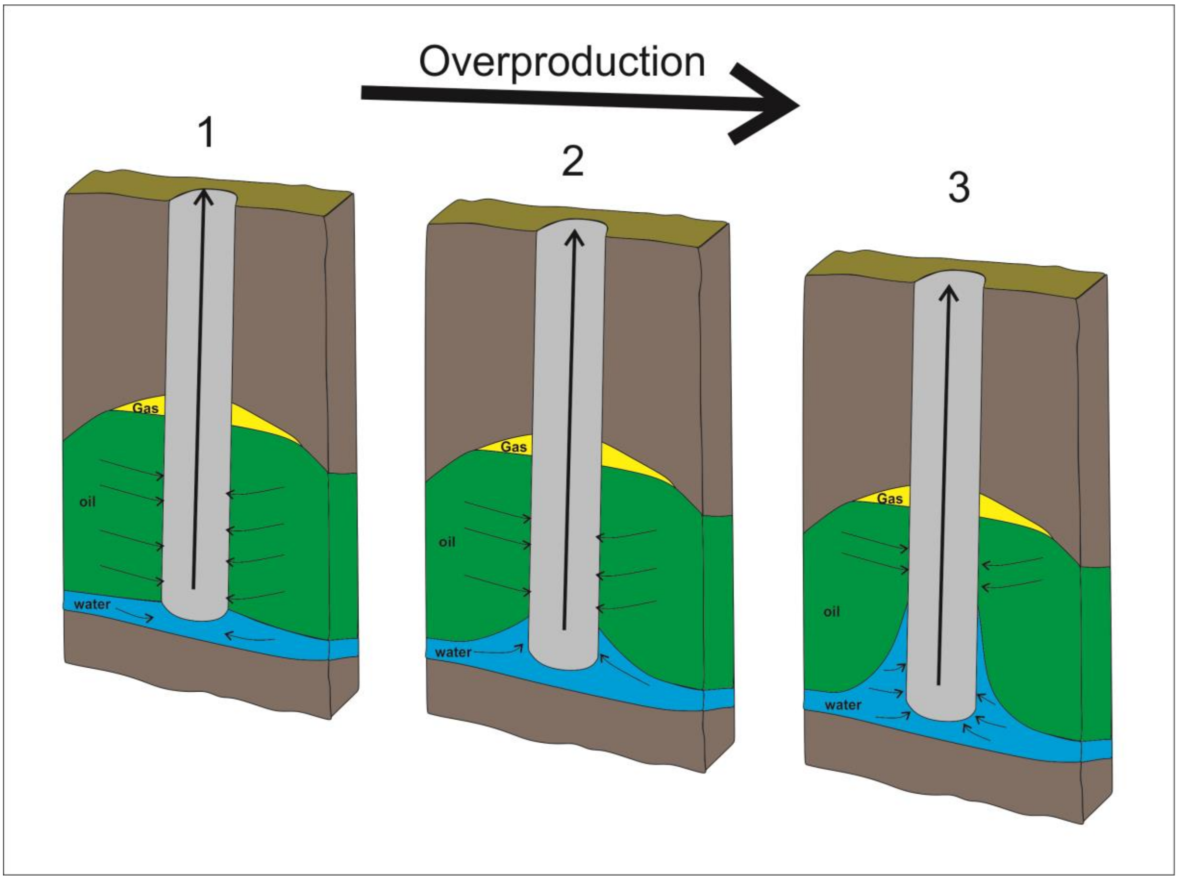

Figure 18 The effect of overproduction on the creation and extension of the water coning phenomenon in oil wells.

4.1.4 Reservoir heterogeneity

Heterogeneity refers to the variations in rock properties such as porosity, permeability, and fluid saturation within a reservoir (Lake and Jensen, 1991; Alpay, 1972). Reservoir heterogeneity, such as the presence of natural fractures or fault zones, can also impact water coning (Hewett, 1986; Namani et al., 2007). These heterogeneities can act as preferential pathways for water to flow toward the production well, leading to water breakthrough and water coning (Hewett, 1986; Namani et al., 2007). Additionally, heterogeneity can cause uneven fluid flow rates across the reservoir, which can lead to regions of high water saturation near the wellbore (Hewett, 1986). This can result in a higher likelihood of water coning in those areas.

In a reservoir with high heterogeneity, the presence of fractures or high-permeability zones can exacerbate water coning (Namani et al., 2007). If the fractures are oriented in a way that allows water to flow easily toward the production wellbore, it can result in an increase in water production and a decrease in oil production (Namani et al., 2007; Rashid et al., 2023).

There are two types of fractured reservoirs in the Taq Taq oil field, fractured reservoirs type 1 and fractured reservoirs type 2 (Garland et al., 2015).

Fractured reservoirs type 1, also known as single-porosity reservoirs, are characterized by fractures that provide both storage and deliverability of hydrocarbons (van Golf-Racht, 1982). In this type of reservoir, there is little or no matrix porosity and high permeability record by fracture (Figure 19). The Shiranish and Kometan Formations in the Taq Taq oil field could be considered to be type 1 fractured reservoirs (Garland et al., 2015). The fractures in these reservoirs are typically highly conductive and interconnected, allowing fluids to flow easily through the fractures. These fractures may be natural or induced and may be oriented in any direction (van Golf-Racht, 1982). In these reservoirs, production is often limited by the ability of the fractures to deliver fluids to the wellbore, rather than by the ability of the reservoir rock to store fluids (van Golf-Racht, 1982). Effective production from single-porosity fractured reservoirs requires a good understanding of the fracture network and its connectivity, as well as careful design and execution of hydraulic fracturing treatments to enhance the connectivity of the fractures and improve fluid flow (van Golf-Racht, 1982). Mistakes in reservoir modeling and the amount of production rate in this type of reservoir cause very destructive damage.

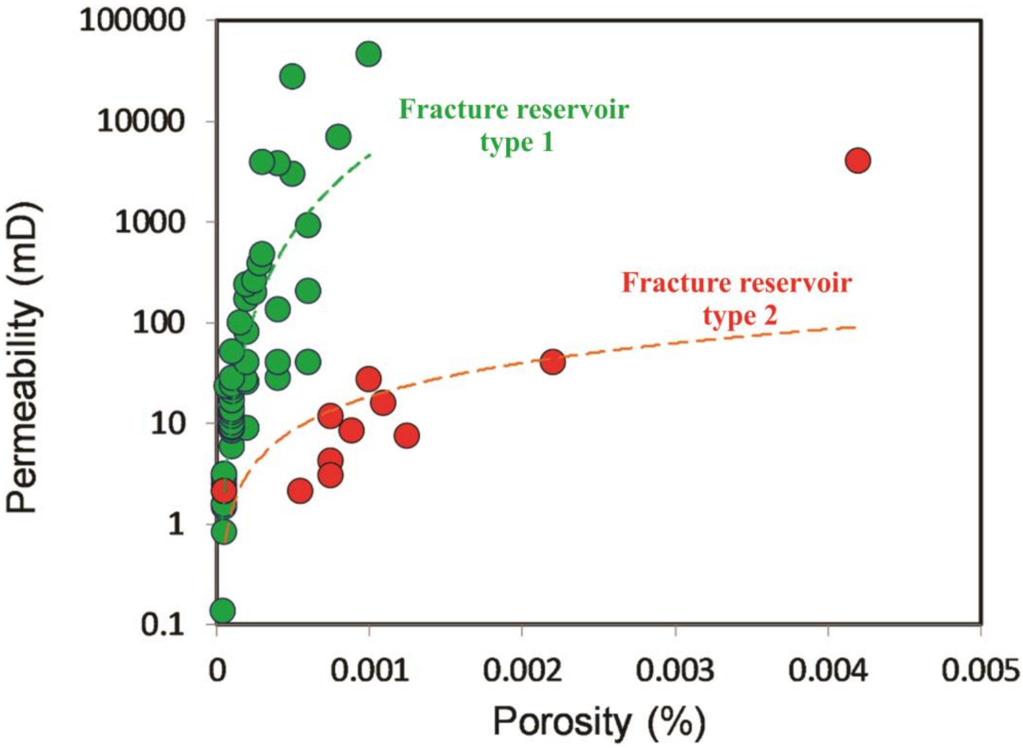

Figure 19 The cross plot of porosity versus permeability shows two different principal hydraulic flow units for type 1 fractured reservoirs and type 2 fractured reservoirs (modified after Rashid et al., 2023).

Fractured reservoirs Type 2 or dual-porosity reservoirs (van Golf-Racht, 1982). In these reservoirs, storage is provided by the matrix, which is the rock material surrounding the fractures, and deliverability is provided by the fractures (Figure 19 and Figure 20; van Golf-Racht, 1982). Qamchuqa Formation in the Taq Taq oil field is one of these types of reservoirs (Garland et al., 2015). The matrix porosity is typically low and the permeability is also low to moderate. The fractures provide high permeability pathways that allow fluids to flow more easily through the reservoir (Figure 20). The fractures can be either vertical or horizontal. The spacing, orientation, and connectivity of the fractures can greatly affect the flow of fluids through the reservoir (van Golf-Racht, 1982). In a dual-porosity reservoir, the flow of fluids through the matrix is typically slower than the flow through the fractures (van Golf-Racht, 1982). As a result, the production rate from these reservoirs is often limited by the ability of fluids to flow from the matrix into the fractures. The increase in oil production in this type of reservoir in an unprincipled manner can cause the phenomenon of water coning.

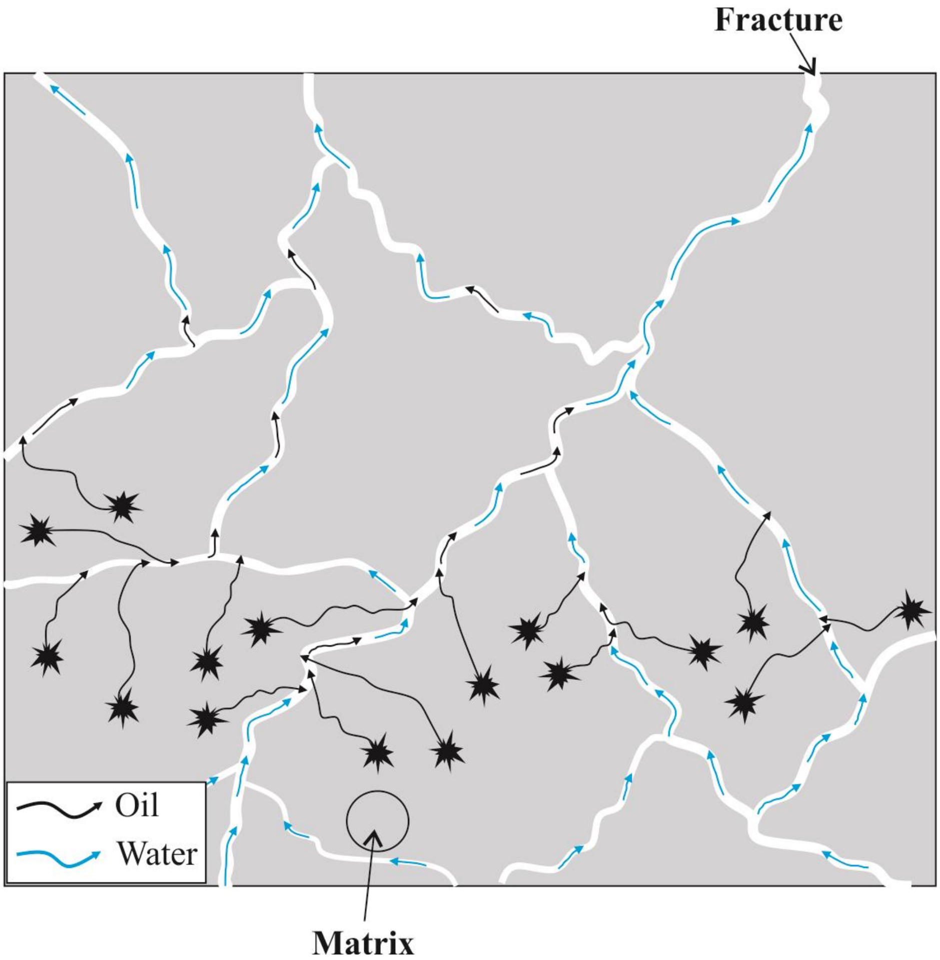

Figure 20 Schematic model of type 2 fractured reservoirs in which Storage is provided by the matrix and deliverability is provided by the fractures.

4.2 Important Methods of Preventing the Phenomenon of water coning

Managing water coning requires a holistic approach that encompasses various aspects of reservoir engineering and management. This includes conducting a thorough engineering analysis of the reservoir, studying production data, evaluating well performance, and considering the dynamic interaction between oil and water zones (Zhang et al., 2020; Troncoso and Oyarzún, 2018; Riazi et al., 2017; Renard et al., 1995). A comprehensive reservoir management strategy enables the selection and implementation of the most appropriate preventive measures. It is completely clear, which reservoirs can vary significantly in terms of their geological properties, fluid composition, permeability distribution, and connectivity (Wojtanowicz et al., 1994). These characteristics directly influence the behavior of fluids, including water coning tendencies (Wojtanowicz et al., 1994). Therefore, preventive measures need to be customized to the unique features of the reservoir to effectively prevent water coning (Riazi et al., 2017; Renard et al., 1995). Continuous monitoring of well performance, fluid levels, pressure changes, and production data is crucial to effectively prevent water coning (Riazi et al., 2017). Ongoing surveillance helps in detecting any changes or trends that may indicate the onset of water coning. It enables timely adjustments to production strategies and the implementation of corrective measures as needed (Riazi et al., 2017). By considering the reservoir characteristics and operational requirements, and by adopting a comprehensive reservoir management approach, oil companies can proactively prevent water coning in oil wells (Wojtanowicz et al., 1994). This involves continuous analysis, monitoring, and optimization to ensure the chosen preventive measures remain effective throughout the production life of the well.

Now day, to prevent the phenomenon of water coning, there are several methods that are used by various oil companies around the world. To prevent this phenomenon in different oil wells, several important strategies can be implemented. These approaches are aimed at minimizing the contact between oil and water zones and maintaining the integrity of the oil production. Here are some of the key ways to prevent water coning:

Well Placement: Optimal well placement is crucial to minimize the risk of water coning. Wells should be strategically located away from the water zone to reduce the chances of water breakthroughs. Horizontal or directional drilling can be employed to access the reservoir at an angle that minimizes water intrusion (Al-Afaleg and Ershaghi, 1993).

Perforation Strategy: Selective perforation allows for targeting specific zones of the reservoir with lower water saturation. By perforating intervals that have higher oil saturation and avoiding areas with higher water saturation, the risk of water coning can be reduced (Al-Afaleg and Ershaghi, 1993).

Reservoir Pressure Management: Proper reservoir pressure management is important in preventing water coning. Maintaining adequate reservoir pressure can help to keep the oil and water zones separated (Al-Afaleg and Ershaghi, 1993; Dabiri et al., 2017). Techniques such as gas injection or water injection can be employed to maintain pressure and push the oil column upward, preventing water breakthrough.

Water Control Measures: Implementing water control measures, such as the installation of water control valves or packers, can help restrict water influx into the wellbore. These measures provide a physical barrier to prevent water from entering the production zone and mitigate water coning risks.

Reservoir Characterization: Accurate reservoir characterization is essential to understand the distribution of oil and water zones within the reservoir (Abdi et al., 2019; Tiab and Donaldson, 2015). It enables better well planning, identifying areas with high water saturation, and implementing preventive measures accordingly (Tiab and Donaldson, 2015).

Reservoir Simulation and Modeling: Utilizing reservoir simulation and modeling techniques helps in predicting the behavior of the reservoir and identifying potential water coning issues (Dabiri et al., 2017). These tools allow for evaluating different production scenarios, optimizing well placement, and designing effective production strategies to prevent water coning (Dabiri et al., 2017).

The oil companies active in Taq Taq oil field by conducting detailed geological and engineering studies as well as accurate reservoir modeling and modeling other similar oil fields in the Zagros basin should have predicted that this oil field has special characteristics.

This means that they could predict that the characteristics of this oil field cause the potential of water coning to occur in it so that precise measures can be taken to prevent this phenomenon.

4.3 Methods of solving the problem of water coning in the Taq Taq oil field

The choice of the most suitable solution or combination of solutions to address water coning in an oil well depends on the specific characteristics of the well and reservoir. Each reservoir has unique characteristics, including permeability, porosity, fluid properties, and geological formations (Høyland et al., 1989; Karp et al., 1962; Al-Anazi and Islam, 2017; Xu et al., 2019) . These factors influence the behavior of fluids and the occurrence of water coning. Therefore, the selection of solutions should consider the reservoir's heterogeneity to ensure an effective and tailored approach (Høyland et al., 1989). Considering these factors, reservoir engineers and experts analyze the data related to the well and reservoir, including well tests, production history, geological information, and fluid properties, to determine the most appropriate solution or combination of solutions (Høyland et al., 1989; Xu et al., 2019). This analysis ensures that the chosen approach addresses the specific challenges posed by water coning in that particular well and maximizes oil production while minimizing water production (Glimm et al., 1983). Therefore, a comprehensive understanding of the well and reservoir characteristics is crucial in selecting and implementing the most effective solution to mitigate water coning (Glimm et al., 1983).

Here are some of the most important ways to mitigate water coning in the Taq Taq oil field:

Drilling a horizontal well: by drilling a horizontal well, the aim is to place the wellbore in the reservoir horizontally across the productive zone rather than vertically. This horizontal orientation allows for a larger contact area with the oil reservoir, increasing the length of the wellbore exposed to the oil-bearing formation (Figure 21). This, in turn, helps to maximize oil production and minimize water coning.

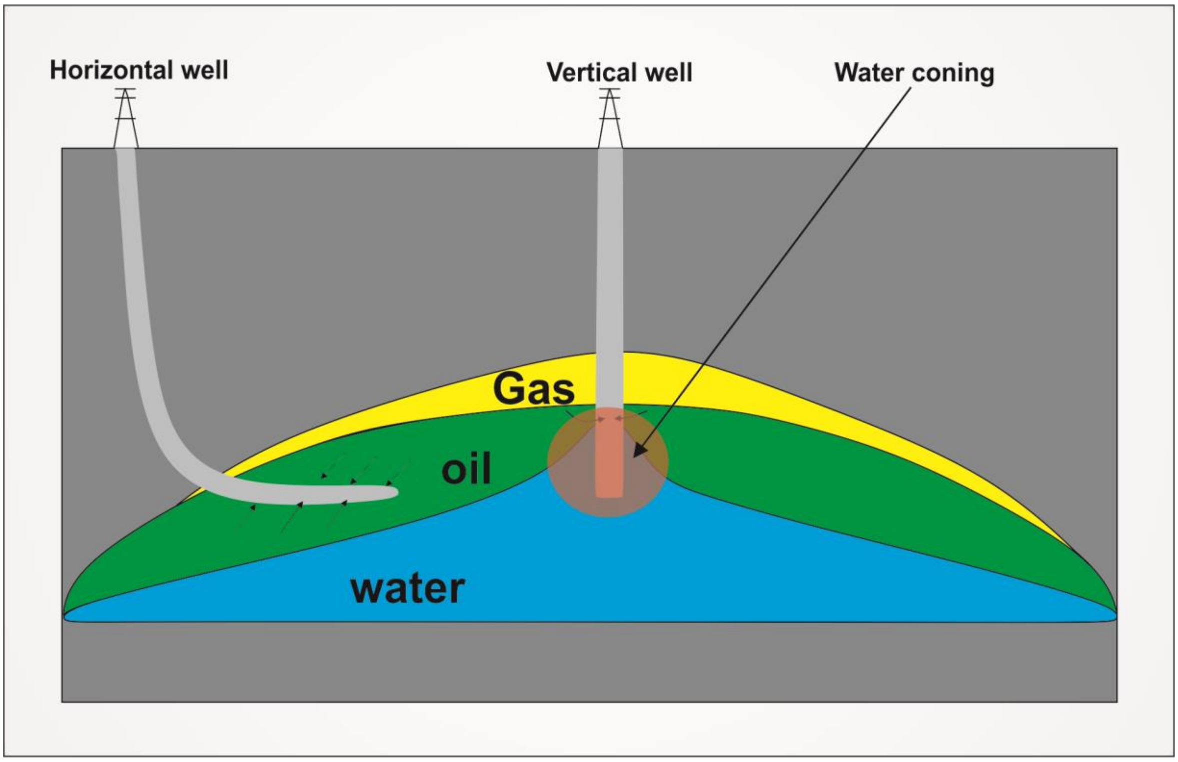

Figure 21 Schematic model of horizontal drilling to solve the problem of water coning in oil fields.

Reservoir Characterization: Conducting detailed reservoir characterization studies in the Taq Taq oil field is crucial to understand the distribution of oil and water zones, permeability variations, and reservoir pressure. This information helps in designing effective mitigation strategies.

Well Placement and Completion: Careful consideration of well placement and completion techniques is essential to minimize the risk of water coning. Horizontal or directional drilling can be utilized to intersect the reservoir at angles that reduce water coning tendencies.

Perforation Strategy: Optimizing the perforation strategy can help selectively produce oil zones and avoid water-saturated areas. Precise placement of perforations in the zones with higher oil saturation can minimize water influx.

Reservoir Pressure Management: Maintaining optimal reservoir pressure is crucial in mitigating water coning. Pressure maintenance techniques such as gas injection or water injection can help to create a barrier against water influx and enhance oil production.

Artificial Lift Systems: Implementing artificial lift methods such as electric submersible pumps (ESPs) or gas lift can help to lift the oil and minimize the impact of water coning. These systems provide additional pressure to counteract water influx.

Water Control Treatments: Applying water control treatments, such as polymer or gel treatments, can restrict water movement and improve oil recovery. These treatments reduce water mobility and enhance oil sweep efficiency.

Surveillance and Monitoring: Regular surveillance and monitoring of well performance, production data, and water-oil contact movement are crucial in detecting early signs of water coning. This enables timely intervention and adjustment of production strategies.

Reservoir Simulation and Modeling: Utilizing reservoir simulation and modeling techniques allows for predicting the behavior of the Taq Taq oil field reservoir and assessing different mitigation scenarios. This aids in optimizing production strategies and implementing effective water coning mitigation measures.

5 Conclusions

In this research, which is based on the detailed study and review of published reports and articles about the Taq Taq oil field some results have been obtained.

By examining and researching the formations that play the role of reservoirs in the Taq Taq oil field, it was found that the reservoirs of this large oil field are type 1 and type 2 fractured reservoirs.

Fractures in these reservoirs were mainly due to the active tectonics of this region.

Research shows that between the years 2014 and 2015, due to some issues, the production of oil from this strategic field has increased greatly, so during the period of 1 year, the production from this field has increased by nearly 40,000 barrels per day. The increase in production has led to the drilling of new wells and has caused the wells of this field to be over-pressured.

The increase in oil production in a short period of time and many fractures in the reservoirs of this oil field have caused the phenomenon of water coning in this field.

Fractures in these reservoirs have allowed water to move quickly and get closer to the wells due to high permeability. And the increase in oil production according to the plan has renewed this phenomenon.

In general, it can be said that the fractured type of reservoirs in this field and the production without a program in a short period of time are the most important reasons for the phenomenon of water coning in the Taq Taq oil field. Also, the phenomenon of water coning has been the reason for the decrease in oil production and increase in water production in this oil field.

In order to solve the phenomenon of water coning in the Taq Taq oil field, according to the special characteristics of this oil field, horizontal drilling is one of the best methods that increases oil production in this important field in Kurdistan region of Iraq. It's important to note that while drilling a horizontal well can be an effective solution to control water coning, it is not the only option. Other methods, such as reservoir pressure maintenance techniques, optimizing production rates, and implementing proper reservoir characterization and modeling, may also be employed depending on the specific reservoir conditions and constraints.

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