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Porosity Evolution of the Early Cretaceous, Qamchuqa Formation in the Northern Part of Iraq

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Abstract

The Qamchuqa Formation was studied in Kosrat Anticline in Dokan area of Sulaimanyia governorate, Kurdistan region, Northeastern Iraq. Fourteen slides of 14 rock samples were made and studied under different microscopes. Petrographic properties and types of pores determined in this study, related to Qamchuqa Formation. The formation consists of three units. The lower unit (162 m) consists of dark grey, massive limestone. The middle unit (139 m) consists of an alternation of grey very coarse crystalline dolomitic limestone and yellowish green marl. The upper unit (384 m) consists of grey massive limestone and dolomitic limestone. The high values of porosity in the Qamchuqa Formation can result from vuggy porosity and the stylolite systems too. The high values of porosity in the last stage of pores evolution can be attributed to intercrystal porosity, vuggy porosity, and secondary fracture systems.

Three types of pores were found in Qamchuqa Formation, these are intercrystal dolomite pores, vuggy pores, and microfractures pores. The Qamchuqa Formation in the present study at Kosrt anticline can be considered as a petroleum reservoir because of the ratio of bitumen materials to the size of pores. As well as, Qamchuqa Formation in the present study is characterized by leakage of petroleum materials to the surface.

Key words: Qamchuqa Formation, Porosity evolution, vuggy pores, intercrystal dolomite pores, microfractures pores.

The Qamchuqa Formation was initially documented by Wetzel in an unpublished report from 1950, while Henson referred to it as the Qamchuqa Limestone in 1954. The formation is composed of approximately 650 meters of alternating layers of well-bedded, gray dolomite and light gray limestone or dolomitic limestone [1].

According to Sadooni and Alsharhan [2], Qamchuqa Formation from the Early Cretaceous period is one of the important reservoir rocks in Iraq's Kurdistan region. It features a high degree of intercrystalline porosity, as well as significant amounts of large vuggy porosity that are associated with fractured dolostone facies [3].

According to Al-Naqib, Al-Shakri and Buday [4, 5, and 6], Qamchuqa Formation from the Early Cretaceous period is a type of carbonate sediment that was deposited in shallow waters, within a broad carbonate platform that existed in a low energy lagoonal environment. The formation is comprised of several sub-environments, such as tidal flats, reefs (including barrier reefs), lagoons, shoals, patch reefs, and fore-slope environments [7, 8, 9, 10, 11, and 12].

Qamchuqa Formation, as defined, consists of neritic limestone, which is frequently highly dolomitized from the Hauterivian to Albian time intervals. Similar limestone formations found in southern and western Iraq during the same period were identified as the Shuaiba (Aptian) and Mauddud (Albian) formations [6].

Chatton and Hart [13], classified the Qamchuqa Formation into two units, with the lower unit being from the lower Albian age and the upper unit starting from the upper Albian age. The same authors believed that the Shuaiba and Mauddud formations were large, separate extensions of the lower and upper units of the Qamchuqa Formation, respectively. All three formations (Qamchuqa, Shuaiba, and Mauddud) primarily consist of neritic limestone, which may vary in dolomite content.

The formation comprises a thick sequence of sediment, which was formed through multiple instances of deposition in the aforementioned sub-environments. As a significant, massive, feature-forming limestone unit in the Lower-Middle Cretaceous succession (Hauterivian to Albian age), Qamchuqa Formation is particularly noteworthy in the Kosrat anticline of Kurdistan region, Iraq.

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Aims of study

- Pores and Fractures evolution under Microscope
- Study of the effects of diagenetic processes on reservoir properties
- Burial column effect in the tectonic framework to interpret the evolution of Pores

Location of study area

The location of the study site is in the Kurdistan region of northeastern Iraq, specifically at the Kosrat anticline, which is situated near the border with Iran and is directly southwest of the main Zagros Thrust Fault. It can be located at the geographical coordinates of 36°12'41"N / 44°50'16"E (Fig. 1).

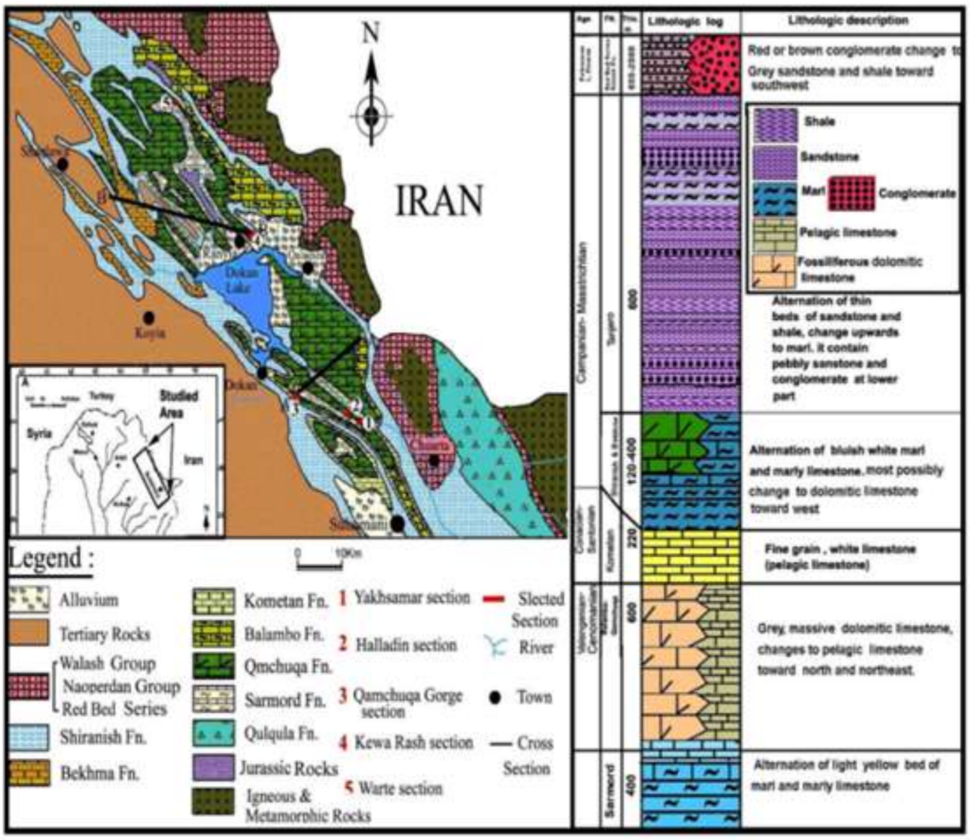

Figure 1: Geological map of northern Iraq [14]. He illustrates the position of the examined section as well as a stratigraphic column.

Tectonic Setting

The study site is situated in the northeastern region of the Arabian Plate and can be divided into two distinct parts. The larger portion is located within the Unstable Zone, specifically the High Folded Zone as depicted in (Fig. 2). The second part corresponds to the northern area of the Mesopotamian zone. Based on the tectonic map of northern Iraq, the region is predominantly composed of subparallel anticlines and synclines with high amplitudes. A significant number of these anticlines exhibit asymmetry, with their southwestern limbs being steeper than the northeastern ones. The strata in the study area have experienced significant deformations, particularly those located in the syncline axis. These deformations were caused by the stress imposed by the Iranian Plate, which resulted in the formation of numerous thrust faults and transverse structures in the region [15].

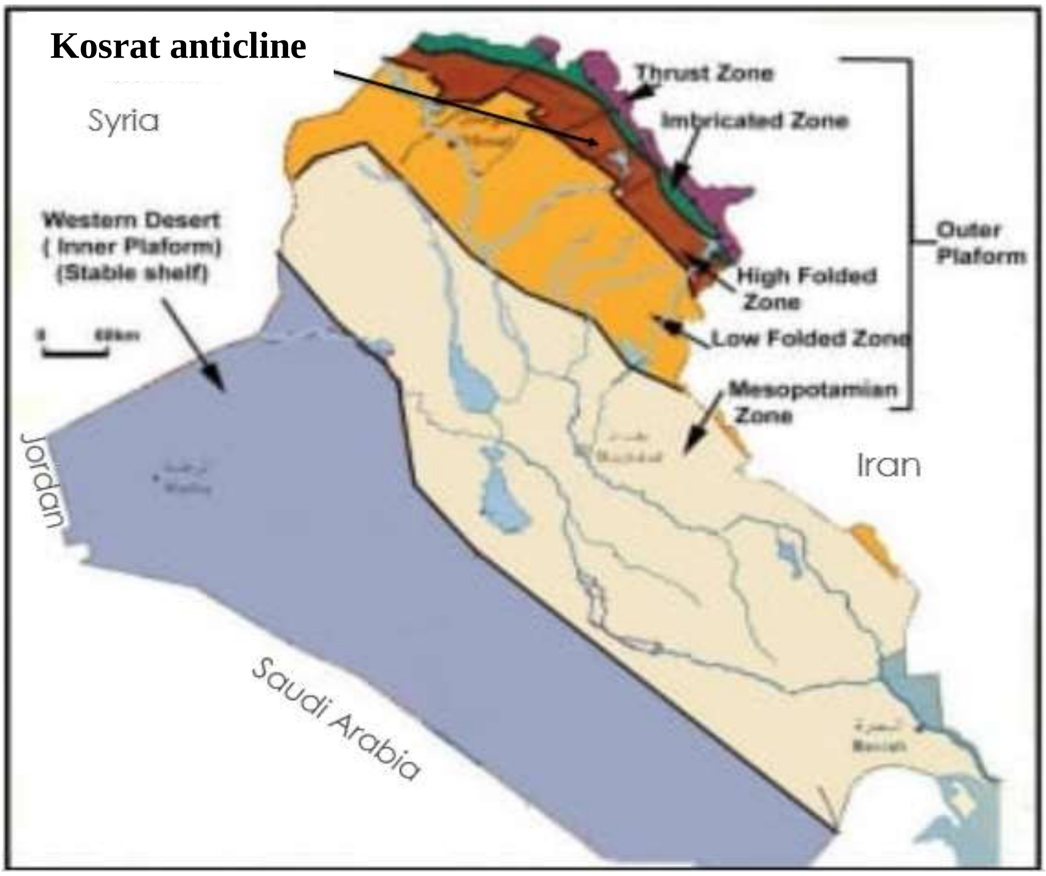

Figure 2: The location of the examined section is illustrated in the tectonic map of Iraq. Modified after [16].

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Methodology

Field Work

A total of fourteen rock samples were collected from multiple outcrops within the Kosrat section, which has a thickness of approximately 650 meters. Within this section, the Qamchuqa Formation is identified by alternating layers of well-bedded, gray-colored dolomite and light gray limestone or dolomitic limestone. The spacing between the samples is around 40 meters and depends on the characteristics of the individual beds (Plate1).

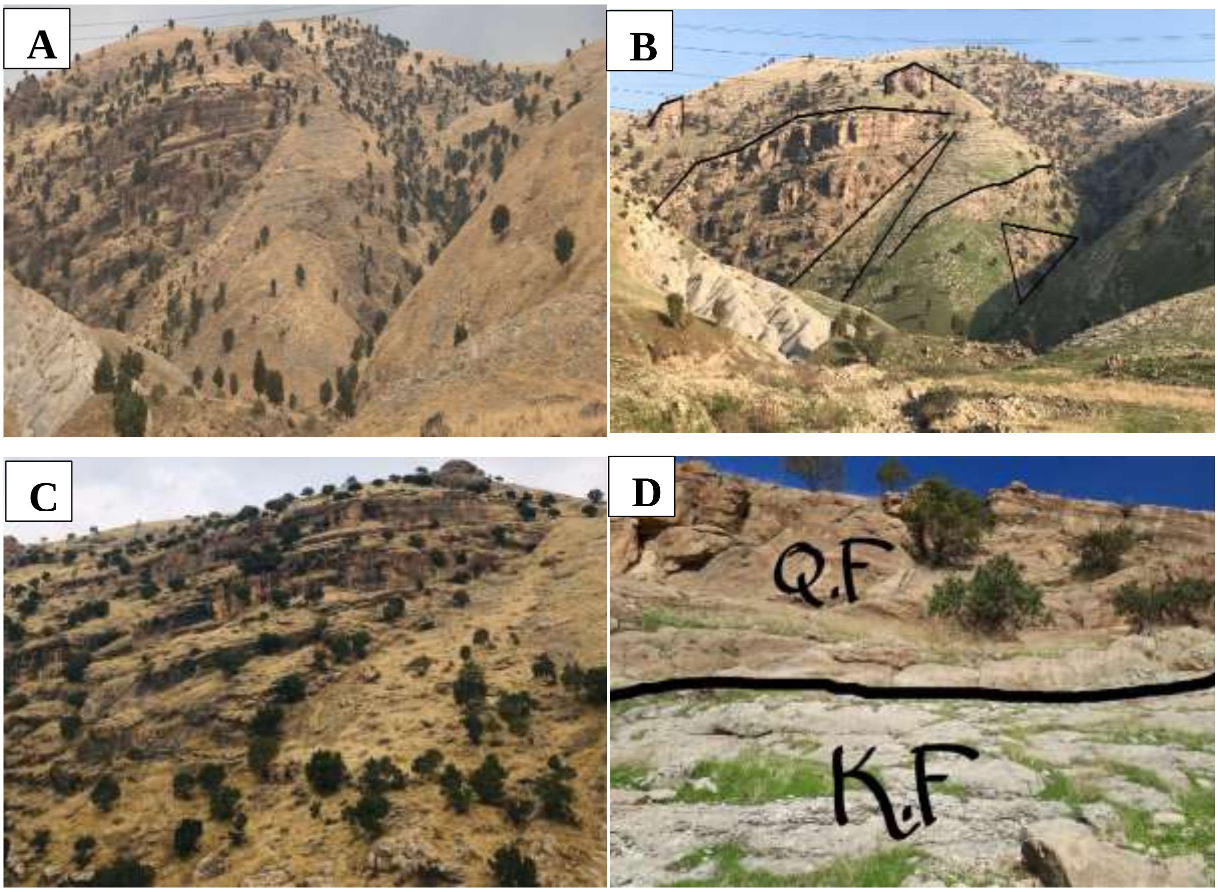

Plate 1: It displays the primary geological features observed during fieldwork conducted in the Kosrat anticline within the Dokan region of northeastern Iraq. The major fault between the Qamchuqa and Kometan formations is indicated by image A. Image B denotes the outcrops of the Qamchuqa Formation (represented by black lines). The contact between the Qamchuqa and Kometan Formations is shown in images C, and D.

Laboratory Work

A total of fourteen rock slides were created at the Department of Petroleum Geology and Minerals workshop, which is located within the College of Science at the University of Diyala. A petrographic analysis was conducted, which involved the microscopic examination of thin sections under a Leica microscope (PN: DM 500). This examination was carried out to identify the petrographic characteristics and types of pores of the samples. Additionally, photographs of the thin sections were taken using an Optika D9 camera.

Results and Discussions

Diagenesis Processes

Diagenesis encompasses all the physical and chemical modifications that take place in sedimentary materials after their deposition on the seafloor, and during their transformation into sedimentary rocks, often under the influence of organic processes. In carbonate rocks, chemical processes are particularly prevalent, such as chemical compaction, dissolution, cementation, neomorphism, dolomitization, dedolomitization, and replacement. Some of these processes can act in conjunction, such as compaction and dissolution, leading to pressure solution and stylolitization in carbonate mud.

The efficacy of diagenesis processes is influenced by various factors, including:

Pressure

As one moves farther away from the main fault within the Kosrat section, the grain size of the Qamchuqa Formation decreases (**Error! Reference source not found.**). The Qamchuqa Formation is comprised of layers of dolomitic limestone that formed due to an increase in pressure on the rock column. There are two distinct types of layers within the rock column of the Qamchuqa Formation, which can result in the creation of a geopressure zone. The uneven compaction of the layers can also lead to the formation of fractures. The hydrostatic pressure in the fluid column is visible in the pore spaces and affects the shape of the pores, depending on the difference between the hydrostatic pressure and lithostatic pressure (**Error! Reference source not found.**2).

Salinity and temperature are factors that impact hydrostatic pressure. In the area under investigation, especially the lower unit of Qamchuqa Formation, which consisted of dark grey, massive limestone. The majority of pores have a circular shape that indicating the level of hydrostatic pressure of pores is sufficient to maintain the shape of the pores (**Error! Reference source not found.**2.C to F). Occasionally, the hydrostatic pressure may be slightly lower than the lithostatic pressure, causing the pores to elongate (**Error! Reference source not found.**3.B). Conversely, in situations where the hydrostatic pressure exceeds the lithostatic pressure, degassing patterns may be observed in the pores (**Error! Reference source not found.**3.A).

Temperature

The influence of temperature can be determined by examining the variety of minerals present at different depths, such as the dolomite crystals found in the Qamchuqa Formation, or through the detection of phase changes in metastable minerals. In the upper unit (384 m) consists of grey massive limestone and dolomitic limestone. The presence of homogenization temperature of fluid inclusions can lead to an increase in the distribution of pyrite and the size of dolomite crystals (Plate 5.A&B). The presence of solid pyrobitumen residue indicates that a process of thermal degradation occurred after the generation and migration of oil, as the temperature in the reservoir rocks increased (Plate 3). Furthermore, the precipitation of calcite or dolomite can affect the ratio of current brine.

Diagenetic fluids

The source of fluids that are found in deep burial conditions can be determined by examining their salinity levels relative to standard seawater. Fluids with salinity levels lower than that of seawater can be categorized as meteoric, marine, or original basin fluids [17]. Conversely, fluids that contain over 100,000 ppm of dissolved solids are considered brines, and their origins can be linked to evaporite deposits.

The chemical composition of diagenetic fluids is highly intricate. The significant variations observed in the compositions of paleofluids result from the ongoing interactions between rock-water and/or the mixing of dissimilar water sources. However, the elemental ratios found in deep burial fluids typically follow the order Na > Ca > Mg [18]. Notably, the Qamchuqa Formation displays a very high Mg/Ca ratio.

The reservoir site

The location of the reservoir is closely linked to the three previously mentioned factors that impact the properties of reservoir rocks. The basin's position includes several sub-factors, including the hydrologic system as the first sub-factor, which encompasses characteristics of flow. The second sub-factor is the tectonic system, which includes plate movement, fault systems, fracture systems, and differential compaction. The location of the reservoir plays a vital role in directing the pathways of diagenesis processes in the burial environment.

Heydari [19], identified three hydrologic regimens that are linked to tectonic burial regimens to understand their effect. These regimens include the passive margin, the collision or active margin, and the post-tectonic regimen.

Furthermore, three characteristics of hydrologic flow have been identified by [20] that are reflected by the hydrologic regimen. The velocity of fluid flow is determined by the density of fluids which is dependent on the temperature and salinity of the fluids. These hydrologic flow regimens include:

The meteoric system is characterized by a fast flow near the surface, driven by gravity. The compactional system has moderate velocities and occurs at depths greater than 1km. The thermohaline system is defined by the density and results in varying flow rates at depths less than 3km.

The results of the petrography study indicate that the permeability of the Qamchuqa Formation is anisotropic. Moreover, the study area is located in an active margin and is characterized by the presence of highly folded zones in the northeastern part of the Arabian plate.

According to our petrographic analysis, Qamchuqa Formation exhibits features of the compactional hydrologic flow regime with the influence of brines in various parts of the reservoir.

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Analyze pore characteristics in their ultimate stage to understand the conditions of the diagenetic environment

The evolution stages of porosity

Understanding the evolution and modification of porosity is crucial in identifying diagenetic environments and determining tectonic burial regimes. As primary porosity transforms into post-secondary porosity, the concept of porosity modification and evolution proves beneficial. However, this transformation takes a considerable amount of time and occurs in three distinct stages: eogenetic, mesogenetic, and telogenetic [21].

The eogenetic stage encompasses the time between the deposition of initial sediments and the deposition of final sediments caused by surficial diagenetic processes. This stage comprises two zones. The first zone is located in the vadose environment above the water table and can be subaerial or subaqueous. The second zone is where the surface of recharged water begins. This includes meteoric water, normal marine water, and evaporated marine water, among others.

In terms of mineralogy, the eogenetic stage involves minerals that are not stable. Dissolution, cementation, and dolomitization are critical diagenetic processes that occur during this stage. These processes result from various environments such as meteoric phreatic, meteoric vadose, shallow marine, deep marine, and evaporative marine [22].

The mesogenetic stage is the second phase during which sediment undergoes the compaction process. This stage is characterized by very slow processes that lead to the modification of porosity. However, the diagenetic processes that occur during the mesogenetic stage take a long time and support the concept of porosity evolution. The deep burial environment is a diagenetic environment that occurs during the mesogenetic stage.

The telogenetic stage is the third and final phase that occurs when rock sequences that have undergone the mesogenetic stage, are exposed to the surface due to unconformities. These rock sequences are once again impacted by surficial diagenetic processes. The term "telogenetic" specifically refers to old rocks that contain highly stable minerals such as calcite and dolomite, which are subject to erosion and weathering due to the effects of surficial diagenetic processes.

Meteoric vadose and meteoric phreatic zones are the most common diagenetic environments during the telogenetic stage. The Qamchuqa Formation located in the Kosrt fold belongs to the telogenetic stage.

Primary porosity

Moore [22], provided a new explanation of the diagenetic stages previously identified by [21]. The porosity classification of the Qamchuqa Formation follows their approach. However, most of the primary porosity has been either completely or partially occluded by blocky dolomite cement and the growth of dolomite crystals. As a result, the volume of primary pores in the Qamchuqa Formation has decreased (Plate 6). The primary porosity in the formation is comprised of one type, which is interparticle porosity.

Interparticle pores refer to the void spaces that are found between dolomite crystals. In the middle unit (139 m) of Qamchuqa Formation that consists of an alternation of grey very coarse crystalline dolomitic limestone and yellowish green marl. Interparticle type of porosity is typically present in the dolomite grainstone microfacies, but it is often occluded by blocky dolomite cement. The interparticle pores are also affected by mechanical compaction in the grainstone microfacies, before the onset of blocky dolomite cementation (Plate 6).

Secondary porosity

Qamchuqa Formation includes several forms of secondary porosity. The secondary porosity forms found in the Qamchuqa Formation belong to the mesogenetic stage, indicating a deep burial environment [23, 24, 25, and 19]. These porosity forms are referenced in (Plates 2, 3, 4, and 5). The secondary porosity encompasses a wide range of porosity types, which included the entire Qamchuqa reservoir. Most of these porosities are classified as dissolution pores, vuggy, outgassing fracture, intercrystalline, post-stylolite, and fracture porosity.

Vuggy porosity is the primary characteristic of Qamchuqa rocks [21]. It refers to a type of pores that form as a result of the dissolution process, which is accompanied by the second oil migration. Vuggy porosity remains open without being covered by sealed materials like blocky dolomite cement, indicating that the open vuggy pores occurred after the widespread distribution of the blocky dolomite cement. Vuggy porosity consists of interconnected pores that are a few centimeters in size. This feature supports permeability in Qamchuqa.

Degassing or outgassing porosity is another type of porosity that occurs after the dissolution process [28], which takes place at different levels within the stratigraphic column of Qamchuqa (Plate 3.A and Plate 4.E&F). These pores are responsible for the release of CO2 gas and/or methane gas when acidic fluids are present. Degassing porosity indicates the activity of the chemical compaction process in Qamchuqa.

Intercrystalline porosity is a type of secondary porosity that occurs as a result of the abundant distribution of euhedral dolomite crystals. Initially, intercrystalline porosity is interconnected during the first stage of the dolomitization process. However, as the distribution of muddy carbonate increases due to ongoing dissolution, it becomes semi-closed. Additionally, the small size of the mud crystals contributes to the formation of cobweb-like structures that infiltrate between the euhedral dolomite crystals. Generally, intercrystalline porosity significantly enhances permeability in Qamchuqa (Plate 5.C&D).

Post-stylolite porosity corresponds to the post-stylolite systems predominantly found within the muddy facies of the Qamchuqa Formation, as indicated by the stylolite volume. Inside the post-stylolite, there are muddy fabrics that resemble a cobweb-like structure. These muddy fabrics enhance the storage capacity of the post-stylolite systems (Plate 3.B and Plate 4.C&E). They function as absorbent materials for storing migrated fluids. Post-stylolite porosity exhibits larger interconnected networks compared to fracture systems, sharing certain characteristics such as the lining of walls between stylolite systems and fracture systems (Plate 3).

Fracture porosity is characterized by multiple generations of interconnected fracture networks, predominantly found in the reef facies of Qamchuqa. Specifically, the secondary generations of fracture systems contribute to the development of fracture porosity in this formation. These fractures serve as pathways for migrated fluids, and they cut across all types of cement. Fracture porosity typically ranges in size up to a few centimeters and may result from the process of differential compaction. The secondary fracture systems are primarily filled with equant calcite cement, euhedral dolomite crystals, and bitumen residue. On the other hand, the primary fracture systems exhibit silicate lining-walls, followed by calcite belts, as observed in the Kosrt anticline field (Plate 4.F).

Additionally, specific secondary porosities become completely sealed as a result of the cementation process (Plate 6. A. B & C), whereas other porosities are partially blocked by the growth of calcite cement crystals (Plate 6. D & F). Certain pores are filled with pyrite and dolomite minerals, suggesting that they originated during the dissolution phase. Consequently, these pore fluids are prone to precipitating as pyrite or dolomite cement within the transport system.

The evolution of porosity is influenced by the chemistry of paleofluids and the characteristics of their sediments.

The evolution of porosity is closely linked to the evolution of fluids in the reservoir, alongside hydrocarbon maturation. Petrographic studies provide substantial evidence of the role played by fluids in altering porosity characteristics. The mesogenetic stage represents an extensive period of fluid evolution, spanning from the final deposition of sediments to the present-day conditions in deep burial environments. The distribution patterns of secondary porosity align with the distribution of microfacies (Figure 3). Primarily, the latest forms of dissolution porosity indicate an active tectohydrologic regime, while the flow regime is characterized as a compactional system.

The formation of new pore patterns in Qamchuqa is attributed to the dissolution and dolomitization processes (Plate 5.C&D). Pores in Qamchuqa can be classified into two main types based on the nature of sediments and the chemistry of paleofluids. The first type consists of intercrystal pores located between dolomite crystals. The second type comprises secondary fracture networks (Figure 4).

The Qamchuqa Formation exhibits high porosity values, which can be attributed to vuggy porosity and stylolite systems. Furthermore, in the later stages of pore evolution, high porosity values can be attributed to intercrystal porosity, vuggy porosity, and secondary fracture systems.

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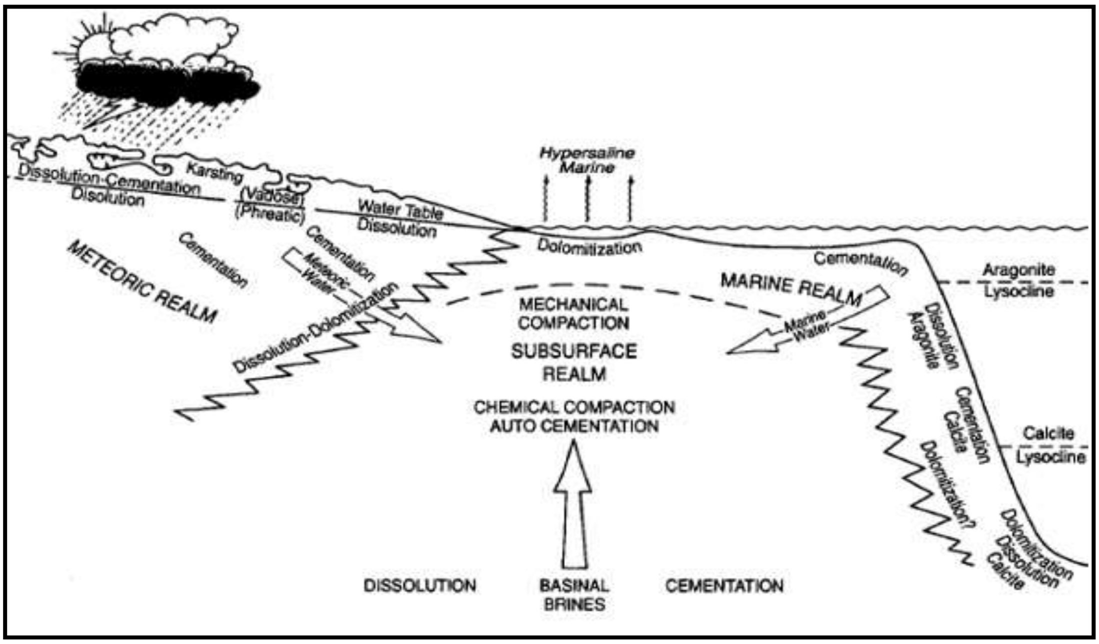

Figure 3: The main diagenetic environments and the common diagenetic processes are drawn based on the concept of porosity modification and evolution [26].

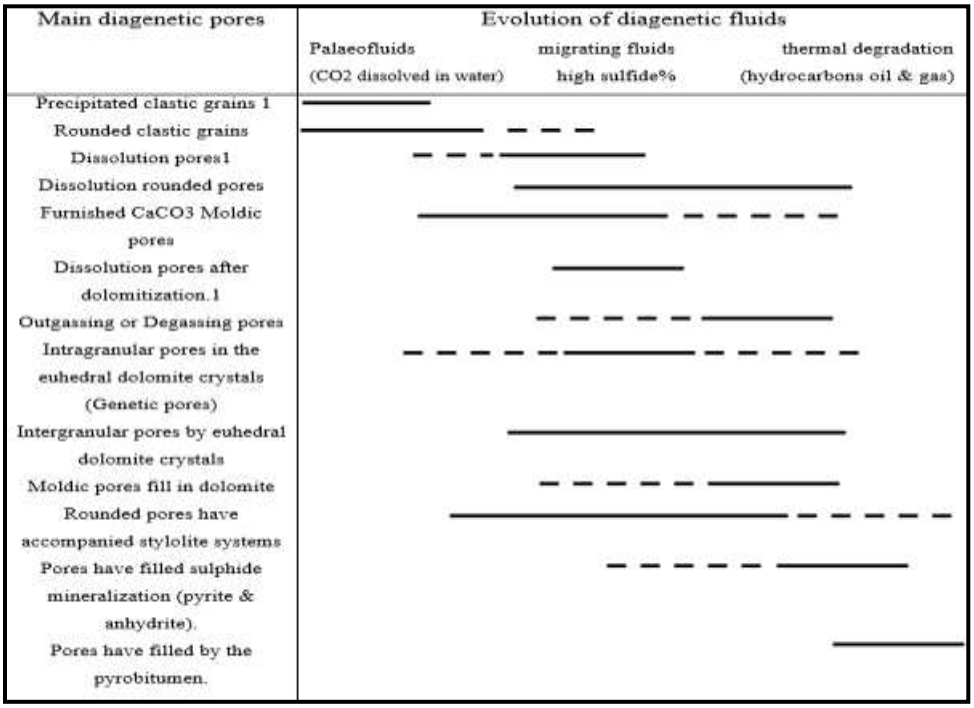

Figure 4: The paragenetic sequence of the porosity evolution is shown the evolution of diagenetic fluids [27].

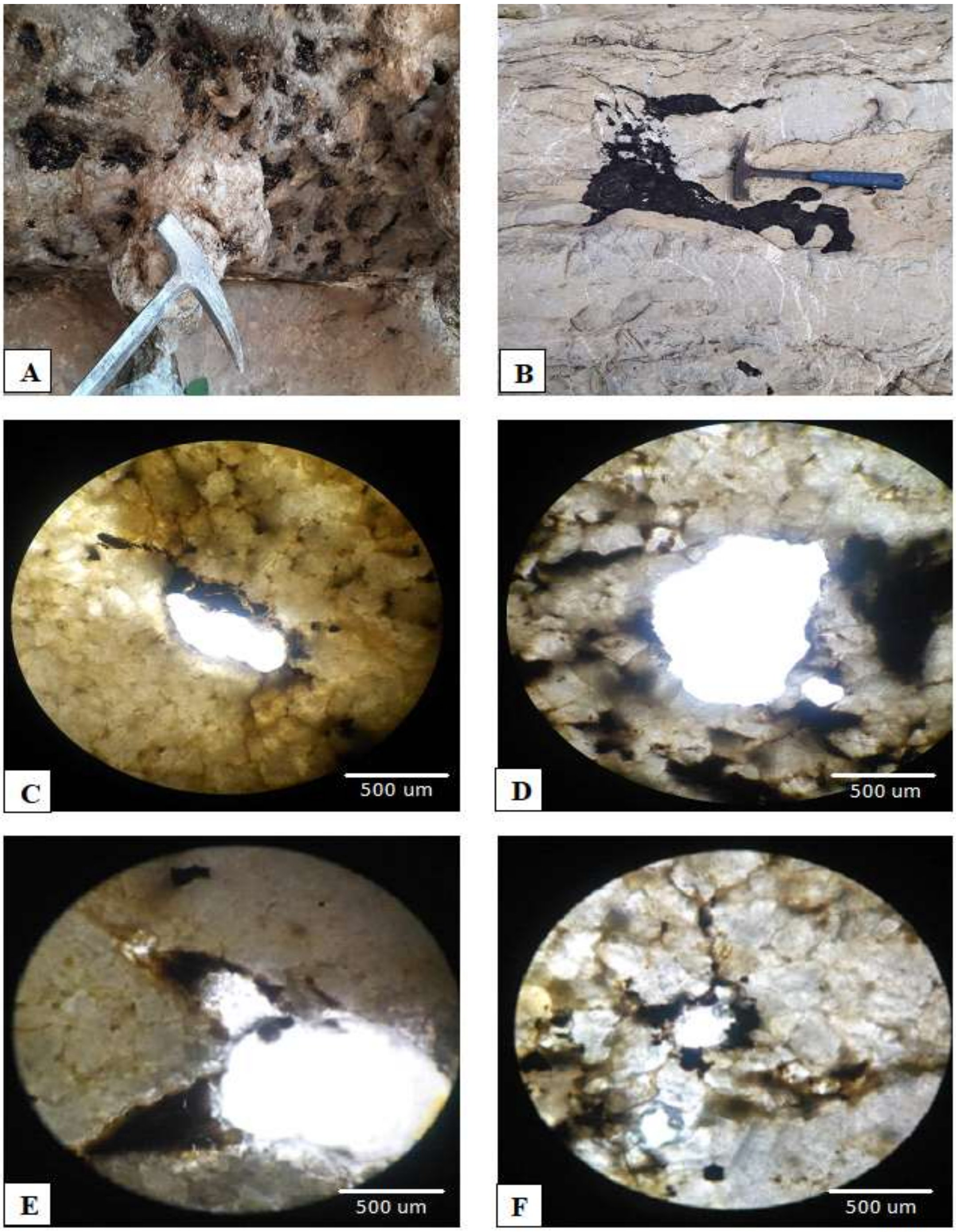

Plate 2: A & B Photos show the leakage of bitumen in Qamchuqa Formation. The final shapes of pores are depend on the difference between the value of hydrostatic pressure and the value of lithostatic pressure in photos of C, D, E & F

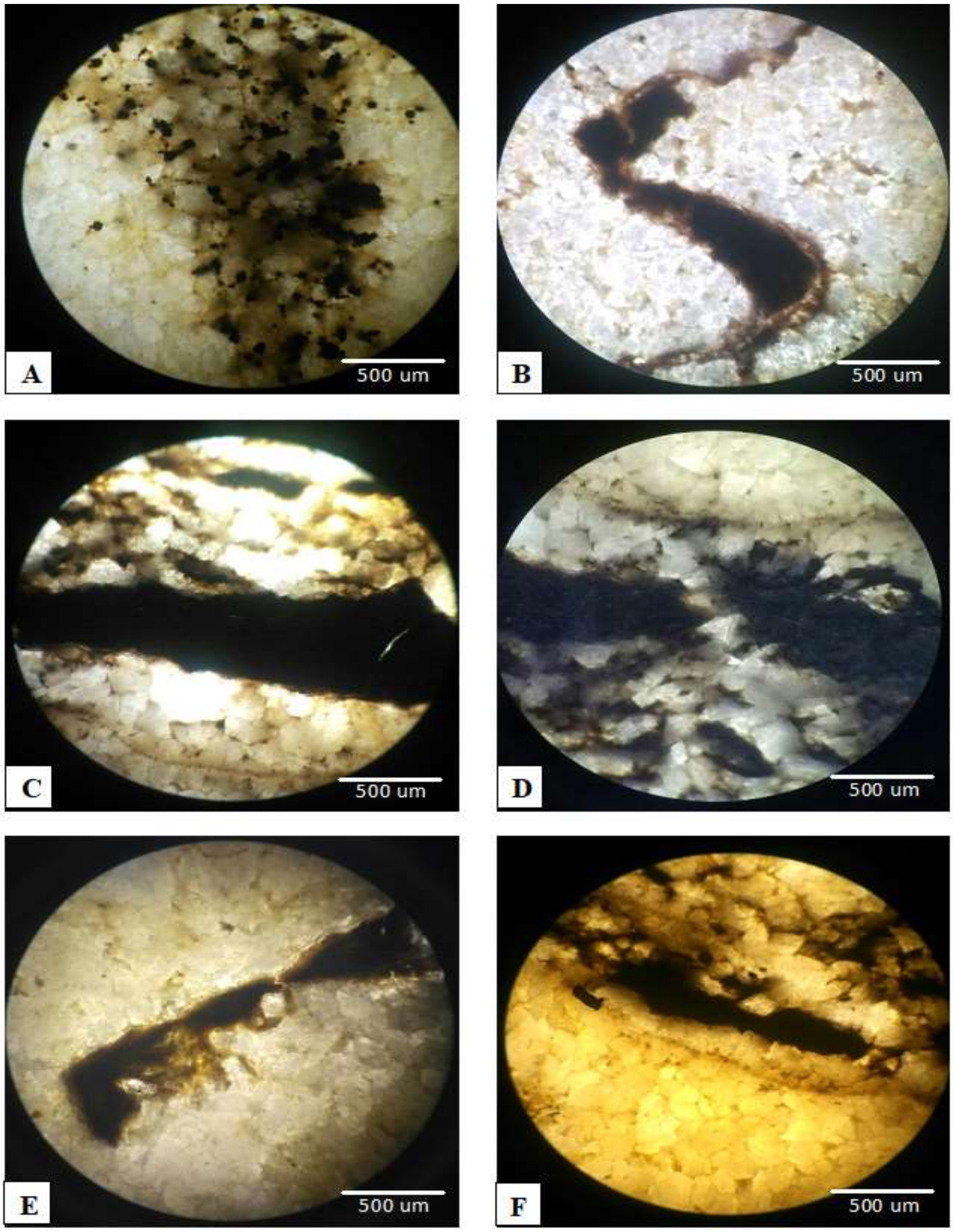

Plate 3: The second stage of distribution of microfractures in Qamchuqa Formation, which is represented by photos A, B, C, D, E, & F sequentially that accompanied by the flow of bitumen through Qamchuqa rocks. The residue of solid pyrobitumen leads us to guess the process of thermal degradation, occurred after the generation and migration process of oil.

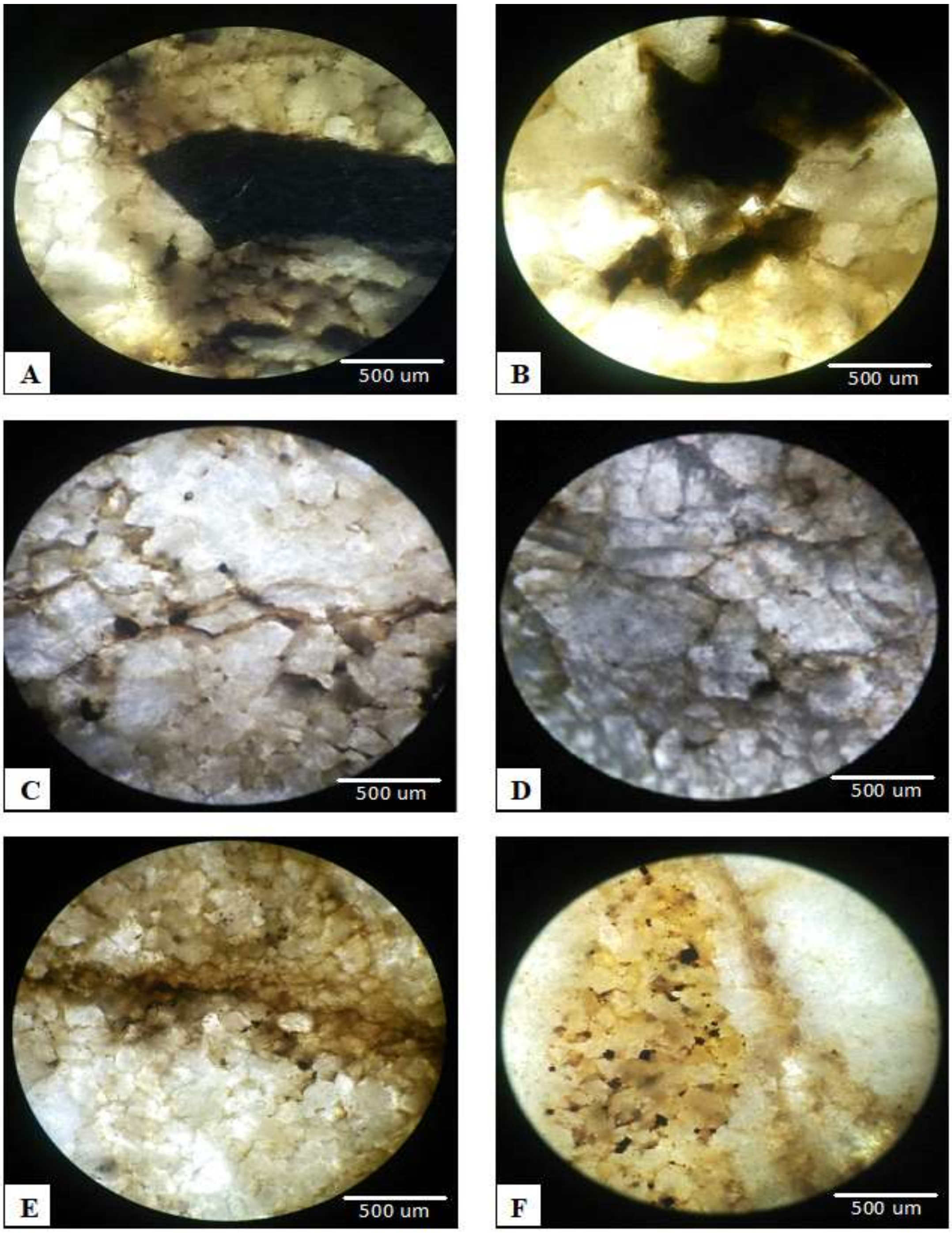

Plate 4: The first stage of distribution of microfractures in Qamchuqa Formation, which represented by photos C, D, E, & F sequentially. Photos A & B show the suddenly flow of bitumen through Qamchuqa rocks, which resulted to first stage of the petroleum migration process.

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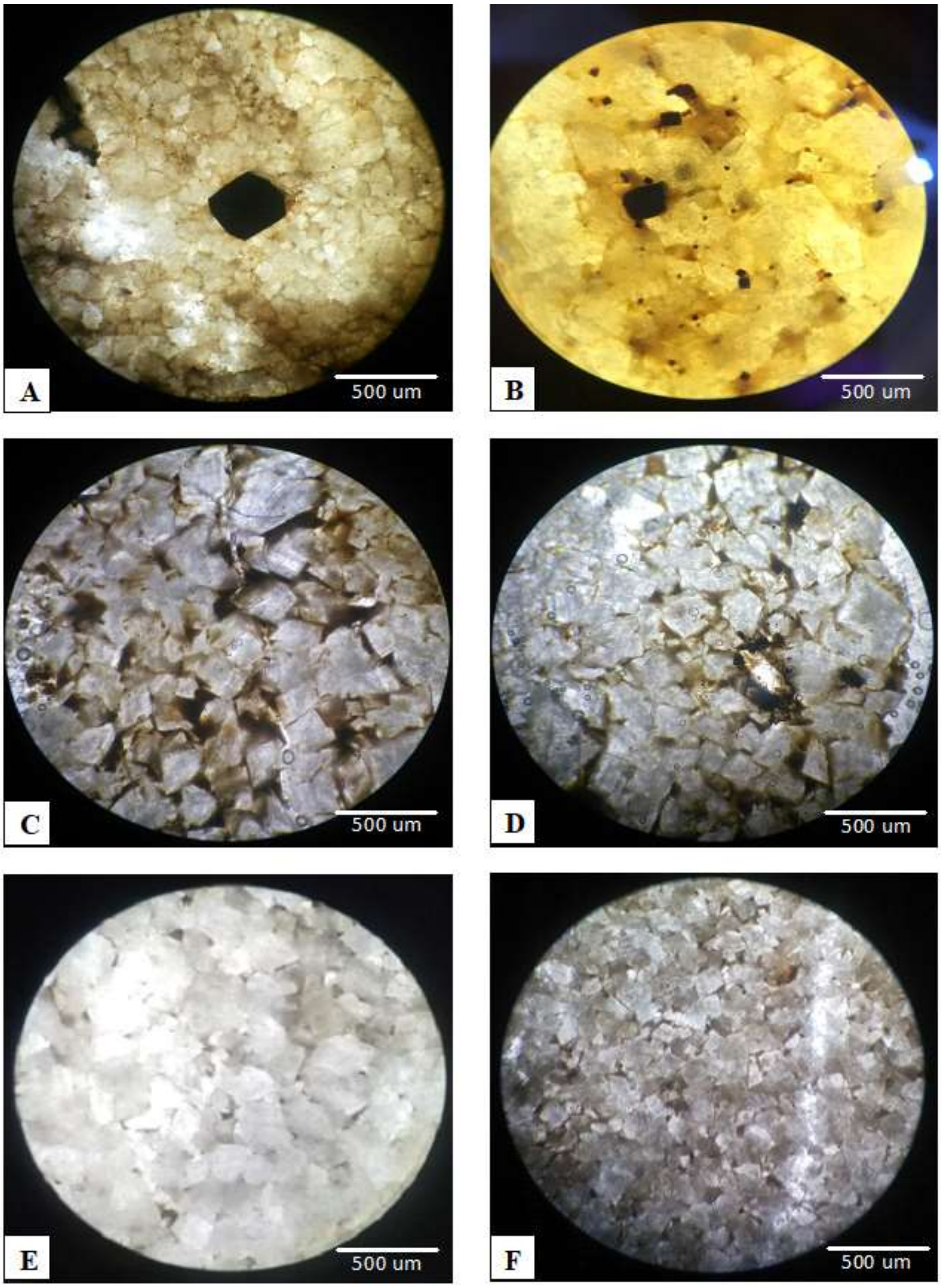

Plate 5: The size of dolomite grains shows the different cases of oil formation at Qamchuqa Formation.

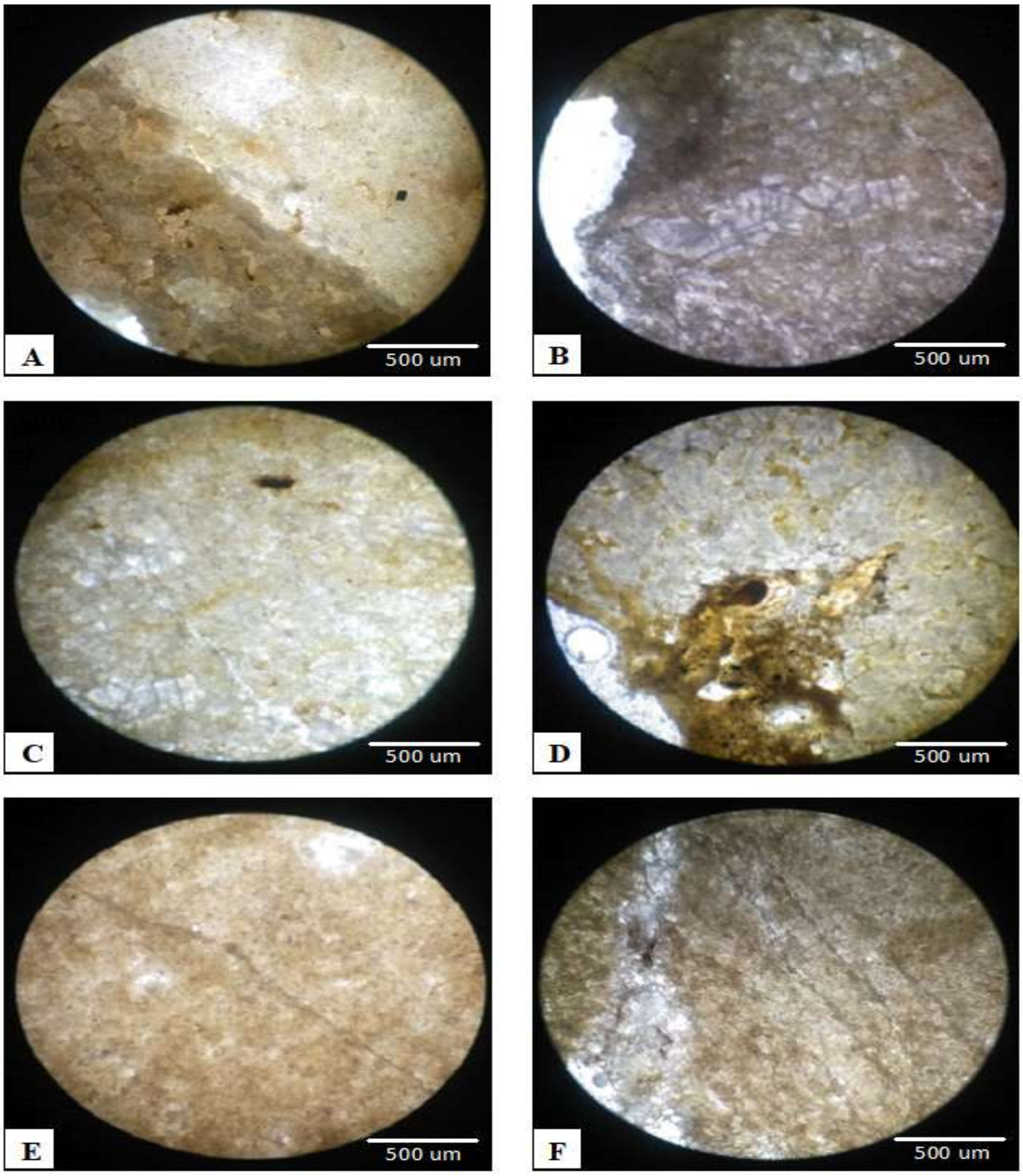

Plate 6: The size of dolomite grains shows the different cases without oil formation in Qamchuqa Formation at the fault zone.

Conclusions

1- Three types of pores have been identified in the Qamchuqa Formation: intercrystal dolomite pores, vuggy pores, and microfracture pores.
2- In the later stages of pore evolution, the presence of intercrystal porosity, vuggy porosity, and secondary fracture systems can account for the high values of porosity.

3- The present study conducted at the Kosrt anticline highlights the characteristic petroleum material leakage observed in the Qamchuqa Formation.

Recommendations

For future research, I recommend conducting a geochemical analysis for detection purposes:

1- To understand the various stages of diagenesis processes, it is recommended to study the major mineral components of the matrix and analyze the trace and heavy metals present.

2- It is better to use the isotope analysis for carbon element, O_2, and Sr to detect the depositional paleoenvironment of Qamchuqa Formation.

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