Chapter

Stylolite in Upper Cretaceous Carbonate Reservoirs from Northwestern Iraq

Ali Al-Juboury, Mohammed A. Al-Haj and Aboosh H. Al-Hadidy

Abstract

Stylolites are commonly observed in the carbonate reservoirs in various oilfield of Iraq including those of upper Cretaceous successions from northwestern Iraq, where they are characterized by stylolite-rich zones in the Cenomanian-early Turonian Gir Bir Formation and to a lesser extent in the Turonian-Santonian Wajna and early Campanian Mushorah formations respectively. The observed stylolites are either large to be identified in the core samples or smaller ones that are well observed in the thin sections and are characterized by variations in amplitude, morphology and accumulated insoluble residues. The recorded stylolites are classified as hummocky, irregular, low and high-amplitudes peaks, and irregular anastomosing stylolites. Stylolites affect the porosity permeability and thickness reduction compaction as the main chemical compaction (pressure solution) that reduce porosity. Whereas, in other places, the stylolites act as seals and stop the upward movement of hydrocarbons. This is also seen for mineralization processes such as silicification that ended near the stylolite surfaces.

Keywords: Stylolites, Solution seams, Hydrocarbon movement, Carbonate reservoir, Cretaceous, Iraq

1. Introduction

The largest hydrocarbon reserves in Iraq are hosted in the Cretaceous, particularly in the Mesopotamian Basin which are composed mainly of carbonate rocks [1]. The Cretaceous succession in Iraq reaches up to 3000 m thick and represents part of the megasequences AP8 and AP9 of the Arabian plate sequence stratigraphy which also forms one of richest hydrocarbon provinces of the world [2, 3]. These carbonate successions include various pressure solution features including stylolites and solution seams. Stylolite is a pressure solution feature commonly observed in carbonate reservoir rocks and usually results in reduction of unit thickness and porosity and permeability of the reservoirs [4–6]. Stylolites commonly form along lithologic transitions or partings as a result of stress due to either overburden pressure or tectonism [6]. In the present work, stylolites in the lower to upper Cretaceous carbonates in the reservoirs from northwestern Iraq have been studied in Gir Bir (Cenomanian-early Turonian), Wajna (Turonian-Santonian) and Mushorah (early Campanian) formations (**Figure 1**) in order to discuss the main types of stylolites and their effect on reservoir quality of the studied carbonates.

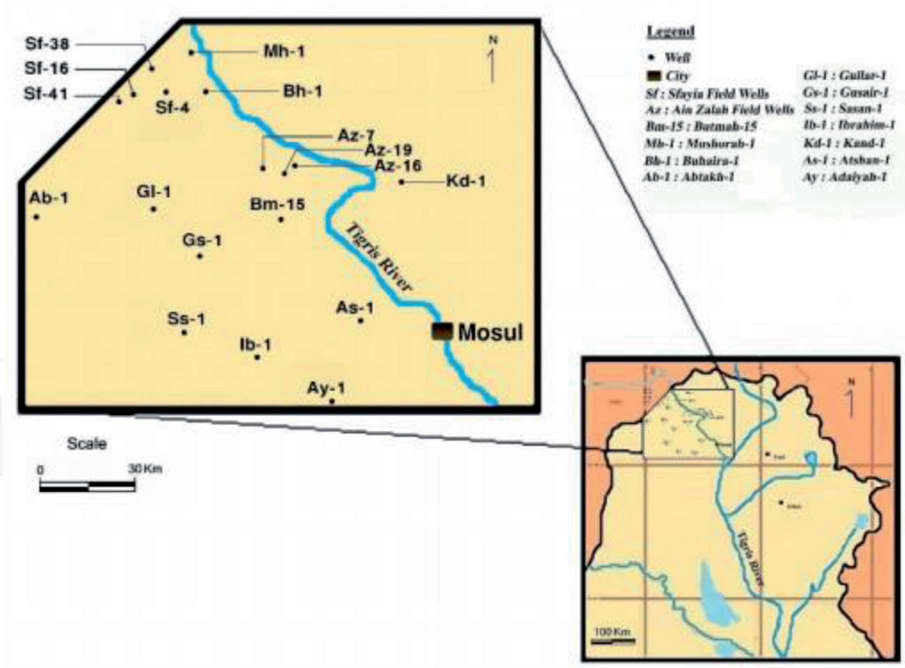

Figure 1.
Location of the studied wells, northwestern Iraq.

2. Geologic setting

Carbonates rocks that form the main lithology in the Cretaceous successions in Iraq and most of the Middle East region are formed mainly due to prevalence of warm equatorial climates [7] leading to deposition of reefal and lagoonal facies of the Gir Bir Formation, the outer lagoonal (shoal) facies of the Wajna Formation and the outer shelf to upper bathyal facies of the Mushorah Formation in the area of study of northwestern Iraq [8]. Tectonically the area of study lies in the Chamchamal-Butmah subzone of the Foot Hill zone of Iraq [9] which is a part of the Low Folded Zone of Iraq (see **Figure 2**) that have been eroded in the upper Cretaceous as a result of several phases of tectonic movements [11]. Therefore, the area was separated due to the effect of Mosul and Khleisia uplift from paleoneotethys main basin.

According to Sharland et al. (2001) [3], the studied formations lie in two of Arabian Plate Megasequences namely AP8 and AP9. The Gir Bir Formation represents the upper part of the late Tithonian-early Turonian megasequence AP8, whereas, the Wajna and Mushorah formations lie in the lower part of late Turonian-Danian megasequence AP9. Due to uplifting in the region, exposure of the shelf led to regional unconformity surface which represents a huge hiatus covering most part of northern Iraq [12] and extends to other parts of the Arabian Plate at the top of AP8 [3], (**Figure 3**). Two reasons were suggested to this unconformity surface; local uplifting of the region followed by obduction and emplacement of the ophiolite in northeastern parts of Iraq [2, 7] or global eustatic decline of sea level in the end of late Turonian [14, 15].

3. Materials and methods

Petrographic study on the carbonate succession from the three studied formations are conducted in order to determine their main petrographic constituents and the

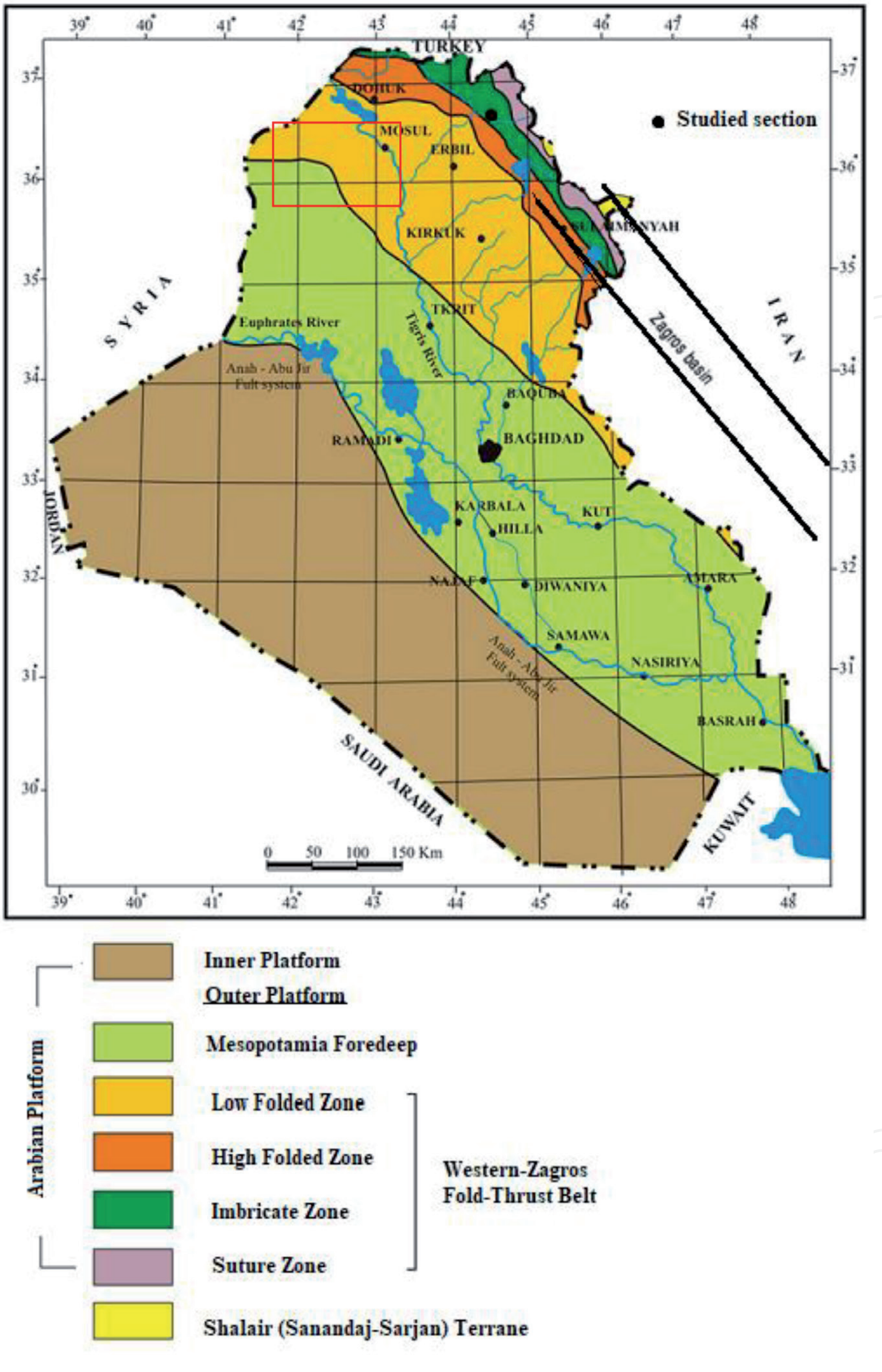

Figure 2.
Tectonic divisions of Iraq and the location of the study area which is marked with a dashed red rectangle [10].

diagenetic processes affecting on the studied carbonates including the fractures and stylolites. This study is performed at the Geology Department of Mosul University, Iraq. SEM analysis on selected samples was conducted at the Steinmann Institute of Bonn University, Germany using a Camscan MV 2300 SEM with a calibrated energy dispersive X-ray analysis system.

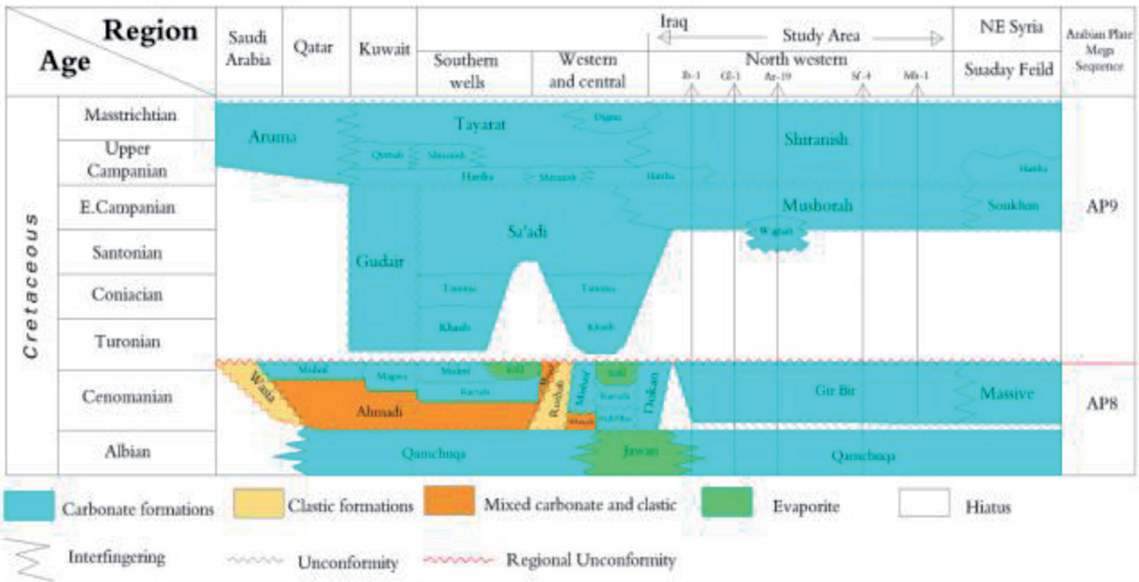

Figure 3.
Stratigraphic correlation of the cretaceous formations including the studied three formations in Iraq and neighboring countries [13].

4. Results

4.1 Lithologic and petrographic description

Lithologic characteristic of the carbonate succession from the three studied formations based on core samples including the commonly observed fractures and stylolites are conducted and representative samples are shown in **Figure 4**, whereas, representative microscopic images are presented in **Figure 5** to illustrate the main petrographic constituents.

4.1.1 Gir Bir formation

Lithologically, the formation dominantly is composed of carbonates in the form of recrystallized and dolomitized limestone with local silicification [16]. Petrographic investigation shows that the main skeletal components are benthonic foraminifera (Miliolids, Alveolina, and Orbitolina) and rudist while peloids and extraclasts are the main non-skeletal constituents (**Figure 5C** and **E**).

It is worth to mention that chemical compaction in the form of pressure solution or stylolitic textures is commonly observed in the studied carbonates of this formation. Carbonates of the Gir Bir Formation were suggested to be deposited in deep shelf margin with rudist buildups in a back reef/shoal environments [17].

4.1.2 Wajna formation

Carbonates of this formation are represented by dark gray limestones, locally silicified, alternated with thinly bedded dolomite including anhydrite nodules in the lower part of the formation and with white to gray limestone with common fractures and stylolites in the upper part of the formation [8, 16]. Petrographically, the carbonates of the formation is composed of benthonic foraminifera (Miliolids and Glomospira) ostracoda and peloids (**Figure 5A** and **B**) that were deposited in shallow marine environment that ranges from supratidal, protected lagoon to outer lagoonal (shoal) environments within two cycles in a regressive setting [8].

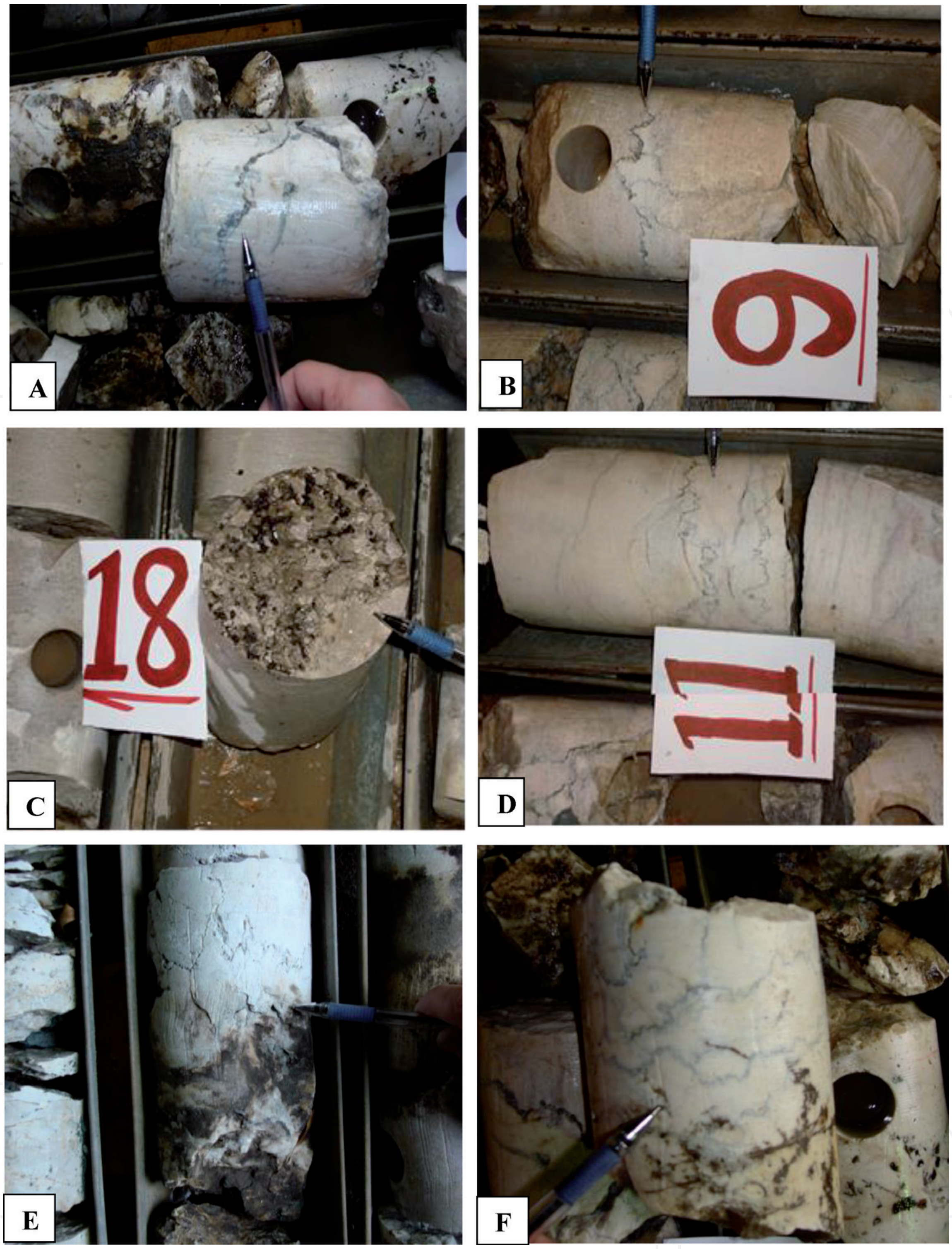

Figure 4.
Representative hand specimens of cores including commonly observed stylolites in the studied formations. A- Solution seams in the Gir Bir formation including organic matter and clayey materials. Well Bh-1, depth 1918 m. B- Stylolite from the Mushorah formation, well SF-16, depth 1844 m. C- Accumulation of organic matter at the lower surface of stylolite, Mushorah formation, well SF-16, depth 1816 m. D- Irregular anastomosing sets, in core from the Gir Bir formation. Well SF-16, depth 1850 m E- stop of hydrocarbon upward movement near the stylolite surfaces, Gir Bir formation well Bh-1, depth 1821 m F- Same as in E, Gir Bir formation well SF-16, depth 1848 m. See ***Figure 1*** *for well locations.*

4.1.3 Mushorah formation

The formation is composed of greenish-gray recrystallized, silicified and marly limestone (Bellen et al., 1959). Hard gray limestone with marl and shale units with common joints and stylolite dominate the lower part of the formation [8].

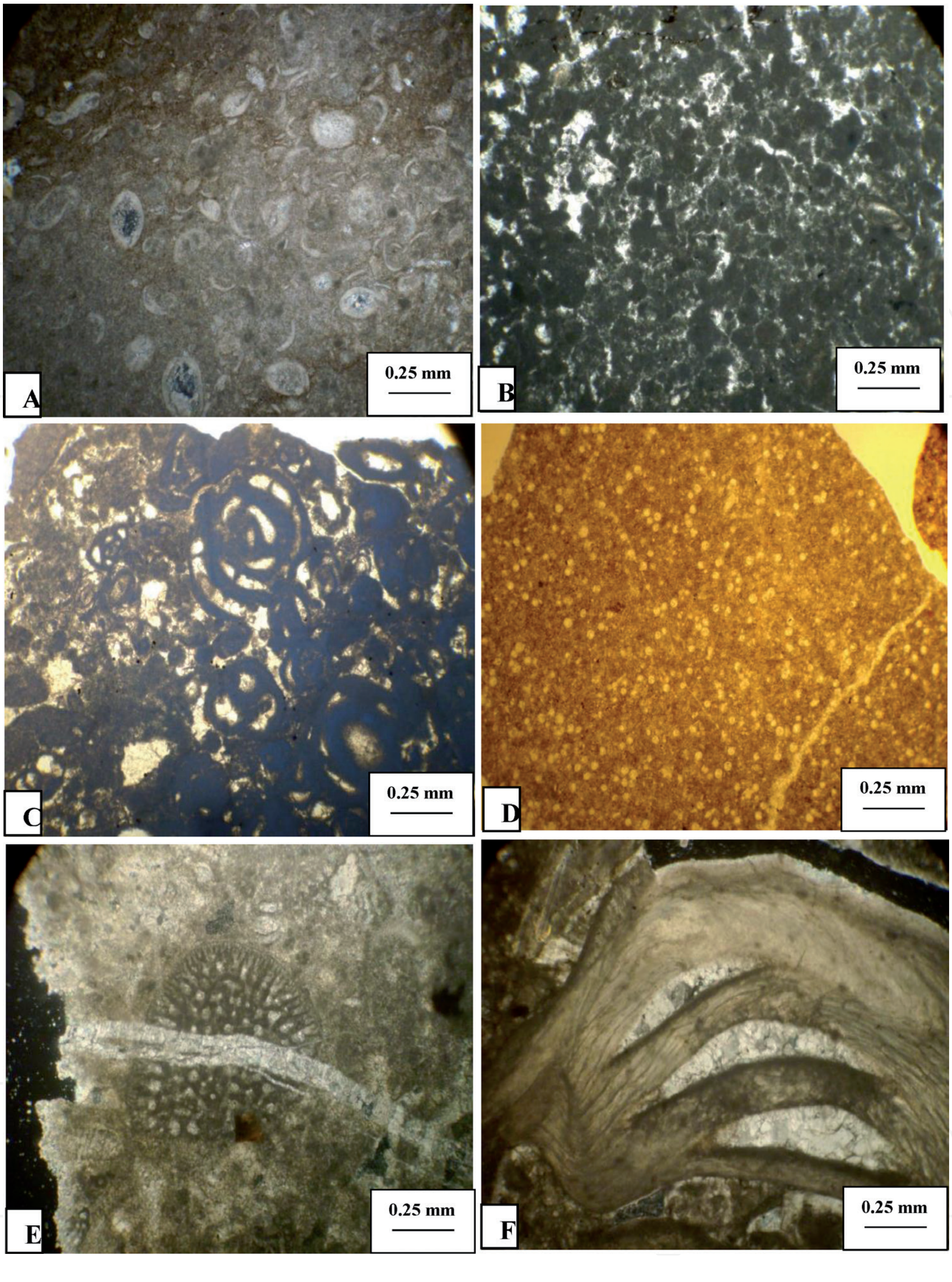

Figure 5.
Common petrographic constitutes in the studied formations. A- Ostracods from Wajna formation. B- Fecal pellets from Wajna formation. C- Milliolids from the Gir Bir formation. D- Calcispheres from Mushorah formation. E- Orbitolina foraminifera from Gir Bir formation, note microsparite filling veins crossing the foraminifera shell. F- Inoceramus from Mushorah formation.

Petrographic study shows that calcispheres, planktonic and benthonic foraminifera and Inoceramus form the main constituents of the formation (**Figure 5D** and **F**) that were deposited in a relatively deep marine environments ranging from outer shelf to upper bathyal.

The carbonates of the studied formation have been affected by several diagenetic processes such as; cementation, compaction, dolomitization, recrystallization, micritization, dissolution and silicification.

4.2 Pressure solution features

Two types of pressure solution features have been recognized in the current study; stylolites and solution seams based on variation in size and amplitude of the pressure solution surfaces in addition to thickness of the insoluble residues commonly exist in between these surfaces as a result of compaction on the carbonate rocks.

4.2.1 Stylolites

Stylolites are the main compaction features that have been recognized in the studied carbonates. They are defined as irregular surfaces formed due to different vertical movements under deep burial conditions [18]. They have various shapes such as columnar, pits, tooth-like etc., and can be commonly identified or differentiated by the concentration of insoluble residues that composed mainly of organic matter or clay minerals in between or near the stylolite surfaces.

In the present study, stylolites are identified either of large, macroscopic stylolites that easily recognized in the cores or finely-sized (microscopic) that are investigated using petrographic or scanning electron microscopes (**Figures 4, 6** and 7).

Macroscopic stylolites in the core samples commonly are characterized by their lateral continuity and their varied thickness of their insoluble residues content. Most of these stylolites are horizontal or semi-horizontal and are parallel to bedding planes which may reflect their formation due to vertical movements [6].

According to classification of [19], several types of stylolites have been identified, these include;

1. Hummocky stylolite (**Figure 6A**), some of them are accompanied by dolomite rhombs (**Figure 6C**).

2. Irregular Anastomosing sets (**Figure 6B**)

3. Low-Amplitude peaks stylolites (**Figure 6F**)

4. High-Amplitude peaks stylolites (**Figure 6D**)

5. Irregular stylolites (**Figure 7A**)

Irregular stylolite is common in the Wajna and Mushorah formations while all types of stylolites are recorded in the Gir Bir Formation.

It is worth to mention that silicification is inhibited near the stylolite surfaces (**Figure 6E**).

High resolution imaging using scanning electron microscopy (**Figure 7B–F**) shows different forms of stylolites with concentration of authigenic minerals such as quartz and calcite near the stylolite surfaces.

4.2.2 Solution seams

They are low amplitude undulose surfaces with insoluble residues that may reach 1 centimeter thick. In the present work, low amplitude, laterally continuous solution seams with clay minerals as the main insoluble residues in between their surfaces are commonly seen (**Figure 4A**). Sometimes, a small-scale micro-stylolites accompanied these seams.

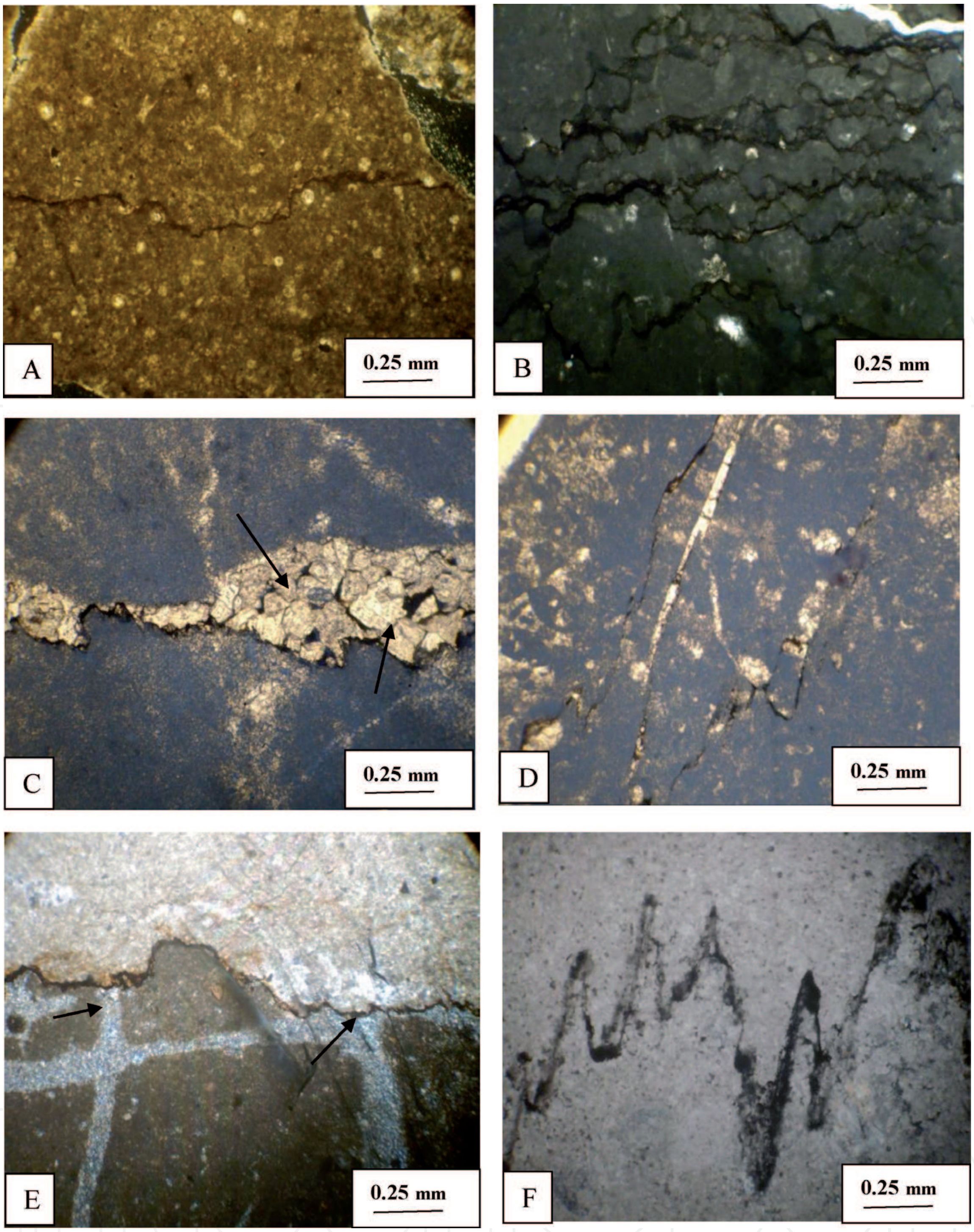

Figure 6.
A- Hummocky stylolite, Mushorah formation. B- Irregular anastomosing sets, Gir Bir formation. C- Dolomite rhombs (arrows) accompanied stylolite surfaces, Gir Bir formation. D- High-amplitude, Gir Bir formation. E- Stylolite inhibiting silicification (arrows), Mushorah formation. F- Low amplitude stylolites, Gir Bir formation.

5. Discussion

Pressure solution features in carbonate rocks are formed as a result of compaction. Stress increase pressure to critical level depending on rock composition then the rocks start to dissolve in order to relieve the stress [6]. This lead to decrease in the unit thickness which in turn affect the petrophysical characteristics (porosity and permeability) and thickness reduction compaction. Pores are commonly filled by cementing materials due to late diagenetic processes affecting on carbonate rocks [4, 20, 21]. Cementation is one of the common diagenetic processes affecting the

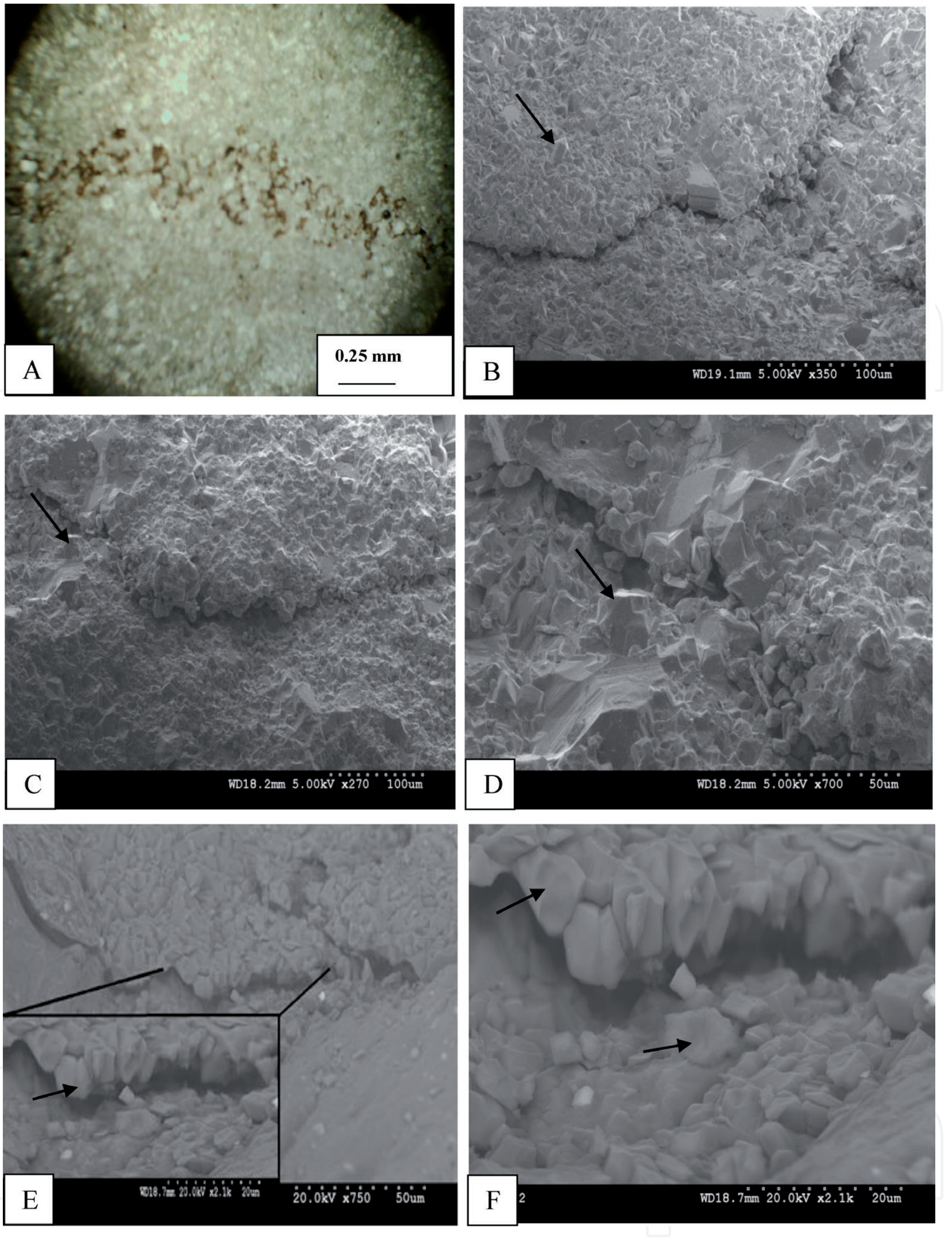

Figure 7.
A-Irregular stylolite, Gir Bir formation B-F, scanning electron micro images showing stylolites and authigenic mineral formation. B, C and D, stylolite with bypyramidal quartz (arrows), Mushorah formation. E, stylolite with calcite formation (arrow), F, enlarged view of E showing calcite grains (arrows).

studied carbonate succession. Various types of cements were recognized such as; blocky, fibrous, drusy mosaic and bladed [8]. Cementing materials inhibit vertical fluid movement which in turns prevent stylolite formation when they filled pores and increase the rock resistance to compaction.

Common occurrence of stylolites and solution seams in the upper part of the Gir Bir Formation (the main recorded reservoir in the present study) may be regarded as the main cause of hydrocarbon isolation and preventing them from upward migration as shown in core samples of the present study (**Figure 4E** and **F**). The main

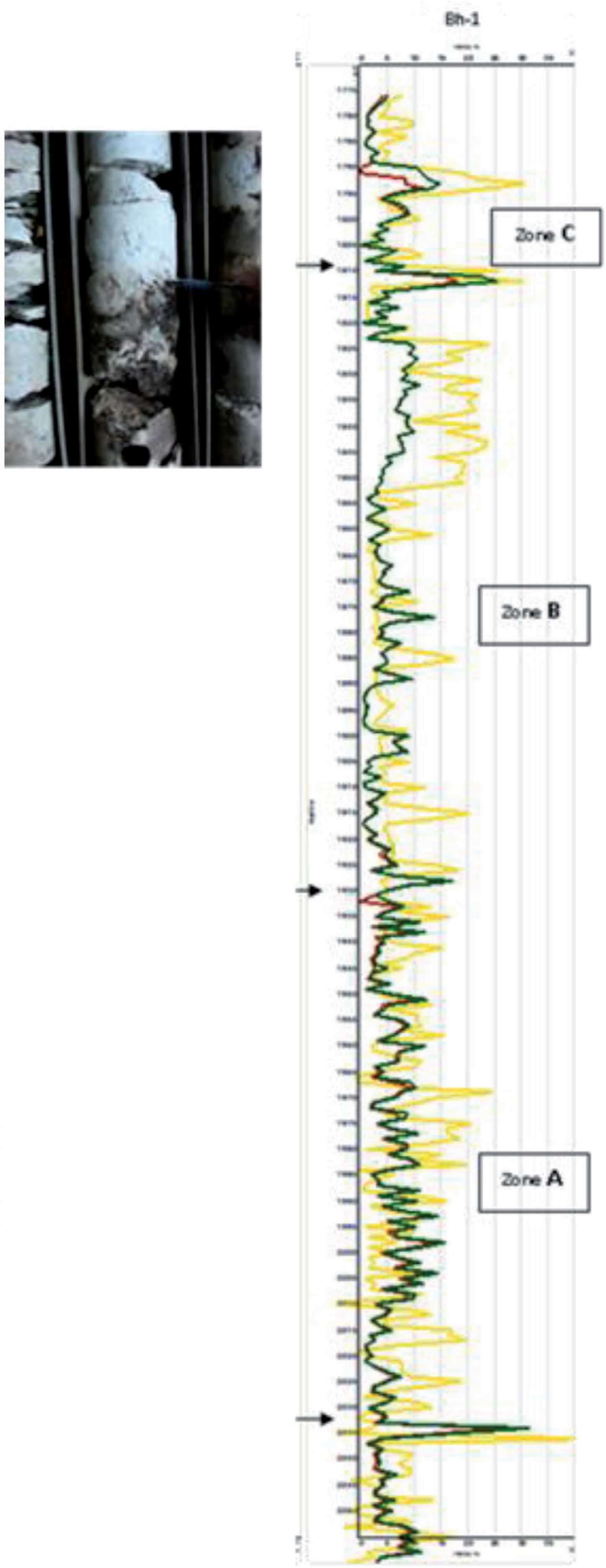

Figure 8.
Representative log showing the total porosity (green), effective porosity (red) and primary or original porosity (yellow) in Bh-1 well, note the higher porosity values in the upper part of zone B (Gir Bir formation) which declined abruptly in the area of rich stylolite occurrence and stop of upward hydrocarbon migration due to compaction and stylolite formation (core samples representing this location, depth 1821 m).

reason for that is the impermeable insoluble residues (organic matter and clay minerals) in between the stylolite surfaces that act as seals and stop the upward movement of hydrocarbons. Thickness of impermeable insoluble residues and lateral continuity of stylolite play a role in fluid movement [5].

Presence of hydrocarbons inhibit further formation of stylolite where the pores are filled with hydrocarbons that resist compaction and fluid movement and precipitation in the pores as a result of compaction [6].

There is also a close relationship between stylolites and minerals deposited by a percolating fluid. Scanning electron microscopic study revealed quartz deposited near the stylolite (**Figure 7B–D**) and calcite (**Figure 7E–F**) which may relate to presence of fluids saturated in Si or Ca that result in such mineralization [22]. Such processes also ended near the stylolite surfaces as seen in petrographic investigation (**Figure 6E**).

It is worth to mention that the Gir Bir Formation includes the studied successions were divided into three porosity zone (A, B and C) based on the values of porosity (primary, effective and total porosity) [8]. It is revealed that the Upper part of zone (B) which represent most of the upper part of the Gir Bir Formation is highly porous and regarded as the main reservoir in the studied succession.

After this high porosity values, the values declined directly in the area of high existence of stylolite in the Gir Bir Formation accompanied with end of hydrocarbon movement near the stylolite due to presence of impermeable materials in between stylolite surfaces (**Figure 8**).

6. Conclusions

Pressure solution features dominates in carbonate reservoir rocks of the Cenomanian-early Turonian Gir Bir Formation from northwestern Iraq which is regarded as the main reservoir in the upper Cretaceous succession of the area of study. Stylolites as common pressure solution results in reduction of unit thickness and porosity and permeability of the reservoirs. Pressure solution features act as a barrier for vertical movement of hydrocarbons in the studied successions especially in the upper part of the Gir Bir carbonate reservoir where the impermeable insoluble residues formed near the stylolite surfaces. These impermeable materials act as seals and stop the upward movement of hydrocarbons. Stylolites also act as a barrier and prevent further movement of mineralization processes such as silicification of carbonate (calcite or dolomite).

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Conflict of interest

All authors have participated in (1) conception and design, or analysis and interpretation of the data; (2) drafting the article or revising it critically for important intellectual content; and (3) approval of the final version.

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