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The Role of Stylolites and its Pattern Attribute on Porosity and Permeability: Evidence from a Lower Cretaceous Carbonate Oil Reservoir, Abadan Plain, SW Iran

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Abstract

Stylolites are localized dissolution surfaces commonly found in sedimentary rocks. Stylolites have been extensively studied for their important role in controlling porosity and permeability through dissolution, precipitation, deformation, and fluid transport in rocks. Prevalent views are that they act as permeability barriers, although laboratory studies are scarce. Here, we report on a systematic laboratory study of the influence of stylolites on permeability in carbonates. Our data demonstrate that the studied stylolites do not act as barriers to fluid flow. When a stylolite occurs perpendicular to the flow direction, the permeability follows the same power law porosity-permeability trend as the stylolite-free material. Stylolite surfaces can play an effective role as open pathways in increasing the effective porosity of reservoir rock, and due to the wide amplitude range of stylolites, it is necessary to ensure that the permeability of facies increases. The stylolites have been classified into three main types based on their properties such as genesis, general shape, size, the difference in amplitude, amount of accumulated insoluble material in their seams, discontinuity of their seam material, and, most importantly, to predict their role in conducting fluid flow has been explained. However, the direction of dominant stress that determines the genetic type of stylolites and all the effective parameters in the burial diagenetic stage, including the pressure, temperature, and soluble ion-rich fluids, can increase or decrease the porosity and permeability values by draining or blocking the pathway produced by this process through quality assessment of carbonate host rock reservoir. Ultimately, based on this, stylolites in some facies of the Fahliyan Formation in the Abadan Plain Zone act as a continuous and connected porosity for fluid flow and, according to their amplitude and morphology, stylolites increased the effective permeability and reservoir quality, especially in the mud-supported facies in this formation. However, our data affirm that all conditions, especially the nature of morphology, are the most influential parameters determining the porosity and permeability of the Fahliyan Formation facies.

Keywords: Stylolite, Morphology, Porosity, Permeability, Fluid Flow, Fahliyan Reservoir.

Introduction

Stylolites are planar structures that accommodate localized contractional strains that form as a result of physicochemical processes that are caused by burial or tectonic compaction [1, 2].

Among sedimentary rocks, carbonate rocks are subject to many post-deposition changes, such as thickness reduction during burial; in other words, they are highly heterogeneous due to their properties. This issue is more affected by various diagenetic processes than any other factor. Therefore, in addition to the inherent nature and particle sizes that formed the rock, various factors, such as diagenesis, affect the limestone's mechanical behavior. Furthermore, a decrease in the porosity and permeability in these rocks can be seen due to diagenetic processes such as compaction, particularly chemical compaction as compression solution [3, 4].

Stylolites are the product of compressive dissolution at the point of grain contact, which is considered lateral expansion and represents local stress in carbonate rocks. Because stylolites affect fluid flow, they have always been taken into consideration. Concerning the magnitude of the impact of this process, it can be said that the stylolites, in some cases, can even reach 1 km long. In the past, their effect on fluid flow was challenging in sedimentary geology, petroleum geosciences, and

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structural and engineering geology. Stylolites are created by connecting multiple horizontal and vertical solution seams [5]. Stylolites, which have a large quantity of insoluble mineral residues, also have more potential and power to create a barrier against the passage of fluid flow. These insoluble minerals are linked to the host rock: clay minerals, organic materials, or iron compounds. Examining the heterogeneous carbonate reservoir quality requires a comprehensive analysis of the porosity-permeability relationships. For a century, petroleum geologists have debated the relationship between stylolite behavior and reservoir porosity and permeability changes. Therefore, many carbonate petrologists have suggested stylolite ducts as the sixteenth type of porosities of the classification of Choquette and Pray [6].

In the course of the sparse studies that have been done in this area, it has been suggested that the stylolitization process not only has a negative effect on the reservoir quality but can be a path for the flow of organic and inorganic fluids [7]. Nevertheless, what explains the nature of the effect of stylolites on the porosity and permeability of reservoirs is their morphology and the features of their distribution pattern. Therefore, this study clarifies the effect of the morphology of the stylolitization process on the quality of the Fahliyan Reservoir.

Geological Setting

The Abadan Plain is the western portion of the Iranian Zagros area between the Arabian Shield to the southwest and the Zagros folded and thrust belt (ZFTB) to the northeast (Figure 1A). Beyond the Zagros frontal fault, the sedimentary cover is observed to be barely affected by the Zagros folding. The Abadan Plain Basin is part of the Mesopotamian foredeep basin, which is a narrow belt that extends from northern Iraq country to the Persian Gulf of Iran [8, 9], (Figure 1B). A part of the Abadan Plain Basin is located on a paleohigh known as the Burgan-Azadegan paleohigh. Structural surveys in the Burgan-Azadegan highlands show the continuation of uplift during the Jurassic to the Upper Cretaceous period, with the highest uplift occurring during the Late Cretaceous period. Abdollahie-Fard et al. [10] believe that the formations of the Bangestan group, which are located at the top of the Burgan-Azadegan paleohigh, under the influence of tectonic movements, have the lowest thickness [11].

The thickness of the Fahliyan Formation at the type locality, on the Kuh-e-Dal near the Fahliyan Village on the south flank of the Fahliyan Anticline, is about 283 m [12]. The lower boundary, with sedimentological evidence of subaerial exposure (sucrosic and dark brown dolomites of the Surmeh Formation), is unconformable, and the upper boundary, with marls and thin limestones of the Gadvan Formation, is conformable (Figure 1C). This formation at the subsurface section (Gachsaran Oil Field, well #55) consists of 582 m of limestone, which unconformably overlies the evaporate of the Hith Formation (Late Jurassic) and conformably underlies the Gadvan Formation [13].

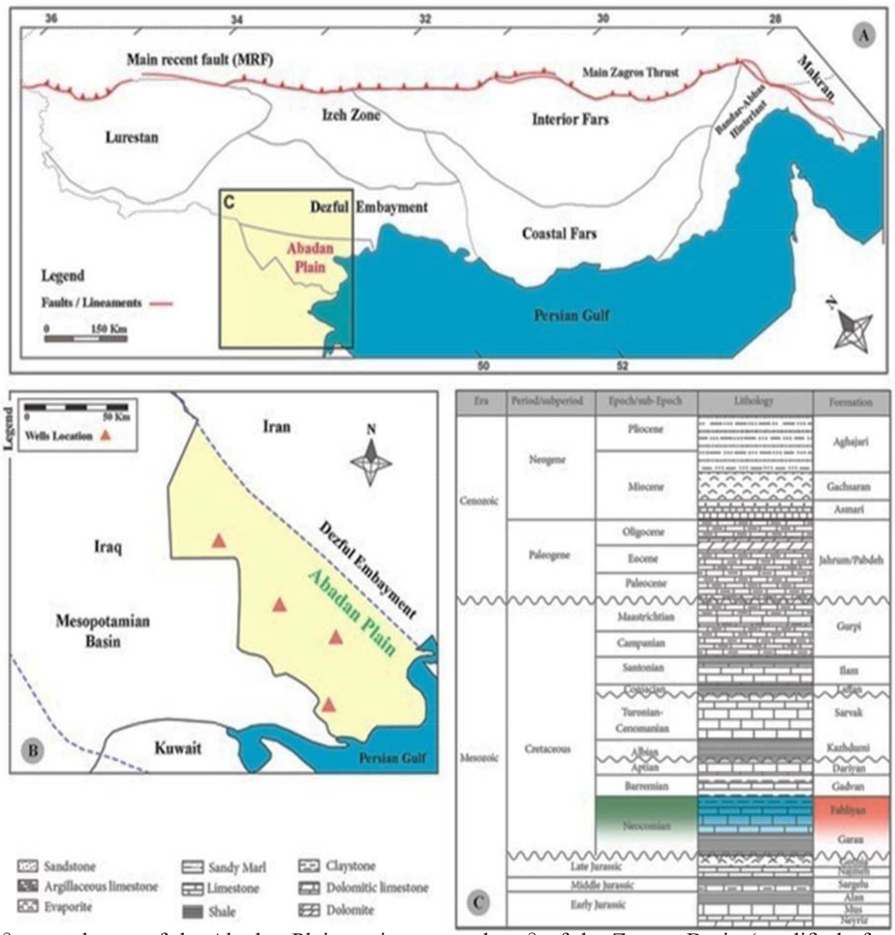


Fig. 1 A) Geological–structural map of the Abadan Plain region at southwest of the Zagros Basin (modified after [14]). B) The general lithostratigraphy column of the Abadan Plain (modified from [15]). C) The location of studied wells on the map of the Abadan Plain Basin and contiguous area.

Materials and Methods

This study aims to investigate the effects of stylolite morphology on porosity and permeability based on laboratory measurements using some of the carbonate core-plugs. Our dataset comes from the Fahliyan carbonate reservoir with >300 meters of available cores and a 90% recovery factor. The first step for sample selection was macroscopic studies of the drilled cores, and they have been classified based on their geological features, appearance, and lithology. Then, a combination of macroscopic evaluations and some petrophysical logs such as total porosity (PHIT), effective porosity (PHIE), formation micro imager (FMI), and gamma-ray (GR) were used to select the best zones for core-plugging (Figure 2). Afterward, these core-plug samples were cleaned with common solvents (Toluene and Methanol) to remove contamination such as hydrocarbons, salts, or other impurities. For routine core tests (Rcal), these plugs were dried in the conventional oven for 24 hours. Then, their porosity, permeability, and grain density were measured by helium porosimeter, gas permeability, and Pycnometer tool, respectively.

To evaluate the internal structure structures (such as vugs, high- and low-density patches, stylolites, and fractures) of the selected plugs, three/two-dimensional imaging of computed tomography (CT-scan) is one of the applicable methods for better understanding the stylolitic networks (Figure 3A), which can be examined by three-dimensional imaging of the internal structure of the core-plug samples to investigate the relationship between porosity and permeability with various changes in the stylolite seams and fracture (Figure 3B). In addition to these tests, thin section, X-ray diffraction (XRD), and scanning electron microscope (SEM) data were used for sample selection and better interpretation (Figure 4A). The geochemical analysis is used to determine the mineral types in the stylolite seams by XRD and SEM, particularly for three-dimensional imaging of solution seams and stylolites, and pore spaces geometry and mineralization of their surfaces and detection of secondary-mineral morphology associated with diagenetic processes used (Figure 4B).

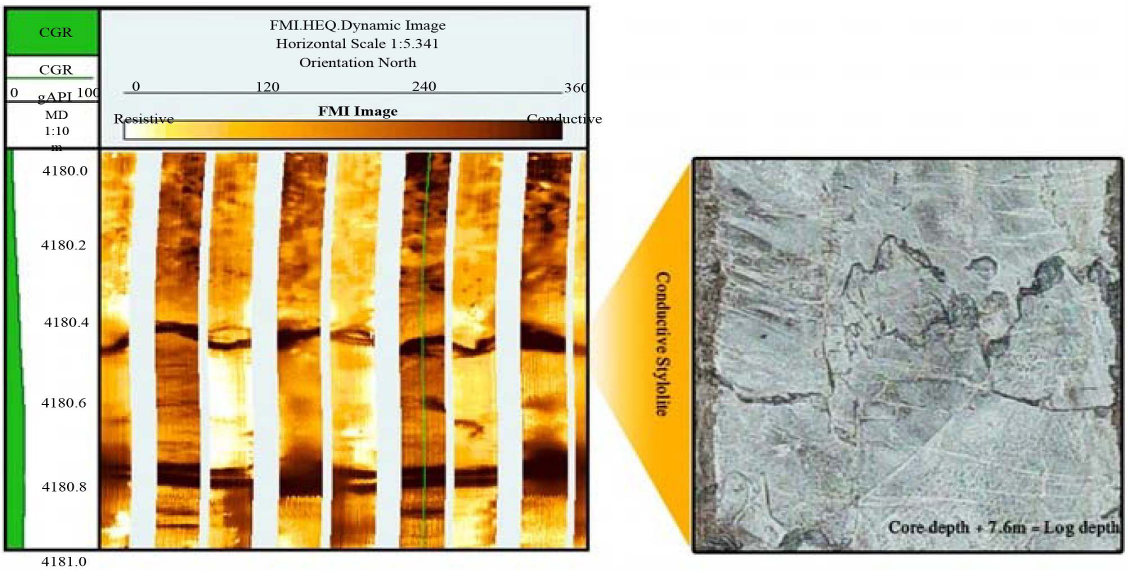


Fig. 2 A conductive (clay filled) stylolite in the Lower Cretaceous limestone from the Zagros Basin, SW Iran (*x#oil-well*) detected by formation micro imager (the FMI log clearly shows stylolites separated) around *4180.6 m* is seen on core around *4173 m*.

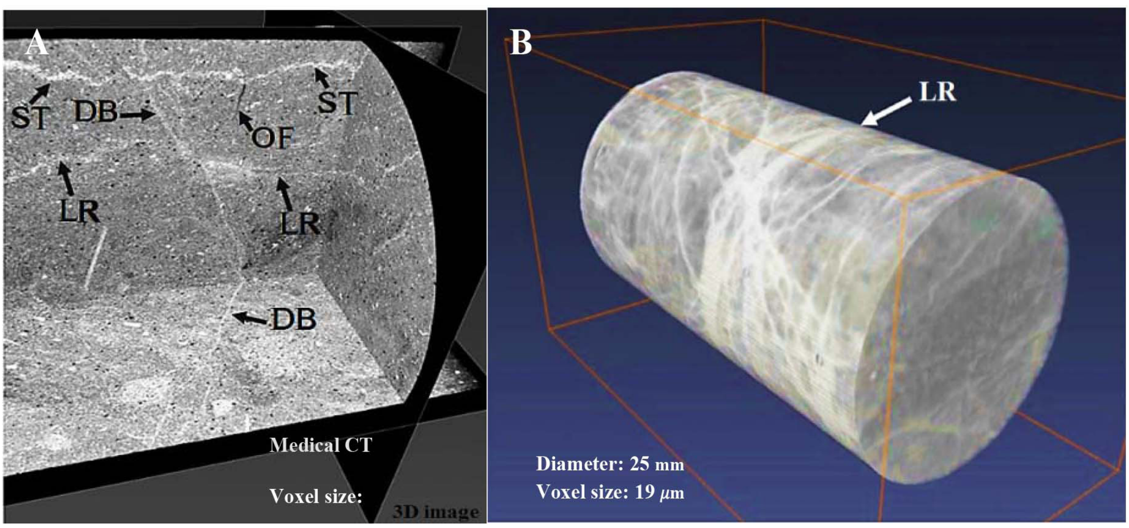


Fig. 3 A) Three-dimensional imaging from outside of core plug sample. B) CT-scan images of a core plug sample, three-dimensional view of x, y, and z sections through the sample. Abbreviations) DB: deformation band; LR: sedimentological layering; ST: stylolite; OF, open fracture (adapted from [16]).

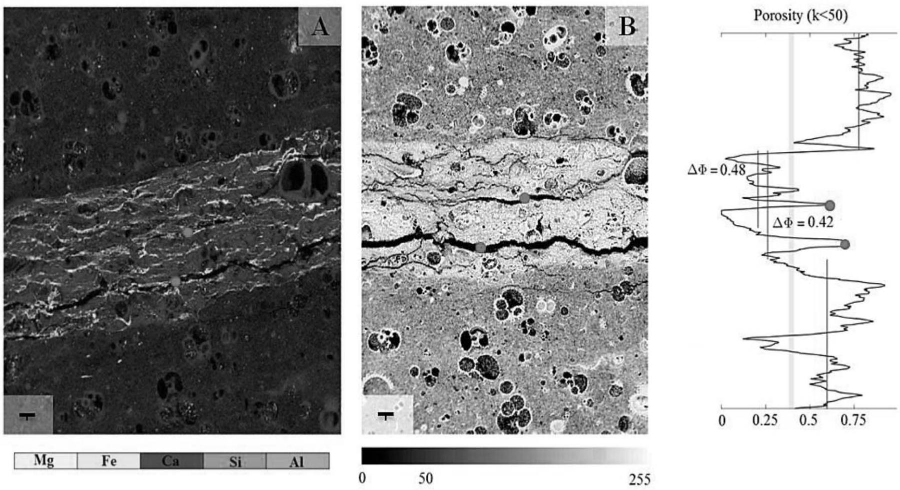


Fig. 4 Stylolite display by scanning electron microscope, *Scale bars*: *100 µm*. A) Based on SEM-EDS analysis, the main components of facies are stained. In this image, mineralization on stylolite seams is marked green, explaining its morphology. The EDS map shows Ca depletion and Si, Mg, Al, and Fe enrichment within stylolite seams; this means that after stylolite formation, mineralization of non-calcite compounds occurred along the stylolite seams. Therefore, according to Fig. B, the porosity in the stylolitic surfaces has increased. B) SEM-BSE images of porosity in variably developed stylolites. BSE images are rotated so the stylolite is parallel. Bar-graph normalized to distribute the image across the entire range of gray color (0 is black or low density, 255 is white or high density). The fraction of dark pixels (<52) per row is used as a measurement of porosity changes (Δϕ). According to this image, the porosity in the stylolite development zone has increased; based on Figure A, the opening along the stylolite and the surrounding mineralization, as well as the reduction of mineralization porosity along some of the seam is evident, the red points indicate well development of stylolites and consequently the increase in porosity (modified after [17]).

Results and Discussion

Stylolite Formation

Stylolites form as compressive features during pressure dissolution, where ions are dissolved and deposited in another location; this process is accelerated by high stresses (Figure 5). Stylolites begin forming in areas of high porosity and stress and then finish forming in areas of low stress and porosity. Dissolution occurs in these high porosity areas and thus results in a high concentration of solutes. Low porosity areas have a lower solute concentration, so the dissolved ions naturally move towards these areas. Here, in these areas of low porosity, the dissolved minerals are deposited, and the stylolite is formed [18]. When pressures are high, porosity is lowered, and the dissolution process is accelerated, thus increasing the likelihood of stylolite formation [19].

Types of Stylolites

The classification of stylolites should be explained in terms of their genesis. Stylolites usually form parallel to bedding because of overburden pressure, but they can be oblique or even perpendicular to bedding due to tectonic activity. Therefore, two main sedimentary and tectonic stylolites in carbonate rocks are investigated. According to the mechanism of stress regimes in the Abadan Plain area, which is explained based on the vertical stress caused by overburden pressure, the majority of stylolites in the studied samples were sedimentary, and all the studies conducted in this research are based on identified sedimentary stylolites.

Morphology of Stylolites

The origin of stylolites is most commonly referred to as pressure-dissolution contacts. The serrated pattern depends on the heterogeneity in solubility between the two contact layers within which the stylolite is formed. A planer seam will take shape if one layer has more or less the same solubility as the other layer. The initial setup of an interface that has not yet been affected by pinning is presented in Figure 6A..

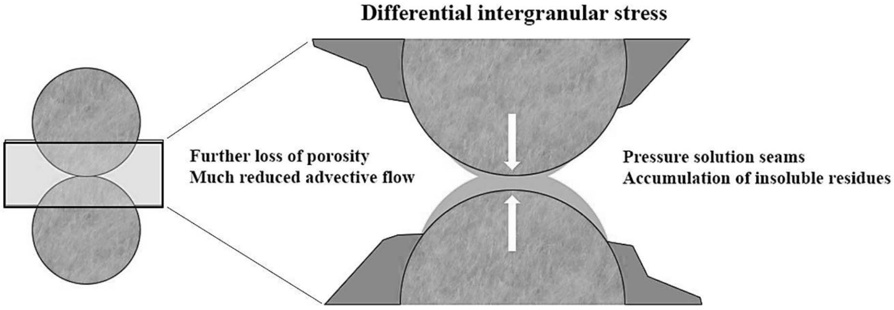


Fig. 5 Schematic of pressure solution to stylolite developing; *i*) High-stress concentration at grain contacts makes the material more soluble. *ii*) Material there migrates along grain boundary to places on sides of grains where stress is lower and deposits.

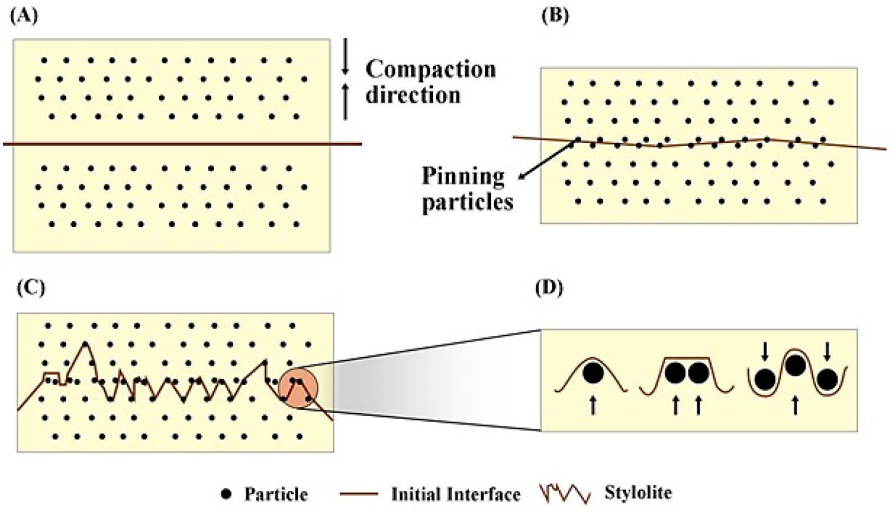
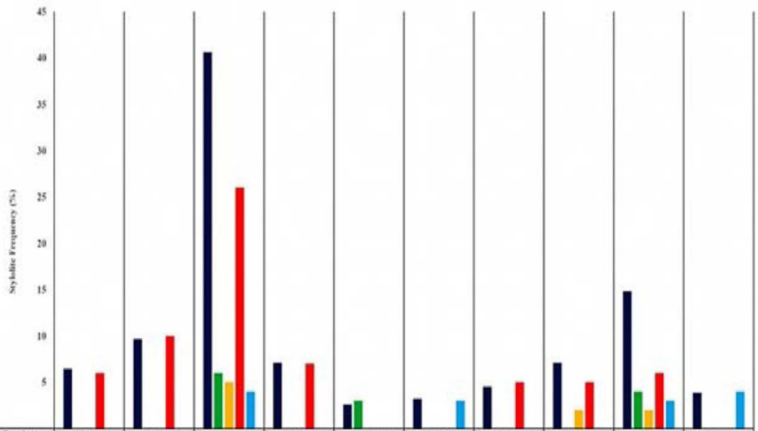


Fig. 6 Schematic illustration of stylolite evolution. *A*) Initial setup with an initial interface that has not yet been affected by pinning particles. *B-C*) Progressive growths of stylolite, the particles are pinned in different directions, creating a rough interface. *D*) Structures that are created of different pinning particles, a spike structure which is created by a particle pinning in one direction, teeth by two particles pinning in one direction, and teeth by particles pinning in two directions.

The irregularity of the dissolution of particles in carbonates depends on the content ratio of each element, implying that a greater difference in dissolution rate between each element will initiate the stylolite formation. When stylolites are created in a homogenous rock, a lesser form of roughness procreates and so only from one direction [20]. The irregularity of the dissolved surface is because the sucrosic particles tend to dissolve at the same rate, affecting the stylolite structure with the same speed and disconformity. As demonstrated in Figure 6B, the pinning of particles in a homogenous environment creates a less serrated morphology compared to Figure 6C, where the morphology is more serrated and profound. The pinning of particles behaves differently if the stylolite propagates in a homogenous environment compared to a heterogeneous environment. In a heterogeneous environment, the particles tend to pin with two larger particles from the same side of the stylolite, and teeth formation starts forming. The rate of formation of teeth can also show how the direction of pinning occurred. If the formation of teeth is also pinning from the opposite direction, the stylolite formation will evolve faster. This phenomenon is presented in Figure 6D, and examples are demonstrated regarding pinning one or several particles from one or multiple directions. The properties of the pinning will affect the amplitude and wavelength when it intersects with the profile of the stylolite. It will then indicate which lithological environment was present during the stylization. In a homogenous environment, there are only particles pinning in one direction, and therefore a more of a "pen" shape peak will form due to the one-way direction of the pinning particle [21]. Stylolites in the Fahliyan Formation are rectangular/ seismogram-pinning (high amplitude), suture/sharp peak, and simple wave (low amplitude) types (Figure 7), [3]. Rectangular or high amplitude stylolite is the laterally continuous surface on the core scale and variable insoluble residue accumulation among surfaces. Usually, this geometry type of stylolite has an amplitude >1cm and is more common in heterogeneous facies (Figure 8A). The accumulation of insoluble residue is at its highest in the stylolite peaks or head seams; typically, less residue is collected along the stylolite lateral seam. Due to the poor accumulation of insoluble discontinuous residue in the lateral seam, this stylolite is considered a poor barrier for vertical fluid-cross flow. In contrast, stylolites with a thicker continuous lateral seam are considered more effective as a barrier for cross-fluid flow [21, 22]. Seismogram pinning implies that the stylolite experiences noise on several scales, which is important for compaction estimates (Figure 8B). A seismogram pinning stylolite in this classification has a median surface with small-scale roughening and one or several large teeth with a pinning source [3]. The rectangular and seismogram pinning stylolite types were merged into a single class by Alsharhan and Sadd [22]. The third type of stylolite (suture/sharp peak) has an individual surface laterally discontinuous surface and residue accumulation along individual surfaces. This geometry type of stylolite has an amplitude < 1cm (Figure 8C). These stylolites are common in impermeable stratigraphic intervals [23], and they have a high rate of insoluble residue buildup, which will decrease the fluid cross flow [3]. The lateral continuousness with the stylolite is therefore associated as an impermeable unit and an important barrier for fluid cross-flow. Solution seams are also common in networks of wispy seams. The final type is the simple wave-like stylolite, which is low amplitude stylolite (<1mm), mostly common in very thin laminated argillaceous limestone, and is often disconnected [24]. This kind may form a significant barrier to fluid cross-flow, commonly occurring in homogeneous facies (Figure 8D).

Effects of Stylolitization on Porosity and Permeability

Variable proportions and types of pores are present in stylolitized Fahliyan Formation limestones, including molds, vugs, fractures/microfractures, intergranular and intragranular macropores to micropores (Figures 9 and 10). Stylolitization reduces the porosity, permeability, and thickness of the host limestone bed. But the type of facies texture (grain or mud supported), diagenetic conditions, the angle of stylolites surface, and the type and chemical nature of the fluid are the most important parameters that can act as paradoxical factors on the increase of porosity and permeability (Figure 9).



Depth (m)	4000-4100	4100-4200	4200-4300	4300-4400	4400-4500	4500-4600	4600-4700	4700-4800	4800-4900	4900-5000
Total	6	10	41	7	3	3	5	7	15	4
Rectangulr			6		3				4	
Seismogram			5					2	2	
Sharp peak	6	10	26	7			5	5	6	
Wave like			4			3			3	4

Fig. 7 A histogram has been constructed to show the distribution of different types of stylolite morphologies that were identified in samples from the Fahliyan Formation, based on changes in depth.

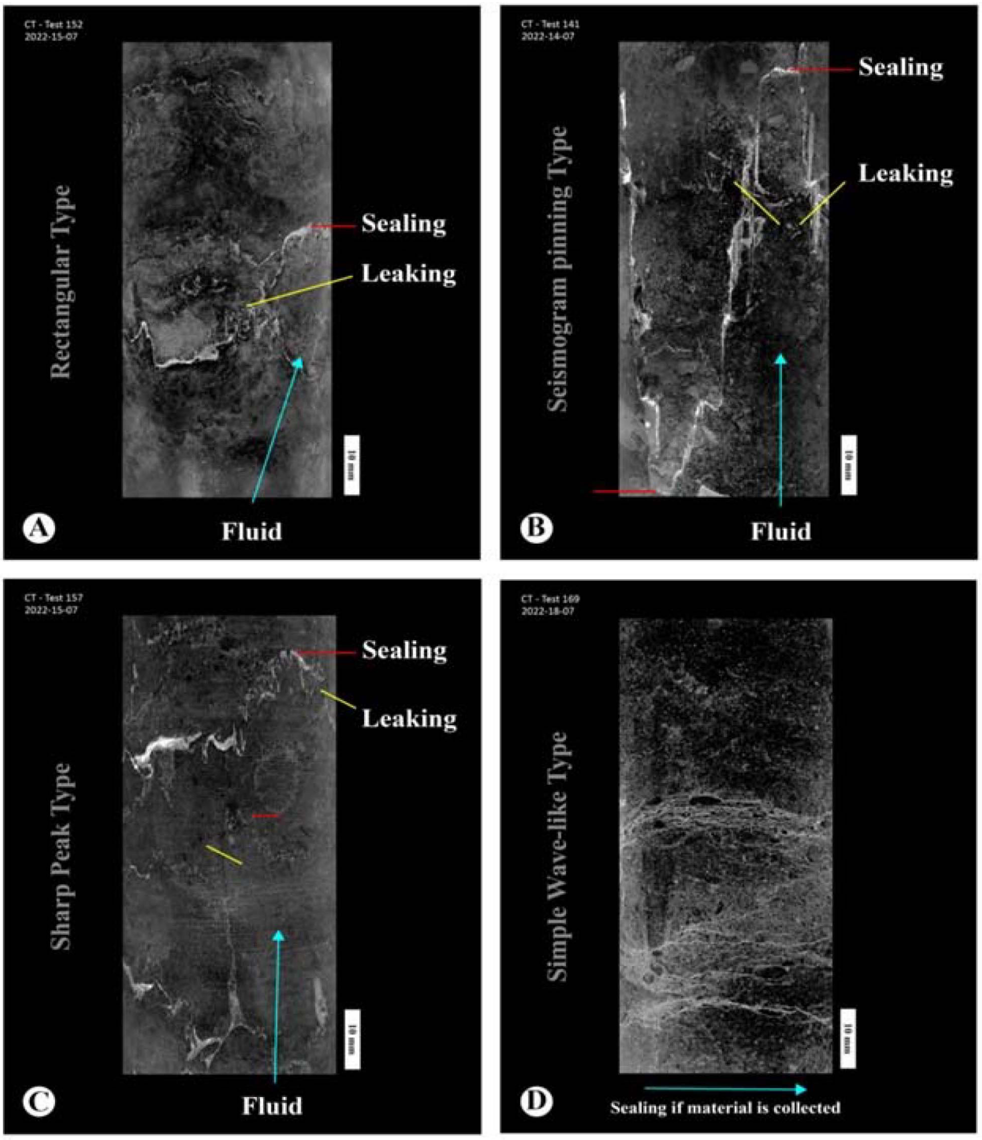


Fig. 8 Stylolite type detection using CT-Scan images of some samples. *A*) Rectangular type, *B*) Seismogram pinning type, *C*) sharp peak type, and *D*) Simple wave-like type. The different shapes of the stylolites show heterogeneity of permeability across different types (assuming the insoluble material that the stylolite collects is sealing). The sides of the teeth remain potential pathways for fluids (Leaking).

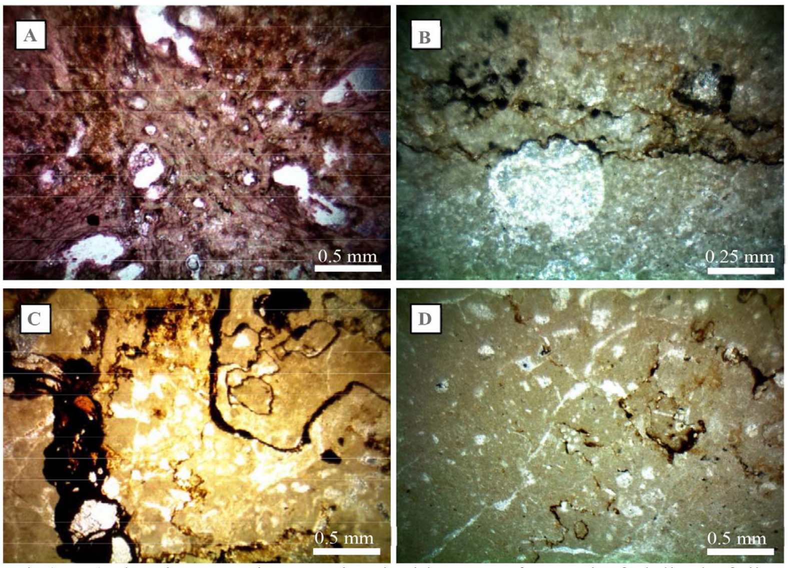


Fig. 9 Optical photomicrograph (XPL) showing porosity associated with types of pores in stylolite host limestones. *A*) Intergranular and moldic partly cemented by calcite and vugs in close relationship with solution seams, *depth: 4266.4 m*. *B*) Intragranular porosity and microporosity in calcified ooid near a stylolite in the margin of grain, *depth: 4250.8 m*. *C*) Bitumen engulfing along a stylolite surface, with partially dissolved rhombic dolomite crystals embedded in bitumen, depth: 4278.5 m. *D*) Microfractures partly cemented by calcite and crosscutting a stylolite, depth: *4270.7 m*.

In this research, the studied samples based on Rcal analysis of two main types were classified: a) stylolite-bearing and b) stylolite-free samples. The stylolite-bearing samples of conductive (Figure 10) and resistive stylolite surfaces were categorized. The conductive stylolites category also includes conductive seams and argillaceous streaks. Similarly, the resistive stylolites category also includes dense streaks. Like the low-quality bed boundaries, conductive stylolites show dominantly north-northeast dip azimuth with quite a large spread (Figure 11).

On average, in the stylolite-free, effective porosity in grain-supported facies is around 12.93%, whereas in mud-supported facies, it is only 5.7%, but higher than in equivalent stylolite-bearing limestones. On average, permeability in the stylolite-free grain-supported facies is around 3.4 mD, higher, and in mud-supported facies, around 0.45 mD lower than in equivalent stylolite-bearing limestones. Mudstones with relatively high permeability reflect open or partly calcite-cemented microporosity that is more common in the stylolite-bearing (Figures 12 and 13).

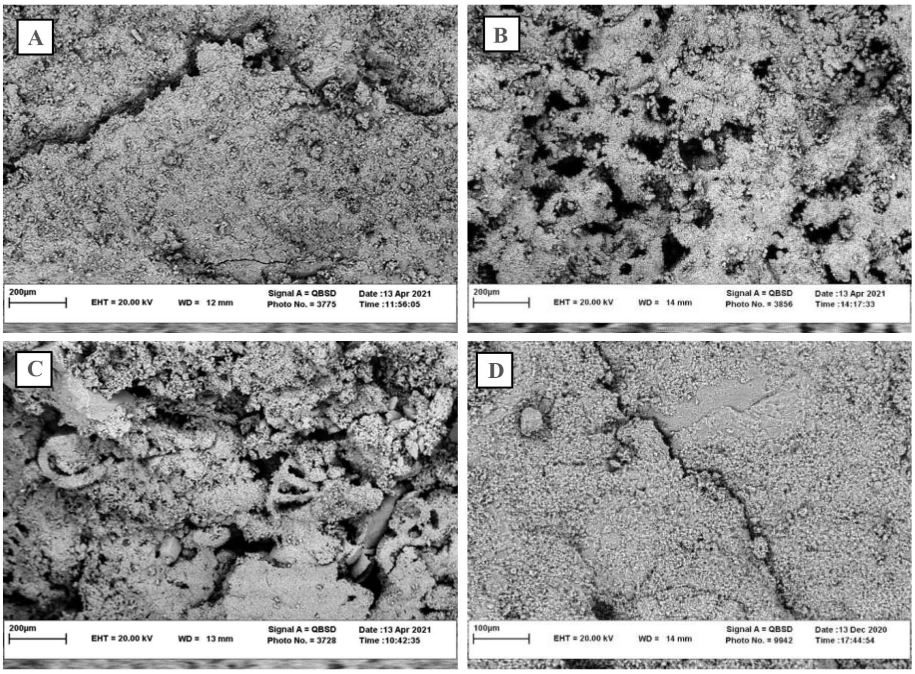


Fig. 10 Scanning electron microscope (SEM) showing porosity associated with types of pores in stylolite-bearing host limestones. *A*) The opening in microstylolits due to horizontal stress function. *B*) Micropores and vugs are typically cemented; Microporosity in mudstones and wackestone is higher in stylolite-bearing facies (av. 4.7%) than stylolite-free facies (av. 2.3%). *C*) Intragranular porosity and microporosity in wackestone facies in close relationship with stylolite. *D*) Connective microfractures in mudstone facies that are partly cemented by calcite.

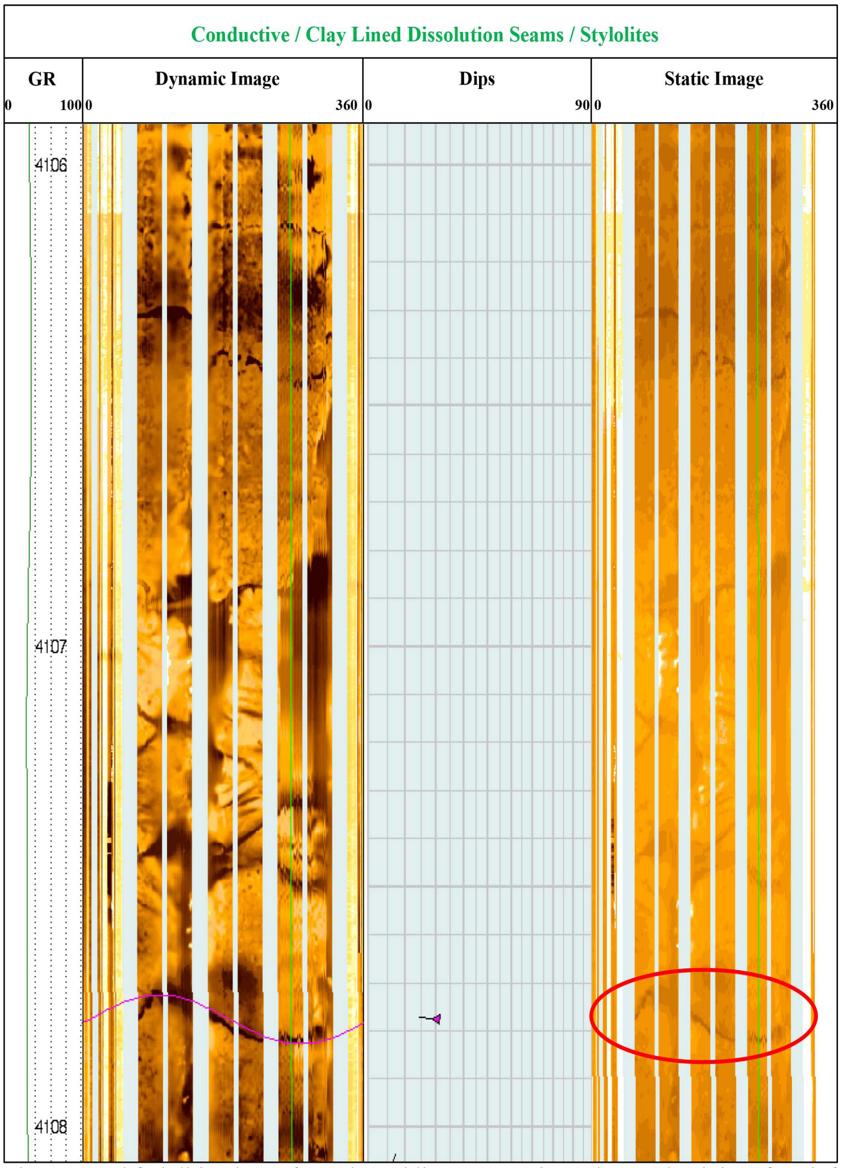


Fig. 11 Example of conductive seams / stylolitic planes from the Fahliyan Formation. The conductivity of such features is possibly due to clay filling or lining along or within their planes.

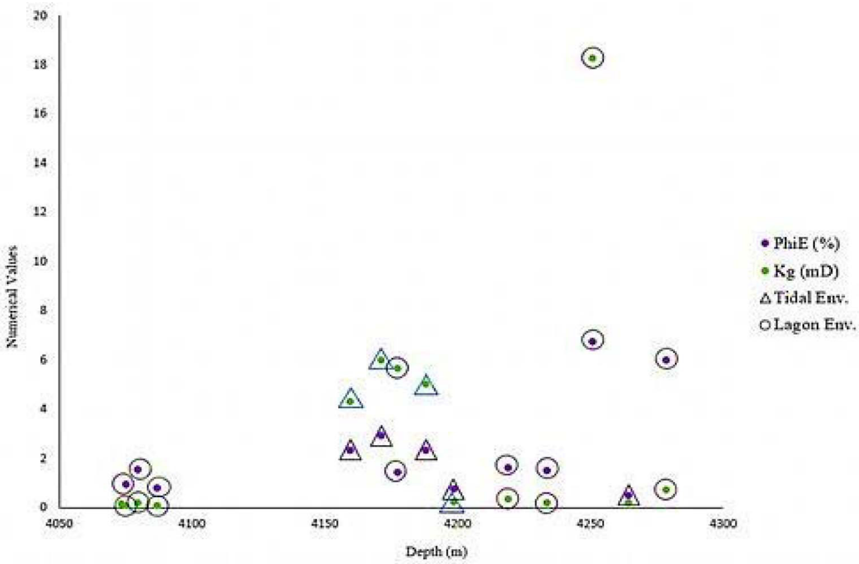


Fig. 12 The diagram showing the values changes of effective porosity and gas permeability of stylolite-bearing samples (mainly mud-supported facies) based on the depositional environment of the samples, which is specified in the form of a triangle (tidal flat) and a circle (lagoon).

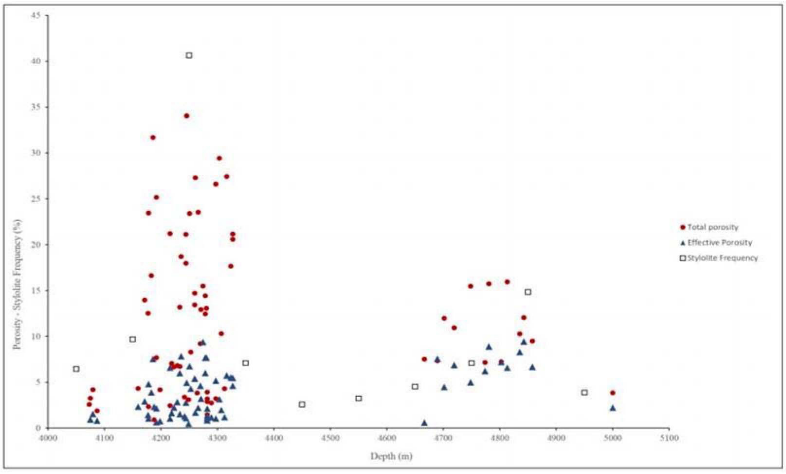


Fig. 13 Scatter plot of total porosity and effective porosity of stylolite samples based on the Fahliyan Formation depth changes in the Abadan Plain area. Based on the diagram in Figure 7, the average depths of 4200-4300 and 4800-4900 m of the Fahliyan Formation with an increase in the concentration of stylolites and the porosity of stylolite-bearing samples also increased, which is proof of the effect of stylolitic zones on the increase in porosity of the studied samples.

Conductive stylolite samples in the mud-supported facies have effective porosity and permeability higher than grain-supported facies (on average 15.2% and 4.2 mD), even equivalent in the closed stylolite bearing samples. Close stylolites are more abundant in the mud-supported than the grain-supported. Macroporosity and microporosity are relatively high (up to 17%) in some grainstones in the facies-hosted stylolites. Visual comparison of stylolite distribution and porosity in host limestones indicates that intervals where stylolites are common have lower porosity than those where stylolites are few or absent. However, packstones and grainstones in the [closed] stylolite-bearing, which may contain only scattered stylolites, have higher porosities in the vicinity of stylolites than those around 0.5m farther away (Figures 12 and 13).

It should be noted that the formation of stylolite is one of the complex diagenetic processes that directly or indirectly affect other diagenetic processes such as dissolution, cementation in the form of accumulation (due to condensation), precipitation (due to saturation) and mineralization, the formation of local microfractures in the peaks of stylolite or the release of microparticles (resulting from the fragmentation of the allochems in) during its formation, which leads to a reduction in porosity (Figure 14). Therefore, in addition to a comprehensive study of fluid flow, such as determining the origin and formation, should be considered all the diagenetic changes imposed on the host rock [4] because the transition between mechanical and chemical compression as mentioned depends on the mineralogy, petrophysical properties of the sediment, burial depth and temperature changes [25].

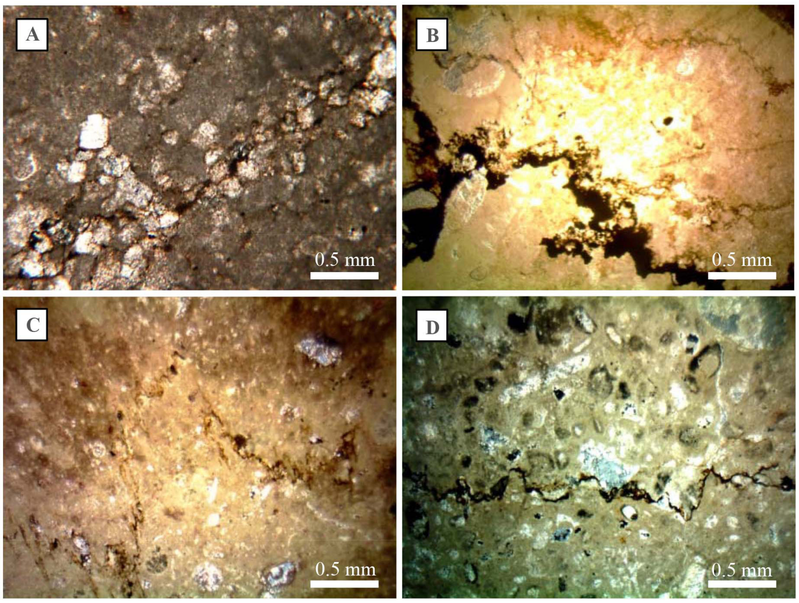


Fig. 14 Optical photomicrograph (XPL) showing the relationships between stylolite formation and diagenetic processes during the stylolitization evolution. *A*) Transit of diagenetic fluid and dolomite precipitation controlled by the stylolite surfaces, *depth: 4195.7 m*. *B*) Bitumen engulfing calcite along a stylolite, *depth: 4280.5 m*. *C*) Pyrite and calcite in a stylolite surface. Microfractures are suggested to have formed perpendicular to the stylolites (crest of amplitude) during stylolitization, so it is worth mentioning that the mass released during stylolitization occludes much of the microporosity (in the form of cementation) in host mudstone, *depth: 4336.5 m*. *D*) The concentration of clay mineral along the stylolite surface, *depth: 4050.2 m*.

In general, the main parameters making stylolites a positive or negative feature in porosity and permeability are linked with their morphology and pattern of their surface, their filling material (solid or gas), the factors of diagenetic condition (fluid fluxes, pressure of CO_2, pH, and temperature), the tectonic history (performance of lateral stress leading to relative opening of stylolite) and the nature of the fluid transiting trough them (highly corrosive fluids circulating along faults and using stylolite to invade the host rock). It appears that stylolite can also act as a barrier by cementing locally part of the reservoir. However, the time of stylolite formation compared to the time of oil charge is very important (Figures 14 and 15). Stylolites formed before the oil charge may be significant barriers to fluid flow because they may be entirely cemented compared to stylolites formed after the oil entrapment that remain open because of the presence of hydrocarbons impeding the cementation and the closure of stylolites [7, 26, 27].

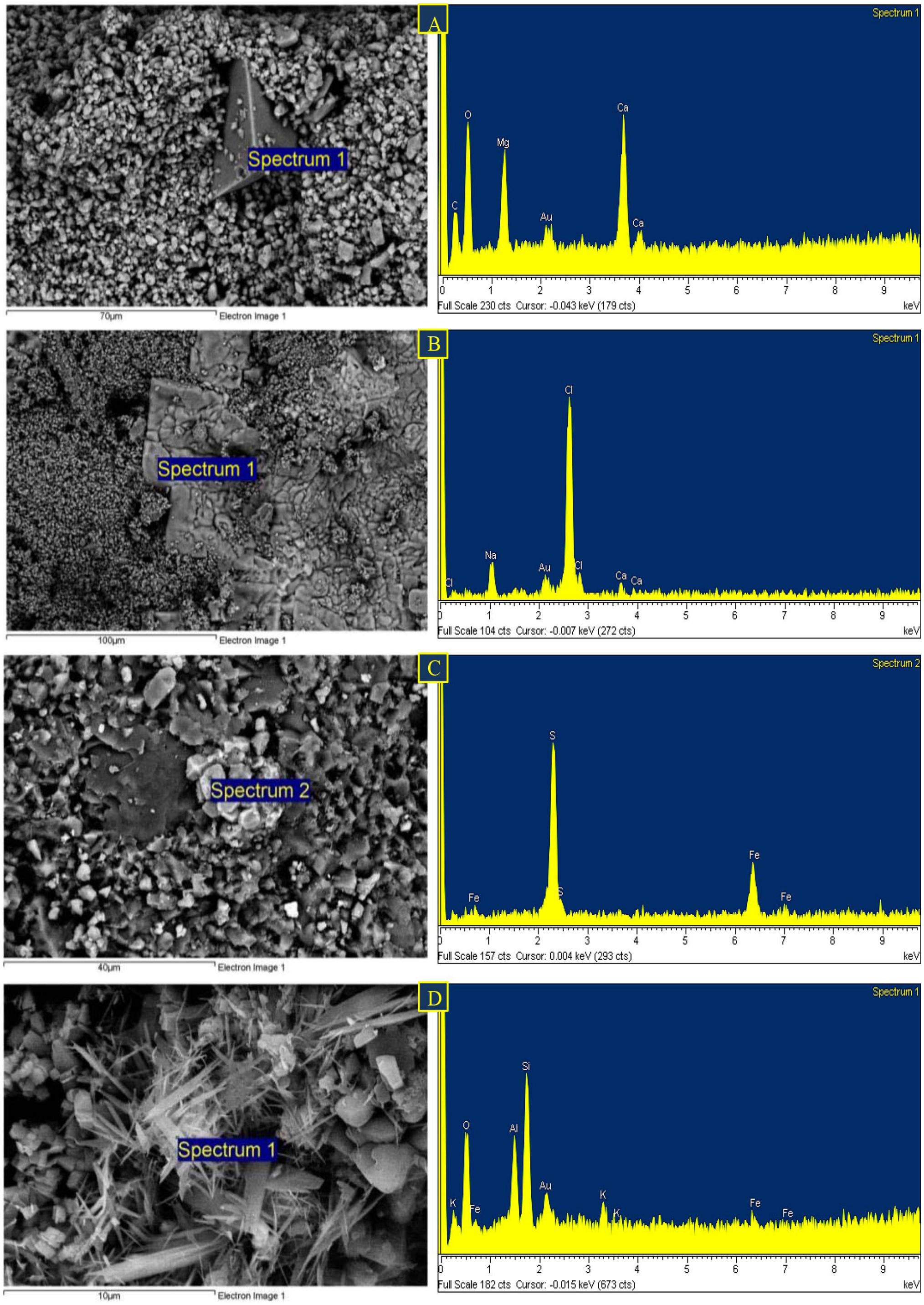


Fig. 15 Stylolite display by scanning electron microscope based on SEM-EDS analysis. *A*) Dolomite (flux of Mg-rich fluids) and calcite (engulfed, engulfing, or replacing other types of cement) filling along clay-rich stylolite. *B*) Halite crystallization by brine flux (high salinity) along stylolite surface. *C*) Pyritization along stylolite surface. The sulfur required to form may reflect thermochemical sulfate reduction. *D*) Presence of clay minerals along stylolitic surfaces. A concentration of clays in fine-grained facies is suggested during marine transgressions.

Origin of Stylolites and Microfractures

The bedding-parallel orientation of most stylolites in the Fahliyan Formation suggests that the formation was due to overburden stress during burial. In this research, according to the study of general stress in the Abadan plain and macroscopic examination of stylolites in well cores as well as genetic classification of stylolites in plug samples from well cores, all samples that have been collected and studies in this research show sedimentary stylolites. Microfractures were arranged sub-perpendicular to the dissolution surfaces (Figure 16). Some were aligned along the vertical segments of the stylolites (Figure 9D). They are commonly filled with calcite cement and less commonly remain open or filled with saddle dolomite or bitumen (Figures 9D and 14B). Microfractures are more common in mud-supported than grain-supported facies and in flanks than in the crest of anticlines [28]. The presence of microfractures also impacted the diagenesis of stylolite fillings near stylolites. These are aligned perpendicular to the stylolites and might have formed parallel to the main stress during stylolitization owing to the overburden stress if the pore fluid pressure exceeds the maximum horizontal stress and tensile strength of the rock [29, 30, 31]. The observation that microfractures are more common in mudstones than in grainstones indicates that they formed after the lithification of these microporous limestones.

Reservoir Quality Associated with Stylolite

The general point of view about stylolites is that they affect the porosity and permeability of the host rock and reduce them and are also a barrier against fluid flow. But, despite their negative effect on the reduction of porosity and permeability, in this study, there is evidence of the positive effect of this feature. It has been explained by porosity and permeability, especially along the surfaces of the mud-supported facies (Figure 12).

The effect of hydrocarbon replacement is important to diagenesis and reservoir quality evolution (Figures 17-20). As the stylolite evolves, further dissolution of limestone occurs, precipitating cement near the stylolite and creating partly or complete filling of the pores. This phenomenon affects the reservoir quality since the pore space is reduced as the cementation occurs due to stylolitization. It can work as a barrier to vertical fluid flow. When exploiting a new reservoir, it's therefore important to determine how the evolved stylolite's maturity has progressed to work as this kind of barrier. According to Carozzi and Von Bergen [31], the porosity is discontinuous through the stylolite and is affected by how the dissolution precedes between the stylolite walls. The dissolution of limestone due to stylolitization is reprecipitate as cement along the stylolite, inducing partial or total filling of the pore space between nearby grains. This process inhibits the fluid flow of hydrocarbons and has significant importance to the quality of the barrier. Due to the quality and presence of barriers when exploiting a new reservoir, it is of the highest necessity to investigate the development of stylolitization. The pressure and stress created between deeply buried sediment grains tend to dissolve and increasingly correlate with lithostatic pressure. The areas of the grains not in contact with other grains may only be exposed to pore fluid pressure and, thus, a generally lower stress. Reducing stress on the grains will inhibit the dissolution and, thus, reprecipitation of the grains. The permeability will depend on the insoluble materials continuing as the permeability will decrease, and matrix cementation will occur adjacent to pressure-solution seams, reducing permeability. The dissolute material has to be transported to prevent such a decrease of permeability in the locality of the pressure surface, away due to the concentration gradient between high-pressure areas and low-pressure areas [21, 32].

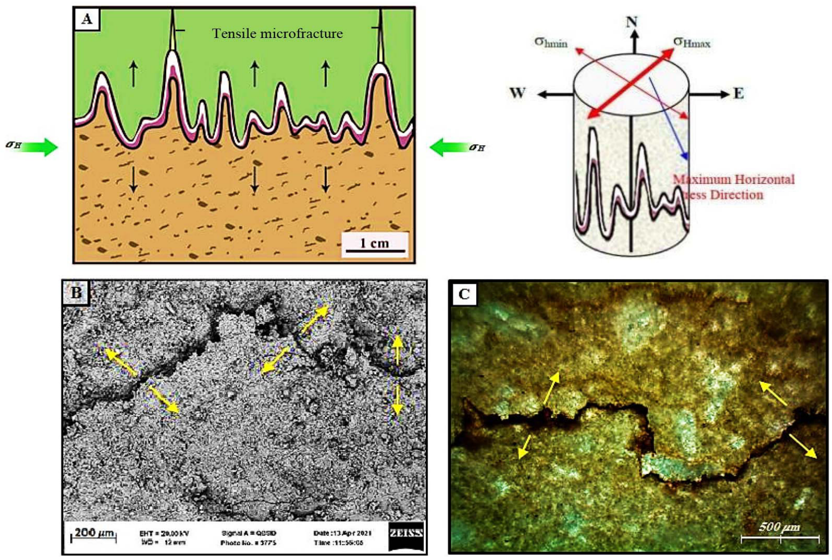


Fig. 16 *A*) The application of the maximum horizontal pressure increased and opened the stylolite channels and acted as a baffle on its discontinuous surfaces, which led to the creation of a possible pathway for fluid flow and subsequent cementation in the form of mineralization, accumulation, or precipitation along the stylolite surface (modified after [28]). If the fluid is acidic, it leads to dissolution and even increases the surface area of the stylolite. *B*) SEM image and *C*) microscopic image (XPL light) show the stylolite opening due to the traction system's operation at the crest of the field at a *depth of 4316.6 m.*

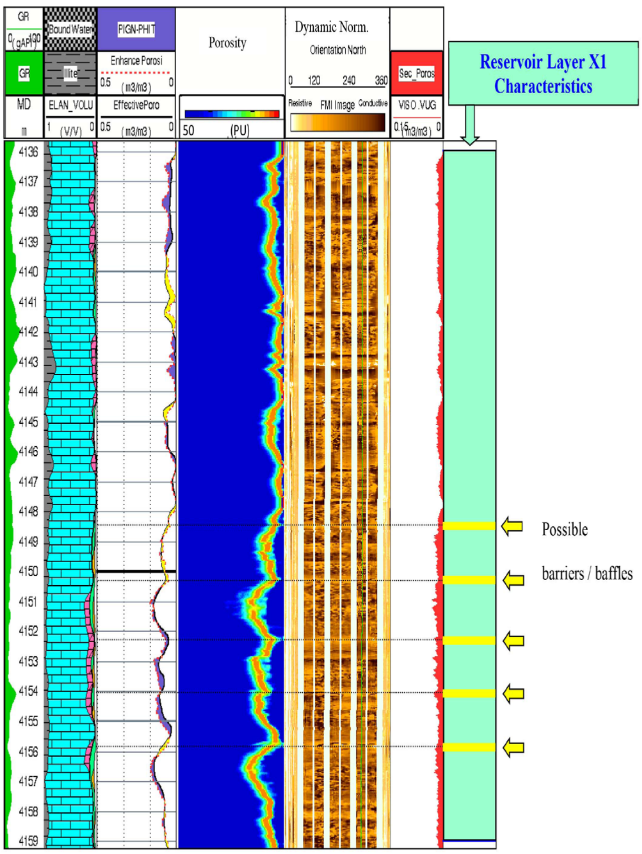


Fig. 17 Porosity analysis and open hole evaluation results along with FMI images across the Fahliyan Layer X1 highlight characteristics of the layer. Possible vertical flow barriers or baffles due to dense streaks / stylolites are indicated.

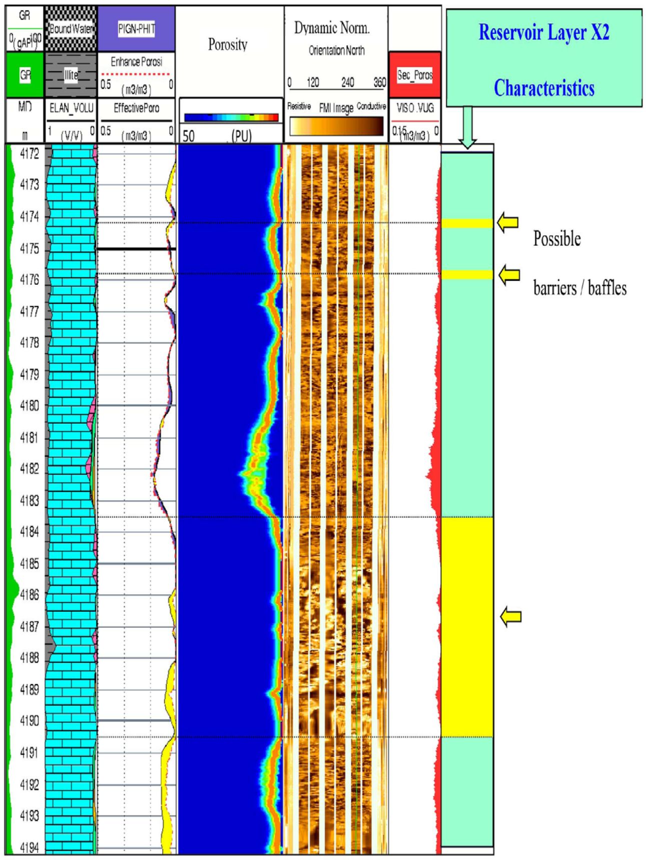


Fig. 18 Porosity analysis and open hole evaluation results along with FMI images across Fahliyan Layer-*X2* highlight characteristics of the layer. Possible vertical flow barriers or baffles due to dense streaks / stylolites are indicated.

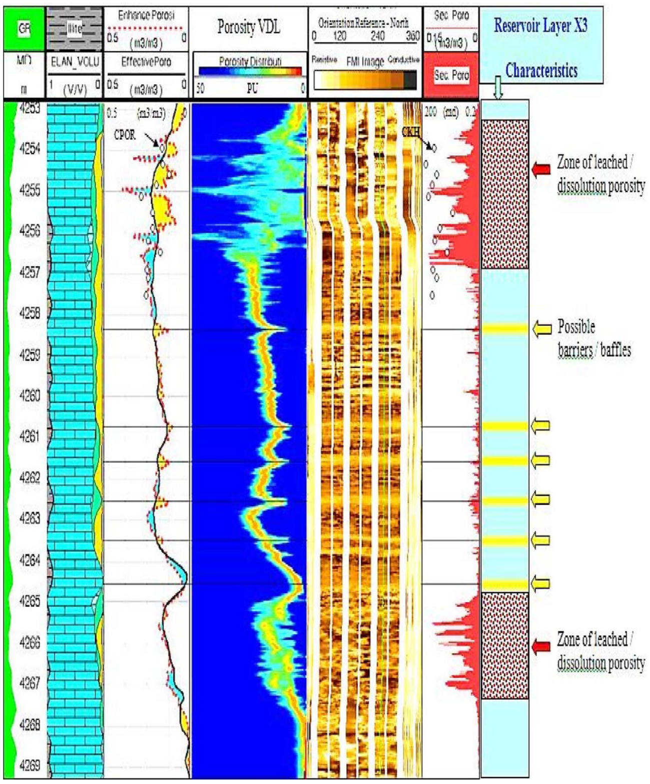


Fig. 19 Porosity analysis and open hole evaluation results, along with FMI images across Fahliyan Layer *X3*, highlight characteristics of the layer. Possible vertical flow barriers or baffles due to dense streaks/stylolites are indicated. Zones of higher secondary porosity (and possibly good flow units) are also marked.

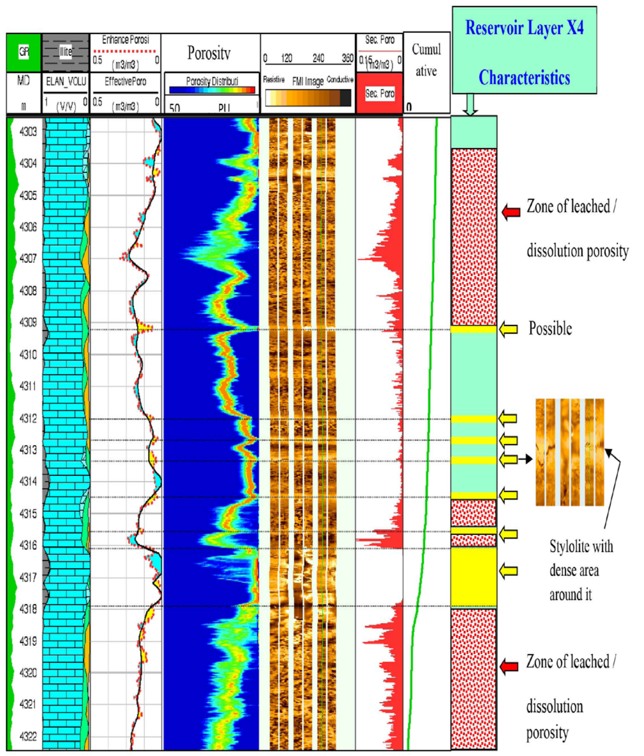


Fig. 20 Porosity analysis and open hole evaluation results along with FMI images across Fahliyan Layer *X4* highlight characteristics of the layer. Possible vertical flow barriers or baffles due to dense streaks / stylolites are indicated. Zones of higher secondary porosity (and possibly good flow units) are also marked. Perforated intervals are shown in black to the left of the depth track.

Conclusions

Stylolites are a dominant feature in the carbonate reservoir rocks of the Neocomian Fahliyan Formation in southwestern Iran, which is considered the main reservoir in the lower Cretaceous succession of the Abadan Plain. This manuscript provides a brief review of the reservoir performance of the stylolitization process on porosity and permeability. Our study investigates how the stylolitization process affects reservoir properties and discusses the impact of its pattern attribute on reservoir fluid flow and storage. Based on our observations, stylolites were classified into three categories based on their genesis, morphology, and attributes: I) sedimentary and tectonic, II) rectangular/seismogram-pinning (high amplitude), suture/sharp peak, and simple wave (low amplitude) types, and iii) open and closed stylolites. Our findings indicate that the porosity and permeability in the mud-supported facies are lower than those in the grain-supported facies. However, stylolites with high amplitude have the ability to adjust the porosity and permeability in the mud-supported facies.

The increased porosity and high connectivity of stylolites in the mud-supported facies result in elevated permeability. Diagenetic fluids may not always decrease porosity as they can bind clay minerals and increase permeability on a microscopic scale. Stylolitization involves two complex paragenetic processes, sedimentation and mineralization, which are effective blocking agents of hydrocarbon flow and reduce the quality of the carbonate host rock. The impact of stylolites on fluid flow may differ from previously thought and can result in reduced host rock porosity, which can hinder regional fluid migration. The development of stylolites is critical in determining barrier quality, and all factors that influence their formation must be considered. Finally, as the knowledge of the development of the stylolites for a specific barrier is important to determine the barrier quality, all dependable factors of stylolitization need to be considered.

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