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Diagenetic Features and Porosity Development for Hartha Formation in the Balad and East Baghdad Oil Fields, Central Iraq

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Abstract

The Hartha Formation (age Late Campanian – Early Maastrichtian) is considered an important oil reservoir in Iraq. The petrography and the diagenetic features were determined based on the analyses of 430 thin sections from selected wells within Balad and East Baghdad oil fields, Ba-2, Ba-3, EB-53, Eb-56 and EB-102.

The most important and common diagenesis processes that affect Hartha Formation include Cementation, Neomorphsim, Micrtitization, Dolomitization, Compaction, Dissolution, and Authigenic minerals. This diagenesis deformation on Hartha Formation has overall accentuated the reservoir quality heterogeneity.

The reservoir quality evolution is affected by destruction by grain compaction mechanical and chemical (stylolitization) causing decreases in porosity and permeability. The porosity is continuous through stylolite and is affected by dissolution precedes between the stylolite walls. The permeability decreased due to cementation. These processes led to seven proximately heterogeneity units in the Hartha Formation, characterized by a decrease in their porosity as barrier units of the Balad Oil Field. While in the East Baghdad oil field the effective porosity units appeared with less thickness of the barrier unit.

The reservoir quality enhancement has resulted from dissolution, recrystallization, and partial dolomitization appeared alternately with the barrier unit in the upper part of Hartha Formation of Balad and Baghdad Oil Fields.

Keywords: Diagenetic processes, Hartha Formation, Balad and East Baghdad Oil Fields, Central Iraq.

الخصائص التحويرية وتطوير المسامية لتكوين الهارثة في حقل نفط بلد وشرق بغداد ، وسط العراق

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الخلاصة

يعتبر تكوين الهارثة (الكامباني المتأخر – ماستريختي المبكر) تكوينًا مهمًا بسبب خصائصه الصخرية والبتروفيزيائية التي تجعله خزانًا للنفط في العراق. تتناول الدراسة الحالية بتروغرافية وتحديد الصفات التحويرية بالاعتماد على دراسة الشرائح الرقيقة لـ 430 شريحة نموذج لآبار مختارة ضمن حقول نفط بلد وشرق بغداد (بلد -2 و بلد -3 و شرق بغداد -53 وشرق بغداد -56 وشرق بغداد -102).

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من أهم وأشهر عمليات االتحويرية التي تؤثر على تكوين الهارثة ما يلي: الأسمنت والتحول الجديد والتحلل الدقيق والدلمتة ولاحكام والذوبان بالاضافة الى المعادن المكونة ضمنيا ولقد أبرز التغير التحويري في تكوين الهارثة بشكل عام عدم تجانس جودة الخواص المكمنية.

تأثرت الخواص المكمنية للحجر الجيري بتدمير جودة الخزان عن طريق ضغط الحبيبات ميكانيكيا والكيميائيا (الستايلولايت) مما أدى إلى انخفاض في المسامية والنفاذية. المسامية هي في الواقع متقطعة من خلال تاثير الاحكام اضافة الى تأثرها بكيفية انحلال بين حدود الستايلولايت .بالتالي سيتم تقليل النفاذية لأن الحشوة سيتم سمنتتها بواسطة محلول الضغط والتي سيتم تقليلها. أدت هذه العمليات إلى تكوين سبع وحدات غير متجانسة في تكوين الهارثة في حقل نفط بلد. بينما في حقل نفط شرق بغداد ظهرت وحدة الحاجز بسماكة اقل.

وقد نتج تحسين جودة المكمن عن الذوبان ، وإعادة التبلور ، والدلمتة الجزئية والتي ظهرت بالتناوب مع وحدة الحاجز في الجزء العلوي من تكوين الهارثة في حقل نفط بلد و في حقل نفط شرق بغداد.

Introduction

The Hartha Formation deposited in Late Campanian – Early Maastrichtian is an important carbonate formation in Iraq due to its petrographic and petrophysical characteristics that make it an oil reservoir in some regions. The Hartha Formation was defined by Rabanit in 1952 from well Zubair-3 in the Mesopotamian Zone of the south of Iraq [1]. According to Aqrawi, et al., 2010 [2], the Hartha Formation is divided into upper and lower Members, in central Iraq, with eight lithofacies based on petrographic and petrophysical characteristics. These are rudist biostromal carbonates; echinoderm-rich packstons; grainstons with shallow–water; larger foraminferal shoal facies; peloidal facies; deeper–water marly facies and fine-grained muddy carbonates [2].

The Hartha Formation is within the Khleisia High and Stable Shelf and is overlain by the Shiranish Formation [3, 4, 5, 6 and 7].

Al-Zaidy, et al., 2013 [8] studied sequence stratigraphy and reservoir characterization of the Hartha formation in the Ahdab Oil Field and recognized six main facies associations in the studied succession. These are basinal, open shelf margin, foreslope, rudist biostorm, shoal and restricted platform (lagoon), and nine petrophysical horizons.

Diagenetic processes were defined as all the changes in grain size, volume, particle shape, chemical composition, or crystalline structure of the sedimentary rocks after their detrital, biogenic, or crystalline compounds have been deposited [3]. Diagenesis provides important data and information about the basin development post the depositional conditions, water formation composition, and temperature [4].

Diagenesis begins during the stage of depositional, from the initial precipitation period, and continues to the burial and uplift stages. The diagenesis of carbonate rocks can happen in the marine environment during the deposition of sediments, near the surface where fresh waters penetrated these sediments, or in the brines water of the deeper subsurface. The porosity and permeability are very important for reservoir properties. Most digenetic changes affect the porosity of sediment and thus must be considered in the hydrocarbon exploration [5]. The most important and common diagenesis processes that affect Hartha Formation are Cementation, Neomorphsim, Micrtitization, Dolomitization, Compaction, Dissolution, and Authigenic minerals.

The aim of the present study is to describe the diagenesis processes and evaluation of the petrophysical properties which affected the Hartha Formation in selected wells from Balad and East Baghdad oil fields (Figure 1).

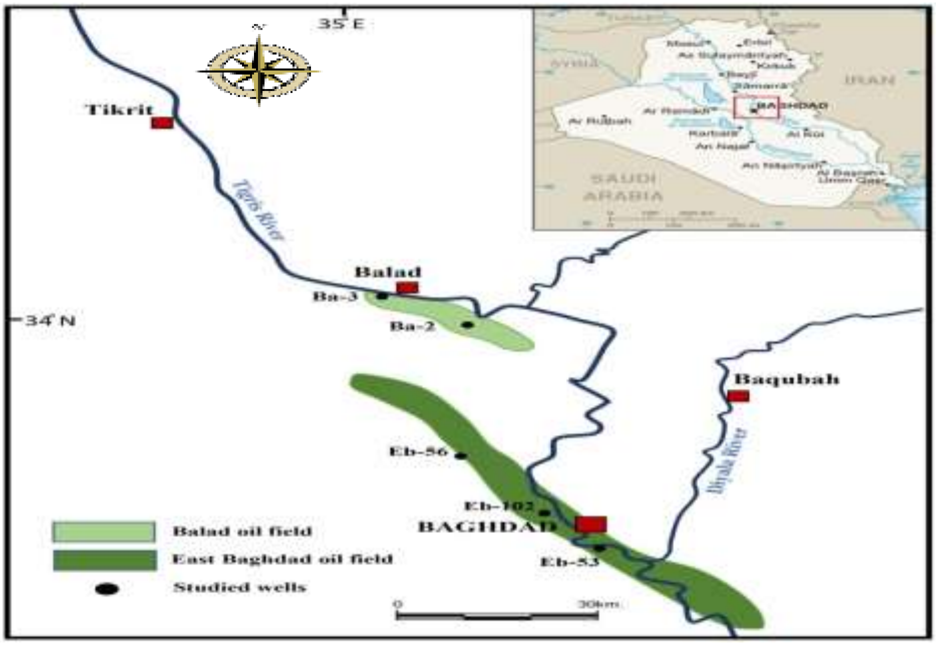


Figure 1: location map for Balad and East Baghdad Oil Fields.

Methodology

The studied area is including two oil fields located in central Iraq, East Baghdad and Balad Oil Fields (Figure 1). East Baghdad Field is a group of Oil Fields that lies in the middle of Iraq located east of Baghdad. It is 11 kilometers wide and 64 kilometers long and it was discovered in 1976. Balad oil field is located in the middle of Iraq along the Tigris River within Salah Al-din province about 70 Km northern Baghdad.

Five subsurface sections were selected from the wells of two oil fields: EB-53, EB-56, EB-102, Ba-2 and Ba-3 to determine the depositional environments of the Hartha Formation and stratigraphic sequence. For this purpose, more than 430 thin sections previously prepared by the North and Center Oil Companies, were described, interpreted, and studied petrographically. Analysis of gamma-ray, density, neutron, sonic, and resistivity logs was used to study the volume of shale, and porosity types, which was applied according to the procedure in Figure 2. The thickness of Hartha Formation in the studied wells are range from 222.5 to 248 m for the East Baghdad oil field and from 314 to 593 m for the Balad oil field (Table 1).

Table 1: Thickness of the Hartha Formation in the studied wells

No.	Well ID	Top	Bottom	Thick.	No. of thin sections	Study method
1	Balad-2	1680	1994	316	134	Logs & core
2	Balad-3	1681	2274	593	169	Logs & cuttings
3	East Baghdad- 53	1680.5	1903	222.5	68	Logs & cuttings
4	East Baghdad- 56	1600.5	1849	248.5	18	Logs & cuttings
5	East Baghdad-102	1638	1865	227	41	Logs & cuttings

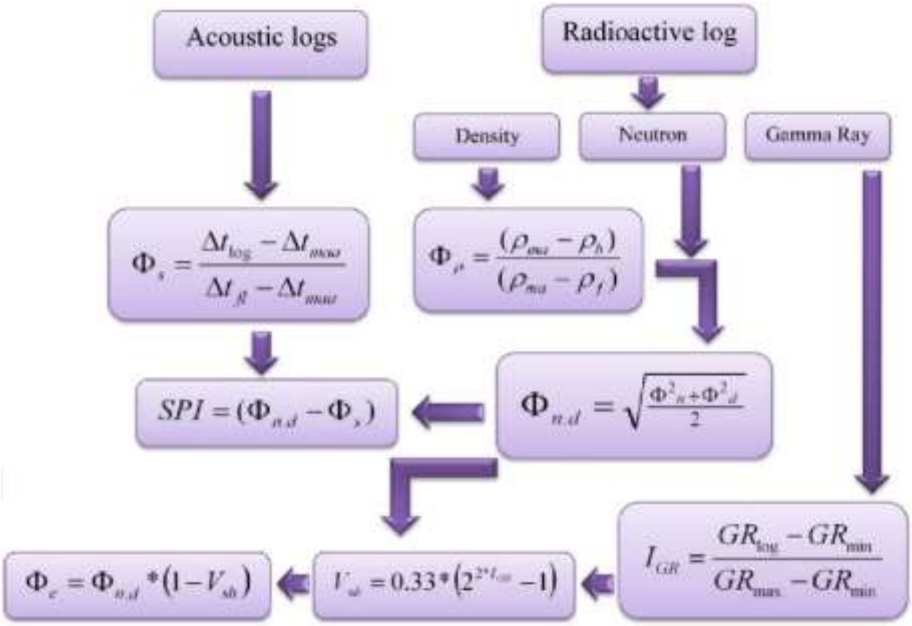


Figure 2: Diagram showing steps and equations used in the present study [7].

Results and Discussion

The Hartha Formation is a conformable overlaying by the Shiranish Formation, while the lower contact of this formation is usually an unconformity by often marked a basal conglomerate with Saddi Formation.

Carbonate diagenesis environments

The diagenesis processes reflect the effect of different digenetic environments; marine phreatic, mixing, and meteoric phreatic. The understanding and interpreting of these processes and their products are important to distinguish the diagenetic features and criteria that account for many of the petrophysics characteristics for the carbonate succession and determination of their values as a reservoir property [9]. In carbonate succession, digenesis processes have far greater effects on the ultimate reservoir quality because of the greater potential value for chemical reactions during the burial stage [10]. The main controls and factors on carbonate digenesis are the mineralogic composition and chemistry of crystals, the waters pore chemistry, water dynamic and movement, the rates of dissolution and precipitation, particle size, and the interaction of the organic materials.

The extents and paths of digenetic activities and processes are determined by the stability of thermodynamic for the carbonate rocks and minerals which dissolved and/or precipitated new materials, the saturation states and conditions of the digenetic fluids, and the available surface area for the reaction [4]. Lime mudstone and wackestone were initially altered by the marine phreatic zone. The diagenetic features in these carbonate fabrics (microfacies) contain pyrite crystals as an occasional authigenic. The features in bioclastic wackestones and packstones indicate the alteration within the meteoric, phreatic, and mixing zones.

Diagenetic processes

The most important diagenetic processes in the Hartha Formation are cementation, neomorphism, micritization, authigenic minerals, dolomitization, compaction, stylolization and dissolution. Classification of porosity is considered in this research as well. Carbonates of the Hartha Formation have been affected by both early- and late-stage diagenesis. These processes are described below:

Cementation

Cementation is the carbonate precipitation and growth of new crystals of calcite, dolomite mineral or anhydrite (Plate 1- E &F) in the space of void, thus leading to processes of lithification [10, 11 and 12].

There are many types of cement such as (1) Blocky Cement (2) Granular Cement (3) Drusy mosaic Cement, and (4) Isopachus Cement. These cements are present in various microfacies filling inter- and intragranular pores and fractures. These cements are believed to be of later diagenetic origin.

The variation in cement types reflects different diagenetic environments. Drusy cement formed in the phreatic and vadose zone, while blocky cement formed under vadose zones in meteoric and marine water [6].

- Blocky Cement

Blocky cement is characterized by comprising medium to coarse-grained crystals without any orientation. Which is characterized by various sizes of crystals with distancing the crystal boundaries [4]. Blocky cement is considered a late diagenetic process [6] (Plate. 1-A & G).

- Granular Cement

This type of cement is represented by anhedral to subhedral shaped calcite crystals ranging sized from 10-60 mm, and usually with the crystals' preferred orientation [4 and 6]. (Plate 1-B). The granular cement is generated in a meteoric/vadose environment, meteoric to the phreatic environment, and a deep burial environment [4 and 8].

- Drusy mosaic Cement

The mosaic cement is characterized by the pore filling calcite crystals, with increasing crystal size towards the center of the interparticle and intraskeletal pores, molds and fractures. The calcite crystals are non-ferroan, equal to elongated with anhedral to subhedral crystals [4]. Drusy cement forms as a late diagenetic process [6] (Plate 1-C).

- Isopachus Cement

It is an even-thickness (uniform-thickness coating around grains). It is generally made up of needles or acicular aragonite crystals or high Mg-calcite laths and may occur within chambers and hollows of many skeletal particles in the shallow sea environment. This type of cement is common in association facies shoal, shallow open, and semi-restricted (Plate 1-D &G).

Neomorphsim:

According to Bathurst, 1983, [12], the term neomorphism is the transformation of the minerals and including the diagenetic replacement processes (Plate 2-A). While the recrystallization to microsparite process refers to changes in the size and shape of the crystal, in addition to the crystal lattice without a change in the mineralogy. Neomorphsim usually affects the micritic matrix and skeletal grains of Hathra Formation (Plate 2-B).

Micritization

The main compound of any rocks of limestone usually consists of carbonate lime mud or micrite as groundmass (Plate 2-D). Because of the small grain size or crystals of calcite in the micrite, the micrite origin identification is so difficult to impossible.

Micritization is representing a diagenetic process where the grains margins of the carbonate's compounds or the total volume of grains are replaced by cryptocrystalline or microcrystalline of the carbonates. The term micritization is used in the context of the studies of modern carbonate lagoonal settings [12]. In the study during the syngenetic and early stages of the diagenetic changes affecting the modern skeletal particles. The term is referring to thin, non-laminated coating grains of very fine-grained micrite around the carbonate particles, particularly skeletal or non-skeletal grains. Micritization involved the formation of micrite envelope around the grains, where the porosity and permeability are reduced by filling the original pore space of the rock. The process commonly occurs in relatively low-energy, shallow marine environments.

This type of digenesis process is present in the study of carbonate rocks (Plate 2-C).

Authigenic minerals

This type of mineral was growing after the sediment deposition during the diagenesis stage [4]. In sedimentary rocks it is common to find a record of multiple diagenetic events based on the authigenic minerals. The main type of authigenic minerals recognized in the studied thin section are Iron oxides (hematite) (Plate 2-F & G) and sulfides (Pyrite) (Plate 2-E). Iron oxide can result from oxidizing fluid and its falling porosity. Depletion of oxygen by bacteria may result in the formation of iron sulfides (Pyrite).

Dolomitization

Dolomitization is representing the early or late stages of diagenetic replacement of the dolomite by calcite mineral [4]. Early dolomitization is reflected by the presence of floated homogeneous texture and similar size of the dolomite crystals. In some times the dolomitization process may affect the limestone incompletely forming the dolomitic limestone where may be preserved the original depositional texture.

Dolomitization can be associated with two processes, the first, the process replacement including the coupled dolomite dissolution with forming the calcite, and/or the second process including the dolomite dissolution which result in the secondary porosity, and later calcite mineral precipitation either during the same process or forming a different solution at another time interval [13].

Several models discussed the model types of dolomite texture and recognized eight dolomite rocks according to crystalline size dolomite (Figure 3) [14].

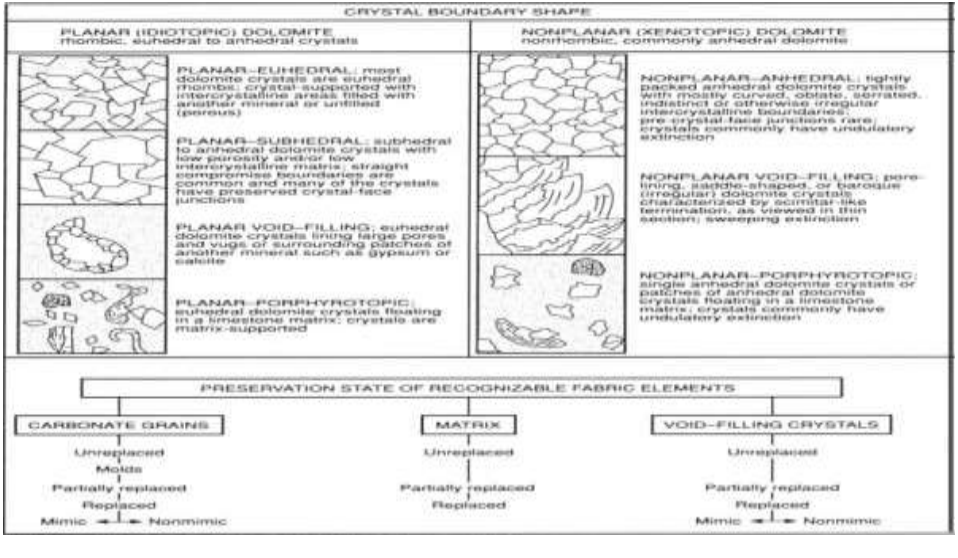


Figure 3: Dolomite textural classification [After 14]

Crystal size distributions are classified as unimodal and polymodal. Whereas crystal shapes are classified as Planar-e (euhedral), Planar-s (subuhedral), and nonplanar-a (anhedral) [15 and 16]. The following dolomite-rock textures have been defined:

- **Dolomite texture 1: Planar-Euhedral**

Most crystals of dolomite are characterized by euhedral rhombs in this type. Typically, dolomite crystal is supported with the inter-crystalline filled area with another mineral or unfilled. It’s very common in the dolo-mudstone – wackestone facies (Plate 3-G)

- **Dolomite texture 2: Planar-Subhedral**

This type comprises dense mosaics with medium to coarse subhederal to anhedral dolomite crystalline. Dolomite crystals are cloudy centers with clear rims to totally cloudy crystals, non-mimic replacement of carbonate grains (ooids, peloids, intraclasts, fossils, and fossils fragments) (Plate 3-A). In this type, it is hard recognition the original deposition texture.

- **Dolomite texture 3: Planar Void-Filling**

This type is characterized by euhedral coarse milky white to clear dolomite crystal (Plate 3-H). This type occurs as lining large pores or surrounding patches of another mineral such as calcite.

- **Dolomite texture 4: Planar - Porphyrotopic**

This type comprises euhedral dolomite coarse crystals surrounded by small crystal groundmass (Plate 3-F). The crystals are clear and skeletal grains are surrounded within

- **Dolomite texture 5: non-planar –an (anhedral) dolomite**

This type comprises packed and dense mosaic dolomite crystals (Plate 3-D). The crystals in this type have serrated, curved, irregular, or otherwise unclear boundaries. The crystal is showing a vague non-mimetic replacement of carbonate grains. This type of composite dolomite occurs in a burial environment and it’s represented by original high values of porosity and permeability.

- **Dolomite texture 6: Non Planar –Void Filling**

Pore lining, saddle shape, or baroque (irregular) dolomite crystal characterized by a scimitar. This type didn't found in the present study (Plate 3-E).

- **Dolomite texture 7: Non-Planar - Porphyrotopic**

Single or patches of anhedral dolomite crystals floating dolomite crystals in a limestone matrix; crystals commonly have adulatory extinction (Plate 3-B).

According to Moore, 1989[17] three general dolomite types are noticed in studied sections:-

Scattered, coarse, euhedral dolomite rhombs with strong, often light crystal zone (cloudy center clear rimmed), generally associated with stylolite and pressure solution all suggest deep burial dolomitization (Plate 3-C).

Pervasive coarsely zoned crystalline dolomite (cloudy center clear rim) may exhibit fabric selectivity and well-developed porosity, or may form dense interlocking mosaics (Plate 3-A) and floating dolomite crystal (Plate 3-F). The late stage of dolomitization is represented by **Saddle dolomite texture**, which is common, as mentioned above, and generally occurs as very late pore-fill cement and is characterized by cloudy coarse crystals. Saddle dolomite destroys porosity and reduces permeability (Plate 3-D).

Compaction:

This process includes mechanical and chemical compaction, where:-

- Mechanical type is a process caused by sediments overburdening and resulting in a general reduction of the porosity and volume of the rock. The overburden of thickness (a load of sediments) necessary to produce the structures of compaction is controversial. Overburden is resulting in mechanical failure and fragmentation of the grains. Mechanical compaction is mainly followed by pressure solution which is recorded by the stylolite and seams of the solution [12] (Plate 4-A, B and C).

➢ Chemical type of compaction is represented by the pressure solution which results in stylolite's and seams of solution formed under the burial and overburden conditions [4] Solution seams are swarm-like parting or isolated which are distinguished by thin seams, often with insoluble residues accumulation [4] (Plate4-D).

Stylolites are wavy or rough seams of dissolution that evolve during the intergranular pressure solution [17]. Stylolization occurs due to tectonic stresses or an increase of overburdened pressure rock.

According to Koehna, et al., 2016 [19] classification there are 4 types of stylolites (Figure 4):

1- Rectangular layer is representing a sensible class without any addition of facing up or downwards. Some rectangular stylolites shapes can also develop normal roughening, and they have many different properties than the dominant typical layer (Plate 4-E).

2- Seismogram pinning shaped type which refers that the experiences of noises stylolite on several different scales and this type is important for the compaction features determination (Plate 4-G).

3- Suture sharp peaks type which represents a single class, because it is difficult to distinguish when a stylolite became a sutured shape and when it is a sharp peaked-shape. In the simulations these shapes can be resulting from the same noise and then differentiating them is not useful. The Suture sharp type would incorporate normal growth stylolites with only a small noise scale, as well as the stylolite layer growth where the old layer was gone. The latter is hard to distinguish from the stylolites with normal roughening, and therefore they are both included in one single class (Plate 4-F).

4- Simple wave-like stylolite type, which is uncommon in the present study (Plate 4-H).

The first two classes of stylolites typically are showing signs of pinning skeletal, non-skeletal grains or beds. While the other two types (suture/sharp peaks and simple wave-like stylolite) do not show any evidence of the larger scale pinning structure and only sometimes developed into straight teeth.

In the present study, all types of stylolites are present. The shape suggests formation during different stages of diagenesis or under different conditions, when dolomite appears associated with stylolites, this usually happened in the first type which indicates a late stage of diagenesis meaning that there is high compaction causes a decrease in porosity. In the suture and simple types, the stylolites form weak areas through which the hydrocarbon presents in it when a little compaction occurs and continuously increases compaction the seams were formed. The corroded morphology of some rhombic dolomite crystals within bitumen-rich stylolites may be attributed to the corrosive action carried out by organic acids. These events are typically attributed to post-stylolitization events, potentially able to open stylolites and make them pathways for corrosive fluids and bitumen formation [20].

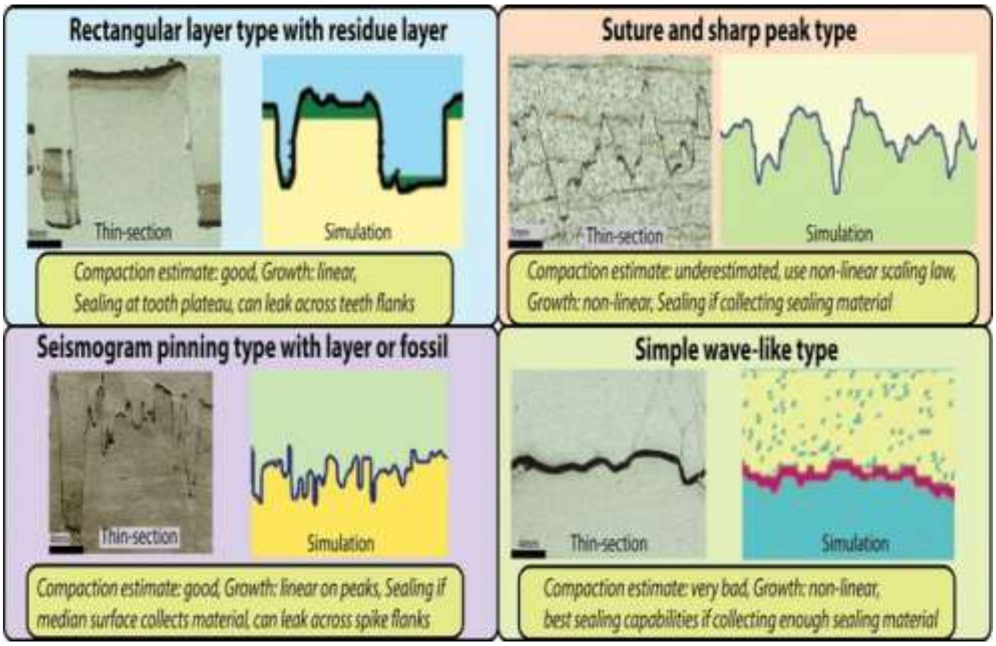


Figure 4: Stylolites types [After 18]

Dissolution

The dissolution process is occurring when the rock and water system is out of equilibrium. In this case, the water is under saturation with respect to CaCO3. For example, the meteoric water dissolves CaCO3 until the saturation equilibrium is reached between the rocks and water [3]. It is the result of the solution conditions of unstable minerals such as aragonite or high magnesium calcite, and the chemical composition of the pore water. The carbonate solubility is increasing with decreasing temperate and increasing acidity (decreasing pH values) [19, 20 and 21].

Dissolution may be occurring during any time in the burial stage of the carbonate succession development, after the mineral stabilization, will generally be characterized by non-fabric selective dissolution, where the forming pores cut across all the fabric elements such as particles, cement material, and the matrix [16]. These pore types are dominant called vuggs, caverns, and channels, which depend on the pores size [21]. These changes are most likely to occur during the early stage of diagenesis (eogenetic process), such as the evolution of the meteoric water system in the shallow shelf succession; late stage in the history of burial or late stage of diagenesis (mesogenetic processes), where the maturation of hydrocarbon or the dewatering of shale may be provided of fluids aggressive; or finally, during anytime or stage of the burial history, when carbonate rocks have been exhumed by an unconformity surface (telogenetic processes) and placed into the contact with the meteoric waters [22]. The processes of dissolution are controlling the zones of porous (secondary porosity).

Classification of porosity

The pore systems in carbonate rocks are much more complex than in siliciclastic rocks [21 and 23]. This complexity was resulting from the overwhelming biological origin of carbonate deposits and their chemical reactivity. Pore structures are the main control of permeability and petrophysical properties. In carbonate succession, the grains are shaped and the presence of intraparticle porosity as well as sorting has a large effective porosity. Many researchers have demonstrated the influence and effect of pore structure upon the petrophysical properties of carbonate successions.

The presence of the pore space within skeletal grains (shells) and non-skeletal grains (peloids) which make up the particles of the carbonate rocks increases the values of porosity over what would be expected from the interparticle porosity alone [11]. Although there is a complex relationship between the porosity values and carbonate fabric, it is an appearance by the inspection that intergrain pores size decreased with the smaller grain size and the closer carbonate grain packing.

Choquette and Pray [22] classified the carbonate porosity and provided a particular descriptive scheme incorporating all essential types of pores which were widely accepted and most commonly used in geological modeling is the genetic type of porosity classification which emphasizes fabric selectivity. The system is divided into two main genetic classifications: (1) the primary pore or the depositional porosity (Plate 5-H), which are porous inherent in the recently deposited sediments and the particles that comprise them and (2) the secondary type of pores system, which are those that forming as resulting of later, in a general post of the depositional stage. Because it affects of the relationship of the primary fabric rocks to the porosity type and the stage of porosity development. This classification of porosity is particularly well suited to the geological modeling that integrates the systems of depositional with the early to late stage of the diagenetic processes in order to determine the porosity evolution through time (Figure 5).

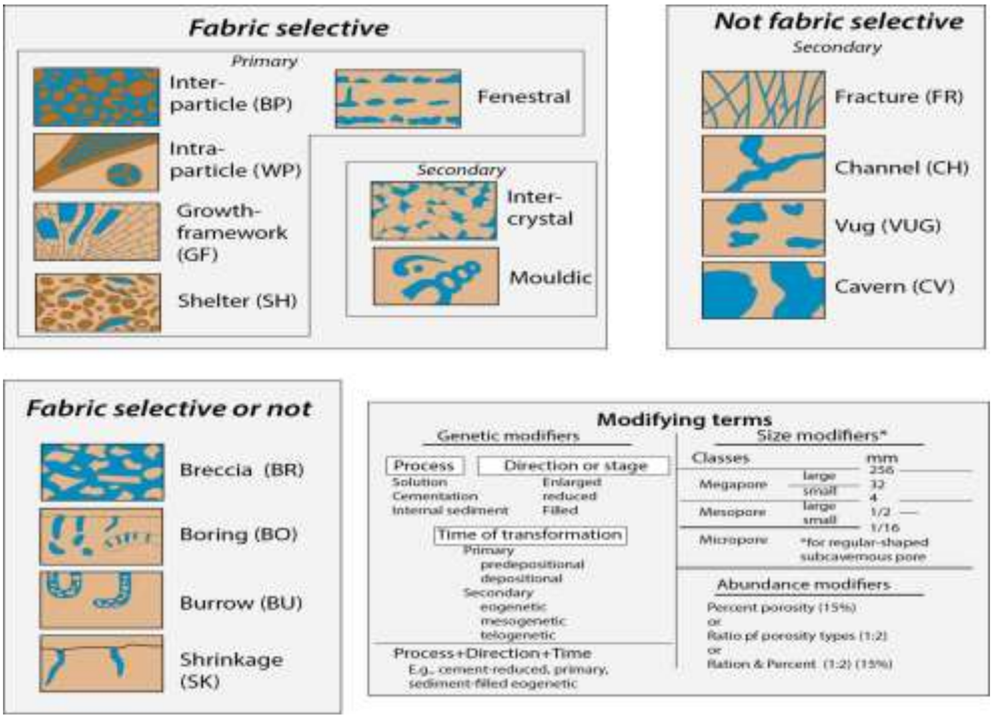


Figure 5: Pore type and porosity classification [After 21]

In primary porosity, pore boundary shape and location of the pore are determined completely by fabric elements, while in secondary pore systems, porosity may be either fabric selective or not, depending on diagentic history [24]. Different types of porosity were recognized in the Hartha Formation:-

Fabric-selective pores

The selective fabric type has their porous which defined by the elements of fabric for the carbonate rocks, such as particles or crystals [25].

- **Interparticle Porosity type**

They are space which occurred within particles either of the primary origin or forming through the decay the organic materials in the carbonate skeletal grains [26].

The interparticle type of pores is determined in the grains dominated carbonate rocks such as grainstone (Plate 5-B).

Some pores in the studied succession may be destroyed by the cementation and late stage of dolomitization processes.

- **Intra-particle Porosity type**

This type is representing the porosity type within the carbonate grains and particles, especially in the skeletal grains. Such the intarparticle porosity is commonly much localized and its effectiveness will be depending on the micro permeability of the carbonate grains and on the overall fabric of carbonate rocks [26].

This type of porosity is primary and rarely forms via dissolution processes and is associated with bioclastic wackstone microfacies. (Plate 5-A).

- **Intercrystalline porosity type**

This type of porosity between crystals may be secondary origin [26]. These types of porous are forming during the recrystallization or dolomitization processes. Another possibility for this type of porosity is selective dissolution, followed immediately by secondary cementation in the early stages (Plate 5-C).

- **Moldic Porosity type**

The moldic porosity type is entire of secondary origin of porosity [14]. They are formed by the completely selective or partial dissolution and/or grains or crystals recrystallization [27]. (Plate 5-D).

Non-Selective Fabric Pores

The non-selective fabric types of porosity cross-cut the actual fabric type of the carbonate succession [30]. The porosity that is not the selective fabric is entire of secondary origin type and forms as a result of the fracturing and/or solution [14].

- **Vuggy Porosity type**

It is a secondary type of solution pores which are non-selective fabric types [21 and 25]. Vuggy differs from the mold's porosity though, because they cross-cut the primary depositional carbonate textures and fabrics of this succession [26]. These pores are extremely irregular in distribution with no definite shape mode. It represents a solution enlargement of the selective fabric pores presumably due to the interface of meteoric water with seawater in subsurface environments (Plate 5-G).

- **Cavern Porosity type**

Cavern porosity and associated vuggy porosity are major features of hydrocarbon production from the reservoir units (Plate 5-H).

- **Fracture Porosity type**

It is a non-selective fabric and cuts across the carbonate fabric elements of the carbonate succession [24]. Fractures Porosity commonly results from tectonic deformation, solution collapse, or slumping which is associated with the evaporite forming or dissolution of limestone. The fractures porosity type is much dominated and can be greatly increasing the effective porosity or permeability of the carbonate rocks by many times. These types of porosity are mostly common in lime mudstones and wackestones. It may be formed through pressure solution and tectonic movements [27] (Plate 5-F).

- **Channel Porosity type**

Channel type of porosity is referring to the large irregular elongate porous, which is generally associated with the solution enlargement of the fractures [21, 22, 23, 24, and 25] (Plate 5-E).

Porosity development

The total pore volume may operate to increase by mainly two types of processes: - porosity generation by dissolution and porosity as a result of dolomitization [16, 26, 27, 28, and 29].
Fracturing another important process, generally acts to increase permeability rather than total pores volume.

- **Secondary porosity by dissolution**

Dissolution occurring later in the burial history of a carbonate sequence, after mineral stabilization, will generally be characterized by non-fabric-selective dissolution where the resulting pores cut across all fabric elements rather than being controlled by the preferential dissolution of certain fabric elements, such as grans. These pore types are commonly called vugs, channels, and caverns depending on size [21].

- **Secondary porosity associated with dolomitization**

Intercrystalline porosity associated with dolomite from an important reservoir type in a number of settings from supratidal /sabkha to normal marine sequence [30 and 31]. Enos and Sawatsky, 1981 [31] suggested porosity increased with increasing dolomite percentage during the early stage of diagenetic.

- **Secondary porosity associated with fractures**

Fracturing can take place at any time during the burial history of the carbonate sequence. Intense fracturing is present and affects the reservoir characteristics of the large world oil field [32].

Fracturing can be associated with faulting, folding, differential compaction, and hydraulic fracturing within over-pressured zones [32].

These late carbonate fracture fills commonly have associated hydrocarbons as stains and fluid inclusions [26, 27, and 28].

Impact of diagenesis on Hartha Formation

Diagenesis processes in Hartha Formation have overall accentuated the reservoir quality heterogeneity.

The reservoir quality evolution of the limestone has been affected by the following processes:-

1. Reservoir quality destruction by grain compaction mechanical and chemical (stylolitization causes decreases in porosity and permeability. When the stylolite evolves dissolution occurs, which precipitates cement nearby the stylolite and creating filling the pores affecting reservoir quality. According to [31] the porosity is in fact discontinuous through stylolite and affected by how the dissolution precedes between the stylolite walls. The permeability will be decreased because the matrix will be cemented adjacent to pressure solution seams which will be reduced. Cementation also causes destruction to Reservoir quality by filling the pore with different materials.

2. Reservoir quality enhancement has resulted from dissolution, and recrystallization, partial dolomitization, which was previously explained in porosity development.

3. Reservoir quality preservation, which resulted from dissolution with partial cementation.

According to (Figures 6, 7, 8, 9, and 10) the porosity increase in darker areas and can form effective porosity units. The diagenesis effect could destroy the porosity and form barrier units, compaction mechanical and chemical (stylolitization) causes decreases in porosity and permeability, late stage of dolomitization and the authigenic minerals destroyed porosity. Cementation could be preservation the porosity if it is partial, but it can be destructive if it is total by filling the pore in different material.

In Balad oilfield, the process led to seven units for well no. 2 and eight for well no.3 in Hartha Formation. While in East Baghdad the barrier units appeared with varying thicknesses and more units. The presence of

Reservoir quality enhancement has resulted from dissolution, neomorphsim, dolomitization in the early stage. Which appeared alternately with the barrier unit were three of them in the upper part of Hartha and the others in the lower part of Balad oil field with approximately the same thickness. While in Baghdad oil field showed high thickness in the lower part of Hartha and less thickness in the upper part except for EB-102, there is no effective zone in the bottom.

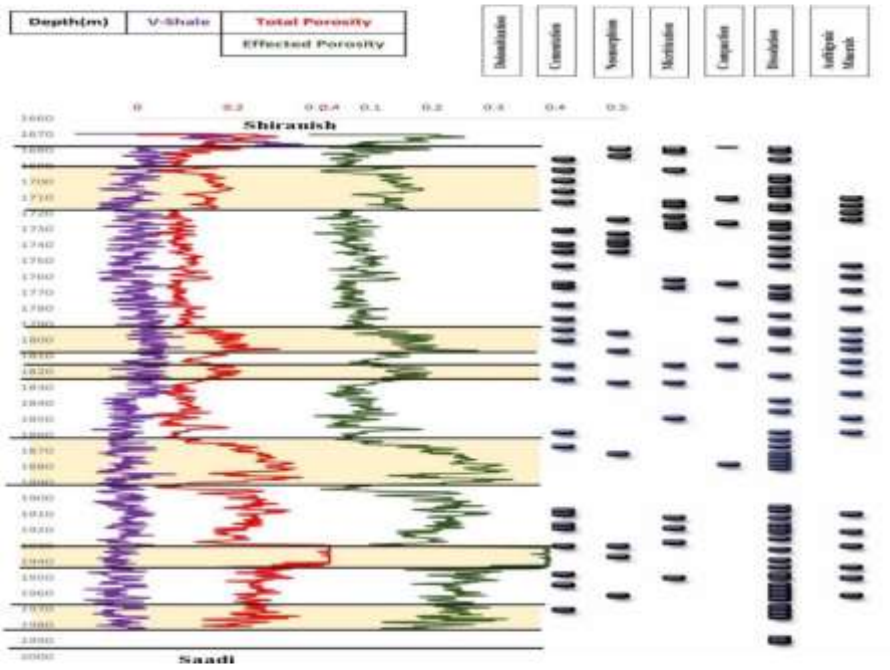


Figure 6- Porosity zone in well Ba-2

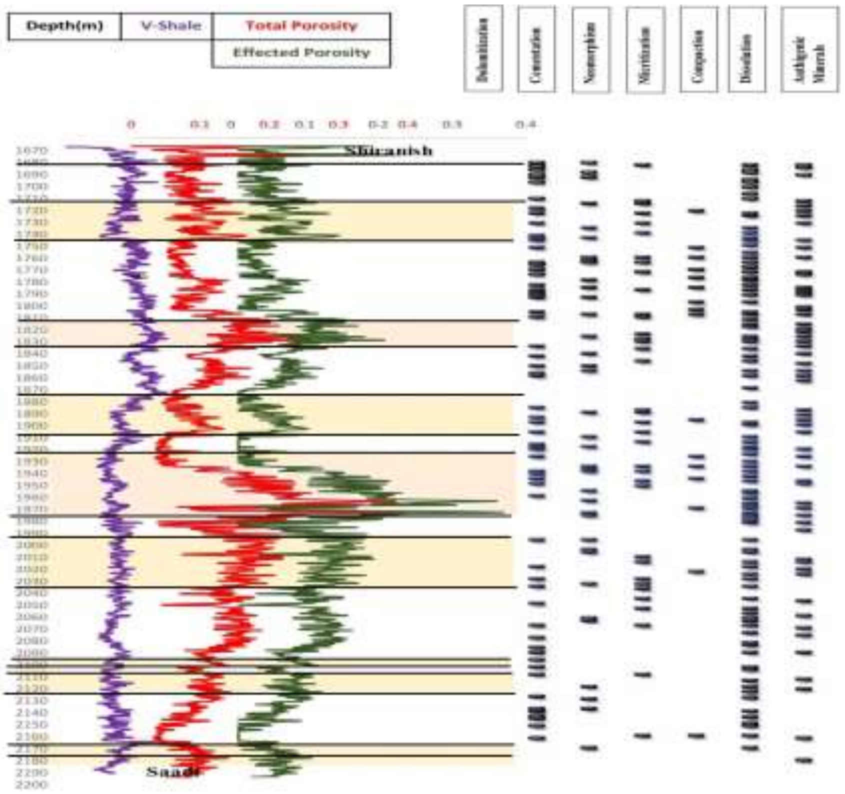


Figure 7- Porosity zone in well Ba-3

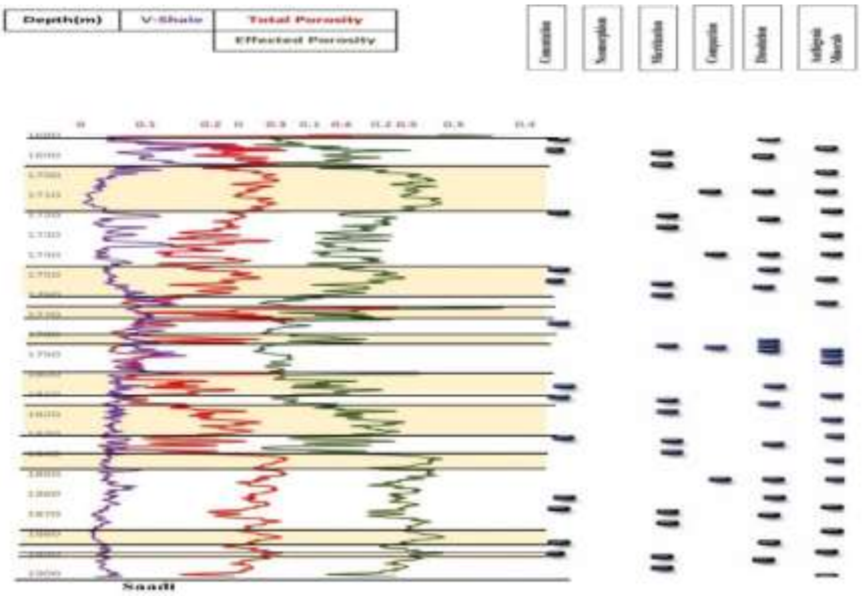


Figure 8- Porosity zone in well EB- 53.

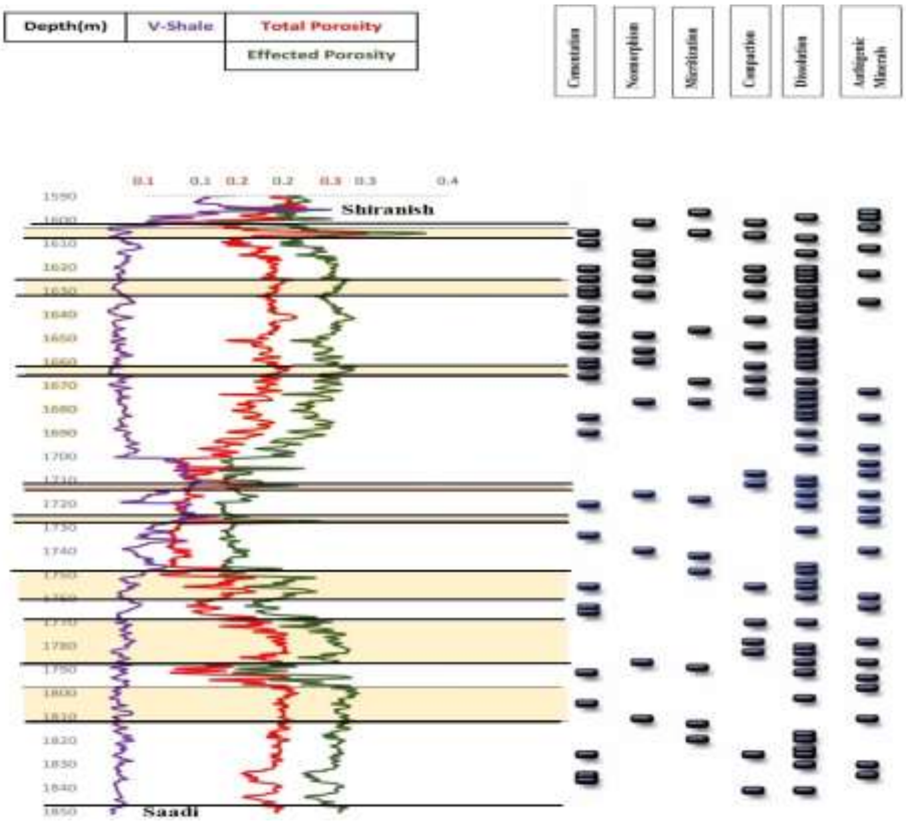


Figure 9: Porosity zone in well EB- 56

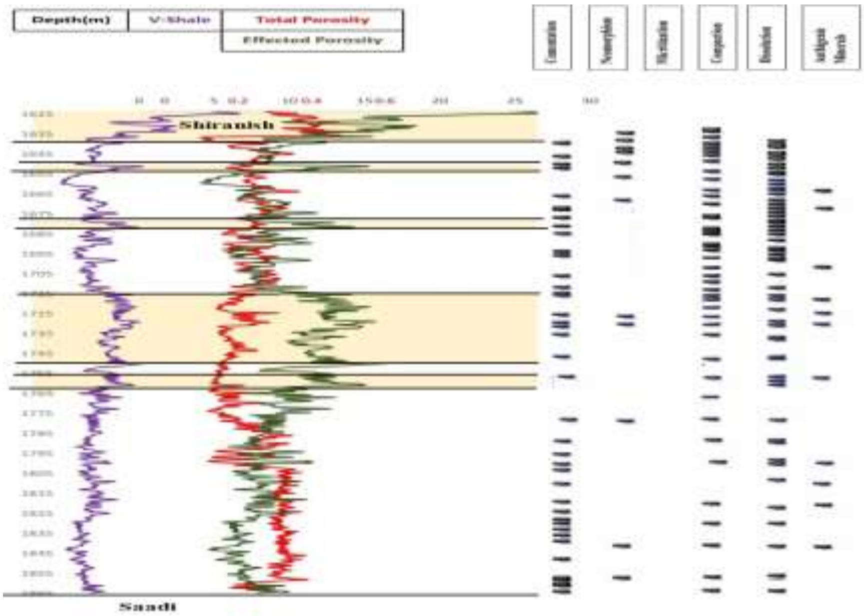
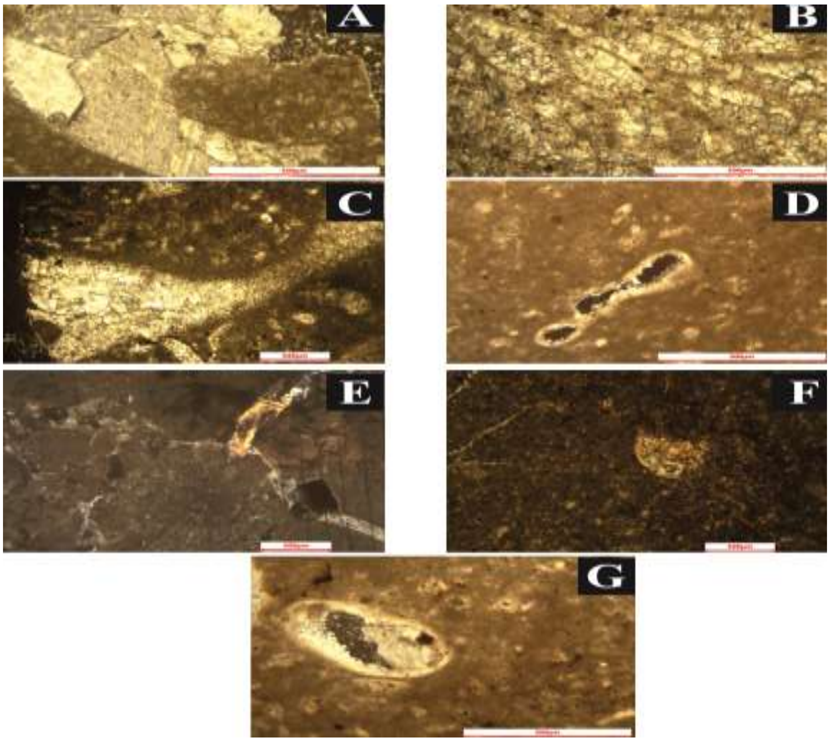


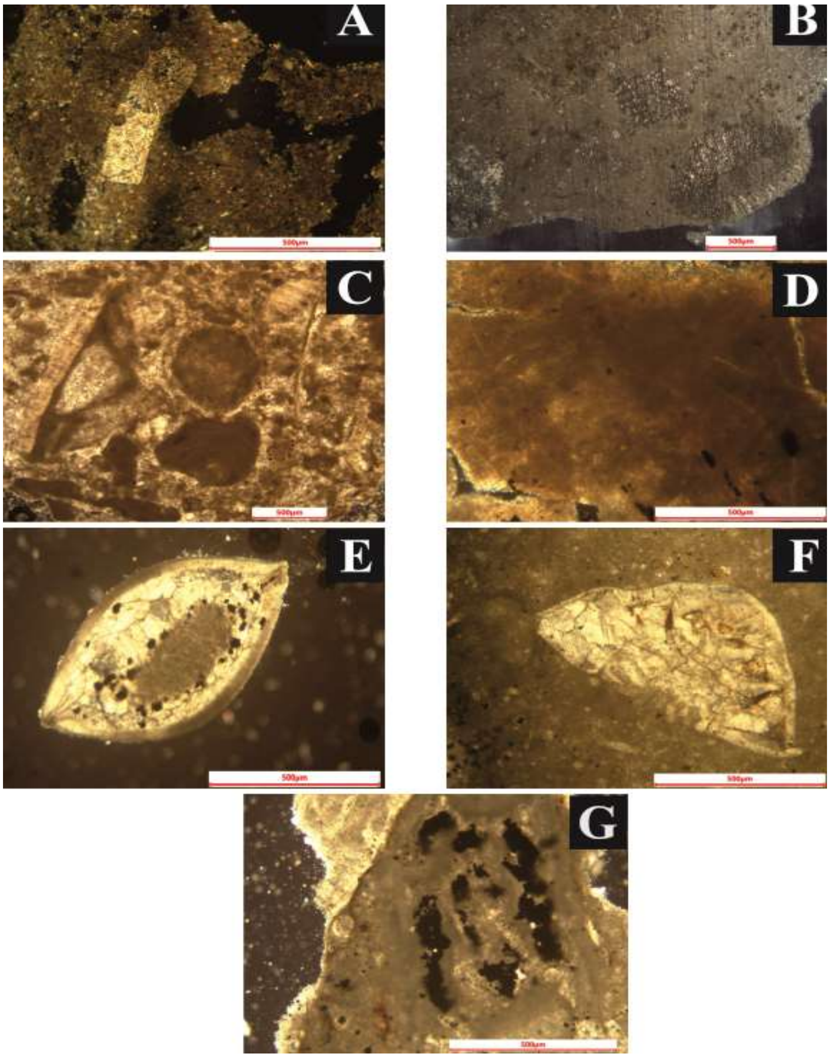
Figure 10: Porosity zone in well EB- 102

Plate -1-



A- Shell fragment fill with blocky calcite cement, Ba-3 Depth 2134m.
B- Orboitoids fill with granular calcite cement, Ba-3 Depth 1888m.
C- Rudst fragment with drusy mosaic cement, Ba-3 Depth 1682m. with
D- Bioclastic with Isopachus cement with intrapartical porosity, EB-53 Depth 1691m.
E- Anhydrite cement, EB-102 Depth 1686m.
F- Silica cement fill foraminifera, Ba-2 Depth 1850m.
G- Blocky and Isopachus cement, EB-56 Depth 1660m.

Plate -2-



A- Neomorphized replacement of anhydrite in Echinoderm fragment with microsparite groundmass, Ba-2 Depth 1924m.

B- Neomorphized replacement in Orbitoid fragment with microsparite groundmass, EB-102Depth 1840m.

C- Micritization, EB-56 Depth 1638m

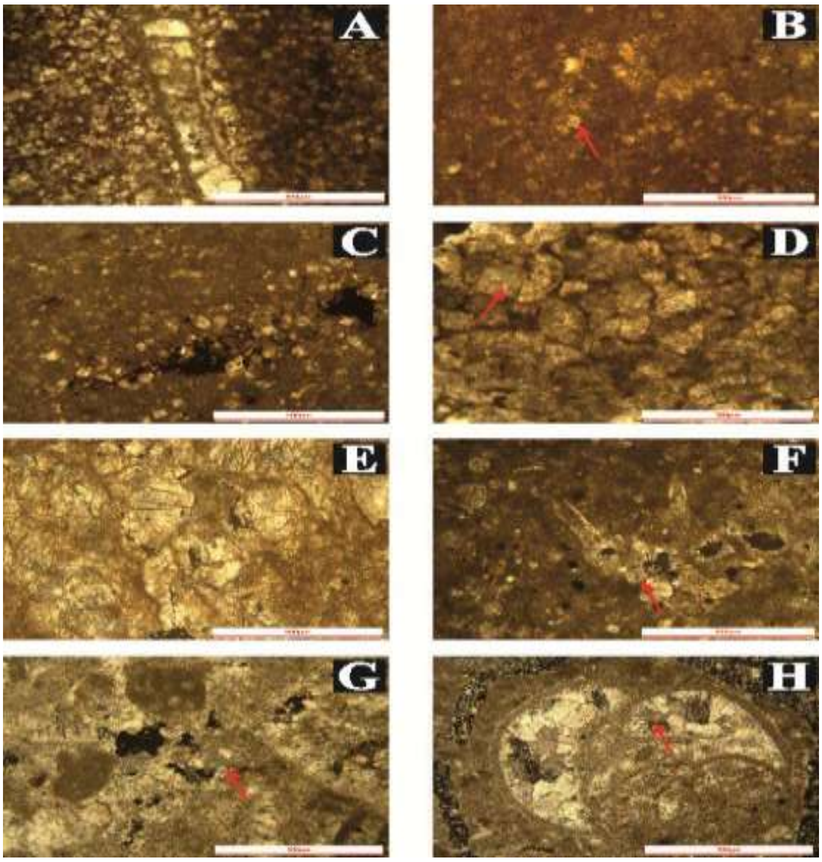
D- Pure micrite, Ba-2 Depth 1720m.

E- Ostracoda with authigenic minerals (Pyrite), Ba-2 Depth 1790m.

F- Rotaliida sp. with authigenic minerals (Iron oxide), Ba-3 Depth 1692m.

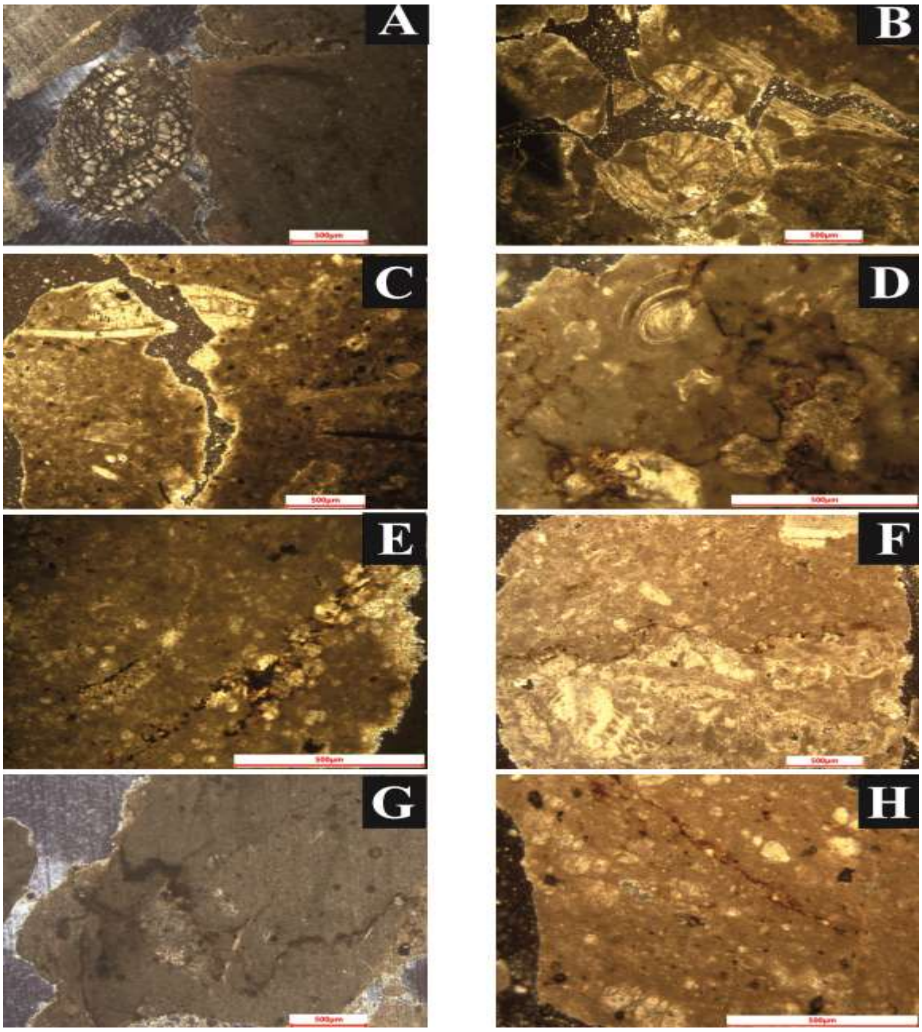
G- Highly destroyed Miliolids full iron oxide.

Plate 3



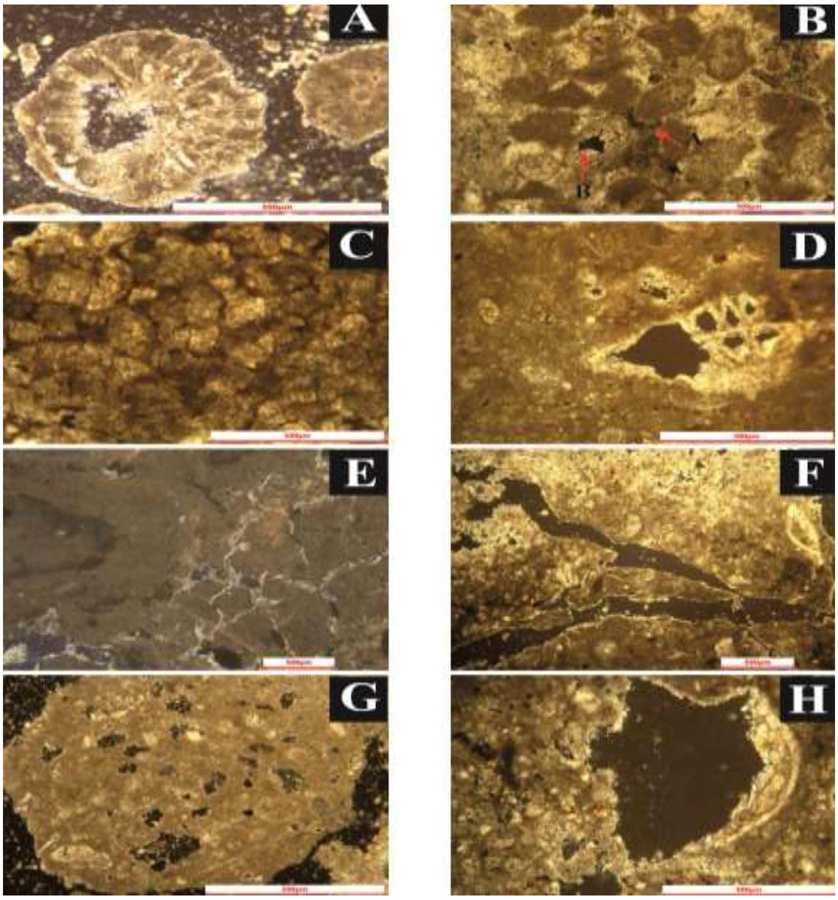
A. Planar –S dolomite**;** Pervasive crystalline dolomite, Ba-3 Depth 1685m.
B. Non Planar - Porphyrotopic fine scattered dolomite crystals in micrite matrix Ba-3 Depth 2040m
C. Scattered euhedral dolomite associated with styloite Ba -2 Depth 1710m.
D. Non Planer - S - A; Saddle dolomite, Ba-3 Depth 2076m.
E. Non Planar –Void Filling; Replaced fossil shells.Ba-3 Depth 2130m.
F. Planar - Porphyrotopic floating dolomite crystal,. Ba-2 Depth 1854m.
G. Planar-Euhedral; Dense and packed mosaics dolomite crystals EB-56 Depth 1626.
H. Planar Void-Filling, EB-56 1628m. Coarse crystalline dolomite (cement).

Plate 4



A- Mechanical compaction, EB-102 Depth 1698m.
B- Mechanical compaction, Ba-3 Depth 1804m.
C- Mechanical compaction with authigenic minerals, Ba-2 Depth 1842.
D- Chemical compaction (Solution seams), EB-65 Depth 1680m.
E- Rectangular layer type stylolite, secondary porosity associated with dolomitization full in hydrocarbon, Ba-3 Depth 1806m.
F- Suture/ sharp peak type styloite, contact between wackstone and packstone, EB-56 Depth 1664m.
G- Seismogram pinning type styloite, EB102 Depth 1690m.
H- Simple wave type stylolite, EB-53 Depth 1738m.

Plate -5-



A- Intrapartical Porosity type, EB-53 Depth 1855m.
B- A- Inter-partical Porosity type and B- Intrapartial Porosity type, EB-56 Depth 1642m.
C- Intercrystalline porosity type, Ba-3 Depth1684m.
D- Moldic porosity type, Ba-3 Depth 2000m.
E- Channel Porosity type, EB -102 Depth1702m.
F- Fracture Porosity type, Ba-3 Depth 1820m.
G- Vuggy Porosity type,EB-56 Depth 1654m.
H- Cavern Porosity type, Ba-3 Depth 1916m.

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