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SILICIFICATION IN THE RUS AND DAMMAM FORMATIONS IN SAMAWA AREA, SOUTHERN IRAQ

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ABSTRACT

Various diagenetic processes have affected the Rus and Dammam Formations of Eocene age. These include dolomitization, dedolomitization, neomorphism, micritization, dissolution, cementation and silicification. In the present study the prominent and distinguished diagenetic process that influenced the rocks of the studied boreholes is the silicification. The petrographic examinations confirm the presence of three main types of silicification including selective, pervasive and minor. The selective silicification is the most common type in the Rus Formation as pore- filling cement after dissolution of sulfates while in the Dammam Formation occurs primarily as replacement material and as late diagenetic void-filling quartz. The pervasive silicification occurs within the Dammam Formation particularly in the middle part where both matrix and bioclasts are completely silicified. Minor silicification only affects echinoderm plates in the Dammam Formation. The petrographic study of the subsurface rocks show that the silicification of the Rus Formation and few rocks of the Dammam Formation occur in meteoric environments as the silica replaced sulfates while the silicification of the Dammam Formation occur within a mixs zone environment where meteoric water, which is the carrier of silica, mixed with marine water producing a solution supersaturated with silica and undersaturated in calcite.

عمليه السلكته لتكويني الرص والدمام في منطقه السماوه جنوب العراق

وفاء فيليب بشير و بسمة اسعد السامرائي

المستخلص

أثرت على تكويني الدمام والرص لعمر الإيوسين عمليات تحويريه مختلفه، شملت عملية الدلمته، إعادة الدلمته، التشكل الجديد، المكرته، الإذابه، السمنته والسلكته. الدراسة الحالية شملت فقط العمليه التحويريه الأكثر بروزا وتمييزا في صخور الآبار المدروسه وهي عمليه السلكته. أكدت الدراسه البتروغرافيه وجود ثلاث أنواع رئيسيه من السلكته وهي الانتقائيه، الكامله والاقل شده. السلكته الانتقائيه هي من الأنواع الأكثر تواجدا في تكوين الرص كسمنت مالئ للفرغات بعد إذابه بلورات المتبخرات، أما في تكوين الدمام فتظهر العمليه بشكل إحلال وكسمنت مالئ للفرغات في عمليات تحويريه متأخره.

السلكته الكامله تواجدت في تكوين الدمام وبالأخص في الجزء الأوسط حيث أثرت كليا على الحشوه والمستاحثات. السلكته الأقل شده أثرت فقط على مستاحثات شوكيه الجلد في تكوين الدمام. كما أكدت الدراسه الصخاريه إن عملية السلكته لتكوين الرص وبعض صخور تكوين الدمام حدثت في بيئات تحويريه جويه والمتمثله بنطاق الماء العذب الذي يقع فوق المياه الجوفيه. أما عملية السلكته لتكوين الدمام فقد حدثت في بيئه مزج المياه الجويه الحامله للسيلكا بالمياه البحريه والناتج عنها محلول فوق مشبع بالسليكا وغير مشبع بالكالسايت.

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INTRODUCTION

Two formations (Rus and Dammam) are recorded in the studied boreholes. The Rus Formation was first defined by Bramkamp (1946, in Bellen *et al*., 1959) from the type section on the SE flank of the Dammam dome in eastern Saudi Arabia. For Iraq, a supplementary type section was introduced by Owen and Nasr (1958) in the well Zubair 3 on the Mesopotamian Zone of Southern Iraq. Al-Hashimi and Amer (1985) found that this formation is not exposed at the surface; but it is encountered in most subsurface wells of south and southwest Iraq. In this study, the Rus Formation is penetrated in four boreholes namely 1, 5, 7 and 8 while the Dammam Formation is recorded in all boreholes 1, 5, 7, 8, 9 and 10 and their core depth intervals are presented in Figure 1. The Rus Formation comprises thick beds of nodular and massive gypsum rocks which characterized by their gray to dark gray and waxy color, partly silicified claystone lithofacies, gypsiferous claystone lithofacies, dolomitized limestone with some gypsiferous fossiliferous miliolidic dolostone containing nodules of anhydrite and marl. Jassim and Goff (2006) found that the Dammam Formation consists mainly of neritic shoal limestone often recrystallized and/ or dolomitized, nummulitic in the lower part and miliolids-bearing in the upper part. In the present study the Dammam Formation comprises dolomitized limestone, intraclastic dolomitized limestone, nummulitic limestone and dolomitized nummulitic limestone which either partially or completely silicified. The Dammam Formation lies uncoformably over the Rus Formation. The contact is marked by greenish gray waxy claystone bed (Tamar-Agha, 1984). In the present study, the contact is taken at the first appearance of 3 meters of nodular gypsum in borehole1 while in boreholes 5, 7 and 8; the contact is marked by 5.6 – 0.3 and 34.3 meters respectively by the presence of gypsiferous calcareous claystone bed.

There are several studies dealing with the studied formations in the area. Hereinafter is a summary of the most important works. Al-Hashimi and Skocek (1981) found that the replacement of evaporite minerals by quartz is a common feature in the succession of platform sediments deposited on the eastern margin of the Arabian Shield and can be recognized variable textures and shapes of pseudomorphic quartz after gypsum. Al-Hasani and Skocek (1983) studied the origin and the importance of bipyramidal quartz in Dammam Formation. Tamar-Agha (1984) found that silicification is a common feature in these formations, particularly in the vadose zone. He added that chert in the Dammam Formation is common at certain levels and comprises a variety of silica polymorphs such as quartz filling the pores, cavities and fossil chambers while chalcedony is present less frequently and found as fillings to form rounded framboidal cavities, The nature of the chert is replacive and the replacement took place during the diagenetic alterations.

Yahya (1986) recognized two types of silica in the Dammam Formation **A)** Authigenic silica precipitated as cement in pores including mosaic quartz, bipyramidal quartz, microcrystalline granular quartz, spherulitic chalcedony and chalcedony overgrowth and **B)** terrigenous silica. Shather (2011) recognized silicification within the Dammam Formation in Samawa section as chert nodules within the nummulitic packstone. Ajar *et al*. (2012) studied petrographically the rocks of the Dammam Formation and recognized the pervasive silicification in basic sections within the bioclastic foraminifera, particularly in packstone and grainstone. These facies are subjected to severe dissolution where the original shapes of the bioclasts are still preserved and then to extensive silicification in which all the rocks are completely silicified by microquartz replacing groundmass and as cement filling interparticle, intraparticle, biomolds and cavities with equant subhedral to euhedral aggregates of megaquartz. Basher *et al*. (2015) studied the silicification in south Samawa area and found that the silicification is selective and only affects few shell fragments in the Dammam Formation and the appropriate chemical conditions to dissolve calcite and precipitation of silica includes supersaturation of pores solution by silica and decrease of pH and temperature.

The purpose of this study is to demonstrate the different types of silicification, focus on the fabrics of silicification, the extent of silicification, source of silica, paragenetic sequence and time of silicification.

This study is based on thirty five samples obtained from six boreholes drilled by the Iraq Geological Survey during execution of detail geological mapping in South of Samawa area Southern Desert of Iraq in 2013 – 2014 (Table 1 and Fig.1). The thin sections of these samples are examined petrographically by using polarizing microscope in order to describe and interpret the diagenetic silicification features, to observe the fabrics of silicification and to recognize different types of silica.

Table 1: The geographic co-ordinates and the core depths intervals of the of the Dammam and Rus Formations of the studied boreholes

Well no.	Geographic co-ordinate		Core depth intervals (m)	
	Latitude	Longitude	Dammam Formation	Rus Formation
1. BH1	31° 05' 00"	45° 07' 00"	2.8 – 122	122 – 126.8
2. BH5	31° 07' 37"	44° 56' 20"	2.0 – 131.5	131.5 – 143.5
3. BH7	30° 54' 54"	44° 59' 58"	5.8 – 69.5	69.5 – 136.5
4. BH8	30° 29' 16"	45° 06' 15"	1.8 – 107.4	107.4 – 141.7
5. BH9	30° 57' 33.5"	45° 12' 9.8"	2.5 – 109.7	– – –
6. BH10	30° 50' 51.8"	45° 14' 48.5"	1.4 – 104.2	– – –

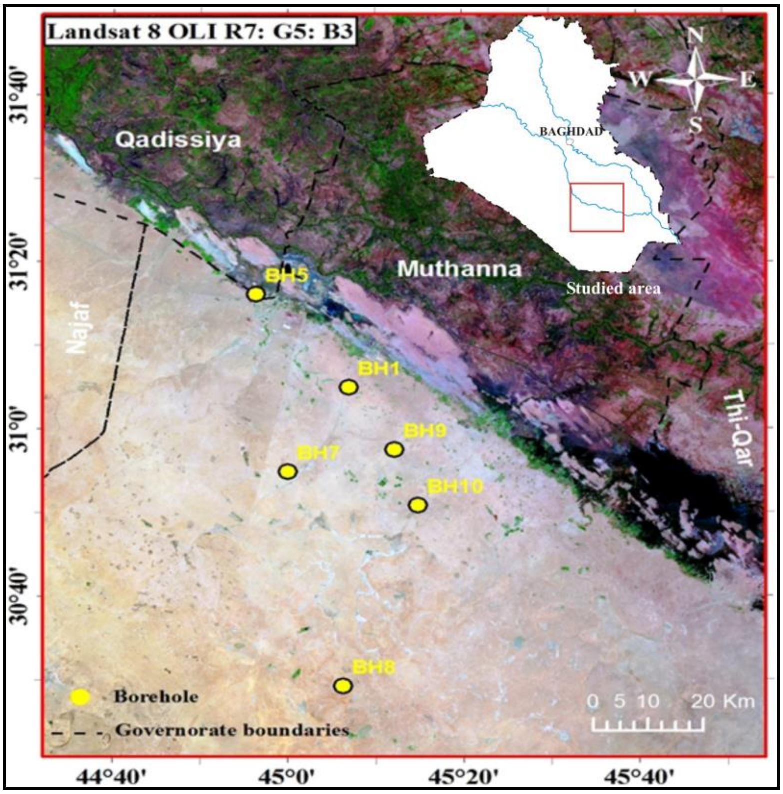


Fig.1: Location map and Satellite image of the studied boreholes

DISCUSSION OF THE PROCESS OF SILICIFICATION

In this study, the silicification is the ubiquitous diagenetic process affecting a variety of rock-types including gypsum, claystone and carbonates and ranges from selective to pervasive and minor. In gypsum and claystone, particularly in Rus Formation, the original evaporites are replaced by different kinds of authigenic silica while in Dammam Formation, the effect of silicification on carbonate rocks involving the partial or complete replacement of shell fragments by silica as well as precipitation of pore-filling silica cement. Silica precipitation in place of former sulfates is less abundant in Dammam Formation than in Rus Formation.

The silicification of Rus and Dammam Formations is described below and their distributions within the examined lithological columns are shown in Figure 8 – 13.

– **Silicification in the Rus Formation**

In Rus Formation, three different petrographic types of authigenetic silica are recognized including microquartz, megaquartz and chalcedonic quartz. These crystals are originated from direct precipitation as pore-filling cement and only developed in boreholes (5 and 7). It is common in the upper part of this formation within the claystone and massive gypsum lithofacies. The fabrics of silicification in these boreholes take the form of the original shape of sulfates (vanished evaporites) including isolated euhedral quartz (Fig.2A), isolated lath euhedral shaped (Fig.2B), isolated subhedral quartz crystal coated by rosette interlocking megaquartz (Fig.2C), subhedral isolated authigenic quartz overgrown by micrograined quartz and then coated by rosette (Fig.2D), subhedral coated by microquartz and then by megaquartz (Fig.2E), prismatic authigenic quartz coated by radial chalcedony (Fig.2F), prismatic megaquartz overlayer by chalcedony and then coated by granular aggregates of subhedral megaquartz (Fig.2G), subhedral megaquartz coated with several layers of fibrous chalcedony (Fig.2H), rosette consisting of subhedral macrograined quartz (Fig.2I), isolated spherulitic chalcedony (Fig.2J), spherulitic radial chalcedony overgrown by subhedral megaquartz crystals (Fig.2K) and mosaic of equant subhedral to euhedral radial megaquartz (Fig.2L). The occurrence of authigenic quartz euhedral as isolated or as aggregates are interpreted as filling voids created by dissolution of sulfate crystals (Friedman and Shukla, 1980). The isolated spherulitic chalcedony is considered as diagnostic of evaporite replacement and occurring as pseudomorphs of gypsum (Folk and Pittman, 1971). Chalcedony overgrown by microquartz and megaquartz cement is associated with evaporite silicification (Milliken, 1979 and Murray, 1990). These fabrics interpreted as filling pores created by dissolution of sulfate crystals which can indicate vanished evaporite. The silicification in this formation indicates a change in pH conditions of the pore solutions and the groundwater plays a decisive role in the sulfate dissolution and quartz precipitation. They are often found in facies affected by saline or hypersaline pore waters in intertidal environments or supratidal sabkha flats.

– **Silicification in the Dammam Formation**

Silicification is a diagenetic process affecting many carbonates facies although the silica forms minor components of these carbonates. It is manifested, in carbonates, by the partial or complete replacement by silicified biogenic remains and as cement filling pores. Petrographic examination of the core samples of the Dammam Formation in the study boreholes reveals the presence of selective, pervasive and minor silicification.

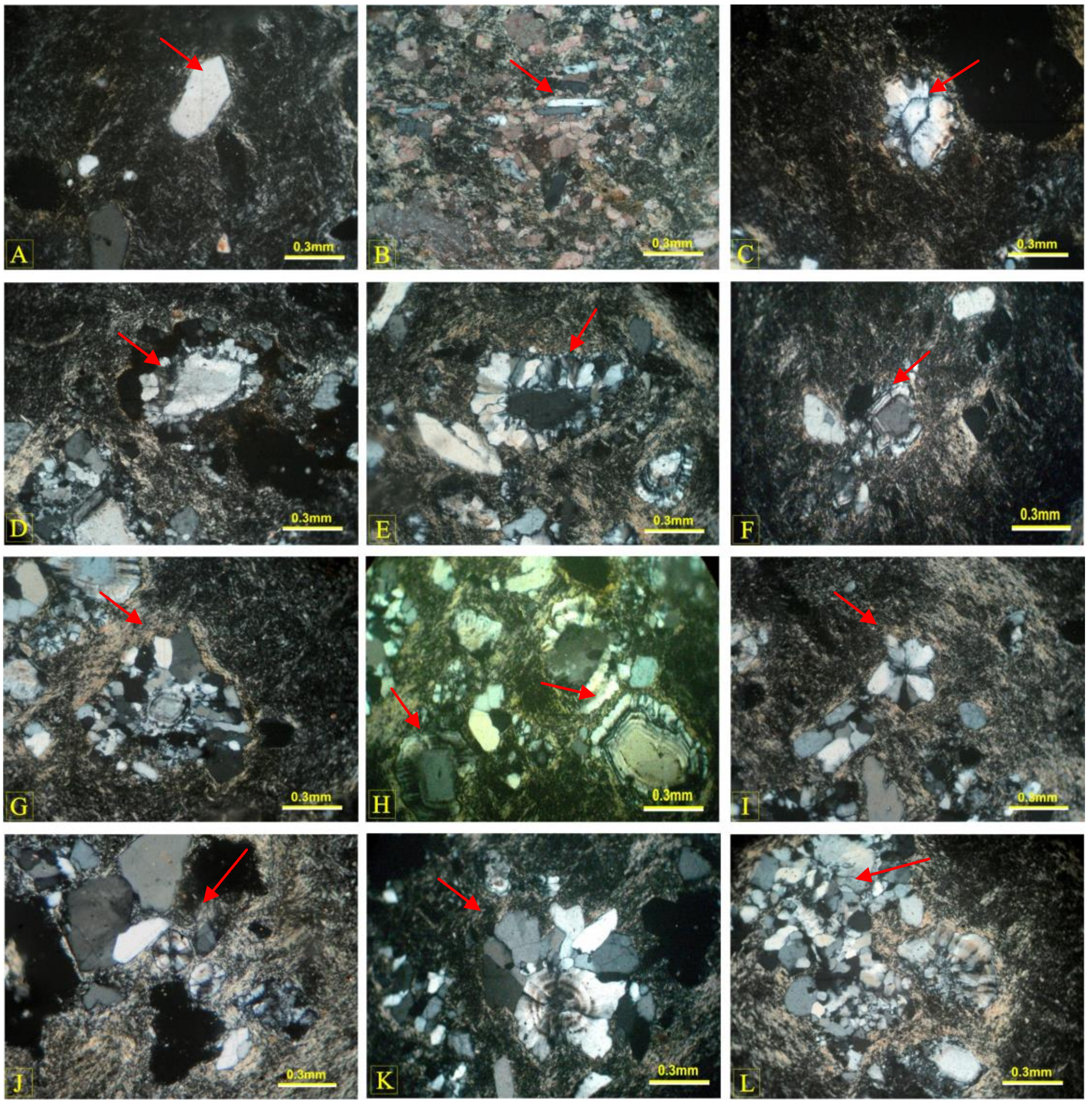


Fig.2: Silicification in the Rus Formation
A) Isolated euhedral quartz, BH.7, **B)** Isolated lath euhedral shaped, BH.5, **C)** Subhedral megaquartz coated by rosette, BH.7, **D)** Subhedral isolated authigenic quartz overgrown by micrograined quartz and then by rosette, BH.7, **E)** Subhedral coated by microquartz and then by megaquartz, BH.7, **F)** Prismatic authigenic quartz coated by radial chalcedony, BH.7, **G)** Prismatic megaquartz overlayer by chalcedony and then coated by granular aggregates of subhedral megaquartz, BH.7, **H)** Subhedral megaquartz coated with several layers of fibrous chalcedony, BH.7, **I)** Rosette consisting of subhedral macrograined quartz, BH.7, **J)** Isolated spherulitic chalcedony, BH.7, **K)** Spherulitic radial chalcedony overgrown by subhedral megaquartz crystals, BH.7 and **L)** Mosaic of equant subhedral to euhedral radial megaquartz, BH.7

– **Selective silicification**

Selective silicification is a common authigenic silica type observed in the carbonate rocks of the Dammam Formation. This type of silicification is developed at various depths and occurs primarily as replacement materials and as late diagenetic void-filling quartz as discussed below:

– **Selective silicification of bioclasts:** In this study, the shell fragments of pelecypods are found to be among the most affected bioclasts by selective silicification and either completely or partially replaced by fiberous chalcedony with a preferred orientation parallel to the shell microstructures (Fig.3A and B). The silicified shells occur particularly in crystalline dolostone which consist of ghosts of fossils and in nummulitic bioclastic wackestone/ floatstone in most of the studied boreholes. Hesse (1989) interpreted a "selective replacement" for this type of silicification as parts of the carbonate host rocks is unaffected and the other part is influenced by the diagenetic silica. In this type, the original texture of the shell fragments is almost completely preserved. The shell fragments consist mostly of fiberous in most of the core rocks and rarely prismatic crystals as in borehole 9 at 79.7 meter depth. The difference in the susceptibility to silicification may be related to the shell microstructure, biological group, skeletal mineralogy, size of organisms, and organic content of the bioclasts (Young and Rongyu, 2012). According to Maliva and Siever (1989), both microstructure and the bulk pore water silica concentrations control replacement of shells. The selective silicification of the shells may be attributed to organic matter acting in some way as a catalyst, which may increase carbonate solubility (Hesse, 1987). Jacka (1974) suggested that organic decomposition products create a special microenvironment conductive to silica- replacement.

– **Cementation of pore spaces by selective silicification:** Pore spaces filling by silica is common in the middle member of the Dammam Formation of boreholes (1, 8, 9 and 10). This process includes replacive minerals grow in the place of pre-existing minerals. Two minerals are recognized which selectively replaced by silica.

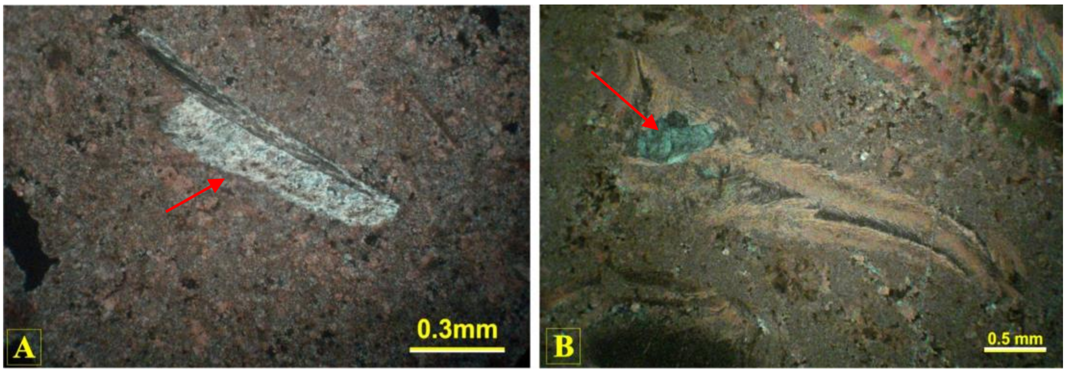


Fig.3: Selective silicification replaces bioclasts **A)** Complete replacement of shell fragments by fibrous chalcedony, BH.1 and **B)** Partial replacement of shell fragments by fibrous chalcedony, BH.5

– **Cementation of carbonate pores by authigenic silica:** This process involves cementation of pore space of carbonates by selective silica in crystalline dolostone, crystalline dedolostone and in the nummulitic facies particularly in wackestone and packstone/ floatstone. The reported authigenic silica is found to fill interparticle pores and vugs with mosaic of subhedral to euhedral interlocking megaquartz (Fig.4A), intraparticle pores (chambers of fossils) by crystals of megaquartz (Fig.4B), biomolds by microquartz grade into elongate subhedral to euhedral megaquartz towards the center of biomolds forming distinctive drusy silica (Fig.4C), intraskeletal pores filling by coarse mosaic of subhedral to euhedral interlocking radial megaquartz (Fig.4D) and rhombohedral pores (Fig.4E). Maliva and Siever (1988) found that silicification of calcitic fossils occurs along thin solutions films at which calcite dissolves and silica precipitates. Correlation among some replacement quartz types and fossil indicates that the shell microstructure and bulk pore water silica concentration control replacement quartz type (euhedral quartz terminations at some quartz-calcite contacts). According to Maliva and Siever (1988) the solution film must be supersaturated with silica and undersaturated with respect to shell carbonate. In boreholes (5 and 7), bryozoa are present consisting of vesicular tissue filled with radial quartz after cement of calcite. As a result, vesicular fabric can be responsible for this kind of silicification (Fig.4F). In addition, their skeletons originally may have consisted of low-magnesium calcite.

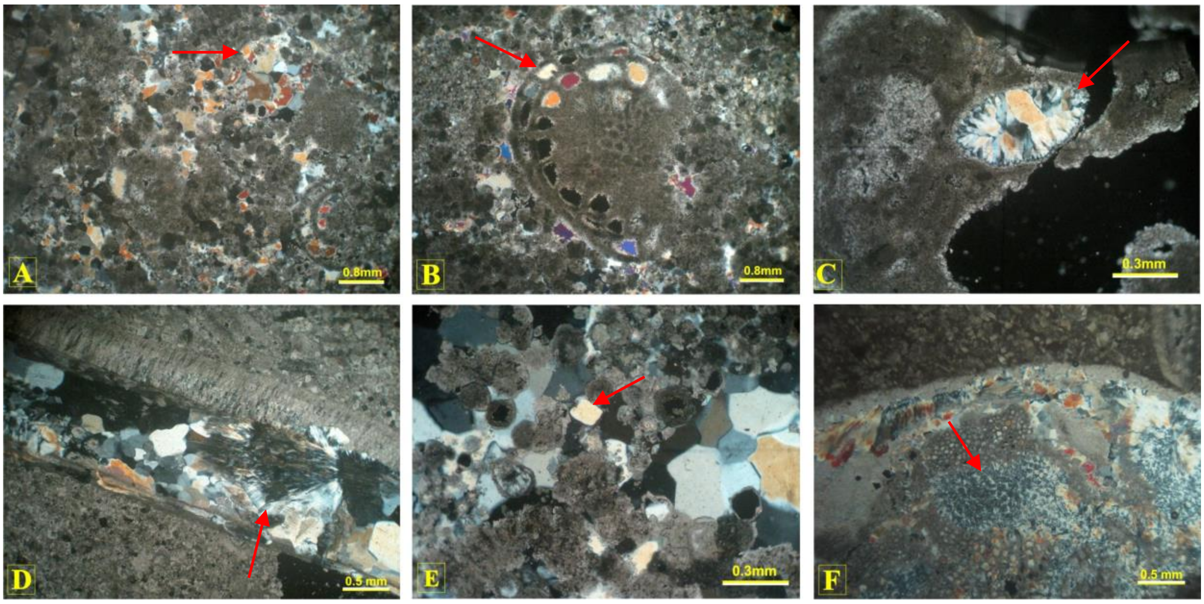


Fig.4: Cementation of carbonate pores by authigenic silica
A) Interparticle pores and vugs filled with mosaic of subhedral to euhedral interlocking megaquartz, BH.10, **B)** Intraparticle pores (chambers of fossils) filled by crystals of megaquartz, BH.10, **C)** Biomolds filled with drusy silica, BH.10, **D)** Intraskeletal pores filled by coarse mosaic of subhedral to euhedral interlocking radial megaquartz, BH.8, **E)** Rhombohedral pores filled with silica, BH.10 and **F)** Vesicular tissue of bryozoa cemented with radial quartz after cement of calcite, BH.9

– **Cementation of sulfate pores by authigenic silica:** Silica replacement of the former evaporite is limited in the carbonate core rocks of the Dammam Formation and occurs in boreholes (1, 8 and 9), particularly in the crystalline dolostone lithotype and in the gypsiferous dolomudstone facies. The silica seems to replace the original gypsum usually forming gypsum pseudomorphs including isolated idiomorphic quartz (Fig.5A) and rosette consisting of subhedral megaquartz (Fig.5B) leading to the conclusion that these quartz crystals may have been deposited in a hypersaline environment. The replacement of sulphate by silica can be explained by that the pore solutions in carbonates of arid climate exhibit often pH > 9 and are capable to dissolve some amount of silica. Undersaturated solutions of silica become unstable at contact with sulfate due to the sudden drop in alkalinity. This is the basic reason of silica precipitation in place of former sulfates (Al-Hashimi and Skocek, 1981). This type of silica took place at a late diagenetic stage.

– **Pervasive silicification:** This type of silicification is only developed in the middle member of the Dammam Formation of borehole no. (1) at 62.8 meter depth. The thickness of this bed is 1.7 meters. It is formed as a result of extensive process of silicification and only observed in nummulitic facies, particularly in bioclastic floatstone. In this facies, the silicification is not texture selective and attacks fabric of the rock and the whole of the rock becomes silicified.

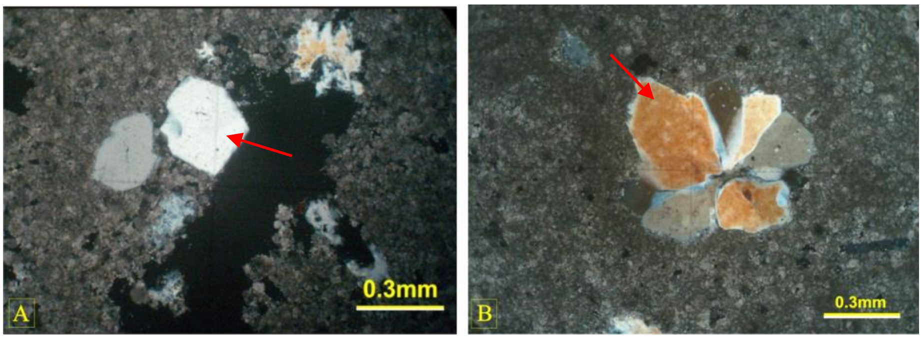


Fig.5: Cementation of sulphate pores by authigenic silica **A)** Isolated equant idiomorphic quartz, BH.1 and **B)** Rosette consisting of subhedral megaquartz, BH.1

– **Minor silicification:** In echinodermal bioclastic wackestone and echinodermal bioclastic packstone microfacies, the silicification is minor and only affected few fossils such as echinoderm plates (Folk, 1975). In echinoderm plates, the fabric of silica is found as pore-filling in the cellular shell structure. Microquartz and radial chalcedonic quartz occur in a radiating arrangement forming a spherulitic growth structures (Fig.7A and B). The spherulitic chalcedony occurs as coalesced masses within carbonate rocks indicating a diagnostic of carbonate replacement as in Folk and Pittman (1971), Fig.6.

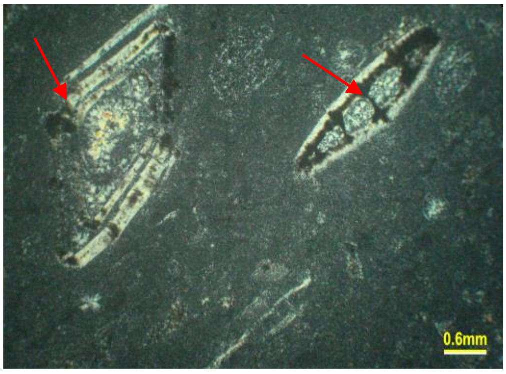


Fig.6: Pervasive replacement, BH.1

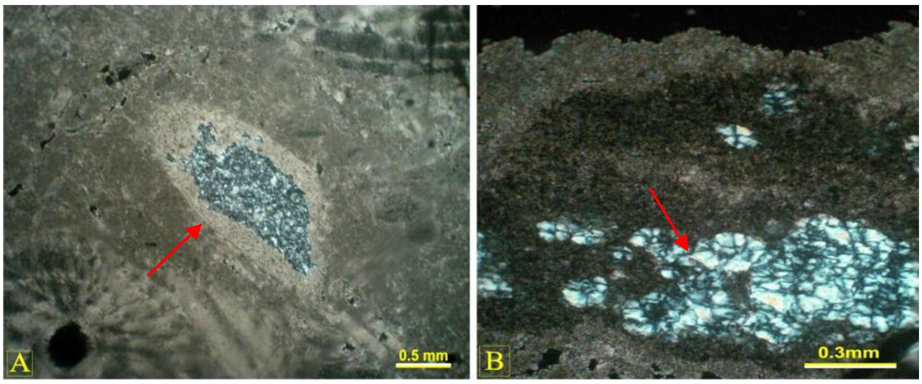
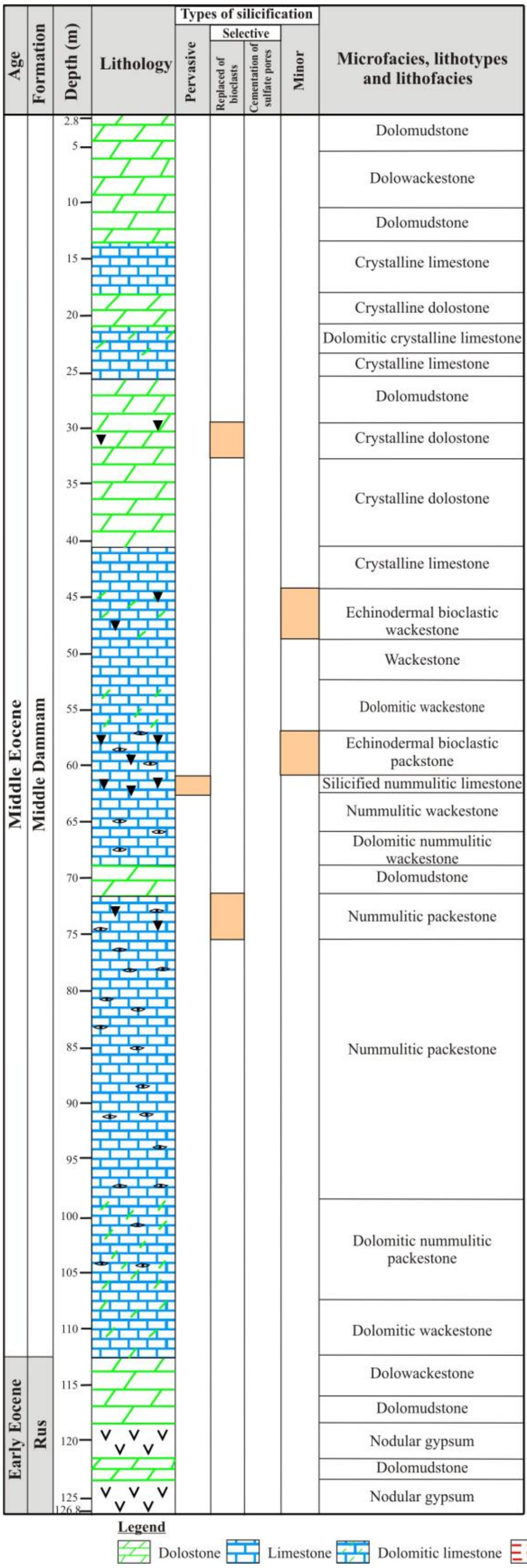


Fig.7: Minor silicification: **A)** The center of the echinoderm plates cemented with microquartz BH.1 and **B)** Radial chalcedonic quartz occurring in a radiating arrangement forming a spherulitic growth structures developing as coalesced masses indicating a diagnostic of carbonate replacement, BH.1



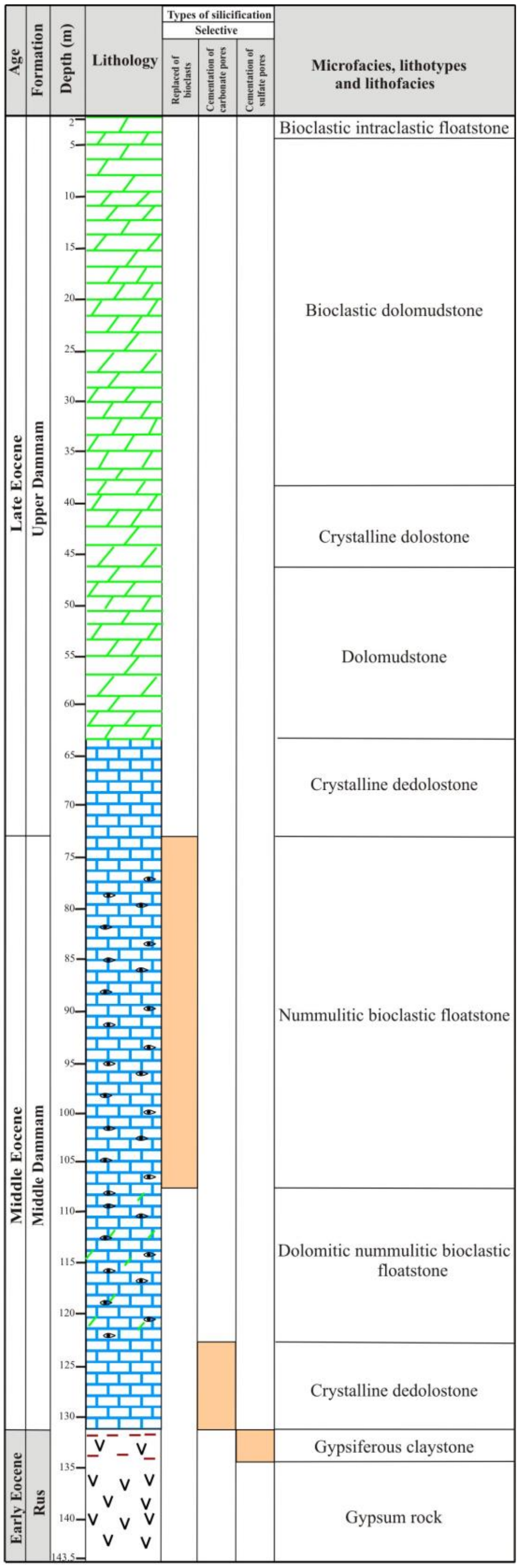
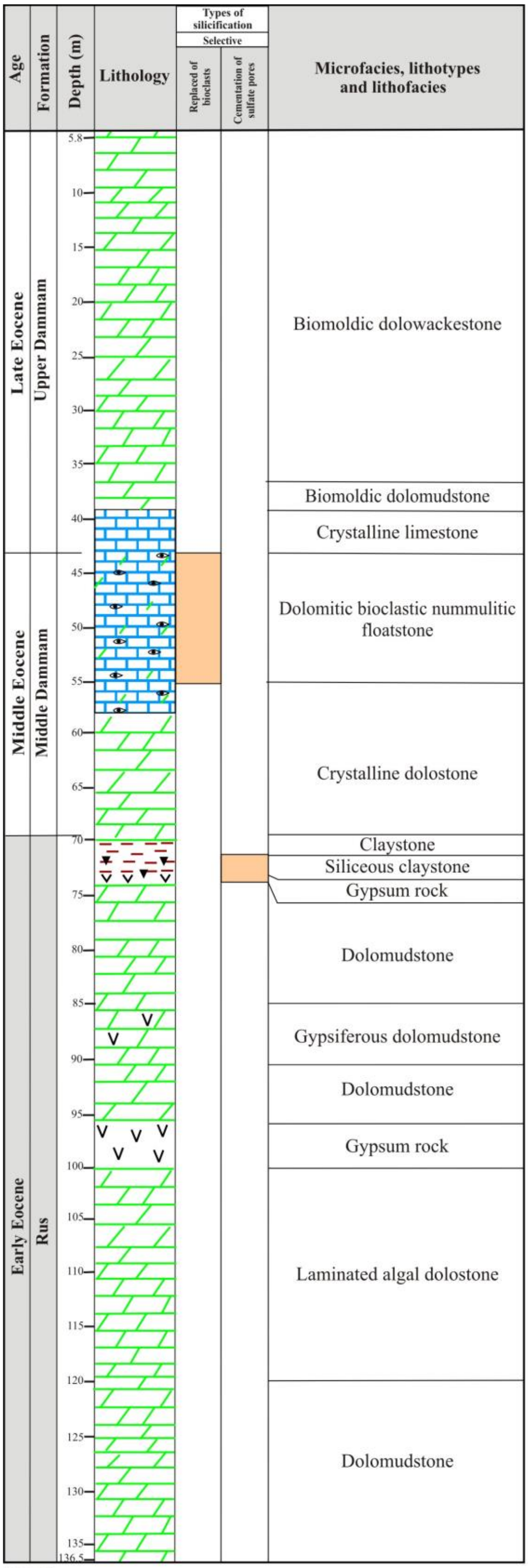
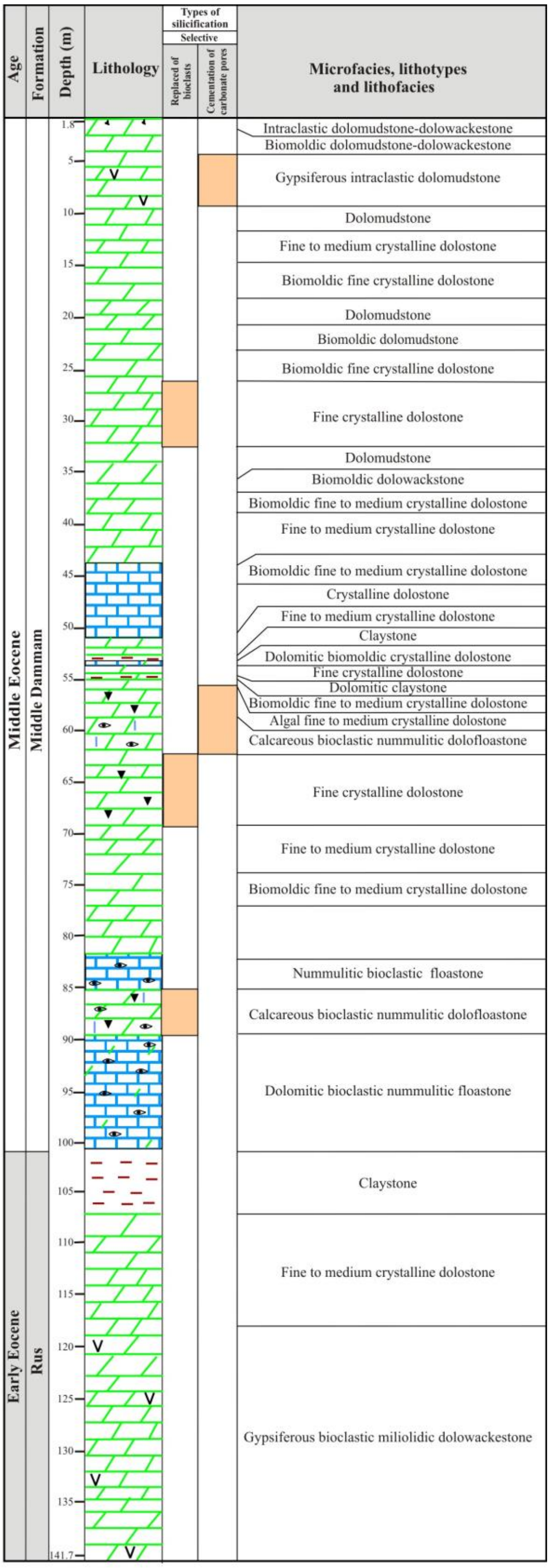


Fig.8: Columnar subsurface section of borehole 1 showing types of silica, microfacies and lithofacies

Fig.9: Lithological column of borehole 5 showing types of silica, microfacies, lithotypes and lithofacies





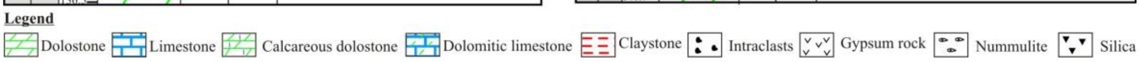


Fig.10: Lithological column of borehole 7 showing types of silica, microfacies, lithotype and lithofacies

Fig.11: Lithological column of borehole 8 showing types of silica, microfacies, lithotypes and lithofacies

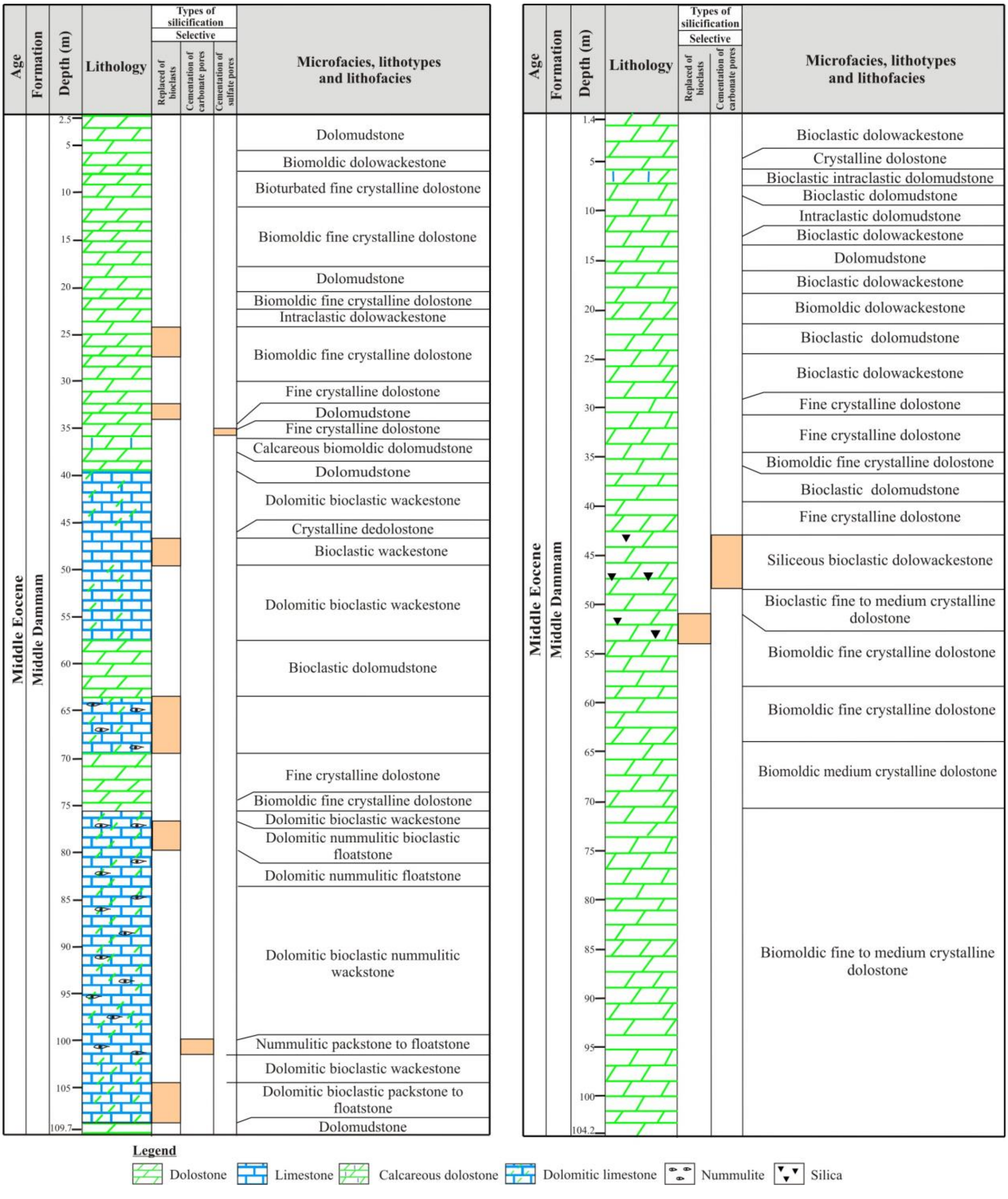


Fig.12: Lithological column of borehole 9 showing types of silica, microfacies and lithotypes

Fig.13: Lithological column of borehole 10 showing types of silica, microfacies and lithotypes

PARAGENETIC SEQUENCES

The paragenetic sequence shows the relative time of diagenetic processes effects in the studied boreholes which formed in the two main environments: meteoric vadose and mixing zone. Meteoric vadose diagenesis is common in Rus Formation and less frequent in Dammam Formation consisting of cementation of sulphate pores by authigenic silica. Diagenetic mixing zone processes in Dammam Formation consist of dissolution of bioclastic grains and cements forming the secondary porosity such as moldic, intraparticle, interparticle and vuggy which either filled partially or completely by silica. Pervasive and minor silicification as well as selective replacement of shell fragments also related to mixing zone. All these diagenetic processes occur within the eogenetic zone (near-surface diagenetic processes occurring in the time between the deposition of sediments and their burial within the zone of active surface-related processes and surface-promoted fluid migration). Sediments are mineralogically unstable; their porosity is medium to high, modified by dissolution, cementation and dolomitization. The features recorded in these sediments are given below (Fig.14).

- **Meteoric environment**

In most of the subsurface samples of the Rus Formation in this study particularly in claystone and gypsum lithofacies and few rocks of the carbonate facies of the Dammam Formation, selective authigenic quartz occurs as void-filling cement created by dissolution of sulfate crystals (gypsum). Descending meteoric waters in arid climate is one of the prerequisites of evaporite minerals precipitation and their replacement with more stable minerals due to their high alkalinity (Al-Hasani and Skocek, 1983).

The presence of different kinds of silica microfabrics recognized in this study (microquartz, megaquartz and fibrous chalcedony) provides unequivocal evidence for an evaporite precursor. These fabrics are mostly formed in fluids derived from the activity of meteoric water in the vadose zone and took place at late diagenetic stages. Silica replacement of former evaporite seems to be associated with meteoric water activity (Knauth and Epstein, 1976; and Geesling and Chafetz, 1982). Milliken (1979) found that all silicification of sulfates has probably occurred at temperatures of less than 40 °C.

- **Marine-meteoric mixing environment**

Petrographic observations show that pervasive silicification occurs within the nummulitic facies particularly in wackestone/ floatstone in middle part of the Dammam Formation. Knauth (1979) suggested a model for certification of carbonate in the diagenetic mixing zone between the meteoric vadose/ phreatic and the underlying marine zones where both dolomitization and silicification occur. In the mixing zone environment, the meteoric water which is the carrier of silica mixes with marine water producing a solution of low pH, undersaturated with respect to $CaCo_3$ but supersaturated with respect to quartz. This solution allowed the precipitation of authigenic silica (pervasive silicification). Migration of silica-rich solutions of the mixed meteoric-marine may be also responsible for minor silicification of echinoderm plates and selective silicification of the shells (Abu El Ghar and Hussein, 2005). The cementation of carbonate pores by authigenic silica is also reported within this environment.

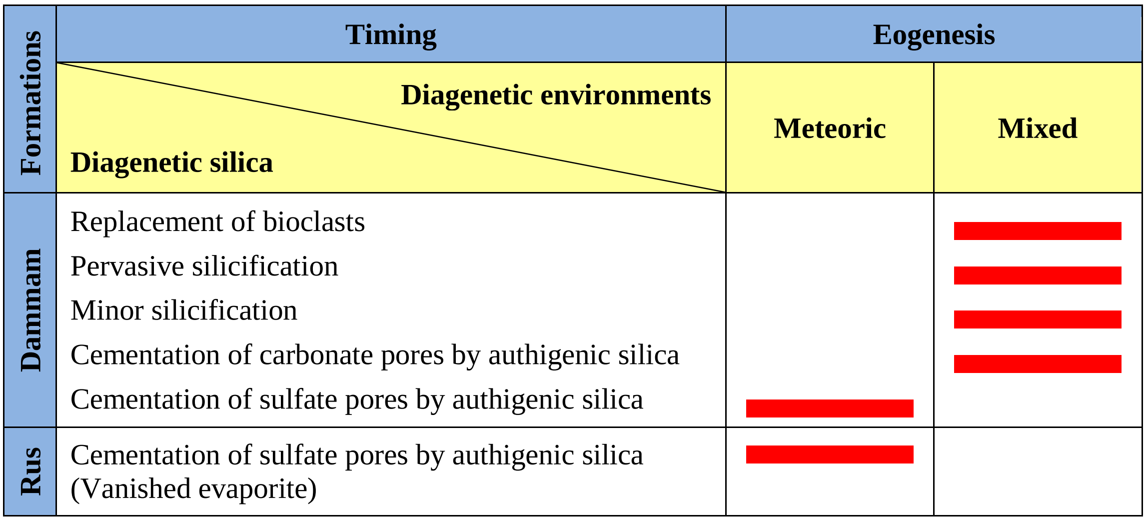


Fig.14: The major diagenetic environments of the formations in the studied boreholes

CONCLUSIONS

This study has the following conclusions:

- The silicification in the subsurface succession of this study involves replacement by silica and precipitation of silica in pores. Three types of silicification are observed in the Dammam Formation depending on the extent of silicification. Pervasive which is the most extensive type replacing micritic matrix as well as fossils. Selective is less extensive where part of the carbonate host rocks are unaffected and the other parts are influenced by diagenetic silica and minor silicification which is not extensive and less common in the rocks of the holes studied.
- Authigenic silica of the Rus Formation occurs in claystone and evaporite lithofacies while in Dammam Formation is reported in carbonate facies.
- Petrographic studies lead to the interpretation of two diagenetic stages including meteoric and mixed marine-meteoric environments.
- Mixed marine-meteoric environmental conditions caused the formations of different forms of silicification in Dammam Formation including the pervasive silicification, minor silicification, selective replacement of shells by fibers chalcedony and the cementation of carbonate pores by authigenic silica.

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