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The Diagenetic Processes History of Kometan Formation (Upper Cretaceous) in Azmir Anticline, Sulaimani Governorate, NE Iraq

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A BSTRACT

In This research, the effect of diagenesis processes has been examined on the Kometan Formation, a fractured carbonate petroleum reservoir in the northern Iraq, that dates from the Upper Cretaceous period., and is located within the tectonostratigraphic megasequence known as AP9 on the Arabian plate. The main objectives of this study involve examining the impact of different diagenetic processes on the Kometan Formation. This investigation is based on the analysis of twenty thin sections by using a polarized microscope, all collected from a specific region on the southwestern side of the Azmir anticline, located in the northeastern vicinity of Sulaymaniyah City. This study identifies several diagenetic processes that have influenced the Kometan Formation, including micritization, dissolution, cementation, neomorphism, silicification, compaction, fracturing, and pyritization. These processes have taken place across three diagenetic environments: marine phreatic, meteoric, and burial. Diagenetic processes of Kometan Formation are particularly prominent in burial and common in meteoric setting, and relatively rare within the marine phreatic conditions. These processes are classified into three distinct diagenetic stages: early (eogenesis), middle (mesogenesis), and late (telogenesis).

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تاريخ العمليات التحويرية لتكوين الكوميتان من العصر الطباشيري الاعلى في طية أزمر، محافظة السليمانية، شمال شرق العراق

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الملخص

تم في هذا البحث دراسة تأثير العمليات التحويرية على تكوين كوميتان، وهو صخور كاربوناتية مليئة بالكسور وخازنة للنفط في المنطقة الشمالية من العراق، يعود عمر التكوين الى العصر الطباشيري الأعلى ويقع ضمن التسلسل التكتوني الطبقي الضخم للصفيحة العربية المعروف ب AP9 . تتضمن الأهداف الرئيسة لهذه الدراسة تأثير العمليات التحويرية المختلفة على تكوين كوميتان من خلال تحليل عشرين مقطع رقيق تحت المجهر المستقطب من مقطع مختار على الطرف الجنوبي الغربي لطية ازمر المحدبة شمال شرق مدينة السليمانية. تحدد هذه الدراسة العديد من العمليات التحويرية التي أثرت على تكوين الكوميتان، بما في ذلك المكرتة والتحلل والسمنتة، والتشكل الجديد، والتكوين السيليكي والانضغاط والتحول الى البايرايت. وقد حدثت هذه العمليات عبر ثلاث بيئات تحويرية أساسية: البحرية، والنيزكية، والدفنية. تكون العمليات التحويرية لتكوين كوميتان بارزة بشكل خاص في الدفن وشائعة في البيئة النيزكية، ونادرة نسبيًا في الظروف البحرية. تم تصنيف هذه العمليات إلى ثلاث مراحل تطورية متميزة: المبكرة (التولد) والمتوسطة (التولد المتوسط)، والمتأخرة (التولد النهائي).

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Introduction

The Kometan Formation is a significant geological unit situated within the western part of the Zagros foreland basin, which hosts several major oil fields, including Hamren, Taq Taq, Khabaz, Jambur, Kirkuk, and Bi Hassan (Aqrawi *et al*., 2010). The original definition of this formation (Dunnington, 1953 in Bellen *et al.* (1959). The designated type section for studying this formation is located in the vicinity of the Kometan and Endezah villages, situated to the north of Rania in northeastern Iraq. This formation in type section is characterized by approximately 36 meters of lightly colored, thinly bedded limestone containing globigerinal-oligosteginal composition. In certain areas, silicification is observed, with the presence of chert nodules and glauconite, particularly at the formation's base. Belonging to the Upper Cretaceous period, the Kometan Formation serves as a vital petroleum reservoir composed of fractured carbonate rocks in the northern region of Iraq. It occupies the lowermost part of the tectonostratigraphic megasequence AP9, which spans from the Late Turonian to the Danian period (Sharland *et al.*, 2001). The Kometan Formation, which is particularly prominent in the Sulaimaniyah province within the Kurdistan Region of northern Iraq, is widely recognized by various researchers (Kaddouri, 1982; Al-Jassim *et al*, 1989; Abawi and Hammoudi, 1997; Hammoudi and Abawi, 2006; Haddad and Amin, 2007; Jaff *et al*., 2015; Balaky *et al*., 2016; Assad and Balaky, 2020; and Sulaiman *et al*., 2023).

Their findings collectively indicate that the Kometan Formation spans from the late Turonian at its base to the early Campanian at its uppermost section from north and northeastern Iraq.

The goal of this research is to investigate the formation's diagenetic processes and showing the logical sequence of the major diagenetic events that affected Kometan Formation in the studied section.

Geological setting

The area under investigation is situated on the southwestern limb of the Azmir anticline, located northeast of Sulaimani City at the longitudes 45^0 28^- 310 E and latitudes 35^0 36^- 129 N (Figure 1). According to the Tectonic subdivision of Iraq (Jassim and Goff, 2006), the studied section falls within the High Folded and Imbricated zones. Specifically, it is part of the Balambo-Tanjero tectonic zone, which is recognized as one of the four zones within Iraq's unstable shelf (Aziz and Lawa, 2001). The prominent anticline in the region is the Azmar Anticline. The flank of the Azmar Anticline comprises Late Cretaceous soft rock formations, including the Tanjero and Shiranish formations, while the limbs of these anticlines consist of Early Cretaceous carbonates. The core of the anticlines is generally formed by Early Cretaceous to Jurassic formations. The geological setting in the Sulaimaniyah-Azmar area is notably intricate. The core of the Azmar anticline is primarily composed of the Sarmord and Lower Balambo formations (Karim *et al*., 2013). However, Ahmed *et al*., (2016) indicate that the core of this fold consists of Berriasian-Valanginian rocks of the Balambo Formation, which outcrop along the Sulaiymanyah-Azmar main road.

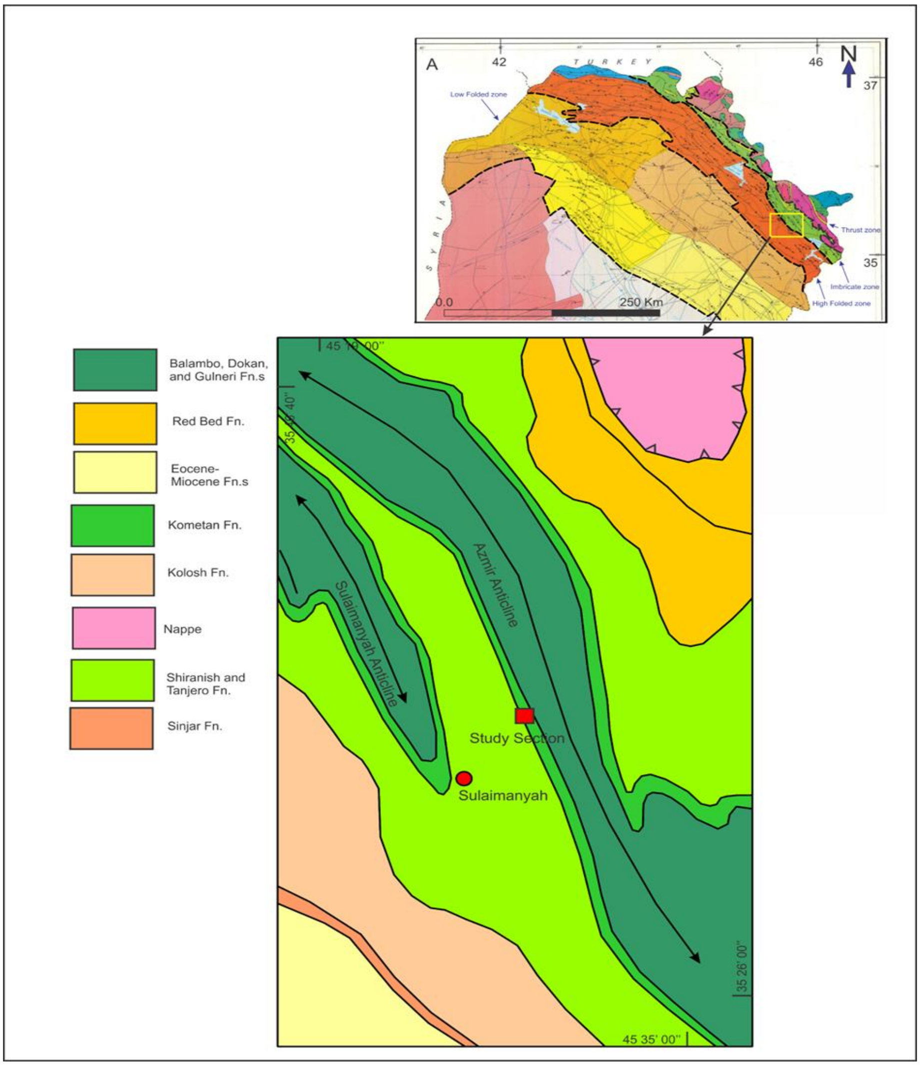

Fig. 1. Regional and tectonic maps of the studied area.

The studied section is situated on the northeastern periphery of the Arabian platform and is distinguished by extensive folding and faulting (Amin, 2009). The structural makeup of this region has been molded by two significant tectonic occurrences: obduction during the Late Cretaceous period and subsequent uplift in the Late Tertiary (Jassim and Goff, 2006). According to Al-Qayim *et al.,* (2012) during the period of Late Cretaceous formed foreland basin with flexural subsidence outcome by the obduction of radiolarite- melange, and associated magmatic bodies over the Arabian margin. The type and composition of forland basin are the huge amount of the detrital flysch sediments. Several studies on the base of sedimentological, stratigraphic, and paleontological analysis, concluded that Kometan Formation deposited in a deep marine environment (Ameen, 2008; Balaky, *et al*., 2016; Malak, *et al.,* 2021; Al-Hazaa, *et al*, 2021; Taha, 2022; and Sulaiman *et al.*, 2023;).

Materials and Methods

Two main methods were used to complete this study: First of all, the fieldwork, through this all the field outcropped features, such as toughness, color, layer thickness, the characteristics of interlayer contacts, and various other physical attributes, were thoroughly described. Additionally, the study examined both vertical and lateral variations within the layers. A total of twenty rock samples were gathered from the outcrops of Kometan Formation. Secondly, twenty thin sections were meticulously prepared for detailed analysis in the laboratory facilities of the Department of Geology at Sulaimani University.

Results

Stratigraphy

In the studied area, Kometan Formation has an approximate thickness of around 80 meters on the southwestern limb of the Azmir anticline, situated in the northeastern vicinity of Sulaymaniyah city. This formation primarily consists of finely grained limestone, ranging in color from white to yellowish. The limestone beds are well-defined and often contain chert nodules, which are irregularly scattered but tend to exhibit a horizontal arrangement in the middle of the formation (Figures 2 and 3). Towards the upper part of Kometan Formation, stylolite structures have developed, running parallel to the bedding planes of the limestone. The formation of these chert nodules in Kometan Formation has been attributed to various factors, both replacement and cementation processes. According to McBride and Folk (1979) the chert beds could have resulted from the diagenetic organization of silica or the complete replacement of limestone layers by silica. (Price, 1977) proposed that additional sources of chert units could be depositional, occurring below the carbonate compensation depth (CCD), in the absence of internal sedimentary structures, with continuous and gradual sedimentation leading to the formation of extensive chert beds and a uniform rain of radiolarians. Numerous studies (Youkhanna, 1976; Abawi and Hammodi, 1997; and Al-Khafaf, 2005) have been focused on determining the age of formation, which has been identified as Late Turonian to Early Campanian. The upper boundary of the Kometan Formation is unconformable with the overlying Shiranish Formation. The presence of Thalassinoides burrows on the hardground surface at the top of Kometan Formation and the unconformity surface are clear indicators of bioturbation (Glossifungites ichnofacies) (Buday,1980; Malak, 2015; Ameen and Gharib, 2014; and Jaff *et al*., 2014 and 2015). However, Taha and Karim (2009); Taha (2008); and Karim *et al.,* (2008) who argue that this boundary is conformable. The lower boundary of Kometan Formation is established by its contact with the Gulneri Formation (Al-Khafaf, 2014; and Karim *et al.*, 2013, 2016, and 2018). This same contact is also recognized in the Dukan area (Bellen *et al.,* 1959; Ameen and Gharib,2014; and Malak *et al*., 2021). According to Taha and Karim (2009), this lower contact between the Kometan Formation and the Gulneri Formation in the Dukan area is considered conformable. Conversely, the Kometan Formation overlies the Qamchuqa Formation within an imbricated zone (Asaad and Balaky, 2020).

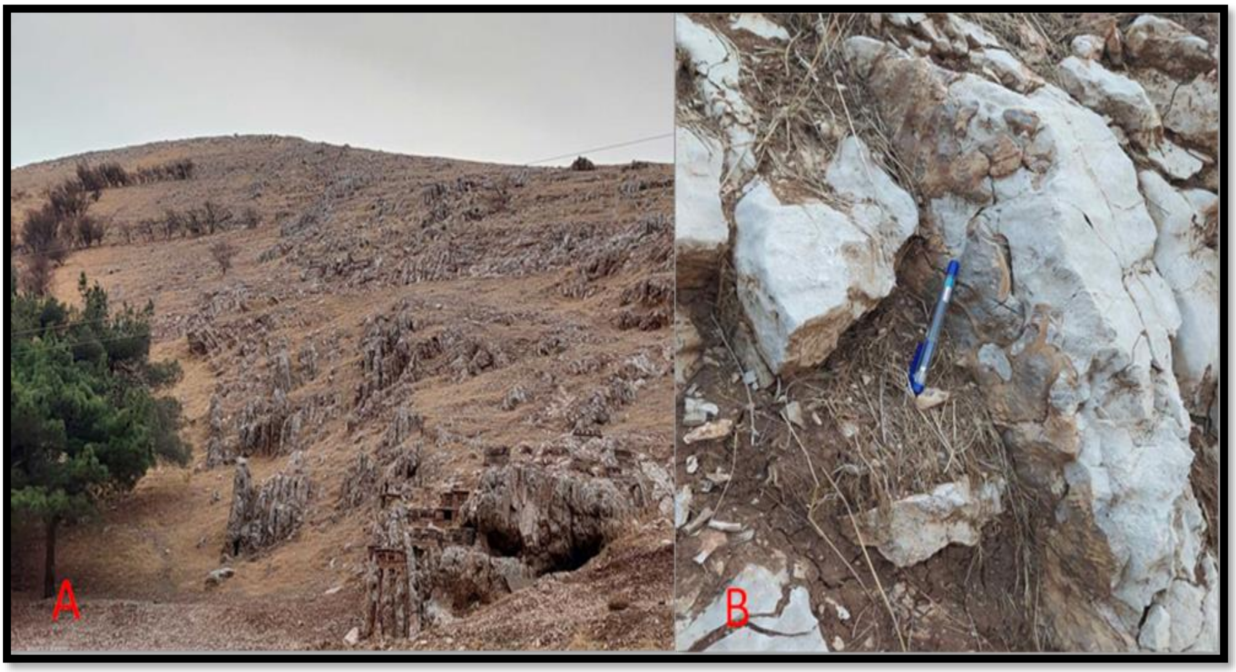

Fig. 2. (A) Highly joint and fracture well bedded limestone of Kometan Formation, (B) chert nodules horizon pattern presents in the middle part of Kometan Formation.

Petrography

A total of twenty thin sections were prepared for petrographic analysis. The results of this analysis reveal that this formation is predominantly composed of a micrite groundmass along with various types of skeletal grains, particularly planktonic foraminifera. Notable species within this foraminiferal group include *Gansserina gansseri, Globotruncanita conica, Globotrancana arca*, *Muricohedbergella holmdelensis*, *Planoheterohelix planata*, *Planoheterohelix globulosa*, *Planoheterohelix reussi*, *Marginotruncan coronata*, *Whiteinella brittonensis*, *Helvetoglobotruncana helvetica*, *Whiteinella aprica*, *Marginotruncana* sp., *Dicarinella primitive*, *Hedbergell delrioensis*, and *Globotruncana* sp., with rare instances of calcispheres.

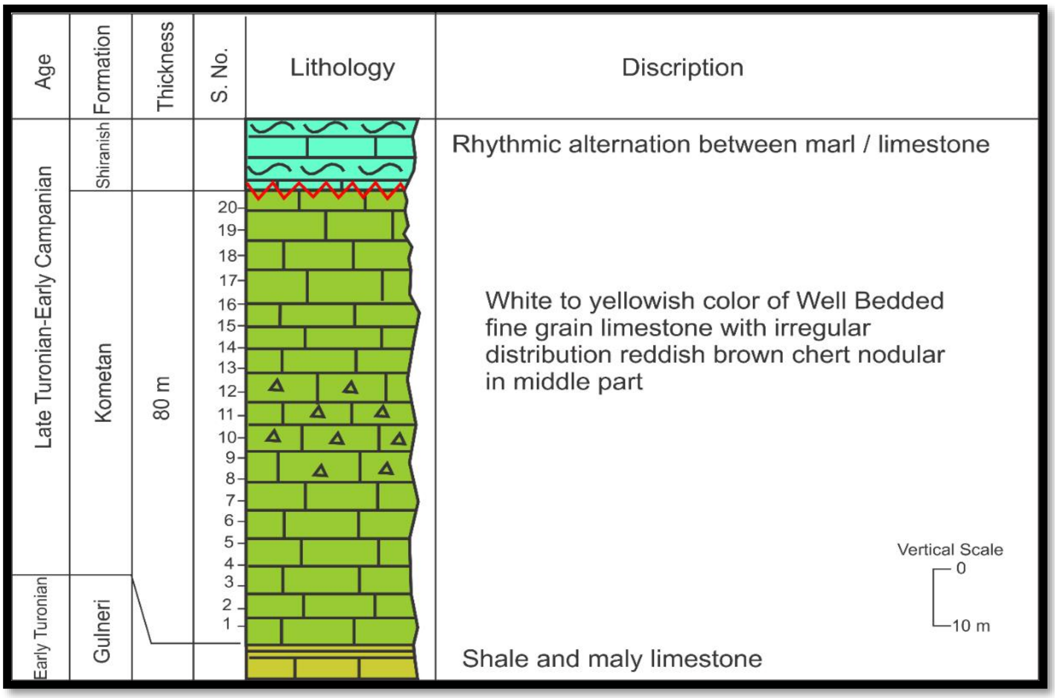

Fig. 3. Stratigraphy column of Kometan Formation at studied area.

Diagenesis processes

Diagenetic processes encompass the entire array of physical, chemical, and biological transformations that take place in sediments under low temperature and pressure conditions both before and after burial, typically near the Earth's surface (Flugel, 1982). In the context of carbonate rocks, diagenetic processes exhibit greater variability compared to their siliciclastic counterparts. This variability is attributed to the inherent instability of the minerals found in carbonate rocks (Bathurst, 1975). The common recognized diagenetic processes within the Kometan Formation are the following:

Micritization

Micritization refers to an early diagenetic process originating from the activities of organisms that bore into carbonate deposits, such as endolithic algae or fungi. This activity manifests as a micritic envelope or rim (Bathurst, 1975). Additionally, micritization is characterized by the action of non-calcareous algae, fungi, and bacteria that break down bioclasts or non-skeletal grains, subsequently encasing them in a micritic layer (Okon, 2015). Micrite may form micritic envelops around larger grains or fossils. This association can be indicative of the micritization process and the early diagenetic history of the sediment (Tucker, 1993). These are characterized by fine crystalline calcite, constituting a dark and dense micrite that forms a ground mass and coats certain skeletal grains (Plate 1A). The present of finely crystalline micrite within the sedimentary matrix is indicative of ongoing micritization processes (Folk, 1974). It has been observed in marine phreatic zone (logman, 1980)

Dissolution

This process significantly impacted a majority of the fossil shells and the ground mass. It arises from chemical interactions within the pore water, resulting in the dissolution of minerals that are prone to instability, such as aragonite or high-Mg calcite. The solubility of carbonates is known to increase with greater acidity (lowering of pH) and reduced temperatures (Nichols, 2009). The extent of dissolution primarily hinges on the duration that sediments are exposed to meteoric water (Shakeri, 2014). The dissolution of aragonite and high-Mg calcite shells took place in meteoric settings where chemically active acidic meteoric waters infiltrate or flow through the vadose zone into the phreatic zone (Mandurah, 2012). Within the analyzed samples, Dissolution is occurred in uplifting expose the rocks to meteoric diagenetic environments during telogenesis stage indicative by vuggy porosity, while moldic porosity may be formed in meteoric phreatic environments during eogenesis stage (Plates 1B and 1C).

Cementation

Cementation is the process of chemically precipitating carbonate crystals within the empty spaces or voids that exist in sediment or rock, serving to consolidate and interlock individual grains or particles (Kumsa, 2017). Additionally, cementation, as a significant diagenetic process, plays a crucial role in the transformation of soft sediment into solid limestone (Okon, 2015). Based on the results of the present petrographic analysis, two cement types were observed, including calcite cement such as granular, and blocky cements and quartz cement.

Granular calcite cement

Granular cement is the predominant form of cementation found in the Kometan Formation, filling both the shells of planktonic foraminifera and fractures (Plates 1A,1D, 2B and 2D). Furthermore, the presence of this cement serves as an indicator of eogenesis stage diagenetic processes (Flugel, 2010).

Blocky calcite Cement

This type of cement was observed in the form of coarse calcite crystals without a particular alignment, and it effectively occupied the fractures, thereby reducing the overall porosity (Plate 1E). Typically, this type of cement takes place in the later stages of diagenesis. A significant period of time is necessary for the deposition of this type of cement during the late stages of diagenesis processes (Israa and Zhang, 2021). Interestingly, it is formed through the dissolution of aragonite minerals, a process facilitated by the relatively lower levels of acidity within the freshwater phreatic zone (Longman,1980). Additionally, this cement variety forms in meteoric vadose settings, resulting from uplifting processes during the telogenesis stage, as well as in deep burial environments during the mesogenesis stage (Flugel, 2010)

Neomorphism

Neomorphism, it comprises all alterations between minerals or polymorphs (Folk, 1965). This process is associated with meteoric phreatic conditions in sediment (Longman, 1980). Neomorphism type observed in the studied samples is recrystallization and also it is microspar-pesedospar, aggrading neomorphism type. This neomorphic spar can be recognized by irregular crystal boundaries (Plate 1F).

Silicification

The silicification of carbonate rocks can manifest through two fundamental processes: the replacement of carbonate minerals by silica or the recrystalization of silica filling the voids within the rock (Flugel, 2004). The replacement mechanism implies that silicification can transpire either during early or late diagenesis stages (Tucker, 2001). The presence of microcrystalline quartz in the ground masses of the analyzed samples indicates a replacement process, signifying middle diagenesis processes during mesogenesis stage. On the other hand, the formation of coarse crystalline quartz filling fracture porosity through cementation suggests late diagenetic processes during the telogenesis stage (Plate 2A).

Compaction

This diagenetic process involves a reduction in the overall volume, thickness, or porosity of sediments. It occurs due to the accumulation of excessive material or the buildup of pressure within the Earth's crust resulting from geological forces and movements (Flugel, 1982). There are two primary types of compactions: physical (mechanical) compaction and chemical compaction (Longman, 1980).

Physical(mechanical) compaction

Mechanical compaction is a process that leads to a reduction in the overall bulk volume of grains or results in a tighter arrangement of grains, often causing grain deformation or reorientation (Meyers, 1980). Several common indicators of mechanical compaction within the Kometan Formation are as follows:

1. Fractures: Typically, these fractures are filled with calcite cement and silica cement (Plates 1D, 1E, 2A, and 2B).
2. Overly dense packing of skeletal grains (Plate 2C).
3. Veins that have infiltrated and intersected fossils (Plate 2E).

Chemical compaction

This phenomenon is commonly observed in the grains that experience dissolution under the applied stress of overburden, resulting in what is known as the pressure solution effect (Bathurst, 1975). In the studied section, a type of chemical compaction referred to as stylolite is recognized. Stylolites are formed by pressure solution, tectonic pressure, or the dissolution of limestone along specific planes due to the effects of overburden pressure (Wanless, 1979). Among the most prevalent forms of stylolites observed in the thin section samples are irregular suture contacts resulting from varying vertical movements. These stylolites exhibit peaks of both low amplitude (Plate 3A) and high amplitude (Plate 3B).

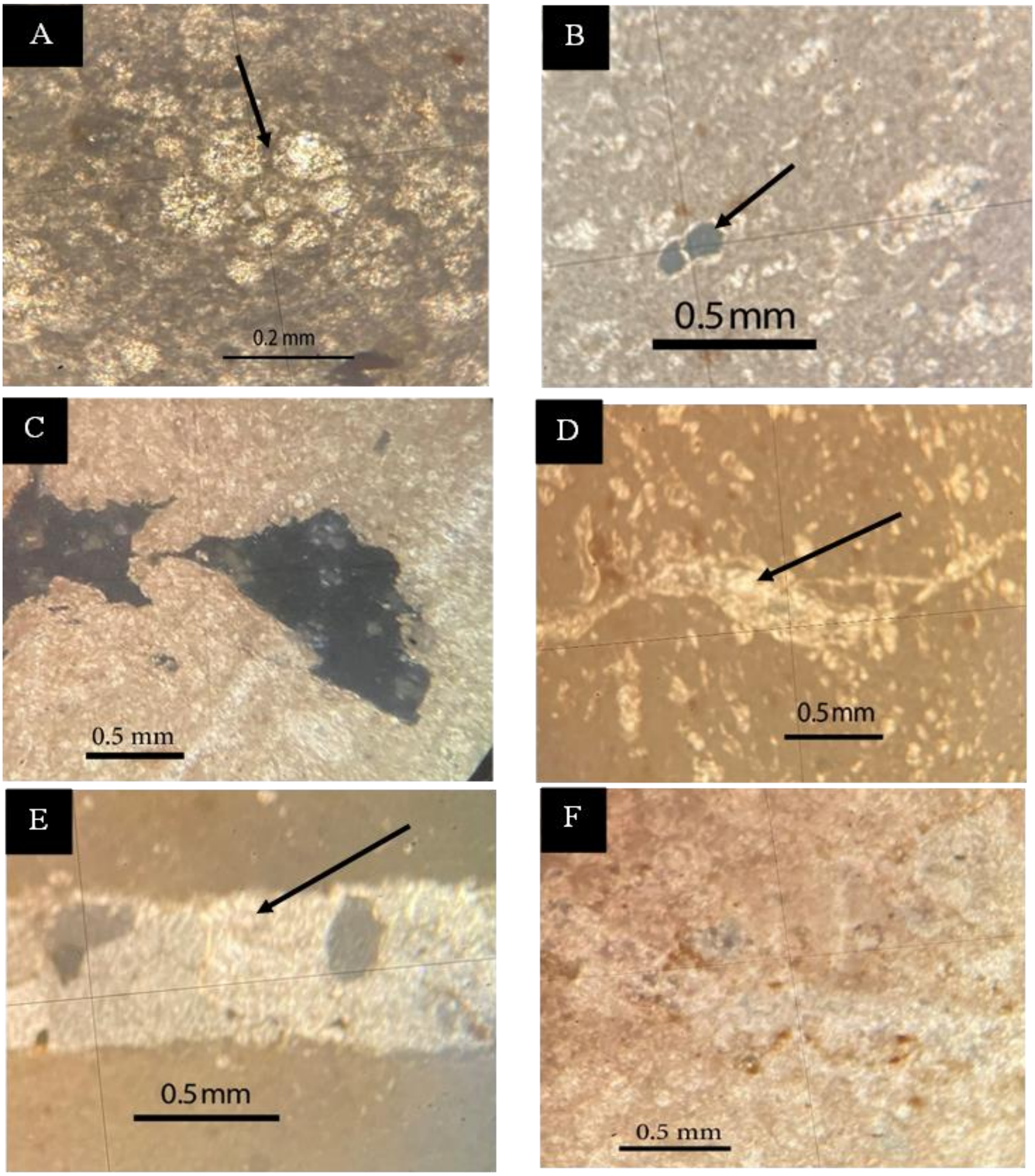

Plate 1. (A) Micritization processes (micrite envelope surrounding planktonic foraminifera) s.no. 1, xp. (B) Moldic porosity formed by dissolution s.no. 5, pp. (C) Dissolution processes caused vuggy porosity s.no. 7, pp. (D) Fracture filled by granular calcite cement s.no. 4, pp. (E) Fracture filled by blocky calcite cement s.no. 19, xp. (F) Neomorphism affected the groundmass s.no.2, xp.

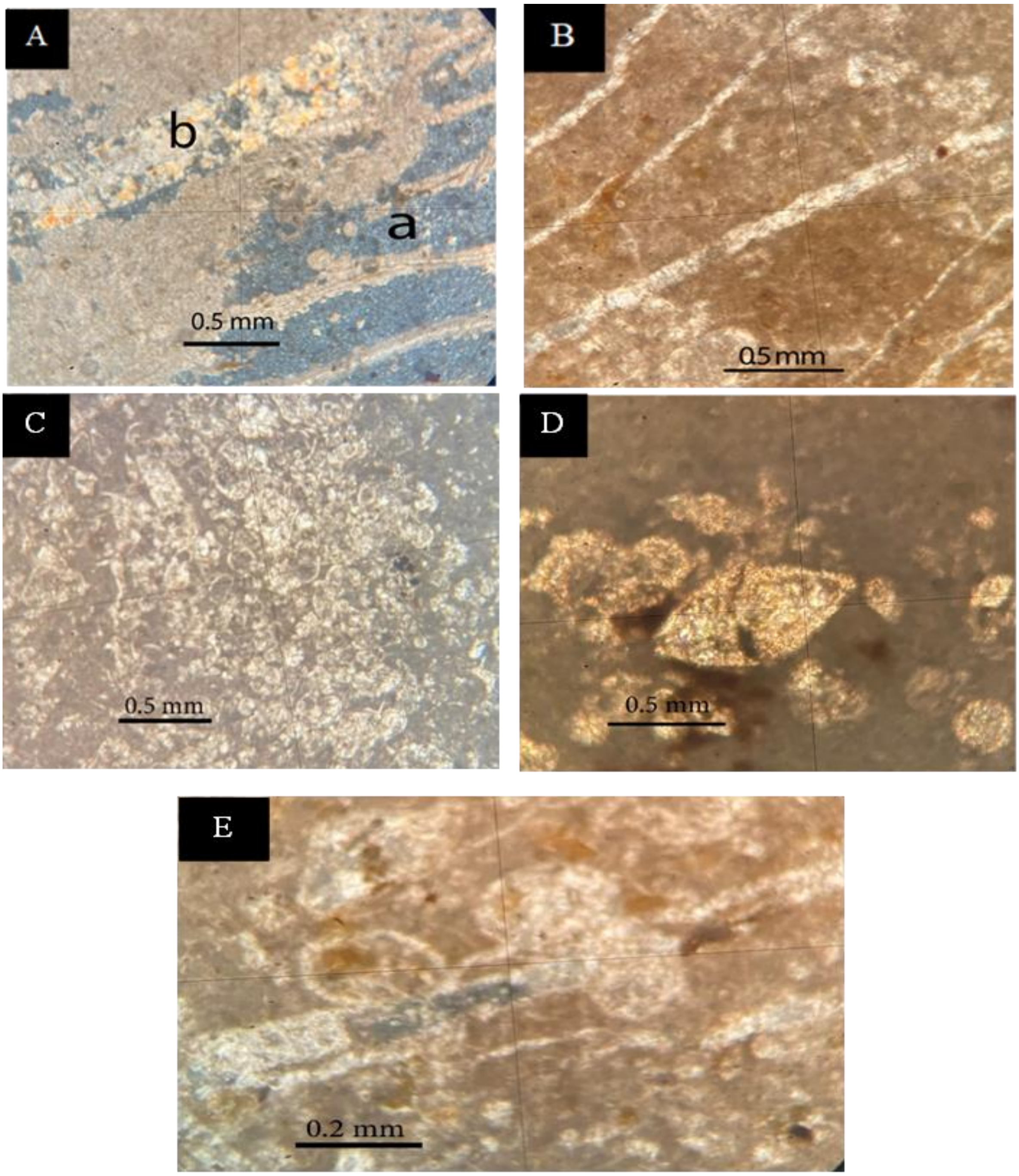

Plate 2. (A) silicification within ground mass can occur as microcrystal quartz (a) and coarse crystalline quartz within the fracture (b) s.no. 12, xp. (B) Fracture filled with granular cement s.no. 8, xp. (C) Physical compaction caused over close packing of skeletal grains s.no. 9, pp. (D) Moldic porosity filled with granular cement s.no. 11, pp. (E) Veins penetrated fossils s.no. 10, xp.

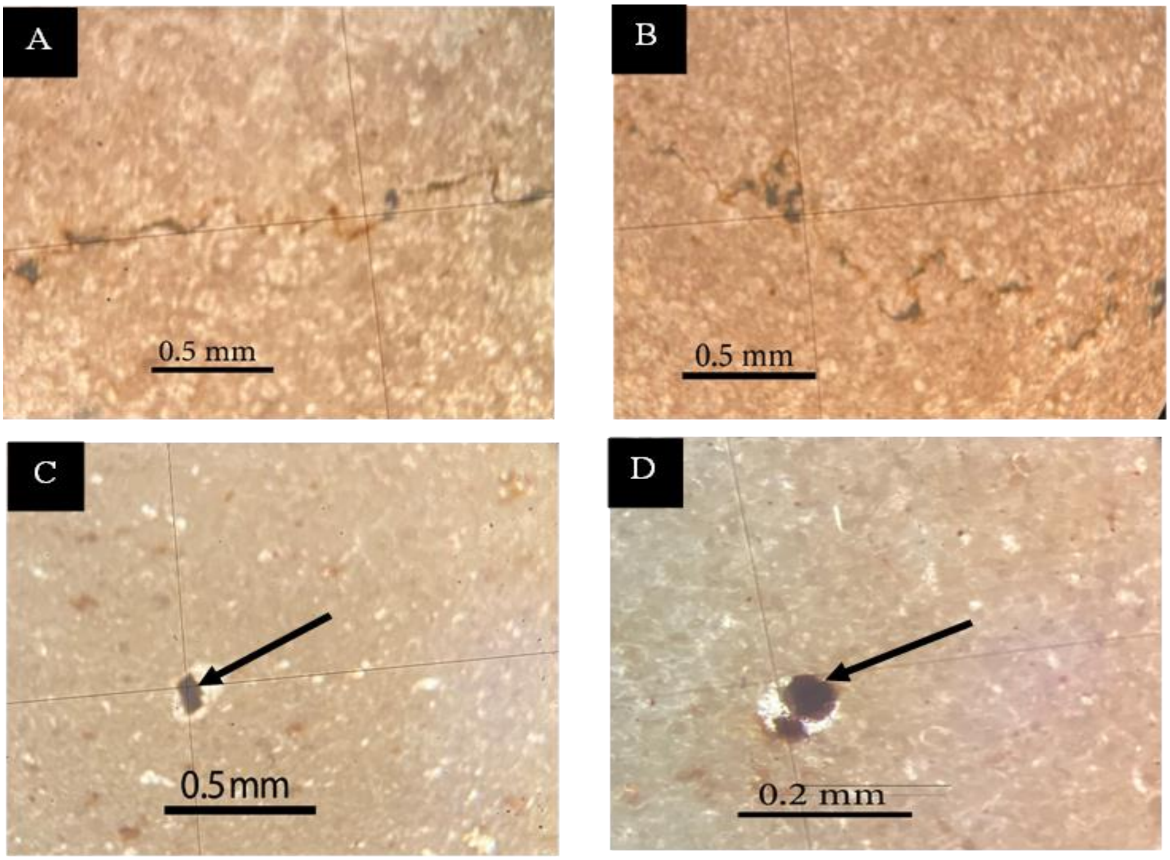

Plate 3. (A) Low amplitude of stylolite s.no. 17, xp. (B) High amplitude of stylolite s.no. 18, xp. (C) Pyritization (crystal of pyrite) s.no. 16, pp. (D) Spherical pyrites s.no. 16, pp.

Fracturing

Fracturing processes are evident within the Kometan Formation and are typically the result of various factors, including deformation, heightened overburden pressure, changes in sediment properties, tectonic uplifting, and folding and faulting that occurred within the sedimentary basin. These fractures have been filled with calcite and silica cements (Plates 1D, 1E, 2A, and 2B).

Authigenic Mineral (Pyrite)

Pyritization involves the development of various crystal structures of pyrite and typically occurs within reducing environments. These conditions are often influenced by the decomposition of organic matter, driven by anaerobic bacteria, or by the activity of sulfate-reducing bacteria in solutions rich in sulfate (Hudson, 1982). These reducing conditions, which are essential for pyritization, are accessible during the initial stages of burial when anaerobic bacteria become active (Larsen and Chilingar, 1979). The samples under study predominantly exhibit small spherical and crystalline pyrites (Plates 3C and 3D).

Diagenetic environments

The order of diagenetic processes in a carbonate system is shaped by various factors, including sediment characteristics, particle size and texture, mineral composition, the type of pore fluids, and the prevailing climate conditions (Tucker and Wright, 1990; Tucker, 1993, and Flugel, 2004). Based on petrographic examinations of the analyzed samples from the Kometan Formation, it is evident that distinct diagenetic alterations take place in different diagenetic stages, encompassing marine, meteoric, and burial diagenetic environments.

Marine phreatic diagenetic environments

This diagenetic environment inferred by micritization, and physical compaction. In the analyzed samples of the Kometan Formation, micritic envelopes are frequently observed, and these envelopes provide valuable insights into the diagenetic processes that occurred in a marine phreatic environment (Tucker, 2001) (Plate 1A). According to Dickson (1999) micritization represents the early diagenetic stage occurring at the interface between sediment and water in low-energy, shallow marine environments with low sedimentation rates. Also, the increased overburden pressure resulting from physical compaction at this stage induces the formation of overly dense packing of skeletal grains (Plate 2C).

Meteoric diagenetic environments

The meteoric diagenetic environment is subdivided into vadose and phreatic meteoric environments (Scholle, 2003). Meteoric diagenesis in both areas was revealed by the occurrence of dissolution, cementation, neomorphism, silicification, and fracturing. Dissolution (moldic porosity), early granular cementation and neomorphism are represent early meteoric phreatic diagenetic environment in the studied samples, the meteoric phreatic marks the initiation of diagenetic dissolution processes, leading to the dissolution of metastable skeletal and non-skeletal grains and the subsequent creation of secondary porosity. The secondary voids, or moldic features (Plate 1B), that arise from previous dissolution processes formed by carbonate dissolution are may be subsequently filled with granular calcite cement (Plate 2D). This cement may suggest precipitation occurring in a relatively meteoric phreatic diagenetic environment (Tucker, 2001). During this stage, neomorphism (plates 1F) is particularly effective in meteoric phreatic diagenetic environments.

Subsequently, late stages of diagenetic processes (telogenesis) happen in the area of unsaturated above the meteoric phreatic zones, because of late diagenetic processes exerted their influence on these sediments following the uplift associated with the Alpine orogeny, specifically during the Upper Cretaceous epoch when the basin underwent folding and faulting. Late meteoric after the tectonic uplifting diagenetic environment comprises dissolution (vuggy porosity), fracturing, cementation (blocky cement) and silicification (coarse crystalline quartz). In the uplift setting of diagenesis in the Kometan Formation during this period, the most significant processes contributing are secondary porosity include dissolution (resulting in vuggy porosity) (Plate 1C) and fracturing (Plate 1E, 2A). Following uplift, the carbonate rocks of Kometan Formation was affected by dissolution due to the influx of meteoric water. This process resulted in the formation of a secondary porosity (vuggy porosity). The filling of fractures and the occurrence of blocky cementation take place during the later stages of diagenesis (Plate 1E), coinciding with uplift, which is known as Telogenesis (Vincent *et al*, 2007). Moreover, the presence of coarse crystalline quartz within fractures resulting from the recrystallization of silica minerals within fractures (Plate 2A), indicates an even later stage of diagenesis. According to Bathurst (1987) mention that the recrystallization of silica minerals occurred within fractures, where there may be increased fluid flow and higher concentrations of silica, recrystallization can occur. Silica minerals may dissolve and then precipitate in the form of new crystals, commonly quartz, within the fractures. The source of coarse crystalline quartz derived from hydrothermal processes, characterized by the circulation of heated fluids within rock formations, play a role in the creation of coarse crystalline quartz cement. These fluids often contain dissolved silica, which can undergo precipitation as quartz cement when environmental conditions undergo alterations (Boggs, 2009).

Burial diagenetic environments

The Kometan Formation undergoes various diagenetic processes within deep burial environments, including chemical compaction (stylolite), physical compaction, silicification, and pyritization. These processes are not uniform but vary in their timing and impact (Vincent *et al*., 2007). In the late stages and deeper parts of burial, the chemical composition of lime mud contributes to the creation of stylolite because of the overburden pressure on sedimentary rocks increases with burial depth. As the pressure increases, minerals within the rocks may undergo dissolution at points of contact, resulting in the formation of stylolites (Plates 3A and 3B). subsequently, stylolite provide valuable information about the burial history, pressure conditions, and chemical changes that these rocks have undergone over geological time (Tucker, 2001). Also, during this phase, fracture (Plates 1D, 1E, 2A, and 2B). and veins that penetrate fossils (Plate 2E) are occurred. Additionally, Fine crystalline quartz is produced as carbonate rock undergoes silicification within the ground mass, resulting in the replacement of the original carbonate rock with chert (Plate 2A). The source of this type of silica from the radiolarian chert beds found in the Qulqula Group, extensively exposed in the thrust zone (Buday and Jassim, 1987; and Al-Barzinjy, 2008). According to Jassim and Goff (2006) radiolarian chert represents the predominant composition of the Qulqula Group. This phenomenon suggests middle diagenesis processes during mesogenesis. Pyritization processes occur during the early stages of burial (Plates 3C and 3D).

Diagenetic sequence

The sequence of diagenetic processes can be derived from paragenetic relationships identified in the petrographic study (Tawfik *et al.*, 2018). The Kometan Formation underwent eight diagenetic processes such as micritization, neomorphism, dissolution (moldic and vugs porosity), cementation, silicification, compaction, fracturing, and deposition of authigenic minerals (such as pyrite). The diagenetic stages have been categorized into eogenetic, mesogenetic and telogenetic stages for identified the diagenetic evolution of the studied samples, is used (Figure 4). The diagenesis processes take place during early stages of eogenesis including micritization, neomorphism, dissolution (moldic porosity), granular texture cementation, and physical compaction. An early micritization known as micrite envelopes affected thin shell of planktonic foraminifera and the ground mass. The origin of this micrite envelope by chemical processes, such as dissolution and reprecipitation, contribute to the transformation of the original carbonate material into micrite. This chemical alteration is often influenced by the presence of organic material, microbial activity, and changes in pore water chemistry (Boggs, 2009). The next diagenetic processes after micritization are neomorphism process, it is recrystallization type involves the dissolution and reprecipitation of minerals in the carbonate rock, this process can lead to the development of new crystals, altering the texture and structure of the rock (Tucker, 2009).

Diagenetic sequence →	**Eogenesis (early diagenesis)**		**Mesogenesis (Middle diagenesis)**	**Telogenesis (Late diagenesis)**
Diagenetic environments → **Diagenetic processes ↓**	**Marine phreatic**	**Meteoric**	**Burial**	**Meteoric**
Micritization	———			
Neomorphism		———		
Dissolution (Moldic porosity)		———		
Dissolution (Vugs porosity)				———
Granular cement		———		
Blocky cement				———
Silicification (fine crystalline quartz)			———	
Silicification (coarse crystalline quartz)				———
Physical compaction (over dense packing of skeletal grains)	———			
Physical compaction (veins)			———	
Chemical Compaction (stylolite)			———	
fracturing				———
Pyritization			———	

Fig. 4. Paragenetic sequence of Kometan Formation in Azmir Anticline.

Two phases of dissolution have been observed. The first phase involving dissolution internal structure of planktonic foraminifera and other bioclasts which lead to moldic porosity, these phenomena indicating partial to complete dissolution of foraminifera (high Mg calcite grains). (Janjuhah *et.al.*, 2021) suggested that meteoric interfaces, such as surfaces exposed to air and the water table, could serve as potential locations for high CO2 influx. This influx could result in greater dissolution of high magnesium calcite (HMC) grains, and precluding the dissolution of low magnesium calcite (LMC) grains. The second face of dissolution is the non-fabric selective matrix dissolution occurring within a range from deep burial mesogenetic conditions to deep meteoric telogenesis settings, is considered to occur in the middle to late stage of diagenesis. Subsequently, some these porosities were filled with cement. Cementation processes are happened in different diagenetic sequences where the initial cement formed is granular cement, representing the first generation. granular calcite cement filling the fractures part of the pore-spaces between grains and some chambers of foraminifera. This type of cement may occure in the meteoric phreatic zone. At early stage of diagenesis, mechanical compaction induces the creation of overly dense packing of skeletal grains.

The second stage of diagenesis is the mesogenetic stage, it consists of mechanical compaction (physical) and chemical compaction (stylolite), pyritization and silicification (fine grain quartz (microcrystalline quartz). Mechanical compaction is recognized in studied samples formed by overburden pressure caused breakage of grains and veins that have infiltrated and intersected fossils. Stylolite are present in the upper part of the Kometan Formation, resulting from the pressure-induced dissolution of grains and sediments, tectonic pressure, or the dissolution of limestone along specific planes due to the effects of overburden pressure. This process serves as a crucial supplier of $CaCO_3$ for the cementation that occurs during burial. Furthermore, the existing presence of pyrite in rock samples suggests the initiation of burial diagenesis processes in the early phases of mesogenesis. The present fine crystalline quartz (microquartz) within the matrix indicated formed by replacement carbonate mineral with silica minerals (Tucker, 2001). Fracturing, dissolution leading to vuggy porosity, and the filling of veins with coarse crystalline quartz and blocky cementation represents the last episode in the diagenetic history known as telogenesis. In this stage fracture observed in different form and size formed by tectonic uplifting caused cross-cut ground mass, skeletal grains and after that this fracture filled with blocky calcite cement and silica. These features indicated the late stage of diagenesis during telogenesis.

Conclusion

1. Thin section analysis of the studied samples from the Kometan Formation reveals the impact of numerous diagenetic processes, including micritization, dissolution, cementation, neomorphism, silicification, compaction, fracturing, and pyritization.
2. These diagenetic changes within the Kometan Formation occurred in three different environmental contexts, encompassing Marine phreatic, meteoric, burial diagenetic environments.
3. The diagenetic processes within this formation are prevalent in meteoric with occurrence in burial environments, but they are relatively rare in marine phreatic environments.
4. Paragenesis sequence of diagenesis processes including early stage eogenesis: (micritization, physical compaction (over dense packing of grains), dissolution (moldic porosity), cementation (granular cement), neomorphism, middle stages mesogenesis: (compaction, silicification (fine crystalline quartz), pyritization and stylolitization), and late stage telogenesis: fracturing, dissolution (vuggy porosity), cementation (blocky cement) and silicification (coarse crystalline quartz).

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